Stand-scale biogeochemical sustainability of forest harvesting in central New Hampshire

Matthew A. Vadeboncoeur

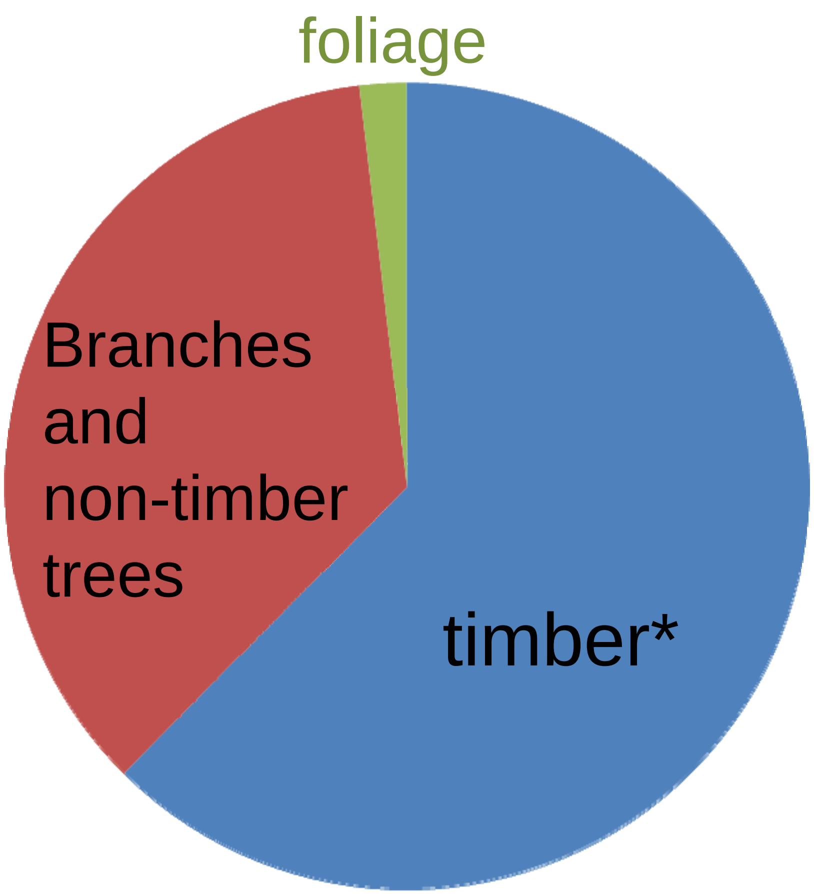
Ruth D. Yanai, Steven P. Hamburg

Joel D. Blum, Erik A. Hobbie

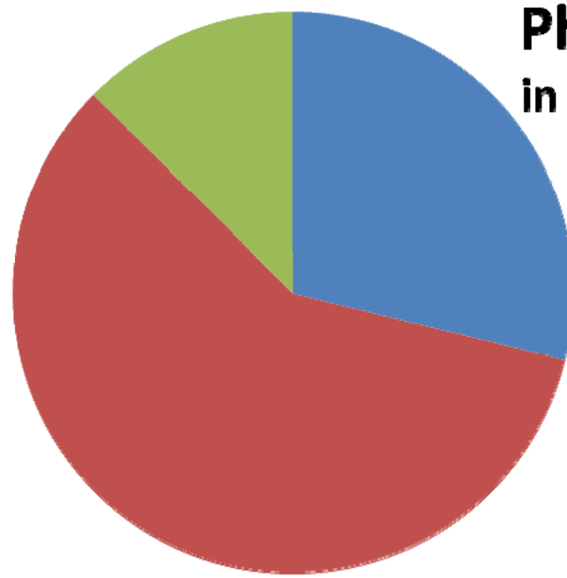

When the forest is harvested, nutrients are removed.


Regrowing forests must get “new” nutrients from the soil.

