Quantifying Uncertainty in Ecosystem Studies

Carrie Rose Levine and Ruth Yanai
SUNY ESF
Department of Forest and Natural Resource Management

Northeastern Soil Monitoring Cooperative

March 13, 2012

What contributes to uncertainty in ecosystem budgets?

UNCERTAINTY

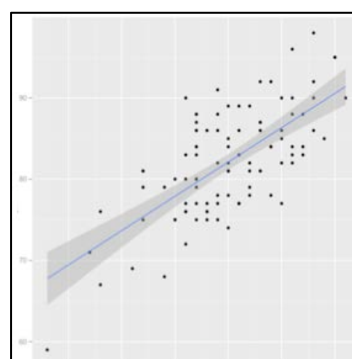
Natural Variability

- Spatial Variability

- Temporal Variability

Knowledge Uncertainty

- Measurement Error



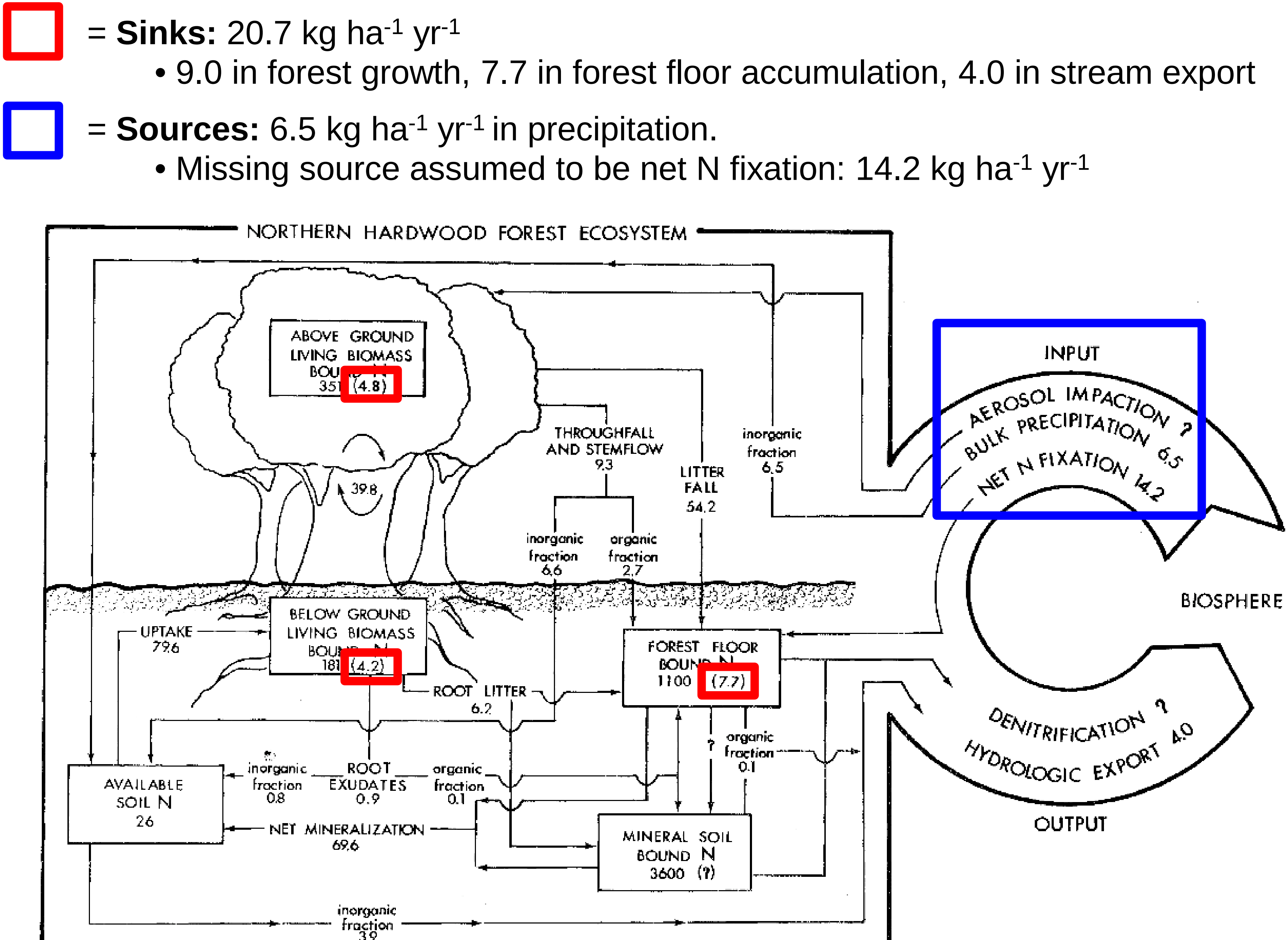
- Model Error

= **Sinks:** 20.7 kg ha^{-1} yr^{-1}

- 9.0 in forest growth, 7.7 in forest floor accumulation, 4.0 in stream export

= **Sources:** 6.5 kg ha^{-1} yr^{-1} in precipitation.

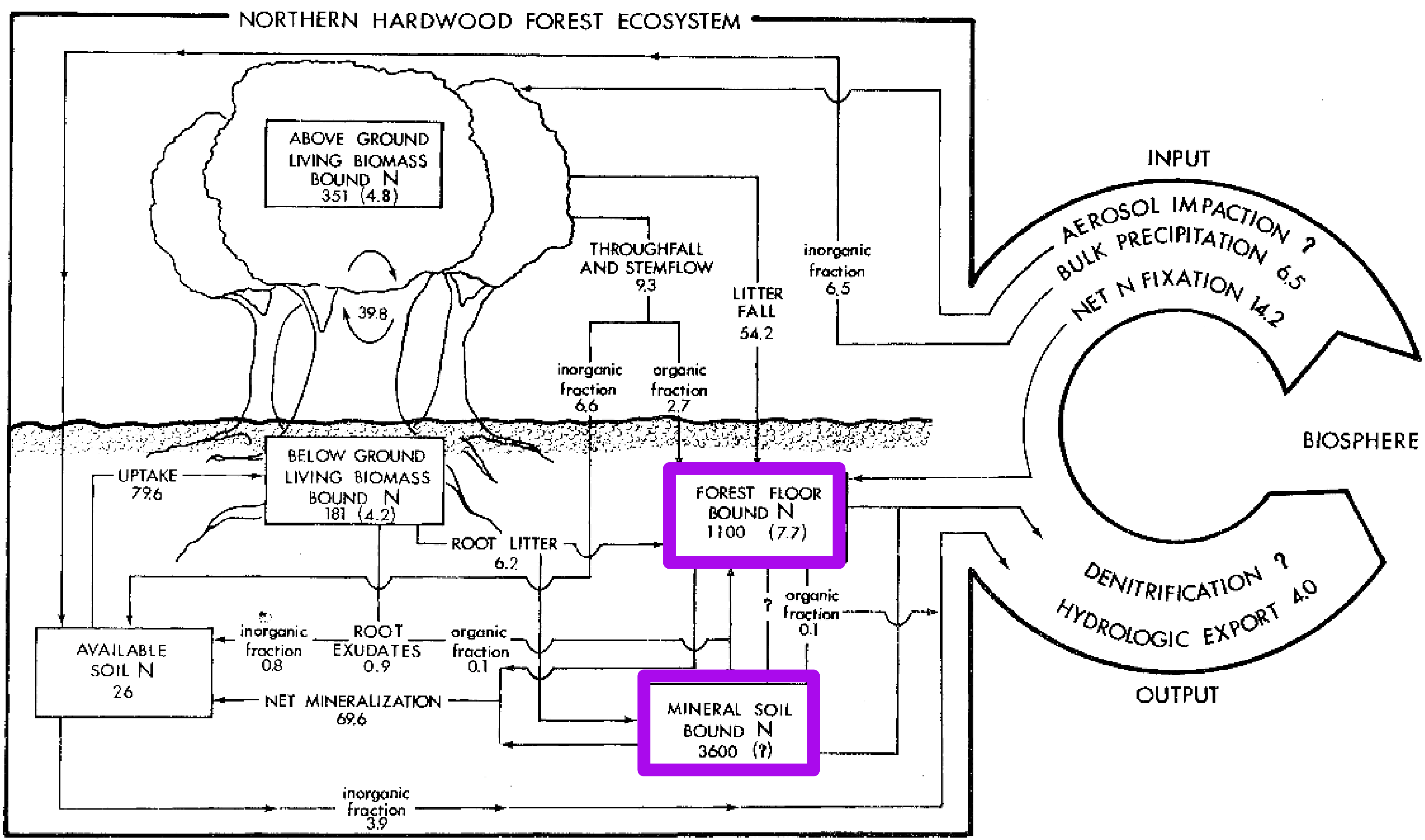
- Missing source assumed to be net N fixation: 14.2 kg ha^{-1} yr^{-1}

