CHAPTER 19

Soil Conditions

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Soil scientists have evaluated linkages between forests and soils for many years (e.g., Alway and McMiller 1933). The traditional soil surveys of landscapes in the United States are purposive, selecting for analysis sites that are deemed representative "of an extensive mappable area" (USDA Soil Survey Division Staff 1993). By contrast, the Soil Quality Indicator by the Forest Service, U.S. Department of Agriculture, is a statistically-based survey of forest soils in the United States. The design and sampling strategy of the Soil Quality Indicator is powerful, and it lends itself to addressing questions at broader spatial scales than most other research programs. An additional benefit of the program is that field samples are archived for later and complementary analyses.

The Soil Quality Indicator collects information on several different aspects of the soil resource: compaction, erosion, physical properties, and chemical properties (O'Neill and others 2005). To investigate soils, five Evaluation Monitoring (EM) projects have been funded under the national Forest Health Monitoring (FHM) Program of the Forest Service. One project has evaluated soil compaction, three projects have examined variation in soil chemistry (including an assessment of soils in the archive), and one was a cross-indicator analysis with down woody materials (DWM) to quantify carbon stocks. There have been no funded investigations of erosion or soil physical properties.

Projects on Soil Compaction

NC-EM-03-02: Soil Compaction Effects on Site Productivity and Organic Matter Storage in Aspen Stands of the Great Lakes States—Visual evidences of compaction are reported on phase 3 plots, but links between soil physical properties, compactability, and observed levels of surface compaction do not exist. This project addressed the need to interpret the ecological significance of observed compaction. Is sensitivity to compaction correlated with levels of compaction observed on phase 3 plots? Specific objectives initially included:

1. Identifying functional relationships between soil physical properties (e.g., texture, aggregate stability, soil organic matter, penetrability, shear strength) and levels of compaction reported on detection monitoring plots using digital soil survey data.

2. Developing spatial models of potential sensitivity to soil compaction based on soil physical characteristics, slope, and local hydrology by using digital models to stratify the region into soils that are at high and low risk for compaction.

3. Testing models by establishing experimental field plots on recently harvested and control plots within soils at high and low risk for compaction.

A review of the project's output (posters, interim reports, and manuscripts) indicates that objectives 1 and 3 were addressed.

Field crews installed FIA-like field plots on five national forests throughout the Lake States (Steber and others 2005, 2007;[2]). Plots in aspen (*Populus* spp.) clearcuts were paired with plots in adjacent unharvested landscapes. Field sampling occurred both on soils that are sensitive to compaction (loams, silts, and clays) and on those that are not (sands and sandy loams). The crews gathered visual evidence of compaction (USDA Forest Service 2007) and quantitative measurements of surface soil compression strength, bulk density, resistance to penetration, and saturated hydraulic conductivity [Steber and others 2005, 2007; (see footnote 2),]. Significantly, field procedures included both standard phase 3 protocols and additional methodologies for comparison.

The comparison of visual with quantitative measurements is particularly informative. Quantitative methods detected differences in compaction not discerned with visual observations collected with current phase 3 protocols (table 19.1). Steber and others (2007) also confirmed earlier observations by Amacher and O'Neill (2004) that an inexpensive pocket penetrometer measuring surface soil strength can be very effective at detecting compaction.

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[2] Kolka, R.K.; Steber, A.; Brooks, K.N.; Perry, C.H. In review. Harvest season, soil texture and landscape position influence soil compaction in northern Minnesota aspen harvests. Canadian Journal of Soil Science.

Table 19.1—A comparison of plot condition group means based on soil risk level. [1, 2]

	Aspen clearcuts		Undisturbed stands	
	High	Low	High	Low
Visual assessment of compaction (percent)	63a	66a		
Surface soil strength (lbs/in^2)	33.6a	23.9b	5.3c	4.4c
Bulk density 0–4 inches (lb/ft^3)	103.0a	90.5b	78.0c	71.8c
Bulk density 4–8 inches (lb/ft^3)	103.0a	95.5a	88.0b	86.8b
Saturated hydraulic conductivity (ft/day)	9.45a	62.66b	28.61a,b	167.98c

[1] Adapted from Steber and others (2007).
[2] In each row values followed by different letters are significantly different at $\alpha = 0.05$.

The occurrence of compaction in the Minnesota's aspen landscape is not limited to wetter toeslope positions. In fact, "both upper (summit) and lower (toeslope) topographic positions were susceptible to compaction in fine-textured soils when comparing summer versus winter harvesting" (see footnote 2). Landscape position does not have a similar influence on compaction in coarse-textured soils. Field research motivated by the compaction detected in the phase 3 plot network led the authors to recommend harvesting only in winter or on frozen ground for sites with fine-textured soils; coarse-textured soils would also benefit from these restrictions (see footnote 2).

