Nutrient and Ecological Histories in Barnegat Bay, NJ

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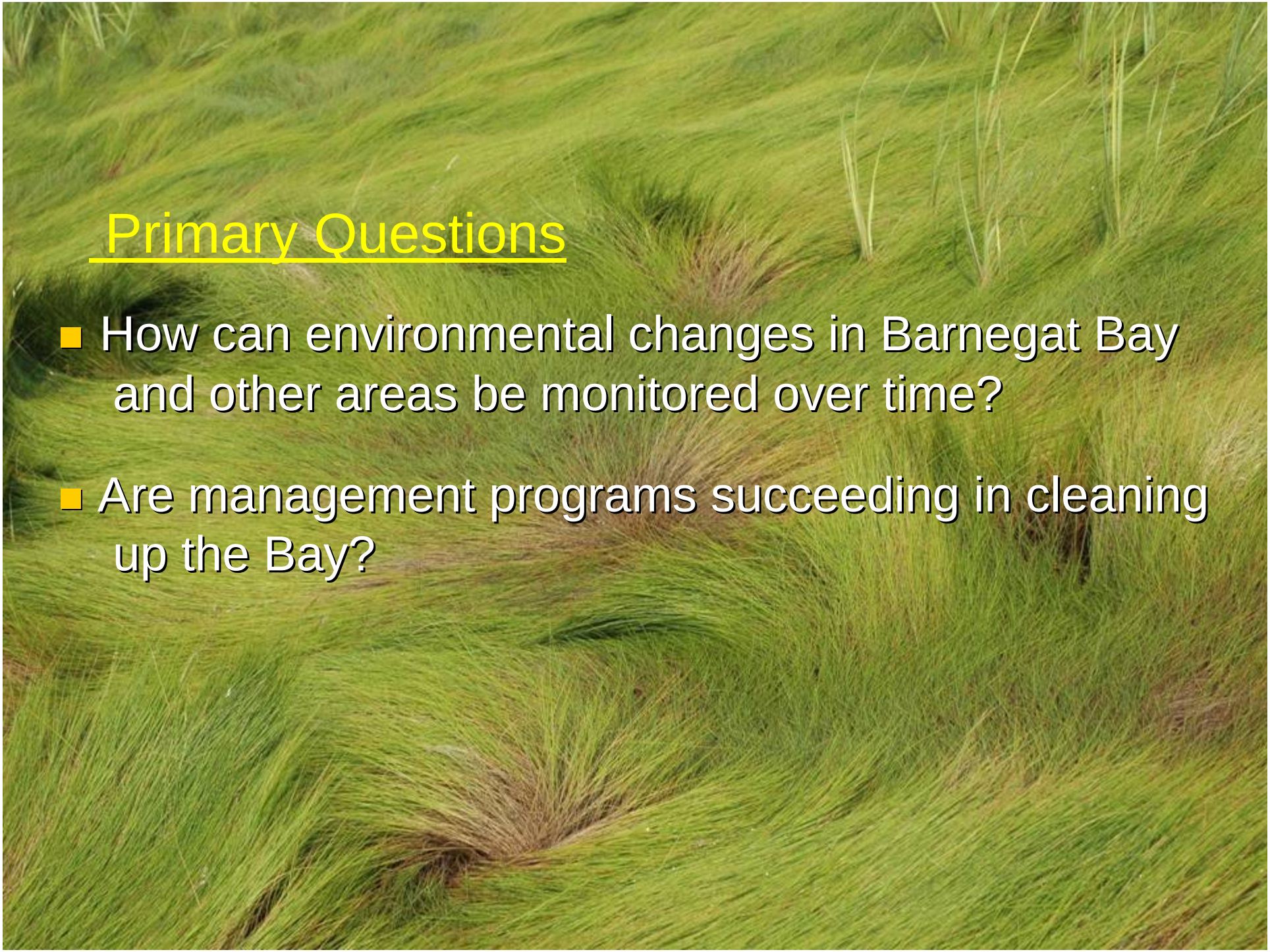
Presentation to
New Jersey Water Monitoring Coordinating Council
September 21, 2011
NJDHSS Laboratory



Primary Questions

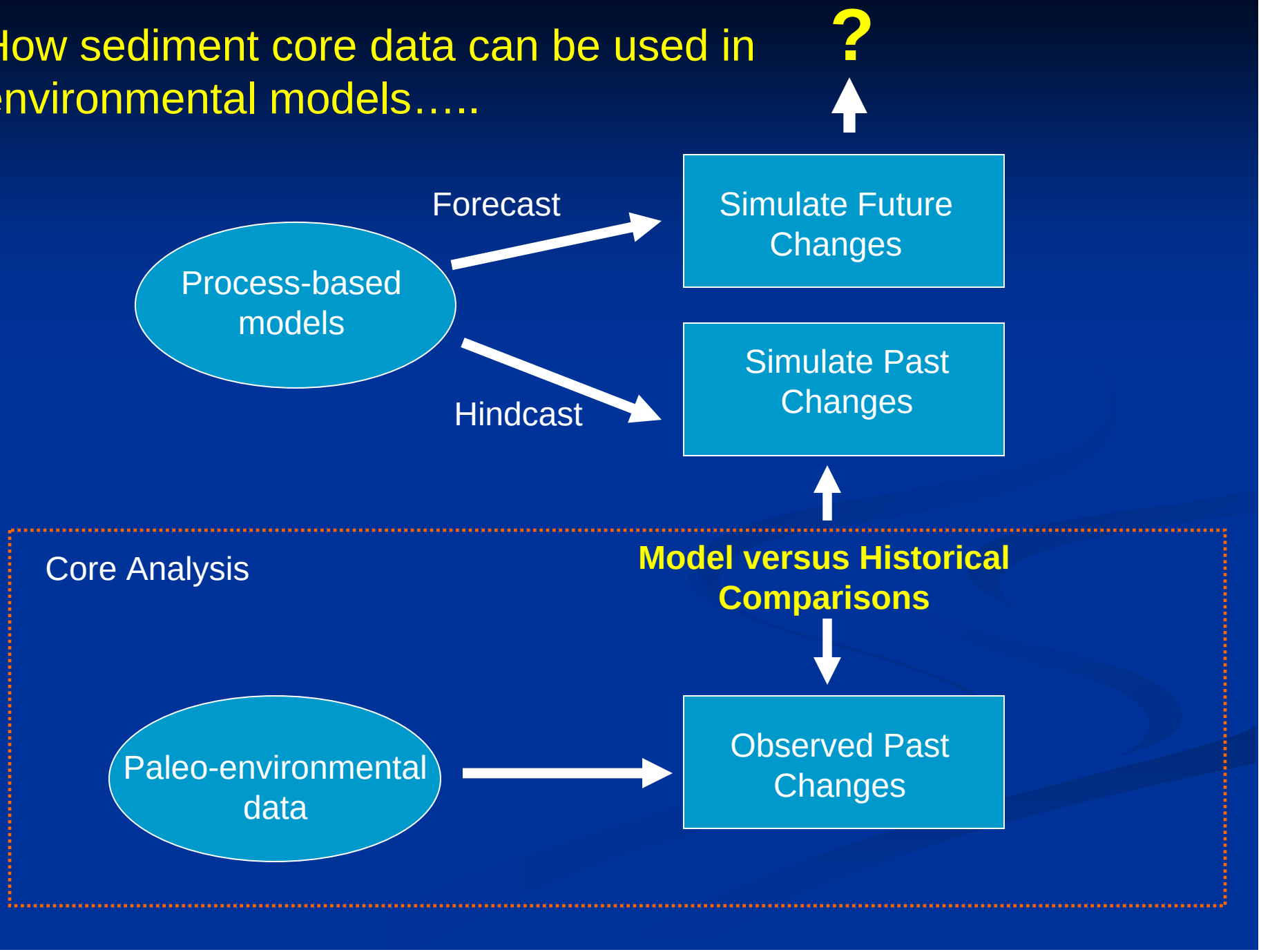
- How can environmental changes in Barnegat Bay and other areas be monitored over time?
- Are management programs succeeding in cleaning up the Bay?

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)

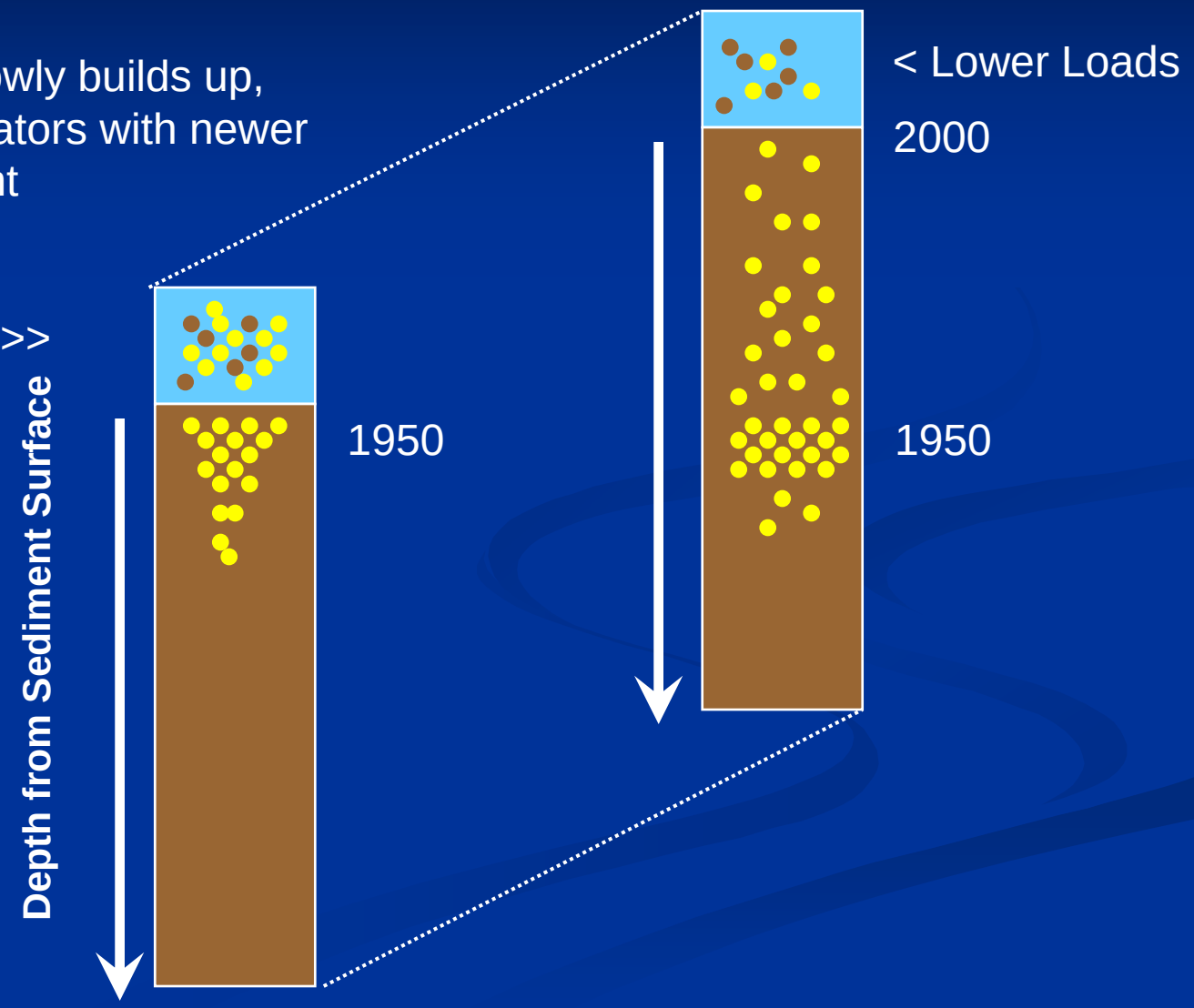
Importance: climate change, pollution control strategies, response time for change…

