Insights and Approaches for Mapping Soil Organic Carbon as a Dynamic Soil Property

Mark H. Stolt, Patrick J. Drohan, and Matthew J. Richardson

Soil Science Society of America Journal (2010)

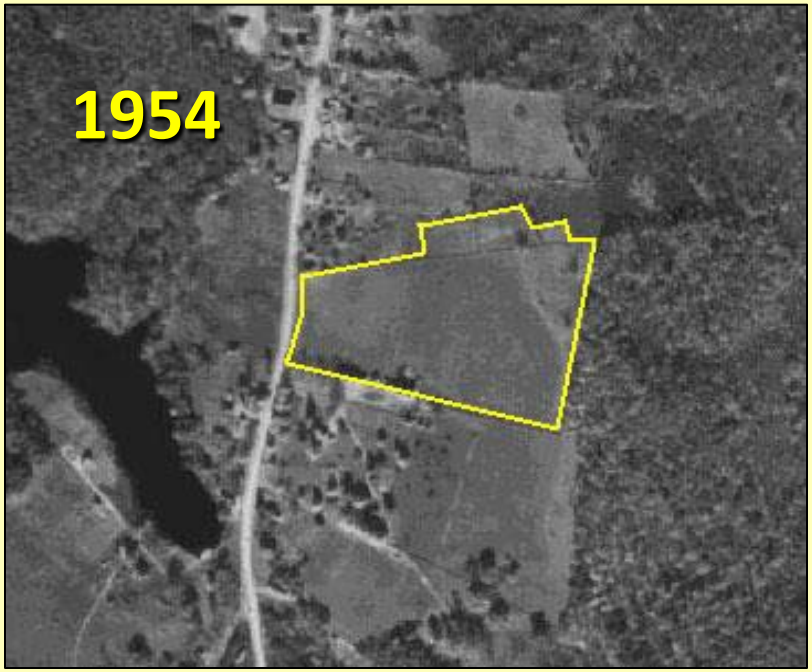
Site Locations

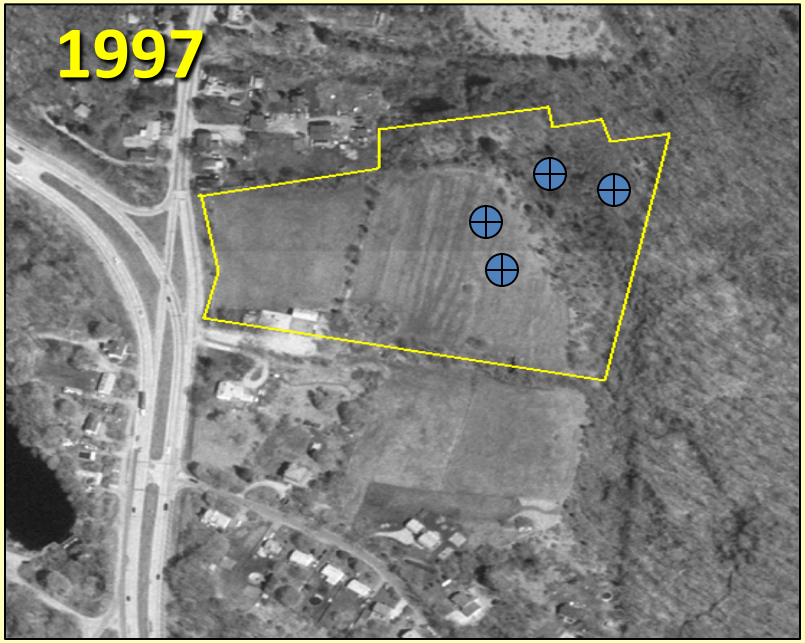
RIGIS

17 sites, ranging in age from 25 to 86 years.

Paired Sites:

- Field and forest having same soil type comprise paired site
- Sample multiple locations within field and forest
- Core trees to determine age and measure SOC
- Difference between field and forest used to calculate rate of C sequestration





Average SOC by horizon and for the upper meter by Anderson Land Cover Class

Anderson Land Cover Level I	O	A	B	C	Upper Meter	Percent of Upper Meter Pool in O and A Horizons	Numeric Phase Value
	Mg ha^{-1}					%	(Mg ha^{-1})
Agricultural	0	55	35	15	103	53	55 (Moderate)
Forest	32	70	40	17	157	65	102 (High)

Add a phase component to the Soil Survey for SOC pools

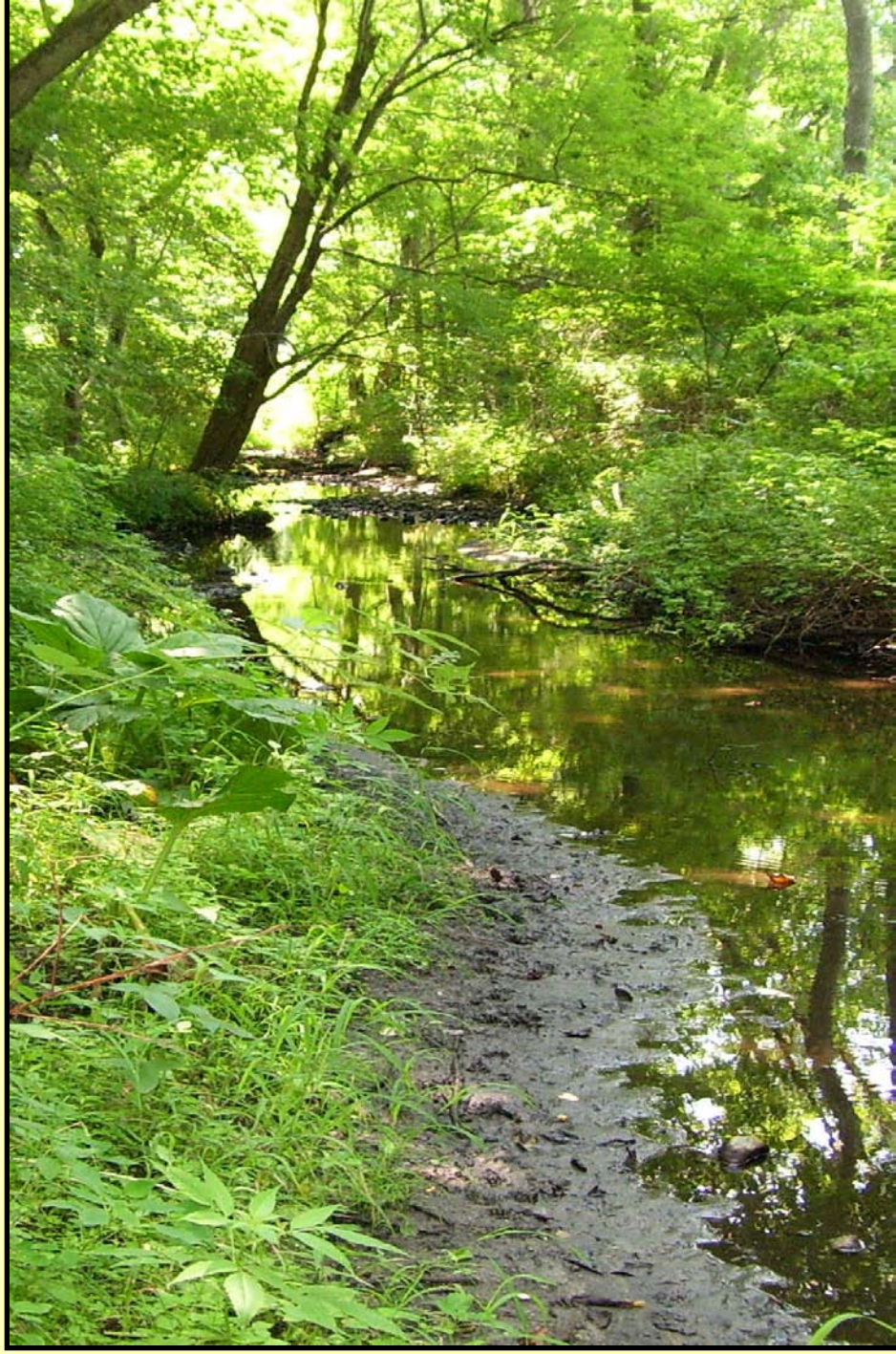
Focus on the O and A horizon

For example: MmB in the soil survey in agriculture would be changed to MmBM

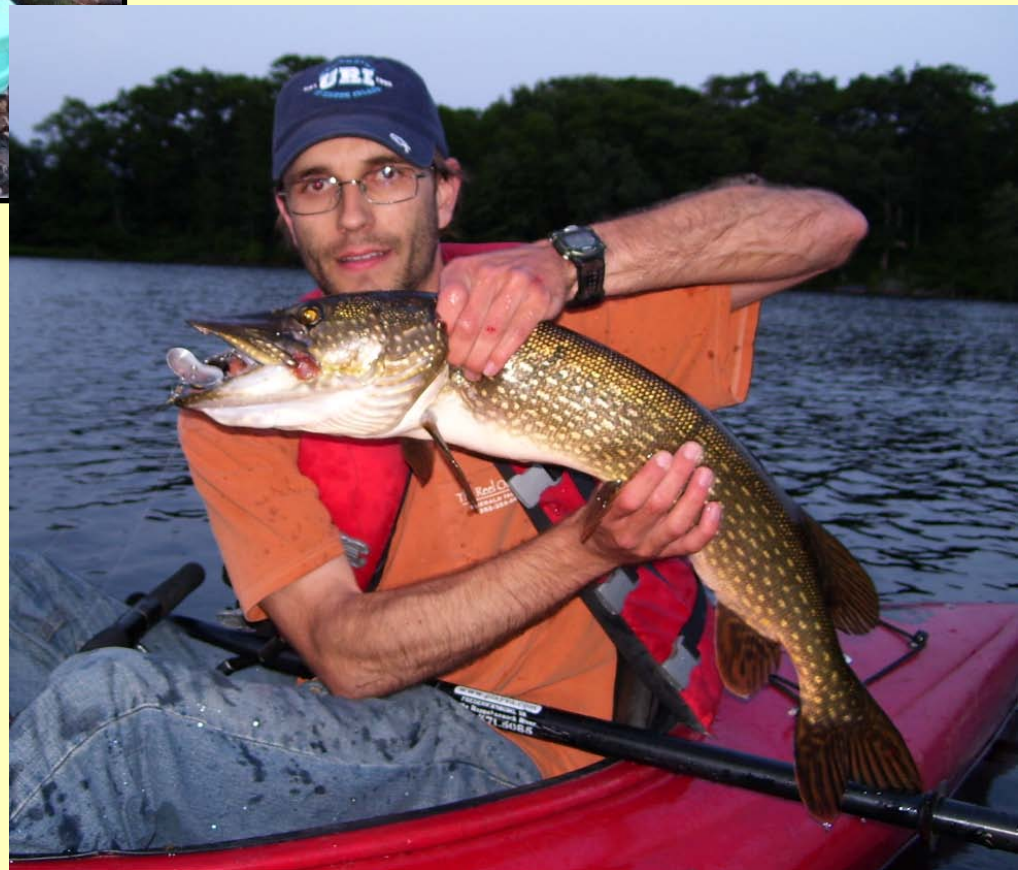
Assessing the Effects of Land Use Change on Riparian Zone Soils in Southern New England

Matthew C. Ricker
Mark H. Stolt

Ecological Applications 2012



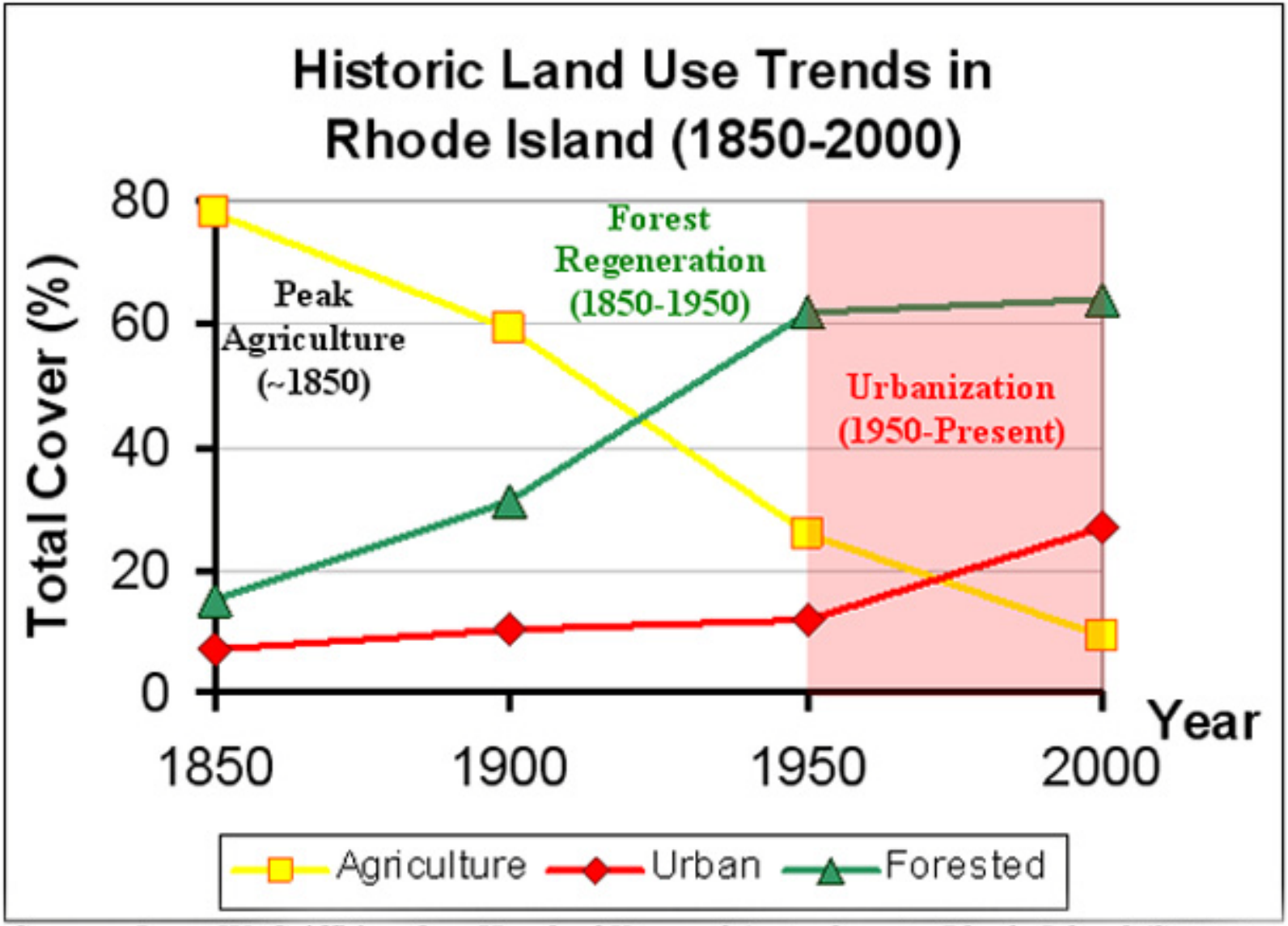
Matt Ricker



RIPARIAN ZONES

- Important links between upland and aquatic systems
- Provide multiple environmental and ecosystem functions
- Form as a result of episodic alluvial deposition
- Land use change may result in impacts to riparian soil functions

Buried horizon (Ab)



Source: Lucy W. Griffiths. *One Hundred Years of Agriculture in Rhode Island (Statistics and Trends)*. University of Rhode Island, Bulletin 378, January 1965, and RIDEM Division of Agriculture.

