Soil monitoring using the Quantitative Pit Method

Lessons from 25 years of digging

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Outline

- **Method Description, history**
- **Who else has used the method? Why?**
- **What have we learned about the study systems?**
- **What have we learned about the method?**
- **25 years of repeated measures in post-agricultural forest stand (Bald Mtn.)**

How to dig a quantitative pit, part 1

- 0.5 m^2 (70.7 cm square) frame secured to ground with rebar. Frame is the reference for all depth measurements, must be immobile.

- Excavation orthogonal to frame.

- O horizons removed, weighed, and bagged.

- Depth to soil surface is taken before and after removing the O, at 25 grid points.

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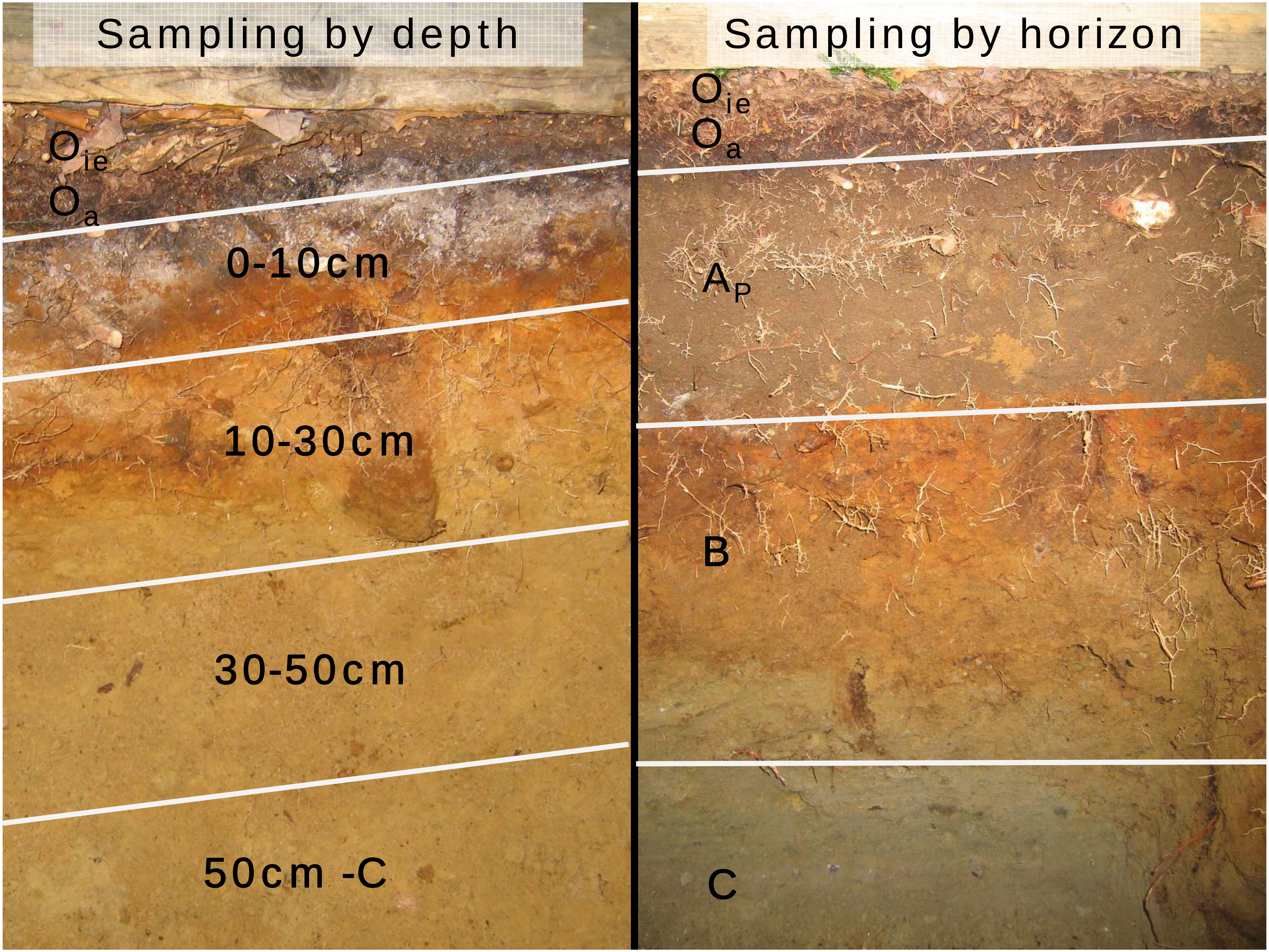
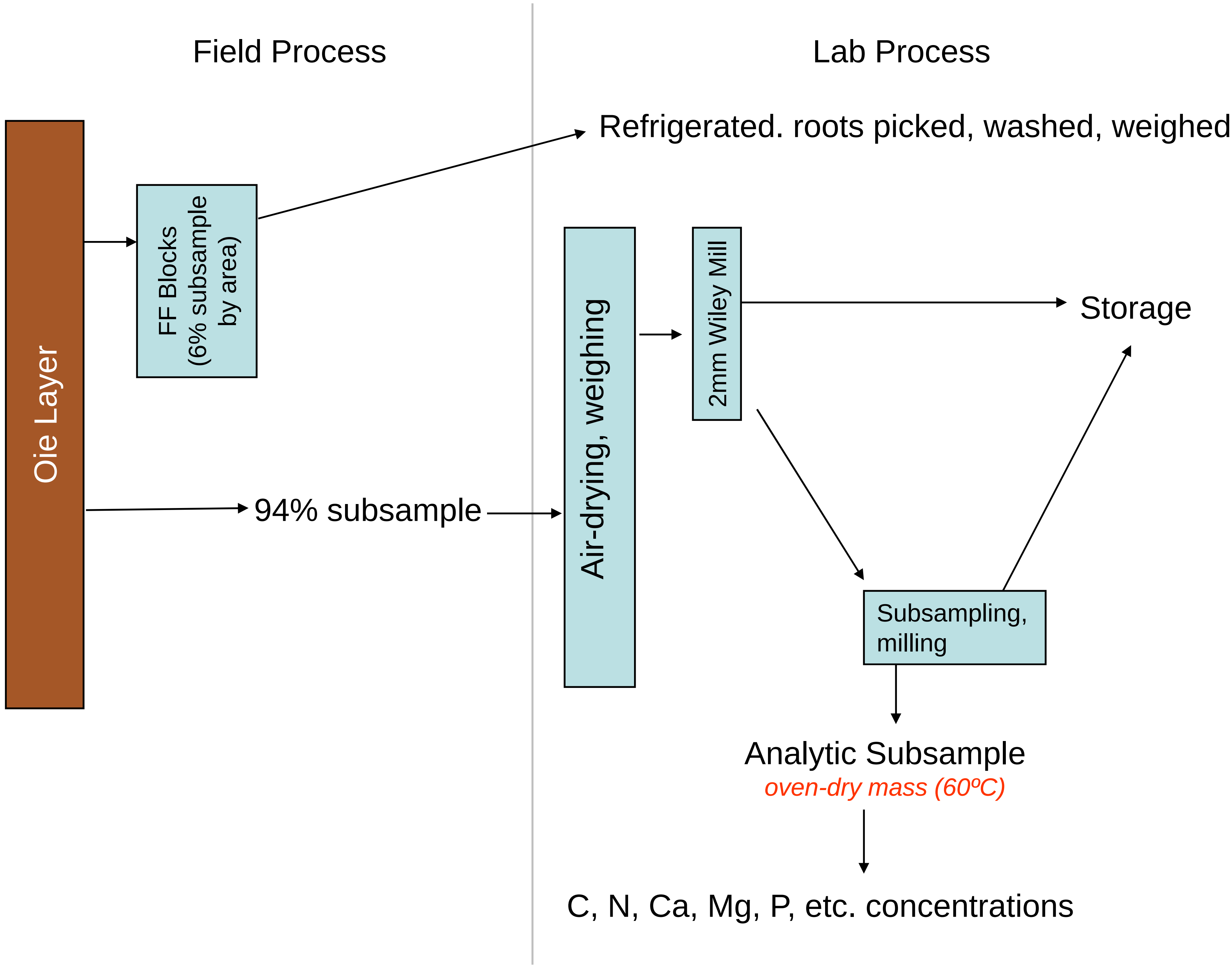
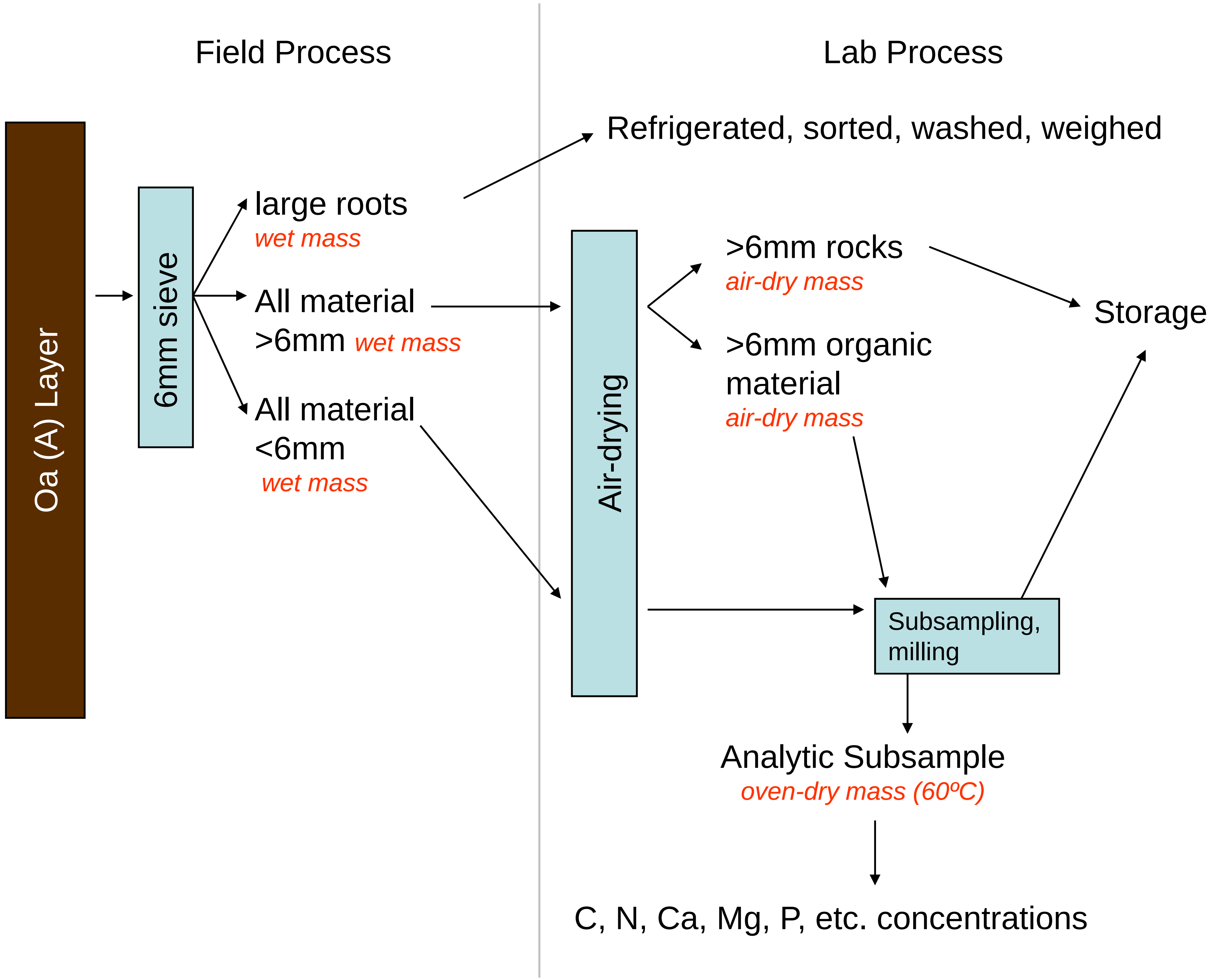
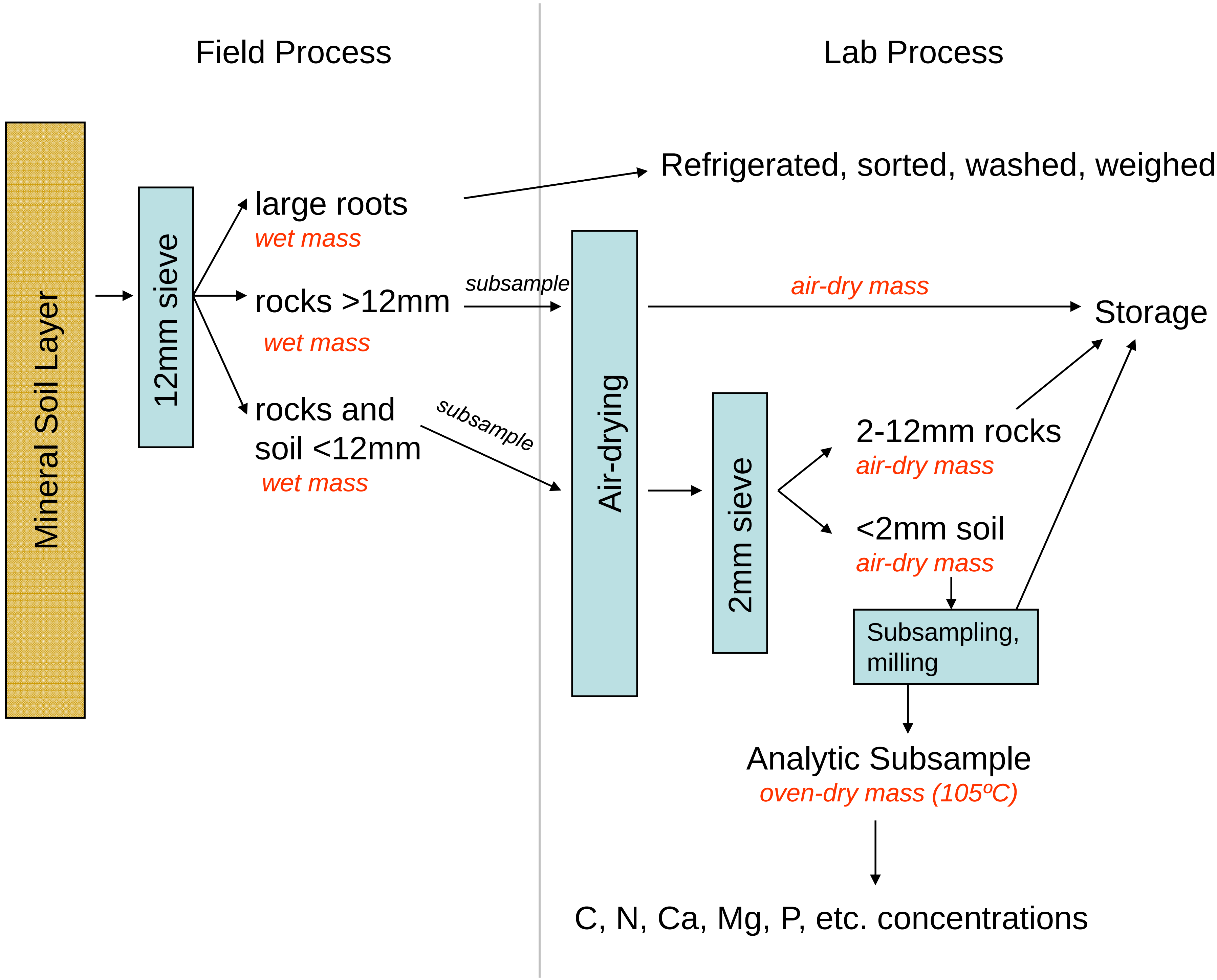