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

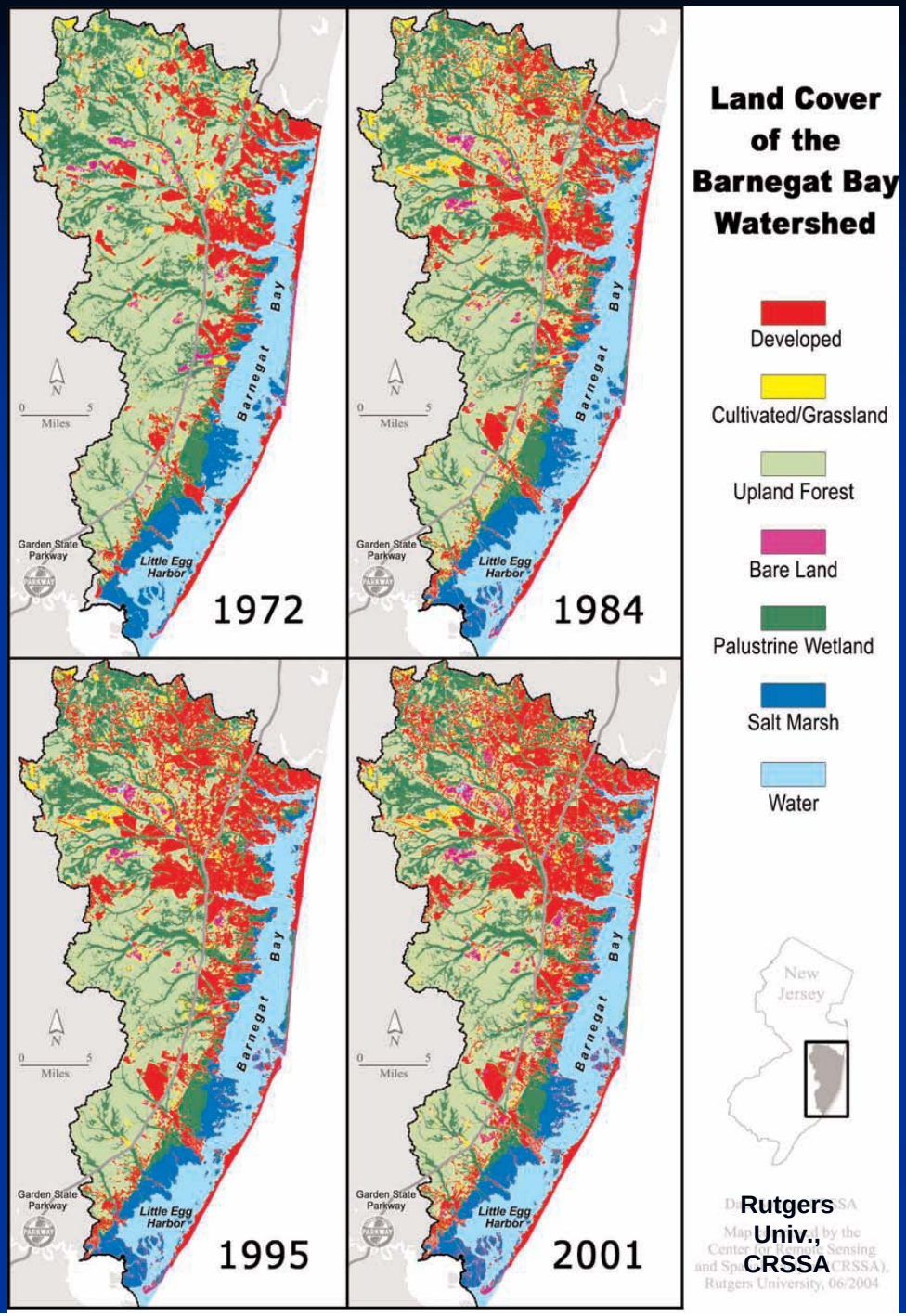


Sediments: an ecosystem's memory

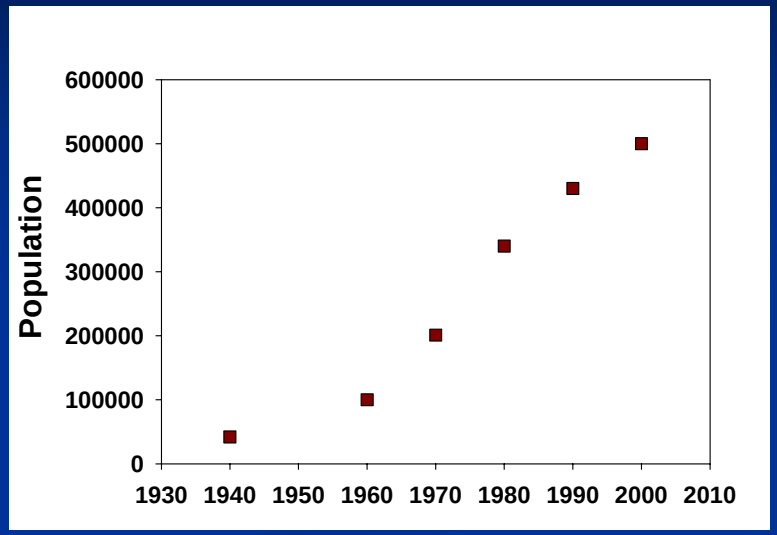
Sediment surface slowly builds up, burying chemicals/indicators with newer sediment



- Chemical-Sediment
- Sediment



Barnegat Bay



TN Load = ~ 5 - 7 X10^5 kg N/yr

<u>Sources</u>

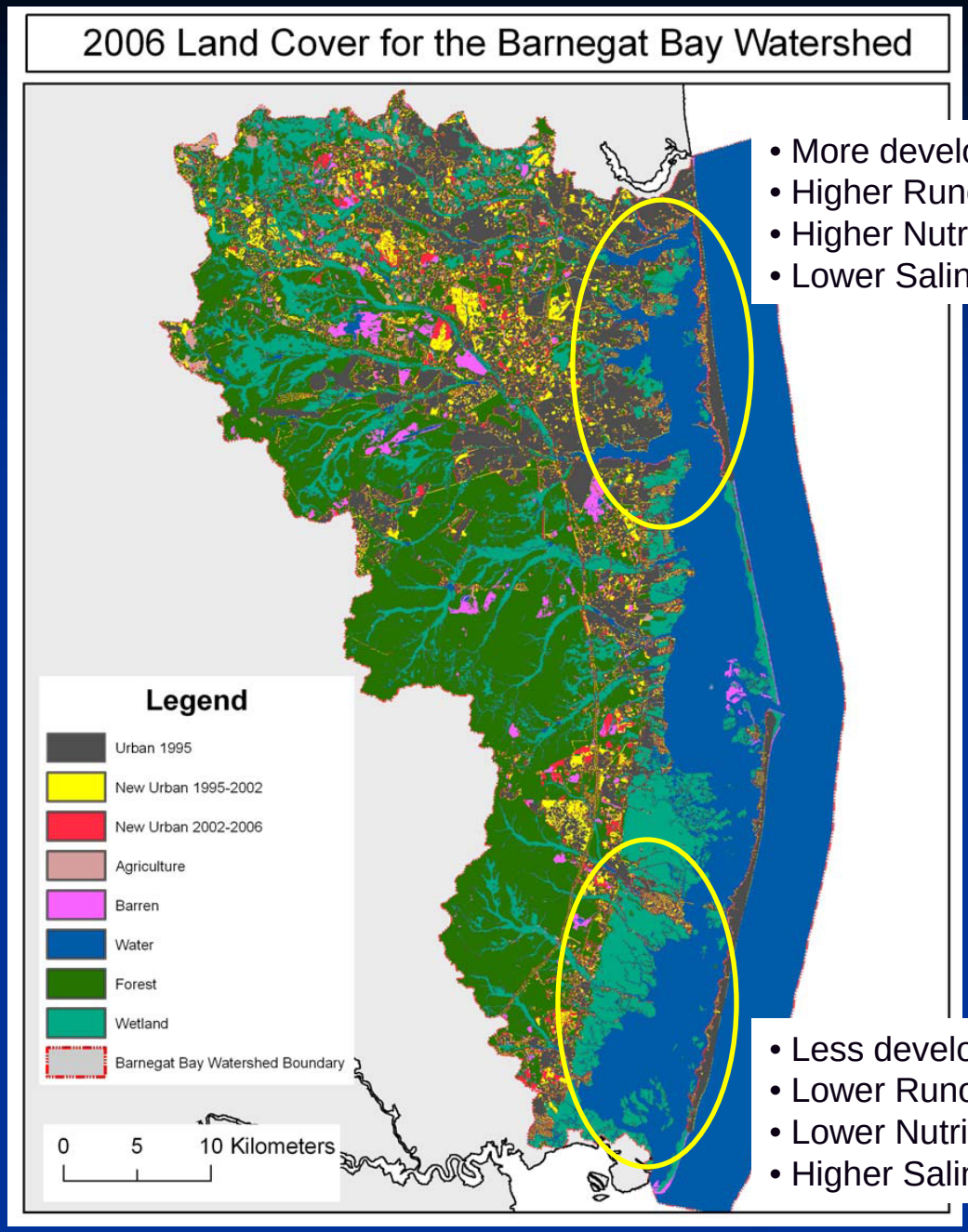
34% > Direct Atmospheric Dep.

12% > Groundwater Discharge

54% > Surface Water

(Hunchak-Kariouk and Nicholson, 2001)

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



- More development
- Higher Runoff
- Higher Nutrient Conc.
- Lower Salinities

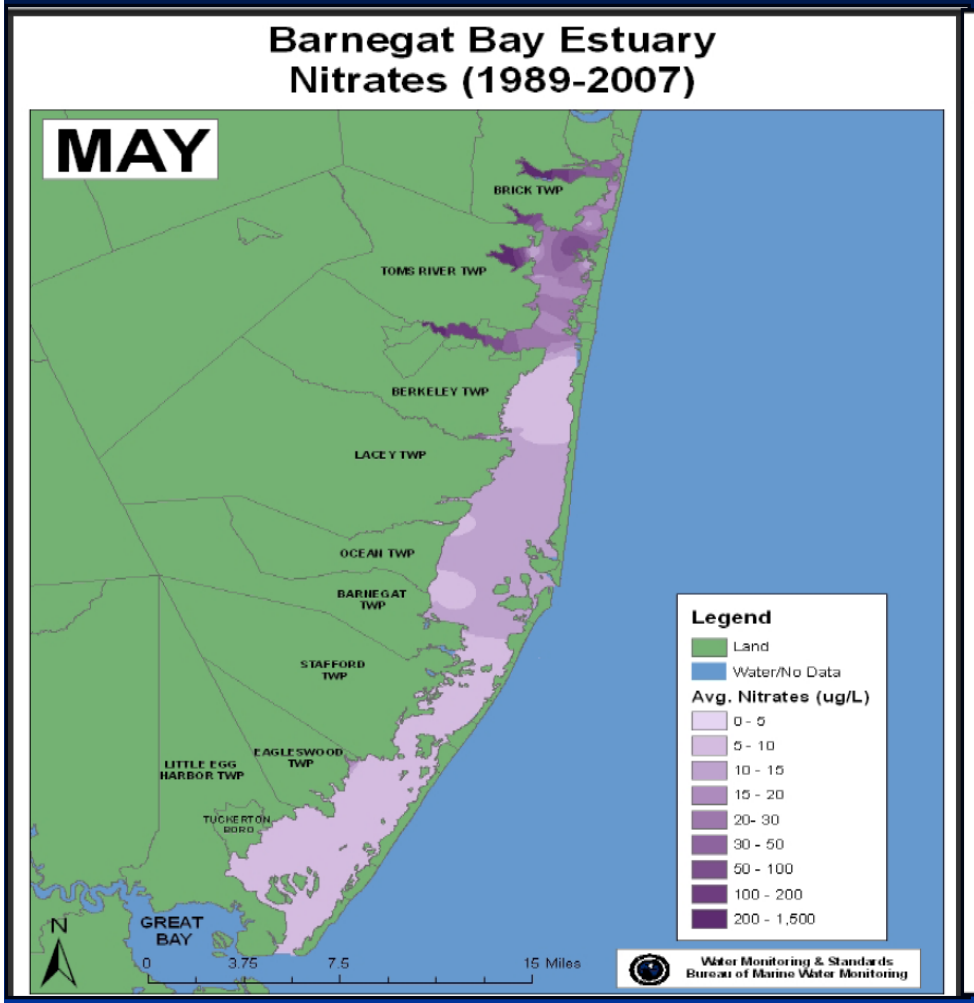
- Less development
- Lower Runoff
- Lower Nutrient Conc.
- Higher Salinities

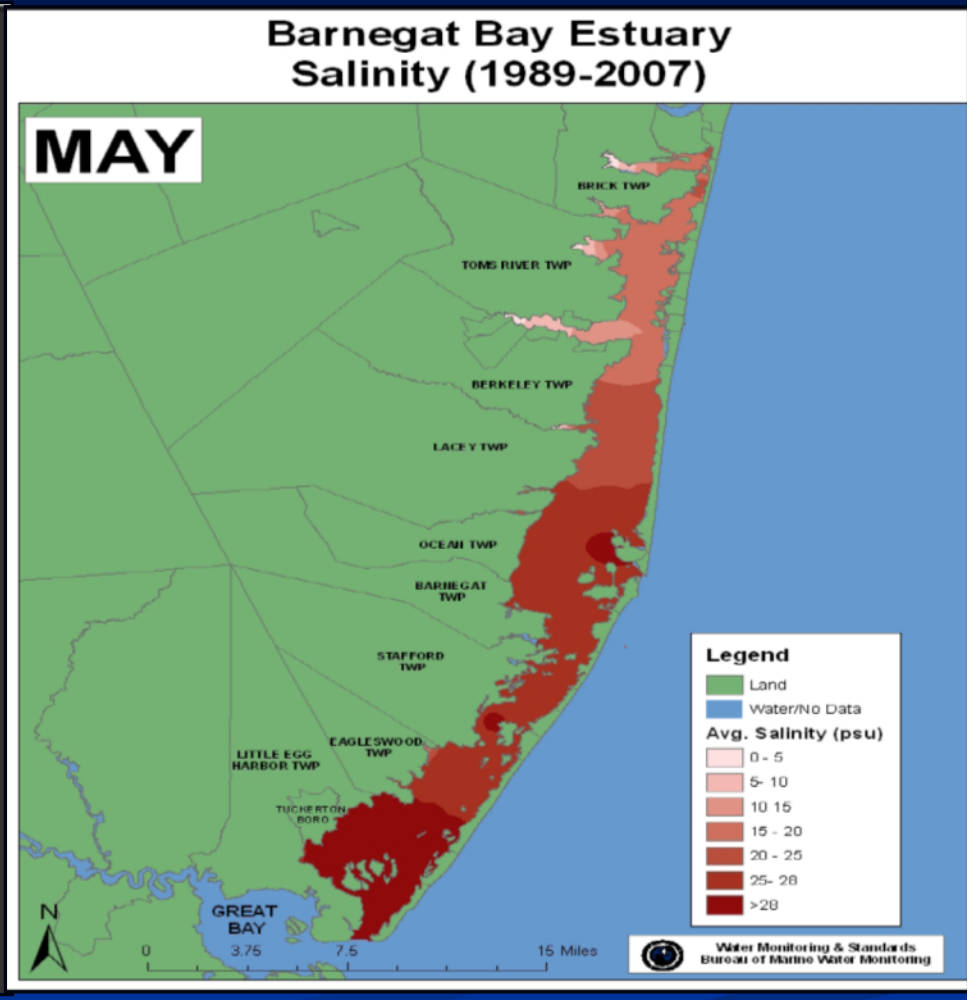
Sampling Program

- Three core locations: upper, mid, and lower reaches. Two cores at each location.
- Sampling in Spring/Summer of 2009
- Final Report April 22, 2011