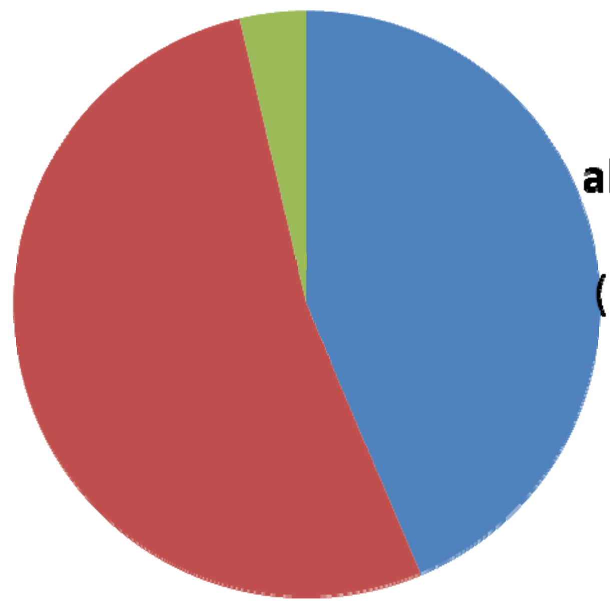
Aboveground dry biomass (200 Mg ha^{-1})



* bole wood and bark of trees >12.7cm DBH



Phosphorus in aboveground biomass (52 kg ha^{-1})



Calcium in aboveground biomass (598 kg ha^{-1})

Watershed 6 lower hardwood zone, Hubbard Brook Experimental Forest, 2007

Q: Given known nutrient stocks and fluxes, how sustainable are various harvesting scenarios?

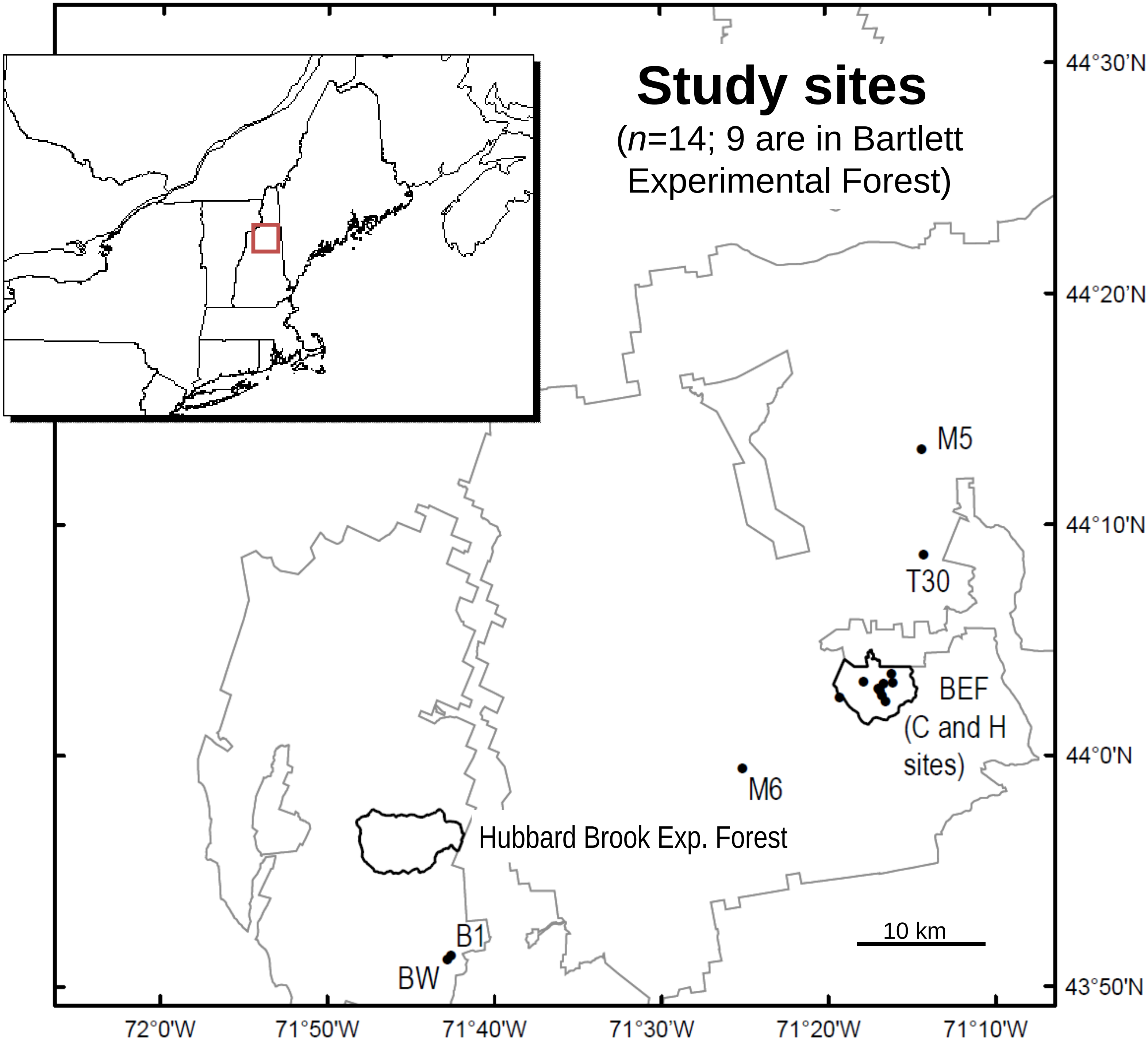
- Which nutrient runs out first?
- How do different soils vary?