Sampling by depth
O_{ie}
O_a
0-10cm
10-30cm
30-50cm
50cm -C
Sampling by horizon
O_{ie}
O_a
A_P
B
C


Federer Chronosequence
Site M5 (clearcut 1977)
Wildcat Mtn, Jackson NH


Field Process
Lab Process
Oie Layer
FF Blocks (6% subsample by area)
Refrigerated. roots picked, washed, weighed
94% subsample
Air-drying, weighing
2mm Wiley Mill
Storage
Subsampling, milling
Analytic Subsample
oven-dry mass (60ºC)
C, N, Ca, Mg, P, etc. concentrations


Field Process
Lab Process
Oa (A) Layer
6mm sieve
large roots
wet mass
All material >6mm wet mass
All material <6mm
wet mass
Refrigerated, sorted, washed, weighed
Air-drying
>6mm rocks
air-dry mass
>6mm organic material
air-dry mass
Storage
Subsampling, milling
Analytic Subsample
oven-dry mass (60ºC)
C, N, Ca, Mg, P, etc. concentrations



Field Process
Lab Process
Mineral Soil Layer
12mm sieve
large roots
wet mass
rocks >12mm
wet mass
rocks and soil <12mm
wet mass
subsample
subsample
Refrigerated, sorted, washed, weighed
Air-drying
air-dry mass
Storage
2mm sieve
2-12mm rocks
air-dry mass
<2mm soil
air-dry mass
Subsampling, milling
Analytic Subsample
oven-dry mass (105ºC)
C, N, Ca, Mg, P, etc. concentrations

Advantages of quantitative pits

- Direct measurement of soil mass per unit area obviates the need to estimate **bulk density** and **coarse fraction** in order to arrive at nutrient stock data.
- Size of pit averages out some of the fine-scale heterogeneity associated with coring.
- Ability to sample around / beneath obstructing rocks and roots, to depth of up to 2 m.
- Accurate sampling of roots <2 cm is a “bonus”

**Intensive Ca Study, Bartlett Exp. Forest
Site C8 (clearcut c. 1890)**

Disadvantages of quantitative pits

- **LABOR INTENSIVE!**
  ~2-10 person-days each for field work alone.
  (translates to ~$100-600 per pit for field labor).

- Impact to study system is necessarily greater than for coring techniques.

- Limited replication within study sites
  (we generally excavate ~3 pits per ha;
  mean distance between pits ~30-50 m).

History of the method

What we've changed since 1980:

- Pits are now $0.5m^2$ rather than $1m^2$
- Depth – deeper pits allow us to address questions about chemistry of parent material, nutrient supply, weathering
- Stainless steel tools
- Digital balances
- All calculations now in spreadsheets
- Lots of archiving and back-up samples

What have we learned?

- Over last 25 years Hamburg and others have collected a lot of quantitative soil data
- Want to understand what has been done and what it tells us about:
  - **Necessity to do quantitative measurements**
  - **Scales of spatial variability**
  - **Temporal variability and trend detection**

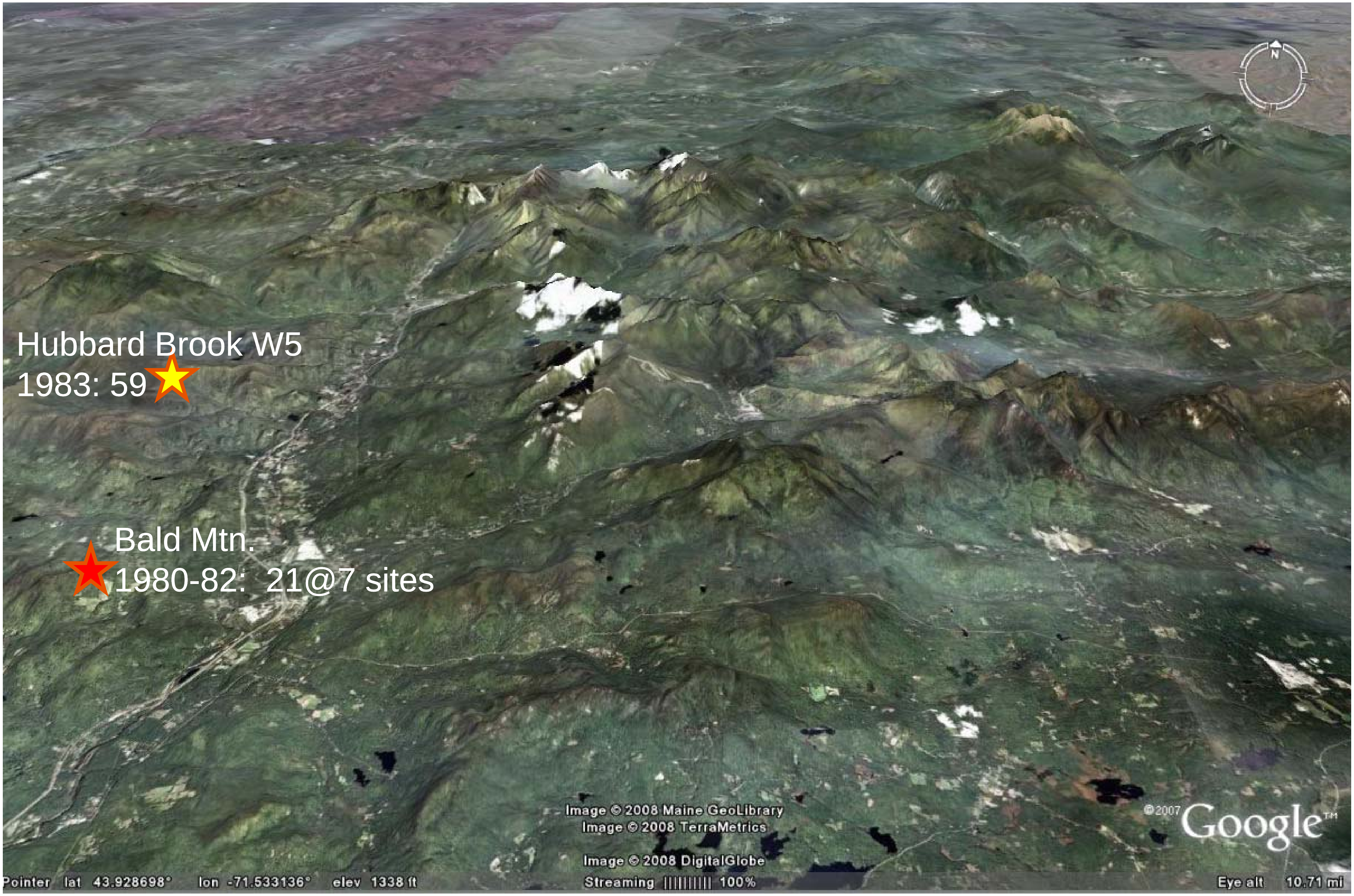
Comparing Quantitative pit studies

- A work in progress…
  - We are trying to evaluate the effectiveness of the quantitative pit method by comparing the results of other studies that use the same method.
  - I have done a review of the literature to see how effective the quantitative pit method has been for different purposes.
  - I will be showing you some of the data I have collected.

The First Quantitative Pits

- First quantitative pit in 1980 by Steven Hamburg (Hamburg 1984)
  - Bald mountain site
  - 21 pits over seven sites
  - Last pits dug there were in 2005
- Second use (Huntington 1988)
  - 1983 Watershed 5 at HBEF
  - 59 pits over 22 ha

Quantitative Soil Pits in the White Mountains



Location of Papers using Quantitative Pit method

- Total papers: 40, including 1 thesis
- Papers in the White Mountains area: 23
  - HBEF Watershed 5: 17
  - Bartlett Experimental Forest: 3
  - WMNF: 1
  - Mount Moosilauke: 1
  - Grafton County: 1
- Papers in the other parts of the United States: 12
  - Northeast region: 9 (ME, MA, NY, CT, RI, and PA)
  - Northwest region: 3 (Washington, Oregon)
- Papers outside the US: 5
  - Czech Republic: 3
  - Amazon: 2
- Journals:
  - Soil Sci. Soc. Am. J., Geoderma, Can. J. Soil Sci., Forest Science, Can. J. For. Res., Soil Science, Biogeochemistry, Forest Ecology and Management, Ecological Applications, Ecosystems, Water, Air and Soil Pollution, Science of the Total Environment

Number of Pits

- Watershed 5 – 239 pits
- Campton former Ag sites (Bald Mtn) – 54
- Bartlett Intensive sites – 18
- Federer Chronosequence – 18
- Campton/ Thornton Residential sites – 10

- Total Pits in US: 690 pits
- Total in Northeast: 614
- Total in Northwest: 76
- Total outside US: 49
- Grand total: 739 pits

Survey of Soil Pit Uses

- The quantitative soil pit has been used to measure:
  - Soil Mass
  - Bulk Density
  - LOI (OM content)
  - Total C, Total N, P, and S
  - Exchangeable cations: Ca, Mg, K, and Na
  - Exchangeable acidity: H, Al
  - Root biomass
  - Different types of carbon: alkyl, aromatic, carbonyl

Difficulties in evaluating this method

Lack of Comparability

1. Not everyone uses the exact same method
   - 0.71m × 0.71m ($0.5m^2$) versus 0.5m × 0.5m pits ($0.25m^2$)
2. Not everyone is measuring the same things
   - i.e. Soil mass, bulk density, carbon, nutrients
3. Not everyone reports what they measure in the same way.
   - Each layer or total solum
   - The layer thickness for each study varies
   - % , content, or concentration
   - Some papers don’t report SE or CV values
   - The number of pits per area varies

Huntington 1988

- Location: Hubbard Brook Experimental Forest, NH, Watershed 5
- 59 pits over 22 ha
- Objective: To determine whether an intensive sampling design could achieve N and C pool size estimates with sufficiently small confidence limits.

Layer	C	CV	N	CV	Mass	CV
	Mg C /ha	%	kg N /ha	%	Mg /ha	%
Oie	11	67	460	61	22	57
Oa	20	95	870	88	66	83
0-10cm	32	29	1,600	31	490	36
10-20cm	27	46	1,200	45	520	50
>20cm	73	72	3,100	74	2,200	63
FF	30	74	1,300	68	88	70
MS	130	45	5,900	48	3,200	50
Solum	160	38	7,200	38	3,300	47

- Sampling Intensity
  - Need 60 pits to detect 20% change with 95% confidence interval.

Huntington 1989

- Location: Hubbard Brook Experimental Forest, NH, Watershed 5
- 59 pits over 22 ha

- Objective: to evaluate the quantitative pit method at bulk density estimation and compare measured values with values predicted by regression analysis.

Layer	Bulk Density	CV	Rock Volume	CV
	Mg /m^3	%	% of total	%
Oa	0.22	104	n.a.	n.a.
0-10cm	0.73	32	0.35	263
10-20cm	0.84	37	0.56	165
20cm-C	0.92	33	0.87	79

Fahey 1988

- Location: HBEF, watershed 5
- 58 pits over 22 ha
- Objective: to quantify the importance of element release from tree root systems after forest harvest.

Species	Size class (cm)	Sample size	Root density (g/cm3)	CV %
Sugar Maple	1-2	20	0.41	6.6
	2-5	20	0.44	6.1
	5-10	21	0.48	7.6
Yellow Birch	1-2	20	0.39	9.2
	2-5	20	0.42	7.4
	5-10	16	0.47	5.9
Beech	1-2	20	0.42	10.5
	2-5	20	0.44	10.1
	5-10	16	0.54	11.9

Root biomass

Soil depth	Root biomass (g/m 2) by root diameter classes (ram)					
	0.6-1.0	**1.0-2.5**	**2.5-5.0**	**5-10**	**>10**	**Total**
Forest floor	40	63	123	216	745	**1,187 (303)**
0-10 cm	37	57	69	109	133	**605 (77)**
10-20 cm	26	46	50	69	248	**440(118)**
>20 cm	31	70	73	88	182	**444(87)**
Total	**134 (13)**	**235 (25)**	**315 (25)**	**482 (47)**	**1,509(394)**	**2,676 (539)**

Other Watershed 5 papers

- Measuring effects of whole-tree harvesting:
- Johnson, C.E. 1990, 1991a & b, 1995, 1997, 1998
  - Changes in soil mass, SOM, bulk density, horizonization, exchangeable cations, acidity, C & N content, trace metals (Zn & Pb), & measuring sample size.
- Zhang 1999
  - Changes in sulfur constituents
- Dai 1999
  - Iron (Fe)
- Pardo 2002
  - ^{15}N
- Hamburg 2003
  - Ca pools
- Ussiri 2003 and 2007
  - Chemical and structural characteristics of SOM

Fernandez 1993

- Location: The Bear Brook Watershed, eastern Maine
- 24 pits over two 600-m^2 plots
- Measured: fine earth, course fragment mass, LOI, N, P, exch. cations, exch. acidity, coarse frag. volume, soil volum.
- Objective: To compare the quantitative sample method with the conventional face-sampling morphological approach in order to characterize vertical trends in soil nutrient pool sizes.

	Soil mass	**CV**	**Root mass**	**CV**	**Total C**	**CV**	**Bulk density**	**CV**
Layer	**Mg/ha**	**%**	**Mg/ha**	**%**	**Mg C/ha**	**%**	**g/cm**	**%**
O horizon	280	121	10	105	44	41	0.14	42
E horizon	1,200	102	2	100	8	45	1.03	33
5cm-Increment	550	29	1	120	11	42	0.65	40
5-40cm	2,400	46	4	170	30	51	0.89	23
40cm-C	3,100	44	1	220	19	103	1.39	29
Total Solum	7,500	22	18	73	111	26	n.a.	n.a.

Sampling Intensity:

Number of samples required for estimates of mean element pools plus or minus 10%

Layer	**Soil Mass**		**Total C**	
	# Pits	**95% conf.**	**# Pits**	**95% conf.**
O horizon	622	50	73	18
E horizon	477	45	90	20
5cm-Increr	36	13	77	19
5-40cm	92	20	114	22
40cm-C	83	19	455	45

Wibiralske 2004

- Location: Pocono Plateau in northeastern Pennsylvania
- 40 pits over 22 km^2

- Objective: to assess the association of soil and vegetation nutrient capital with plant community type and parent material (Illinoian or Wisconsinan till) type in the Pocono barrens.

