Development of Subaqueous Soil Interpretations

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Resource Managers requesting subaqueous soil survey data for specific resource management

- US-EPA
- MD-DNR
- Chesapeake Bay Program
- DE Inland Bay Program
- Various SWCD
- Assateague Island National Park
- Private Aquaculture Industry
- NOAA
- Shellfish Harvest Industry
- Sierra Club
- Maryland Coastal Bays Program
- Baltimore Harbor/Bay Dredging
- US-ACOE
- Pamlico-Albermarle Sound NEP Program

(King, 2003)

Specific Subaqueous Soil Resource Based Interpretations

- Seagrass Restoration
- Crab Habitat
- Clam Stocking
- Sustainable Production Clam, Oyster, and Scallop
- Nutrient Reduction
- Pathogens Pfesteria Cyst Residence Sites
- Benthic Preservation Site Identification
- Wildlife Management
- Habitat Protection for Horseshoe Crab and Diamondback Terrapin
- Dredging Island Creation
- Tidal Marsh Protection and Creation
- Bathymetric Map
- Navigational Channel Creation/Maintenance
- Effects of Dredging on Benthic Ecology
- Off Site Disposal of Dredge Spoil
- Acid-Sulfate Weathering Hazards
- Dune Maintenance and Replenishment
- Carbon Sequestration

Subaqueous Soil Interpretations

- Shellfish management
- Upland placement of dredged soil material
- SAV restoration
- Carbon sequestration
- Contaminant Accumulations
- Moorings

Upland Placement of Estuarine Dredged Material

- Benefits and Uses
  - Beach replenishment
  - Eelgrass (SAV) bed restoration
  - Marketable topsoil
  - Island creation

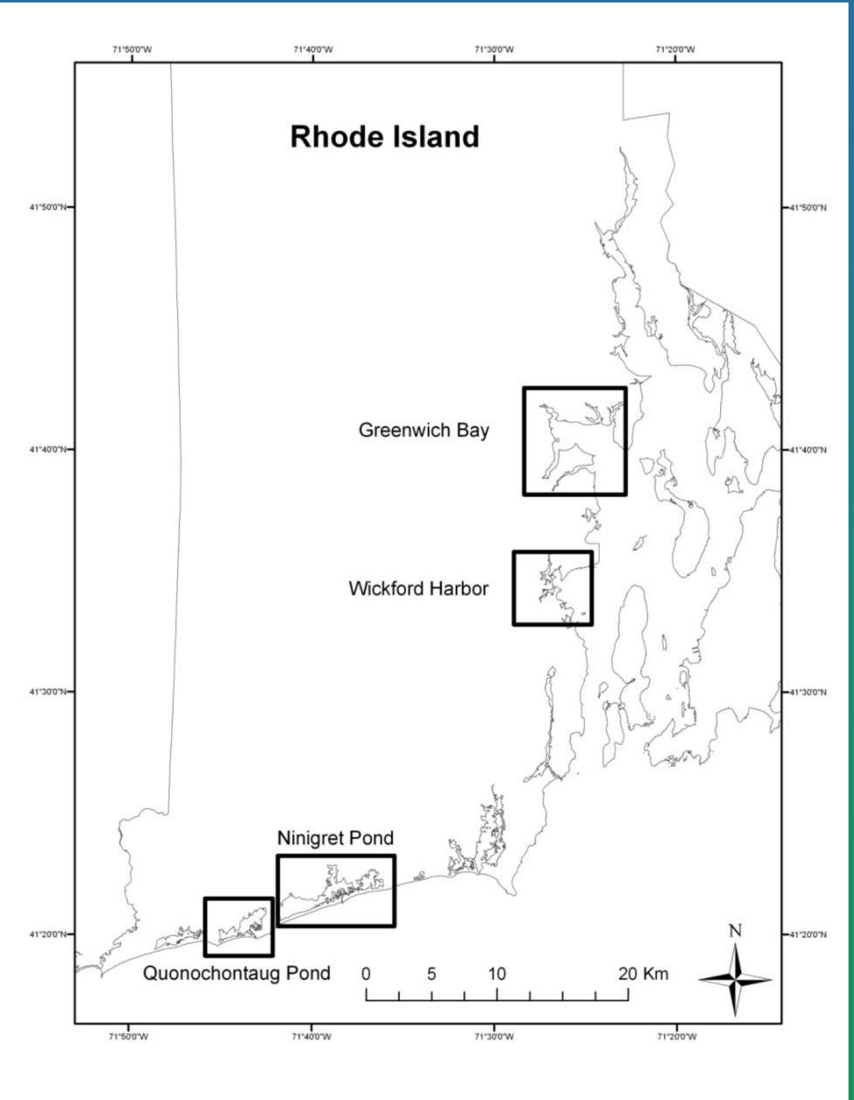
- Hazards
  - Heavy Metals
  - Toxins (organic and inorganic)
  - Petroleum products
  - Salts
  - Formation of acid sulfate conditions

Courtesy: Maggie Payne

What happens to marine dredged material when placed in a subaerial environment and exposed to natural conditions?

Collected Simulated Dredged Material to a Depth of 25 cm

- **Embayments: Wickford Cove and Greenwich Bay**
  - **Spit, Submerged Mainland Beach, Bay Bottom, Mainland Cove**
- **Coastal Lagoons: Ninigret and Quonochontaug Ponds**
  - **Flood Tidal Delta, Washover Fan, Lagoon Bottom, Mainland Cove**



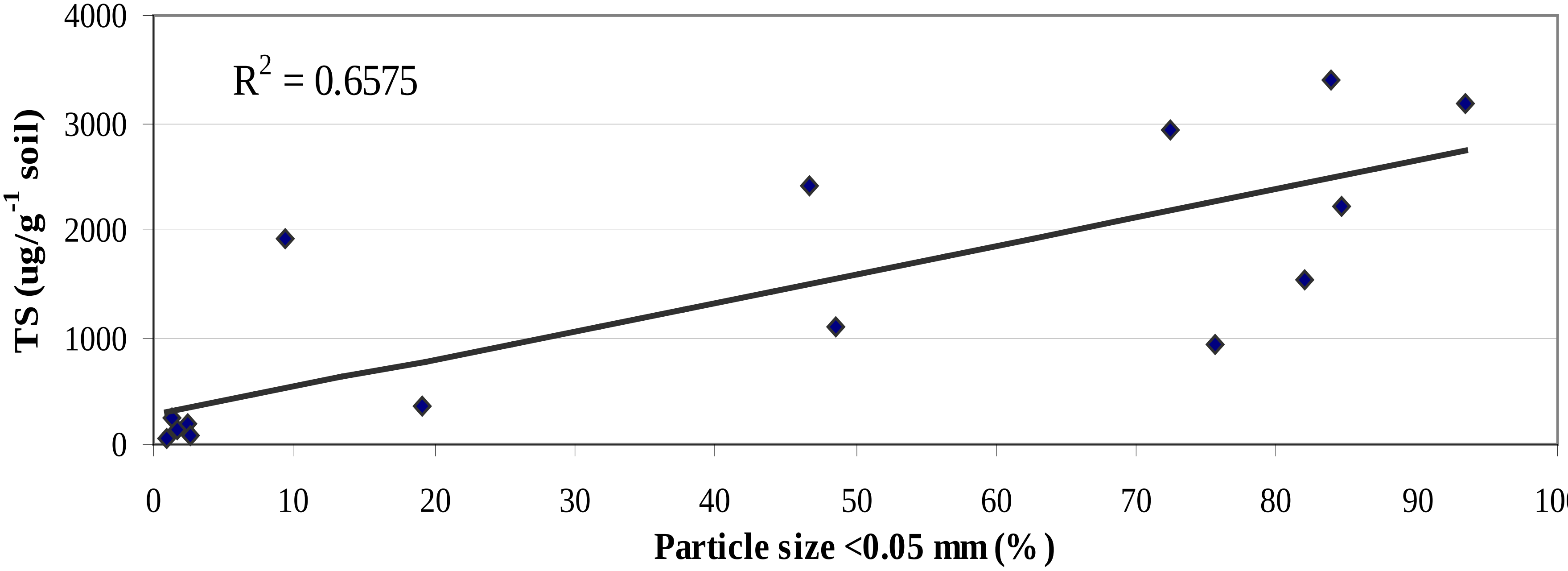
Mesocosm Experiment

- Soil (dredged) materials mixed in a bucket
- Placed into 4 x 10 inch cylindrical mesocosms
- Exposed to natural conditions
- Leachate collected after rainfall
- 4 Mesocosms per landscape (16 per pond)
- 64 Mesocosms

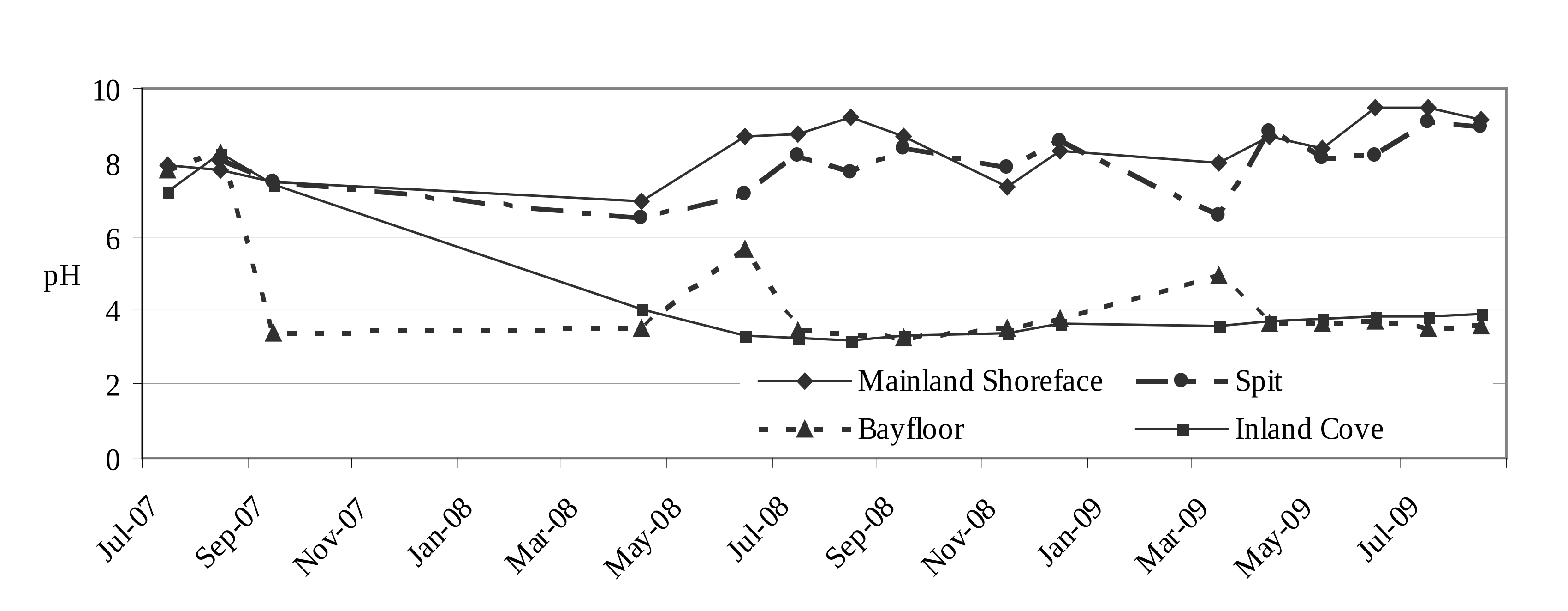
Dredged Material Characterization

Soil Property	Spit, Shoreface, Washover Fan, Flood Tidal Delta	Mainland Cove, Lagoon Bottom, Bay Bottom
Texture	Sand, loamy sand, fine sand	Loamy fine sand, silt loam
SOC %	0.3 to 1.2	3.1 to 6.3
$CaCO_3$ %	0.04 to 0.50	0.25 to 0.93
8 Week Incubation pH	5.0 to 8.5	2.8 to 4.1
Total Sulfur (XRF, $\mu g\ g^{-1}$)	0 to 3260	3280 to 8400
AVS ($\mu g\ g^{-1}$)	0 to 360	10 to 240
CRS ($\mu g\ g^{-1}$)	60 to 1090	930 to 3260

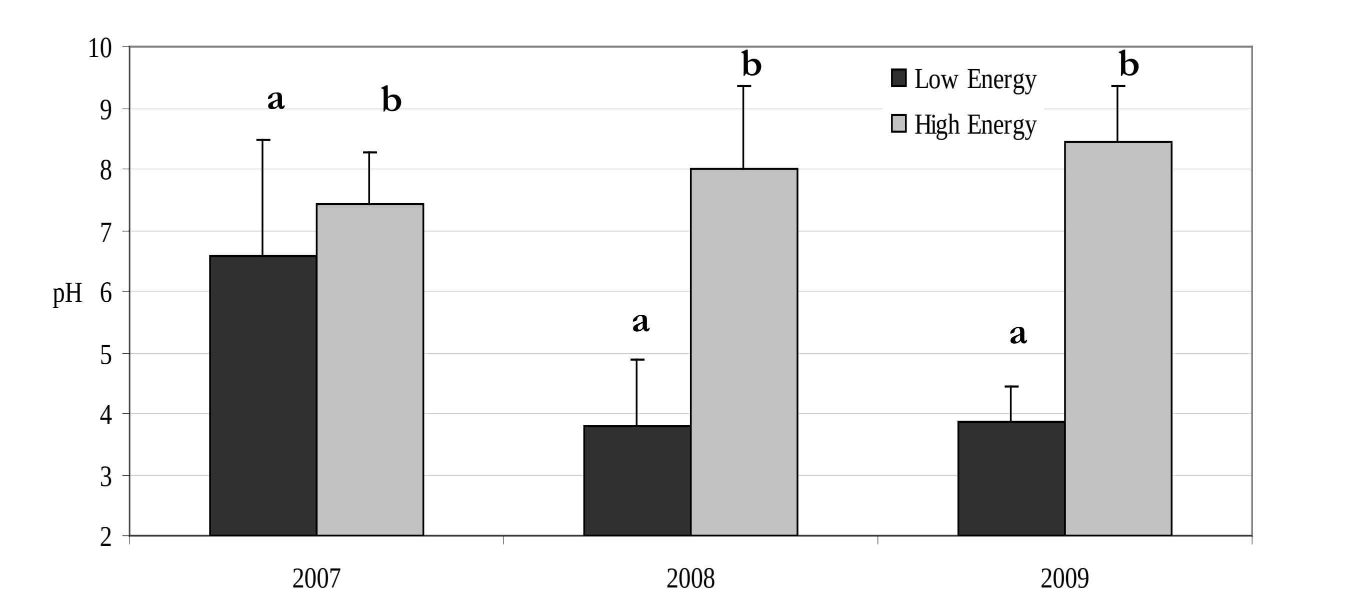
Total inorganic sulfur (AVS + CRS) -- particle size relationship