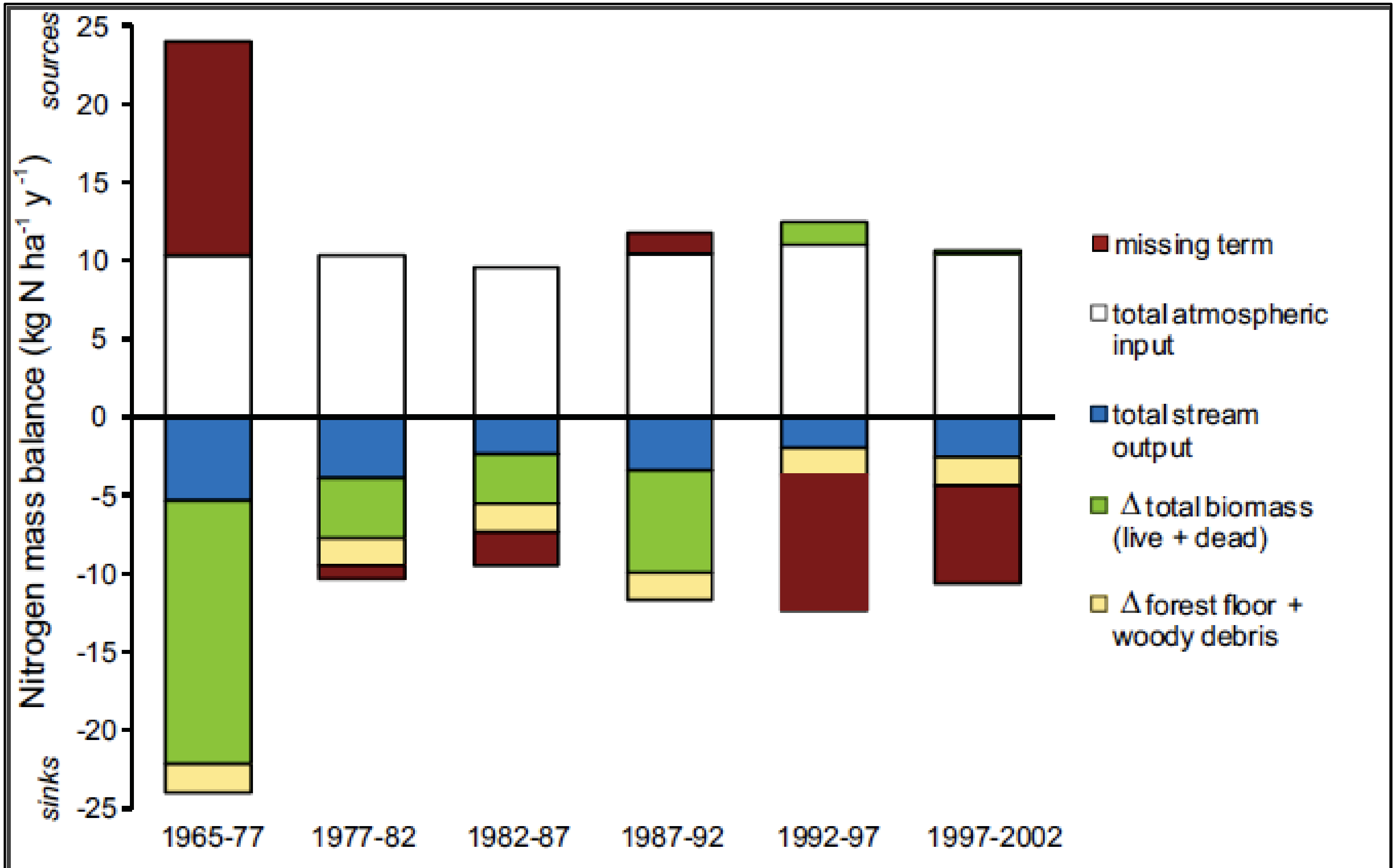


Bormann et al. 1977. Nitrogen budget for an aggrading northern hardwood forest ecosystem. Science 196:4293 (981-983).

• **No associated uncertainty in sources or sinks**

• **Also, note that mineral soil is not considered to be a source or a sink**





Hamburg et al. (*in review, PNAS.*)

- **Black bars represent missing sources or sinks of N in each time period shown.**
    - **Are these missing terms statistically significant? Or can they be explained by including error estimates in these calculations?**

Uncertainty in Change in Soils Over Time

Forest floors:

- At Hubbard Brook, sampled every 5 years since 1977 (60-80 samples per collection date)
- Change described with linear regression and associated uncertainty
  - 95% CI for slope on change in N in forest floors: -21 to +24 kg N ha^{-1} yr^{-1}
  - Mean accumulation rate of 2 kg N ha^{-1} yr^{-1} not significant (from Hamburg et al. *in review, PNAS).*

The uncertainty in the rate of change in N storage in the forest floor alone is greater than the missing source or sink in the ecosystem N budget.