Develop Multi-Proxy Indices of Land Use Change for Riparian Soils

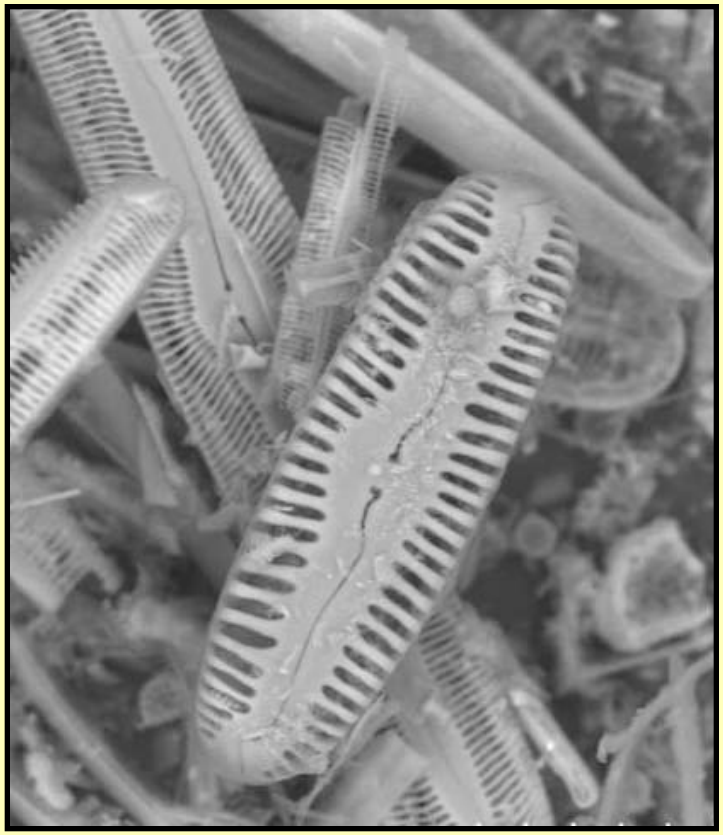
Objectives

1. Establish stratigraphic indices of watershed land use change using a multi-proxy approach

2. Utilize these indices to establish time frames of alluvial deposition

3. Relate riparian sedimentation and carbon sequestration rates to land use

Diatomaceous Earth

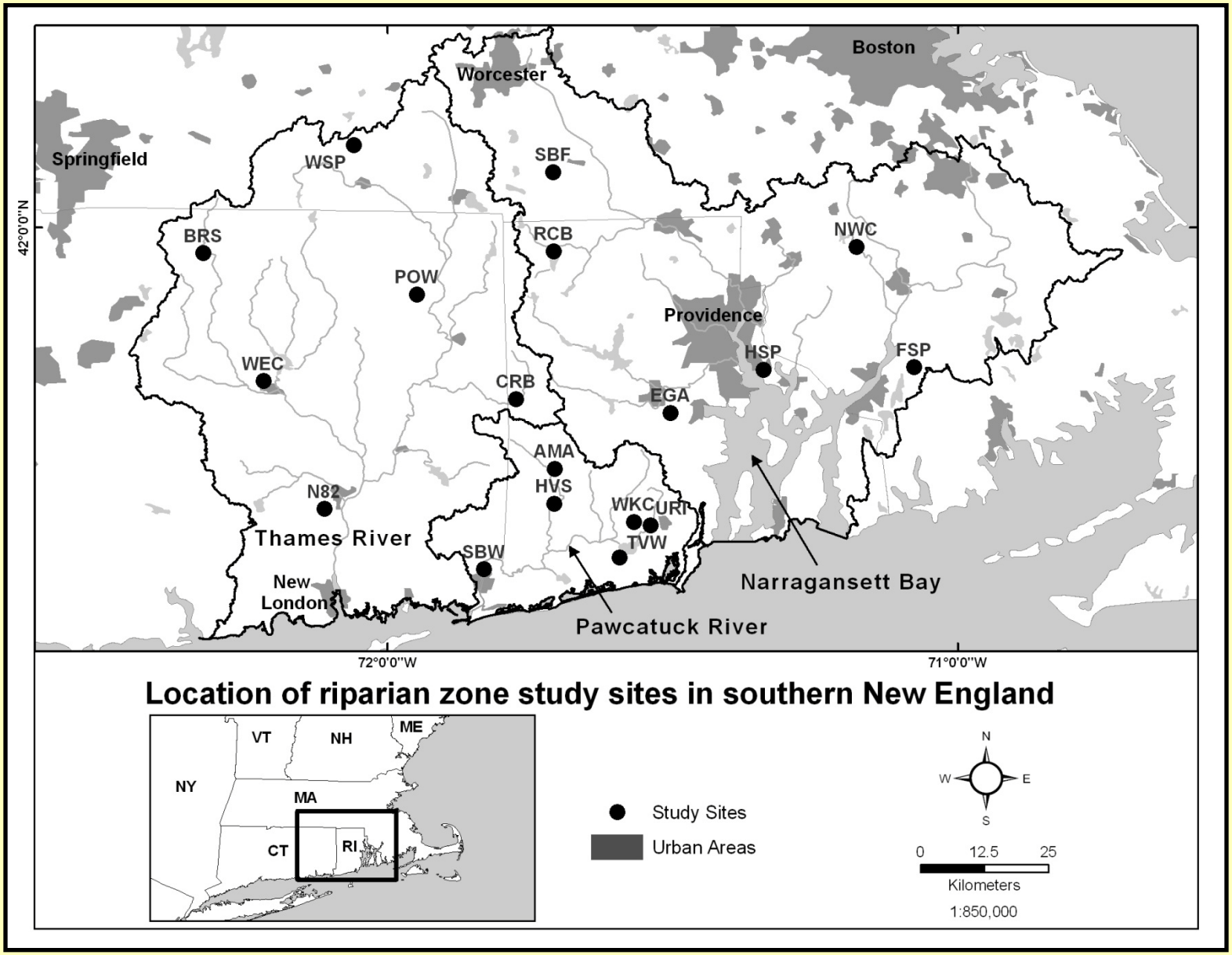


SEM Image
500x Magnification

Methods

- 18 representative headwater watershed riparian sites selected
  - Hydric soils (Inceptisols, Entisols)
    - Formed in alluvium over outwash
    - Raypol, Rumney, Scarboro, and Walpole series
- Varied watershed land use
  - Urban, agricultural, mixed use, forested
- Soil pits dug to 1 m or greater
  - Soils described in field
  - Bulk density
  - PSD
  - Heavy metals
  - Pollen samples by horizon
  - Soil organic carbon (SOC)

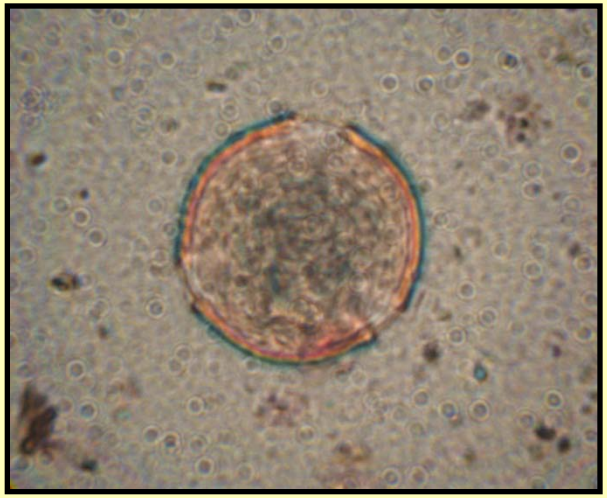
Study Watersheds



4 urban, 4 agricultural, 4 forested, and 6 mixed LU watersheds

General Land Use Periods and Associated Indices

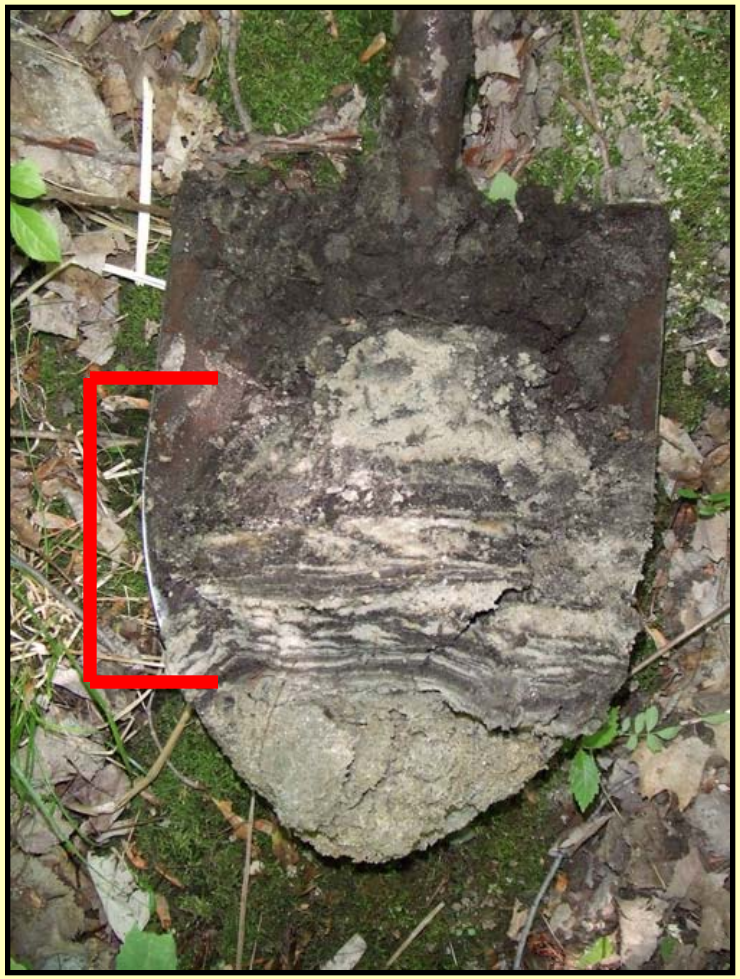
- Constrain riparian soil horizons into three major distinct land use periods
- **Pre-colonial period (17,000 YBP–1650 AD)**
- **Colonial (agrarian) period (1650-1900 AD)**
  - Rise and/or peak **ragweed** and other non-arboreal pollen types
  - Supported by twelve **^{14}C dates**
    - Rise in ragweed dated to **1780±40 AD**
    - Peak ragweed dated to **1850±50 AD**
- **Modern industrial/urbanization period (1900 AD-present)**
  - Increased coarse materials (sand, gravels)
  - Presence of human **artifacts**
  - Rise and peak **pollutant metals** (Pb)
    - Supported by **^{210}Pb cores**



Indices of Land Use Change:

Soil Morphology and Pollutant Metals

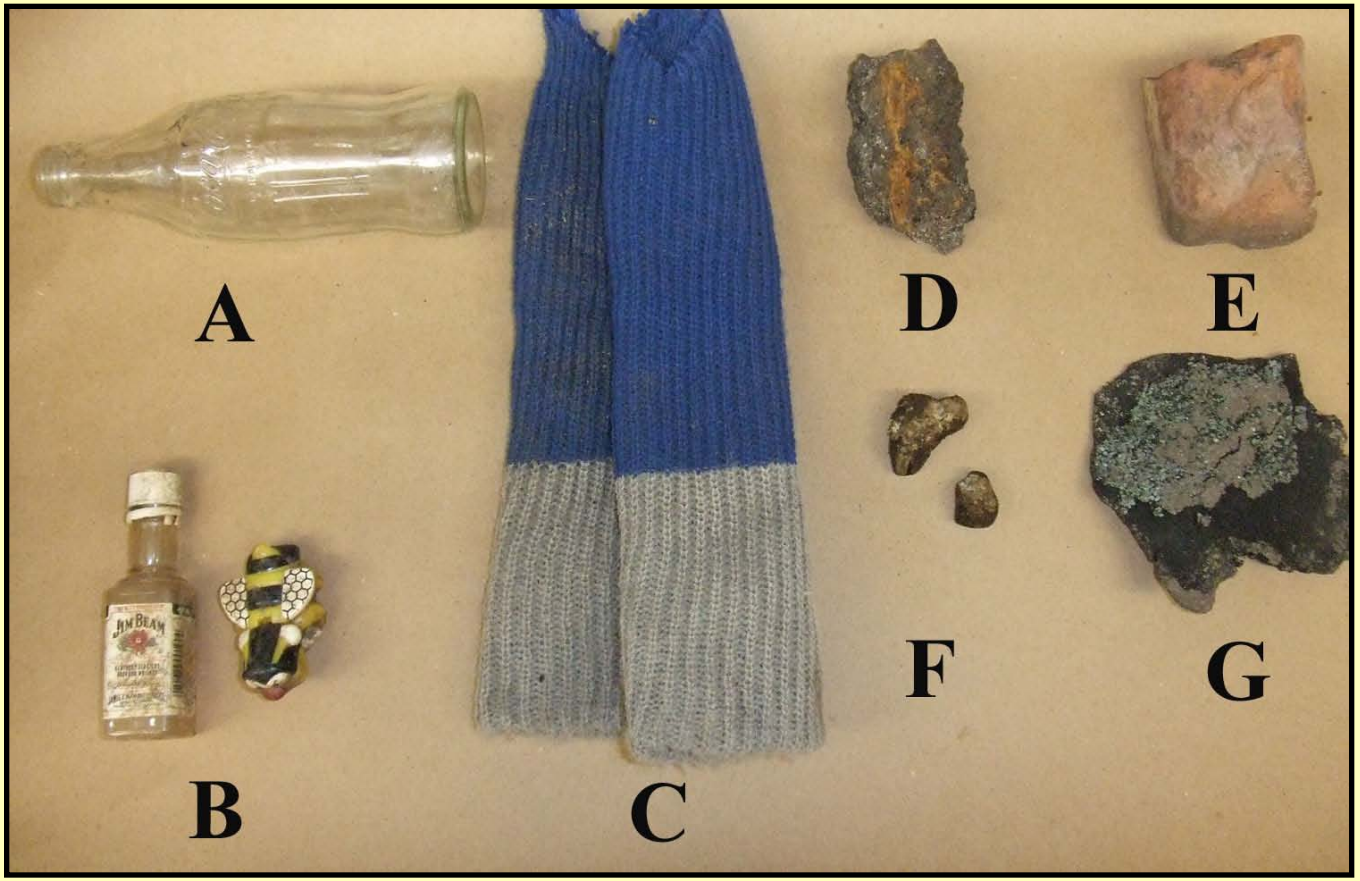
- Particle size distribution
  - Coarser deposits as watersheds undergo extensive LU change
- Buried horizons (i.e. Ab)
- Combination horizons (i.e. A/C)
  - Indicative of short term stability
- Human artifacts (i.e. Cu horizon)
  - Indicative of colonial-urban time periods
- Pollutant metals
  - Pb, Cu, Zn, Cd, As above background levels; on average 3 to 6 times higher in surface horizons



Many sand lenses (A/Cg)

Examples of Riparian "Artifacts"

(One Person's Garbage is Another's Stratigraphic Marker…)

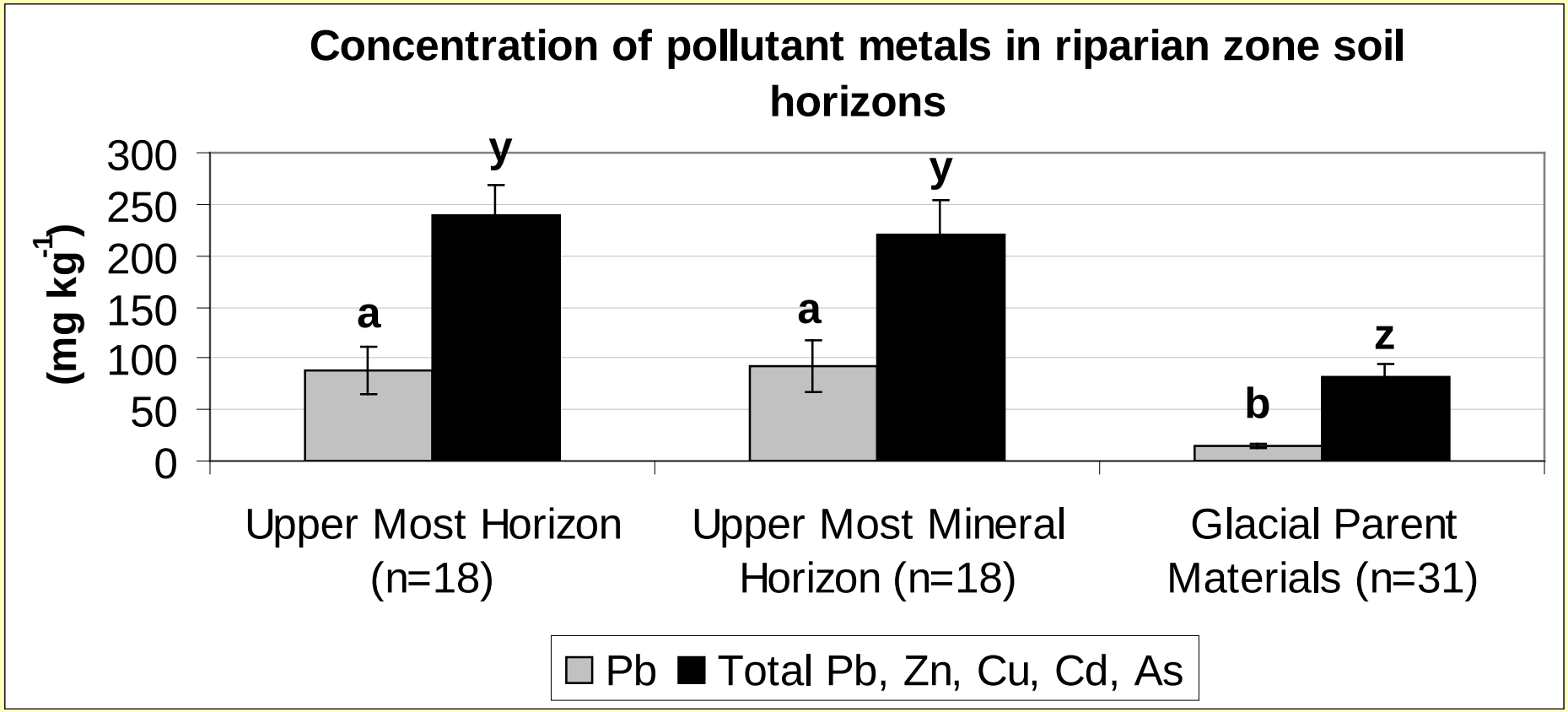


A: Glass 50 cm B: Plastic 15 cm C: Cloth 20 cm D: Asphalt 30 cm E: Brick 50 cm F: Styrofoam 15 cm G: Shingle 40 cm

Pollutant Metals

Indices of Anthropogenic Activities

(1900-present)



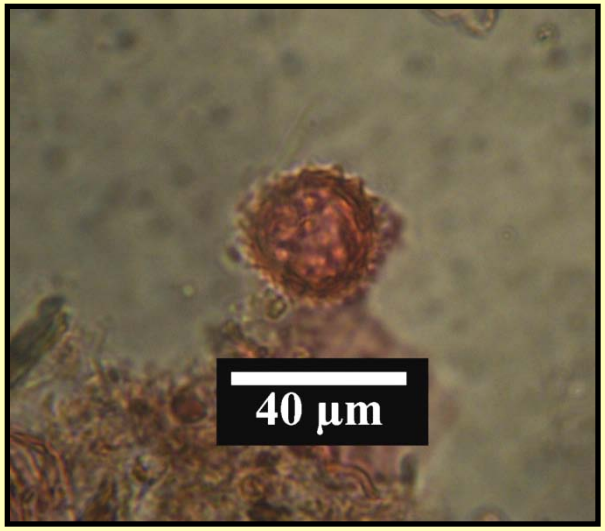
Means with different letters are significantly different (α=0.05)

Metals concentrated near soil surface, likely anthropogenic origins:
1900-present fossil fuel combustion, especially leaded gasoline

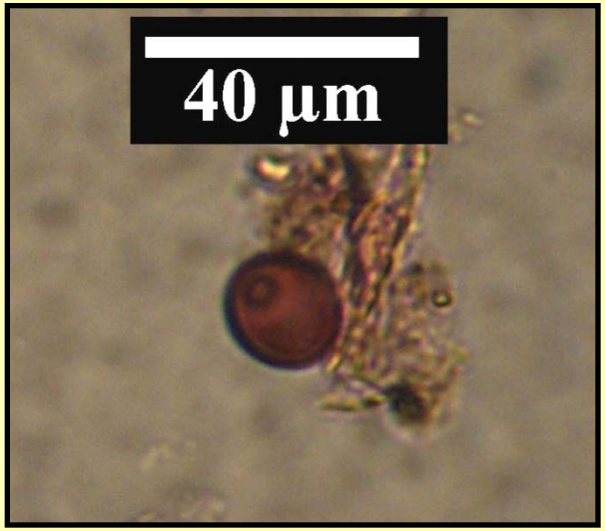
Indices of Land Use Change:

Preserved Pollen (Colonial Period)

- Past land uses affected the vegetation of the region
  - Impacts evident in pollen record
  - Pollen stratigraphy can be used to reconstruct land use
- Pollen indicators, specifically:
  - **ragweed** (*Ambrosia* taxa, family Asteraceae)
  - **grasses** (Poaceae)
  - have been used to date peak land use disturbance in many depositional environments (lakes and ponds)

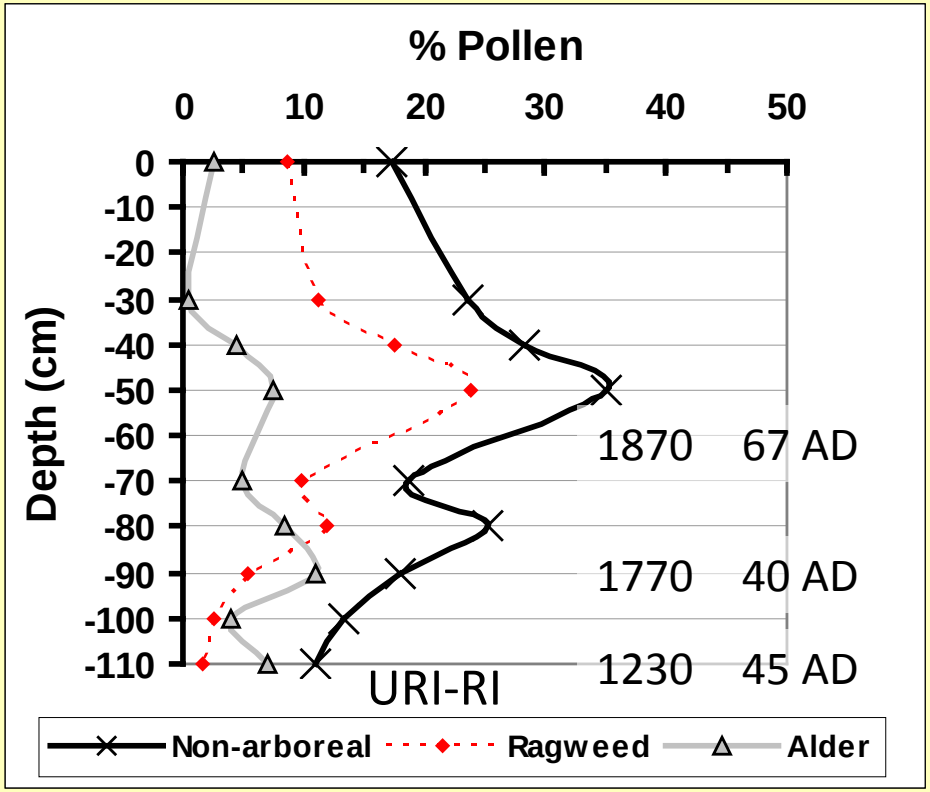


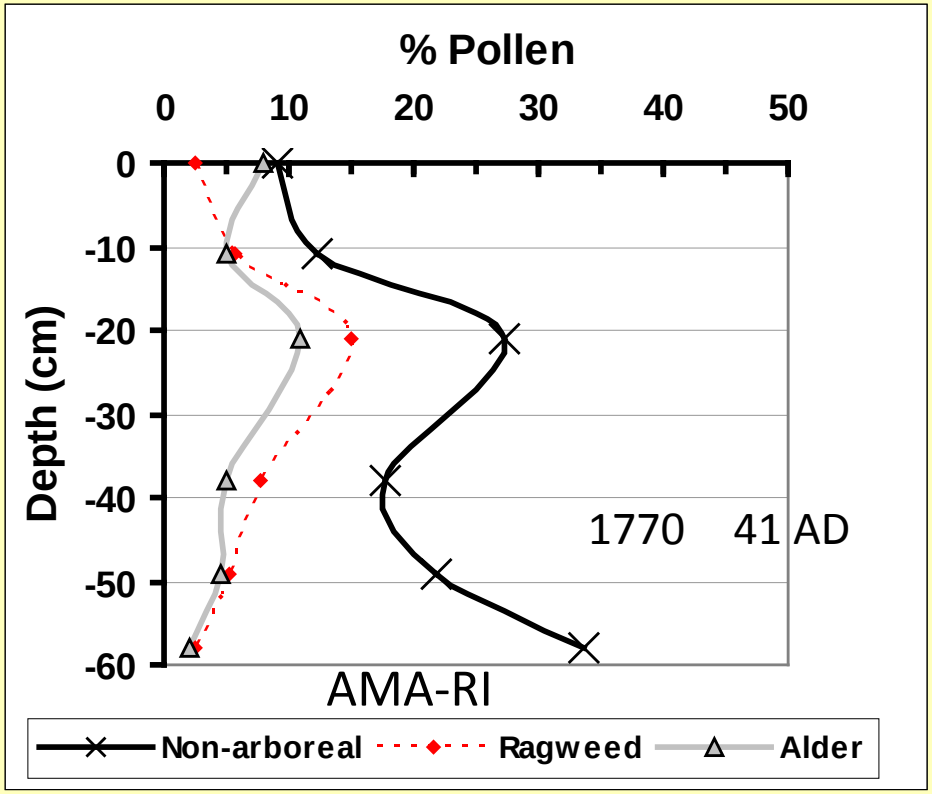
Ragweed pollen (tricolporate, spines)



Grass pollen (monoporate)

