Findings:
This year we published an analysis of N and P limitation of northern hardwood forest recovering from disturbance (Rastetter el al 2013; Fig. 1&2). This publication includes an electronic appendix with the full model description and parameterization. The model software is available on line at http://ecosystems.mbl.edu/Research/Models/mel/welcome.html. The major findings of the project are:

1) Unlike resources like C and water, N and P are tightly cycled within most terrestrial ecosystems with typically over 90% of the nutrient requirements for vegetation being supplied from mineralized soil organic matter. As the ecosystems mature, this tight cycling requires that the rates of nutrient uptake by plants, nutrient return to soils in litter, and net nutrient mineralization all have to me nearly equal. Because of this equality of rates through the cycles, the cycling rates of N and P have to be closely synchronized with the N:P ratio of all steps in the cycle being nearly equal. Disturbance disrupts this synchronization. Our analysis is a re-examination of recovery as a resynchronization of these cycles.
2) The low N:P in harvest residue in our simulations results in an early, post-harvest loss of P relative to N. Because of the slow P supply rate to the ecosystem in weathering and deposition, this P loss limits the long term recovery of biomass. This long-term P limitation results in N loss late in succession, which allows the N and P cycles to resynchronize.
3) Through succession the ecosystem undergoes alternating periods of N limitation, then P limitation, and eventually co-limitation as the two cycles resynchronize.
4) Our simulations indicate that the overall rate and extent of recovery is limited by P unless a mechanism exists either to prevent the P loss early in succession (e.g., P sequestration not stoichiometrically constrained by N) or to increase the P supply to the ecosystem later in succession (e.g., biologically enhanced weathering).

Fahey, T.J., T.G. Siccama, C.T. Driscoll, G.E. Likens, J. Campbell, C.E. Johnson, J.J. Battles, J.D. Aber, J.J. Cole, M.C. Fisk, P.M. Groffman, S.P. Hamburg, R.T. Holmes, P.A. Schwarz, and R.D. Yanai. 2005. The biogeochemistry of carbon at Hubbard Brook. Biogeochemistry 75: 109–176.

Rastetter, EB, R.D. Yanai, R.Q. Thomas, M.A. Vadeboncoeur, T.J. Fahey, M.C. Fisk, B.L. Kwiatkowski, and S.P. Hamburg. 2013. Recovery from Disturbance Requires Resynchronization of Ecosystem Nutrient Cycles. Ecological Applications 23:621-642.