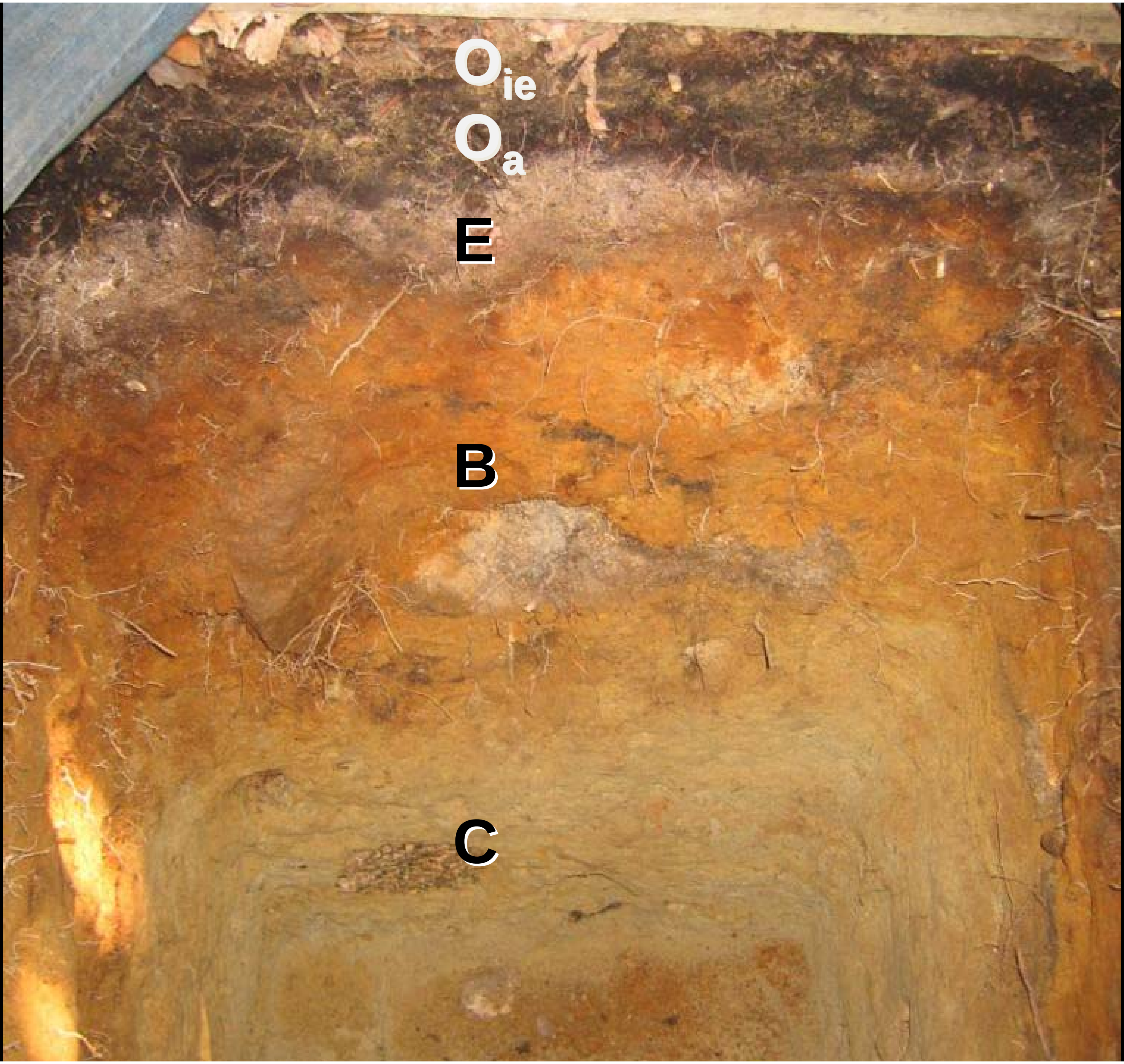
Data

- **Soil nutrient stocks** (kg ha^{-1}) from quantitative soil pits in 14 stands.
  - ***Exchangeable, organic, and apatite extractions of Ca, K, Mg, and P (O + A/E/B + 25cm of C horizon)***
  - Total N (O + B horizons)

- **Aboveground biomass nutrient stocks**
  - **Mature boles only** (HBEF W6 LM 2007 inventory)
  - **Mature whole-tree** (HBEF W5 WTH 1983; Arthur et al. 2001)

- **Atmospheric inputs & stream outputs** of all nutrients from Hubbard Brook (~30-yr mean).


Study sites
(n=14; 9 are in Bartlett Experimental Forest)
M5
T30
BEF
(C and H sites)
M6
Hubbard Brook Exp. Forest
B1
BW
10 km
44°30'N
44°20'N
44°10'N
44°0'N
43°50'N
72°0'W
71°50'W
71°40'W
71°30'W
71°20'W
71°10'W


Oie
Oa
E
B
C

Mass balance model

$$\# \text{ rotations} = \frac{\text{available stock}}{\text{removal} - (F_{in} - F_{out}) * T_R}$$