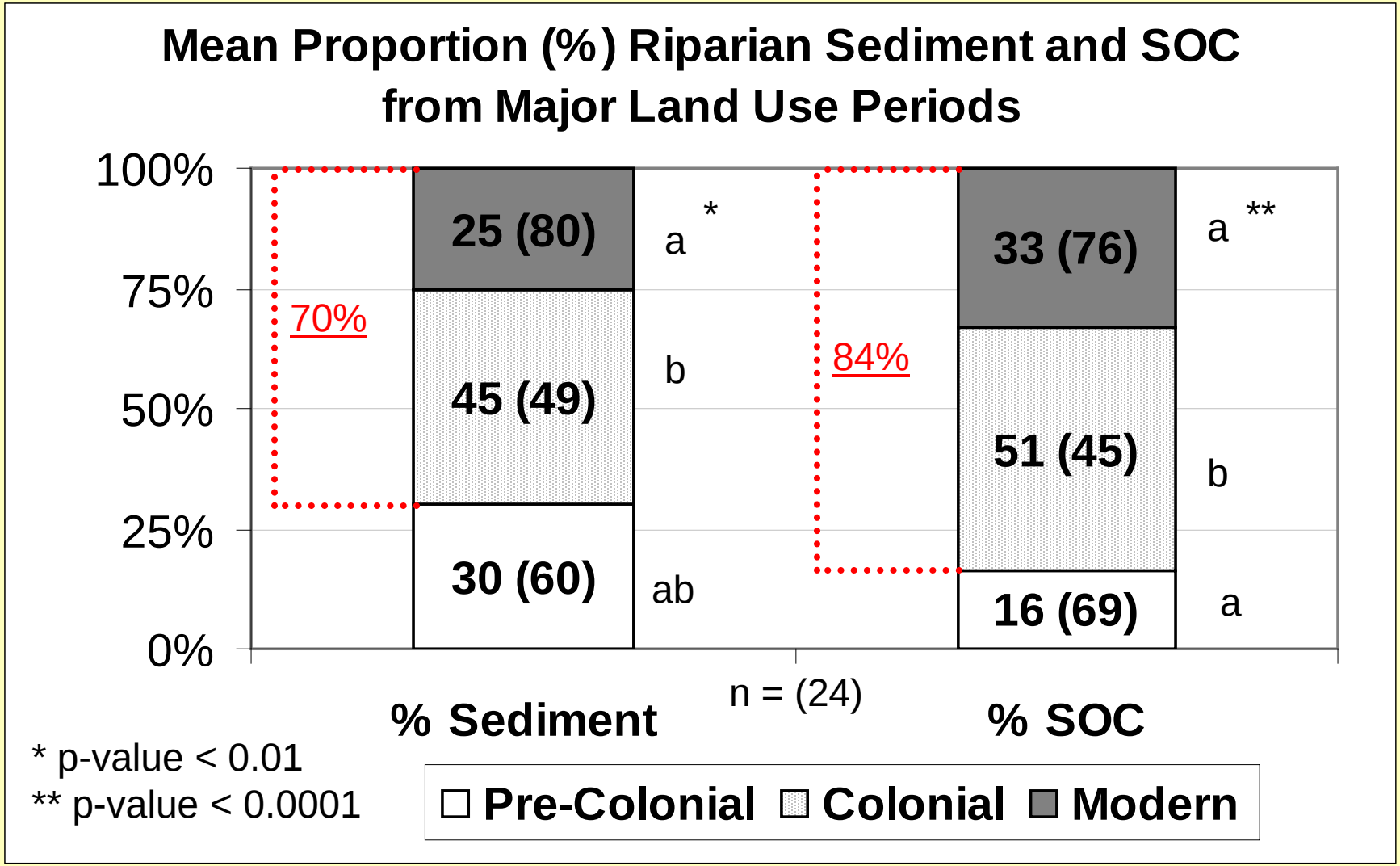
Example Pollen Diagrams



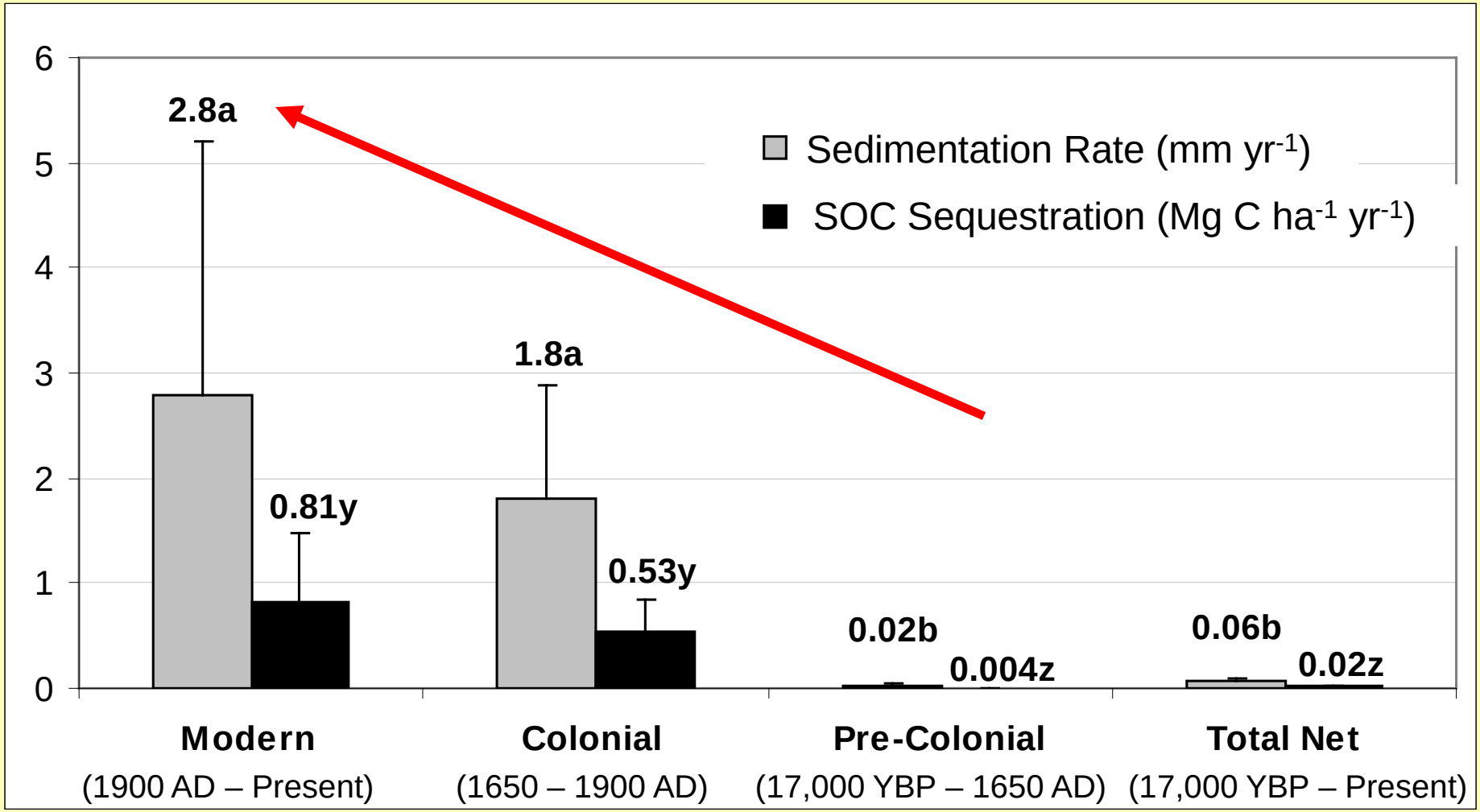


- Moderate to abundant pollen was preserved in subsurface horizons
- Range 300 to >60,000 pollen grains per gram of soil
- Pollen was preserved in horizons dated to >11,000 YBP
- 88% riparian soils contained preserved pollen
- 71% riparian soils contained enough pollen for land use stratigraphy

Average net sediment and SOC distribution by land use period



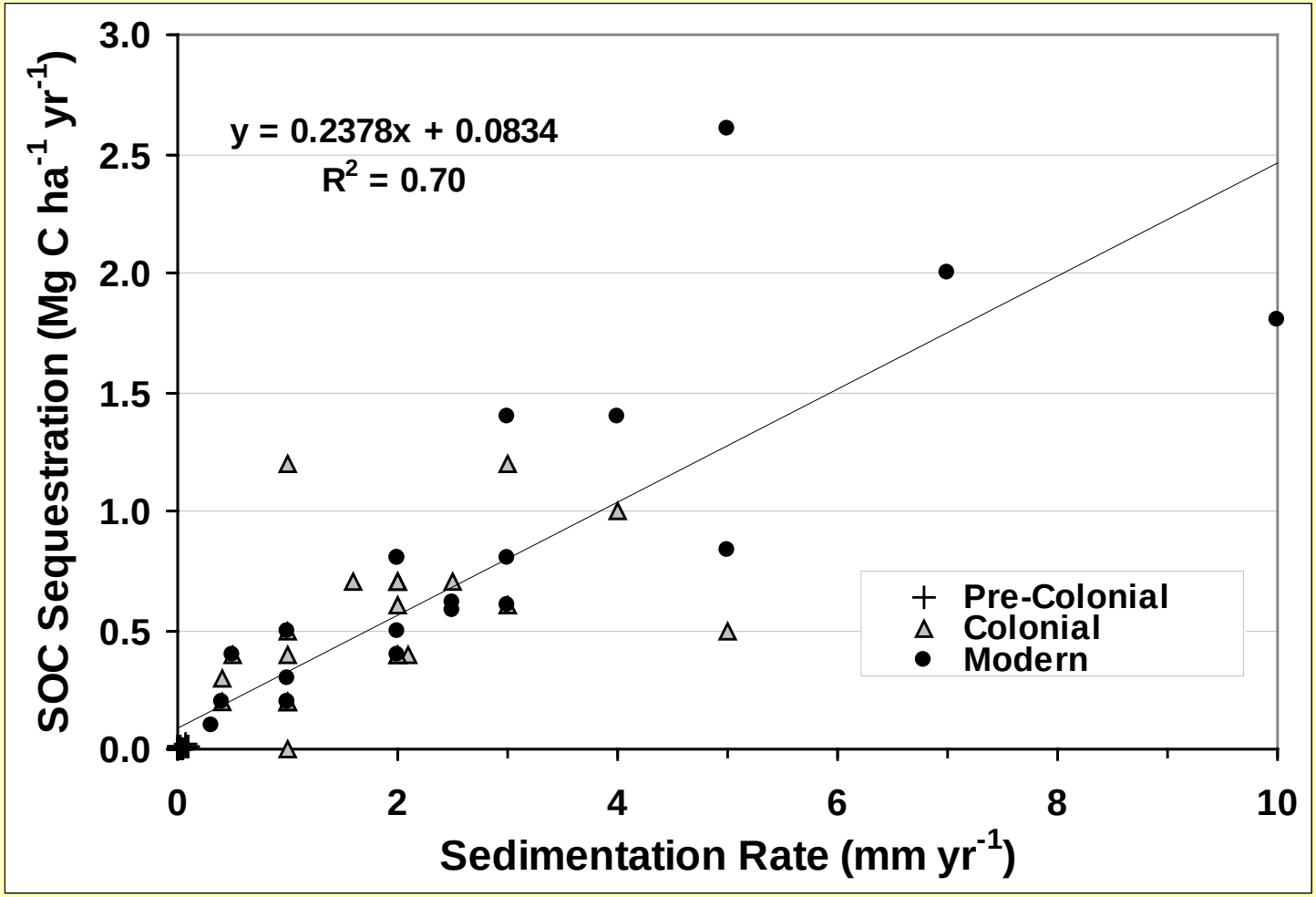
Evaluating Net Sedimentation and SOC Sequestration Rates Utilizing Stratigraphic Indices



- 115x overall increase net sedimentation rates since pre-colonial period
- 225x overall increase net SOC sequestration since pre-colonial period
- Riparian rates for SOC sequestration are 2 to 4 times that of upland forests

Sedimentation and SOC Sequestration:

What is the relationship?



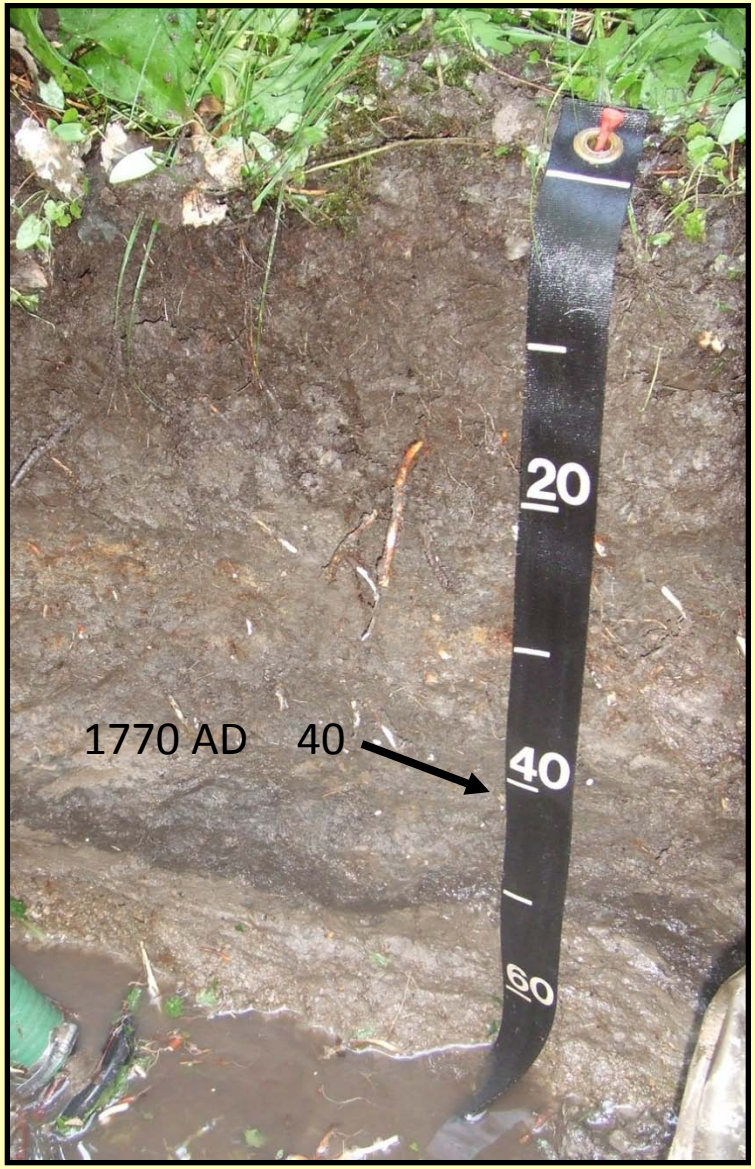
- Suggests sedimentation and SOC sequestration are related.
- Exact driver of this relationship is unclear (burial, C influx, additional surface area?).