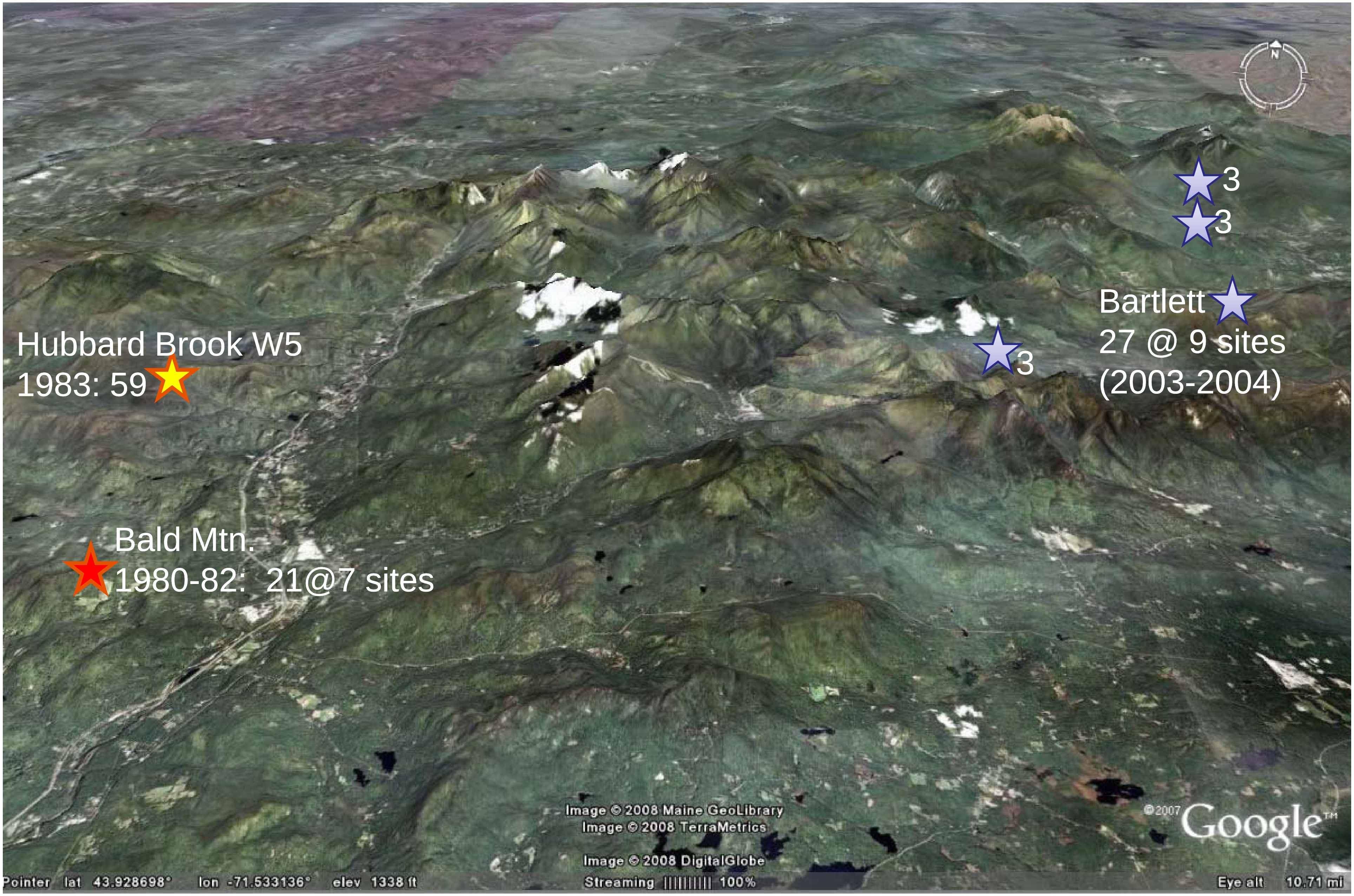
- These are results from the site on Illinoian soil with barrens type vegetation.

	Soil mass	**CV**	**Bulk density**	**CV**	**C conc.**	**CV**
Layer	**Mg/ha**	**%**	**g/cm3**	**%**	**%**	**%**
Oi-Oe	63.6	35	—	—	45.2	6
Oa	136	54	—	—	26.8	28
0-10 cm	702	38	0.87	22	4.2	45
10-20 cm	850	26	1.04	24	2.2	29
20-50 cm	3410	21	1.36	19	0.7	90

Yanai et al. 2006, Park et al. 2007, Vadeboncoeur et al. 2007

- Location: White Mountains National Forest
- 36 pits over 190 km^2
- Pits excavated in hardwood sites of varying ages (post-logging)
- Objective: Accurate budgeting of C, N, and base cations in aggrading forests
- Described root patterns with soil depth and distance to trees, validated the HBEF root allometry equations (Whittaker et al. 1974).

Quantitative Soil Pits in the White Mountains



Yanai 2006, Vadeboncoeur 2007, Park 2007

Federer Chronoseq & Bartlett Intensive sites

	Carbon		Nitrogen		exch. Ca		apatite Ca		coarse frac (%)	
Layer	**mean**	**CV**	**mean**	**CV**	**mean**	**CV**	**mean**	**CV**	**mean**	**CV**
	g/ m2	**%**	**g/ m2**	**%**	**g/ m2**	**%**	**g/ m2**	**%**	**g/ m2**	**%**
Oie	933	51	35	59						
Oa	2564	105	106	96	11.7	127	2.0	114		
0-10	2778	33	133	35	8.5	81	3.6	175	0.2	72
10-30	3030	32	134	36	4.7	139	4.5	125	0.2	66
10-20	2202	58	107	50	5.4	78	8.0	159	0.2	81
20-30	1652	47	78	43	4.0	73	9.5	144	0.2	66
30+	3734	70	167	74	7.4	65	36.2	92	0.3	48
30-50	1719	36	83	40	3.5	123	11.1	127	0.3	57
50-C	1445	72	79	73	3.0	101	31.6	105	0.4	53
C0-25	1041	100	48	90	8.8	257	92.6	160	0.3	55
C25-50	645	112	27	111	28.1	203	165.5	134	0.3	62

Yanai 2006, Vadeboncoeur 2007, Park 2007

Soil layer	Layer thickness	CV	Coarse fraction	CV	Soil mass	CV
	(cm)	(%)	(% volume)	(%)	(kg/m2)	(%)
O	13.2	35	n.a.	n.a.	n.a.	n.a.
0-10cm	10.8	3	30	121	61	43
10-20cm	9.3	4	18	67	79	18
20-30cm	11.8	13	20	43	98	19
30+	50.1	20	17	82	417	9
C0-C25	23.5		54		200	
C25-C50	28.7		45		240	

Root Biomass

		Young Stands		Transitional Stands		Older Stands	
Root diameter	**Layer**	**g/m2**	**CV (%)**	**g/m2**	**CV (%)**	**g/m2**	**CV (%)**
0-1 mm	**forest floor**	90	98	172	46	261	76
	0–10cm	260	31	236	81	227	46
	10–30cm	139	14	180	82	267	11
	30cm-C horizon	258	93	106	150	184	37
	C horizon	23	64	84	61	21	47
1-2 mm	**forest floor**	16	122	32	38	31	40
	0–10cm	48	51	50	20	35	63
	10–30cm	22	56	46	138	50	64
	30cm-C horizon	25	20	33	186	34	122
	C horizon	2	122	19	77	3	82
2-5 mm	**forest floor**	20	147	69	25	51	77
	0–10cm	78	3	84	17	89	8
	10–30cm	45	49	64	19	106	83
	30cm-C horizon	21	82	40	184	45	191
	C horizon	13	226	18	109	2	122

Guadinski 2000

- Location: Harvard Forest, MA
- Pit size: 0.5 m x 0.5 m
- 2 pits over 28 ha
- Objective: to quantify below ground carbon cycles

- No SE or CV values for MS depths

	Bulk Density		Soil C		Total C Stock	
Horizon	g/cm3	SE	g C/ Kg soil	SE	g C/ m2	SE
Oi	0.06	0.01	450	20	380	110
Oea	0.1	0.02	470	10	1640	750
		Range		Range		Range
A	0.35	0.03	270	30	2,400	820
AP	0.54	0.13	60	1	2,620	660
Bwl	0.85	0.07	20	1	1,245	190
Bw2	0.93	0.04	6	1	510	110
Total					8,800	1,310

Silver 2000

- Location: Tapajos National Forest (TNF), 50km south of Santarem, Para, Brazil
- Objective: to explore the role of soil texture in below ground C storage, nutrient pool sizes and N fluxes in highly weathered Amazonian forest ecosystem
- 23 pits over 1,000 ha

Sandy Soils	C	CV	N	CV	P	CV
	Mg C/ha	%	Mg N/ha	%	kg P/ha	%
Forest floor	4.39	32	0.18	33	4.44	41
0–10 cm						
Soil	12.07	17	0.89	20	67	22
Fine root	1.48	22	0.05	24	1.59	21
Coarse root	6	163	0.09	167	2.99	142
10–40 cm						
Soil	29.78	19	3.44	18	277.5	6
Total root	13.88	96	0.2	90	5.18	97
40-100cm						
Soil	39.28	17	3.44	18	563.4	0
Total root	6	122	0.09	133	0.93	123
Total Below ground	112.88	—	8.38	—	923.06	—

Kram 1995

- Location: Czech Republic, at the Lysina (27.3 ha) and Pluhuv Bor (22 ha) catchments, located near Marianske Lazne.
- 5 quantitative soil pits were used to estimate soil mass.
- Objective: to compare biogeochemical patterns of basic cations in two forested catchments exhibiting extremely different lithologies which serve as end-members of ecosystem sensitivity to acidic deposition.

The quantitative pits were used to estimate soil mass.

No SE or CV values were given

Layers	Exch. Bases	SOM	Total C	Clay
	mmolc /m^2	kg /m^2	kg C /m^2	kg /m^2
Lysina				
Oi + Oe	150	1.9	1	ND
Oa	440	6.7	3.7	ND
0-10cm	300	2.8	1.7	0.23
10-20cm	220	2	0.8	0.17
20-30cm	240	2.3	1.7	0.12
30-40cm	230	3.1	1	0.11
40-43cm (to C)	150	1.4	0.4	0.09
Forest floor	590	8.6	4.7	ND
Mineral soil (O-40cm)	980	10.1	5.2	0.63
Pluhuv Bor				
Oi + Oe	370	2.3	1.2	ND
Oa	1,000	2.3	1.2	ND
0-10cm	390	3.2	1.4	0.42
10-20cm	1,070	2.3	0.8	0.98
20-30cm	3,360	2.2	0.2	1.65
30-40cm	5,260	2.1	0.1	1.53
Forest floor	1,370	4.6	2.4	ND
Mineral soil (O-40cm)	10,100	9.8	2.6	4.58

Austin 2006

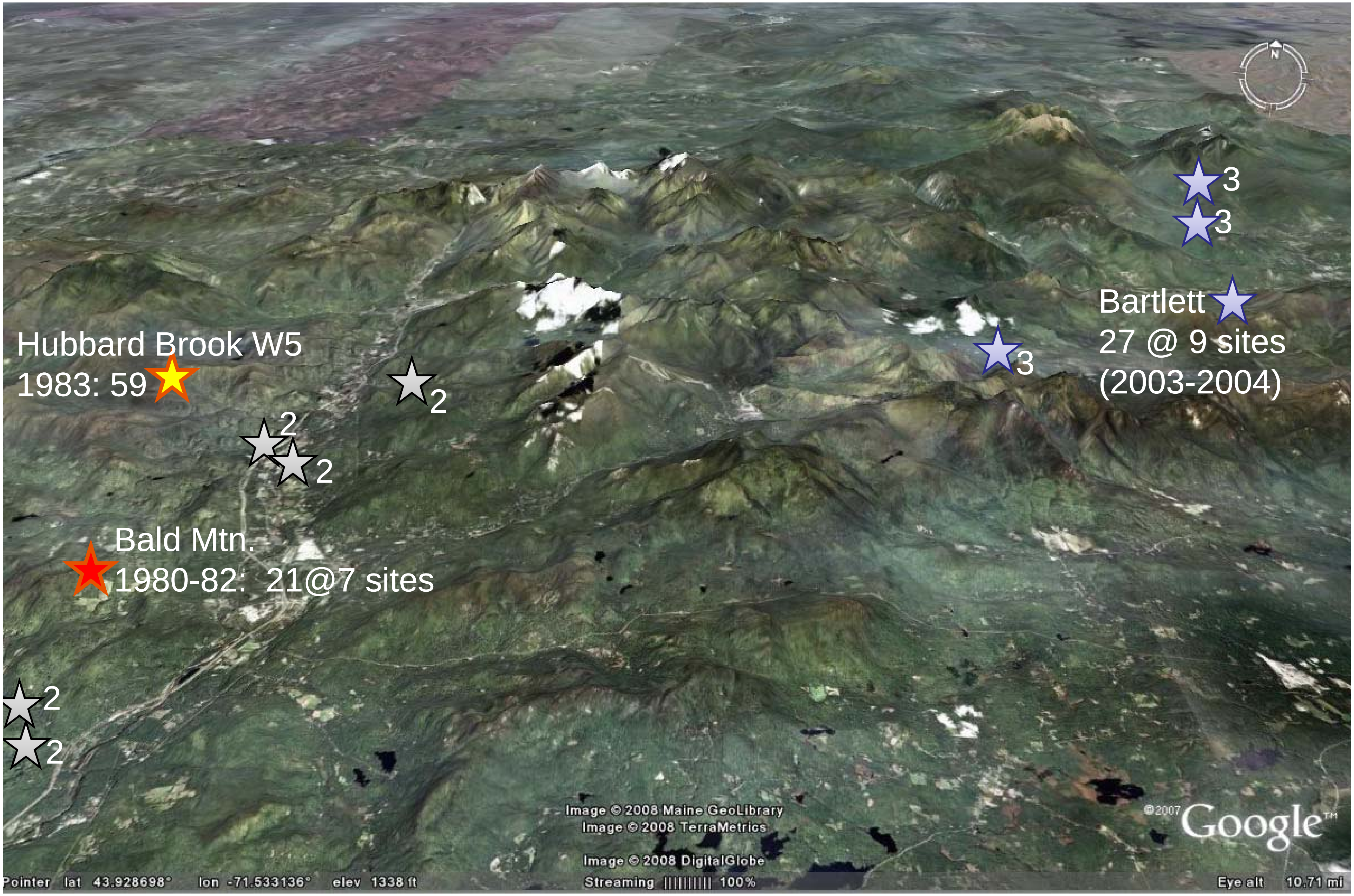
- Location: the towns of Campton and Thornton in Grafton County, NH.
- 5 pits over Campton (135 km^2) and Thornton (130 km^2).