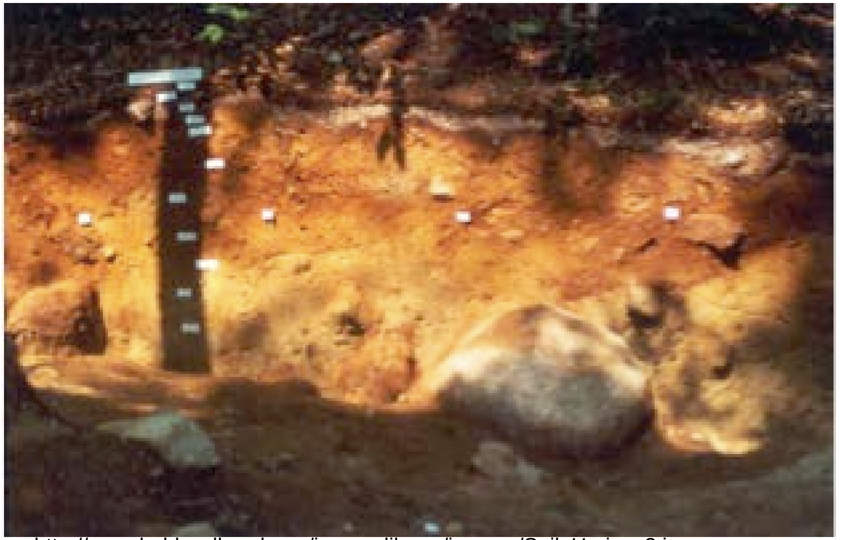
http://www.nrri.umn.edu/worms/forest/soil.html

Uncertainty in Change in Soils Over Time

Mineral soil measurements at W5 at Hubbard Brook, NH:

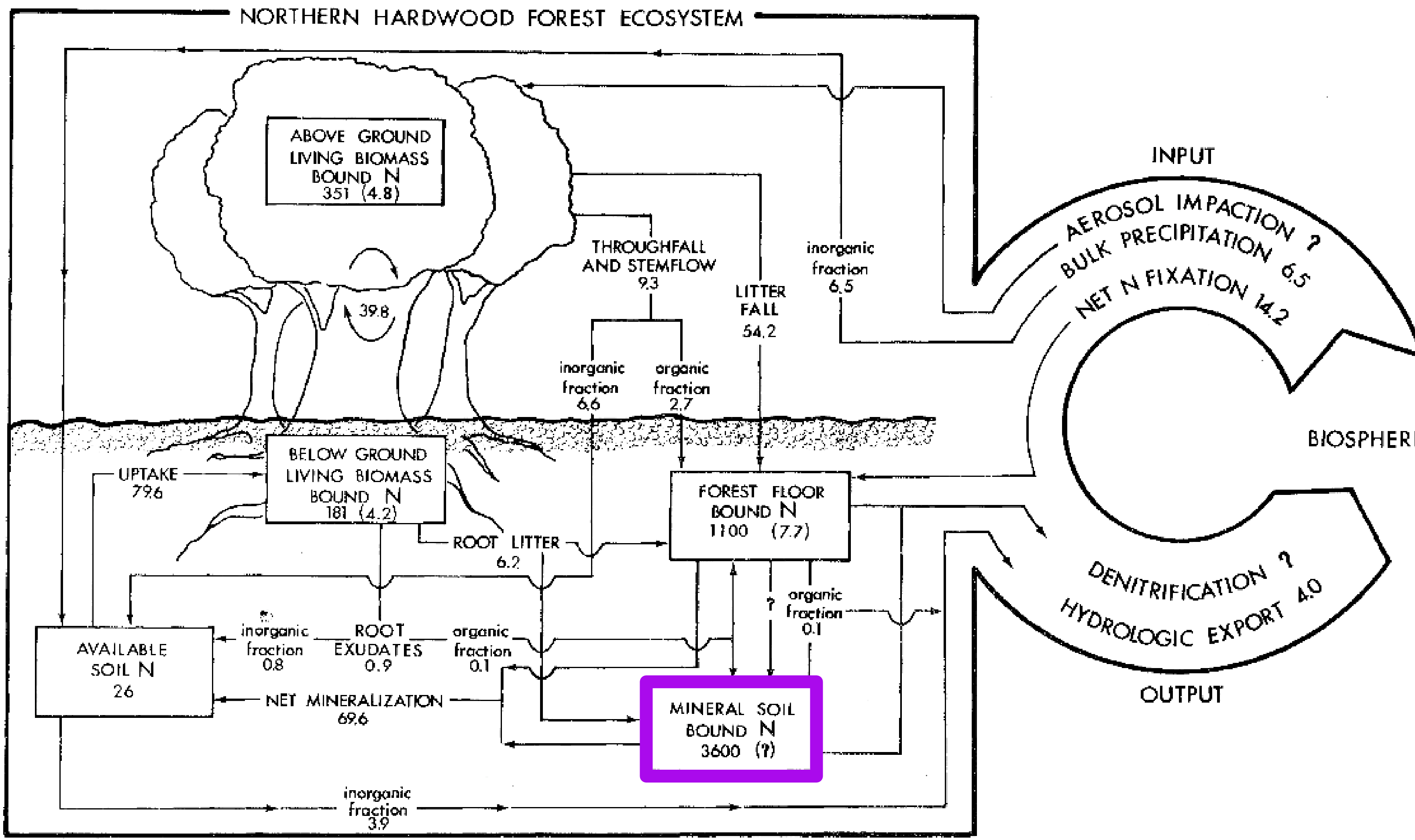
- In 1983, 59 soil pits were dug
  - N in mineral soil 5900 ± 360 kg ha^{-1}
  - Detectable change: 730 kg ha (at 95% confidence)
    - 14.2 kg ha^{-1} yr^{-1} measurable only after about 50 years

- Between 1983 (just prior to whole tree harvesting) and 1998: a decline in mineral soil N of 54 ± 53 kg N ha^{-1} y^{-1} (p=0.049; Hamburg et al. *in review, PNAS*)
- Repeated measurements over 25 years in three second-growth stands (35-90 yrs) and two nearby mowed fields on abandoned agricultural land 10 km south of W6 and on the same soil type declined 33 ± 41 kg N ha^{-1} y^{-1}



http://www.hubbardbrook.org/image_library/images/Soil_Horizon2.jpg

- The uncertainty in the rate of change in N storage in the forest floor >14.2 kg N ha^{-1} yr^{-1}
- Evidence that mineral soil is not a source or a sink, but with large uncertainties



Bormann et al. 1977. Nitrogen budget for an aggrading northern hardwood forest ecosystem. Science 196:4293 (981-983).

Quantitative soil pit sampling method

- Provide direct measurements of soil mass per area
- Allow samples representative of large volumes to be taken
- Relatively unbiased sampling of belowground carbon and nutrient stocks, including roots, coarse organic fragments, and rocks.

Quantitative soil pit in the Bartlett Experimental Forest (Bartlett, NH).

Potential biases

Some belowground pools are commonly excluded by soil sampling methods (coarse material and soil adhering to rocks), others may be counted twice (roots collected with soil):

- **Coarse material:** 4% (C) and 1% (N) in O horizon
- **Soil adhering to rocks:**
  - B horizon: 5% (C) and 5% (N)
- **Roots:**
  - O horizon: 11% (C) and 4% (N)
  - B horizon: 10% (C) and 3% (N)

Sampling procedures should be carefully designed to avoid treating these important pools inconsistently across sites or among sampling dates.