Conclusions

- Soil morphology, pollutant metals, and pollen stratigraphy can be used to successfully date riparian soil deposition

- Land use change has had significant impacts on riparian zone sedimentation and C sequestration
  - Riparian zones acting as large sinks for sediment and C
  - Riparian SOC sequestration and sedimentation may be linked processes

Ab horizon



Are riparian zones “hot spots” for SOC at watershed-scale

Methods

--29 representative riparian soil pedons were examined, (Blazejewski, 2003; Donohue, 2007; Ricker, 2010)

--Soils sampled by horizon to 1 m

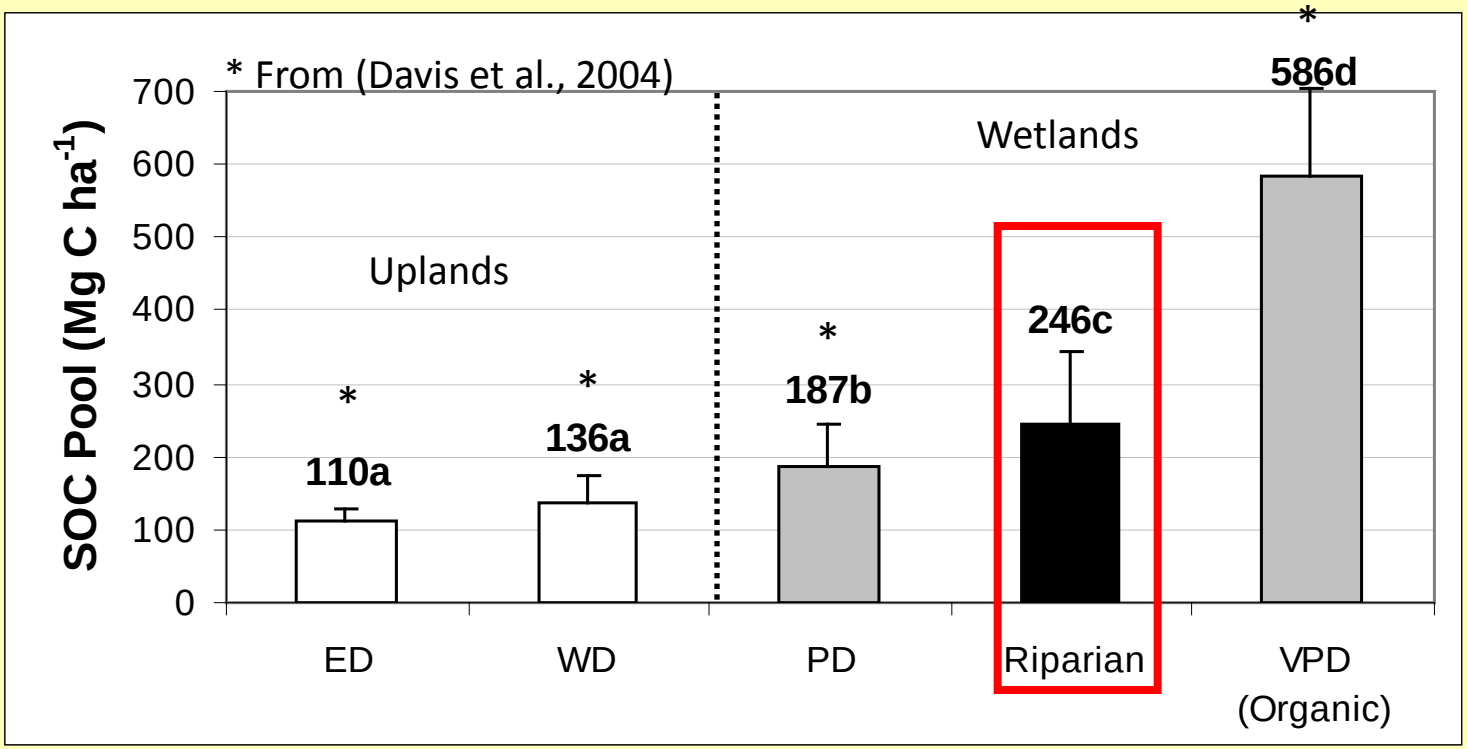
- Bulk density
- SOC
- Calculated SOC pools at landscape scale (Mg C ha^{-1})

--Riparian SOC pools compared to published data (Davis et al., 2004)

Watershed-scale analysis done in GIS

SOC Pools Across the Landscape

- Mean riparian SOC pool was 246 Mg C ha^{-1}
- SOC pools (to 1 m depth) in riparian zone more than all other mineral soils evaluated by Davis et al. (2004)
- Only Histosols contained more SOC to 1 m



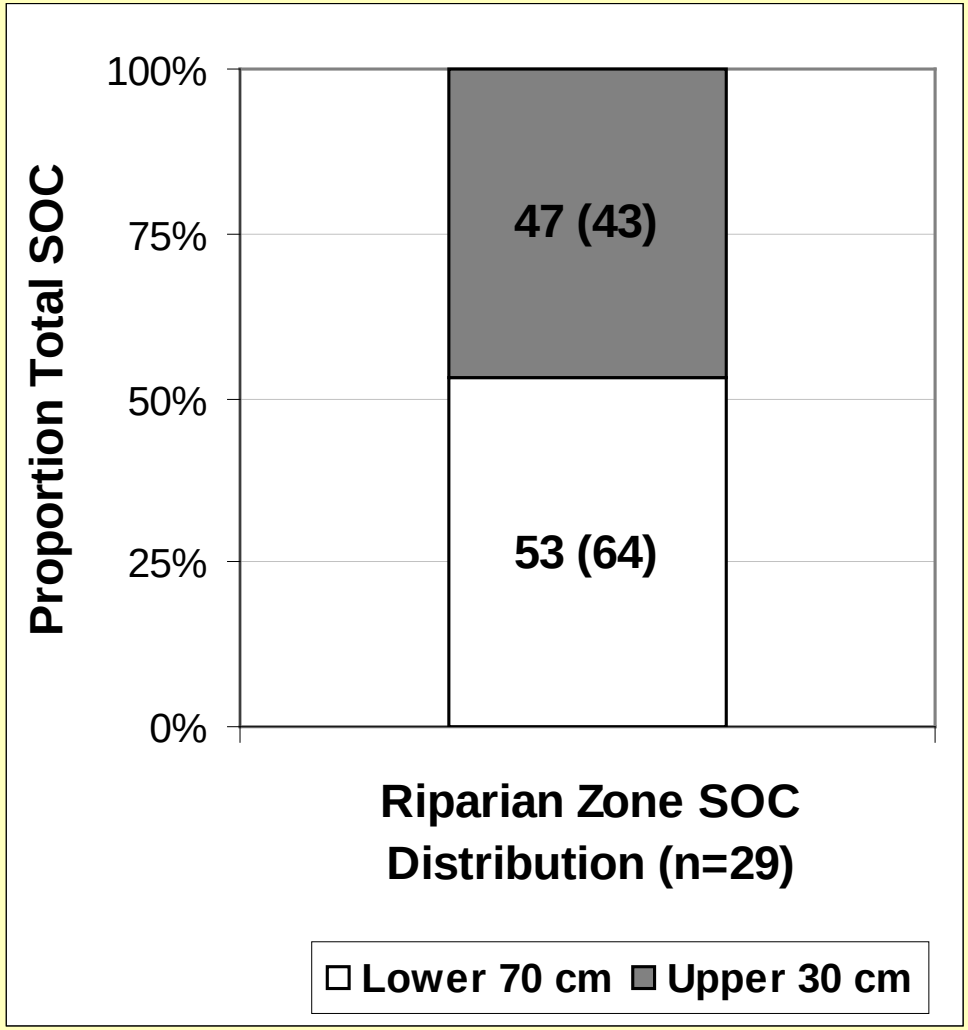
Means with different letters are sig. dif. ($\alpha = 0.05$)

Error bars = 1 SD

Spatial Distribution of SOC in Riparian Soils

- 53% SOC below 30 cm depth
  - By comparison:
  - ED - 30%
  - WD - 30%
  - PD - 45%
  - VPD - 75%

- In addition:
  - 52% of riparian soils studied had buried SOC rich horizons below 1 m
  - Suggests deep burial of SOC is important in riparian landscapes

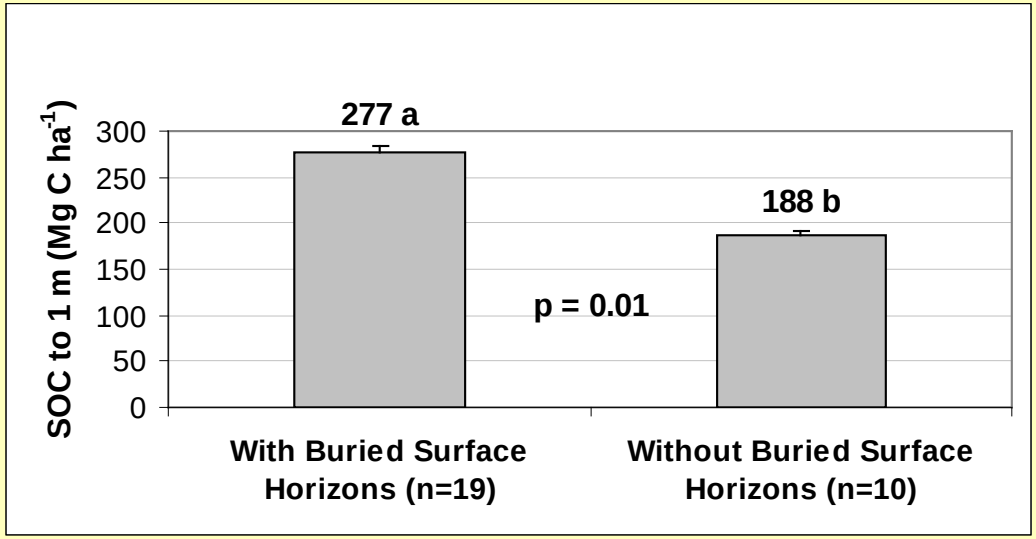


CV (%) in parentheses

Factors Affecting Riparian SOC Pools

Urban Riparian Soil
Norwich, CT

- Many factors tested, none significant
- Differences in SOC with differences in soil morphology
    - Soils with buried surface horizons contained significantly more SOC
    - Suggests riparian soils with high sedimentation contain more SOC



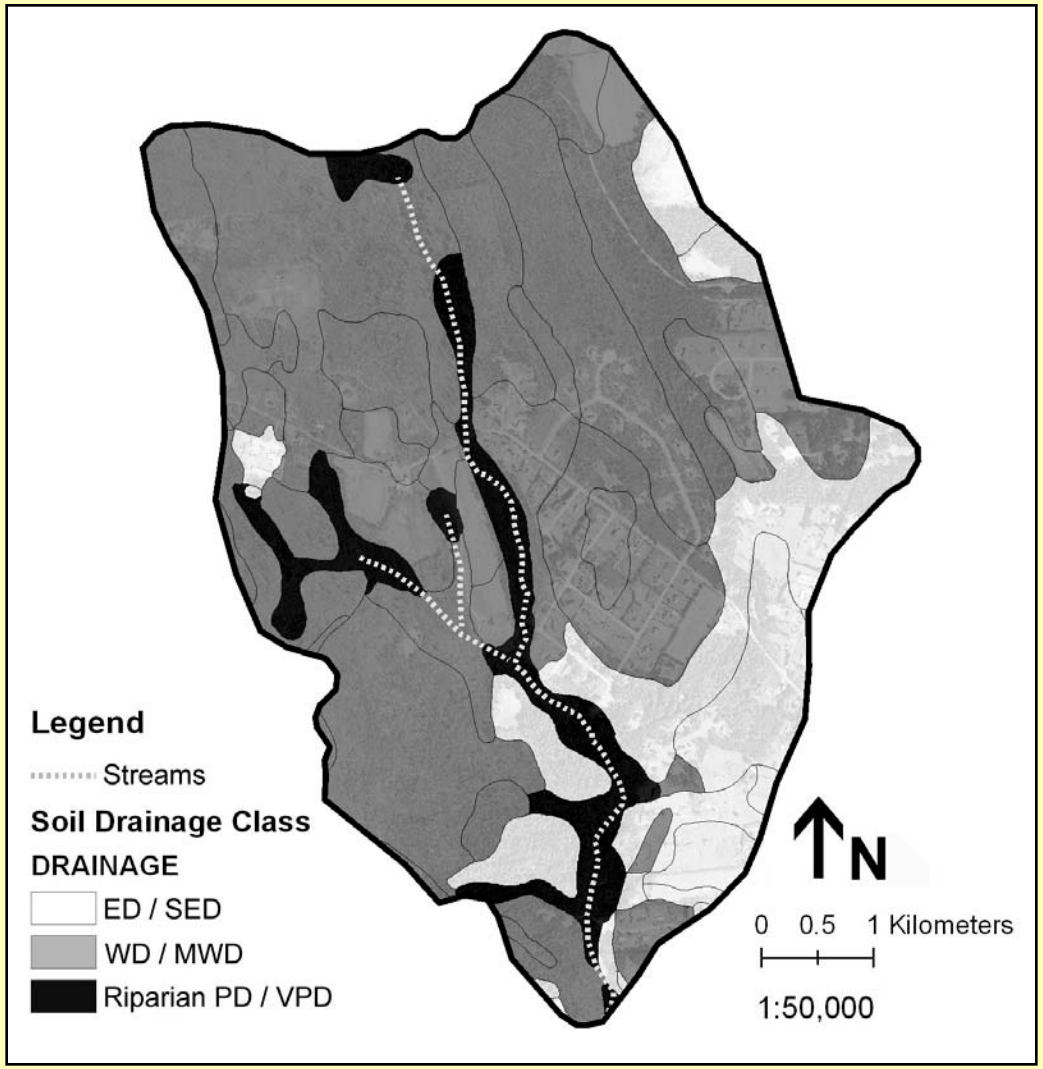
Riparian SOC Pools at a Watershed-scale

- On average, riparian zones comprised 8% of the total watershed area

- Contained as much as 20% of the total watershed SOC

- **Riparian zones occupy small portion of the landscape, but represent large sink for SOC at a watershed-scale**