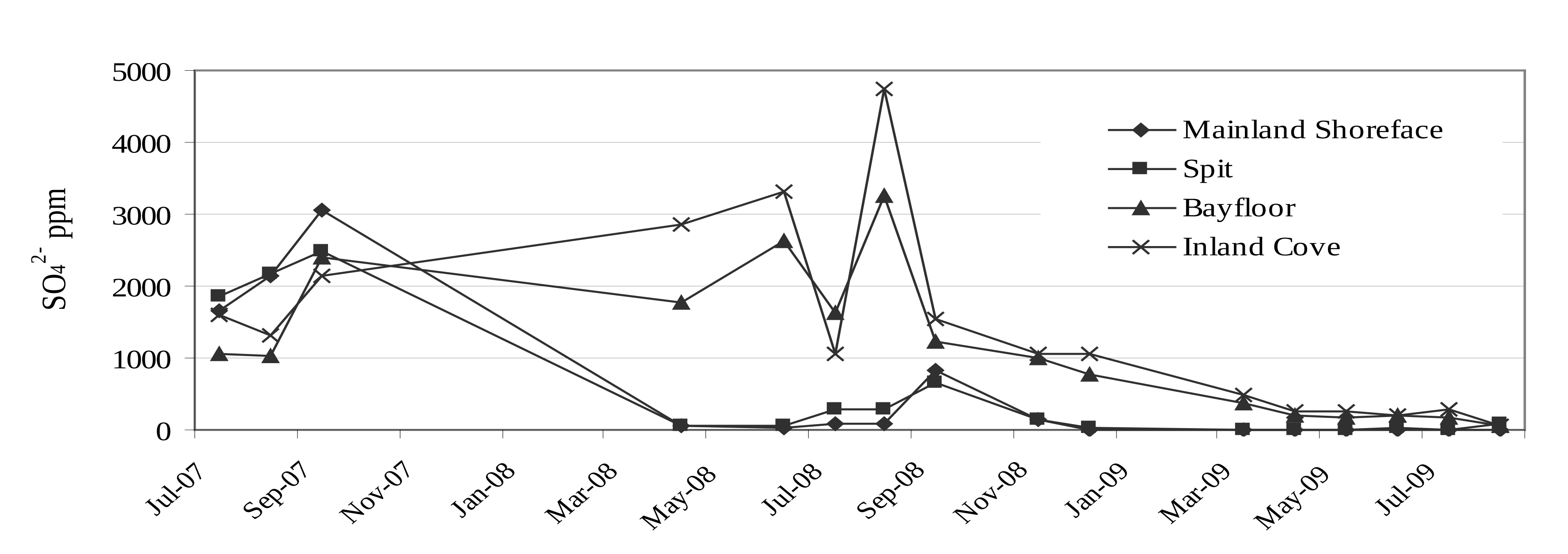
Leachate pH Greenwich Bay



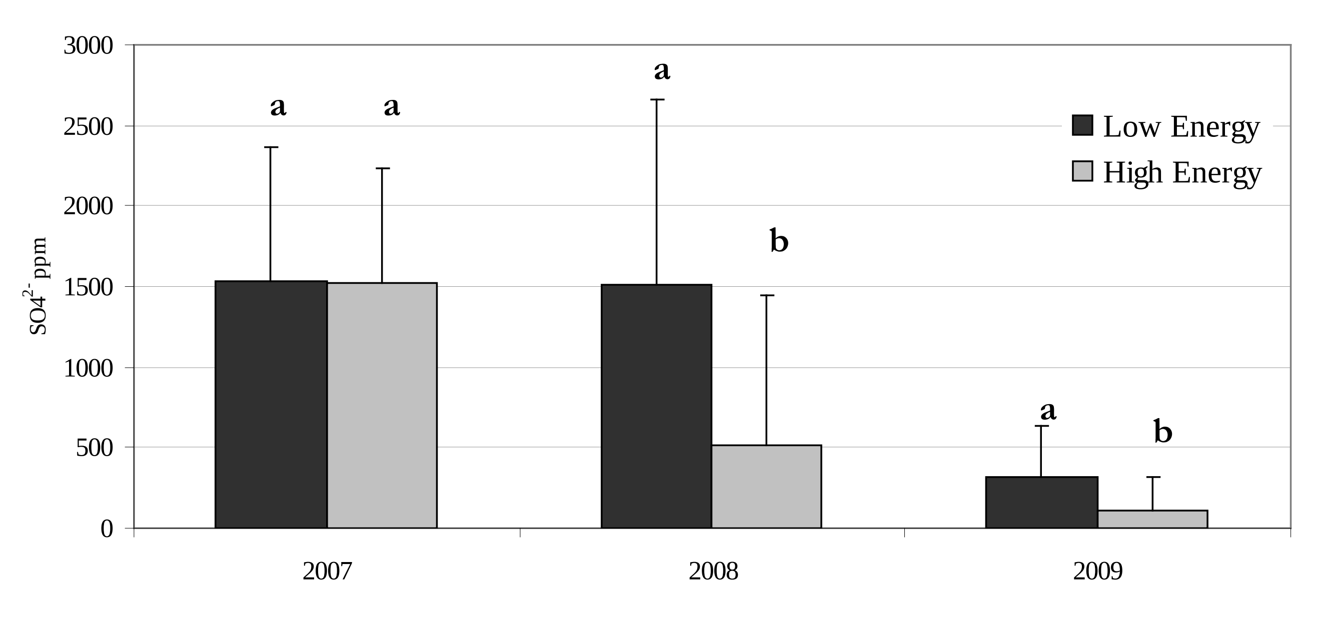
Leachate pH among high and low energy samples by year



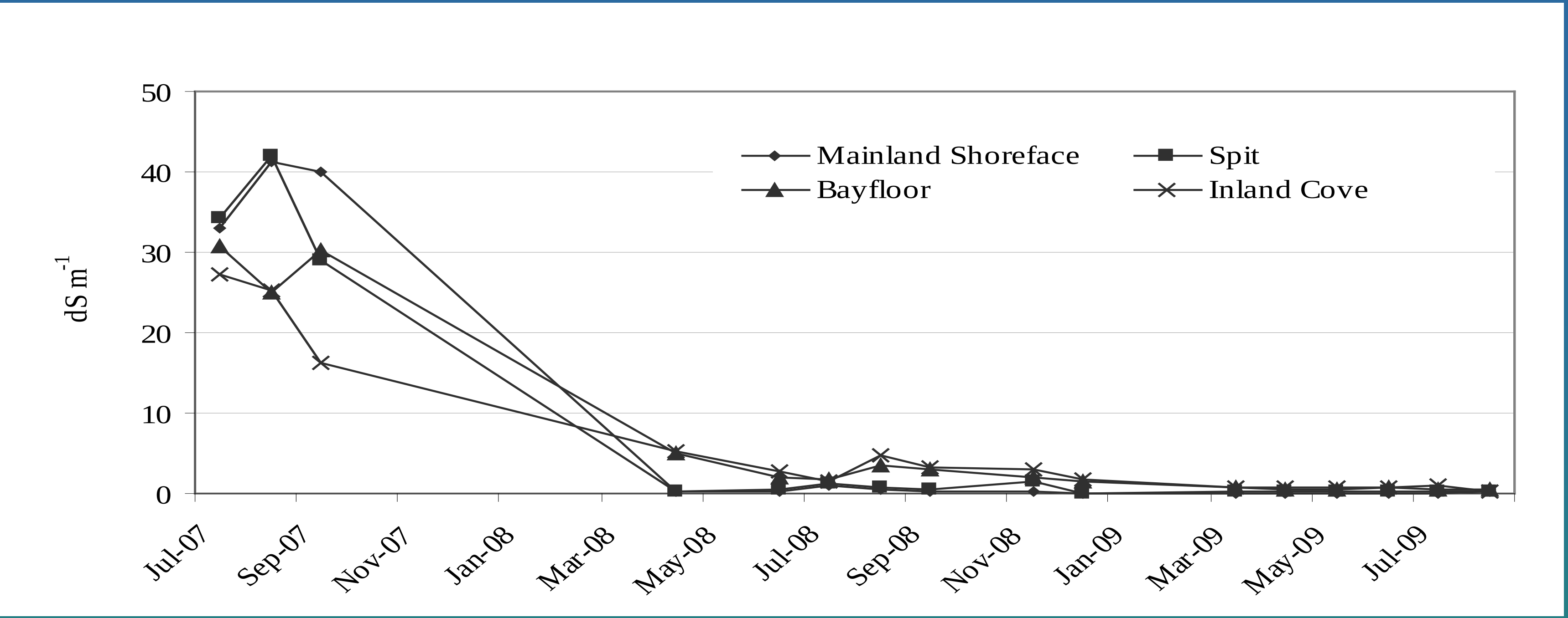
Leachate sulfate content Wickford Harbor



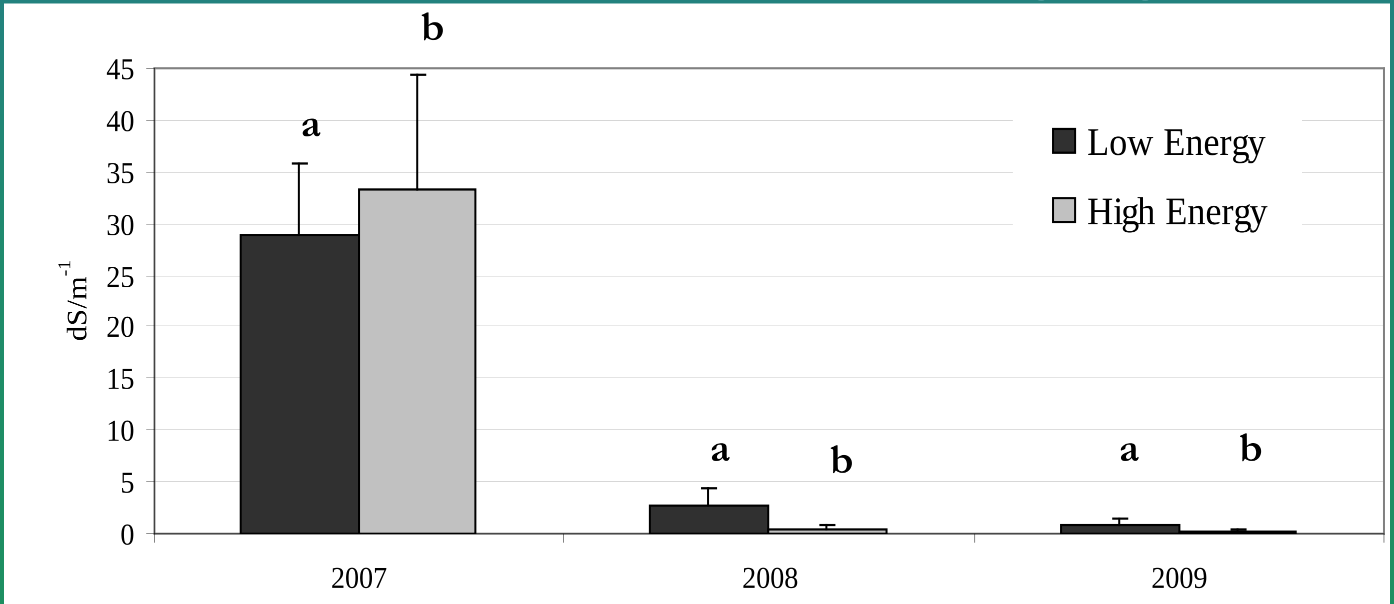
Leachate sulfate content (ppm) among high and low energy samples



Wickford Harbor leachate conductivity

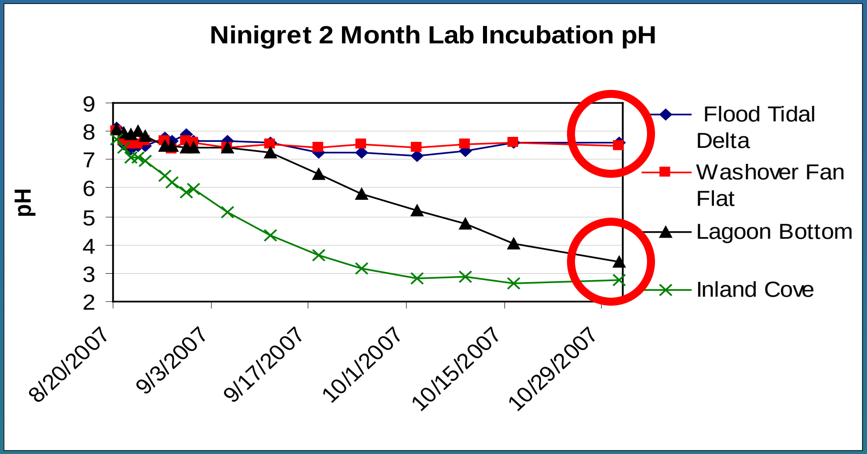


Leachate conductivity (dS m^{-1}) among high and low energy s



Mixed Dredged Material Investigation

Observed a de-coupling of sandy vs. silty landscape units (pH)



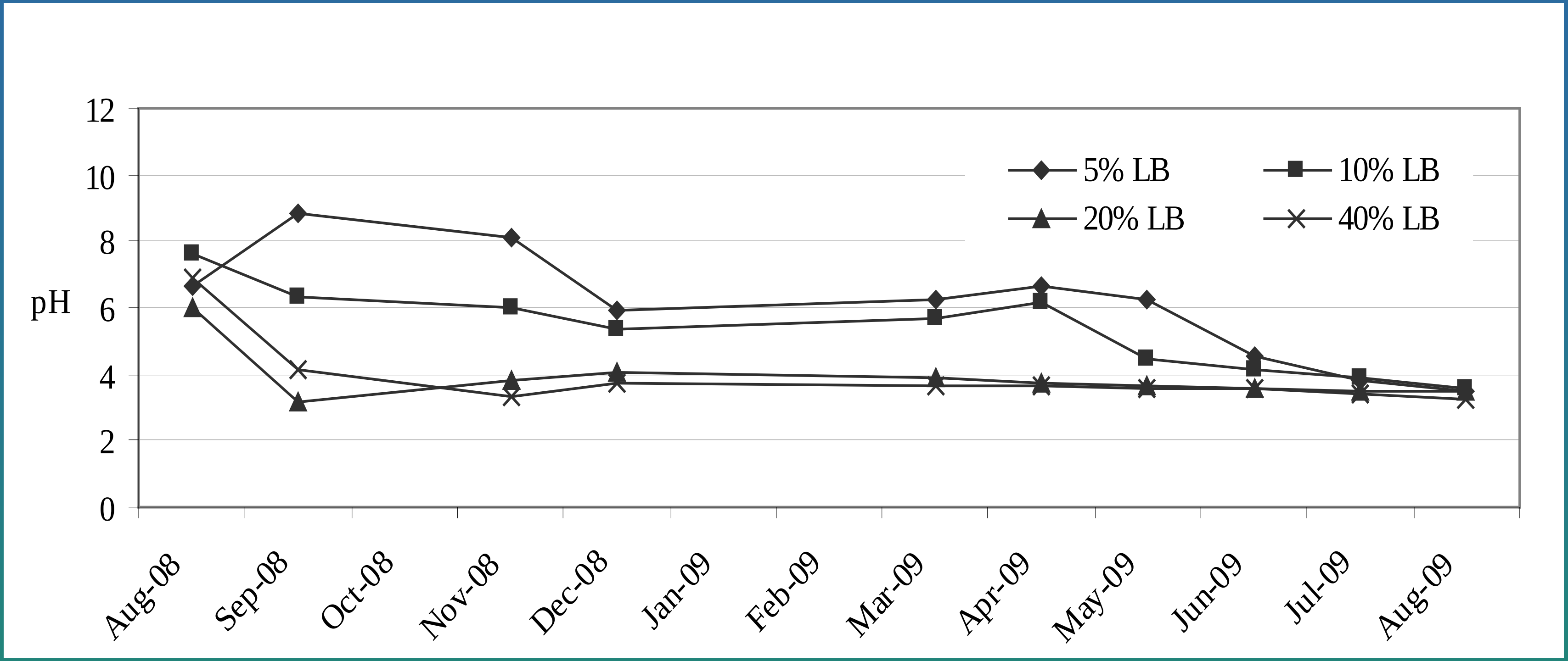
What are the effects of mixing different materials?

- Study Site
  - -Ninigret Pond
- Landscapes
  - -Lagoon Bottom
  - -Washover Fan
- 2 reps per mixture for 8 new mesocosms
- Total of 72 mesocosms

Mixed different Ratios of LB (silty) to WF (sandy)
By volume

5% LB; 95% WF
10:90
20:80
40:60

Mixed mesocosm leachate pH



Implications: Even a small percentage of lagoon bottom material (5%) will affect the chemistry of the dredged materials and lower the pH < 4.0 within a year

Summary and Conclusions

- Upland placement of fine textured materials quickly resulted in acidic conditions (< 2 months) and formation of acid sulfate soils
- Sulfide distribution and texture are controlling factors for creation of acid sulfate conditions
- As little as 5% of fine textured materials (Lagoon Bottom) may influence the extent and duration of the development of acidic conditions
- Salts washout fairly quickly (within 10 months)
- Subaqueous soils should be managed accordingly and separately form one another due to the development of acid sulfate conditions

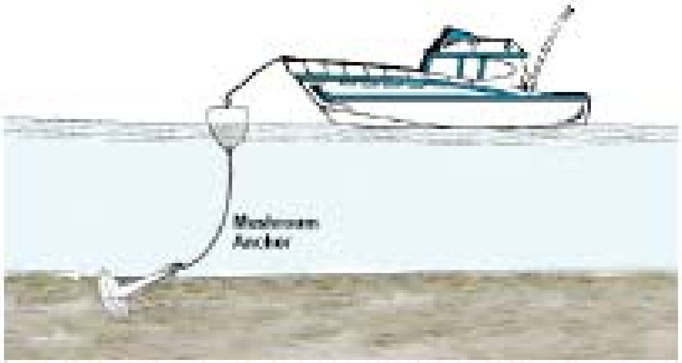


Fig. 2. Mushroom anchors work best in soft bottom materials, loamy to organic soils characterized by high *n* value soil surface layers.