Alternative sampling methods

Soil change over time has high uncertainty if different points are sampled each time, because of high spatial variability. Non-destructive measurement techniques are attractive if they allow remeasurement of the same location.

Inelastic neutron scattering device (INS) being used to measure soil nutrient content at the Bartlett Experimental Forest (Bartlett, NH) in 2009 (Wielopolski et al. 2010).

Rotary Soil Cores

A diamond-tipped, rotary, motor-driven auger

- Very fast relative to quantitative soil pits, but can still extract volumetric samples
- Small footprint: could core very nearby in the future for repeated measurements
- Can core through rocks and incorporate them into sample for better estimates of soil rock volume relative to other coring methods

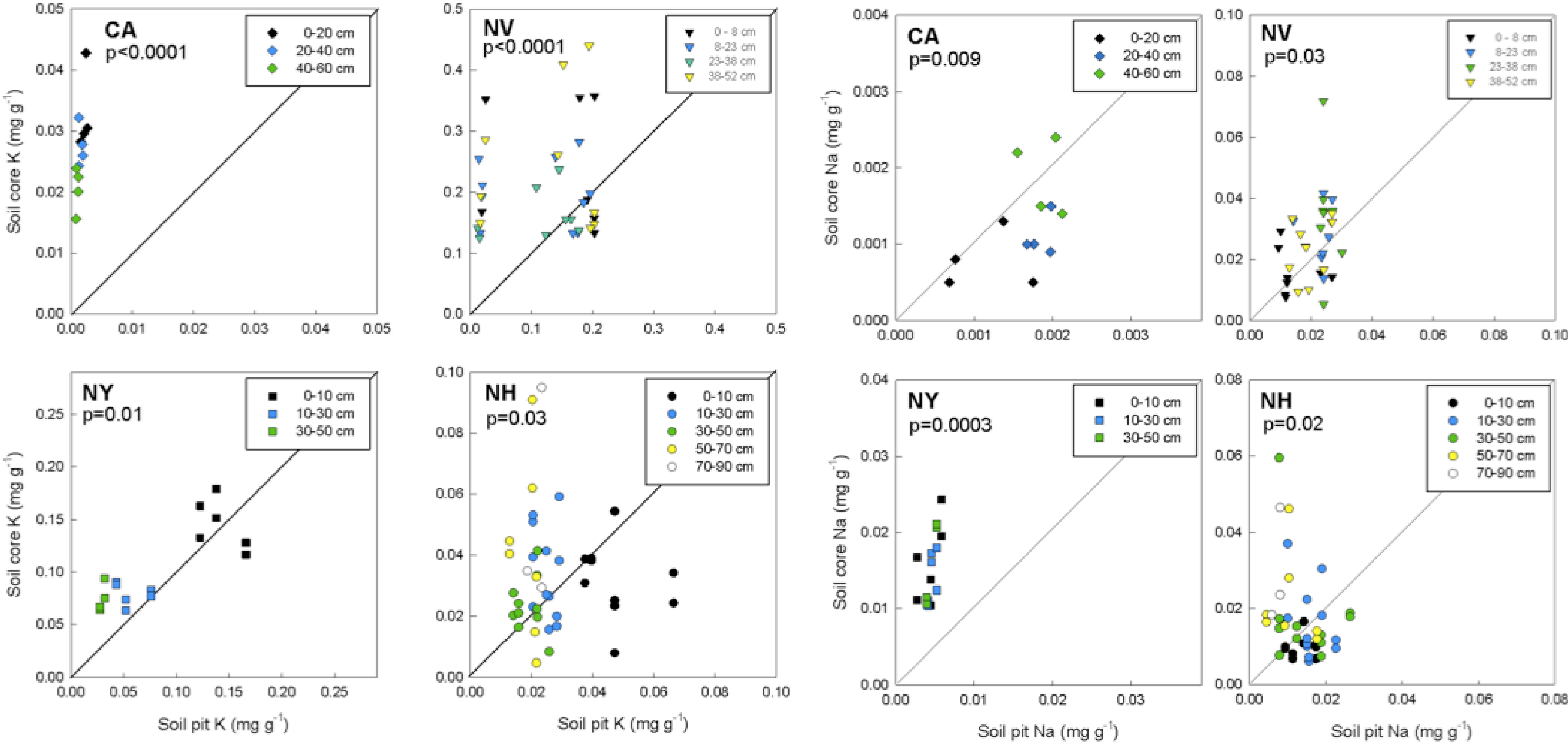
Potential biases

- Rotary action grinds through rock, leading to overestimates of cation concentrations relative to quantitative pits
- Corer cannot sample coarse fragments larger than the diameter of the bit
- In a shale soil, coring increased soil mass and decreased rock mass due to the grinding action of the corer