Projects on Soil Chemical Properties

Project SO-EM-00-03: Examination of Nutrient Cation Status in Western Virginia Forests—The wet and dry deposition of chemicals from the atmosphere has a profound effect on the chemistry of forest soils. One of the principal effects is the depletion of exchangeable base cations from the soil profile (Lawrence and others 1999, Likens and others 1996). Continued calcium depletion in hardwood-dominated forests of the southeastern Piedmont will yield Ca stocks below those required for merchantable timber production in approximately 80 years (Huntington and others 2000), but quantitative studies of the base-cation status in forests of western Virginia are limited. Project SO-EM-00-03 addressed this gap in knowledge by examining linkages between the base status of forest soils, trees, and stream waters in western Virginia's Shenandoah National Park.

Shenandoah National Park is underlain by three major geologies—siliciclastic (sandstones and shales), granitic, and basaltic—so sampling was stratified by bedrock lithology (Welsch and others 2001). Streamwater and soil samples were collected in 14 monitored watersheds. Tree cores of bole wood were collected from northern red oak trees adjacent to the soil sampling pits; this was the most recent sample of wood tissue that did not contain active sapwood.

The effects of atmospheric deposition on soil chemistry varied with bedrock geology. The base saturation of surface and subsurface soil decreases across these lithologies: basaltic > granitic > siliciclastic (Webb and others 2002). Webb and others (2002) were among the first in southeastern forests to observe levels of Ca and Mg in wood tissue mimicking base cation availability in soil and export in streams. The observed levels of Ca and Mg indicate that the siliciclastic landscapes are especially sensitive to loss of base cations which poses particular concerns for forest and aquatic health in these areas (Cosby and others 2002).

Project NE-EM-04-03: Assessment of Forest Health and Forest Sensitivity to Nitrogen and Sulfur Deposition in New England—Project NE-EM-04-03 funded similar research but at a broader scale. The aerial survey program of FHM identifies areas of chronic defoliation, dieback, and mortality, and site-related factors may be involved, and project NE-EM-04-03 identified two objectives that would test this hypothesis:

1. Incorporating phase 3 plots into a regional assessment of forest sensitivity to atmospheric deposition of sulfur and nitrogen.

2. Evaluating current ecological indicators (crown health, growth, and mortality) at the plot level as a comparison between sensitivity and current health status.

No products exist to evaluate the outcomes of this funding support.

Project NC-F-05-04: The Distribution of Mercury in a Forest Floor Transect—In addition to acidifying cations, upland soils are sinks for the atmospheric deposition of mercury (Grigal and others 2000, Kolka and others 2001). Forest fires release mercury into the atmosphere when the forest floor is consumed while mercury concentration in the mineral soil may be unaffected (Amirbahman and others 2004). As industrial emissions come under increasing regulation, the contribution of forest fires to the mercury budget is an increasingly significant unknown. Project NC-F-05-04 funded the development of a spatial model of the mass of forest floor mercury on a transect spanning the Northern United States.

A transect across the northern coterminous United States was selected for two major regions because: (1) the investigators had relatively easy access to these data; the two soils Indicator Advisors are located in the North Central and Interior West regions, and (2) much of the deposition of mercury is believed to be related to industrial emissions which generally flow into the Northeastern region. The Interior West region should be relatively unaffected and the North Central Region should provide a transition.

Samples of the forest floor were collected as part of phase 3 sampling. The study team removed a small part of the archived sample (approximately 0.1 g) and determined the mercury concentration using cold-vapor atomic absorption. This concentration data was combined with the total mass and depth of the forest floor to estimate the mass of mercury stored in the forest floor.

Mercury amounts were highest in the northeastern part of the study region and the northern Rocky Mountains (Perry and others 2006, 2007a, 2007b). This bimodal distribution with high values in both the northern Rocky Mountains and the Great Lake States differs from earlier studies of Hg (Perry and others 2009a). Ecoprovince ($p < 0.001$) and latitude ($p = 0.006$) were both significant predictors of Hg concentration. Preliminary tests on subsets of the data suggested an important predictive role of forest-type groups.