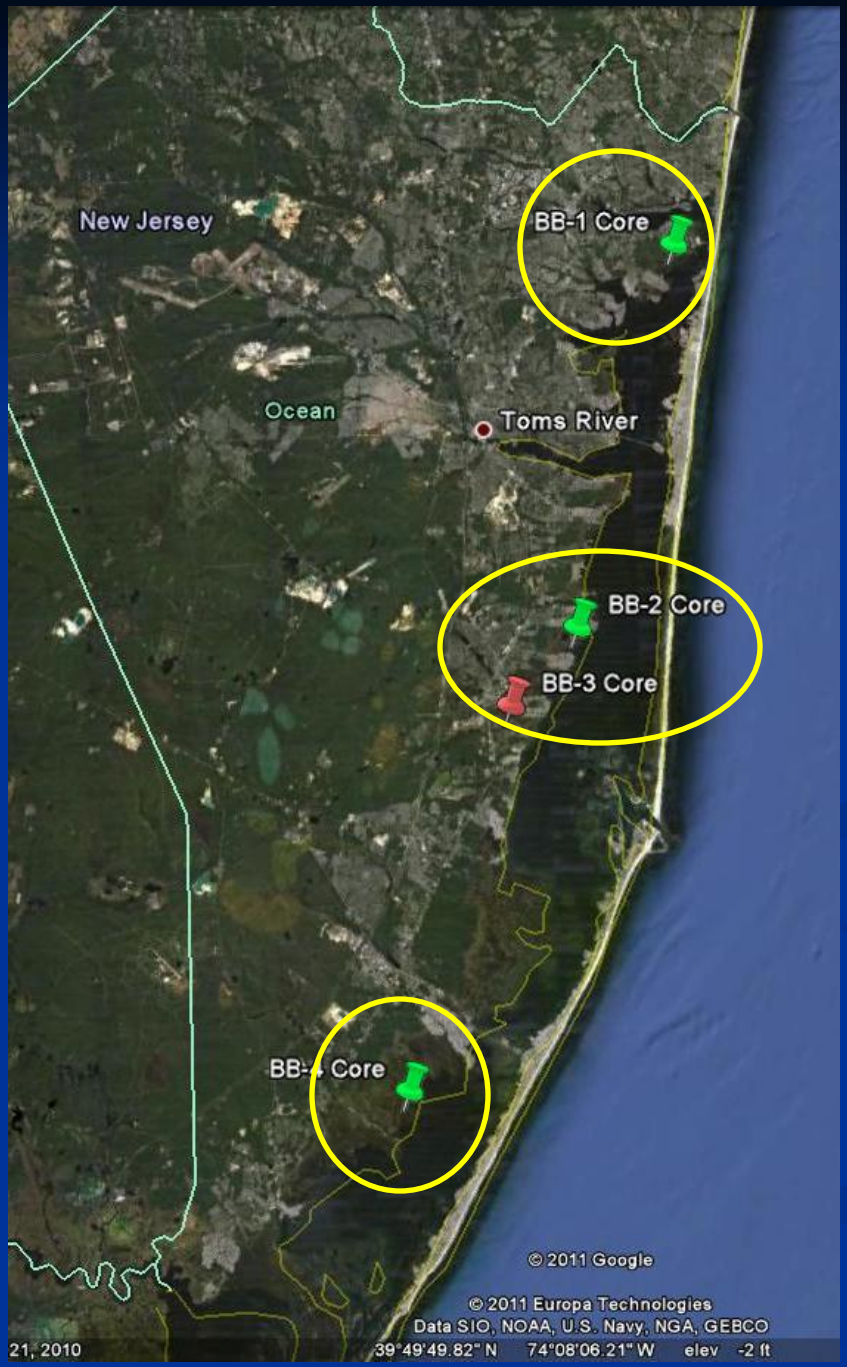
•Taken from Lathrop and Haag (2007)

Nutrient and Salinity Data





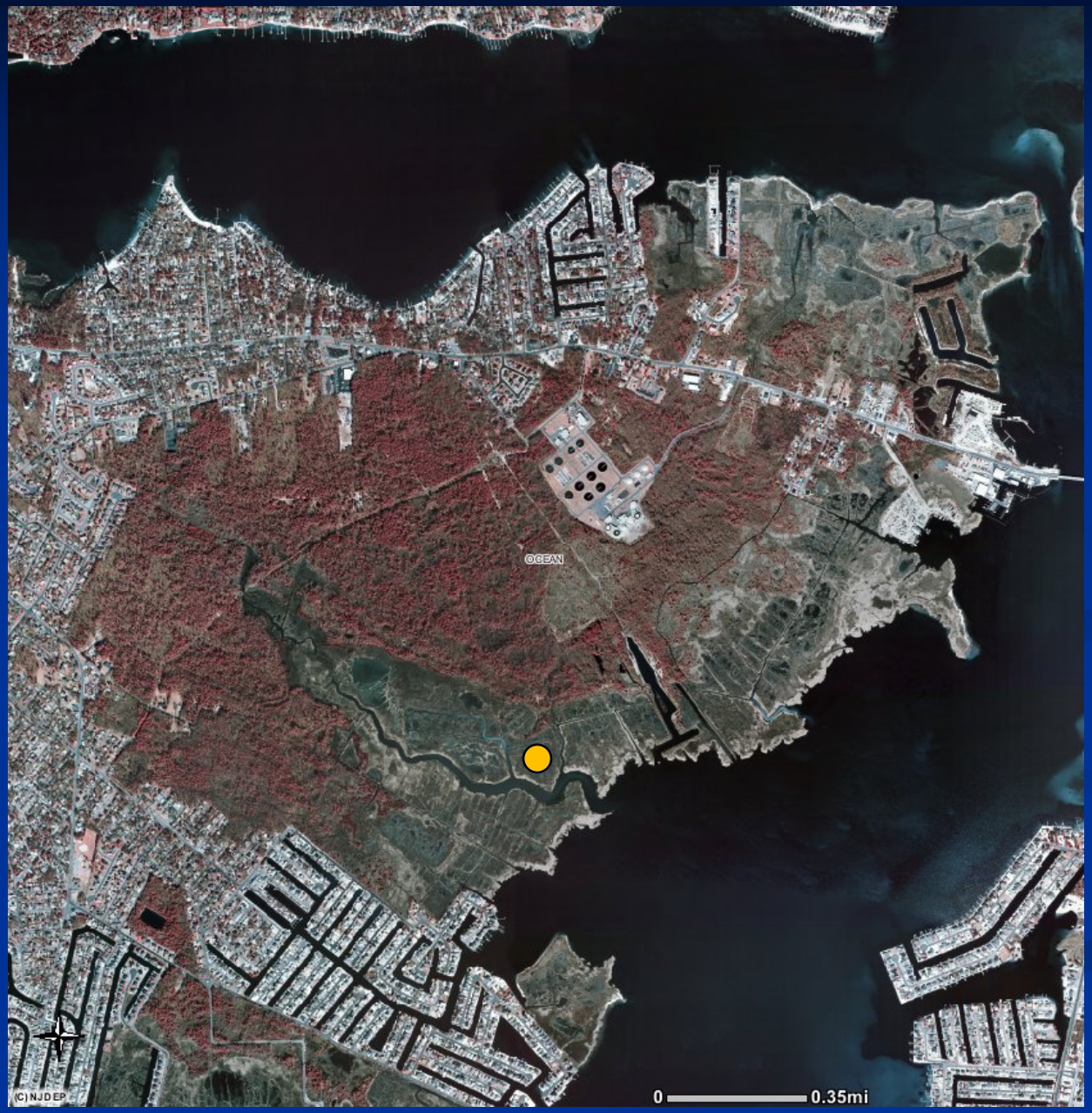
Taken from McGeorge and Connell (NJ DEP)



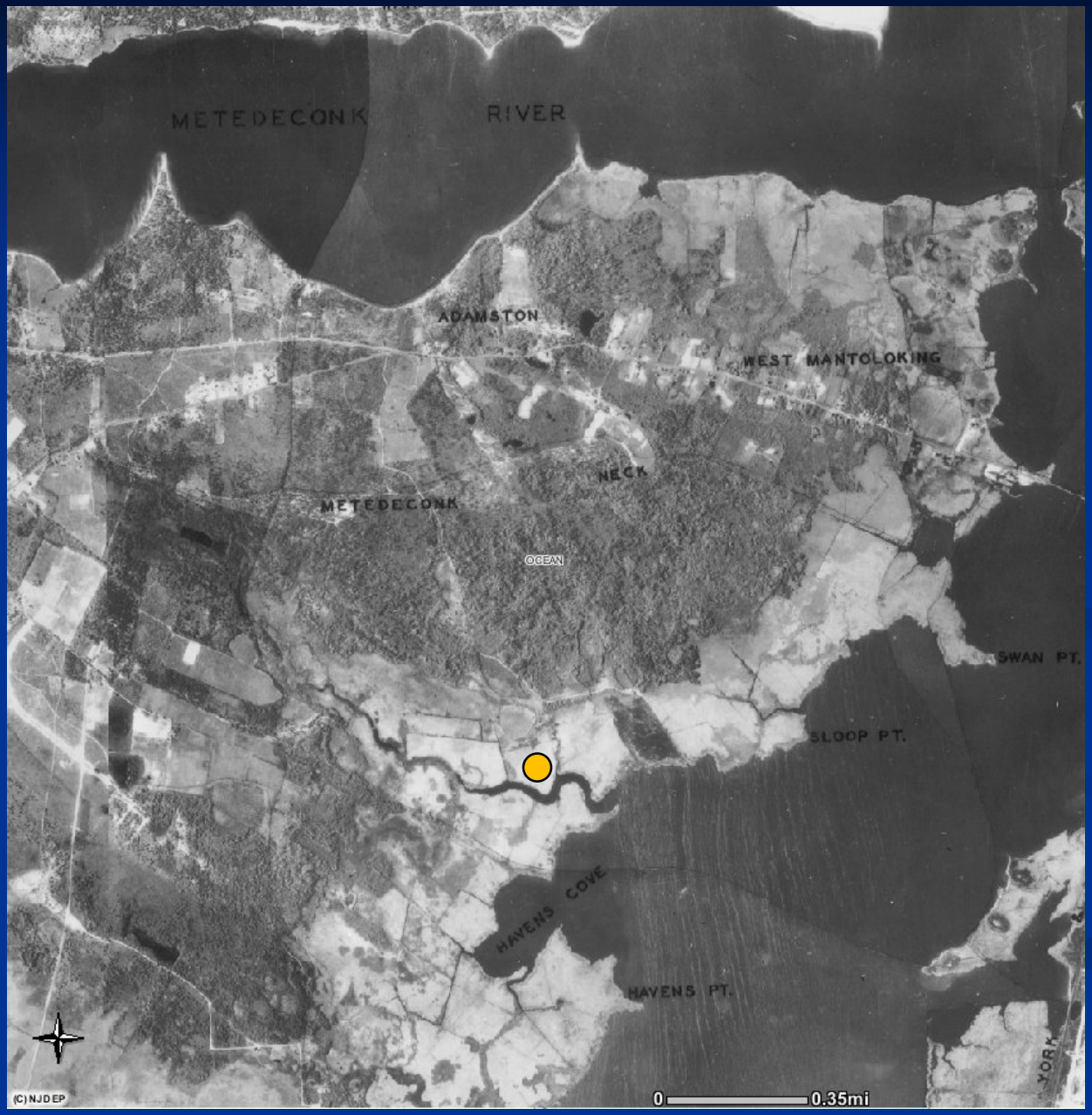
Sample Locations

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

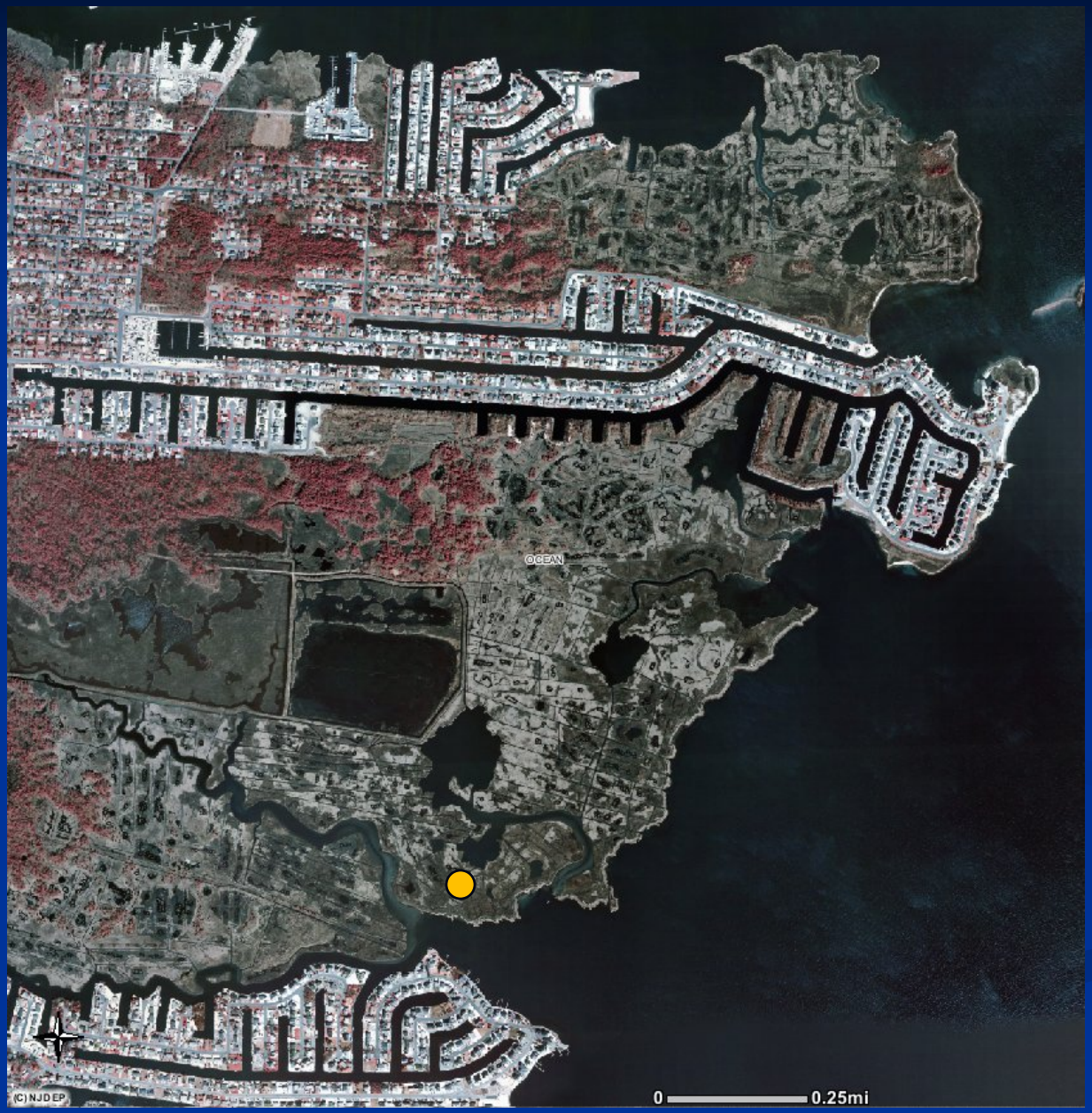
Upper Bay 2002 (BB-1)



Upper Bay 1930 (BB-1)