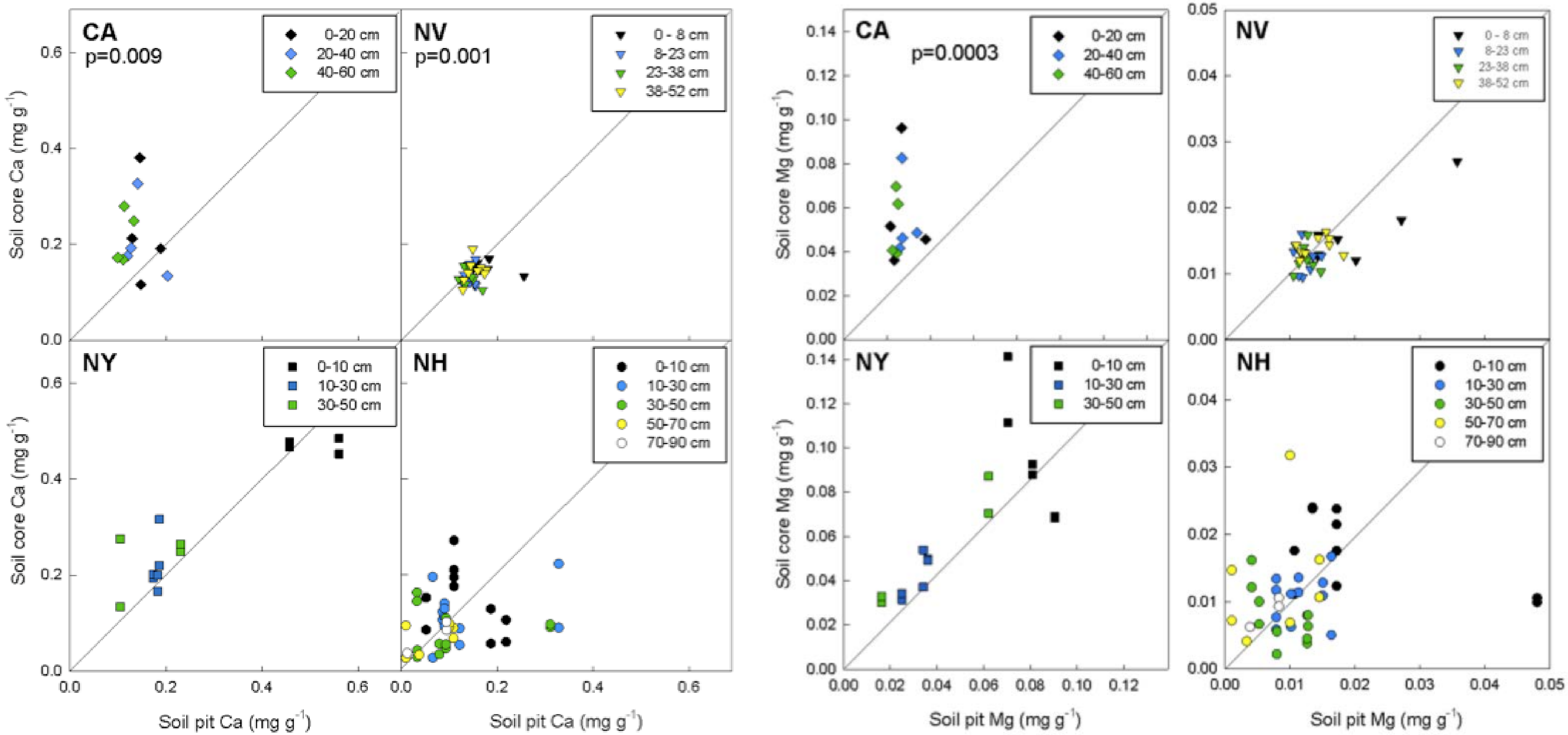
(Levine et al. *in revision, SSSAJ)*

Cores being excavated using a rotary coring device at the Bartlett Experimental Forest (Bartlett, NH).

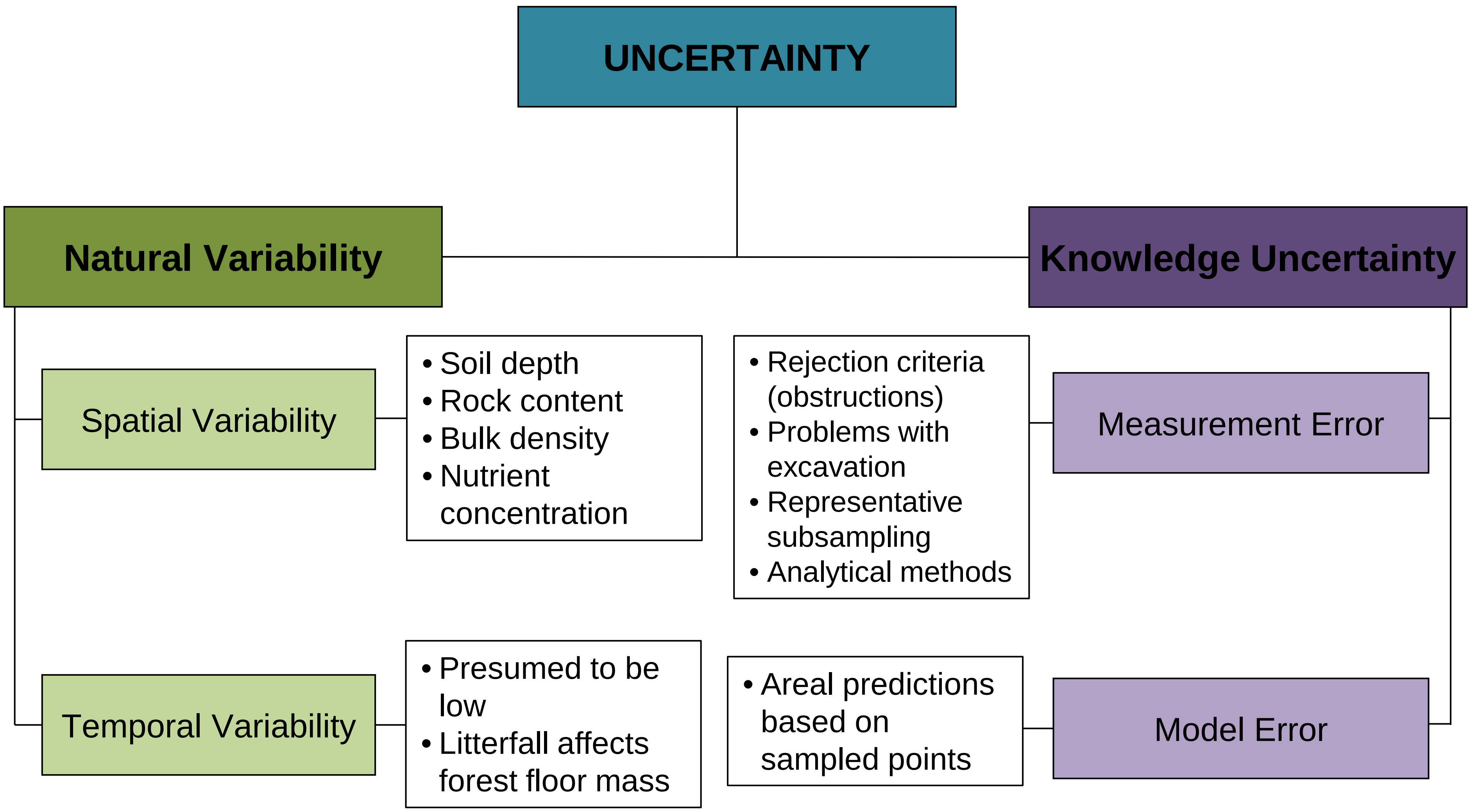
K (mg g^{-1}) / Na (mg g^{-1})



Ca (mg g^{-1}) / Mg (mg g^{-1})