F_{in} = fluxes in:
- atm. deposition
- weathering

F_{out} = fluxes out:
- leaching

T_R = rotation time

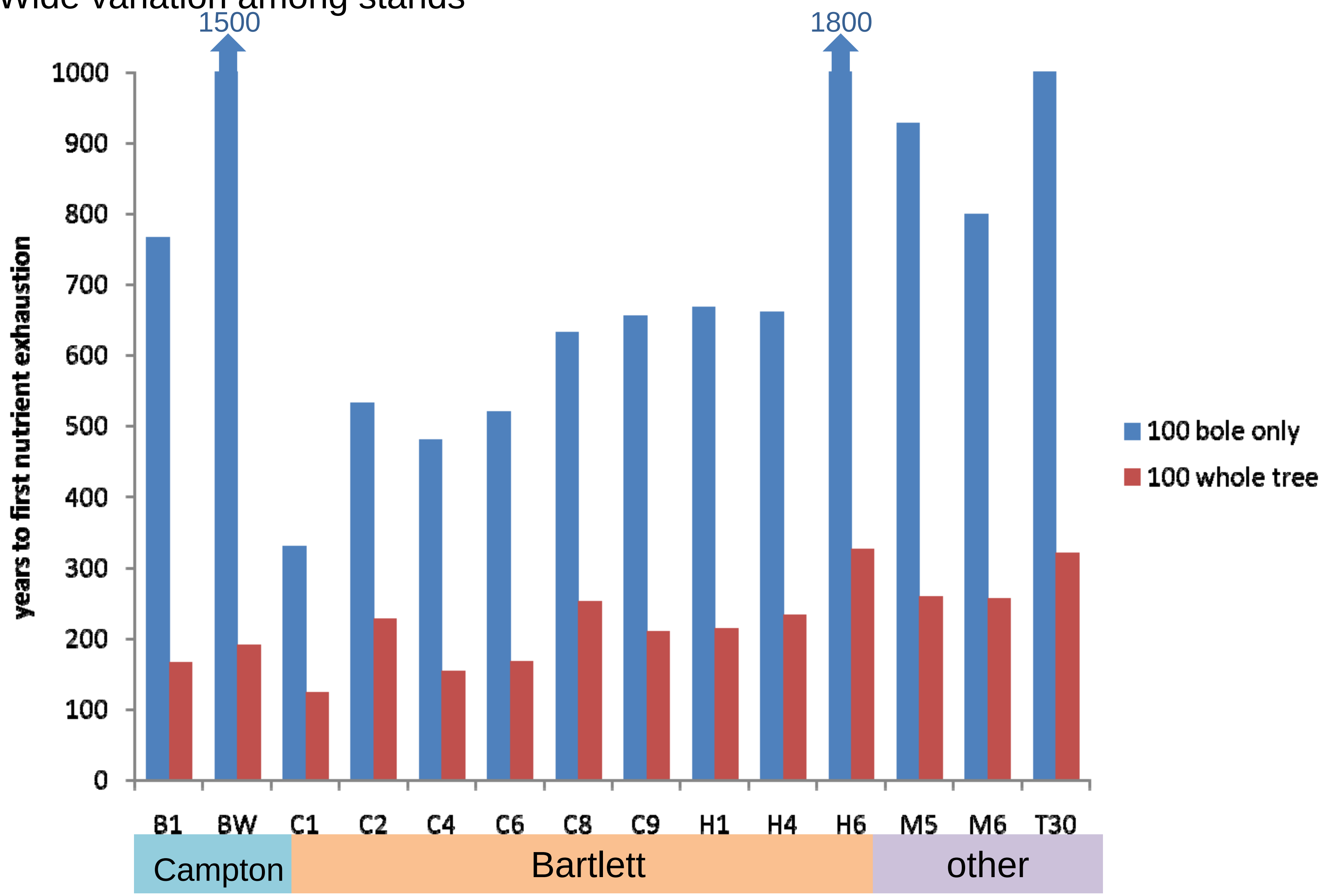
Model runs

- 5 macronutrients (Ca, P, K, Mg, N)
- 2 harvest scenarios
  - 100 year winter removal of 100% of 5+” DBH
  - 100 year winter whole-tree harvest (~92%)
- 14 stands
- For now, assuming weathering, leaching = 0

For each scenario X site, which nutrient runs out first, and how fast?

Results:

- Ca or P usually become limiting first (occasionally K). Never Mg.
- Current N deposition (9 kg ha^{-1} yr TDN) is sufficient to replace N under all scenarios.
- WTH (especially 30 yr) removes nutrients much faster than bole only.
- Wide variation among stands