- Objective: study effects of past land-use history on soil nutrient dynamics.

Soil C content before and after housing development

	Land-Use History		Disturbed		Undisturbed	
Depth		# pits	**Mg C /ha**	**CV(%)**	**Mg C /ha**	**CV(%)**
Total	Plowed	2	108	35	143	27
	Pasture	2	62	11	137	25
	Woodlot	1	139	14	120	38
	Average		96	41	136	9
0-20cm	Plowed	2	37	38	88	25
	Pasture	2	34	9	84	15
	Woodlot	1	46	15	110	32
	Average		38	26	92	26
>20cm	Plowed	2	71	45	55	51
	Pasture	2	28	14	30	70
	Woodlot	1	93	30	15	87
	Average		59	58	41	68

Quantitative Soil Pits in the White Mountains



Quantitative Pit vs. Coring Method

- Example 1: Kulmatiski 2003
  - Location: Yale-Myers Forest in northeastern Connecticut
  - 18 pits over 3,173 ha
  - Objective: compare the ability of the quantitative and core sampling techniques to detect a 10% change in total soil C and N pools.
  - The **pit technique** estimated total C storage at 5.64 +/- 0.32 kg/m2 (n =18, **CV = 6%)**
  - The **core technique** estimated total C storage at 5.63+/0.29 kg/m2 (n = 56, **CV = 5%)**
  - The pit sampling procedure took **twice as long** as the coring procedure.
    - The core sampling procedure: **1.5 person-hours** per plot to sample to 15 cm.
    - The pit sampling procedure: **3.5 person-hours** per lot to sample to 15 cm.
    - An **additional 4.5 h** in the field were required to sample to 60 cm using the pit technique.

	Pit	**CV**	**Core**	**CV**	**Core**	**CV**
	(n=18)	**%**	**(n=18)**	**%**	**(n=56)**	**%**
%C	3.64	12	3.12	6	3.34	3
%N	0.23	13	0.2	10	0.22	41
Bulk Density	0.94	4	0.78	3	0.81	2

Quantitative Pit vs. Coring Method

- Example 1: Kulmatiski 2003 - *Continued*
  - The core technique reduced variance in the sample population, allowing fewer samples **to detect a 10% change** in nutrient storage (**21 core vs. 29 pit samples**).
  - The pit technique allowed quantitative sampling below 15 cm and direct measurement of large coarse fragments.
  - **Our data suggest that composite core sampling is more efficient than, but well supplemented by, pit sampling.**
  - The **accuracy gained** with the pit technique **may not outweigh the loss in sample sizes** that result from an extensive sampling effort (Conkling et al., 2002).

	Pit (n=18)	CV %	Core (n=18)	CV %	Core (n=56)	CV %
%C	3.64	12	3.12	6	3.34	3
%N	0.23	13	0.2	10	0.22	41
Bulk Density	0.94	4	0.78	3	0.81	2

Quantitative Pit vs. Coring Method

- Example 2: Harrison 2003
  - Location: Cedar River Watershed, 60km SW of Seattle, WA
  - Objective: Compare 4 methods for estimating soil C: (i) **large pit (0.5 m2)** excavation, (ii) dug pit with 54-mm hammer-core bulk-density sampling, (iii) 31-mm soil push sampler, and (iv) clod method.
  - 2 sites each with 3 pits over 45 m^2
  - The pit excavation method with sand-displacement volume measurements, which is by far the **most labor-intensive** and **time-consuming**, was considered the **“standard”** by which other methods were compared, as it **didn’t contain any obvious biases**.

Quantitative Pit vs. Coring Method

- Example 2: Harrison 2003 – *Continued*
  - **Soil core** methods **overestimated** the <2-mm soil fraction (samples taken between large rocks).
  - **Core methods often didn't work** due to the **high rock content** (>50%) of the Everett soil.
  - The results suggest that to accurately assess total C pools in these soils, sampling **should include both the >2-mm soil fraction** and **deep soil layers.**
  - In **soils containing** a substantial amount of **coarse fraction material**, we **suggest that excavated pits** or a similar sampling approach **be used**.

Quantitative Pit vs. Coring Method

- Example 3: Park 2007
  - Location: Bartlett Experimental Forest, White Mts., NH
  - Objective: to more accurately measure root biomass.
  - Roots: average CV of 28% for the 0-1 mm roots and 45% for the 1- 2 mm roots.
  - To estimate live fine root biomass with a **20% margin of error** at 95% confidence would require **seven cores** or **five soil pits**.
  - A **10% margin of error** could be obtained with **28 cores** or **20 pits.**
  - **Less effort to collect cores** than to excavate pits, even taking into account the larger number of cores required.
  - **Coring** is a **very efficient method** for studying **fine roots** (<2 mm) in upper soil horizons, but it is **not as effective** as soil pits in **estimating large roots** or roots in rocky soil.
  - The **cores overestimated fine-root** biomass by 27% compared with pits.

Comparing the results

Huntington 1988 60 pits over 22 ha = 2.7 pits/ha			Fernandez 1993 12 pits over 0.06 ha =200 pits/ha			Wibiralske 2004 40 pits over 2,200 ha = 0.02 pits/ha		
Layer	**Soil Mass**	**CV**	**Layer**	**Soil mass**	**CV**	**Layer**	**Soil mass**	**CV**
	Mg /ha	**%**		**Mg/ha**	**%**		**Mg/ha**	**%**
Oie	22	57	**O horizon**	280	121	**Oi-Oe**	63.6	35
Oa	66	83	**E horizon**	1,200	102	**Oa**	136	54
0-10cm	490	36	**5cm-Increment**	550	29	**0-10 cm**	702	38
10- 20cm	520	50	**5-40cm**	2,400	46	**10-20 cm**	850	26
>20cm	2,200	63	**40cm-C**	3,100	44	**20-50 cm**	3410	21
FF	88	70						
MS	3,200	50						
Solum	3,300	47	**Total Solum**	7,500	22			

How effective has the pit been? Common opinions on the method

- **From Huntington 1988, cited by Hooker 2003**
  - Large soil pits allow for **more accurate estimates** of **coarse fragment volume**, improve estimates of < 2 mm **bulk density in stony soils**, incorporate **small scale soil heterogeneity** into the measurements, and should **reduce the sample size** needed to detect significant differences when compared to small pits or cores (Hamburg 1984b, Huntington et al. 1988).

- **Fernandez 1993**
  - **Advantages:**
    - The pit technique **accurately measures total mass** of designated increment and the **coarse fragment** contribution to total mass.
    - Quantitative pit is **better for estimating chemical pool sizes or volumes** of material in the soils because it more **accurately estimates coarse fragment** mass.
  - **Disadvantage:**
    - There is **some mixing of** the morphological **horizons** when sampling by depth intervals.
    - **Labor intensive.** Need **several pits** to produce **statistically meaningful** data, and need enough **depth increments** to capture the morphological heterogeneity in soils with depth.

How effective has the pit been? Common opinions on the method

For element pools

- **Canary 2000**
  - Could not accurately determine **soil bulk density** in **rocky soils** with **standard soil core** or clod methods. Instead, **used quantitative pit**.
  - 75% of soil C to 85 cm was found below the A horizon and 40% was found below 25 cm.
- **Whitney 2004**
  - Sampling performed to depths > 1 m increase total nutrient pools.
- **Harrison 2003**
  - To **accurately assess total C pools** in these soils, sampling should **include** both **the >2-mm soil fraction** and **deep soil layers**.
  - In soils containing a substantial amount of **coarse fraction** material, we **suggest that excavated pits** or a similar sampling approach be used.

How effective has the pit been? Common opinions on the method

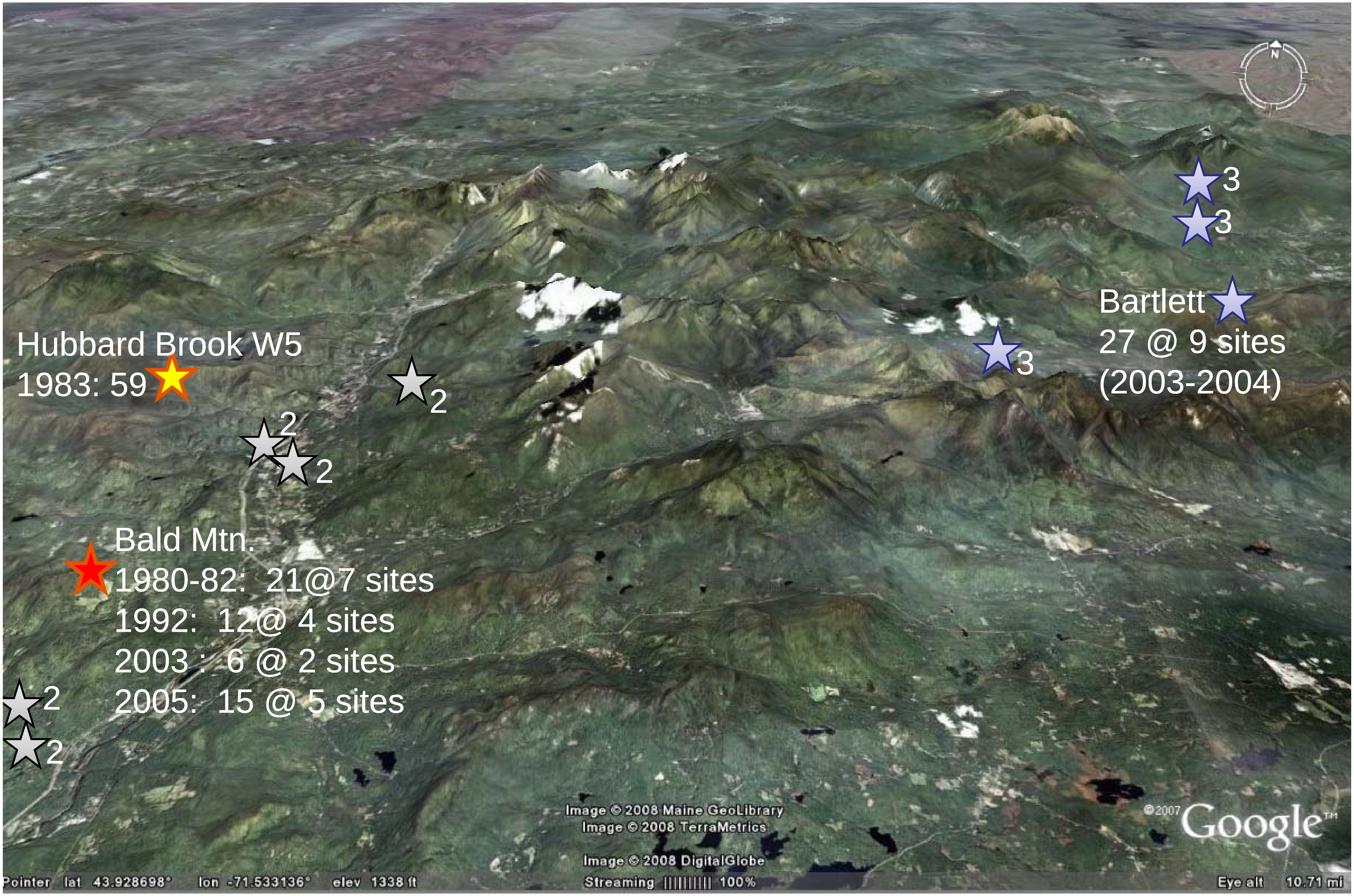
For Roots

- **Yanai 2007**
  - Quantitative pit method allows a **depth distribution** of **roots** to be measured in **rocky soils**.
  - Using soil cores would have missed 1/3 of the fine roots in the organic horizon and top 10cm of soil.
  - Soil pits also **allow larger roots to be studied** than do soil cores.
- **Vadeboncoeur 2007**
  - Quantitative pit estimates of root biomass in the >2 cm size class have **large relative errors**.
- **Fahey 1988**
  - Recommend using a hybrid approach (quantitative pits and regression analysis) to estimate woody root biomass. Because of the **high variation in large size classes** using the quantitative pit methods.

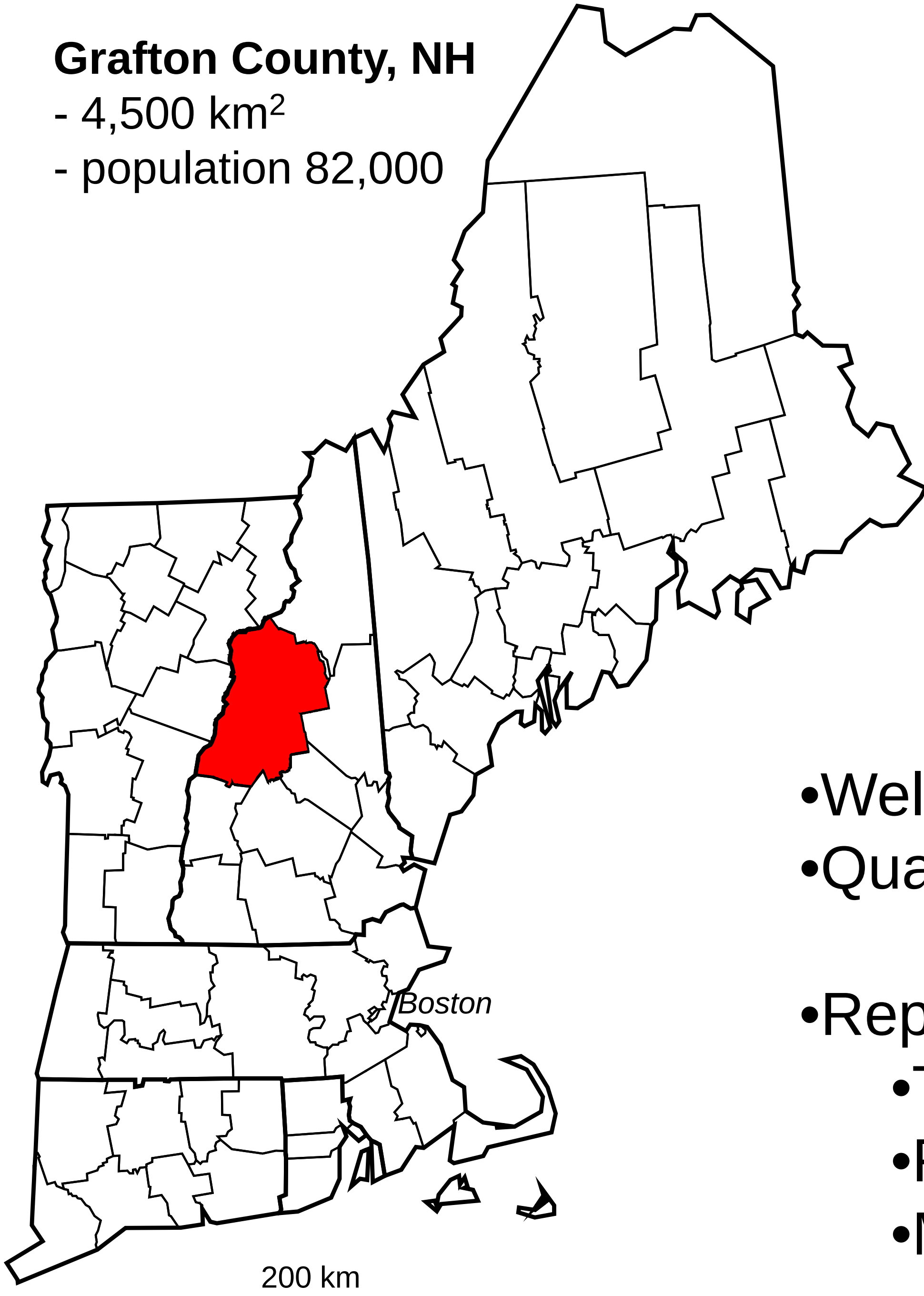
A work in progress: Where to go next in the analysis?