Example GIS Map



Field Estimations of Soil Organic Carbon

M. H. Stolt and M. C. Rabenhorst
University of Rhode Island
University of Maryland

Field Estimations of Soil Properties

- Redoximorphic Features
- Soil Texture
- Soil Organic Carbon
  - Mineral soil materials
  - Mucky modified soil materials
  - Organic soil materials

Field Indicators of Hydric Soils

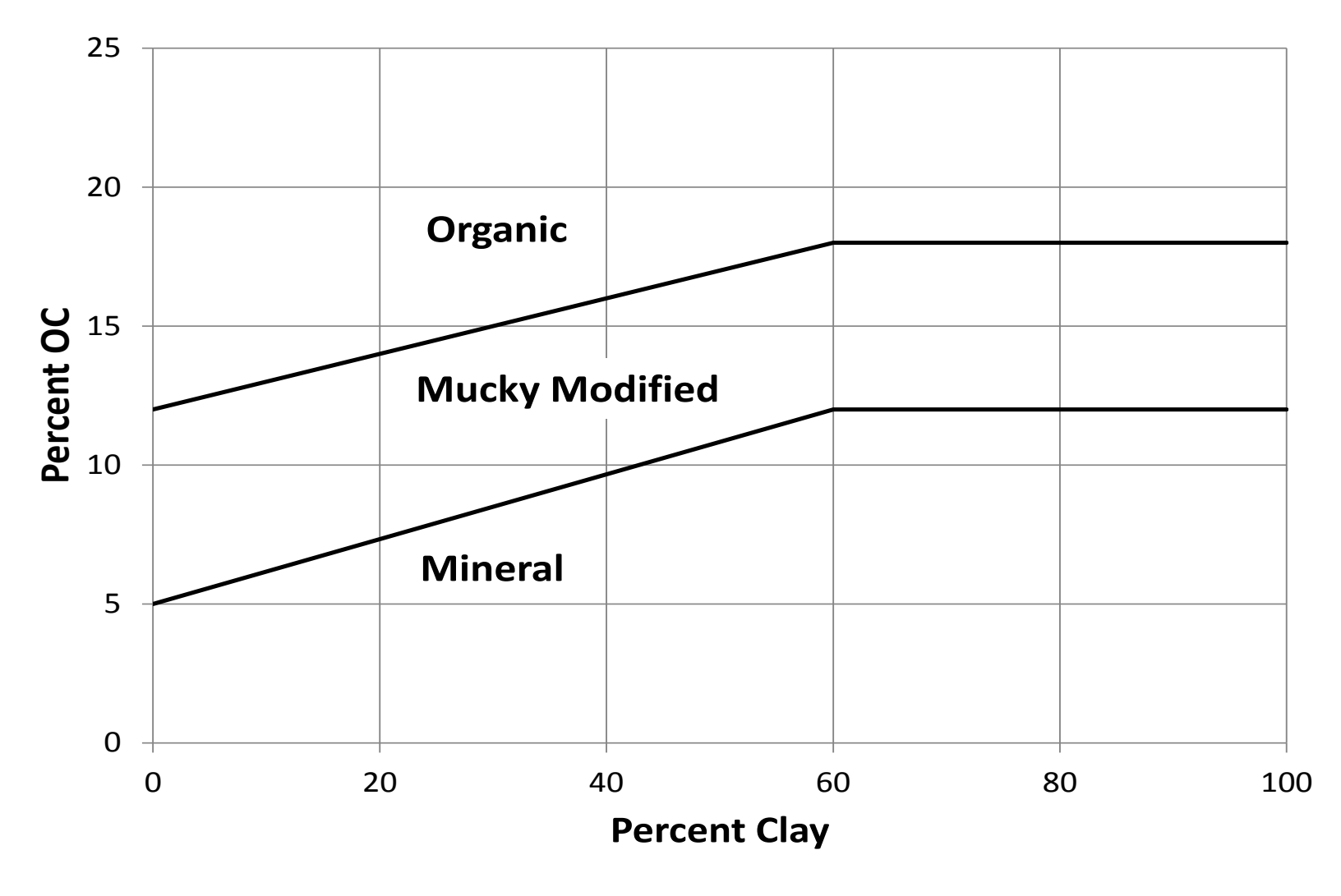
- Thirteen of the approved field indicators of hydric soils (A1, A2, A3, A5, A6, A7, A8, A9, A10, S1, S2, S3, F1) require the recognition of organic or mucky modified materials as part of their definition.

We Asked:

- How well can this be done?

Methodology

- Two parallel studies
- One utilized members and participants in the Mid-Atlantic Hydric Soils committee
- The second utilized members of the New England Hydric Soils Committee
- These groups were selected because they mainly included experienced soil and wetland scientists who had some experience in making distinctions among mineral, mucky mineral, and organic soil materials.

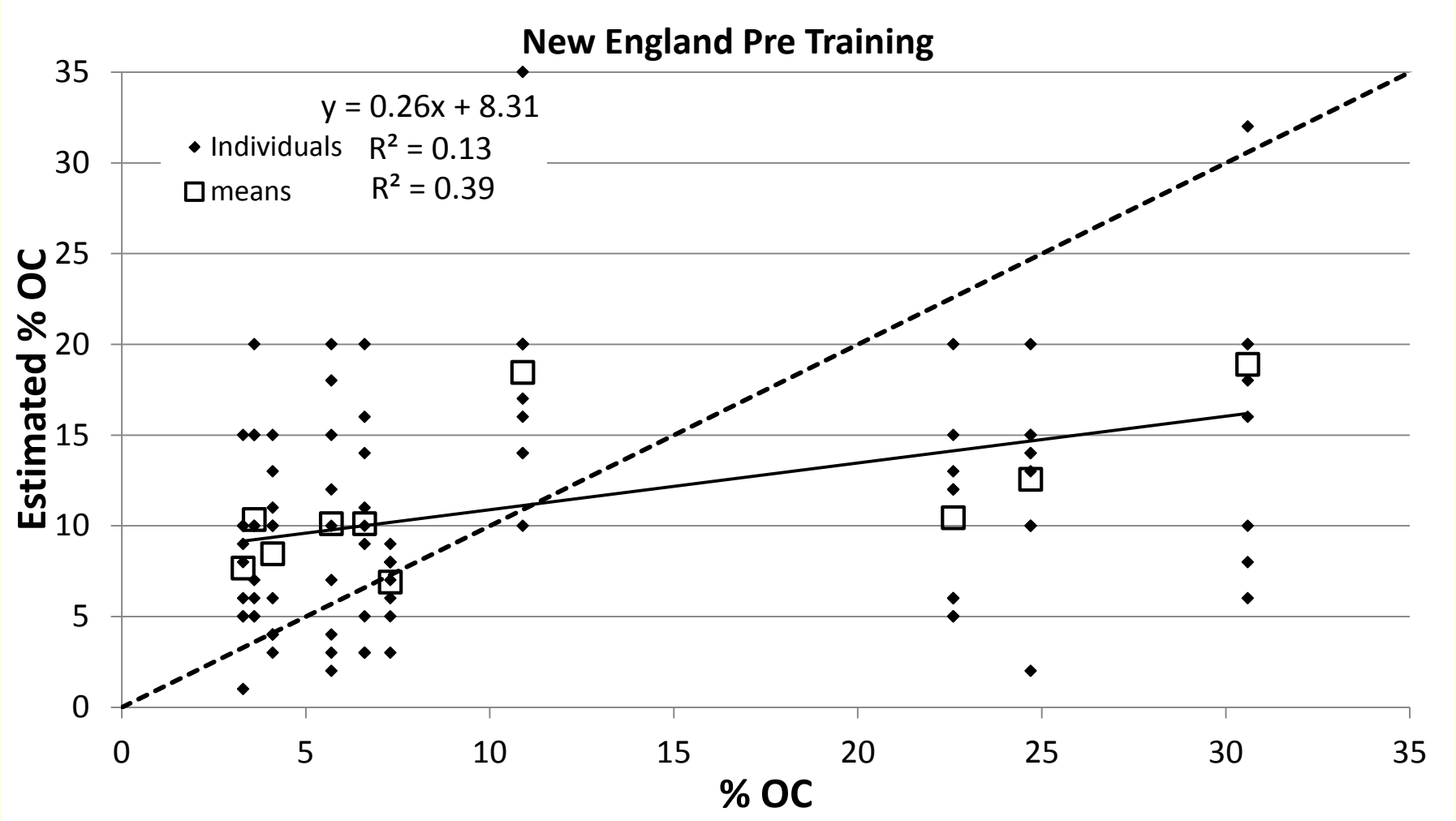


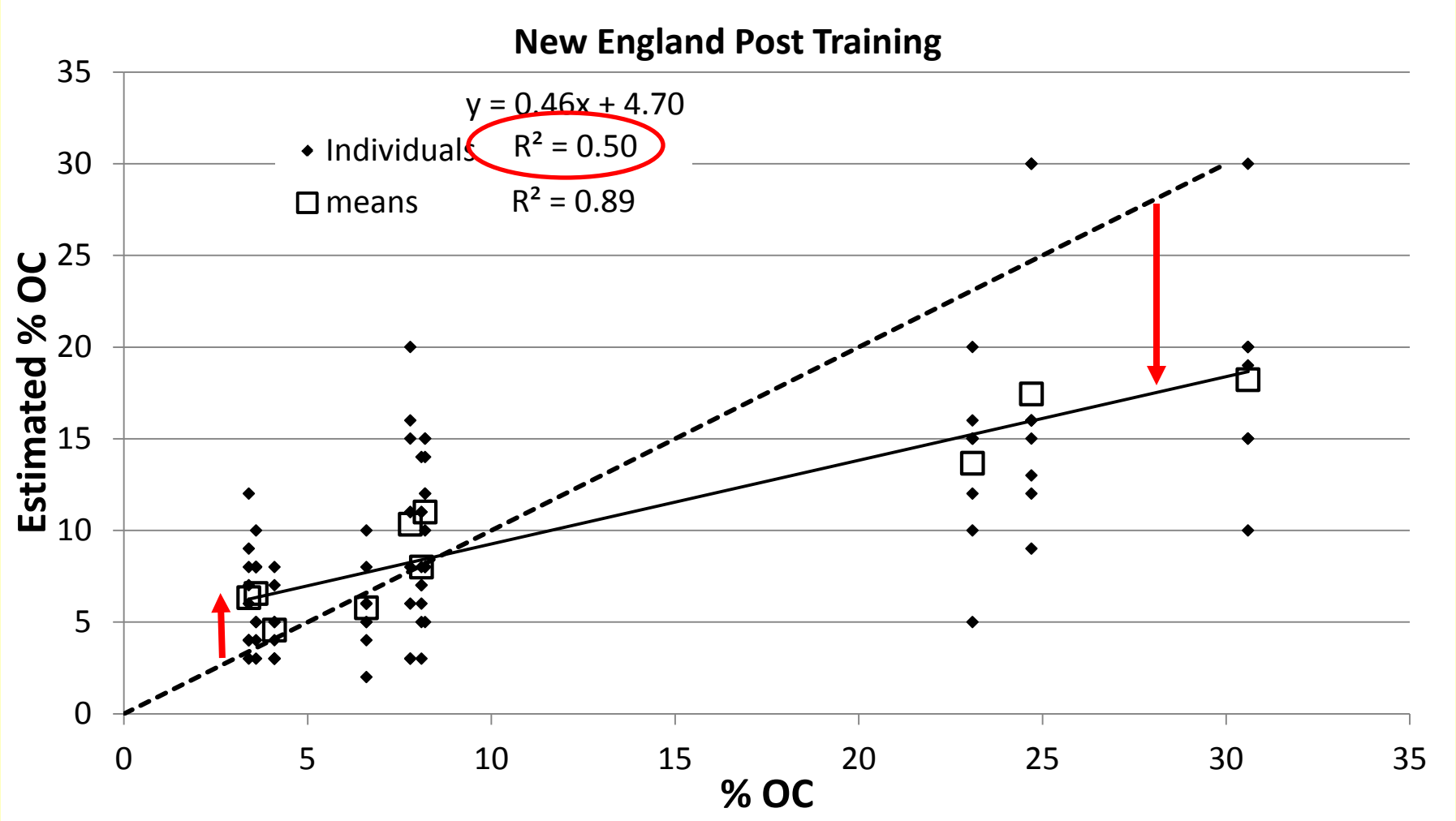
USDA-NRCS. 2010. Field Indicators of Hydric Soils in the United States, Version 7.0. USDA, NRCS, in cooperation with the National Technical Committee for Hydric Soils.

