Uncertainty in accounting for C and nutrient accumulation or loss following forest harvesting

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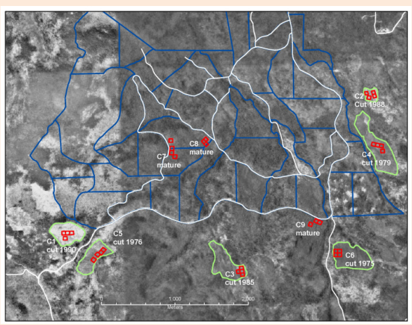
Introduction and Objectives

Forest regrowth following harvesting is an important terrestrial carbon sink. However, it is difficult to quantify forest ecosystem budgets of C and other elements of interest with confidence, and the uncertainties associated such budgets are rarely reported. Tree biomass and forest soils present different challenges: Tree biomass is estimated non-destructively using allometric equations, often from other sites, and these equations are difficult to validate; soils are destructively sampled, which results in little measurement error at a point, but large sampling error in heterogeneous soil environments.

In this study, we report nutrient contents of soil and biomass pools in a northern hardwood forest from replicate plots within replicate stands in 3 age classes (14-19 yr, 26-29 yr, and > 100 yr) at the Bartlett Experimental Forest, USA. We compared variation within stands (i.e. variation among the replicate plots or soil pits in a stand) to variation between stands (i.e. variation among the replicate stands in each age class) and also compared these sources of spatial variation to the sources of uncertainty derived from allometric equations and measurement error (field measurements and laboratory analyses). We hoped to find that measurement errors would be small compared to natural variation, using common sampling methods, and that our replicate stands would allow for interpretation of nutrient budget changes during forest regrowth following harvest.

Sites

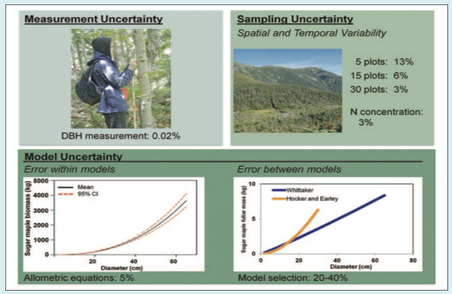


We studied nine sites of three stand ages in the Bartlett Experimental Forest, NH (44° 02-04′ N, 71° 16-19′ W). Two of the sites in each age class (C1, C2, C4, C6, C8, C9) were intensively studied. Soil and root information comes from these sites, with one pit in each of three plots. Stand inventory data were used from all nine stands, plus additional mid-aged and mature stands at Jeffers Brook and Hubbard Brook Experimental Forest (not shown).

Data Collection

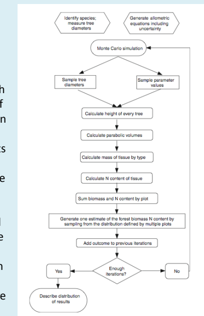
Soils: We excavated quantitative soil pits in 3 plots in each of 6 stands. Soils were collected by depth increment in the mineral soil down to 25 or 50 cm into the C horizon. We used a sequential extraction to define pools in soils (Nezat et al. 2007). Exchangeable Ca was extracted with 1N NH_4Cl. The residue was extracted with cold 1N HNO_3 to dissolve apatite. Silicates were analyzed in a total digest.
Roots: Roots were collected from the same quantitative soil pits (Park et al. 2007). Nutrient concentrations of roots were analyzed in 2007 (Yanai et al., in review).
Tree Inventory: We measured all trees <10 cm DBH within each of four 30 x 30 m plots in all stands. Stems from 2 - 10 cm DBH were measured on subplots.
Tree Allometry and Tissue Chemistry: In the young stands, 12 trees of six species were felled and used to develop biomass equations (Fatemi et al. 2011). The stem wood, bark, branch, and leaves were subsampled for nutrient analysis. The species studied were *Acer rubrum, A. saccharum, Betula alleghaniensis, B. papyrifera, Fagus grandifolia, and Prunus pensylvanicum*. In the mature stands, bark was collected with a chisel, wood by coring, and leaves with a shotgun.
Aboveground Biomass and Nutrient Contents: Aboveground biomass was estimated using allometric equations describing the mass of stem wood, bark, branch, and foliage of trees as a function of DBH. For small trees (<10 cm DBH), we used equations developed at Bartlett (Fatemi et al. 2011). For larger trees, we used equations developed at Hubbard Brook (Whittaker et al. 1974).