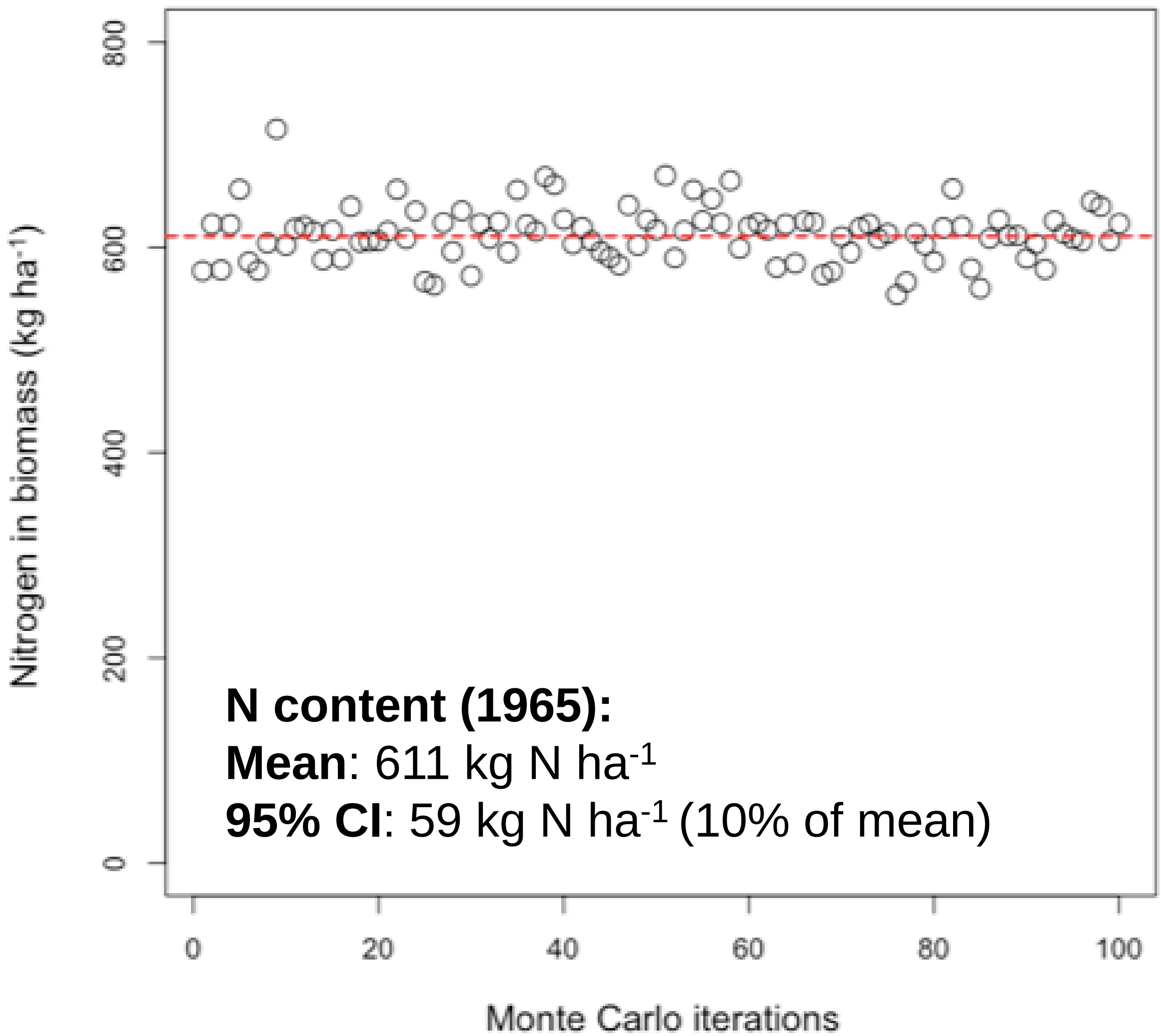


What contributes to uncertainty in soil measurements?



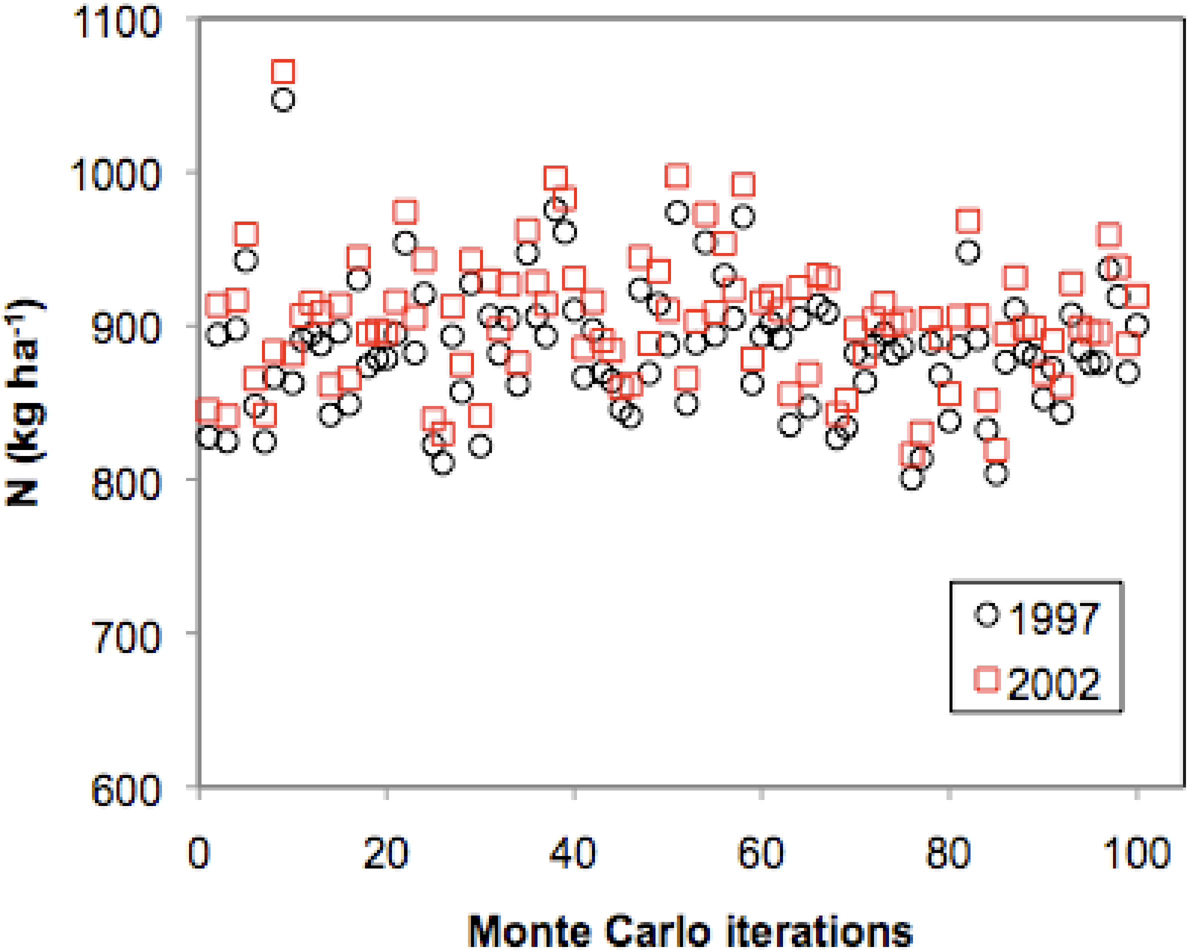
Additional Sources of Uncertainty in Ecosystem Budgets:

- **Nutrient content in forest biomass**



From Yanai et al. Ecosystem Budgets have No Error: A Progress Report on Quantifying Uncertainty in Forest Ecosystem Studies. *In Revision, Journal of Forestry.*