Pre-Training and Post-Training

Sample ID	Location	SOC content (%)	Mineral	Mucky Mineral	Organic
1	NH				
2	RI				
3	MA				
4	MA				
5	RI				
6	MA				
7	NH				
8	MA				
9	RI				
10	MA				

the same 11 people participated in both pre and post

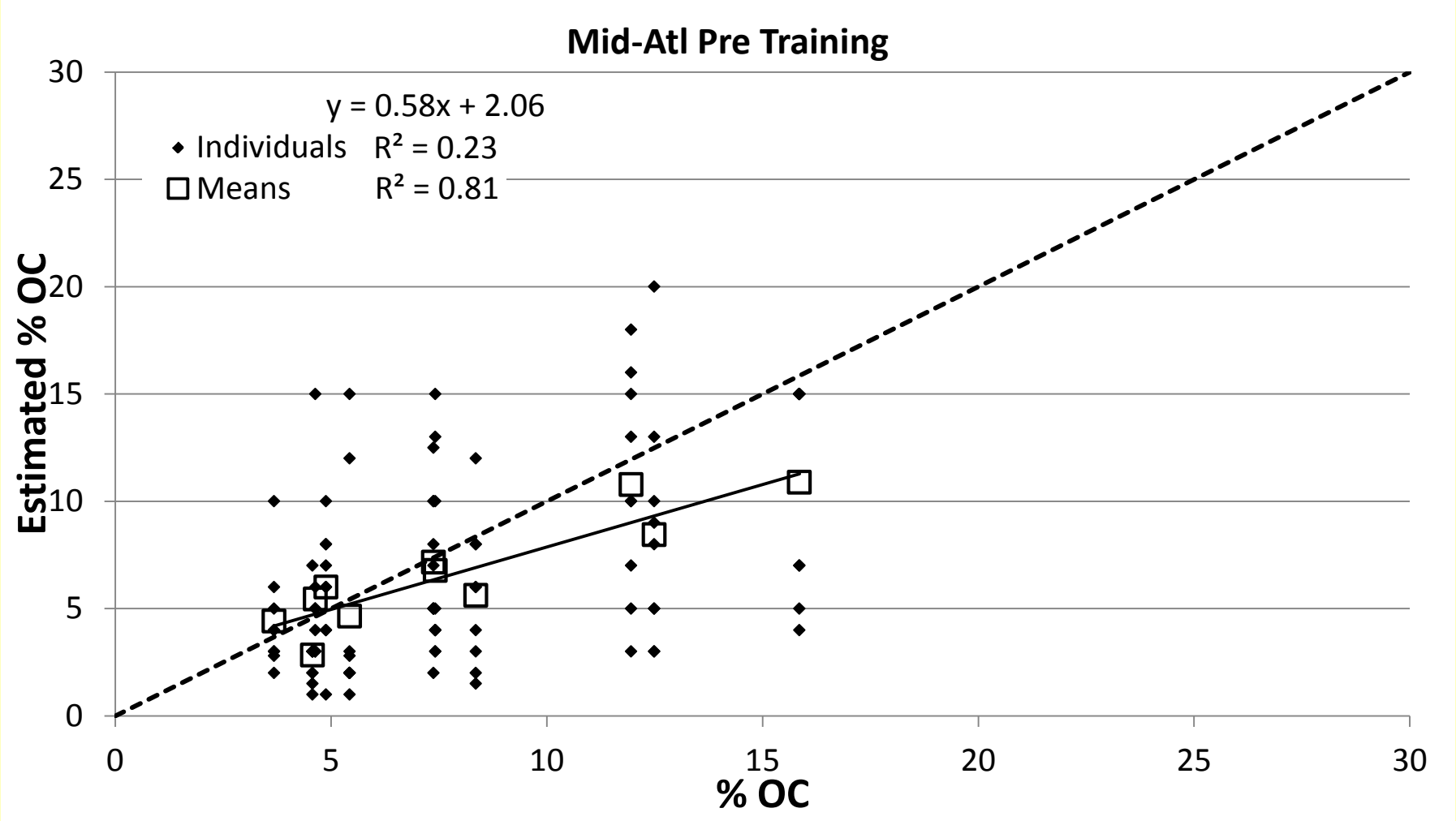

New England Pre Training
y = 0.26x + 8.31
Individuals R² = 0.13
means R² = 0.39
Estimated % OC
% OC
0
5
10
15
20
25
30
35


New England Post Training
y = 0.46x + 4.70
Individuals
R² = 0.50
means
R² = 0.89
Estimated % OC
% OC
0
5
10
15
20
25
30
35

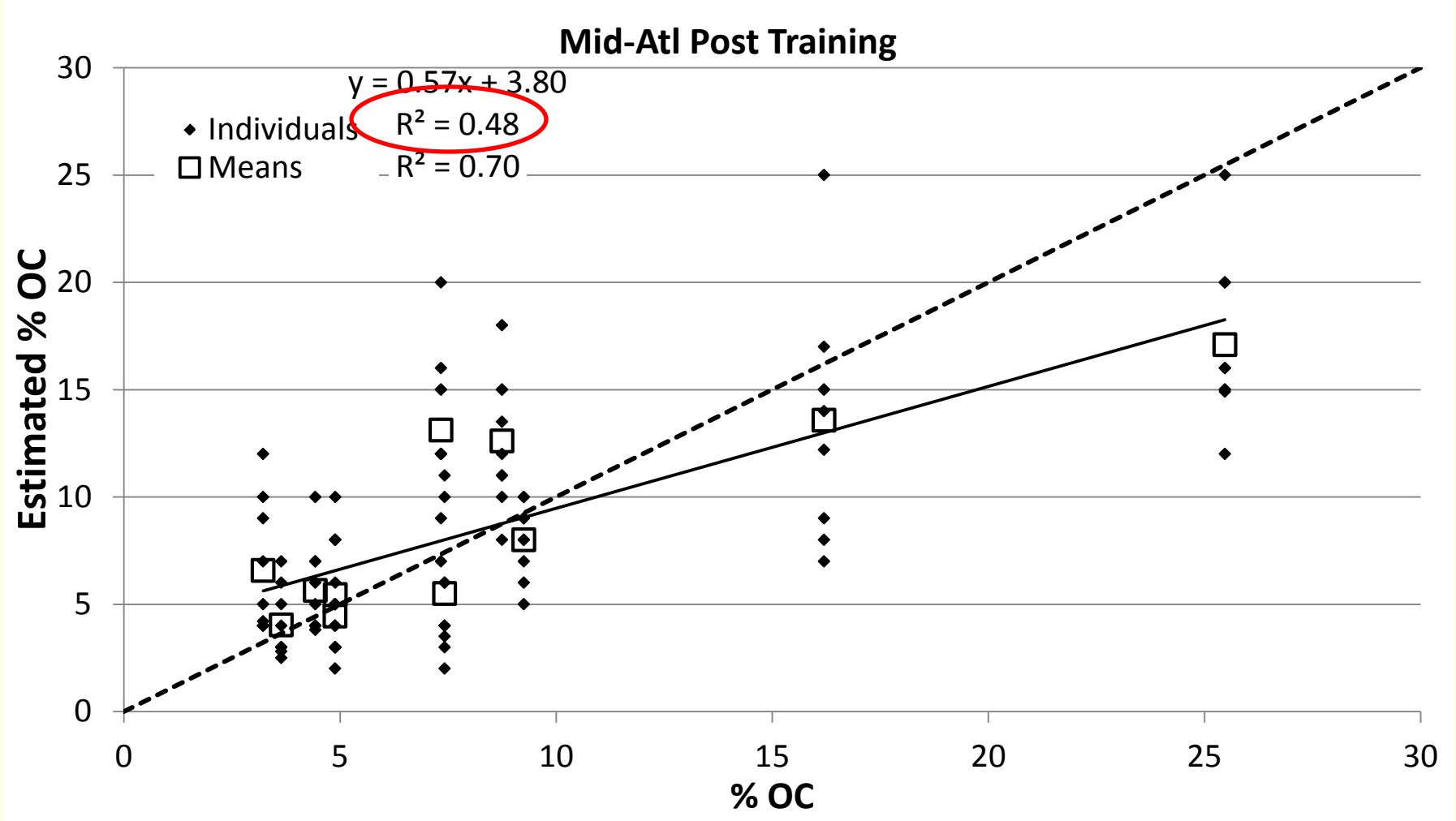
$p < 0.001$

New England Class Assignment Results

Participant	A	B	C	D	E	F	G	H	I	J	K	Average correct (%)
Pre-training Correct (%)	60	50	60	30	30	40	40	50	30	20	40	41%
After training Correct (%)	70	80	50	50	60	100	50	70	70	70	80	68%
Individual Improvement (%)	10	30	-10	20	30	60	10	20	40	50	40	27%


Mid-Atl Pre Training
y = 0.58x + 2.06
Individuals R² = 0.23
Means R² = 0.81
Estimated % OC
% OC
0
5
10
15
20
25
30

$p < 0.001$

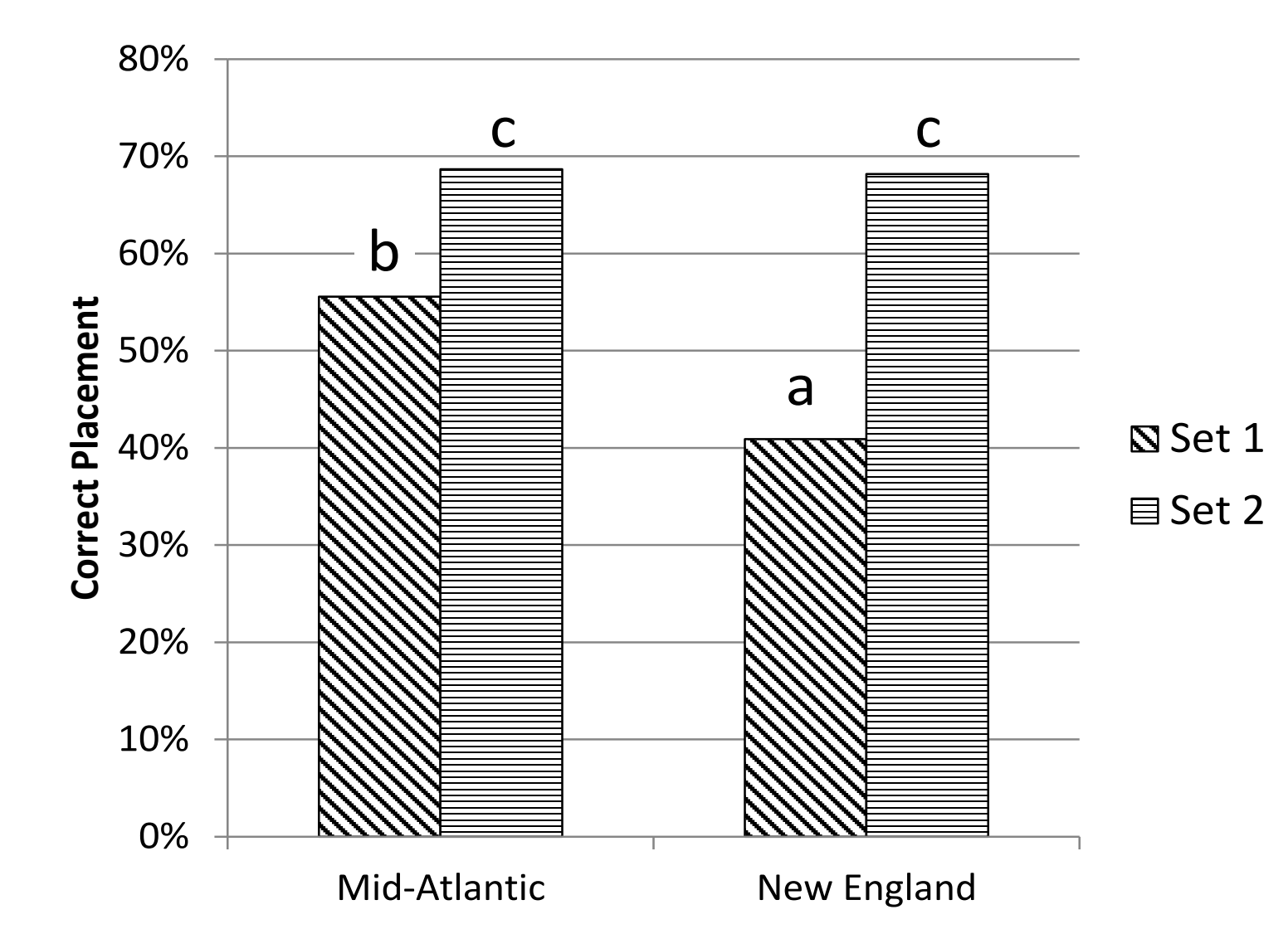

Mid-Atl Post Training
y = 0.57x + 3.80
R² = 0.48
R² = 0.70
Individuals
Means
Estimated % OC
% OC
0
5
10
15
20
25
30

$p < 0.001$

Mid-Atlantic Class Assignment Results

Participant	A	B	C	D	E	F	G	H	I	average correct
Pretraining Correct	45%	55%	36%	45%	73%	64%	64%	45%	73%	56%
Aftertraining Correct	73%	55%	45%	55%	73%	91%	82%	64%	82%	69%
Individual Improvement	27%	0%	9%	9%	0%	27%	18%	18%	9%	13%

Placement into classes: mineral, mucky modified, organic



Summary

- Not easy to estimate SOC and determine between mucky modified and mineral or organic soil materials

- Without training New England folks could only assign the correct class on average 41% of the time.

- Training improved our ability to assign the correct class (68%). This was essentially the same amount as the Mid-Atlantic committee got correct after training (69%)

- In general we over-estimate SOC in mineral soil materials and under-estimate SOC in organic soil materials.

Determination of soil organic soil material (SOM) type. Field is based on visual rubbed fiber content. Lab is based in standard lab rubbed fiber approach and sodium-pyrophosphate color. n = 85.

Method	Fibric	Hemic	Sapric
Field	0	3	82
Lab			

Determination of soil organic soil material (SOM) type. Field is based on visual rubbed fiber content. Lab is based in standard lab rubbed fiber approach and sodium-pyrophosphate color. n = 85.

Method	Fibric	Hemic	Sapric
Field	0	3	82
Lab	8	49	28

Mesic-Spodic Hydric Soil Indicator: Development and Testing

We investigated 33 pedons for which we had 2 to 4 years of surface hydrology data for six sites. Most of the wetter soils had spodic morphology.