- Not a lot of consistency across reports, even for the same method.
- Need a way to accurately compare results of the different studies.
- Continue to search for other papers in the literature.
- Add more information from the results from pits in White Mts. and HBEF W5 data, such as Chris Johnson's resampling work.
- We are open to thoughts on what criteria we should use to evaluate the method and decide whether it should be repeated in the future.

Quantitative Soil Pits in the White Mountains



Grafton County, NH
- 4,500 km^2
- population 82,000

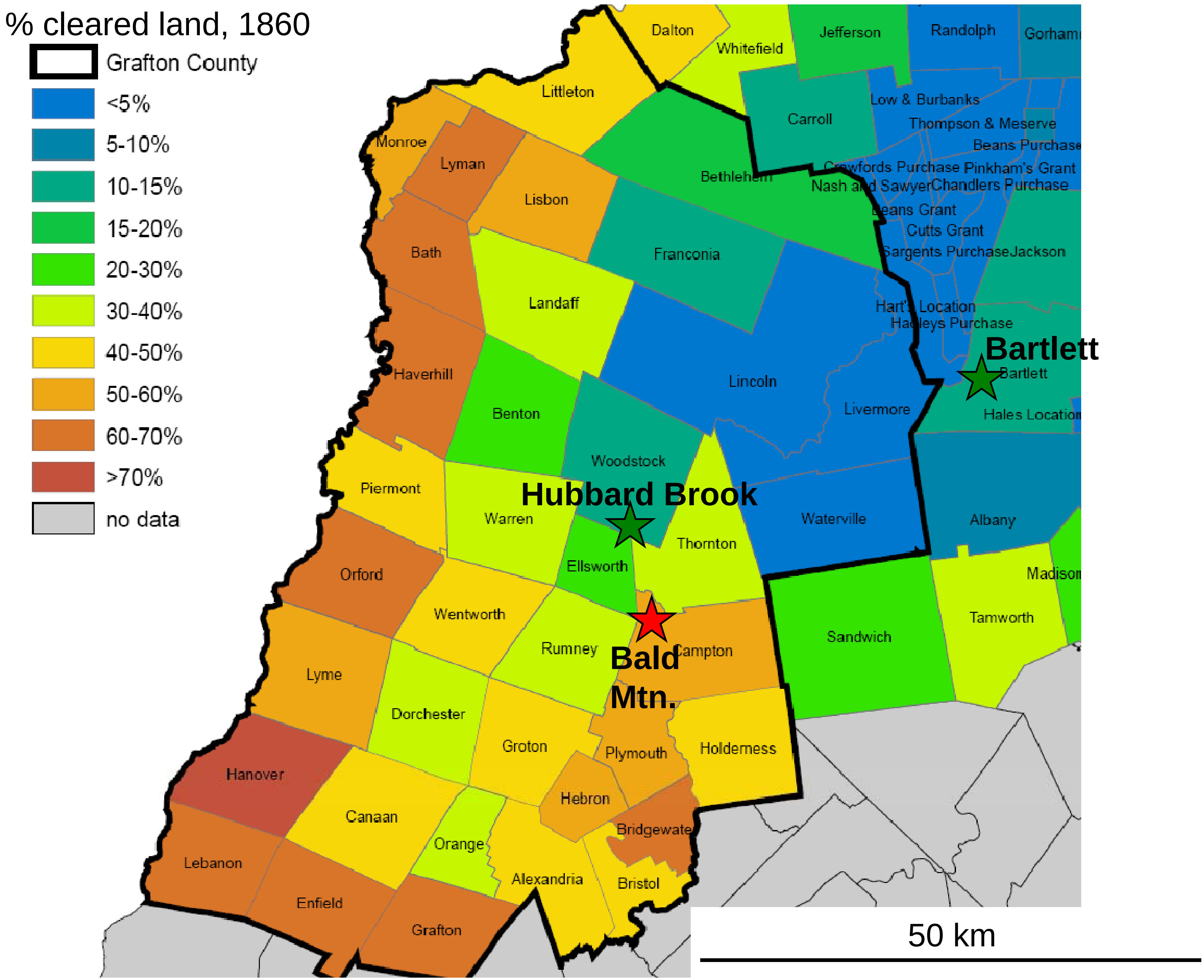


Question

Does land-use history affect patterns of carbon accumulation in northeastern hardwood forests?

Approach

•Well documented land-use history
•Quantitative pit method for measuring soils
•Repeat measurements over 25 y of:
    •Tree inventory
    •Forest floor
    •Mineral soil



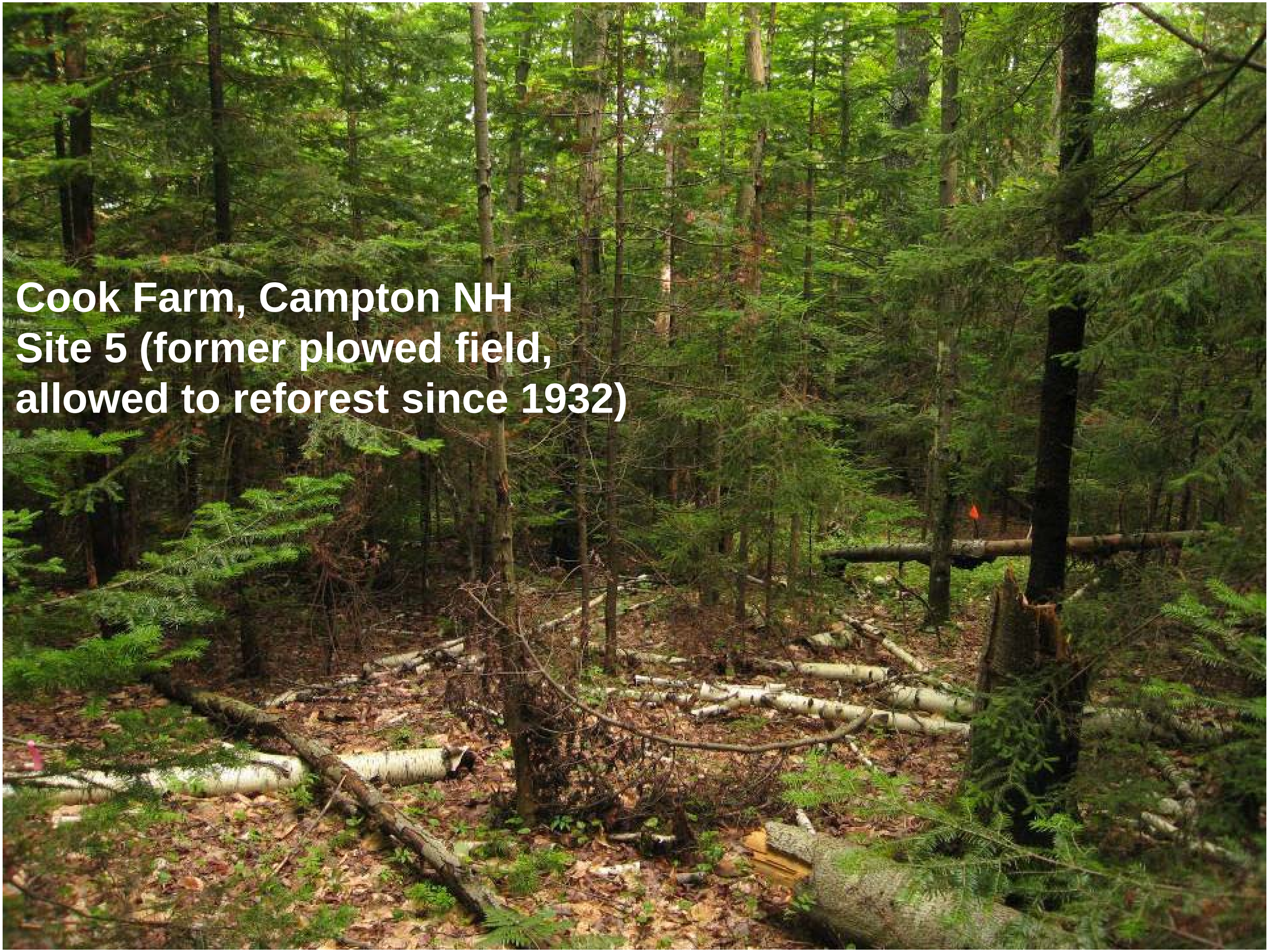
% cleared land, 1860
Grafton County
<5%
5-10%
10-15%
15-20%
20-30%
30-40%
40-50%
50-60%
60-70%
>70%
no data
Dalton
Whitefield
Jefferson
Randolph
Littleton
Carroll
Low & Burbanks
Thompson & Meserve
Beans Purchase
Monroe
Lyman
Lisbon
Bethlehem
Crawfords Purchase
Pinkham's Grant
Nash and Sawyer
Chandlers Purchase
Beans Grant
Cutts Grant
Sargents Purchase
Jackson
Bath
Franconia
Landaff
Hart's Location
Hadleys Purchase
Bartlett
Haverhill
Lincoln
Benton
Livermore
Hales Location
Woodstock
Piermont
Hubbard Brook
Warren
Waterville
Albany
Thornton
Ellsworth
Orford
Madison
Wentworth
Rumney
Bald Mtn.
Campton
Tamworth
Sandwich
Lyme
Dorchester
Groton
Plymouth
Holderness
Hanover
Hebron
Canaan
Bridgewate
Orange
Lebanon
Alexandria
Bristol
Enfield
Grafton
50 km

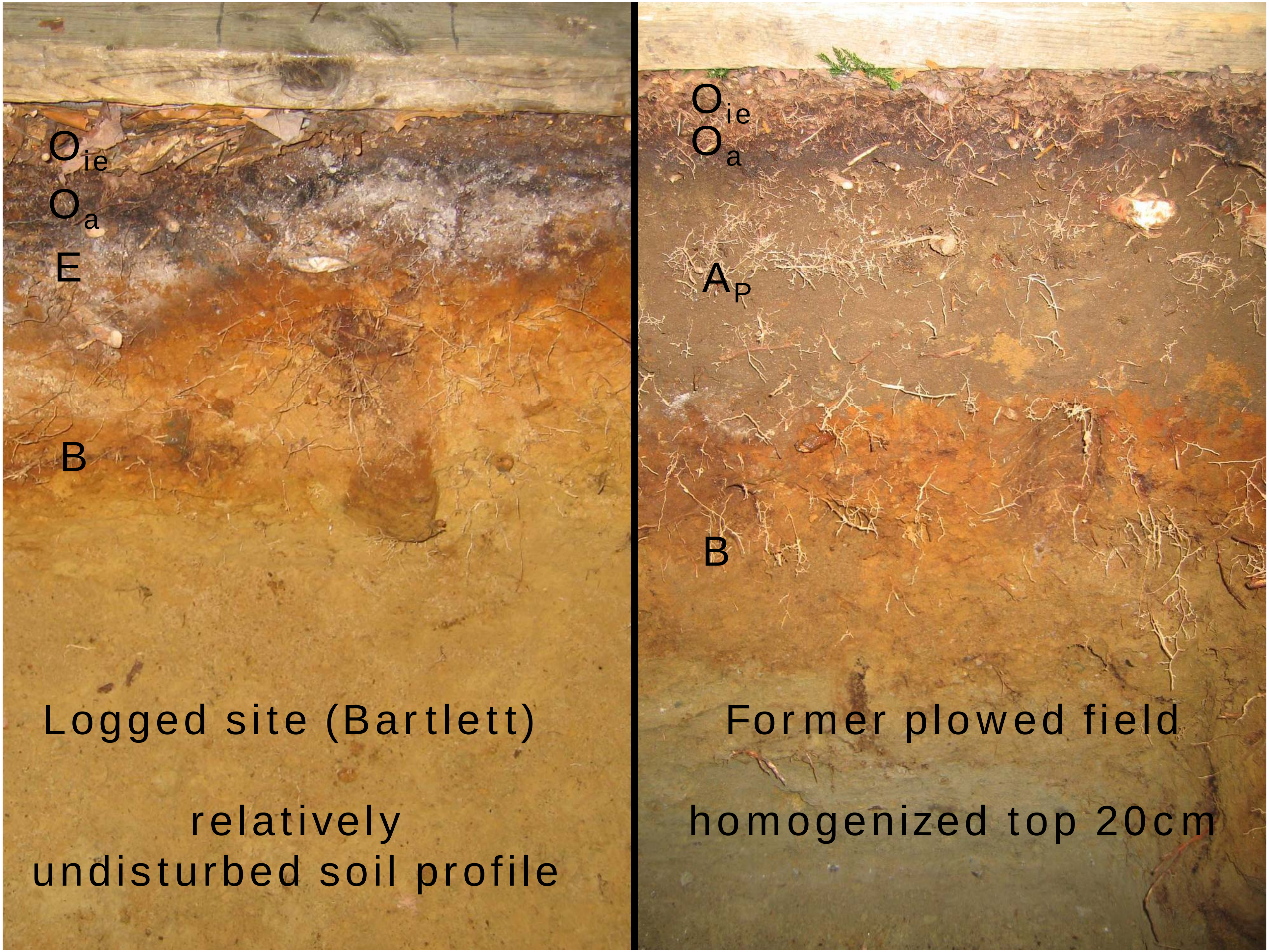
Why does understanding old-field succession matter?