Fig. 3. A map of the mooring interpretation for mushroom anchors in Little Narragansett Bay based on the bottom type of soil material.

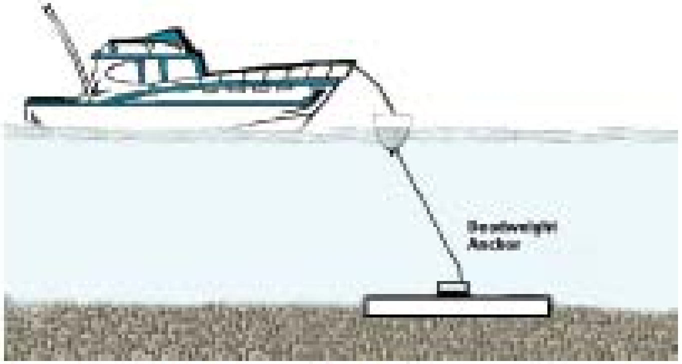


Fig. 4. Deadweight anchors work best in hard bottom materials such as gravel and coarse sands, low *n* value soil surface layers.

Fig. 5. A map of the mooring interpretation for deadweight anchors in Little Narragansett Bay based on the bottom type of soil material.

Surabian, 2007

Eelgrass Restoration and Subaqueous Soils

- *Zostera marina* (eelgrass) is a submerged flowering vascular plant
- Obtains nutrients from soil via roots

Why is Eelgrass Important?

- **High biological productivity (200 to 600 $gCm^{-2} yr^{-1}$)** **Mann, 2000*
- **Habitat for spawning fish, shellfish and benthic infauna**
- **Food source for waterfowl**
- **Trap sediment from water column**
- **Buffer wave activity**

Courtesy: NOAA

Table 10. Success of eelgrass restoration projects in the northeastern US. Sites include full-scale transplant efforts (hectares) and test-transplants of less than 0.01 ha per location (T)

Location	Project	Sites attempted	Sites successful	Size	Reference
Maine	Wells NERR Project	2	0	T	Short et al. (1993)
New Hampshire	NH Port Mitigation Project	5	2	2.52 ha	Short et al. (1995), This study
	NH TERFS™ Method Development	6	2	T	Short et al. (2002)
Massachusetts	NOAA New Bedford Harbor Project	8	5	1.62 ha	Kopp & Short (2000), This study
	EPA Boston Harbor Project	2	0	T	P. Colarusso & M. Chandler (pers. comm.)
Rhode Island	RI Aqua Fund Project	6	1	T	Kopp et al. (1994) B. S. Kopp (unpubl. data)
	NOAA 'World Prodigy' Mitigation	10	2	T	Fonseca et al. (1997) M. S. Fonseca (pers. comm.)
	RI DEM Narragansett Bay Project	2	0	T	Adamowicz (1994)
	Save the Bay, Wickford Harbor	1	1	T	Richardson (pers. comm.)
	NOAA/NERR Seeding Project	3	1	T	S. Granger (pers. comm)
Connecticut	Niantic River Pilot Eelgrass Restoration	1	1	0.04 ha	Short (1988)
New York	NY Sea Grant, Great South Bay Project	1	1[a]	T	Churchill et al. (1978)
New Jersey	NOAA/NMFS Raritan Bay Project	5	0	T	Reid et al. (1993)

[a]Survival monitored for less than 1 yr

Short et al./Mar Ecol Prog Ser 227 (2002) 253-267

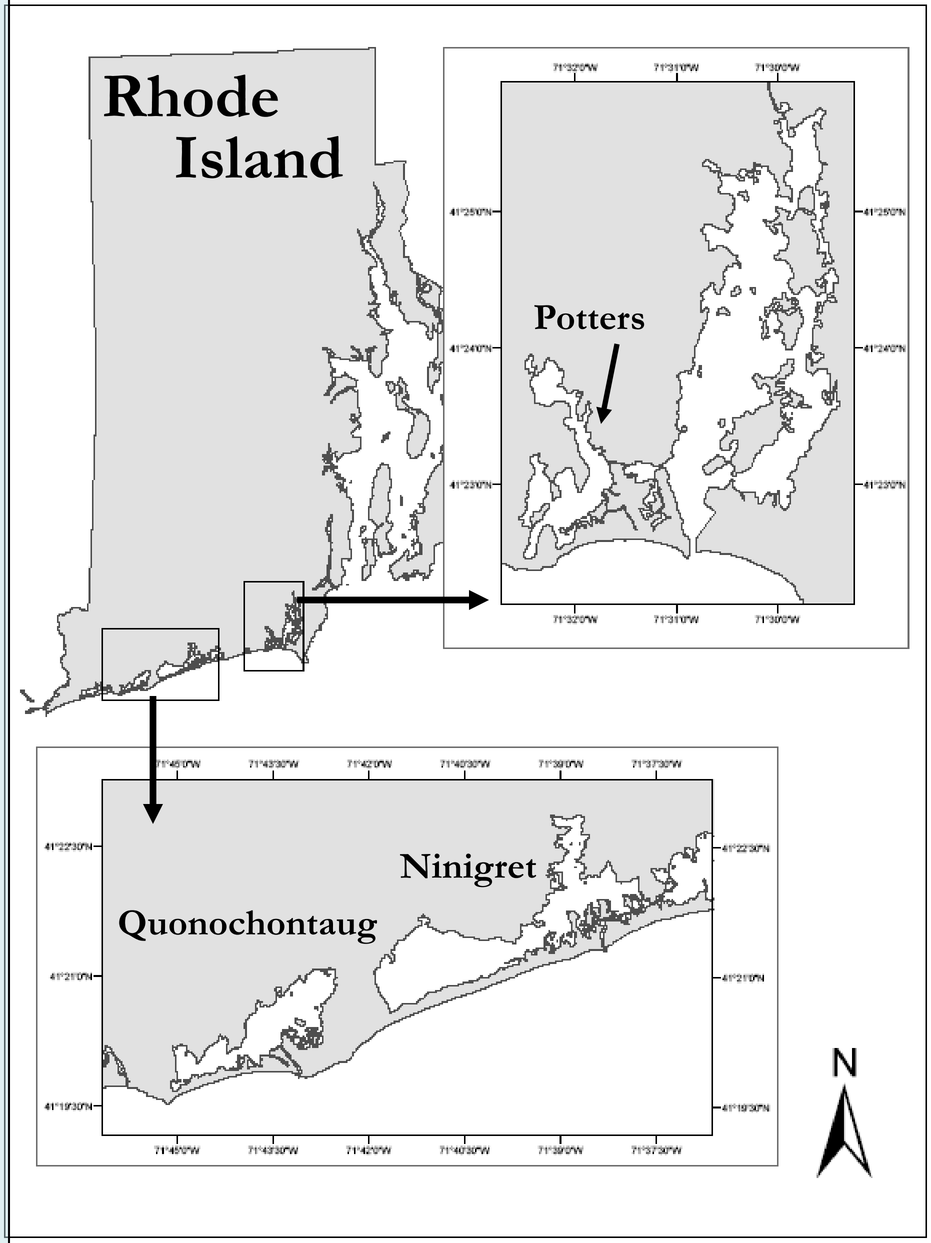
Objectives

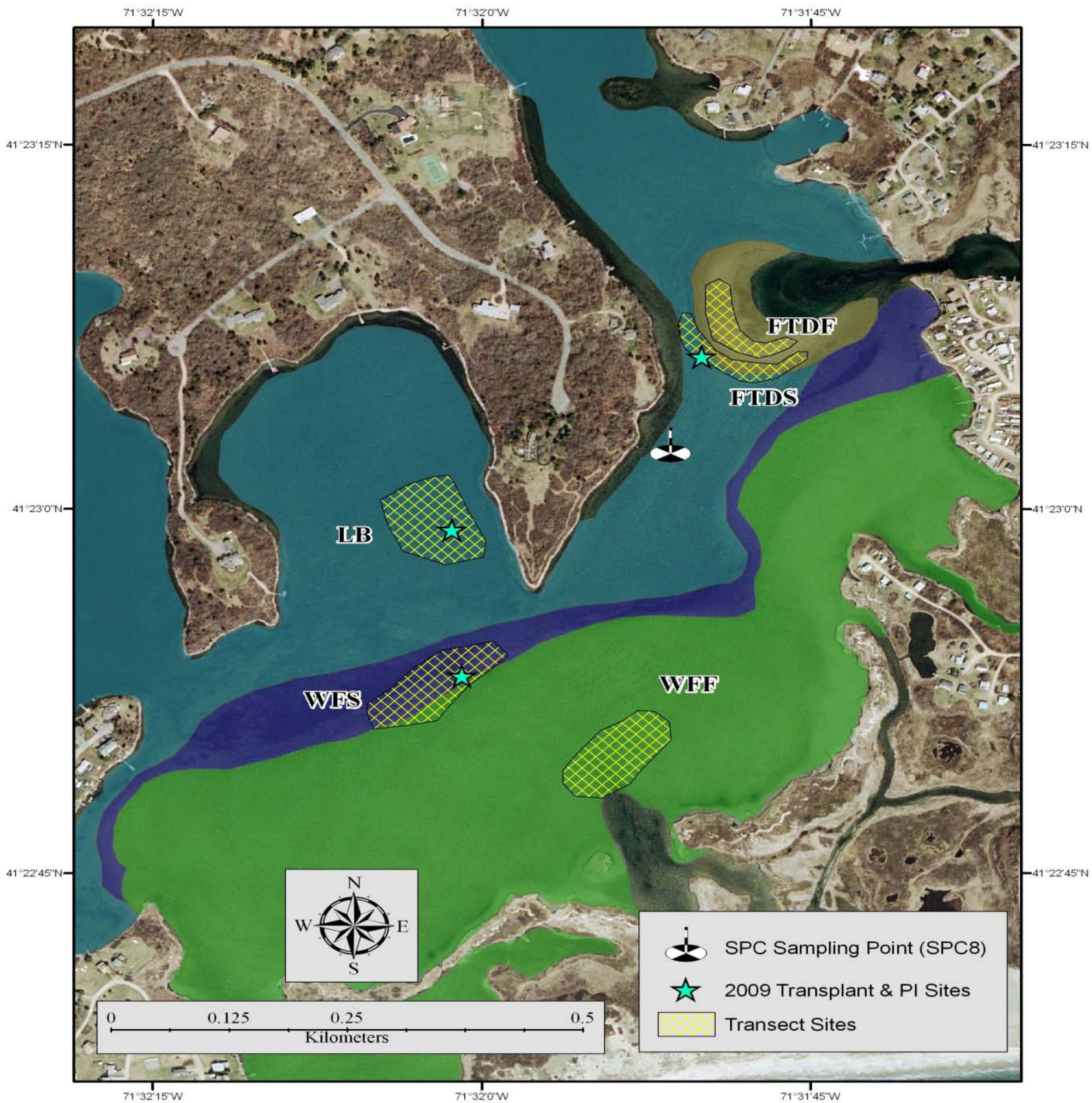
- Assess relationship between soil-landscape units and eelgrass distribution, growth, and transplant success in three coastal lagoons in southern Rhode Island

- Identify soil-landscape units most capable of supporting successful restoration projects

METHODS

- Point intercept vegetation transect method for eelgrass density
- TERF Transplant Method
- Leaf marking technique for determining growth
- Collected soil samples for physical and chemical properties
- Compared parameters across landscape unit types





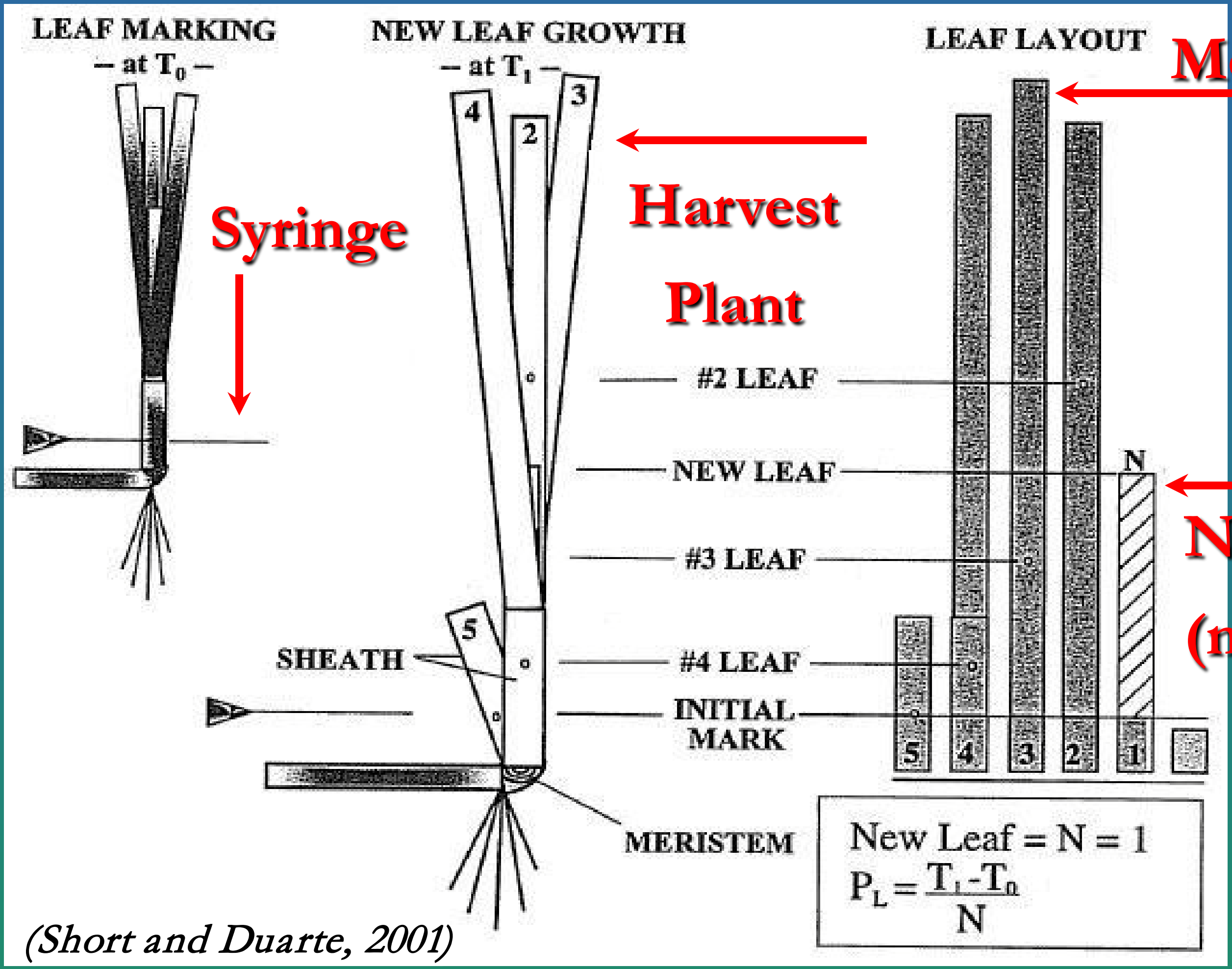
WFF: Washover Fan Flat
WFS: Washover Fan Slope
FTDF: Flood Tidal Delta Flat
FTDS: Flood Tidal Delta Slope
LB: Lagoon Bottom

- **Soil-landscape units group soils that have similar physical and chemical properties**
- **These soil-landscape units offer a wide range in soil properties**
- **These soil-landscape units are the most common units in coastal lagoon ecosystems**

TERF Transplant Method

- Developed by Dr. Fred Short of University of New Hampshire
- Harvest healthy eelgrass and tie shoots to the TERF frame (50 shoots per frame)
- Shoots were arranged so rhizomes within top 1 cm of soil
- Health of the eelgrass transplants determined by counting surviving shoots

Leaf Marking Technique "Plastochrone Interval"



(Short and Duarte, 2001)

- Plastochrone interval (P_L) - interval of time between appearance of new plant parts.
- Eelgrass continually grows new leaves and sheds old leaves
- Growth calculated by dividing weight of mature plant part by P_L.