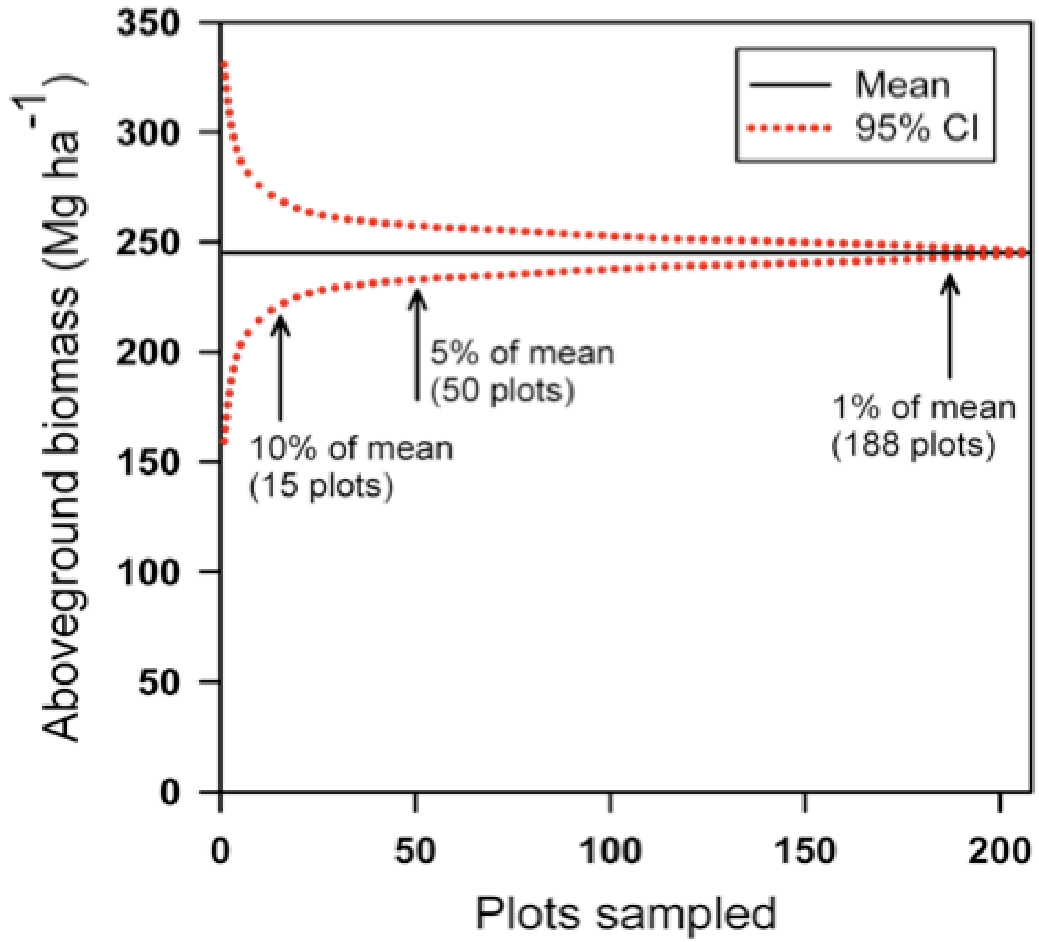
Uncertainty in the change over time of N contents of biomass at the Hubbard Brook Experimental Forest over a 5-year period.



95% CI in mean at one point in time: 108 kg N ha^{-1} yr^{-1} (12% of mean)

95% CI in change over time: 10 kg N ha^{-1} yr^{-1} (1% of mean)

Uncertainty in estimates of biomass N content depends on the number of plots sampled.



• Remember, increasing the number of plots cannot make the estimate more accurate than the uncertainty in the other measurements

• E.g. uncertainty in allometric estimates of N content was 10% of the mean

Sources of uncertainty in nutrient content of forest biomass

Measurement Uncertainty

DBH measurement: 0.02%

Sampling Uncertainty

Spatial and Temporal Variability

5 plots: 13%

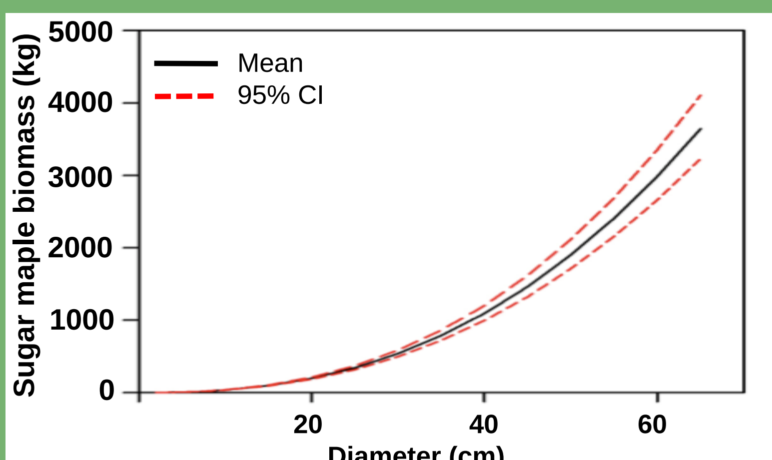
15 plots: 6%

30 plots: 3%

N concentration: 3%

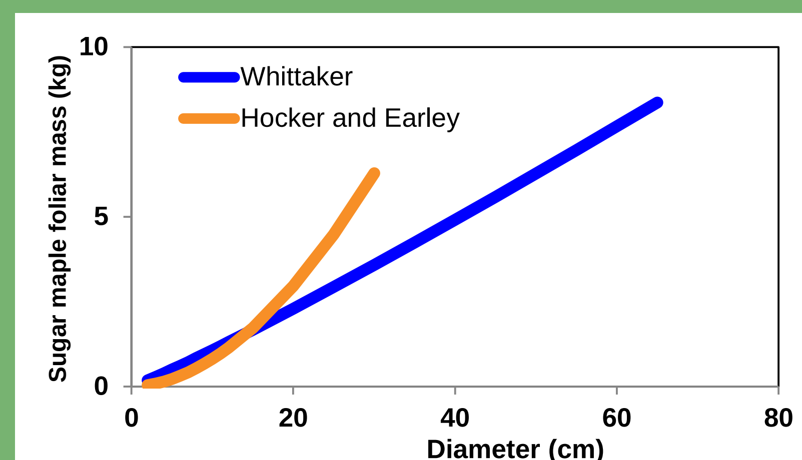
Model Uncertainty

Error within models



Allometric equations: 2-14%

Error between models



Model selection: 20-40% (Melson et al. 2011)