- ~ 70% of the New England landscape is second-growth forests growing on former agricultural lands

- We know relatively little about how much carbon is accumulating on abandoned agricultural lands

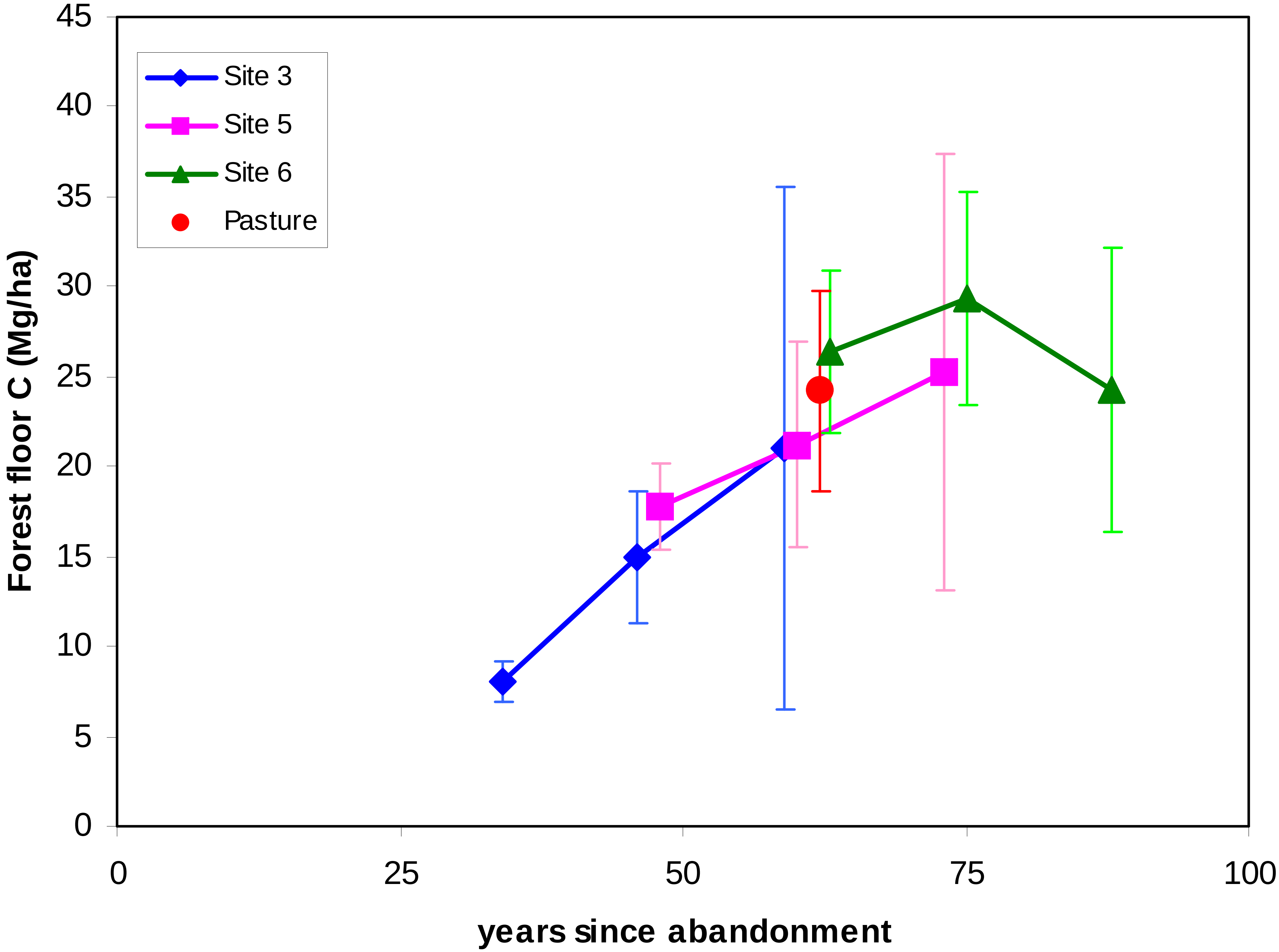
- Recent reports suggest that there is much less carbon accumulating in the temperate zone than previously thought


Cook Farm, Campton NH
Site 5 (former plowed field,
allowed to reforest since 1932)

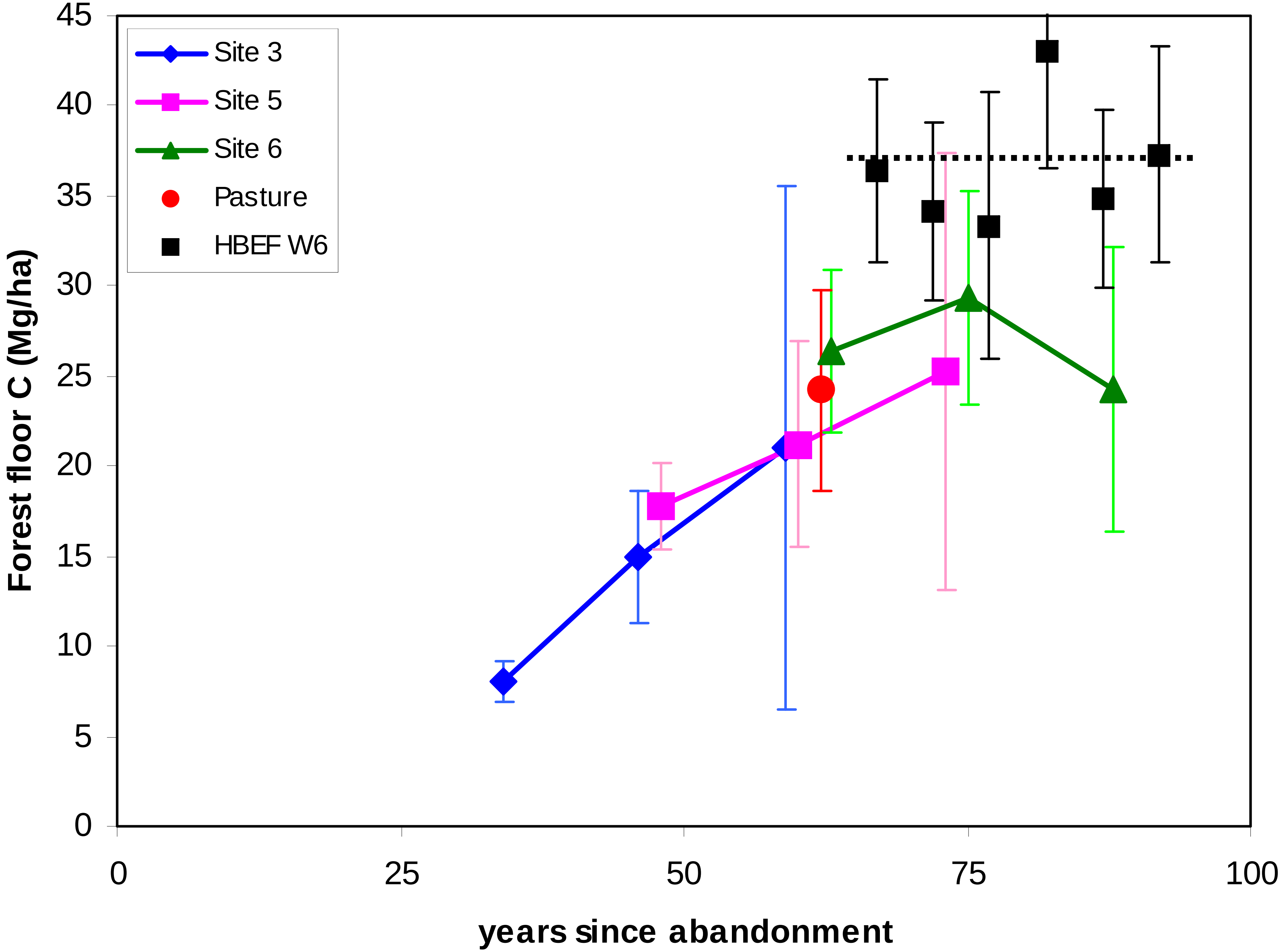

Oie
Oa
E
B
Logged site (Bartlett)
relatively
undisturbed soil profile
Oie
Oa
AP
B
Former plowed field
homogenized top 20cm



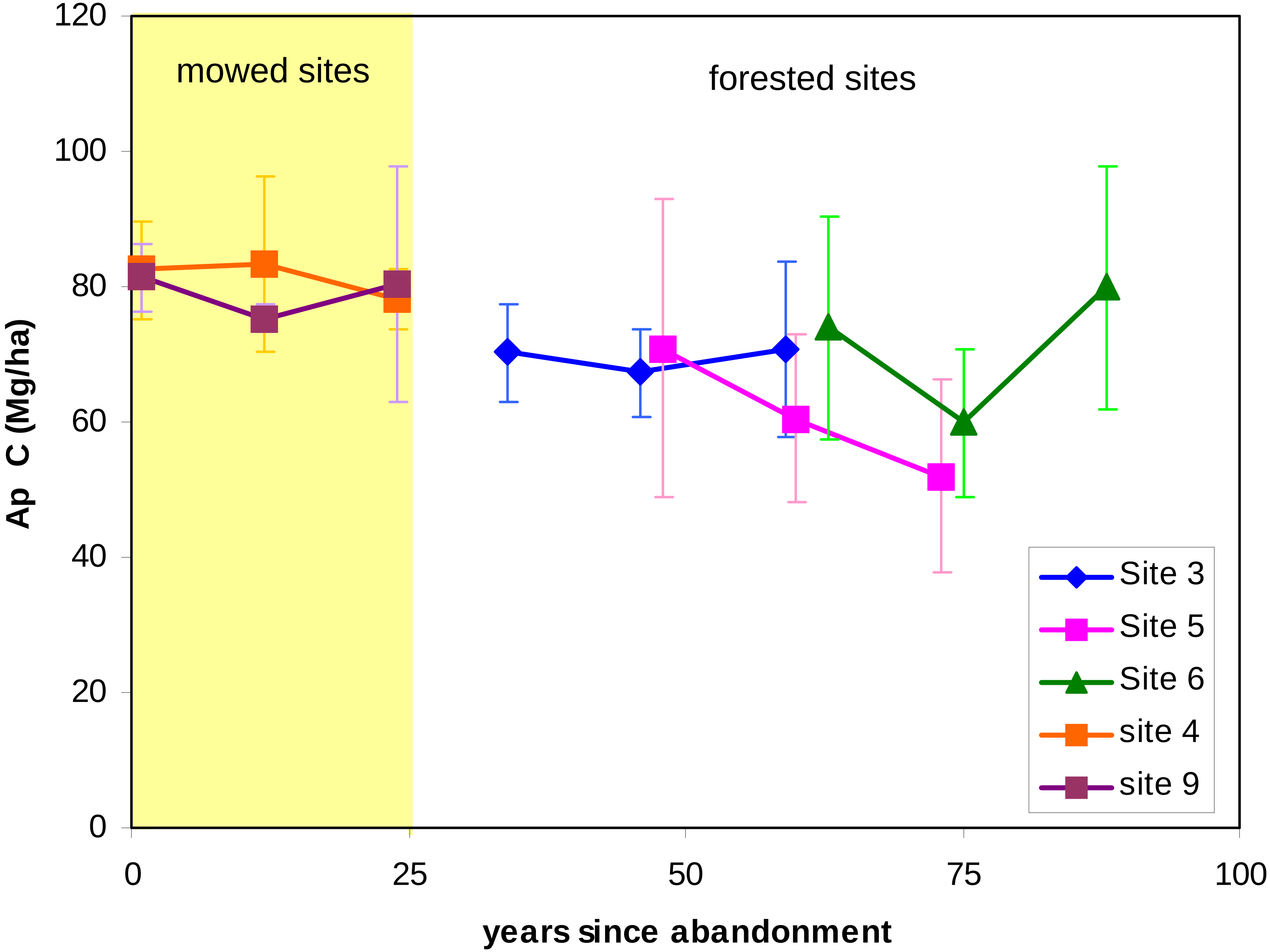
Berry Farm, Campton NH
Site 4 (former potato field,
continuously unforested since 1860)



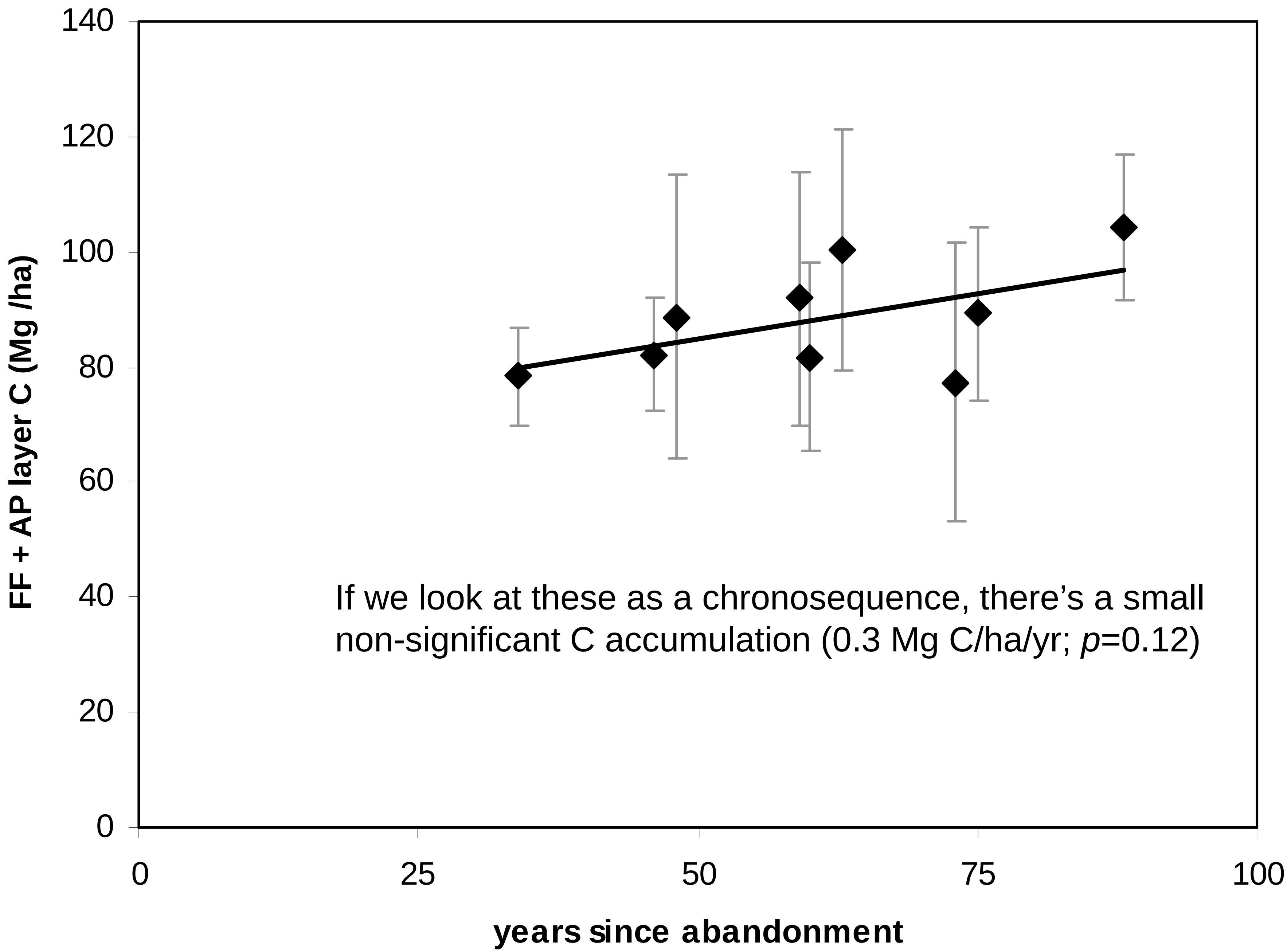
Site 3
Site 5
Site 6
Pasture
Forest floor C (Mg/ha)
0
5
10
15
20
25
30
35
40
45
0
25
50
75
100
years since abandonment