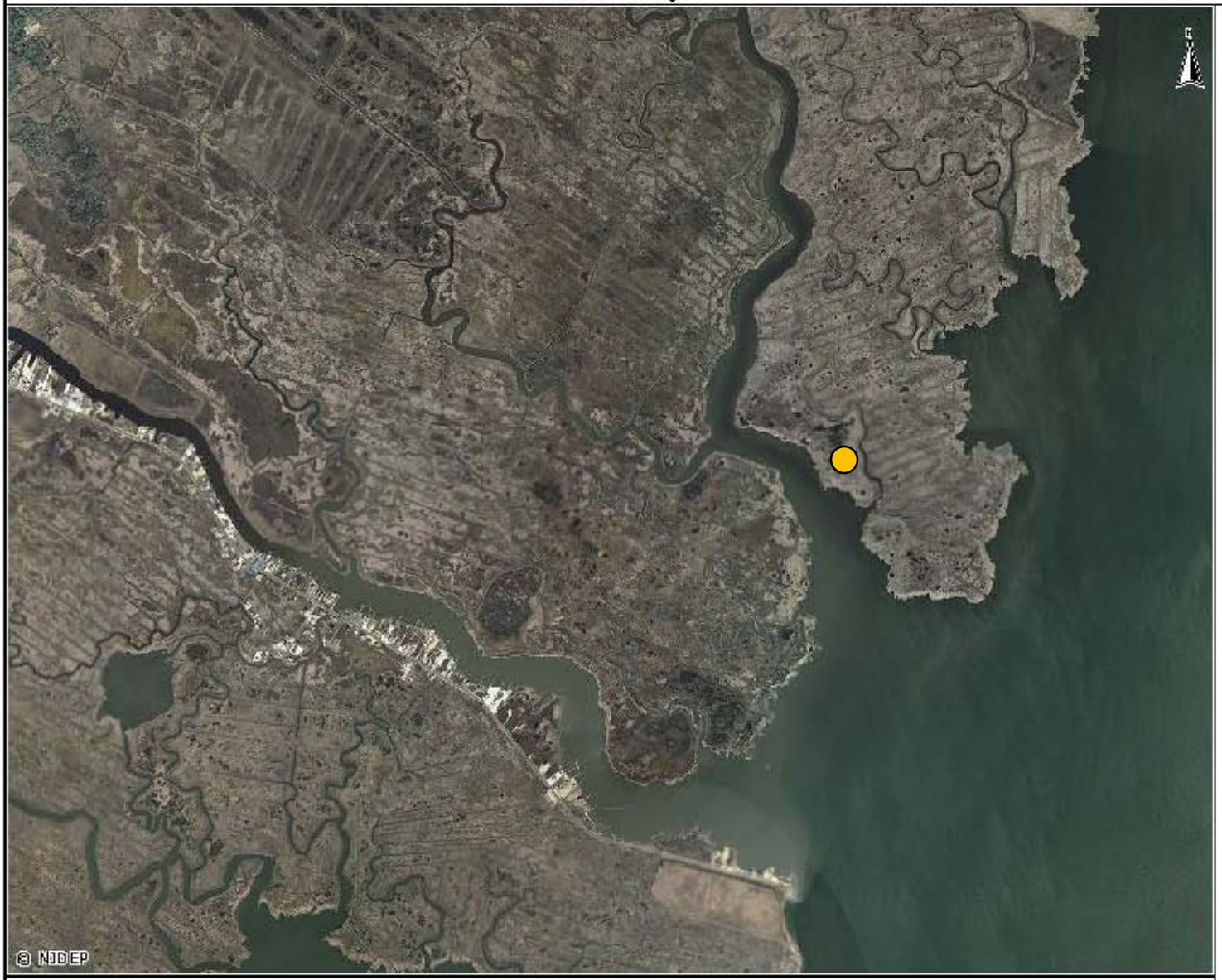


Middle Bay 2002 (BB-2)



Middle Bay 1930 (BB-2)

Lower Bay (BB-4)



Map Printed On {2011-04-01 07:46}

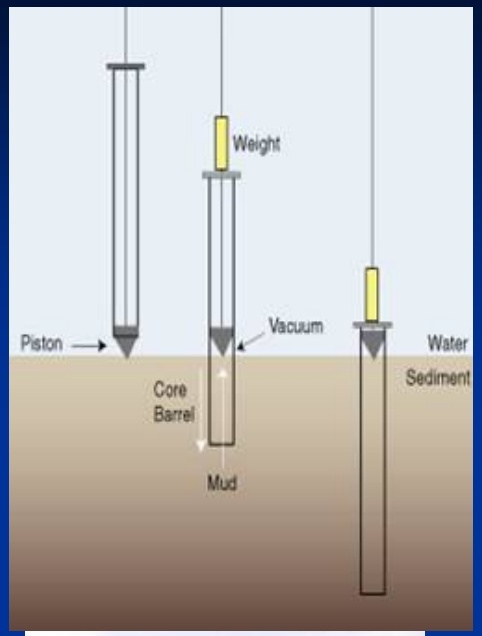
0 0.263 mi

Lower Bay 1930 (BB-4)

Map Printed On {2011-04-01 07:45}

0 0.263mi

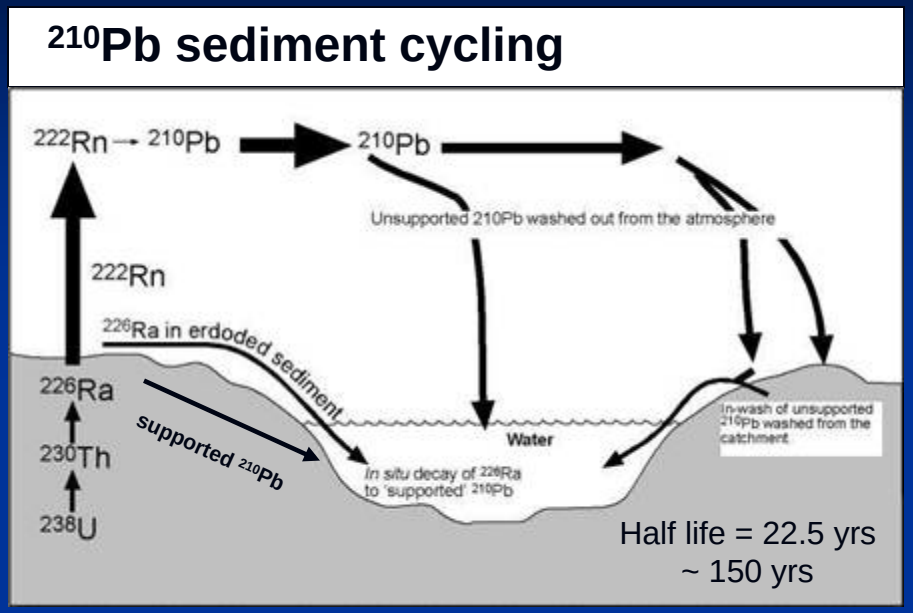
Push-Piston Core: One of many methods for taking a marsh core

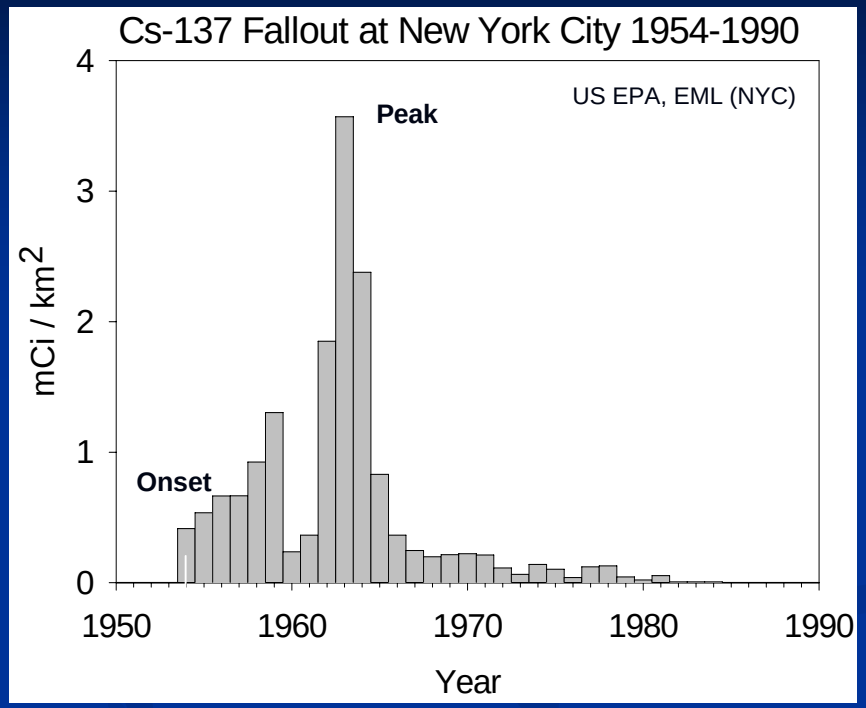


Analytical Parameters

- **Sediment cores were analyzed for:**
  - Organic Carbon, Total Nitrogen and Total Phosphorus (chemical forms)
  - 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

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

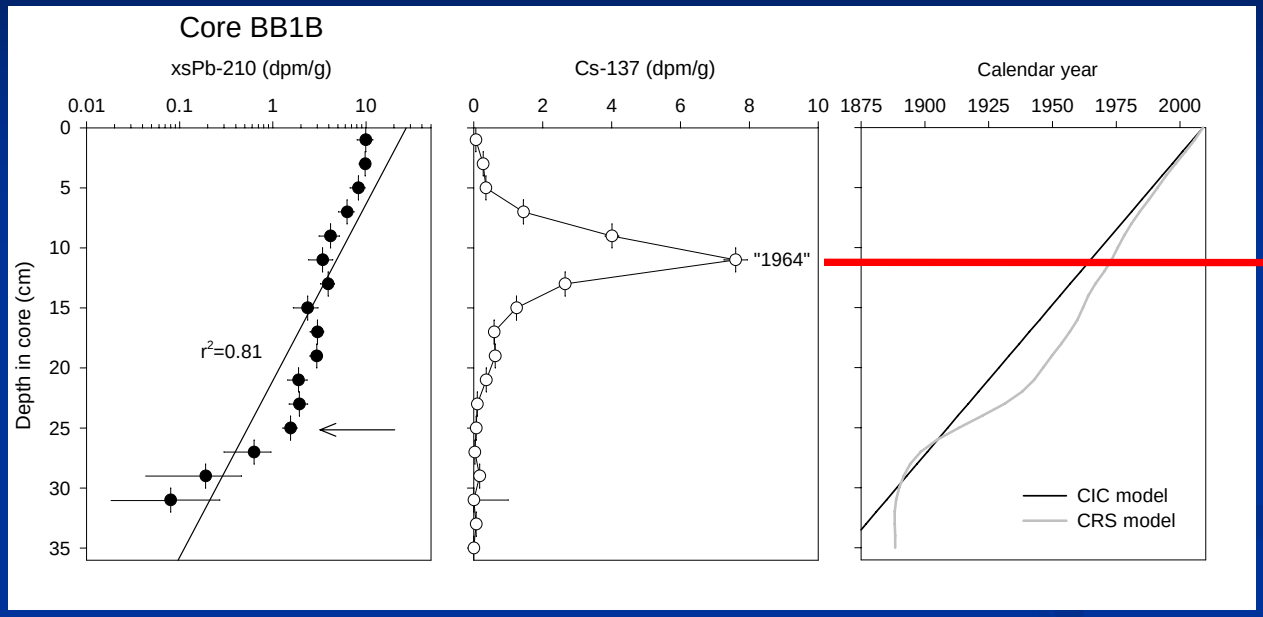




- Particle-reactive
- Pb dating: 100 to 150 yrs
- Supported ^{210}Pb produced by radioactive decay within sediments
- Unsupported ^{210}Pb transported to water from watershed runoff

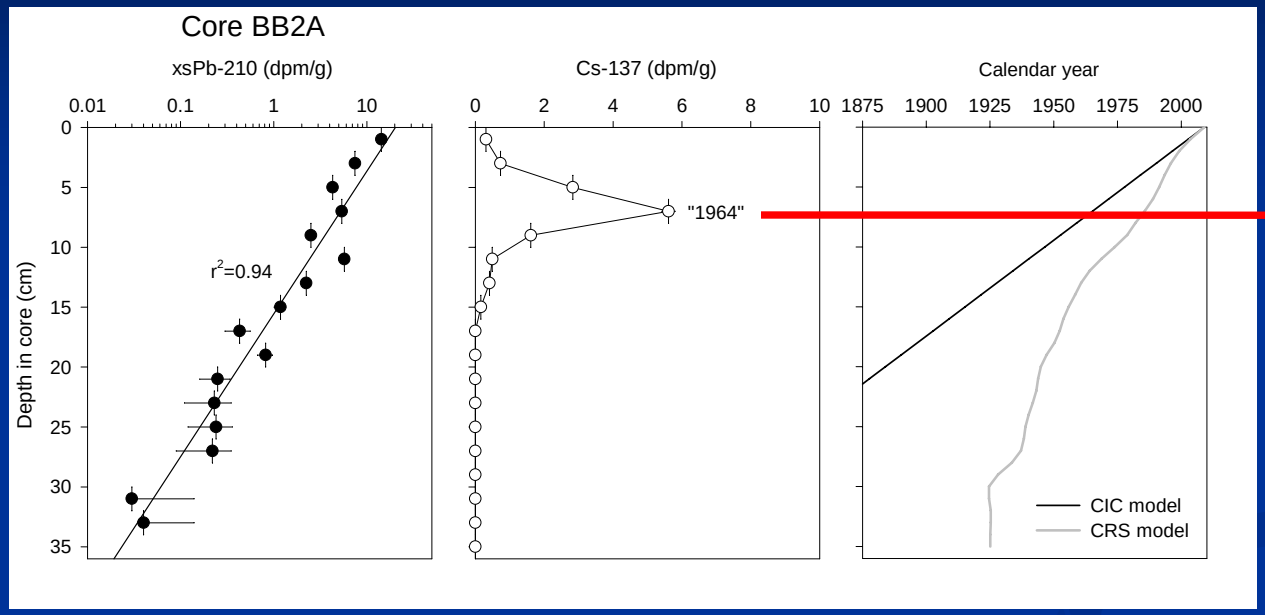
- ^{137}Cs: atomic weapons or power plants
- Onset and peak are used to mark age-depth
- Assume linear rates between dates
- Particle-reactive; can desorb in marine waters

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



Note: ages based on the CIC model

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



Note: 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

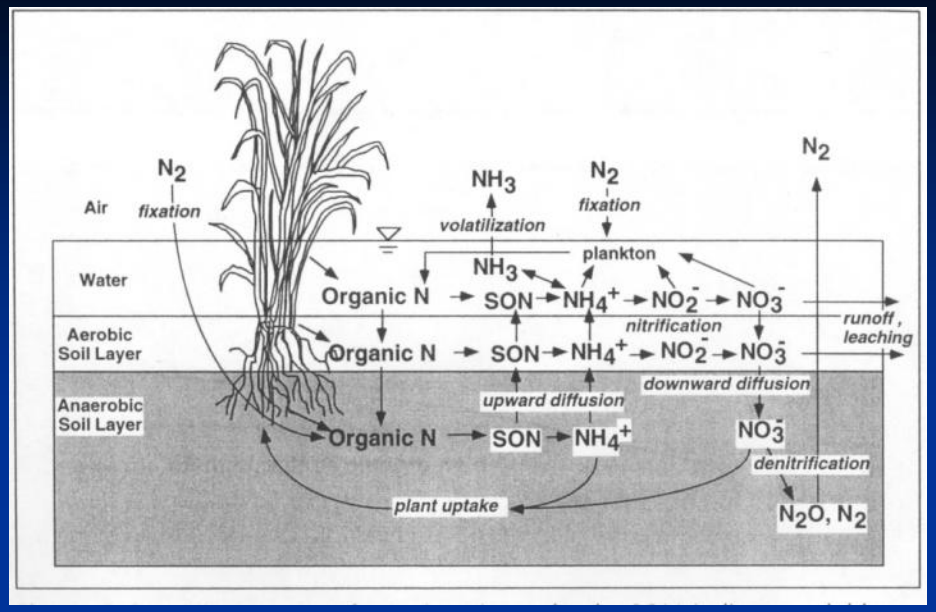
Barnegat Bay Sites:

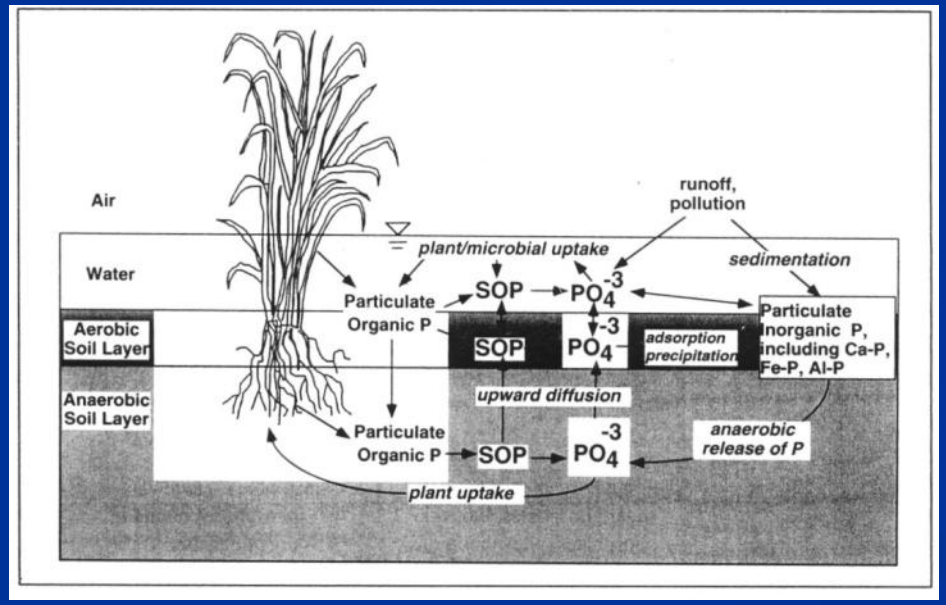
All Sites

Mean 0.25 ± 0.06 cm/yr, n= 4

Max 0.29 cm/yr

Min 0.16 cm/yr

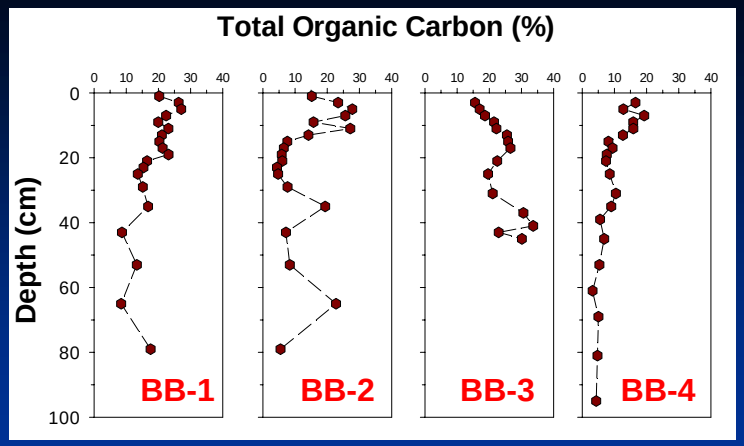


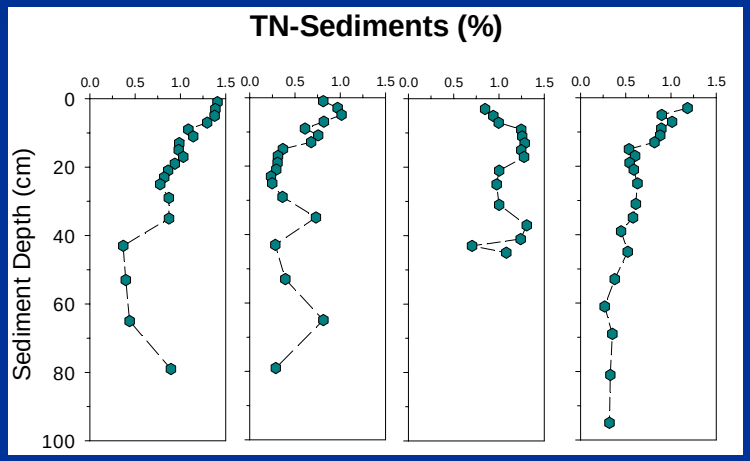


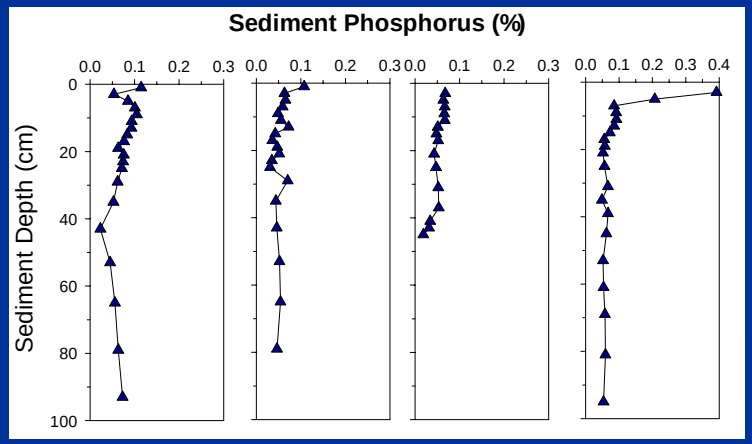
Generalized schematic of nitrogen and phosphorus cycling in wetlands

- Plants and microbial activity are a key component of N and P transformations
- In marine sediments, high levels of sulfide, 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 to some trace metals)

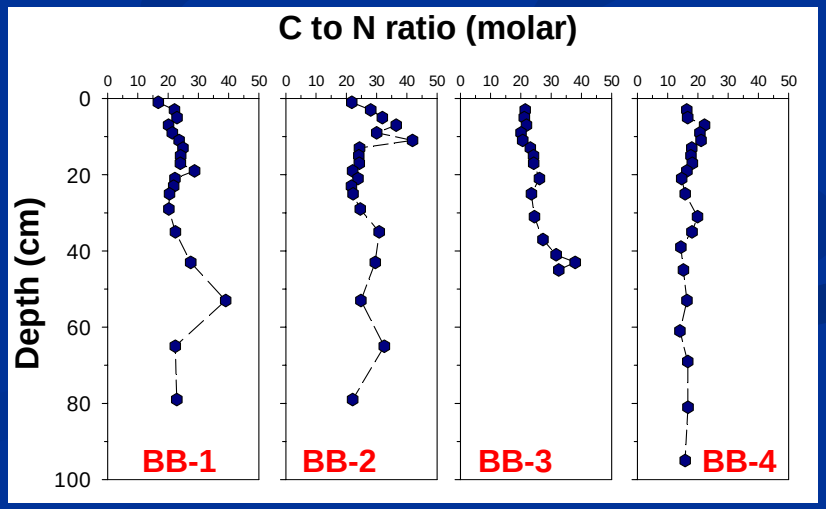
Distribution of CNP with Depth



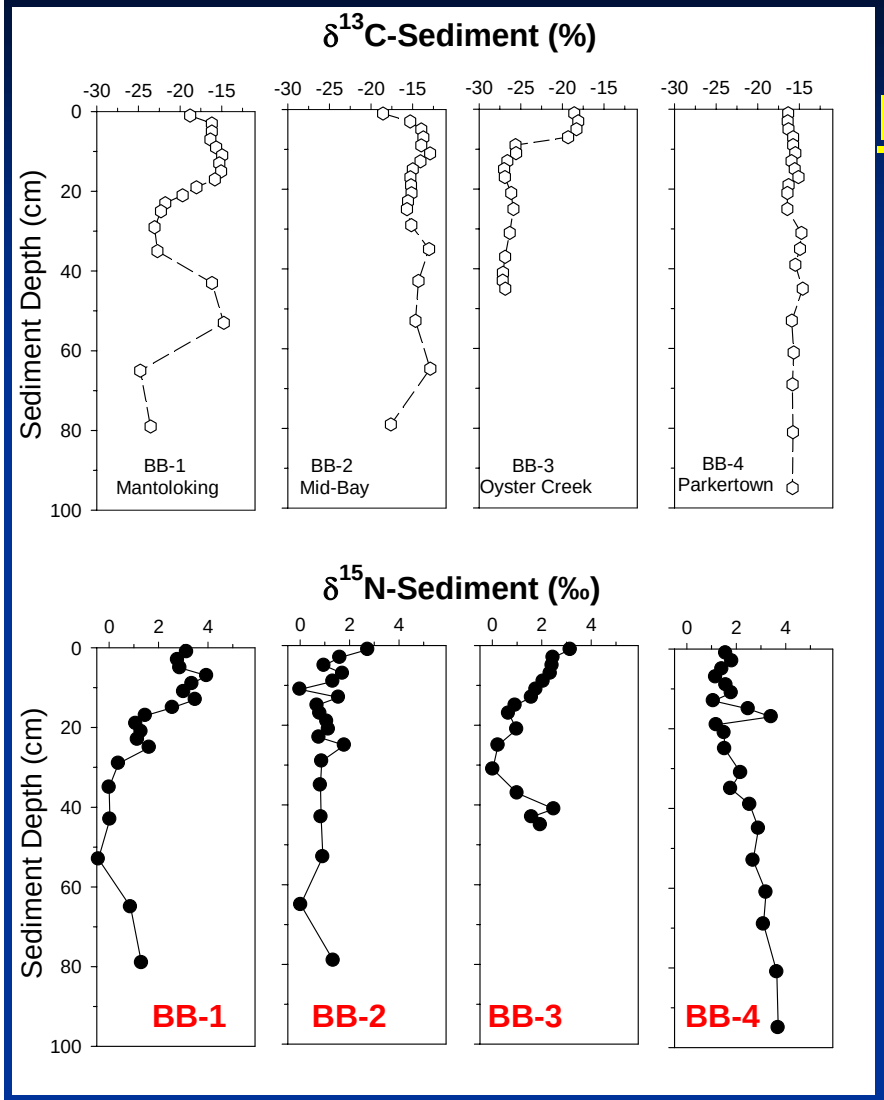




- Robust levels of CNP in BB marsh sediments
- Generally higher concentrations in the upper sections, with more constant levels at depth
- Very high P level observed at the surface of BB-4
- The C to N ratio is fairly constant in the upper 40 cm, except for Core BB-2



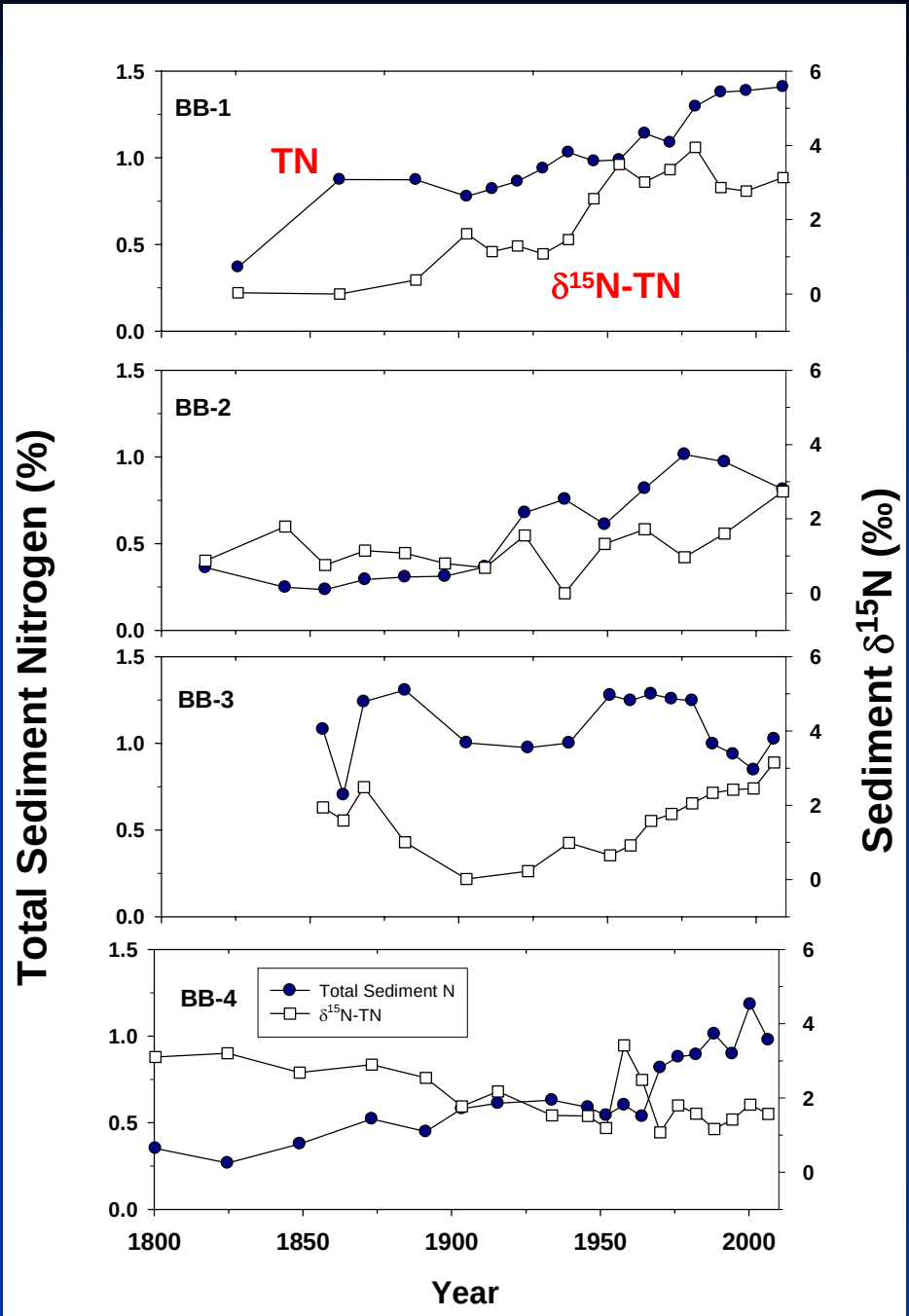
Stable Isotopes of C and N: Indicators of Sources and Change



- *Spartina sp* are C4 plants and would yield $\delta^{13}C$ of OC at ~ -15 to -12 per mil
- Terrestrial plants in this area, as well as algae, are C3 plants and would yield $\delta^{13}C$ of OC at ~ -30 to - 18 per mil (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.

$$\delta X = [(R_{sample}/R_{std}) - 1] \times 1000 \text{ (per mill)}$$

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?)

