Combining Data from the Soil and Down Woody Material Indicators to Estimate Carbon Storage at the Regional Scale

Katherine P. O'Neill[1], Chris Woodall[1], Michael C. Amacher [2], Geoffrey Holden[1]

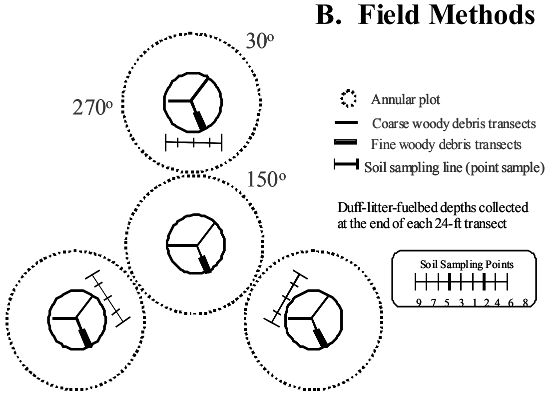
[1] USDA-FS North Central Research Station, [2] USDA-FS Rocky Mountain Research Station

A. Abstract

Down woody materials (DWM), the forest floor, and the upper soil horizons have all been identified as critical reservoirs for organic matter and plant nutrients over timescales ranging from decades to centuries and beyond. However, data on DWM is non-existent for many forested systems and current estimates of soil carbon and nutrient storage are largely based on static soil mapping products that do not reflect changes resulting from differences in land-use or management practices. In addition, soil maps are often biased towards agricultural systems and may not fully account for carbon and nutrients stored in the forest floor and upper mineral horizons.

Data from detection monitoring plots (DM) provide the only nationally consistent source of information for monitoring changes in carbon storage in soils, the forest floor, and downed wood. This paper outlines an initial approach for combining estimates from the soil and DWM indicator programs to produce an integrated, dynamic, assessment of forest floor and soil carbon and nitrogen reservoirs at the regional scale. Quantification of the magnitude of these reservoirs and the rates at which carbon accumulates and decomposes is critical for constraining carbon budgets in forested systems and for meeting reporting requirements under national and international agreements such as the Montreal Process.

B. Field Methods



Coarse woody debris (larger than 3 inches in diameter) is sampled along three 24-ft transects per subplot. Crews record the length, diameter of the large and small ends, and the decay class of each piece. Fine woody debris are divided into three size classes (0.0-0.25, 0.25 to 1.0, and 1.0 to 3.0 inches) and sampled along sub-sections of the transect lines. For FWD, only the number of pieces crossing the transect line is tallied.

Photo by B. Conkling

Samples of the forest floor and litter (> ¼" diameter) are collected volumetrically within a 30.5 cm diameter sampling frame.

Mineral soil samples are collected using an impact-driven coring device to collect samples of known volume at depths of 0-10 and 10-20 cm

C. Estimation of Carbon Storage in Down Woody Material

Σ CWD Transect Lengths	Σ FWD Transect Lengths	Slash Pile Dimensions
Transect Diameter	Counts: 1-hr, 10-hr, 100-hr	Density
Decay Class	Slope	
Specific Gravity		

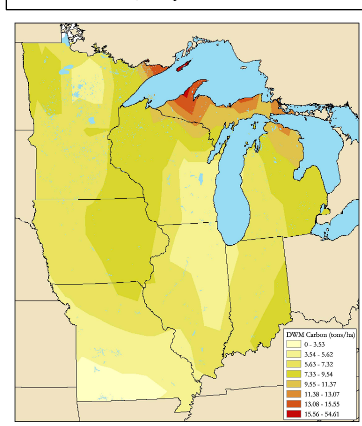
→ **Tons Biomass/Hectare**

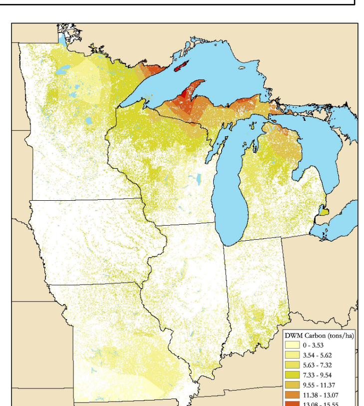
Weight C area^{-1} = biomass area^{-1} * 0.506

Softwoods: 0.521
Hardwoods: 0.491

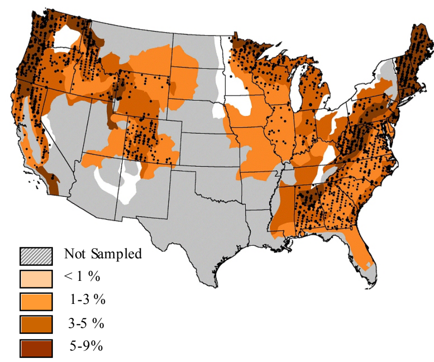
Species data not collected on FWD. Used mean value of these two factors for estimation.