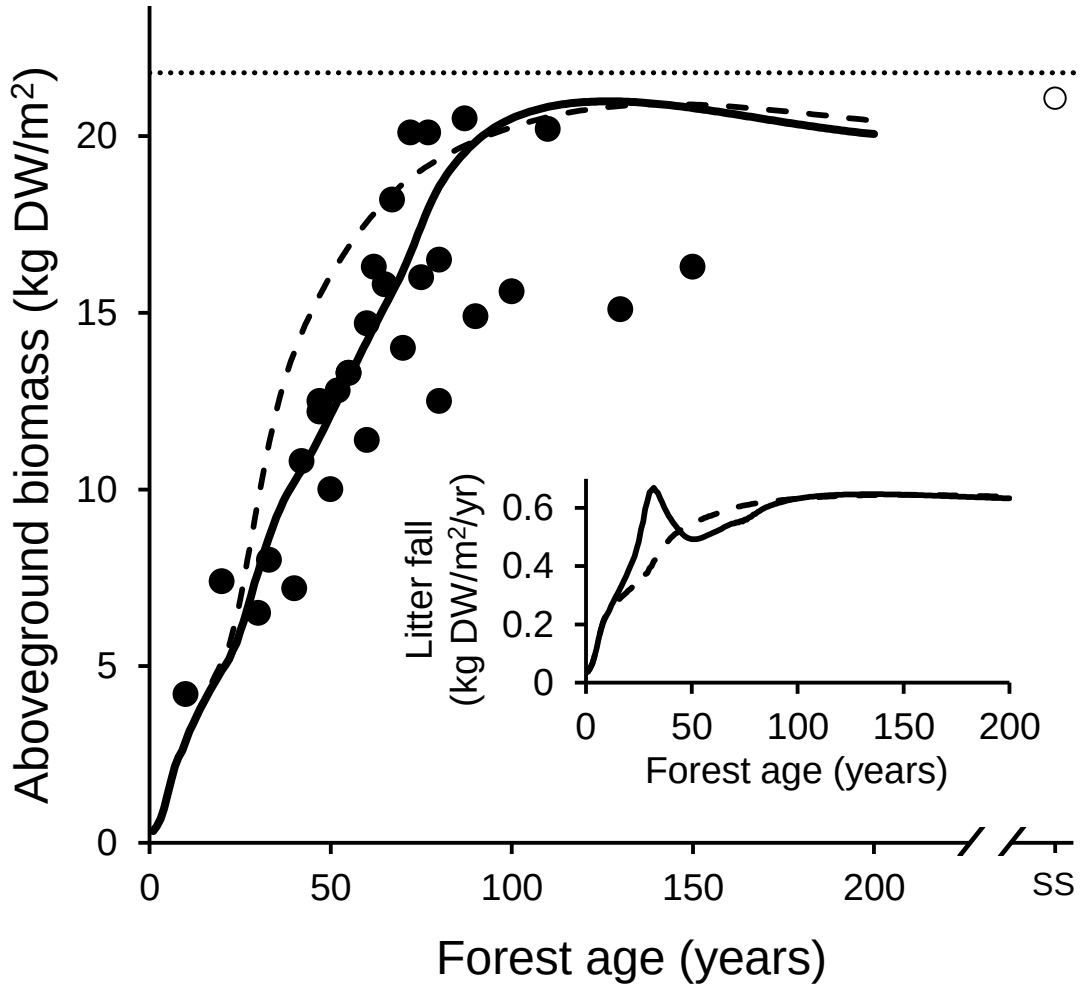

Figure 1: Simulated and observed aboveground biomass in New England forests. Filled circles are data assembled by S.P. Hamburg and his students for the White Mountains of New Hampshire representing repeated observations of a series of sites with differing disturbance histories (unpublished). Horizontal dotted line is the regional average for mature forests. Open circle is the mature-stand data from Fahey et al. (2005) to which the MEL model is calibrated. Solid and dashed black lines are our simulations of recovery following a bole-only harvest using the MEL model. In the simulation for the dashed line, we assumed the relative turnover of woody biomass is constant at the rate calibrated for the steady state. In the simulation for the solid line, we increased the turnover of woody biomass during canopy closure to account for species replacement and stand self-thinning. The inset shows the total litter fall rate for both simulations.

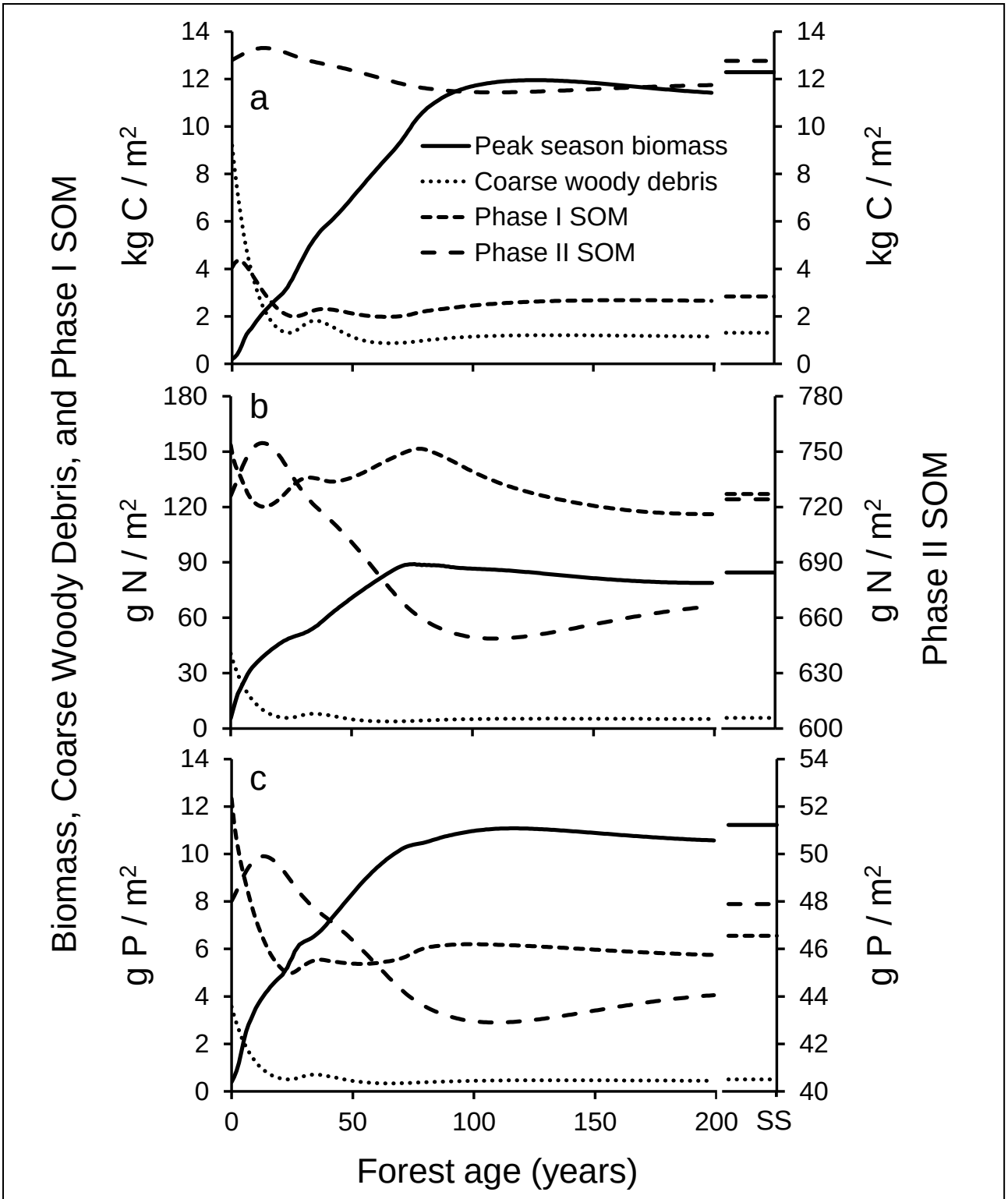

Figure 2: C, N, and P stocks in the major ecosystem components following a bole-only harvest. The steady state (SS) values to which the MEL model is calibrated are graphed on the far right of each panel.

Broader impacts:
R Quinn Thomas, who was a graduate student with Christine Goodale and worked extensively on this project, now has a job at Virginia Tech. Partly because of our interactions on this project, I am a co-PI on a pre-proposal submitted by Quinn to NASA (13-CARBON13-0218: How does accounting for nitrogen modify forecasts of terrestrial carbon fluxes in Arctic ecosystems?). I have presented the results of this project to the Department of Earth and Environmental Sciences, Lehigh University. I am also using the model in an examination of annual to millennial scaling in a series of workshops arranged by Kendra McLauchlan, another manuscript is being developed for this activity. The MEL model continues to be a component of Chelsea Nagy's PhD work at Brown University.