Inferring Past Plant Growth Rates

Using Carbon Stable Isotopes (sediments)

- Enzymes in plants that fix CO_2 prefer lighter isotopes ($^{12}CO_2$)
- Slower growth rates, preferential use of $^{12}CO_2$
- Faster growth rates, less discrimination between $^{13}CO_2$ and $^{12}CO_2$

$^{13}CO_{2aq}$ →

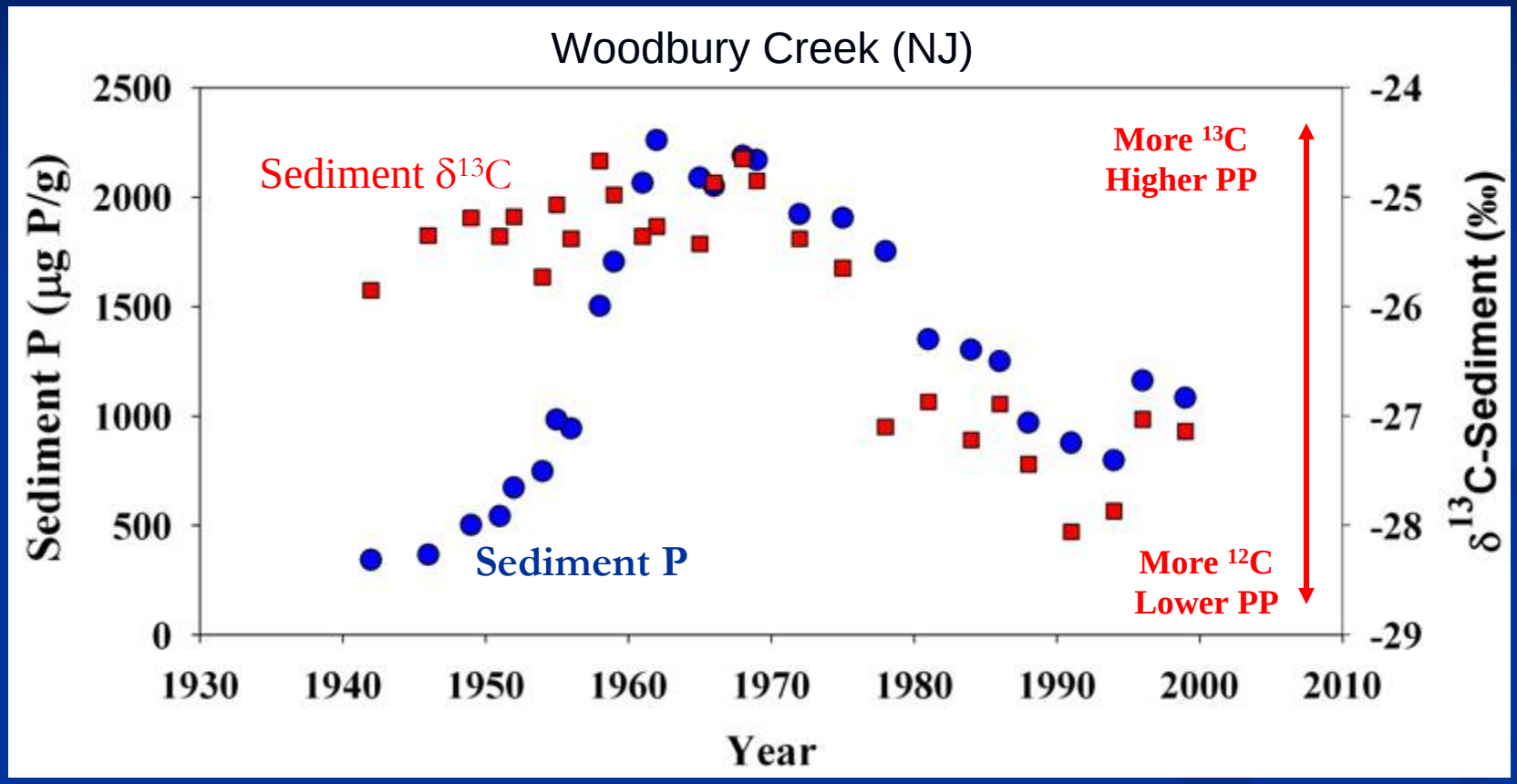
$^{12}CO_{2aq}$ →

Photosynthesis

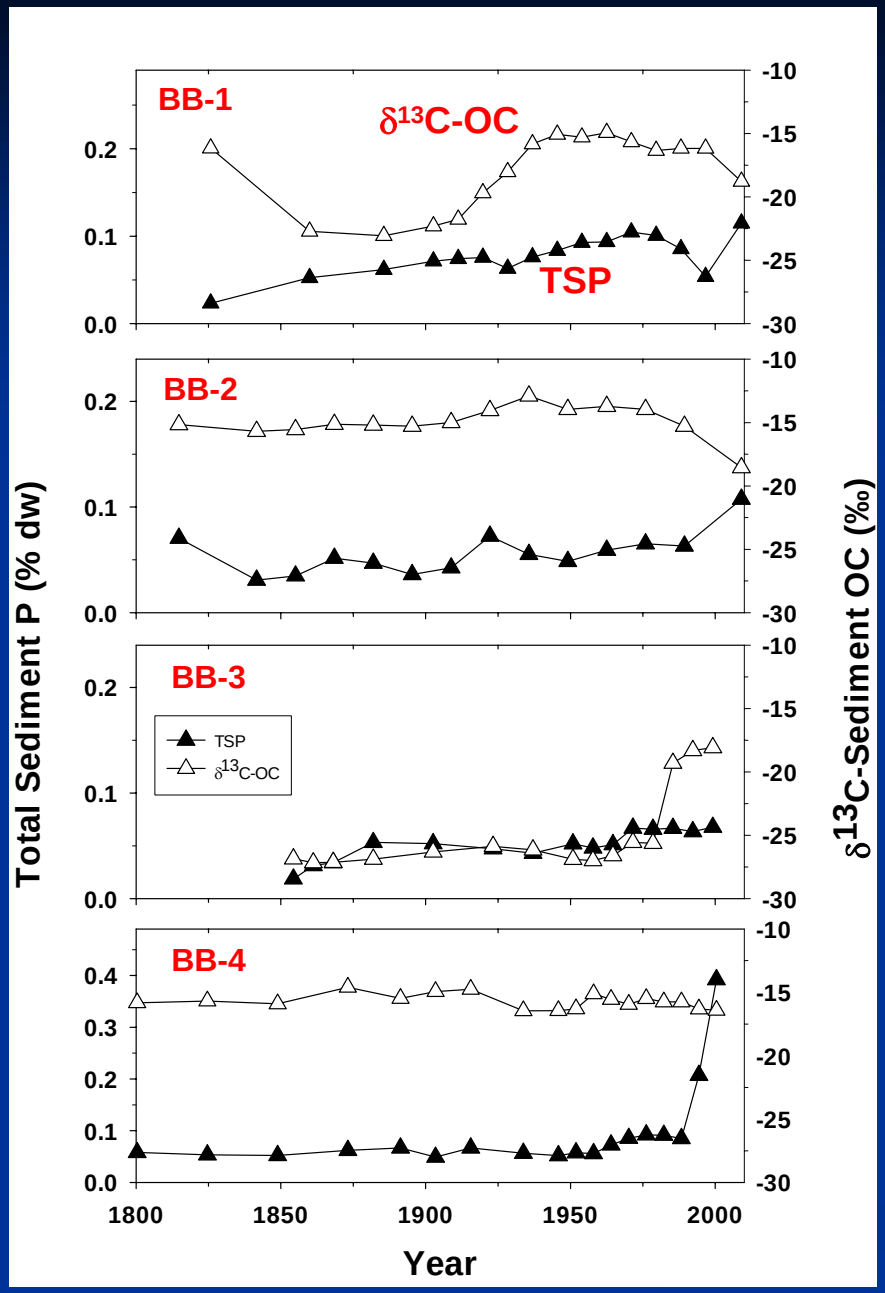
Algae

Can use this difference to help determine system primary productivity

Changes in Sediment Phosphorus and Isotopic Ratio of Carbon Over Time



Relationship between carbon isotopes and phosphorus suggests that the decrease in phosphorus in the tidal river results in lower overall primary productivity/biomass.



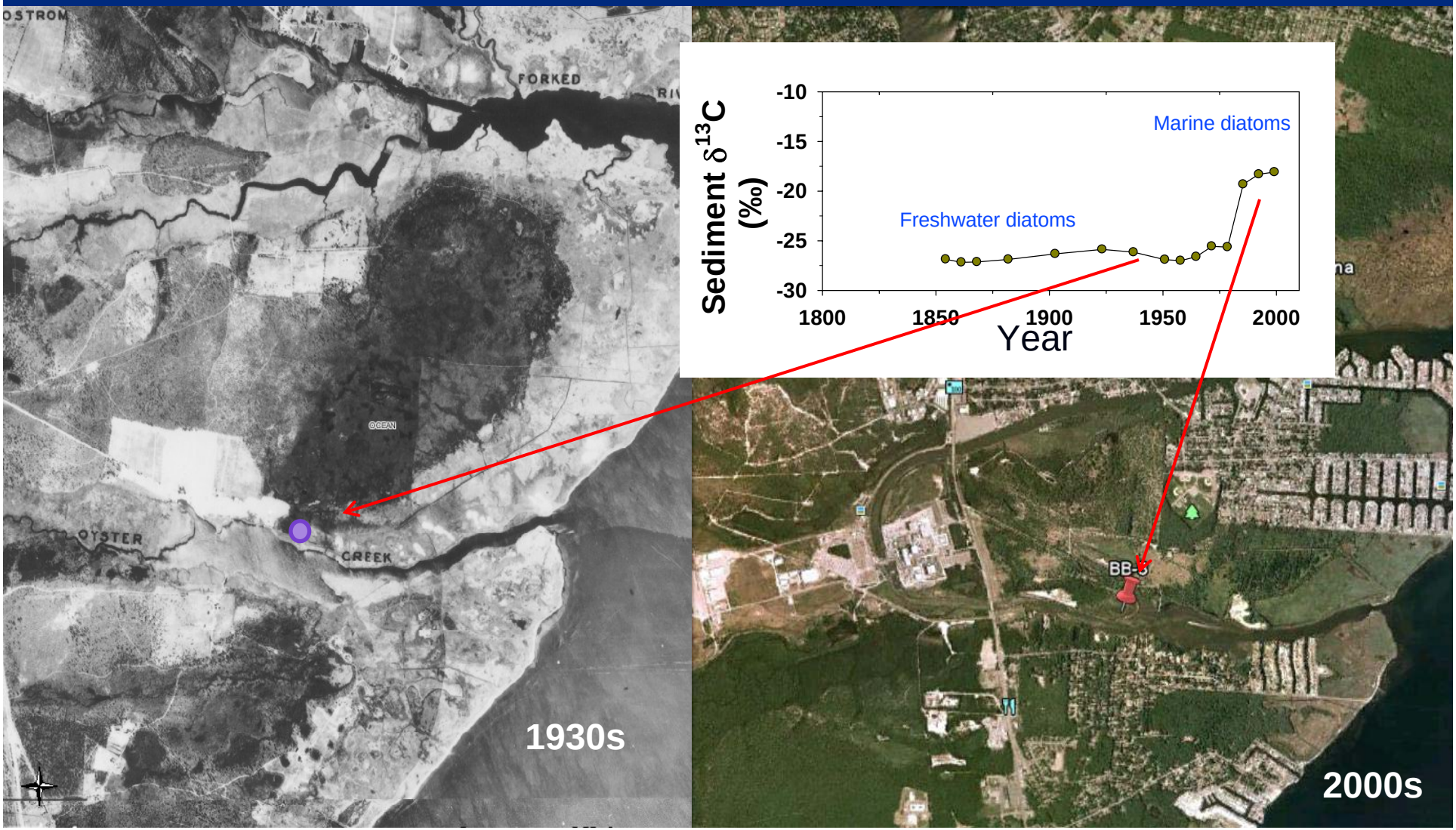
Changes in P with Time

- 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

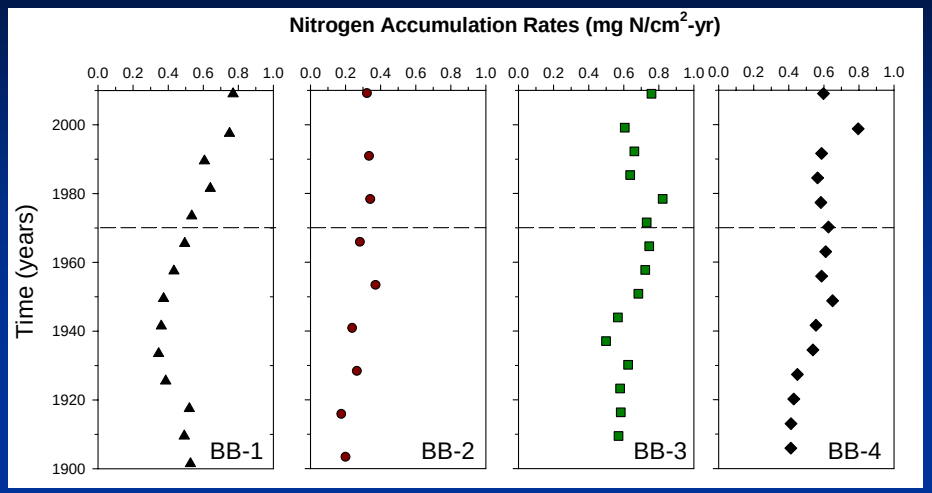
Changes at BB -3

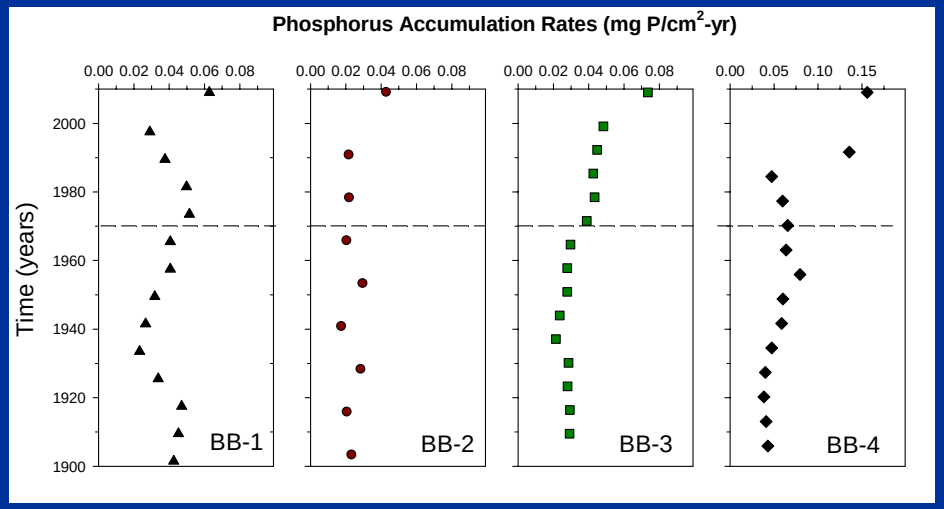
Potential Changes in:

- 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 rate 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

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:		
Core Top Concentration	6.45	0.88
Avg Concentration (50yrs)	5.48	0.54
Burial as % of Inputs		
Core Top Concentration	94%	88%
Avg. Concentration (50yrs)	79±11%	54±34%

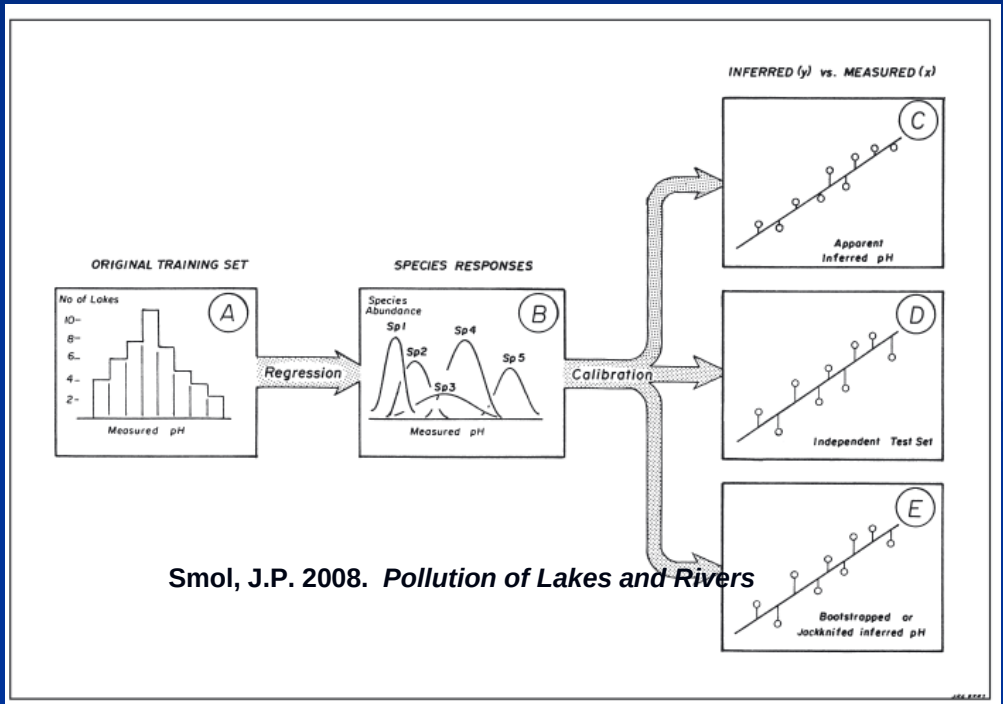
Nitrogen inputs ranged from 6.5 to 7.65 $X10^5$ kg/yr (Hunchak, 2001; Wieben and Baker, 2009; Kennish et al., 2007) while phosphorus input is derived from the Barnegat Bay Characterization Report. Wetland area (26,000 acres, 1.1 $X10^8$ m^2) are obtained from www.crssa.rutgers.edu/ projects/lc/.

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

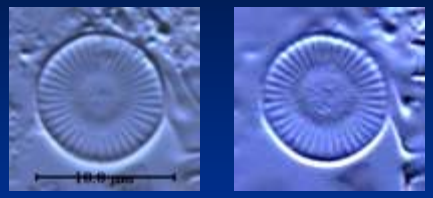


Smol, J.P. 2008. *Pollution of Lakes and Rivers*

Sample and Data Needs:

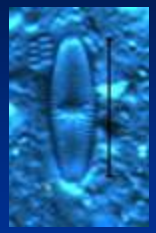
- Well preserved samples
- Calibration set (diatom species versus stressor)
- Adequate separation of the different groups
- Robust change in environmental parameter

High-nutrient diatom species



Cyclostephanos tholiformis

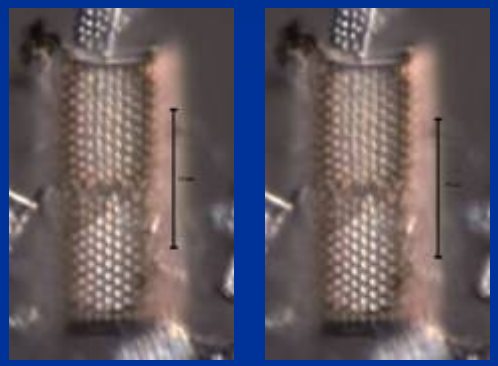
Stephanodiscus minutulus



Navicula minima

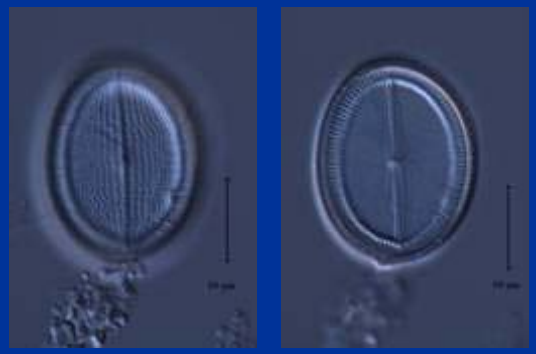
Rhoicosphenia abbreviata

Melosira varians

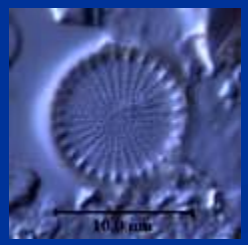


Aulacoseira granulata

Actinocyclus normanii

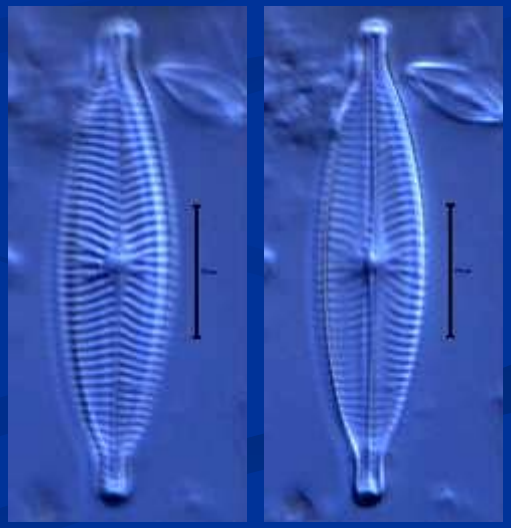


Cocconeis placentula



Stephanodiscus hantzschii

Navicula wildii



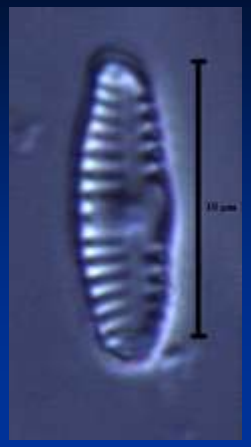
Navicula capitatoradiata

Low-nutrient diatom species

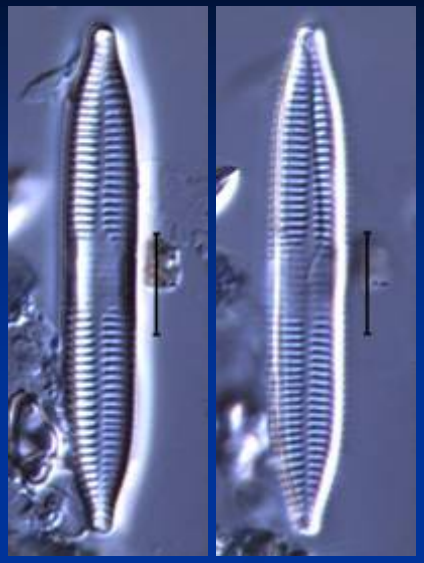
Cyclotella stelligera

Cyclotella pseudostelligera

Cyclotella tripartita



Reimeria sinuata



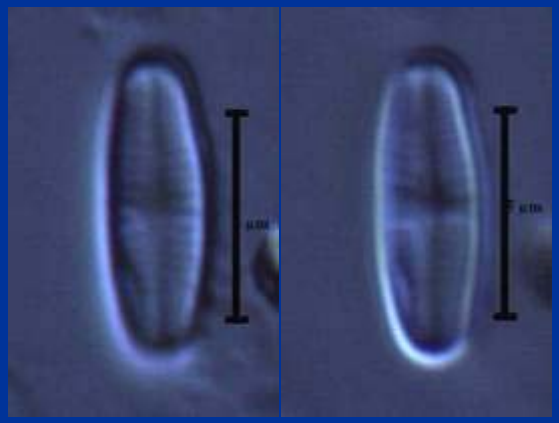
Synedra ulna

Cyclotella comensis

Cyclotella rosii

Staurosirella pinnata

Cymbella affinis

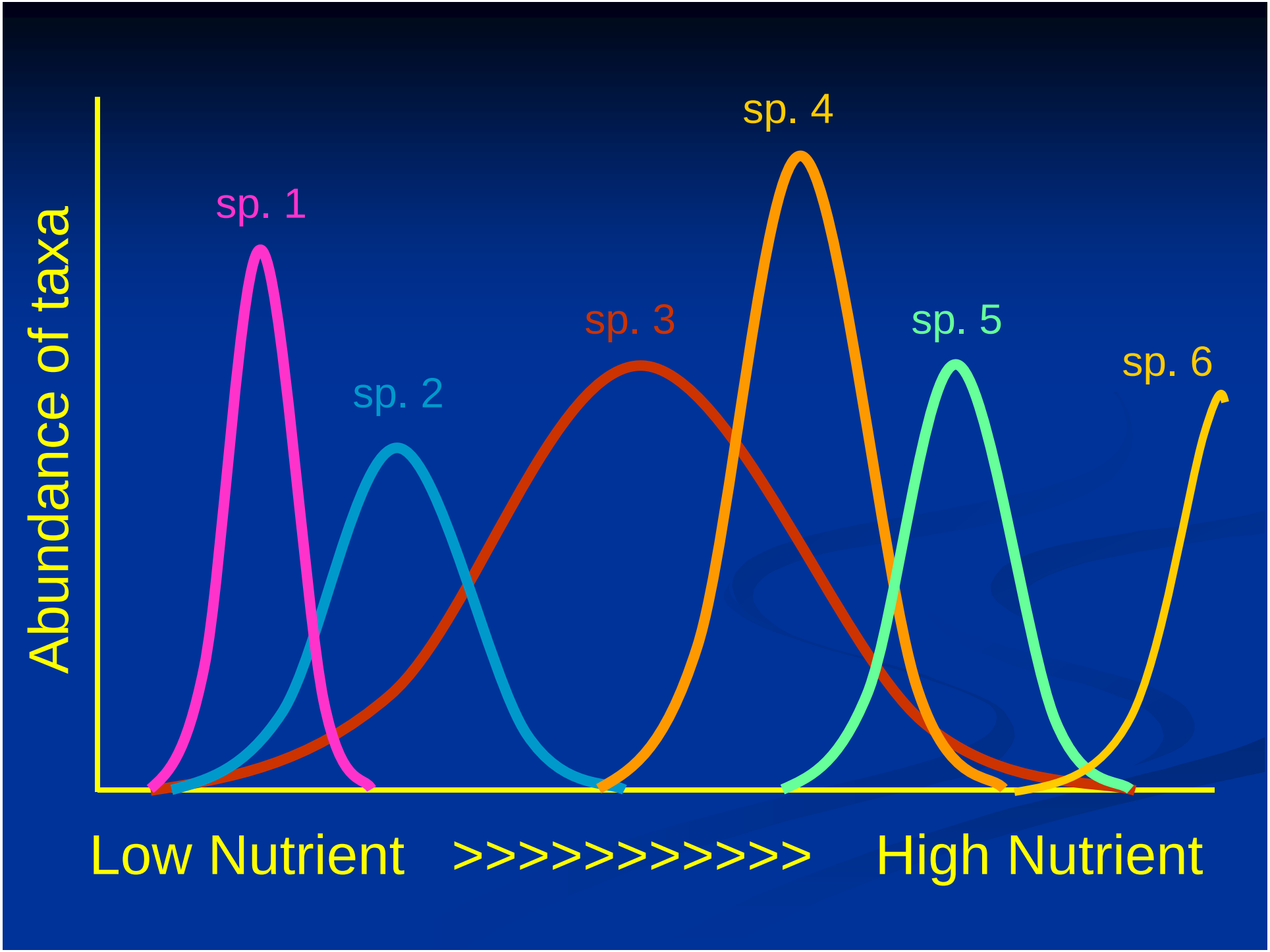


Achnanathidium minutissimum

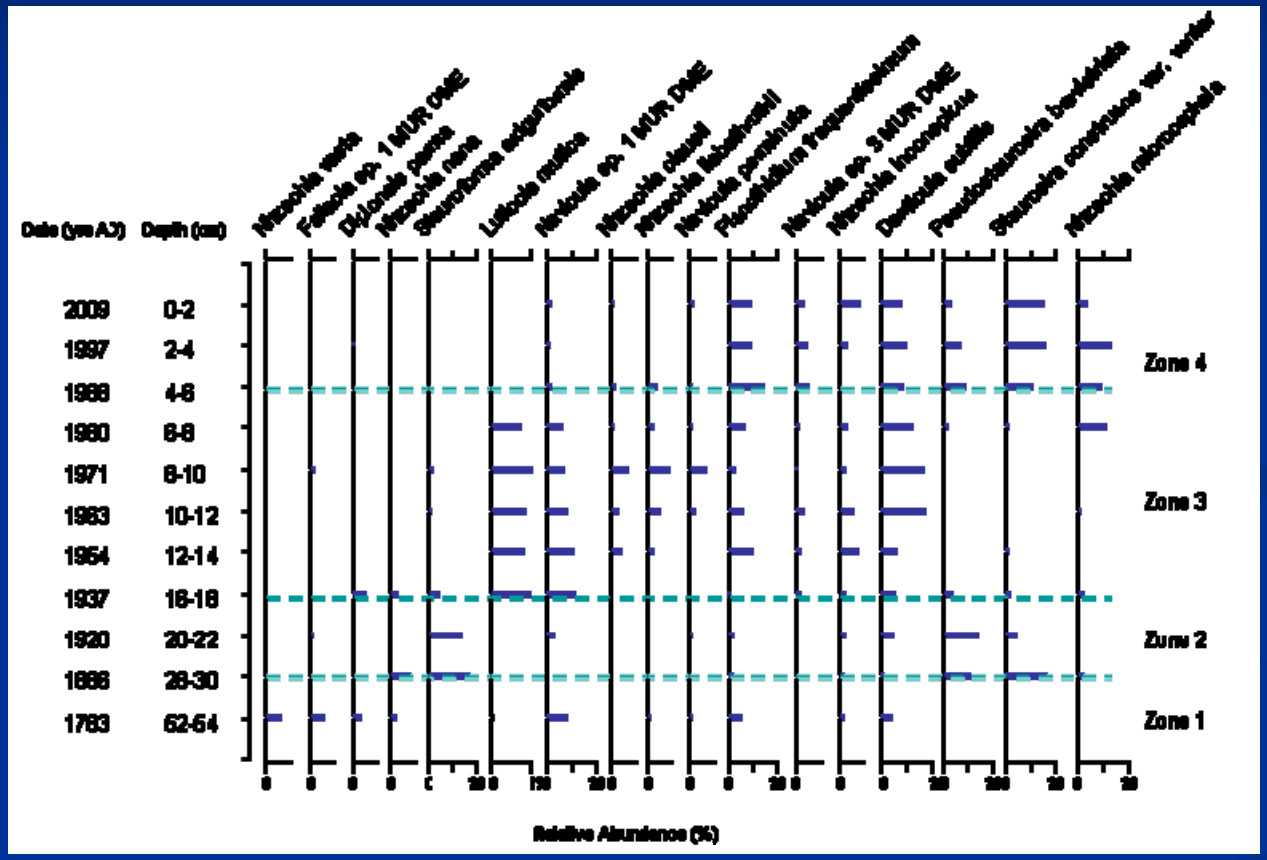
Fragilaria nanana

Encyonopsis microcephala

Fragilaria vaucheriae


Abundance of taxa
sp. 1
sp. 2
sp. 3
sp. 4
sp. 5
sp. 6
Low Nutrient >>>>>>>>>>>>> High Nutrient