			Ca	K	Mg	P
			ALL DATA IN KG/HA/YR			
WEATHERING RATE NEEDED TO BALANCE WTH 100Y REMOVAL			3.0	1.0	0.26	0.17
" " " " " " ASSUMING CONSTANT IN/OUT (HBEF)			5.0	0.9	1.5	0
	a) BASELINE WEATHERING RATES*	**Soil age (ka)**	**Ca**	**K**	**Mg**	**P**
in study region:	Schaller et al. (2010) regional mean	14	0.17	0.62	0.10	0.014
	range	14	0.03-0.34	0.13-1.27	0.02-0.27	0.005-0.025
	Nezat et al. (2004), HBEF W1	14	0.44	1.25	0.15	0.03
for comparison to "current" rates	April et al. (1986), Adirondacks	14	0.6-1.1	1.5-1.8	0.3-0.4	
	Kirkwood and Nesbitt (1991), Ontario	12	0.40	0.43	0.24	
	Bain et al. (2001), Scotland	NR**	0.01-0.03	0	0.002-0.01	
other rates for reference:	Taylor and Blum (1995), Wyoming	11-21	0.3-0.5	0.3-0.6	0.004	
	Elgi et al. (2008), Alps	12-16	1.29	0.01-1.1	0.03-1.41	
	Olsson et al. (2000), Sweden and Finland	9	0.4-0.5	0.5-0.7	0.2-0.5	0.003
	Newman (1995), based on Walker and Syers (1976), New Zealand	6-12				0.03-0.1