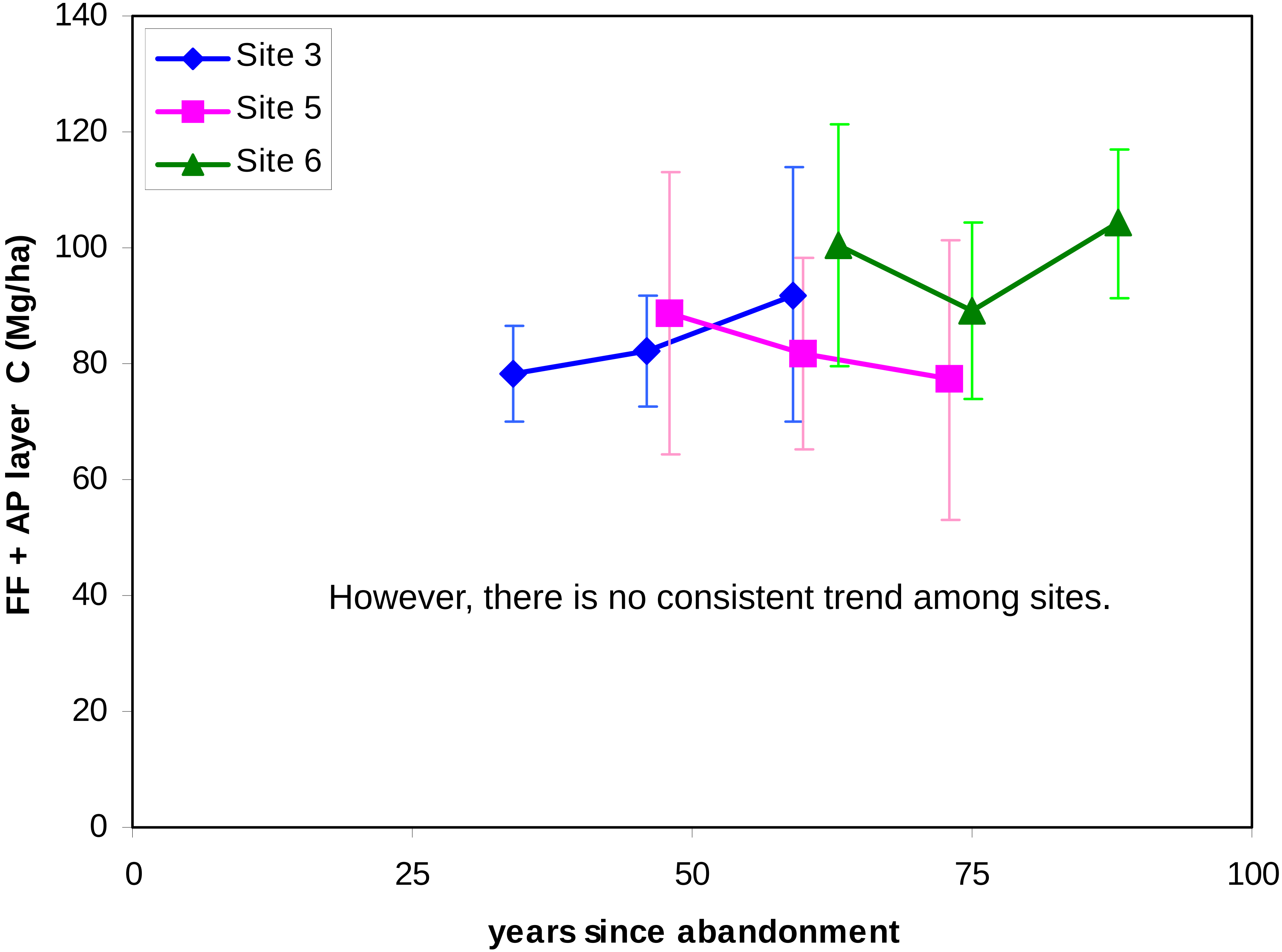
Site 3
Site 5
Site 6
Pasture
HBEF W6
Forest floor C (Mg/ha)
years since abandonment
0
5
10
15
20
25
30
35
40
45
0
25
50
75
100



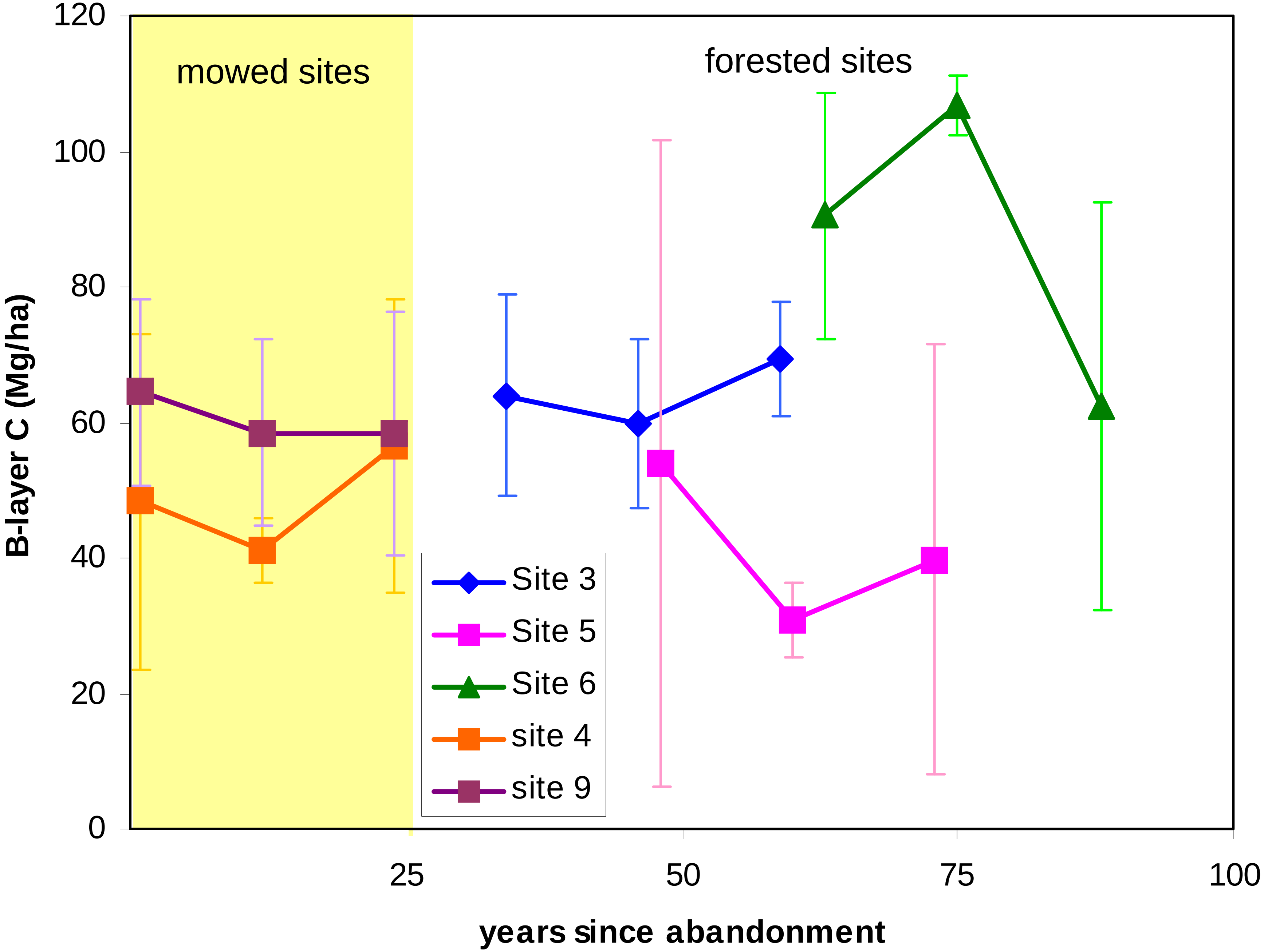
mowed sites
forested sites
Ap C (Mg/ha)
years since abandonment
0
20
40
60
80
100
120
0
25
50
75
100
Site 3
Site 5
Site 6
site 4
site 9



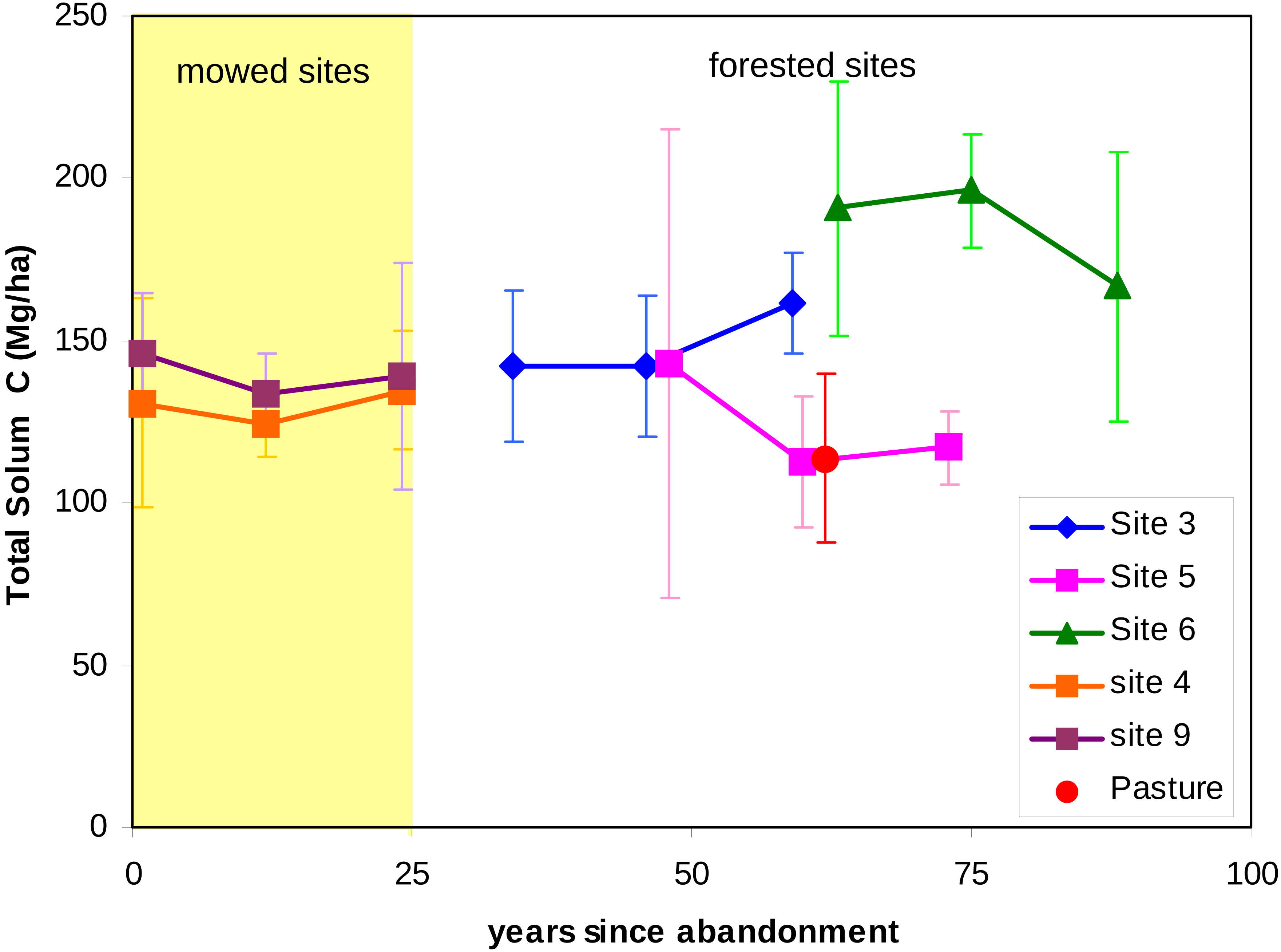
FF + AP layer C (Mg /ha)
140
120
100
80
60
40
20
0
0
25
50
75
100
years since abandonment
If we look at these as a chronosequence, there's a small non-significant C accumulation (0.3 Mg C/ha/yr; p=0.12)



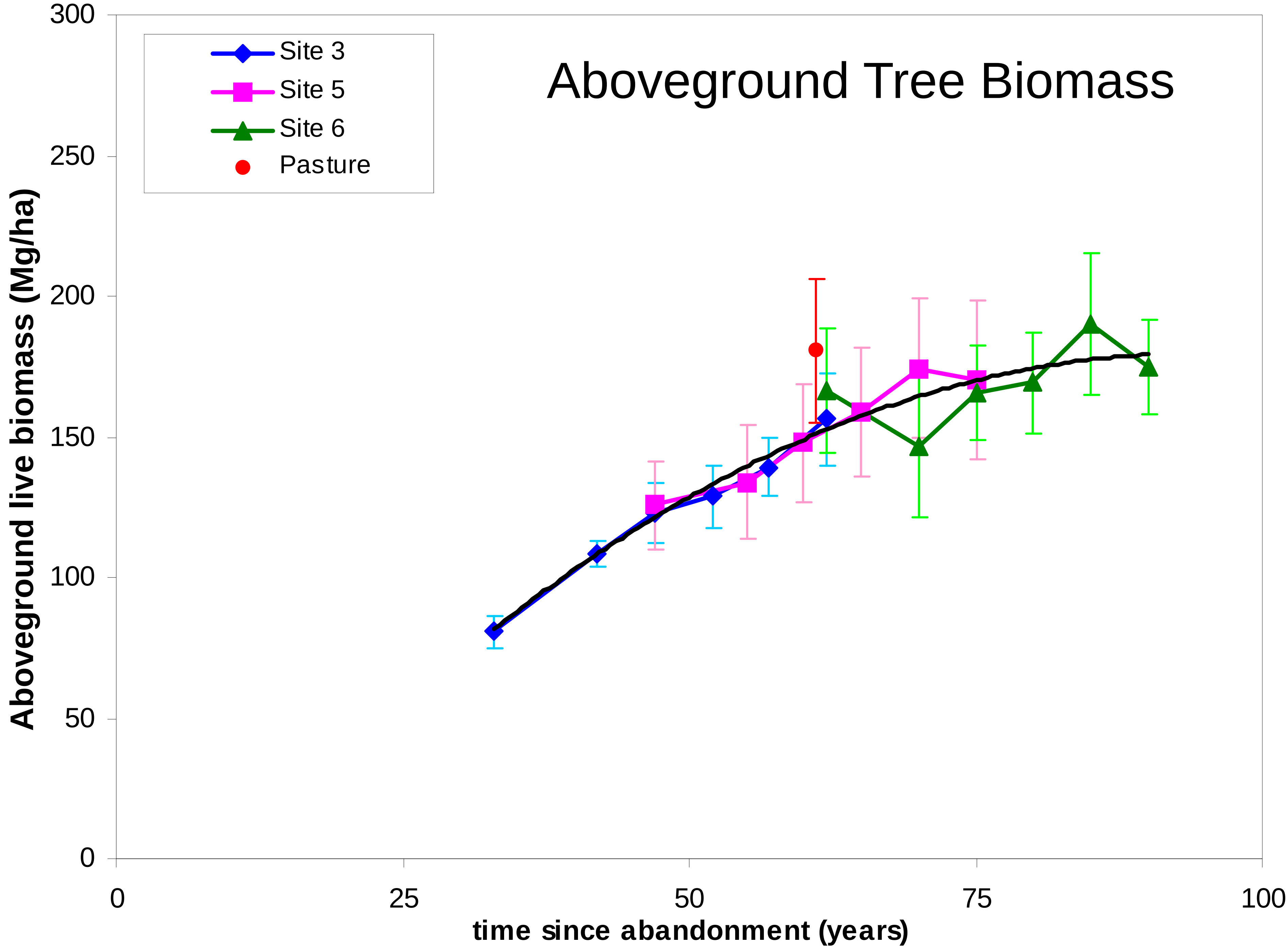
Site 3
Site 5
Site 6
140
120
100
80
60
40
20
0
FF + AP layer C (Mg/ha)
0
25
50
75
100
years since abandonment
However, there is no consistent trend among sites.