Based on the hydrology, 25 pedons were identified as hydric. Five of the pedons met both the NE regional and national indicators. Two of the hydric pedons met the NE regional indicators but failed to meet the national indicator. Eight hydric pedons met national indicators but did not meet New England regional indicators, and 10 hydric pedons did not meet either the national nor regional indicator.

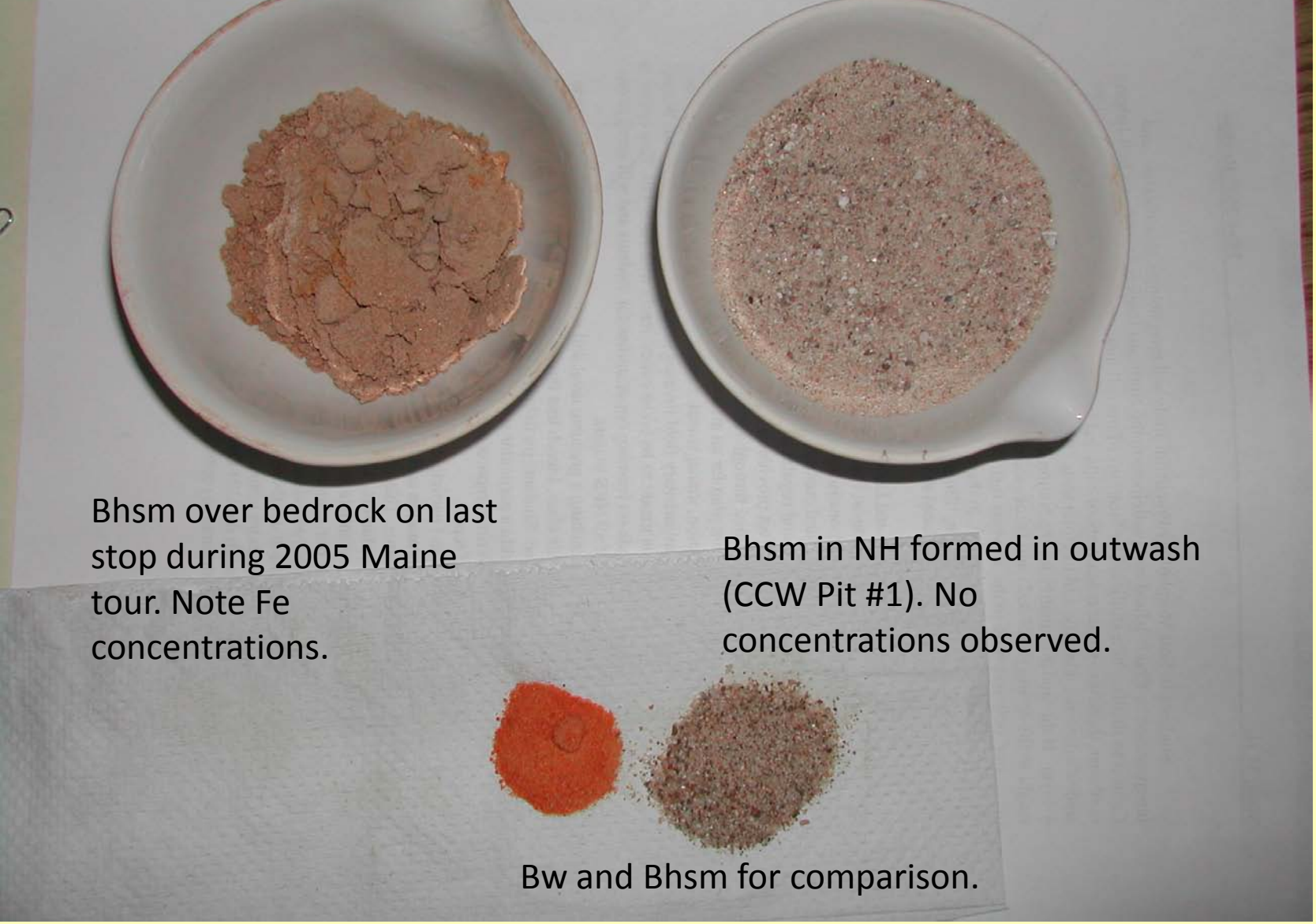
Thus, 40% of the hydric soils reviewed did not meet any indicator and suggested the need for the development of an effective indicator for hydric spodic soils.

Thus, our goal was to develop and test such an indicator.

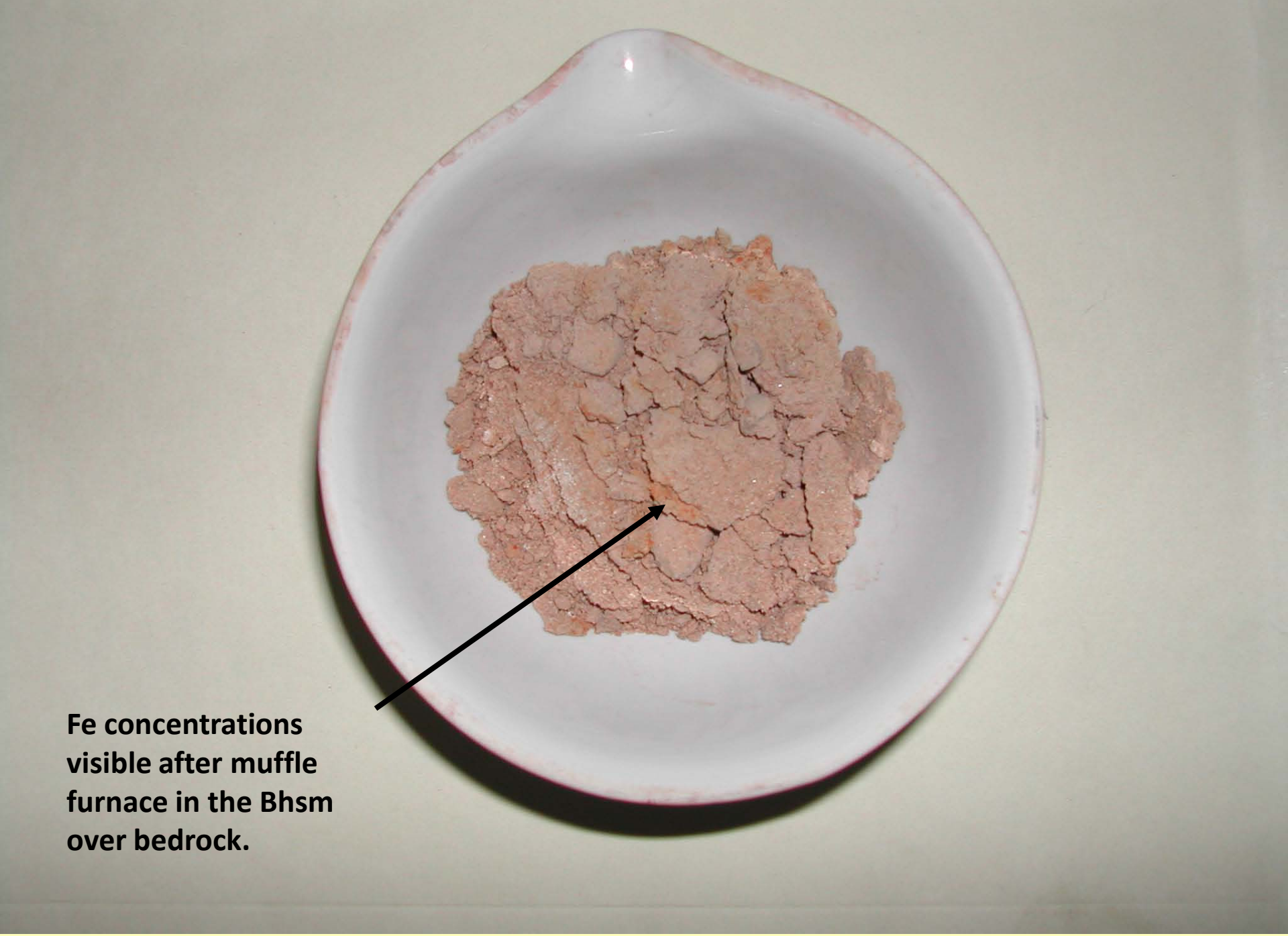
Cooper Cedar Woods (CCW) Pit #1 NH Soil Judging Contest 2005.
Likely an Alaquod or Duraquod.

Plates from Bhsm. Note the mottled appearance that suggests Fe concentrations

Bhsm. Plates and mottled appearance.

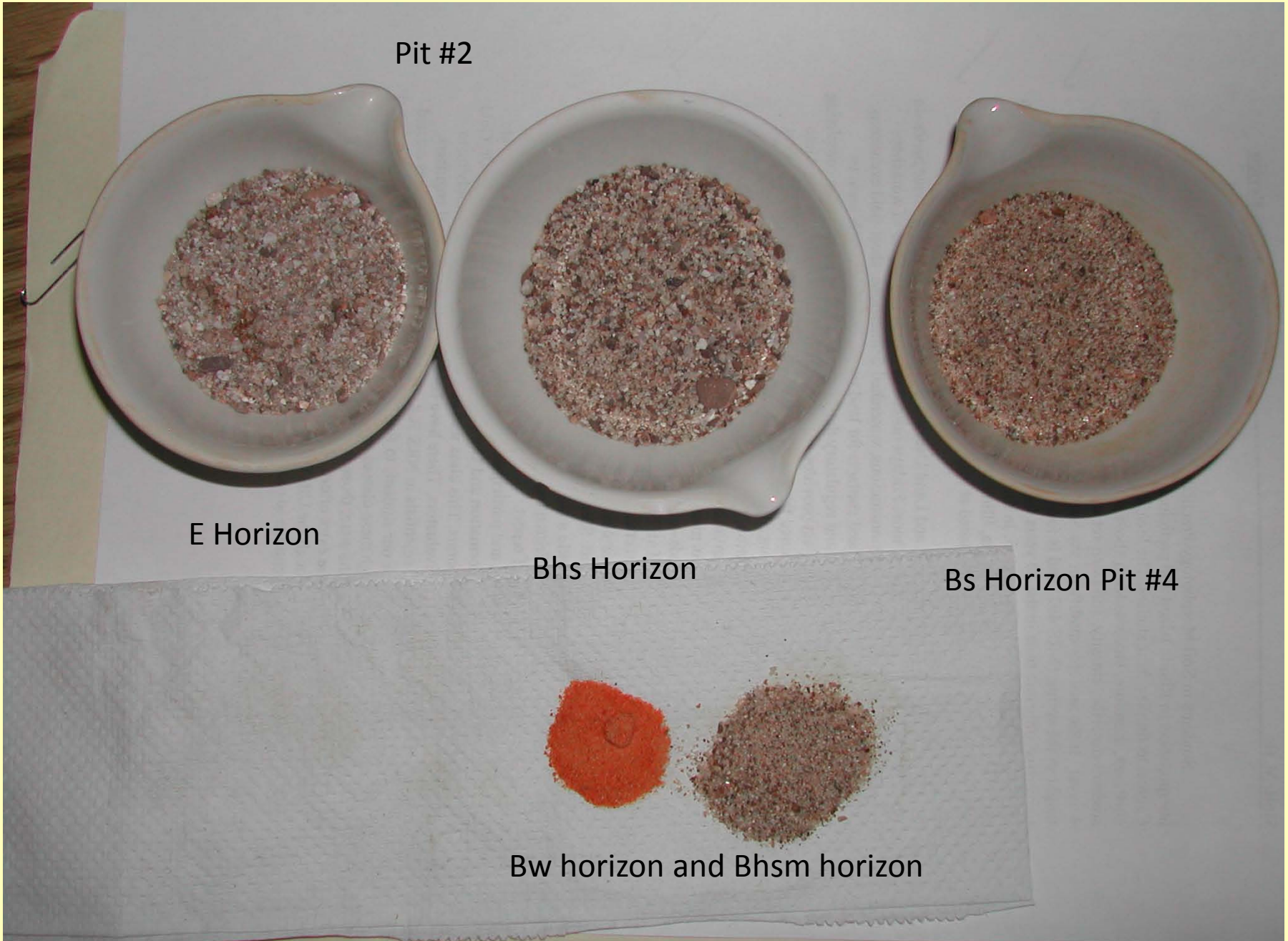


Samples photographed after heating to 550 degrees C in muffle furnace to remove organic matter.



Fe concentrations visible after muffle furnace in the Bhsm over bedrock.

Roque Bluffs Maine 2005 NEHSTC Fall Tour



TA6. Mesic Spodic.

For testing in MLRAs 144A and 145 of LRR R and MLRA 149B of LRR S.

A layer 5 cm (2 inches) or more thick, starting within 15 cm (6 inches) of the mineral soil surface, that has value of 3 or less and chroma of 2 or less and is underlain by either:

a. A layer(s) 8 cm (3 inches) or more thick occurring within 30 cm (12 inches) of the mineral soil surface, having value and chroma of 3 or less, and showing evidence of spodic development; **or**

b. A layer(s) 5 cm (2 inches) or more thick occurring within 30 cm (12 inches) of the mineral soil surface, having value of 4 or more and chroma of 2 or less, and directly underlain by a layer(s) 8 cm (3 inches) or more thick having value and chroma of 3 or less and showing evidence of spodic development.

Dark surface at least 2” thick and;

1) Layer at least 3” thick starting within 12” of soil surface that is 3/3 or darker and shows evidence of spodic morphology; or

2) A layer 2” or more thick occurring within 12” of the mineral soil surface, having value of 4 or more and chroma of 2 or less, **and**

directly underlain by a layer 3” or more thick having value and chroma of 3 or less and showing evidence of spodic development.

- **There are 4 monitoring sites:**
    - **Two in Rhode Island**
    - **Two in Massachusetts**
- **Year 1 data**
    - **all met the indicator,**
    - **showed reduction on IRIS tubes, and**
    - **met wetland hydrology**

Great Swamp Vernal Pool
Mesic Spodic Site

Well

April 2011 – "normal precip"

April 2012 Extreme Drought