	b) WEATHERING RATES INFERRED FROM WATERSHED BUDGETS		**Ca**	**K**	**Mg**	**P**
in study region:	Bailey et al. (1994), Cone Pond		1.2-3.3			
	Hyman et al. (1998), Cone Pond		2.18	1.08	1.09	
	Likens and Bormann (1995), HBEF***		21.1	7.1	3.5	
	Likens et al. (1998), HBEF		2.00-3.12			
	Wood et al. (1984), HBEF ***					1.5-1.8
for comparison to long-term rates	April et al. (1986), Adirondacks		3.3-23.0	0.0-1.2	0.3-3.2	
	Kirkwood and Nesbitt (1991), Ontario		5.4	0.2	1.3	
	Bain et al. (2001), Scotland		1.6	0.0	2.6	

* based on soil profiles, assuming C horizon is unweathered. Long-term means are multiplied by 30% (Taylor and Blum 1995)

** NR = not reported

*** probably greatly overestimated due to uncertainties in the budget approach; see Likens et al. 1994, Likens and Bormann 1995

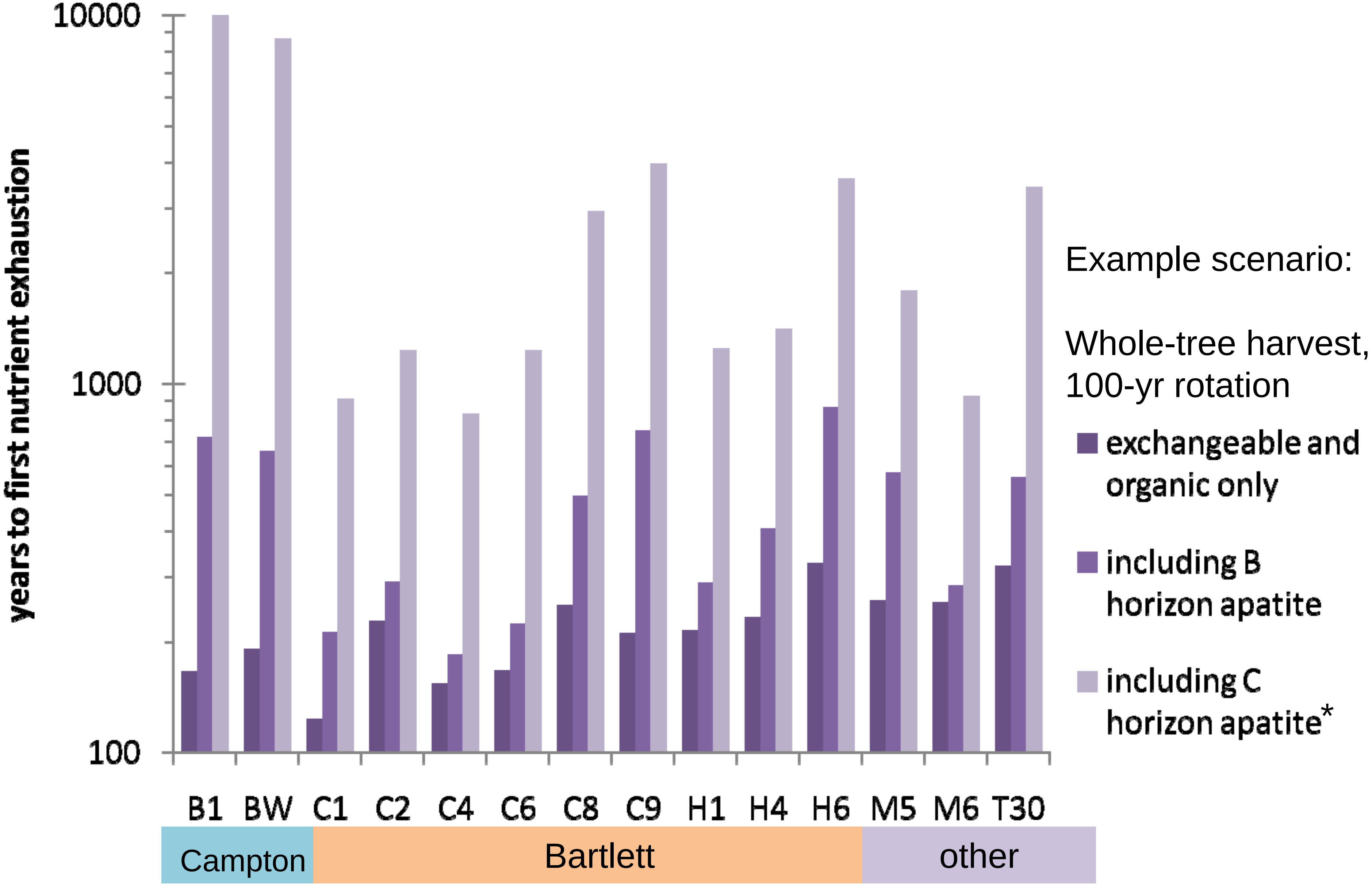
Hypotheses explaining the weathering rate conundrum:

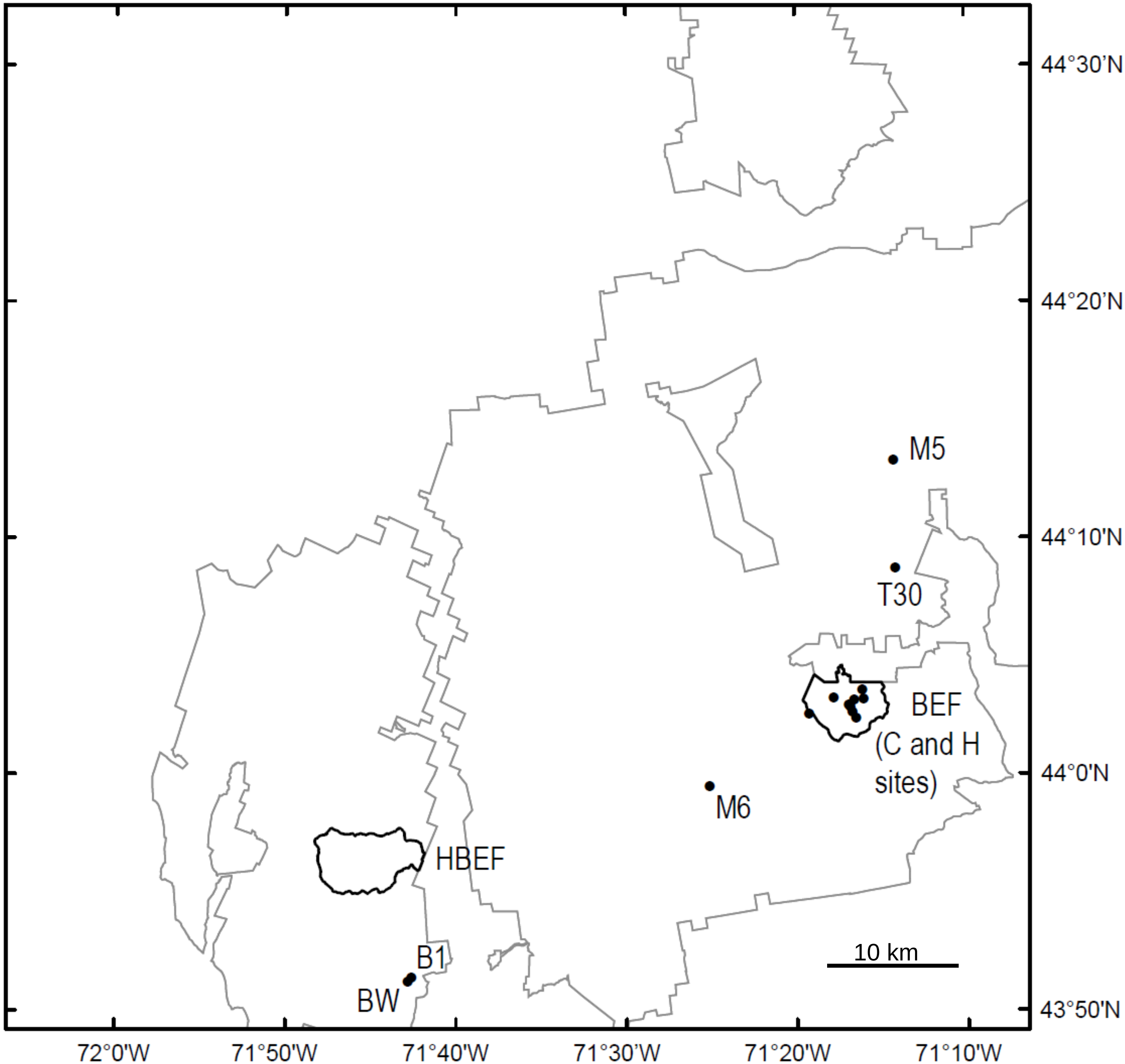
- Erroneous assumptions in one/both methods?
  - C horizon represents time 0 (profile)
  - congruent weathering (watershed)
- Measuring weathering in different pools (soils vs. rock) (Bain and Langan 1995)
- Acid deposition accelerates weathering (Likens)
- Biotic demand accelerates weathering (Hamburg)
  - Is altered C allocation to deep roots (+ mycorrhizae, exudates) related to apparent mineral-soil C losses?