Ninigret Pond Eelgrass Density

	Bradley (2001)		Pruett (2010)	
SAS Map Unit	Average eelgrass cover (% S.D.) (n)	USDA soil texture classification	Average eelgrass cover (% S.D.) (n)	USDA soil texture classification
Flood Tidal Delta Slope	82 ± 14 (4)	Silt loam	68 ± 2 (9)[b]	Very fine sandy loam
Lagoon Bottom	66 ± 37.9 (15)	Silt loam	98 ± 1 (6)[a]	Silt loam
Flood Tidal Delta Flat	0 (2)	Very fine sand	4 ± 1 (9)[c]	Fine sand
Washover Fan Flat	0 (4)	Sand	1 ± 1 (9)[c]	Fine Sand to Sand
Washover Fan Slope	0 (2)	Coarse sand	1 ± 3 (9)[c]	Fine sand

Landscape Unit	n	Average Eelgrass Cover (% *sd*)	USDA Soil Texture Classification Range
Potter Pond			
Lagoon Bottom	9	100 0[a]	silt loam
Flood Tidal Delta-Slope	9	92 9[a]	very fine sandy loam
Flood Tidal Delta-Flat	9	66 23[c]	loamy sand to fine sand
Washover Fan-Slope	9	80 7[b]	loam to fine sandy loam
Washover Fan-Flat	6	4 7[d]	sand
Quonochontaug Pond			
Lagoon Bottom	9	16 31[bc]	Silt loam
Flood Tidal Delta-Slope	6	33 35[a]	loamy sand to fine sand
Flood Tidal Delta-Flat	6	11 15[bc]	loamy sand to fine sand
Washover Fan-Slope	9	3 3[b]	sand to coarse sand
Washover Fan-Flat	9	8 20[c]	sand to coarse sand

Ninigret Pond:

Eelgrass Distribution and Soil Properties

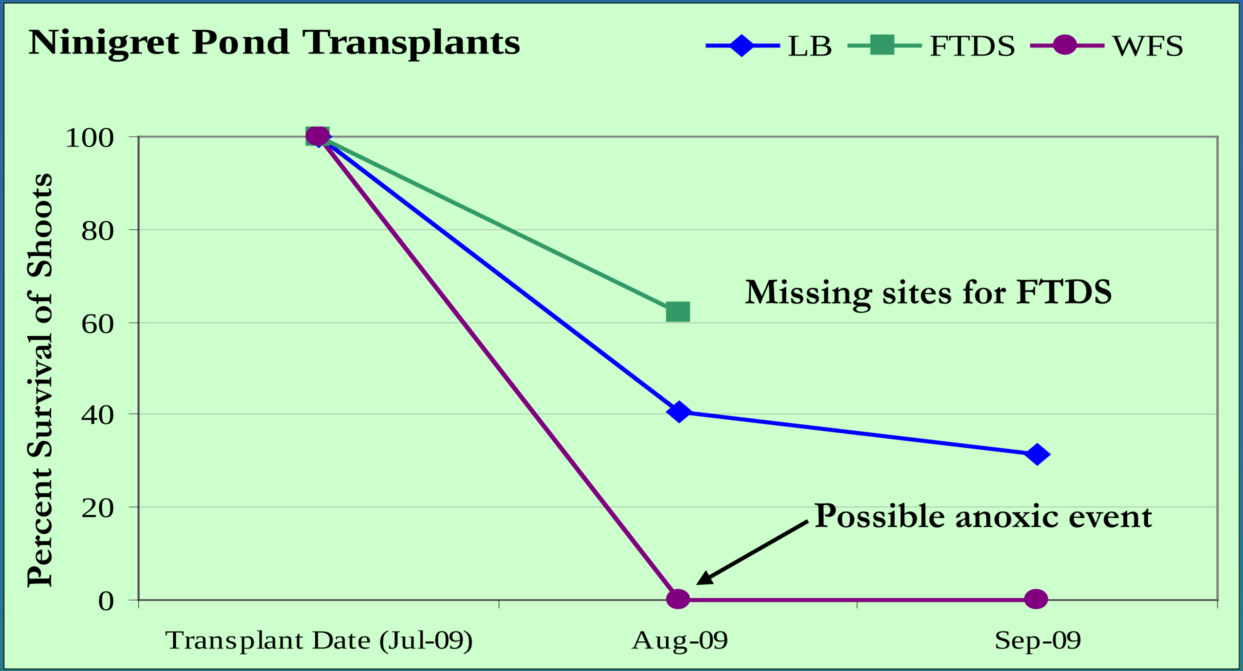
Variable	High (mean se)	Moderate	Low (mean se)	No (mean se)	P-value
	> 60%	60 to 20%	20 to 1%	0%	
TOC (%)	2.7 0.9	-	0.4 0.1	0.5 0.1	0.04
$CaCO_3$ (%)	4.0 1.2	-	1.0 0.1	0.9 0.2	0.05
Salinity (mS)	5.3 0.4[a]	-	3.1 0.2[b]	3.1 0.2[b]	0.0032
pH	8.1 0.1	-	7.9 0.1	7.9 0.1	0.18
Sand (%)	39.2 13.7[a]	-	94.0 1.9[b]	95.9 1.2[b]	0.0019
Silt (%)	48.8 9.1[a]	-	3.8 1.7[b]	3.2 1.3[b]	0.0004
Clay (%)	12.1 5.2	-	2.4 0.8	1.2 0.7	0.10
AVS (ug g^{-1})	38.5 5.5[a]	-	2.9 0.7[b]	2.0 0.3[b]	<0.0001
CRS (ug g^{-1})	305.3 122.0	-	52.6 22.8	61.9 23.1	0.09
TS (ug g^{-1})	343.8 121.9	-	55.5 23.2	63.9 23.3	0.05
n=	5	0	5	4	

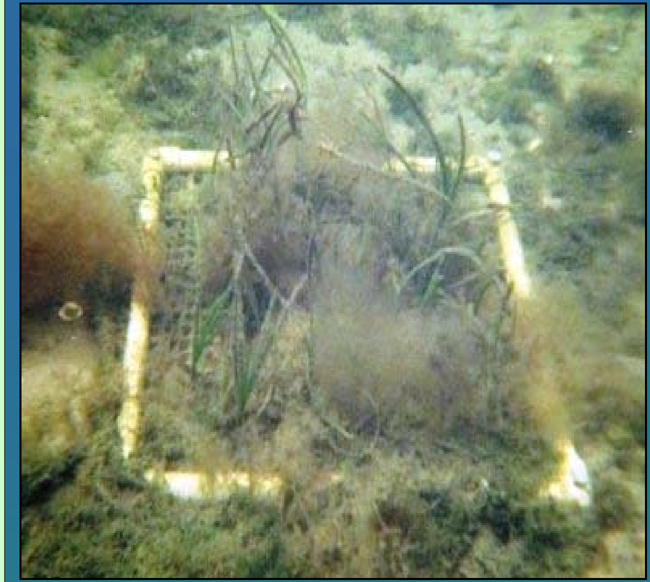
Soil Properties and Eelgrass Distribution

- In Ninigret Pond:
  - Landscape units with high eelgrass cover (>60%) had:
    - High soil salinities
    - High silt contents
    - High acid-volatile sulfide contents
    - Low sand contents

- In Potter Pond:
  - Most landscapes (11 out of 14) had high eelgrass cover (>60%)
  - Each of the 3 remaining transects split between Moderate cover (20 to 60%), Low cover (1 to 20%), and No cover (0%).
  - Made statistical comparisons between cover classes impossible but same trends were seen as in Ninigret Pond (salinity, silt, and AVS higher in high classes vs. Moderate, Low, No classes)

- In Quonochontaug Pond:
  - Very little eelgrass so no significant differences between eelgrass cover classes



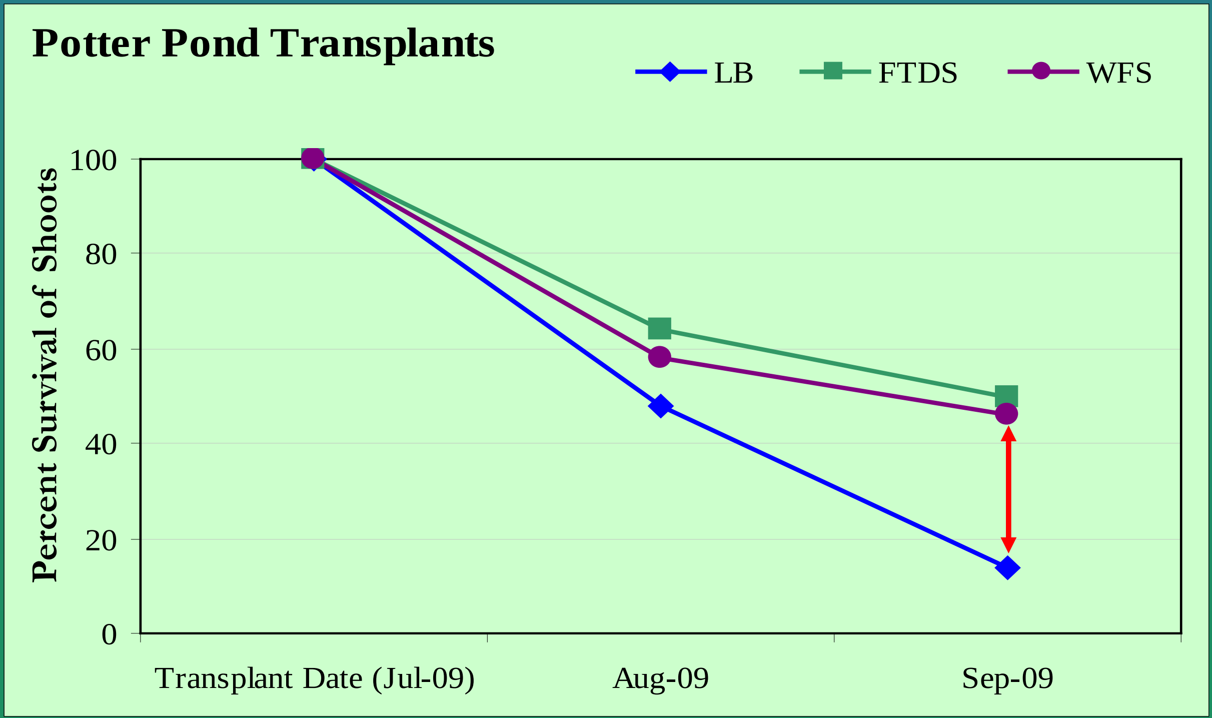


Why lower success in LB units?

• These units had higher SOC and total sulfide contents

• SOC levels >2% have been shown to deter SAV establishment.

• LB units had 6% SOC while FTDS and WFS had 2%.



Production Measurements Results

	Ninigret Pond				Potter Pond			
	WFS	FTDS	LB	p	WFS	FTDS	LB	p
Early Summer								
Shoot Growth Rate (mg dw shoot^{-1} day^{-1})	49.4[a]	13.8[b]	50.0[a]	0.006	19.9[b]	14.7[b]	31.8[a]	0.001
3rd Leaf Length (cm)	72.1[b]	57.3[b]	122.9[a]	<0.0001	77.1[c]	45.8[b]	108.0[a]	<0.0001
Shoot:root ratio (mg/mg dw)	N/A	N/A	N/A		N/A	N/A	N/A	
Late Summer								
Shoot Growth Rate (mg dw shoot^{-1} day^{-1})	7.8[b]	10.8[a]	13.8[a]	0.029	11.8[a]	5.5[b]	13.6[a]	0.0002
3rd Leaf Length (cm)	41.6[b]	43.5[b]	67.7[a]	<0.0001	56.4[b]	45.1[c]	67.9[a]	<0.0001
Shoot:Root ratio (mg/mg dw)	4.6[b]	3.9[b]	7.0[a]	0.0002	5.5	3.7	5.3	0.124
Water Depth (m)	1.4	1.4	1.9		1.1	0.8	1.7	

Eelgrass allocates growth to aboveground biomass from belowground biomass under low light and high SOM conditions

Higher growth rates in LB units in Ninigret Pond in late summer corresponded with higher shoot:root ratios

Summary of Eelgrass Data

- Percent eelgrass cover varies by soil-landscape unit
- Lagoon Bottom and Flood Tidal Delta-Slope units contained highest eelgrass cover
- Lagoon Bottom units had highest growth rates
- High soil salinities, silt contents, and AVS contents were correlated with high eelgrass cover
- Landscape units that supported the most eelgrass and the highest aboveground growth rates (LB) had lower success rates for transplantation
  - May be due to reducing conditions or high SOC stressing transplanted eelgrass

Conclusions and Future Work

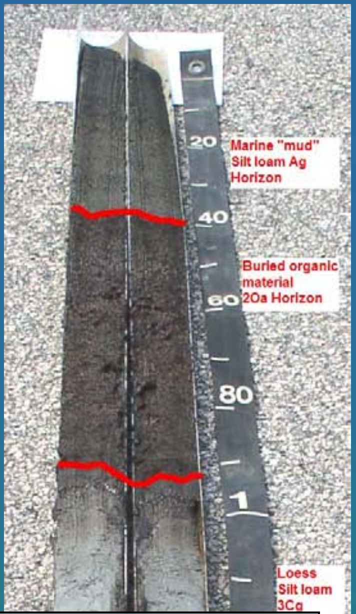
- Soil landscape unit type is important to eelgrass distribution, growth, and transplant success
- Transplant data suggests that the best units for transplant success included:
  - Flood Tidal Delta Slope
  - Washover Fan Slope
- Need to study the success rate of different transplant methods on soil landscape units

Subaqueous Soils and Carbon Pools

- Global warming concerns have sparked interest in investigating the global C cycle
- Upland and wetland SOC pools are often important carbon sinks
- Subaqueous soils have been largely overlooked in soil organic carbon pool studies
- More precise estimates of C sinks and sources are needed to better understand the global C cycle

Objectives

- Explore carbon storage and soil-landscape unit relationship
- Do SOC pools differ among soil type?
- Do subaqueous soils in Rhode Island coastal lagoons contain significant SOC pools?



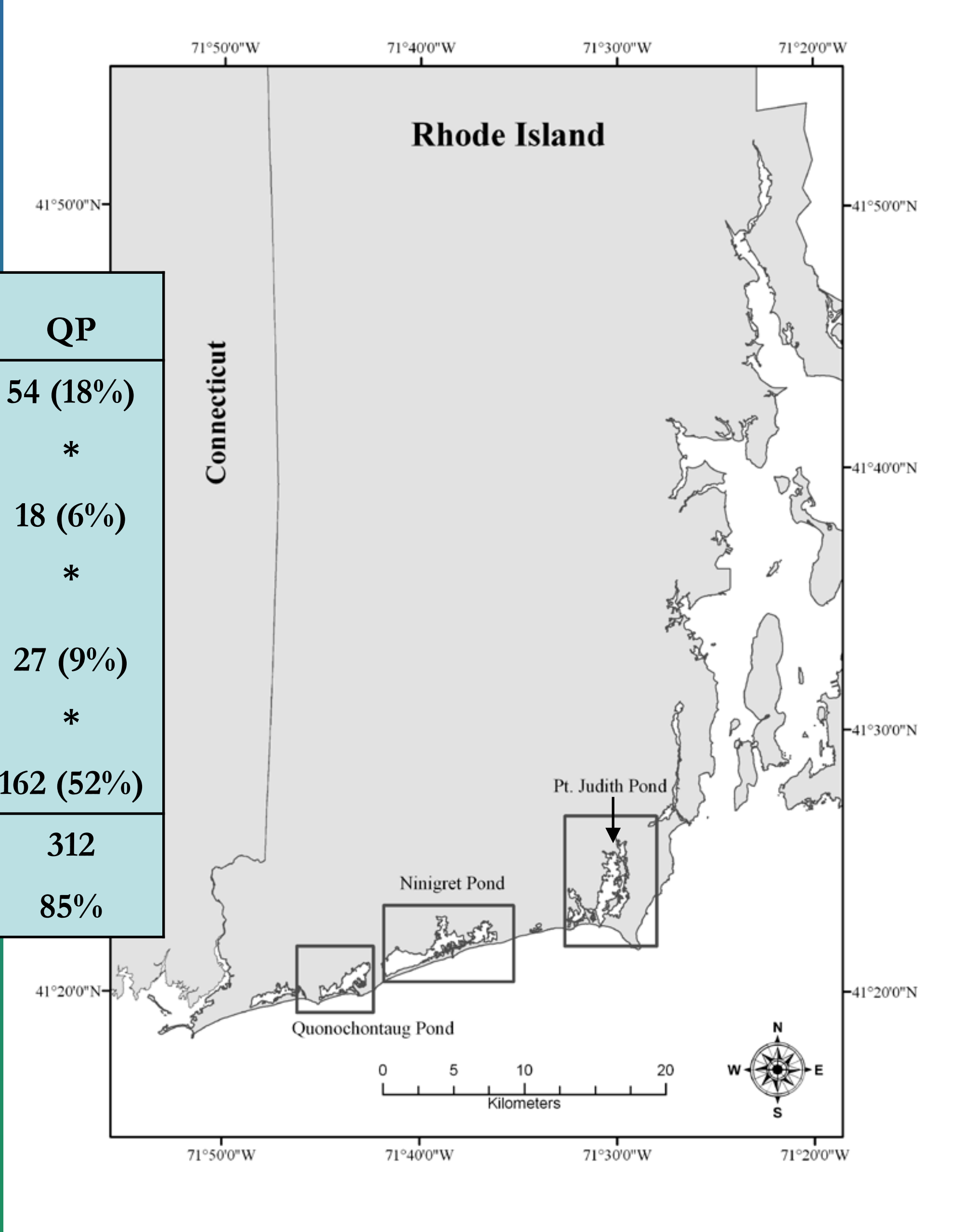
Methods:

- Identify major landscape units in each estuary
- Collect at least 3 soil cores in each landscape unit
- Describe, sample, and analyze each soil horizon for:
  - Soil organic carbon (SOC) (%)
  - Bulk density (Db) (g cm^{-3})
  - Horizon length (L) (cm)
- Determine SOC pool on a weight per area basis (Mg C ha^{-1})

SOC Pool= SOC*L*Db

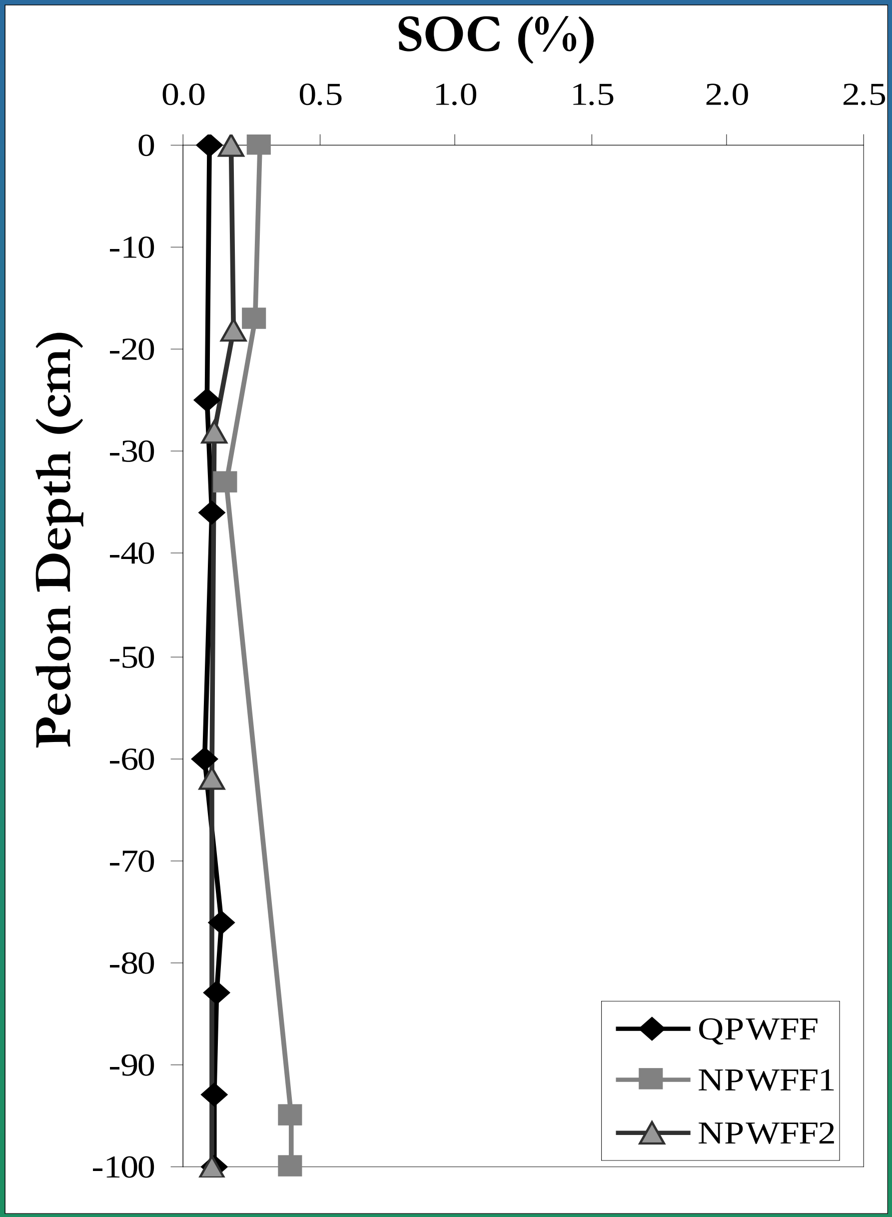
Study Area

Landscape unit	NP	PJP	QP
FTDF	43 (7%)	126 (19%)	54 (18%)
FTDS	*	11 (2%)	*
WFF	135 (15%)	*	18 (6%)
WFS	25 (3%)	*	*
SMB	71 (8%)	40 (7%)	27 (9%)
MC	18 (2%)	39 (6%)	*
LB	289 (43%)	267 (41%)	162 (52%)
Area of Pond (ha)	678	650	312
Percentage of Area	78%	75%	85%

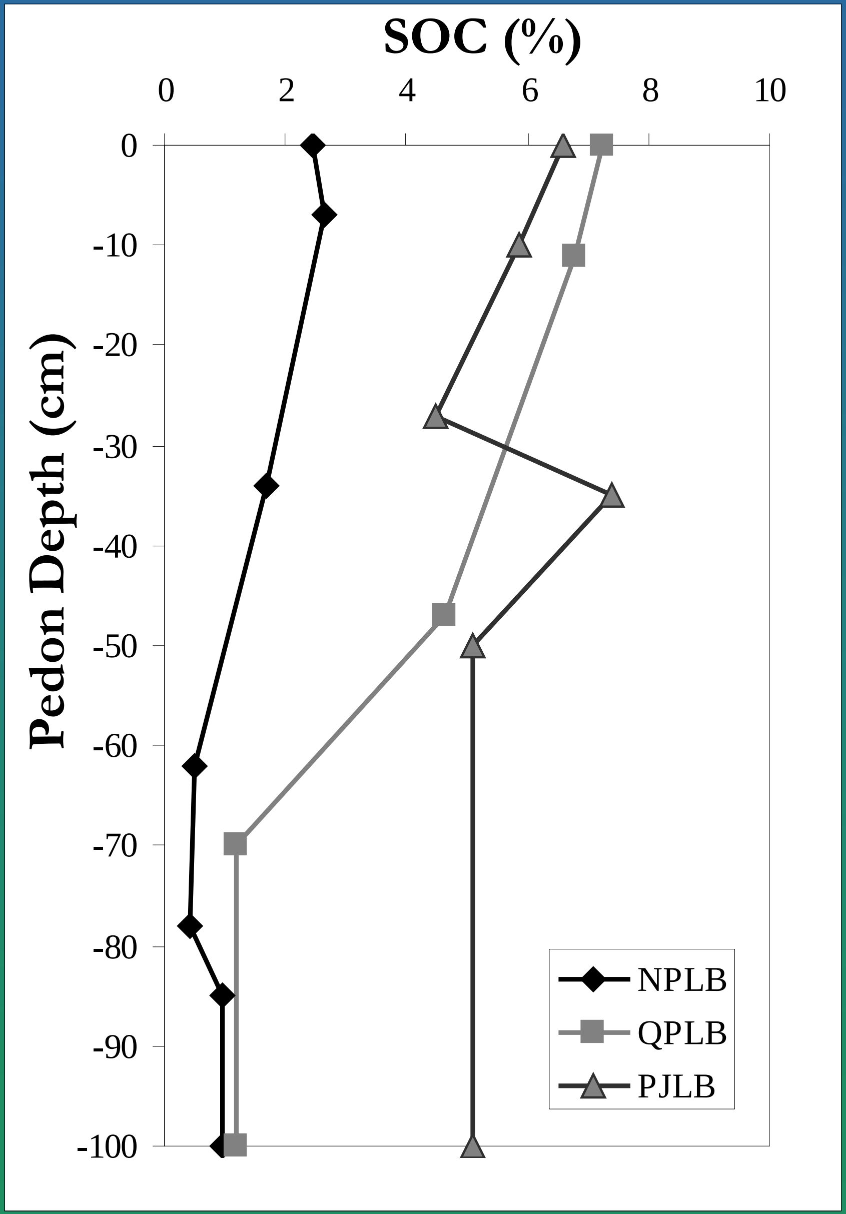


Results

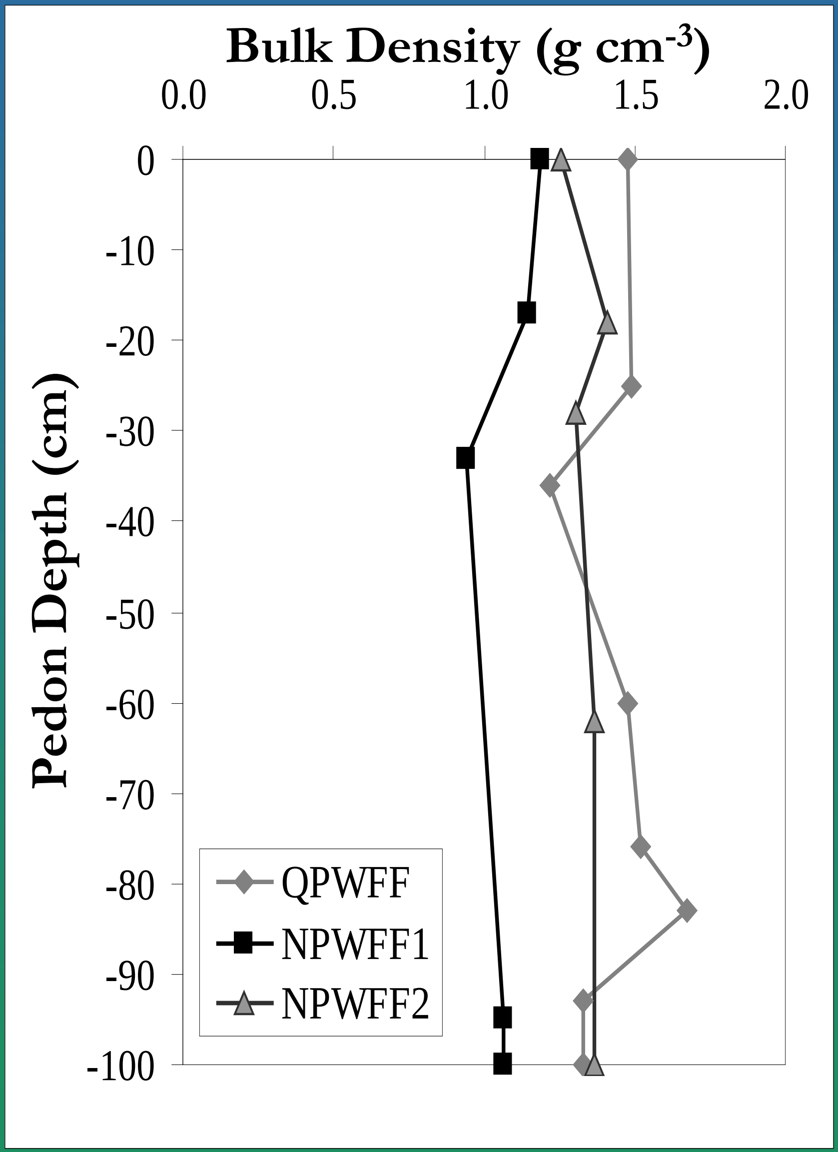
High Energy (WFF)



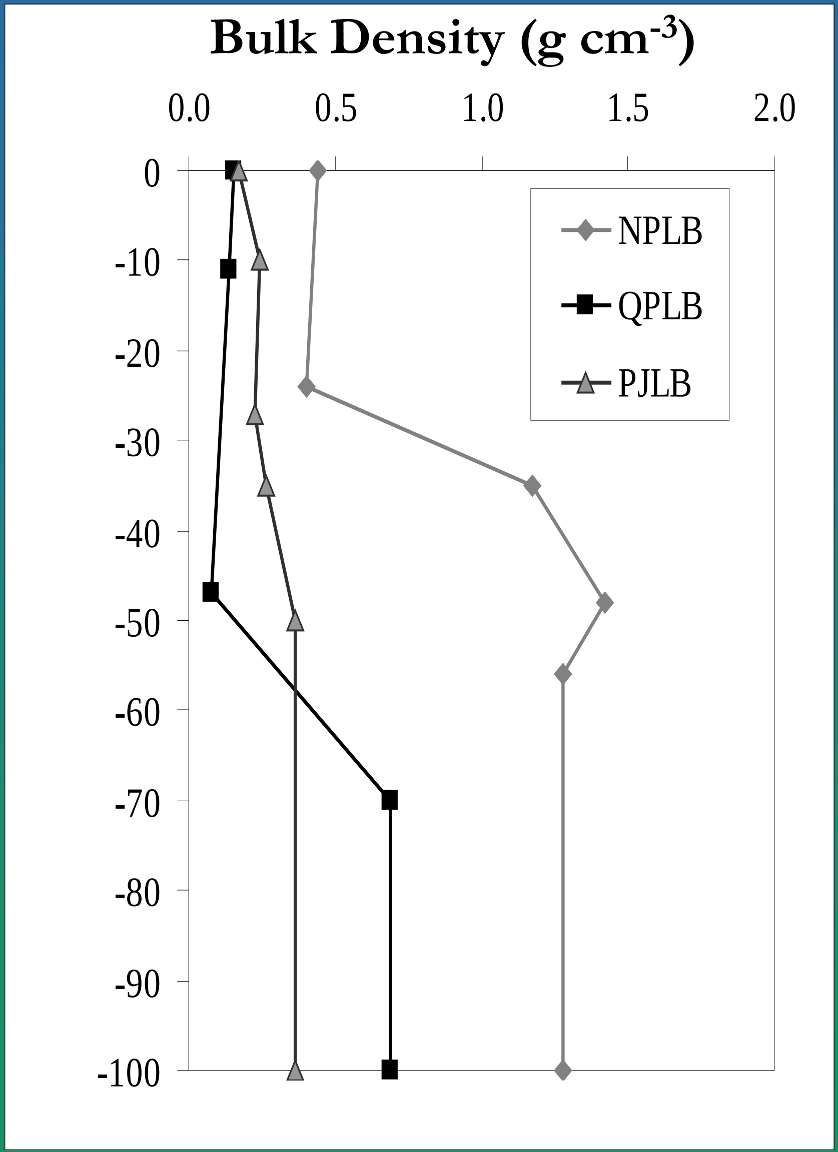
Low Energy (LB)