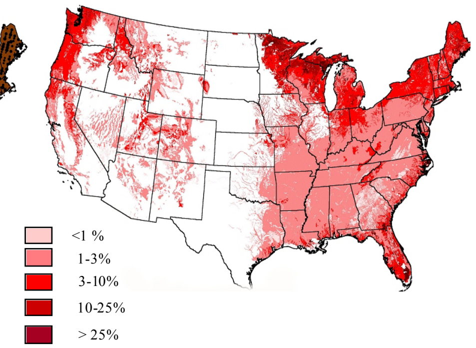
- Plot level summations of CWD, 1000+-hr fuels, and 10-hr fuels; 1-hr fuels, litter, and duff not included. 2001 Data; 227 plots
- Expansion of plot level values using ordinary kriging with an exponential model
- Kriged map masked using Phase-1 forest/nonforest map (NLCD)





D. Estimation of Soil Carbon Storage: Initial Results from 1999-2001





Over long time scales, the amount of carbon stored in the soil represents the long-term balance between carbon inputs (from litter and roots) and carbon losses (by decomposition, fire, erosion, etc.). In general, greater carbon concentrations in both the forest floor and upper mineral soil were found in regions of high precipitation and low temperature, such as the northern and northeastern U.S. General trends compare favorably with estimates derived from STATSGO. Soil organic matter can also be used for reporting on changes in carbon storage in forest soils under Criteria 5 of the Montreal Process Criteria and Indicators.

Soil Organic Carbon Storage

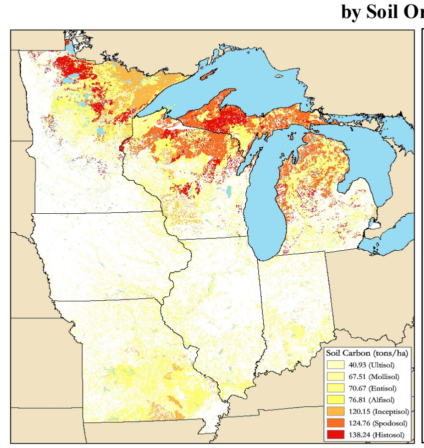
In order to estimate soil carbon storage across the landscape from plot level DM data, we converted %C values to tons C ha^{-1} using bulk density measurements made from the same sample.

Data from each soil layer (forest floor, 0-10 cm, and 10-20 cm) was then aggregated by soil order using mapping units and taxonomic data from the NRCS STATSGO soil database. Mean values for each soil order was then summed to estimate total carbon storage in the forest floor and upper 20 cm of mineral soil.

Equations used to Determine Soil C Storage

Mineral soil (gC cm^{-2})	Bulk density (g cm^{-3}) x thickness (cm) x %C
Mean Forest Floor (gC cm^{-2})	Σ O.D. sample weight /Area (cm^{-2}) x %C / # of samples
Map Unit Layer C (t ha^{-1})	Mean Layer C
Total Map Unit C	Σ Mean Layer C; summation across all layers

Organic Soil Carbon Storage in the Forest Floor and Upper 20 cm of Mineral/Organic Soil Aggregated by Soil Order (1999-2001)



- Forest Floor, 0-10 cm, and 10-20 cm
- 1999-2001 data; 1198 samples from 467 plots
- Data for each soil layer aggregated separately by soil orders (NRCS STATSGO)
- Mean estimate for each layer summed across mapping units
- Data layer masked using FIA forest/non-forest map generated from NLCD imagery

Photos courtesy of the NRCS

For those plots for which crews were unable to obtain a volumetric sample, bulk density was estimated from the STATSGO soils database. First, a depth-weighted, mean bulk density was calculated for each map component (0-20 cm). Then, a spatially-weighted average was calculated for each map unit.