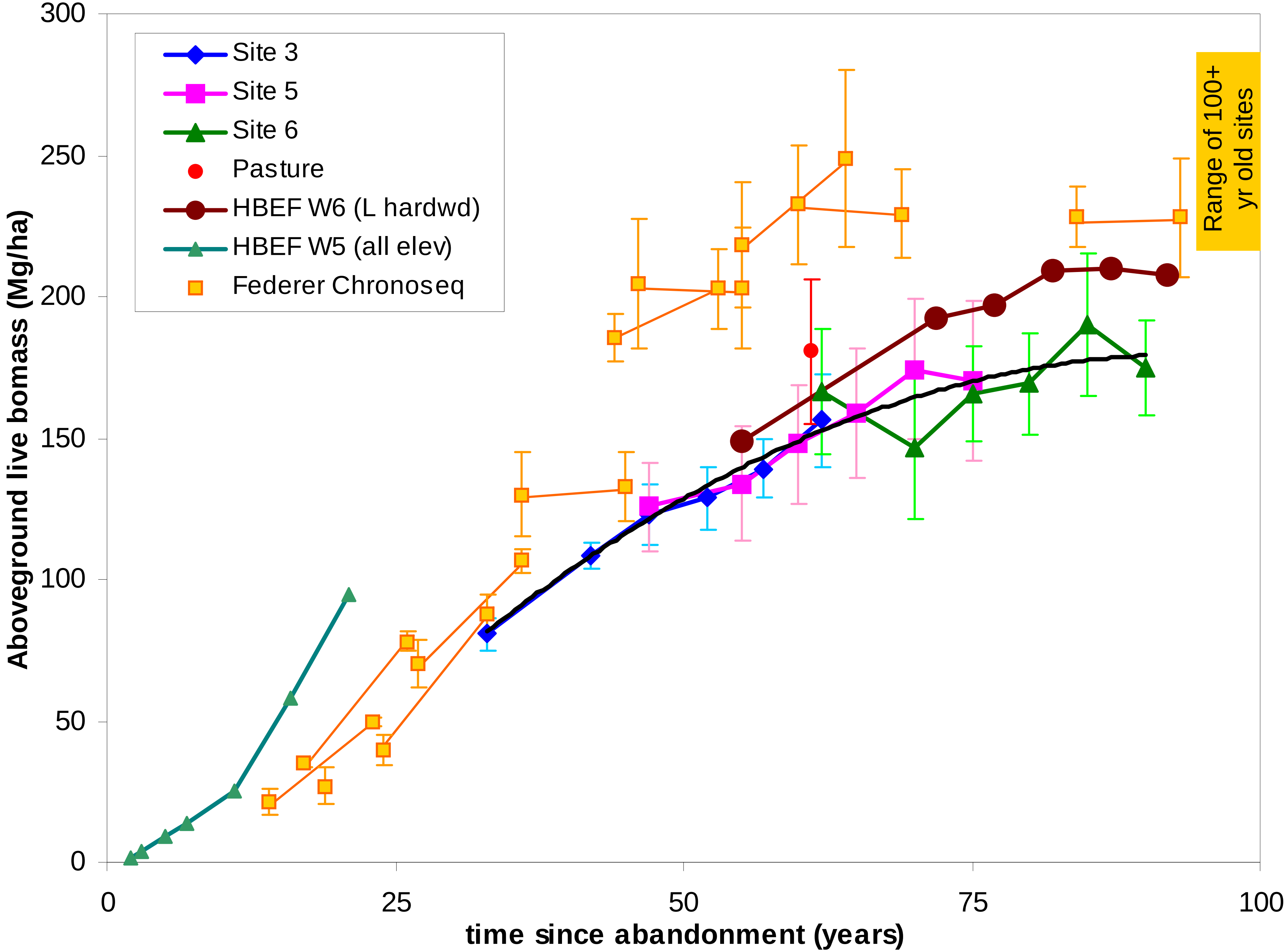
mowed sites
forested sites
Site 3
Site 5
Site 6
site 4
site 9
0
20
40
60
80
100
120
25
50
75
100
B-layer C (Mg/ha)
years since abandonment



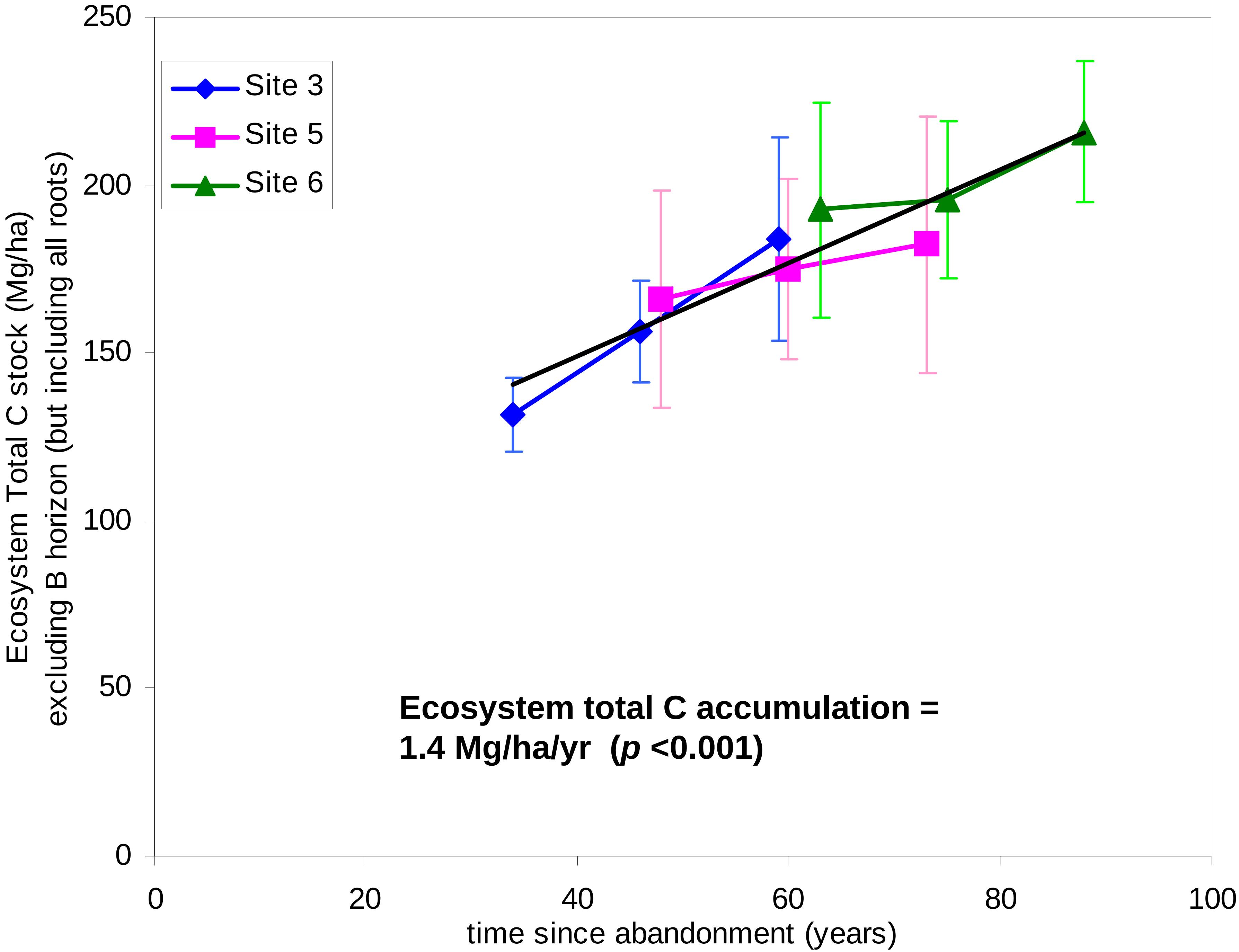
mowed sites
forested sites
Total Solum C (Mg/ha)
years since abandonment
0
50
100
150
200
250
0
25
50
75
100
Site 3
Site 5
Site 6
site 4
site 9
Pasture



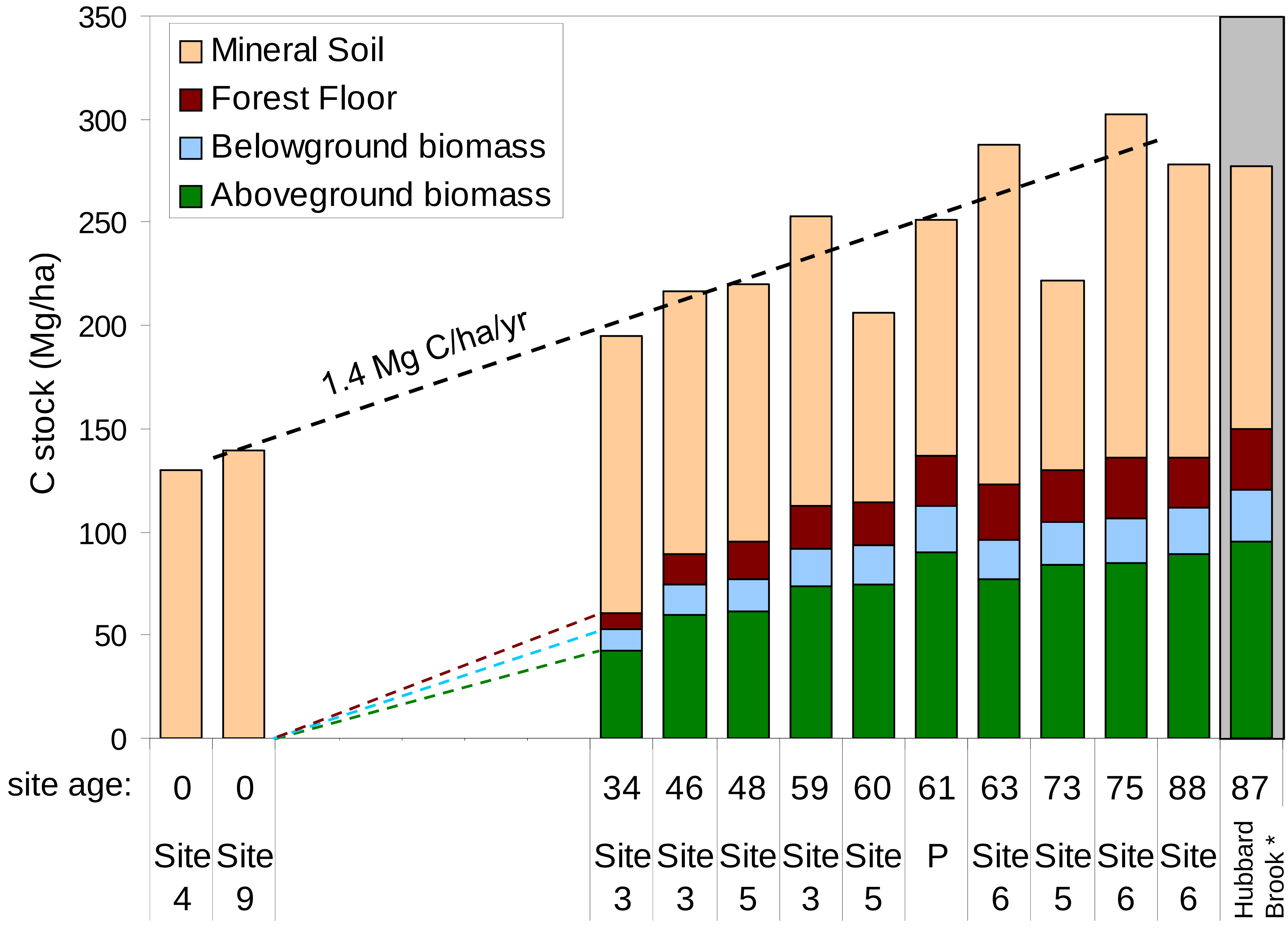
Aboveground Tree Biomass
Site 3
Site 5
Site 6
Pasture
Aboveground live biomass (Mg/ha)
300
250
200
150
100
50
0
0
25
50
75
100
time since abandonment (years)



Aboveground live bomass (Mg/ha)
time since abandonment (years)
Site 3
Site 5
Site 6
Pasture
HBEF W6 (L hardwd)
HBEF W5 (all elev)
Federer Chronoseq
Range of 100+ yr old sites
0
50
100
150
200
250
300
0
25
50
75
100



Site 3
Site 5
Site 6
Ecosystem Total C stock (Mg/ha)
excluding B horizon (but including all roots)
time since abandonment (years)
0
50
100
150
200
250
0
20
40
60
80
100
Ecosystem total C accumulation =
1.4 Mg/ha/yr (p <0.001)



* Hubbard Brook W6 data from Fahey et al. 2005

Question

Does land-use history affect patterns of carbon accumulation in northeastern hardwood forests?

Yes!

BUT, not in the ways the literature would indicate

- Soils are a much smaller sink than chronosequence data would suggest
- Tree biomass will take longer to reach maximum
- Overall less carbon will accumulate on the landscape than previously predicted