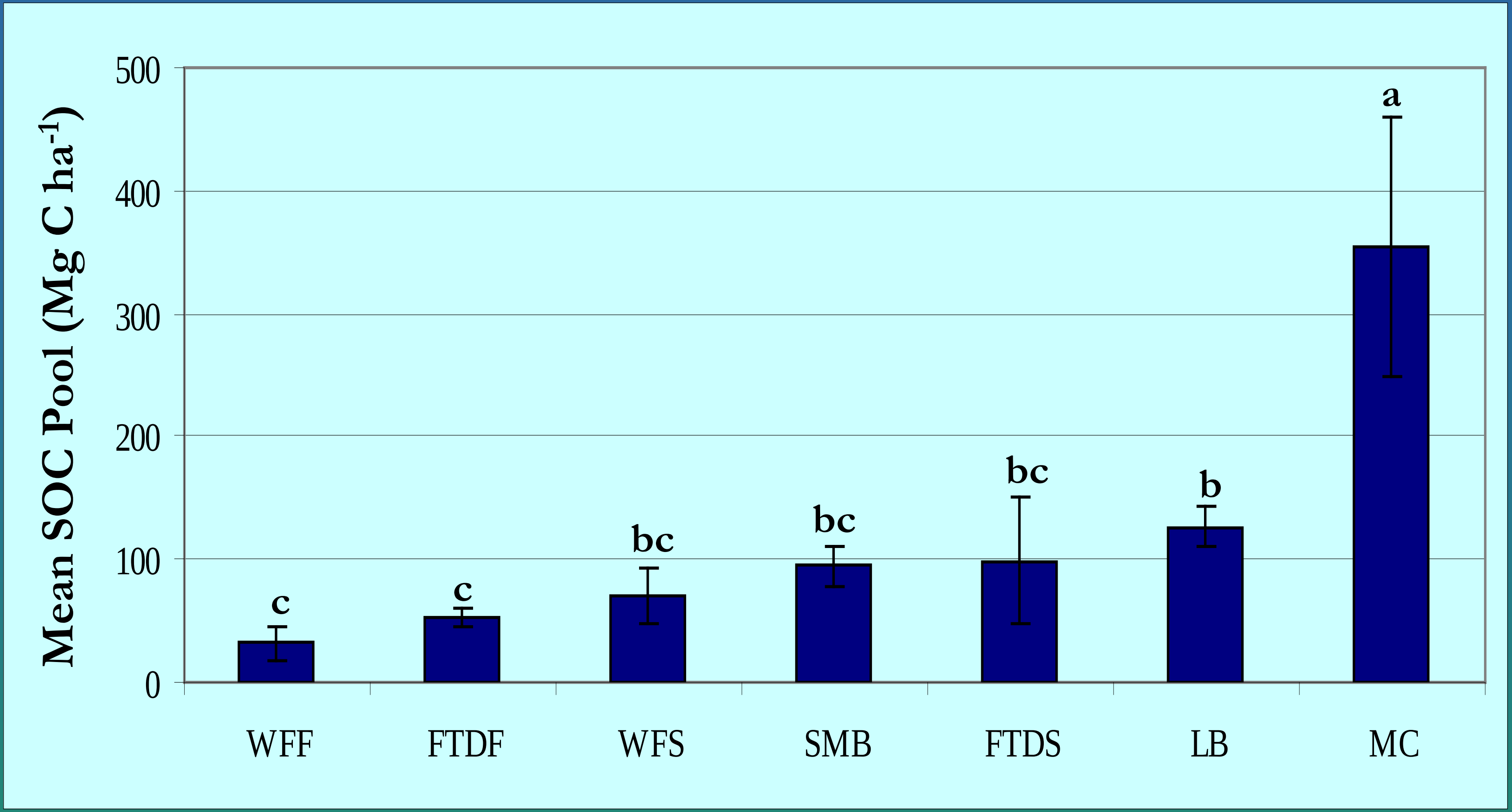


High Energy (WFF)

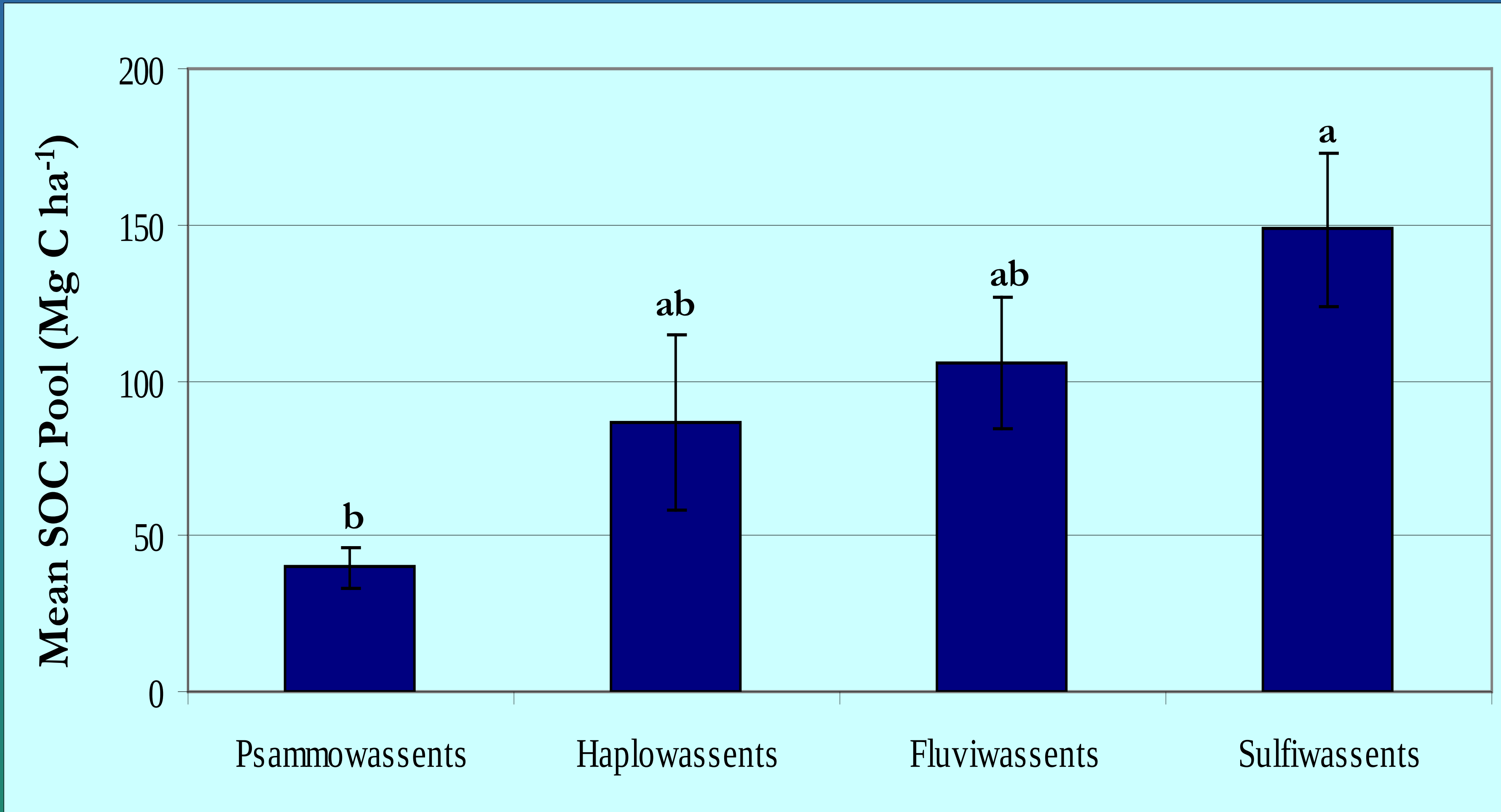


Low Energy (LB)

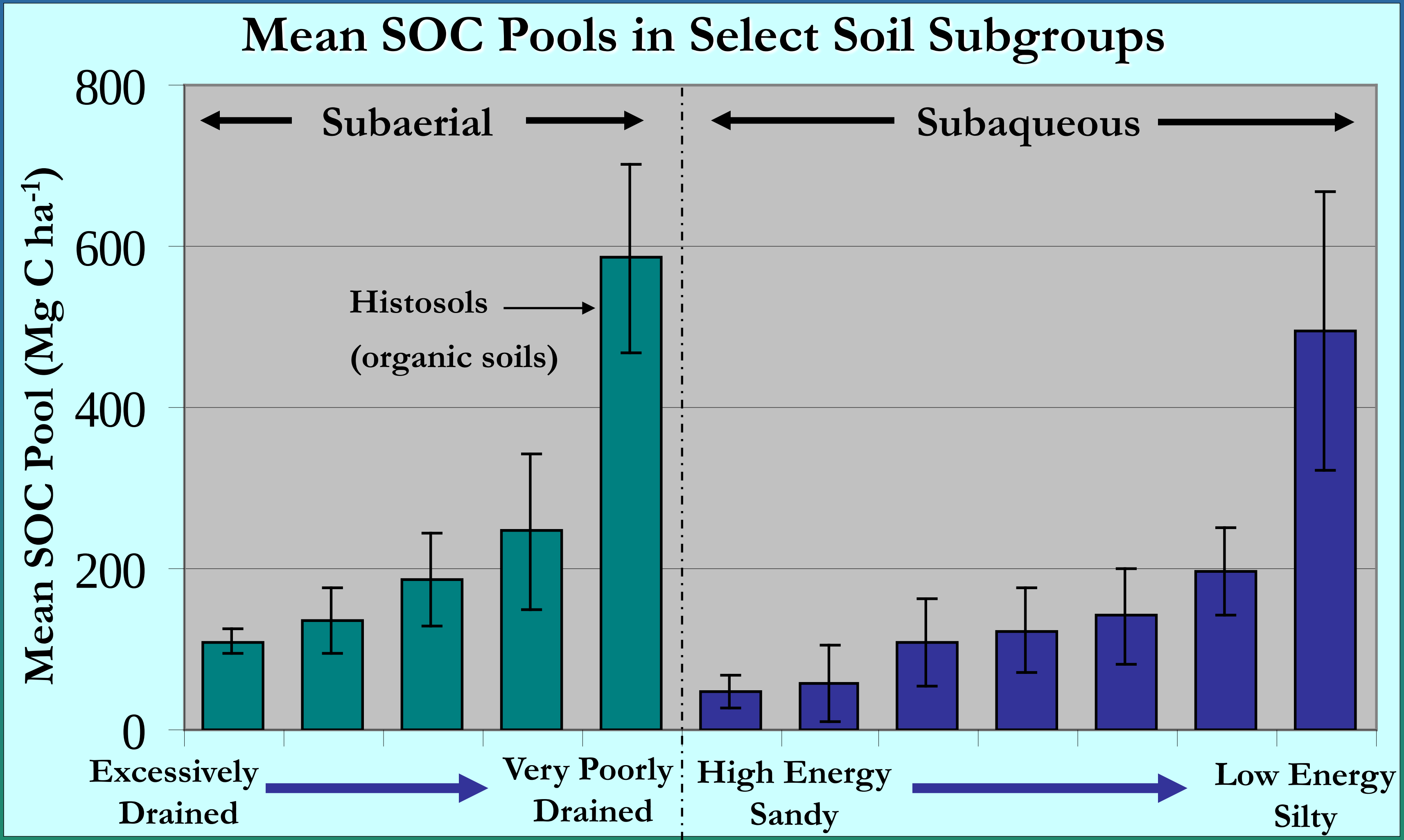




- MC units had highest SOC pools and highest variability
  - -Due to buried O horizons and one organic soil (Wassist)
- LB units had higher SOC pools than the "Flat" units
- Similar relationships seen when each of the coastal lagoons are assessed individually



- Sulfiwassents have fine textures and presence of sulfides
- Sulfiwassents make up the majority of each coastal lagoons studied (> 50%)
- Similar relationships were seen when ponds were assessed individually



- Subaerial data from forested upland and wetland soils

  (Ricker, 2010 and Davis, 2004)

- SOC pools in subaqueous subgroups are comparable to forested soils in southern New England

Soil Organic Carbon Conclusions

- SOC pools significantly differed by soil great group and landscape unit
- Type of depositional environment and presence of buried O horizons important for SOC pools
- Subaqueous SOC pools are comparable to regional and national averages for subaerial SOC pools
- Should be included in global and regional estimates of soil organic carbon pools
- Sequestration rates need to be studied in these subaqueous soils.

Heavy Metals and Subaqueous Soils

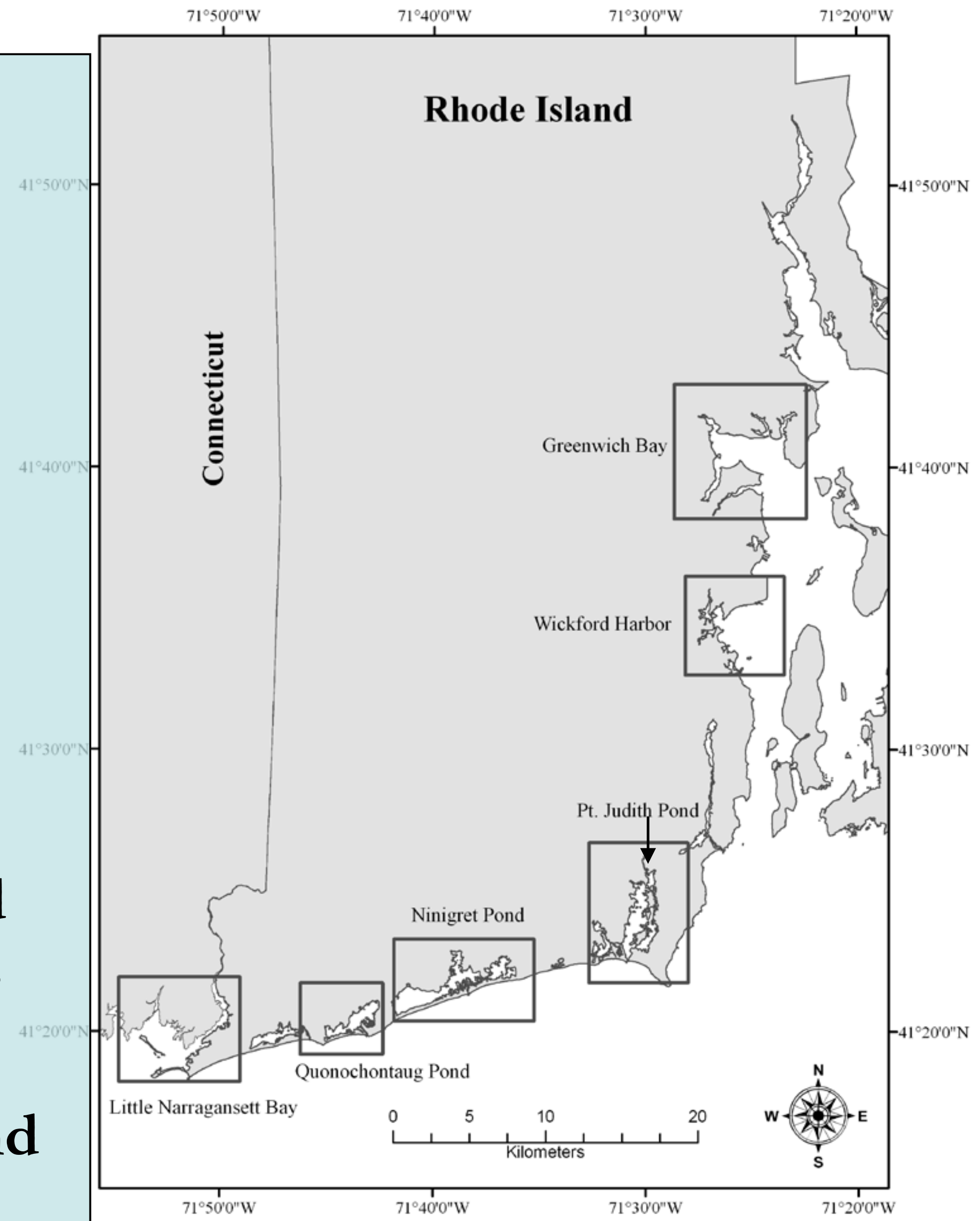
- What is the spatial distribution of surficial metal concentrations in RI estuaries?

- Do metal concentrations differ by soil type?

- Are specific soil types more likely to contain metal pollution?