For each layer:	Mean Bulk Density = $(BD_{high} - BD_{low})/2$
Mean B.D. by Component (0-20 cm):	Mean BD_{layer} x Layer thickness
Mean Map Unit BD:	Mean Comp. BD x $Area_{comp.}$ / $Area_{total}$

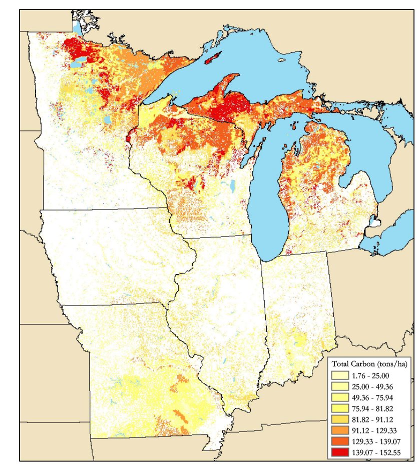
Summary Statistics for Carbon Storage by Soil Order

	Forest Floor	Mineral 0-10 cm	Mineral 10-20 cm
	-------------	tons C/ ha	-------------
Alfisol	4.10 ± 0.33 (132)	46.23 ± 5.61 (131)	26.48 ± 4.6 (126)
Entisol	6.54 ± 0.81 (47)	45.59 ± 12.95 (44)	18.54 ± 2.13 (43)
Inceptisol	5.90 ± 0.47 (67)	85.57 ± 19.61 (47)	28.68 ± 6.30 (38)
Histosol	7.26 ± 1.08 (33)	74.64 ± 23.06 (31)	56.34 ± 23.12 (28)
Mollisol	4.37 ± 0.64 (47)	39.44 ± 5.81 (47)	23.70 ± 3.61 (44)
Spodosol	6.89 ± 0.77 (67)	78.23 ± 18.78 (61)	39.64 ± 13.53 (57)
Ultisol	3.85 ± 1.39 (5)	22.14 ± 2.41 (5)	14.94 ± 2.00 (5)
Grand Mean	5.86 ± 0.47 (468)	55.04 ± 4.46 (425)	29.12 ± 3.01 (399)

E. Combined Estimates for Soil and DWM

Comparison of Field Methods and Estimation Procedures for the Soils and DWM Indicators

	Soil	DWM
Carbon Concentration	Weight %C is directly determined for each sample by lab analysis (dry combustion method)	Predicted using set conversion factors from the literature. In this study, assumed to be equal to 0.506 for all DWM pieces.
Density	Determined directly from field samples. Oven dry weight of soil sample (g) is divided by the volume that the sample was collected from (cm^{-3}) to provide bulk density (g cm^{-3}). In cases where sample was not collected volumetrically, determined from spatially weighted mean values from digital soil survey data (STATSGO).	For CWD (> 3.0 in diameter), estimated from the length, diameter, and decay class estimated recorded in the field. For FWD, density is determined from models.
Estimation Level	Methods designed for a single estimate (without variance) at the plot level. Population estimate must be determined by averaging data within a larger unit such as soil order.	Multiple measurements collected per plot. Methods designed for determining plot level mean values.
Expansion/Interpolation	Scaling to the regional level requires use of ancillary data set such as ecoregion section or soil taxonomic unit (e.g., soil orders)	Scaling done by interpolation (e.g., kriging) of plot level mean values. Plot level means can also be aggregrated using ancillary data such as ecoregion section.



+

- Maps of C storage in soil and DWM converted to raster format
- Soil and DWM carbon estimates summed across 250-m cells
- Rescale legend intervals
- Masked using Phase-1 forest/nonforest map (NLCD)

F. Model Limitations and Directions for Future Research

Limitations

- Mapping uncertainties with soil units
- Statistical uncertainties with STATSGO/SSURGO
- Collection of a single soil sample per plot does not allow for estimation of spatial variability within the plot
- Destructive sampling for soils limits ability to evaluate change over time
- Carbon concentration not directly measured for DWM
- Lack of ancillary datasets for interpolating DWM estimates

Photos courtesy of the NRCS

Future Research

- How do our estimates compare with those obtained by more detailed sampling?
- What are the uncertainties associated with soil and DWM interpolation/expansion techniques and how do we incorporate these into mapped products?
- How do C concentrations in DWM vary across species groups and decay classes?
- How do we address change over time for soil indicator (i.e. destructive sampling and only 1 mineral sample per plot)?