Sources of uncertainty in stream nutrient fluxes

Measurement Uncertainty

- Water chemistry
- Stage height
- Catchment area

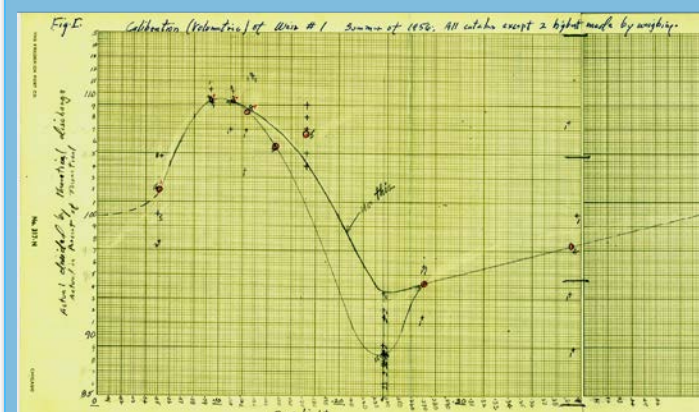
Sampling Uncertainty

Spatial and Temporal Variability

- Across streams
- Across years

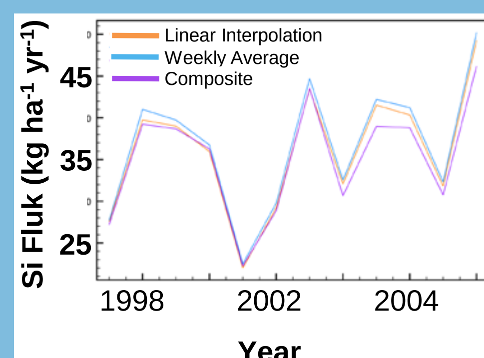
Model Uncertainty

Error within models



Height-discharge calibration

Error between models



Comparison of models

- Model selection
- Gap filling

Current QUEST projects:

QUEST/LTER: A cross-site comparison of hydrologic input-output budgets at LTER sites in the US. Two LTER Working Group Grants:

- 2011: Quantifying uncertainty in streamflow measurements
- 2012: Quantifying uncertainty in precipitation measurements

QUEST/JSPS (Japan Society for the Promotion of Science): Evaluating the uncertainty of estimates of hydrologic outputs of solutes in streamwater at the ecosystem scale. Sites include HB, Coweeta (NC), and Wakayama (Japan).

QUEST/NYSERDA: An assessment of long-term monitoring programs for S, N, and Hg in New York State, funded by NYSERDA. Focused on using uncertainty analyses to determine gaps and redundancies in NY monitoring programs.

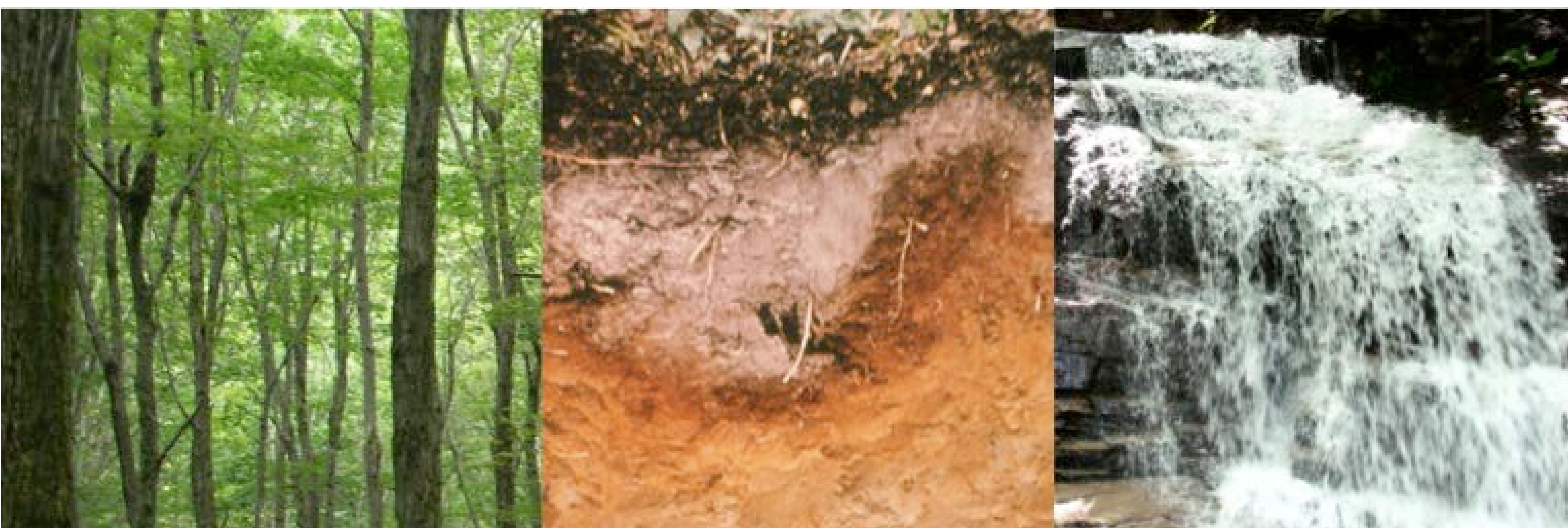
Plans for future projects, workshops, and meetings:

- Pending proposal to NSRC to quantify uncertainty in soils, streams, and vegetation at HB, BBWM, Sleepers River, and Huntington

- Plan to submit a proposal for an NSF Research Coordination Network in August 2012 to promote uncertainty analysis, fund working groups, and continue developing online resources

- A session at the 2012 NERC meeting

- A workshop at the 2012 LTER All Scientists Meeting



Online presence:

- Website: www.quantifyinguncertainty.org
- Current website features:
  - QUEST news items, project summaries, and paper abstracts
  - Library of papers on uncertainty analysis
  - Useful links
- Coming soon:
  - Tutorials on uncertainty (eg. regression uncertainty, Monte Carlo analyses, analytical vs. bootstrapping methods, etc.)
  - Wikis on uncertainty topics

QUEST participants:

QUEST Executive Committee: Ruth Yanai, Mark Green, John Campbell

LTER:

- **Hydrologic Budgets Working Group:** John Campbell, Ruth Yanai, Mark Green, Doug Burns, Jamie Shanley, Brent Aulenbach, Mary Beth Adams, Don Buso, Mark Harmon, Trevor Keenan, Shannon LaDeau, Gene Likens, Bill McDowell, Jordan Parman, Stephen Sebestyen, James Vose, Mark Williams
- **Streamflow Working Group:** Doug Burns, Jaime Shanley, Brent Aulenbach, Mark Green, John Campbell, Ruth Yanai
- **Precipitation Working Group:** Ruth Yanai, John Campbell, Kathie Weathers, Craig See, Shannon LaDeau, Mark Green, Chris Daly

JSPS: Ruth Yanai, Naoko Tokuchi, Eiji Matsuzaki, Mark Green, John Campbell, Amey Bailey, Don Buso, Gene Likens, James Vose, Stephanie Laseter, Jennifer Knoepp

NYSERDA: Ruth Yanai, Greg Lampman, Doug Burns, Kevin Civerolo, Alan Domaracki, Gary Lovett, Jason Lynch

NSRC: Ruth Yanai, Mark Green, John Campbell, Ivan Fernandez, Myron Mitchell, Jaime Shanley

QUESTIONS?

- Ruth Yanai: rdyanai@syr.edu
- John Campbell: jlcampbell@fs.fed.us
- Mark Green: mbgreen@plymouth.edu
- Carrie Rose Levine: crlevi01@syr.edu
- Craig See: crsee@syr.edu

General QUEST correspondance:
quantifyinguncertainty@gmail.com

www.quantifyinguncertainty.org