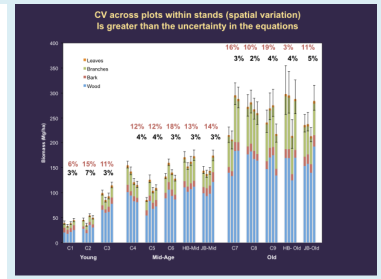
Forest Biomass



Monte Carlo Simulation

The uncertainty in biomass and nutrient contents was evaluated with Monte Carlo sampling (Yanai et al. 2010). Nutrient concentrations of tissues by species were randomly sampled from a normal distribution defined by the mean and standard error of the reported concentrations. The uncertainty in the allometric equations accounts for the number of trees used to derive the regression equations and the value of each observation (diameter of parabolic volume) relative to the sum of squared deviations of the observations used to derive the regression equation (Yanai et al. 2010, Equation 5; Snedecor and Cochran 1989, p. 164). Two hundred iterations of total aboveground nutrient contents for each plot were executed simultaneously for the nine stands. We report the 95% confidence interval (CI) using the fifth-highest and fifth-lowest estimate from 200 iterations. The mean of the iterations differs from the nutrient content without error, as reflected in asymmetrical 95% CIs because the biomass equations are non-linear.





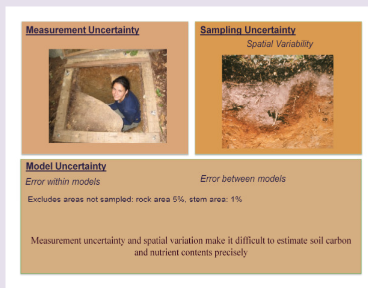
Breaking News!

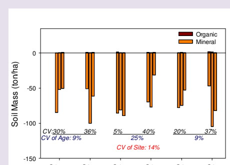
After consultation with QUEST colleagues, we realized that the uncertainty term we had used thus far in our calculations for allometric equations was incomplete – it accounted for the error associated with the regressions, but not for the error associated with individual tree predictions. We are beginning to re-analyze our biomass data with the new error term (Yanai et al. 2010, Equation 6) included. A preliminary analysis of the effect of including individual tree prediction uncertainty indicates that allometric equations are responsible for a larger portion of the total uncertainty than previously thought.

Preliminary re-analysis using data from one plot – table shows the CV of biomass for each component as well as for the summed total.

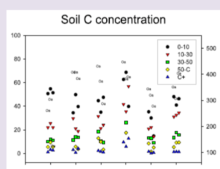
	Original calculation	Including new error term
Stem Bark	7.95%	11.35%
Branches	16.92%	20.21%
Leaves	10.47%	12.49%
Twigs	8.58%	12.49%
Roots	6.96%	9.78%
Light Wood	3.82%	8.44%
Dark Wood	5.16%	11.70%
Sum of Tissue Biomass	5.74%	9.42%

Soils



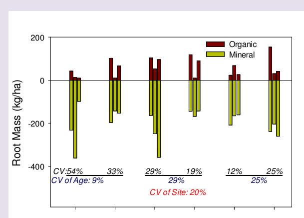


Variation in soil mass within site is greater than across sites.



Variation among pits in soil chemistry was similar to the variation in soil mass. The mean CVs across all horizons and pits were 38-40% for total C (shown here), N, and P concentrations. The CVs for Ca and P in apatite (1N HNO_3 leach) were 59% and 48%, respectively. Exchangeable Mg had an average CV of 42%, and for exchangeable K the average CV was 26%.

Concentrations of nutrients in roots varied least for N (18% average CV among pits within stands). Variation in the base cations Ca, Mg, and K averaged 26-35%. Variation in P was highest (55%). Plot 3 in site C8 has remarkably high P in roots, soils, and aboveground tissues.



Summary and Recommendations

Uncertainty in allometric equations ranged from 2-7% for aboveground biomass, depending on the stand. Variability in measured nutrient concentrations of tree tissues contributed 1-9% uncertainty (N, P, Ca, Mg, K). The spatial variation in biomass among plots (6-19%) was always larger than the measurement uncertainties. For soils, variation in soil mass among pits within stands (28 %) and among stands (14 %) was similar to the variation in nutrient concentrations (average of 39%, depending on the element and extraction type). Research questions that rely on aboveground measurements will have better power to detect small changes than those that rely on soil pools.

Uncertainty analysis can help direct research effort to areas most in need of improvement. In systems such as the one we studied, more intensive sampling would be the best approach to reducing uncertainty, as natural spatial variation was higher than model or measurement uncertainties.

Acknowledgements

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