Stratigraphic Diagram of Diatom Species: BB-1



Indicators

FW, high nutrient

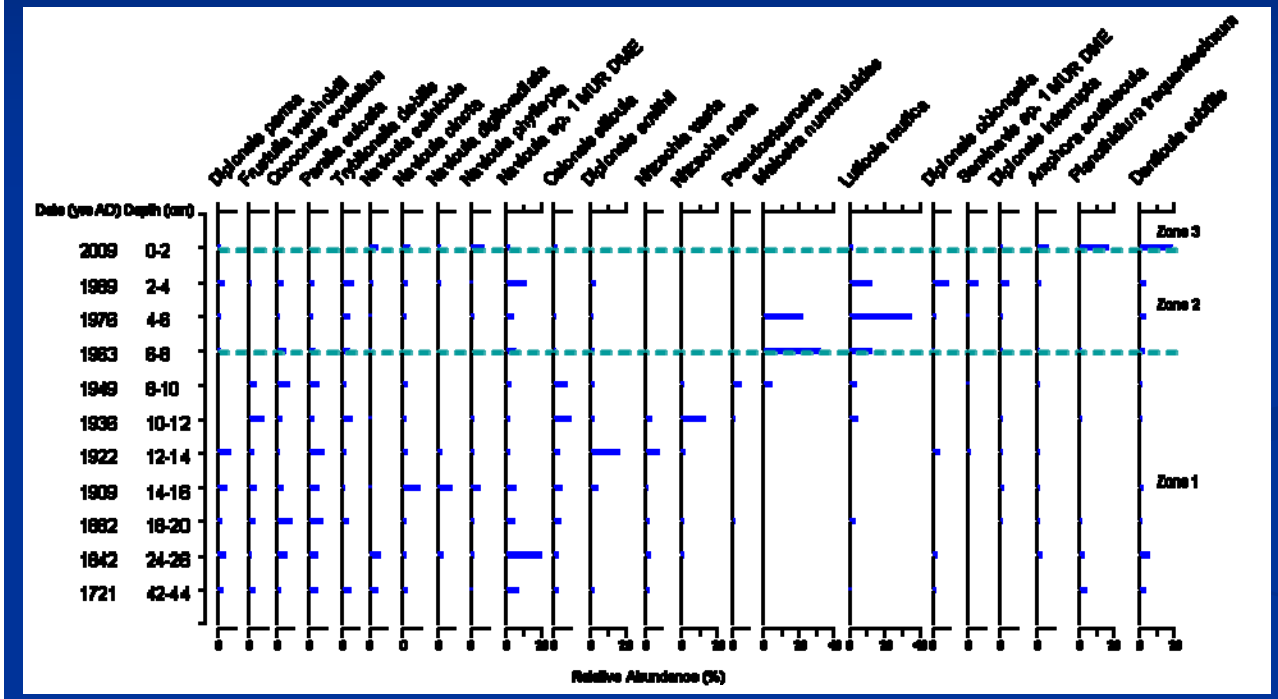
FW/Brackish, high nutrient

Diversity decreases (FW/Brackish)

Diverse group (FW, HN)

145 freshwater and coastal-brackish benthic diatom species were identified in 11 sections (17species present with > 5% abundance)

Stratigraphic Diagram of Diatom Species: BB-2



Indicators

Less diverse, pollution tolerant

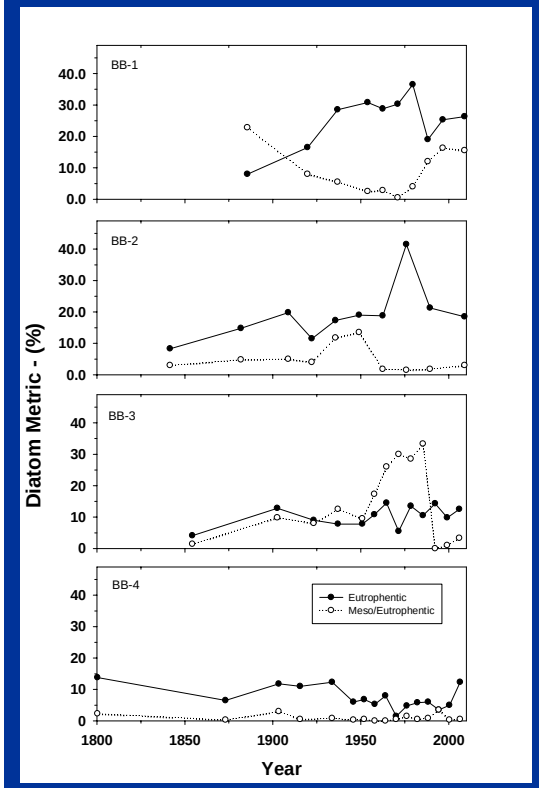
Less diverse, similar to Zone 3

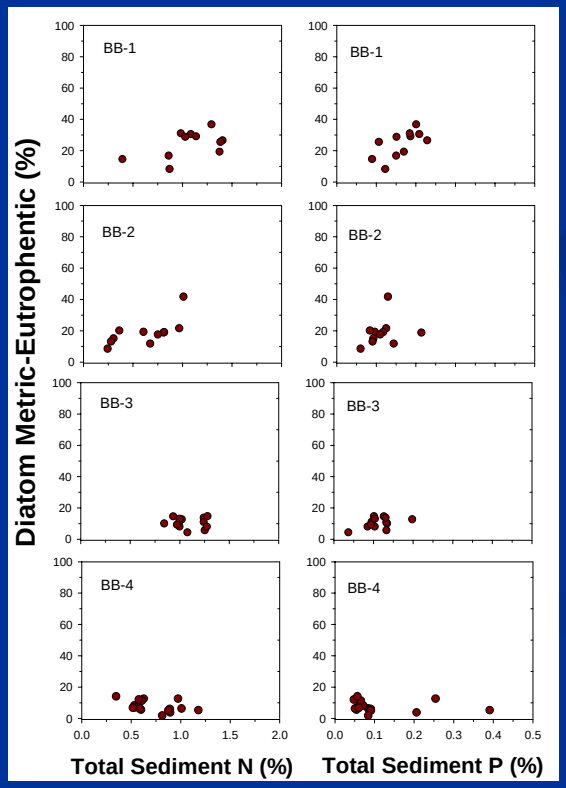
Diverse, Brackish/Marine

172 species were identified in 11 sections (21 species present with >5% relative abundance)

Stratigraphic Diagram of Diatom Species: Short Summary

- Variations in species composition with sharp historical change
- Larger changes in northern bay and less change with depth in the southern bay
- At BB-3, shift from freshwater species to mix marine/brackish species in the mid-1960s
- In all cores, except BB-4, shift to more pollution tolerant species





- Upbay sites show increase in high nutrient species (eutrophentic)
- At BB-3, higher meso-trophentic species between 1950s to mid 1960s.
- Downbay site appears to be less impacted (more undescribed species)
- Relationship between TN (+δ^{15}N) and TP in the upper bay with %eutrophentic species
- Few relationship(s) in the two downbay core samples

Summary and Conclusions

- Marsh accretion rates range from 1.6 to 2.9 mm/yr and are lower than those in the bay shore area of NJ due to lower sediment input. While rates are accreting slightly above global sea level rise (1-2 mm/yr), when subsidence is taken into account there is an apparent accretion deficit (-0.1 to -1.0 mm/yr)

- Changes in N concentrations and δ^{15}N-TN reflect increase N inputs and changes in the source of N over time

- Diatom assemblages and associated metrics indicate major shifts toward more eutrophentic or mesotrophentic conditions starting in the 1940-1950s (cores BB-1, BB-2, and BB-3) relative to population and land development

- Diatoms from all cores indicate a more recent shift starting in late 1980-early 1990; this last shift may represent combined effects from water pollution, nutrient inputs and climate change.

Recommendations

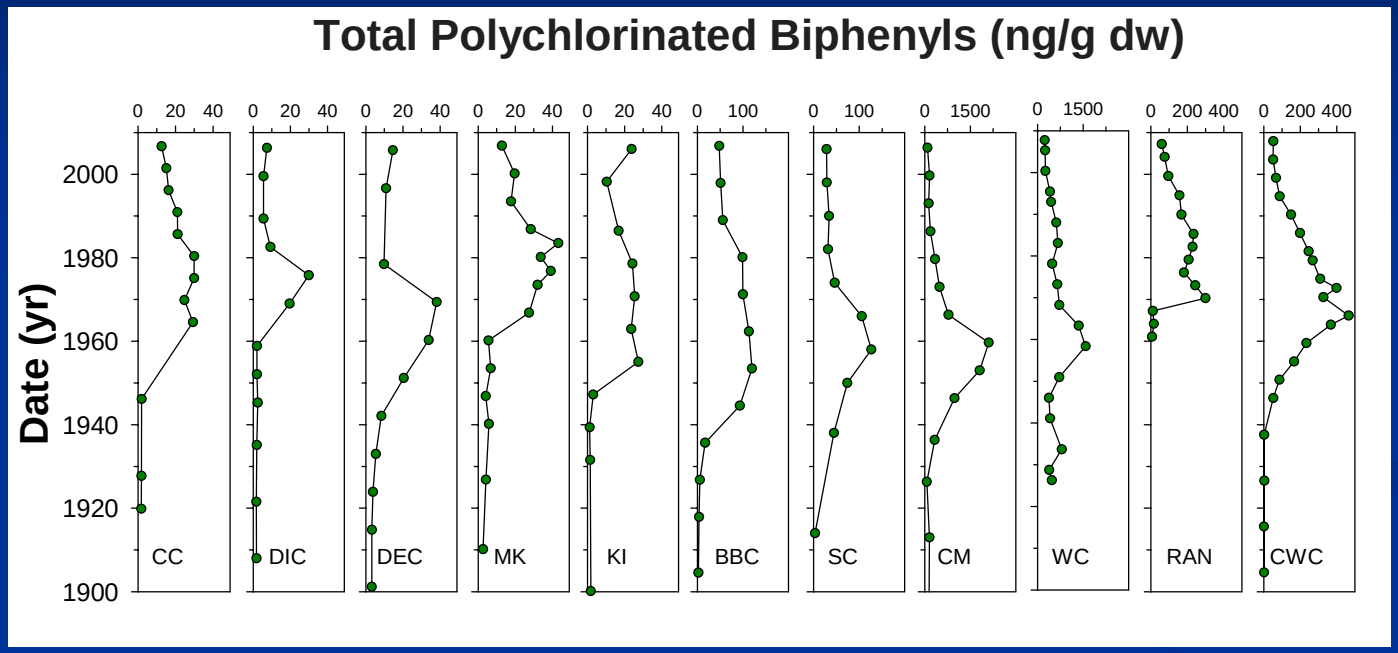
- Since many species found in Barnegat Bay sediment samples have not yet been described in the literature, it is necessary to characterize the un-described species and determine their autecology.

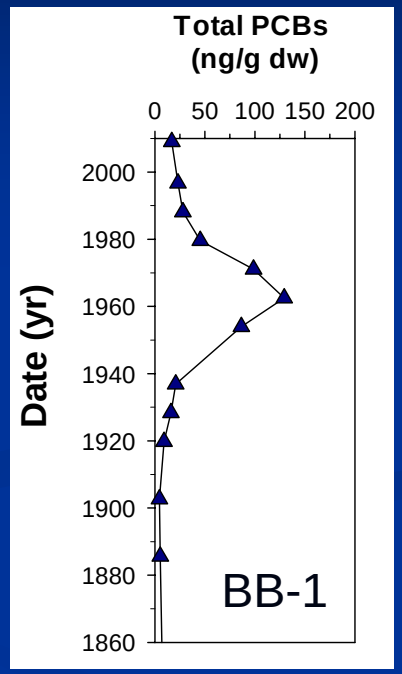
- Develop a surface-sample diatom calibration dataset for Barnegat Bay (and coastal NJ) and adjacent wetlands and use it to determine the ecological preferences of diatom species from this area.

- Analyze the cores for additional indicators of nutrient enrichment, harmful algal blooms, and ecosystem change (e.g, *Aureococcus sp*., dinoflagellates and related geomarkers)

- Results of this project revealed that Barnegat Bay marshes can bury a substantial portion of the N and P entering the bay. Burial is only one method for N sequestration that these marshes can perform. To better assess the total removal potential from coastal wetlands, additional cores need to be taken as well and **importantly**, denitrification studies need to be accomplished.

Total PCBs in Delaware Estuary and Barnegat Bay Marshes





- PCBs first produced in 1920s
- PCBs phased ban in late 1970s

Questions??

Acknowledgements

- We appreciate the funding from NJ DEP and US EPA Region II, the Environmental Associates of the Academy, and Academy Endowment Support.

- Roger Thomas, Paul Kiry, Paula Zelanko, Jared Halonen (UDEL) for field and laboratory assistance.