Model runs

- 5 macronutrients (Ca, P, K, Mg, N)
- 2 harvest scenarios
  - 100 year timber harvest
  - 100 year whole-tree harvest
- 14 stands
- Three levels of nutrient stocks (Ca & P)
  - Exchangeable + organic only
  - Exchangeable + organic + apatite thru B
  - Exchangeable + organic + apatite thru top 25cm of C

Adding apatite (assuming sufficient N inputs, K and Mg weathering)




44°30'N
44°20'N
44°10'N
44°0'N
43°50'N
72°0'W
71°50'W
71°40'W
71°30'W
71°20'W
71°10'W
M5
T30
BEF
(C and H
sites)
M6
HBEF
B1
BW
10 km

Conclusions

- **Landscape variability in soils is important! (5-10-fold variation in # rotations among *ostensibly similar* sites)**
  - parent material mineralogy
  - soil mass (depth & rockiness)
- High weathering rates are an important part of Ca and P budgets of regenerating stands
  - Mechanism?
  - Primary P may be the first “hard” BGC constraint
  - Current best practices give us at least 100 years … but then what?

Acknowledgements:

Project design and logistics:
Elizabeth Hane, Mary Arthur

Field Crews:

- M. Acker
- R. Averbeck
- C. Blodgett
- J. Boley
- H. Clark
- A. Coria
- M. Deringer
- C. Fuss
- M. Germain
- A. Just
- P. Lilly
- S. Miftari
- N. Ross
- N. Shapiro
- D. Tucker
- B. Weeks

Laboratory:
A. Klaue and many others

NSF grants DEB0235650 and DEB9810221