Methods

- Analyzed 91 surface soil samples for heavy metals
- Dried and homogenized samples
- Niton XL3t XRF
- Pb, Zn, As, Cu, and Cr
- Classified soils and separated by great group and soil series
- Compare to DEM background levels and NOAA limits for biological effects

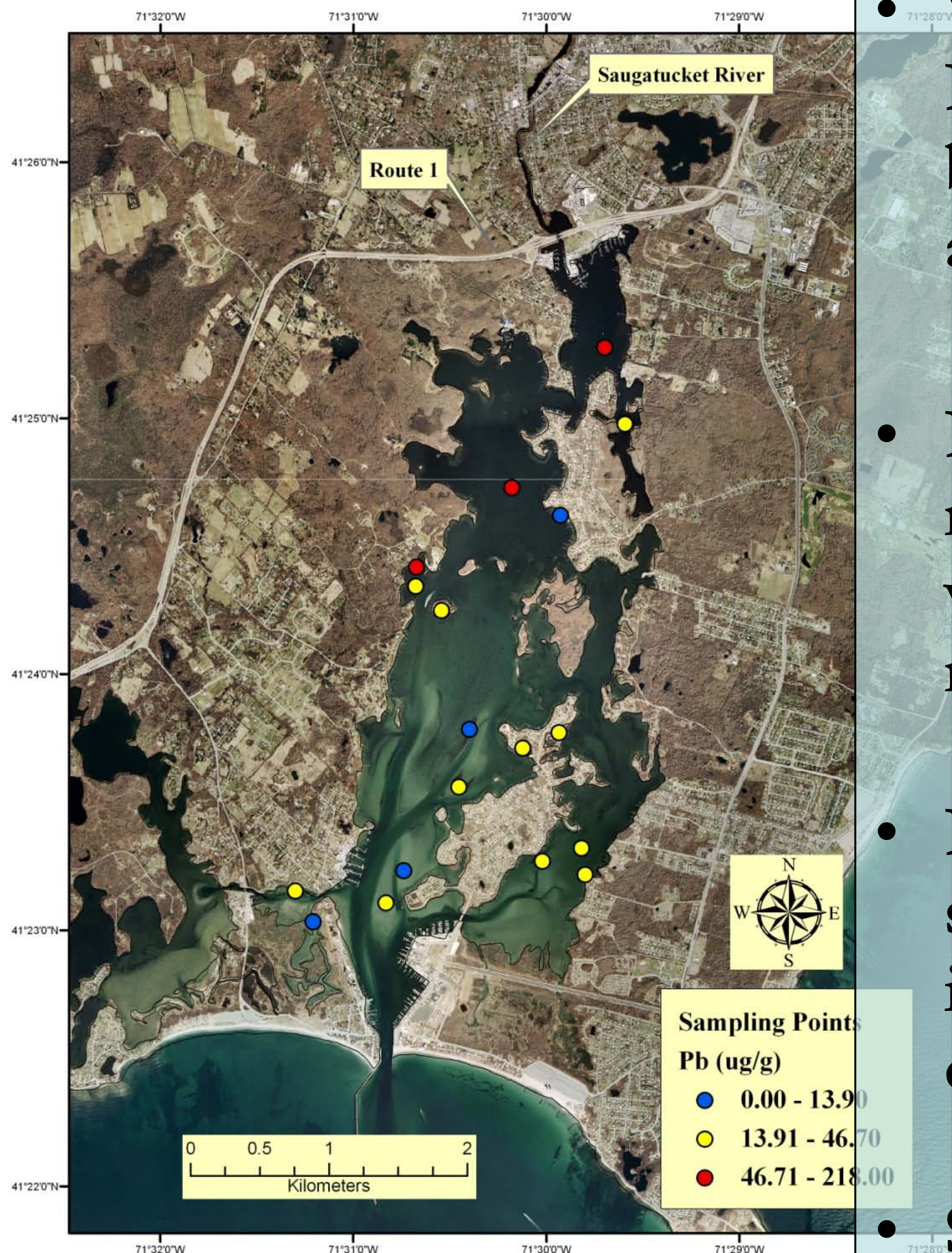


Results

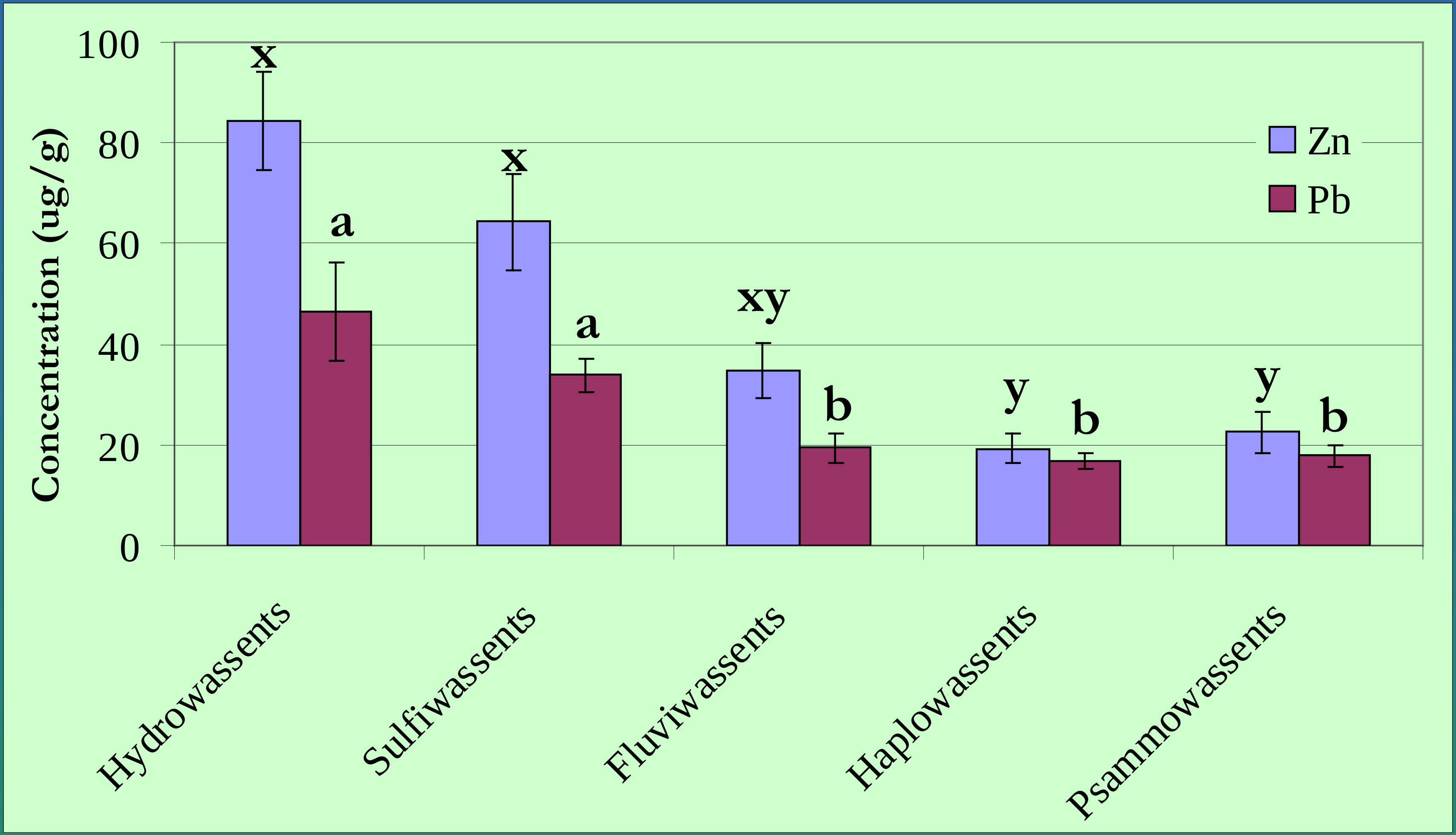
- For As, Cu, and Cr majority of concentrations <LOD

- Pb and Zn most prevalent metals in high concentrations

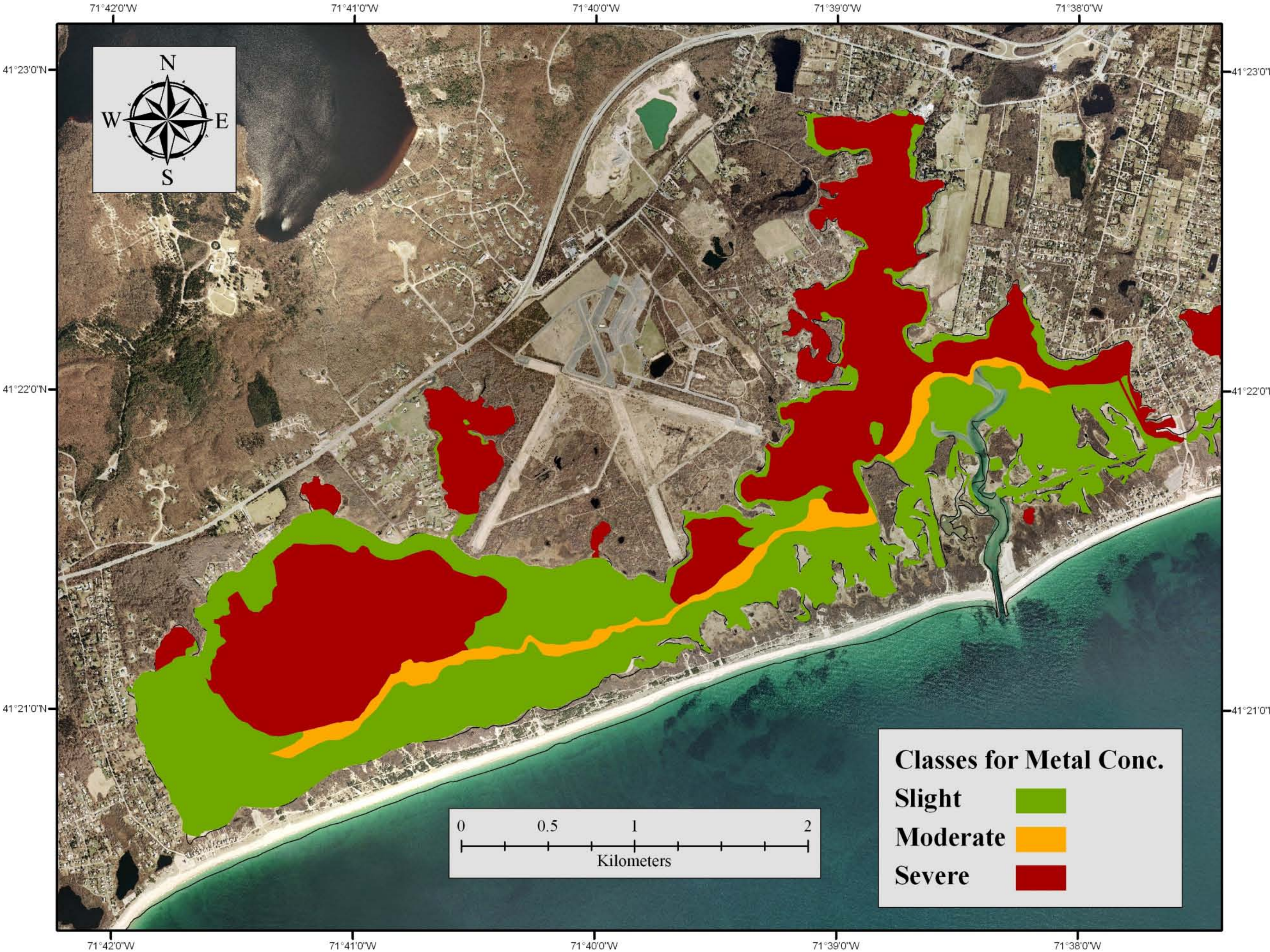
- Possible Sources:
  - Atmospheric deposition (Pb and Zn)
  - Surface water runoff (Pb and Zn)
  - Incinerator waste (Pb and Zn)
  - Gasoline (Pb usage stopped in 70's)
  - Car tires (Zn)



- **Widespread distribution of Pb and Zn above background levels across all estuaries studied**
- **Pb concentrations highest near freshwater/surface-water inputs and lowest near tidal inlet**
- **Proximity to potential sources and tidal inlets important to spatial distribution of metal conc.**
- **Same trends for Zn**



- Hydro and Sulfiwassents contain greater fine materials, SOC contents, and sulfides which bind metals


71°42'0"W
71°41'0"W
71°40'0"W
71°39'0"W
71°38'0"W
41°23'0"N
41°22'0"N
41°21'0"N
N
W
E
S
Classes for Metal Conc.
Slight
Moderate
Severe
0
0.5
1
2
Kilometers

Subaqueous Soil and Shellfish Growth

- **Objective**
  - Estimate shellfish growth on different soil landscape units
  - Eastern Oyster *Crassostrea virginica*
  - Quahog (*Mercenaria mercenaria*)

- **What affects shellfish growth?**
  - Seston (Food availability)
  - Flow Rates
  - Temperature

- **Soils as a surrogate for shellfish growth**
  - Able to map out areas

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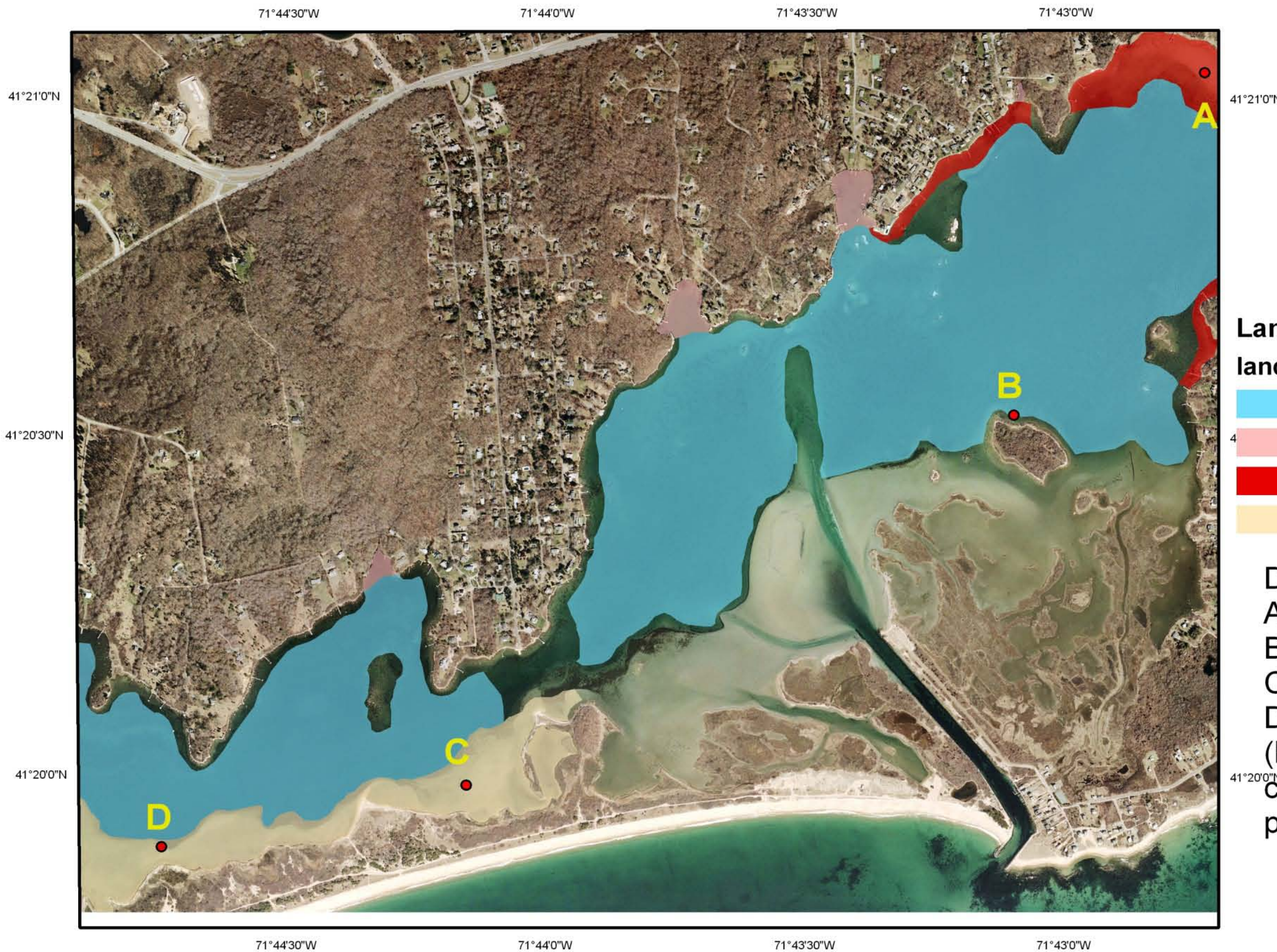
Shellfish Growth Experiment

- **Small scale aquaculture**
  - Ninigret Pond
  - Quonochontaug Pond
- **Landscape units**
  - Washover Fan
  - Washover Fan Slope
  - Lagoon Bottom
  - Mainland Cove
  - Submerged Mainland Beach
- **Soil Characterization**
  - Vibracores taken at each site
  - Described and analyzed
- **Oysters**
  - Grow-out in trays (1m x 1m)
  - 3 trays per site
- **Quahogs**
  - Grown in soil (2 x 2 meter plots)
  - Covered with predator netting
- **Sampling**
  - Growth measured at end of 15 week study period
  - 2 seasons
  - Oysters measured by long axis
  - Quahogs measured by hinge width
- **Water Quality**
  - DO, Salinity, Temperature
  - TSS, Chlorophyll a

Ninigret Study Sites

Alexander Salisbury NRS, URI

Quonochontaug Sites



Landscapes

landscape

- Lagoon Bottom
- Mainland Cove
- Mainland Slope
- Washover-fan Flat

Depth At MLW
A Intertidal
B 10ft
C 2 ft
D 1 - 3ft
(Ranges due to changes over plot area)

0 125 250 500 750 1,000 Meters

N

Alexander Salisbury

Oyster Growth Experiment

June 2008 Oysters put out in Ninigret Pond

- ~ 11,000 oysters mean size of 3.0 cm
- 4 Liters of biovolume were placed into 24 grow-out bags
- 1 Liter of biovolume = 110 - 120 oysters
- 3 Oyster trays per site

Sampling

- 30 Oysters random sampled from each tray (90 per site)
- Long axis measured

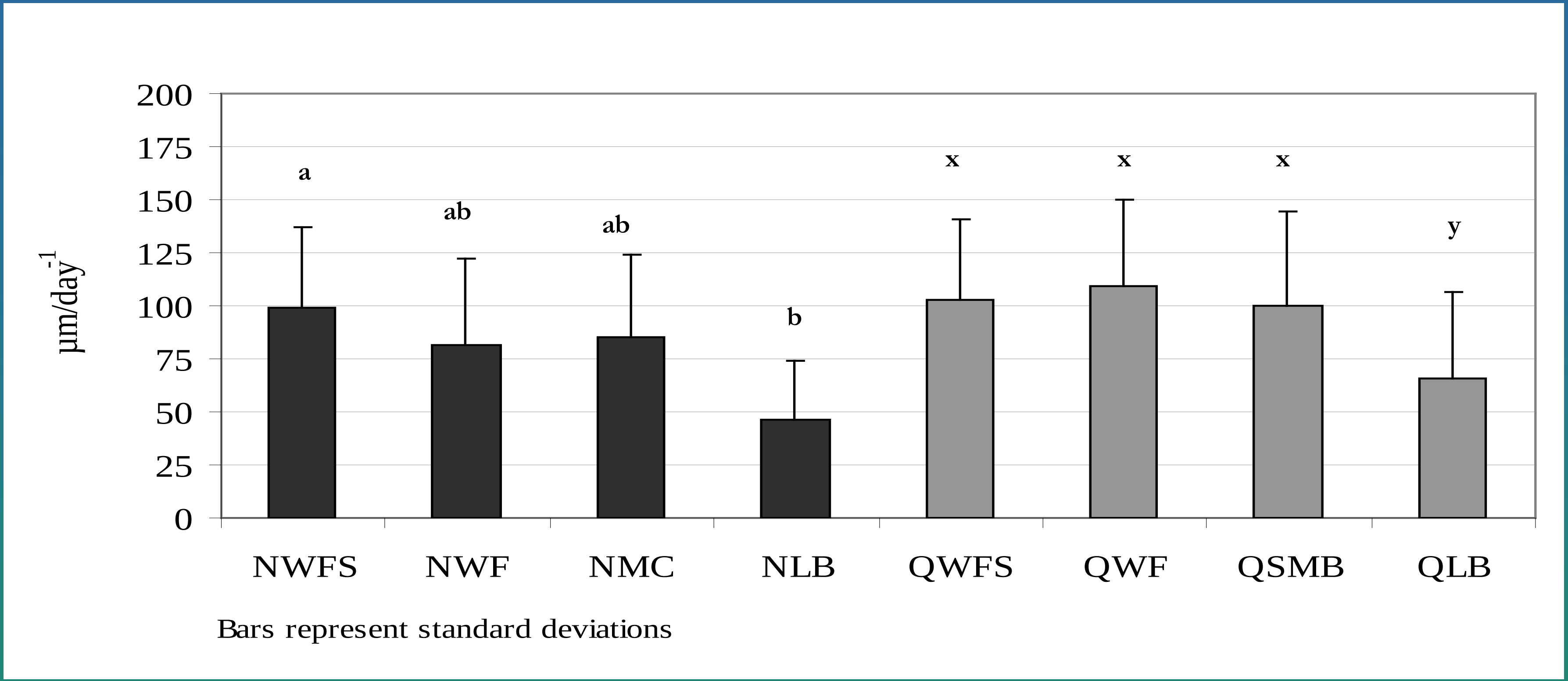
- Oyster/Quahog growth = $(L_2 - L_1) / (t_2 - t_1)$

Growth equals average shell length of 90 individuals in July 2008 (L_1), subtracted from the average shell size (of 90 individuals) in October 2009 (L_2), and divided by the number of days ($t_2 - t_1$)

Site Characteristics

Site	Water Depth (m)	Surface Texture	Subgroup
Ninigret Pond			
WFS	0.96	loamy fine sand	Typic Fluviwassent
WF	1.04	fine sand	Sulfic Psammowassent
MC	1.00	fine sand	Haplic Sulfiwassent
LB	1.00	silt loam	Typic Sulfiwassent
Quonochontaug Pond			
WFS	1.49	sand	Typic Psammowassent
WF	0.79	coarse sand	Fluventic Psammowassent
SMB	0.99	sand	Aeric Haplowassent
LB	3.19	silt loam	Typic Sulfiwassent

Oyster Growth June 2009 – October 2009



Different letters indicate significant differences. Note slow growth on Lagoon Bottom soils

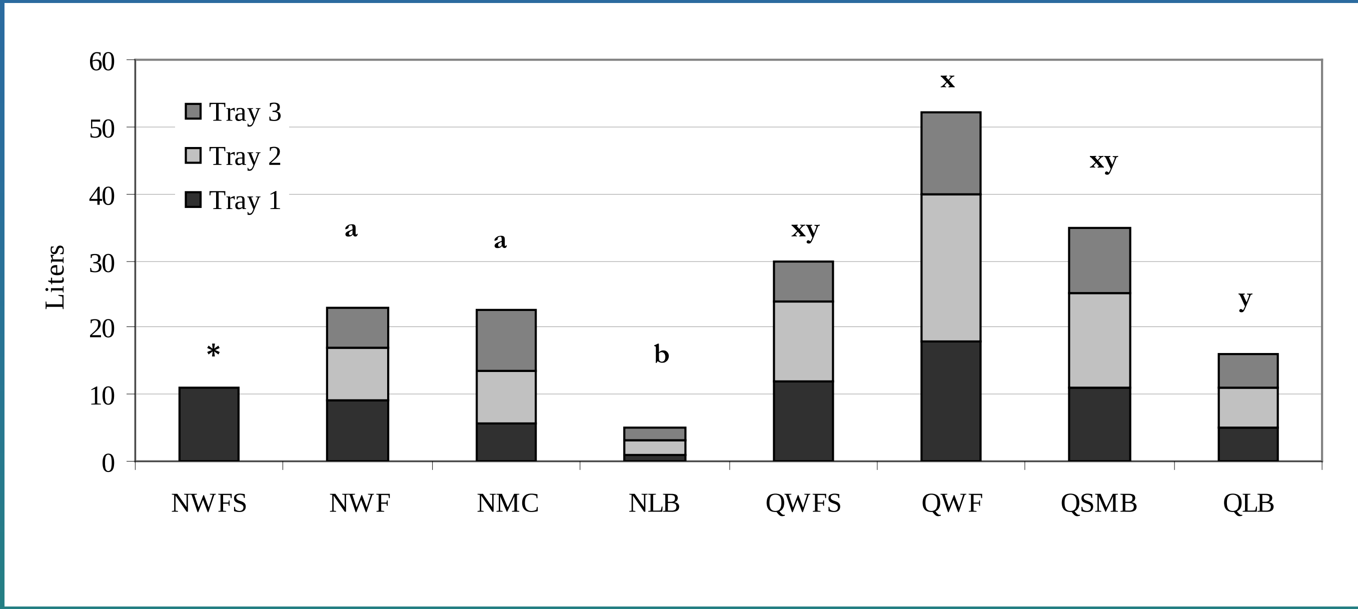
Oyster Growth Analysis
Percentage of Legal Sized Oysters

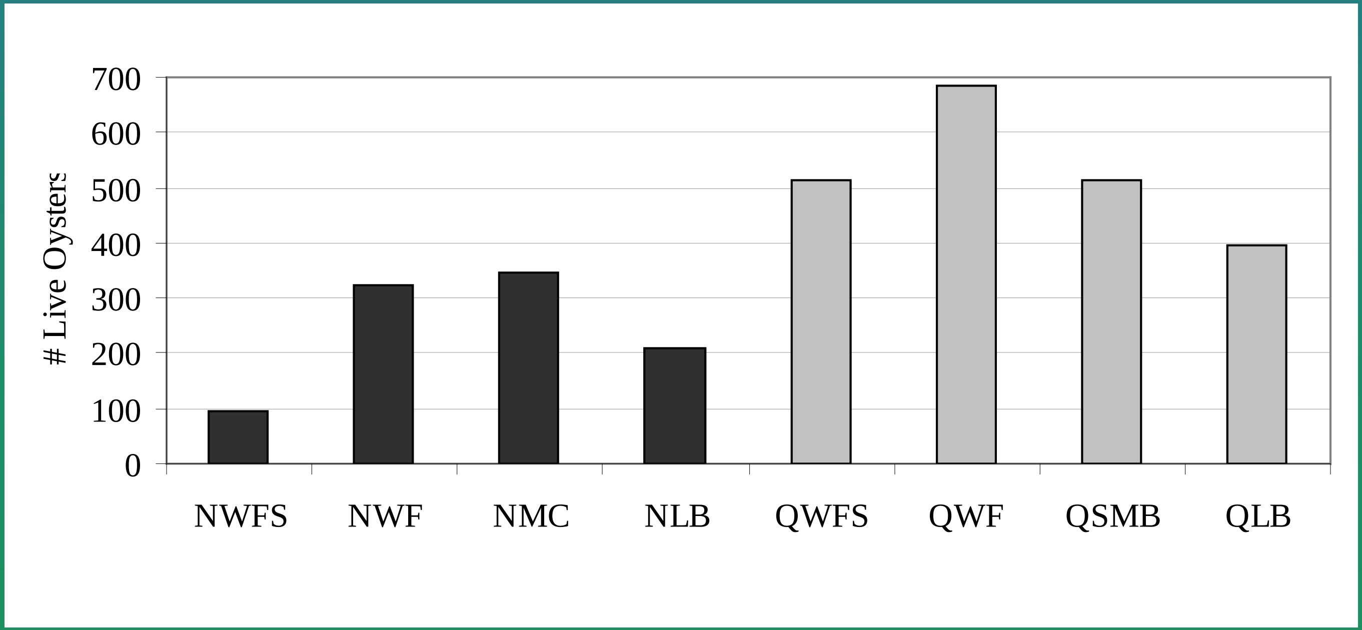
	October 2008	June 2009	October 2009
Aquaculture Site ID	**% ≥ 76 mm**	**% ≥ 76 mm**	**% ≥ 76 mm**
NWFS	0	20	73†
NWF	0	30	44
NMC	0	13	45
NLB	0	0	1
QWFS	3	19	62
QWF	1	24	62
QSMB	2	16	61
QLB	N/A	3	24

Initial shell sizes = 30 mm

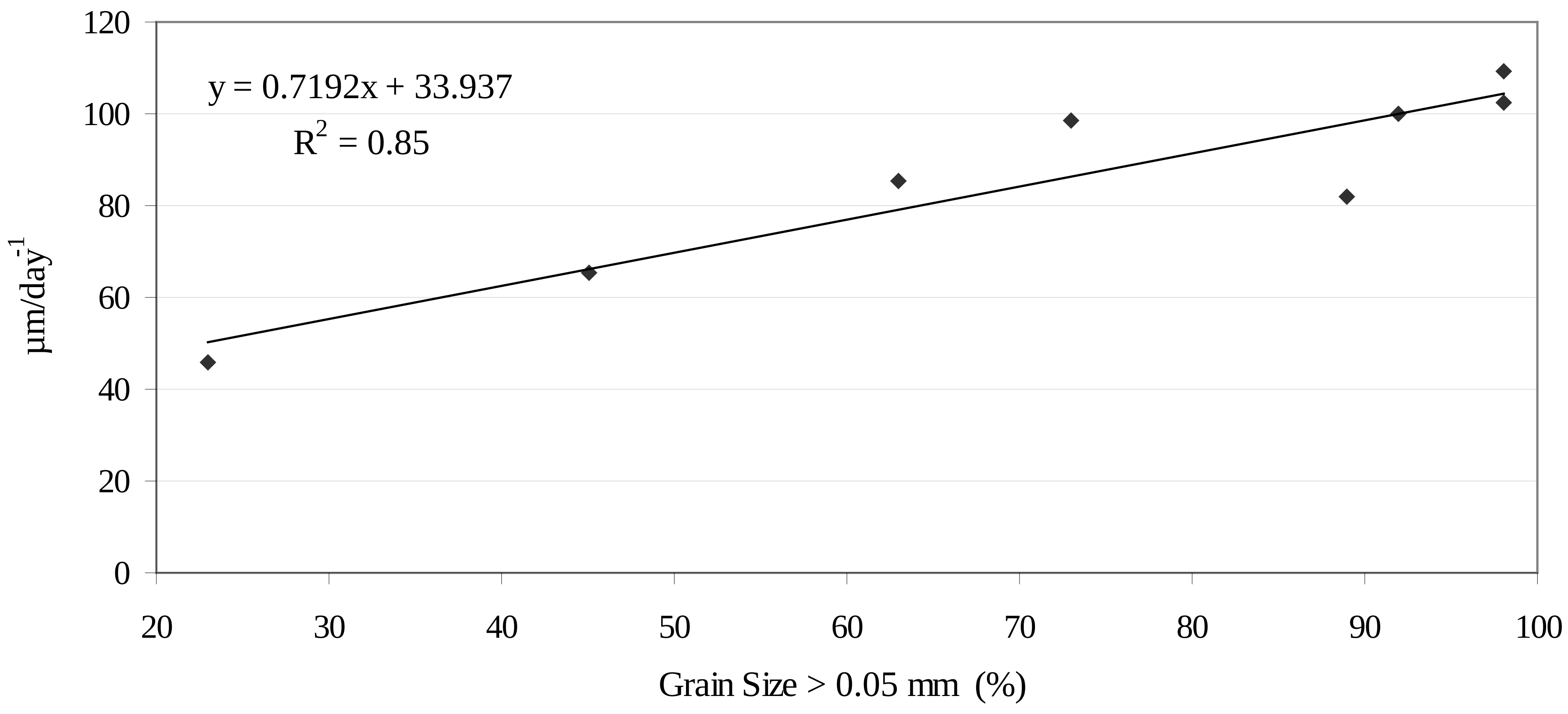
† vandalism, July 2009 unknown lost, number based on 1 oyster t

Oyster Biovolume and Total Numbers October 2009





Grain Size of Surface Horizon Predicting Oyster Growth



Quahog Growth Experiment

- Seed quahogs purchased from Roger Williams University
- Screened to a uniform size and measured by hinge width (Initial = 9.1 mm)
- Placed in soil in August 2008 at aquaculture sites and covered with predator netting
- Retrieved by a modified quahog rake in October 2009 where they were again measured by hinge width
- Ninigret Pond had 420 growing days
- Quonochontaug Pond had 414 growing days

Quahog Growth

Aquaculture Site ID	Final Size (mm)	Growth µm/day^{-1}	Number Recovered
NWFS	22.1[a]	31.0	73
NWF	16.8[b]	18.3	32
NMC	18.1[b]	21.4	115
NLB	N/A	N/A	0
QWFS	17.6[x]	20.6	109
QWF	19.1[y]	24.3	126
QSMB	18.0[x]	21.4	47
QLB†	15.9[z]	16.3	243

†QLB quahogs grown in grow-out bag buried at site

Shellfish Summary

- Oyster Growth (both ponds) 31 mm/year
- Quahog growth (both ponds) 7.9 mm/year
- Shellfish grew faster on coarser textured soils
  - Increased growth rates
  - Greater biovolume
  - Greater survival
- Grain size of surface horizon predictor of oyster growth ($R^2 = 0.85$) (Quahog to sand content $R^2 = 0.50$
- Landscape units containing increases in sand (Washover Fan, Submerged Mainland Beach) more suitable for shellfish aquaculture
- Existing soil surveys can provide managers with a tool for siting future aquaculture farms

Predation by Crab (Left) and Oyster Drill (Right)

Conclusions

- The systematic distribution of soil types in a soil survey are relative to eelgrass distribution, growth, and transplant success, variations in SOC pools, and accumulation of heavy metals

- Once included in subaqueous soil surveys, these tools will be valuable reference information for coastal resource managers, policy makers, and research scientists