Projects on Cross-Indicator Carbon Stocks

Project: SO-F-04-01: Duff and Litter Estimation for the Southeastern U. S.—Both the DWM and Soil Quality Indicators collect data on duff and litter accumulations. The DWM data are generally used for forest fuel analyses (Woodall and Monleon 2008) but scientifically credible estimators of bulk density are needed to best use DWM data for fire risk and fuel loading assessment. The original objective of this project was to obtain and summarize phase 3 soils data to develop needed auxiliary parameters to estimate DWM for the Eastern United States. This objective was revised (Chojnacky and Amacher 2006, Chojnacky and others 2005) to developing a simple field technique for estimating forest floor carbon using litter depth.

Phase 3 soil sampling includes measurements of litter and forest floor thickness (USDA Forest Service 2007). After the accumulated thickness is measured, samples are collected and sent to a regional laboratory for chemical analysis. The result is a set of carbon concentration and soil depth values that can be combined to estimate carbon content per unit area.

The best model of carbon content ($R^2 = 0.56$) included duff and litter depth measurements, the geographic coordinates of the county center where the plot was located, dewpoint temperature, and ecological province (Chojnacky and others 2006). Unfortunately, this model could only be applied to the phase 3 plot network where duff and litter exist. A more widely applicable model was developed that included forest type (conifer versus deciduous forest), climatological data, and ecological province, but its performance was much reduced ($R^2 = 0.22$).

Utilization of Project Results

Three of the projects funded by the EM program were directly related to management, inventory programs, or both and as such, could be expected to influence future activities in the forest. The compaction project (NC-EM-03-02) was completed in partnership with five national forests: Chequamegon-Nicolet, Huron-Manistee, Ottawa, Chippewa, and Superior. The investigators shared their information with the forests and with the FIA program. Their recommendations to amend the Soil Quality Indicator's compaction protocols are under review. Early analyses of Hg are complete (Perry and others 2009a), but additional analyses will need to be completed and published before significant recommendations are available.

Additional soil/DWM cross-indicator analyses of carbon stocks have been published (Perry and others 2009b), but carbon estimation using the Soil Quality Indicator (SO-F-04-01) remains an open subject. The continued use of models to determine soil carbon stocks in national greenhouse gas reporting (US EPA 2009) illustrates the opportunities for research.

Summary of Key Findings

The research supported by EM funding generated several pieces of pragmatic knowledge.

1. The phase 3 protocols for compaction assessment should be modified to include the use of a pocket penetrometer. This simple to use and inexpensive device detects significant soil compaction that is not detected with the current visual assessment protocols.

2. Soil compaction is related to the season of harvest, and this result is independent of landscape position in fine-texture soils. Aspen stands in Minnesota growing on fine-textured soils should only be harvested in winter when the ground is frozen.

3. Siliciclastic landscapes in Shenandoah National Park are especially sensitive to loss of base cations which poses particular concerns for forest and aquatic health in these areas.

4. Ecoprovince and latitude are significant predictors of Hg concentrations in the forest floor. Forest-type groups may also be significant predictors.

5. Carbon content in the forest floor may be roughly estimated from simple measurements of forest floor thickness and ancillary geospatial data.

Suggestions for Further Investigation

Surprisingly few projects have addressed the Soil Quality Indicator, so several methodological and science questions remain. From a methodological perspective, there are two broad categories of questions: (1) random versus purposive sampling designs, and (2) sampling protocols. The Soil Quality Indicator continues to be challenged in some professional circles: can a statistically-based soil inventory yield meaningful results? Increasingly, FIA-type plots are recommended at intensive research locations to facilitate extrapolation of local results to the wider landscape (Hollinger 2008). At the broadest scale, comparisons of the existing sampling design with other purposive approaches based upon expert opinion would be useful. Assessments of statistical power and detection limits would be informative as well. At fine scales, questions remain about the efficacy of the sampling protocols implemented on the plots. Is one mineral soil sample sufficient to define soil chemistry at the local site? Is 8 inches a sufficient sample depth to document soil carbon stocks and detect change? Bailey and others (2004) observed strong relationships between foliar chemistry and the B horizon, often found deeper than 8 inches. Relatedly, how does the answer to these questions change as the region of interest grows from the local site to the region and then the nation? Finally, the protocols need to be continually refined to address the pressing questions. Peatlands, for example, store a tremendous amount of carbon (Batjes 1996, Gorham 1991), but the Soil Quality Indicator database does a poor job of representing peat soils because of shortcomings with the bulk density sampler. Current activity in the forest peat soils of Alaska will begin to address this omission, but additional protocol evaluation in critical areas of the northern United States (Minnesota, Michigan, and Maine) is essential.

Several science questions have been identified but not addressed during the EM proposal process. First, the Soil Quality Indicator samples plots at widely scattered locations in the landscape. Is it possible to fill the gaps between the plots, and how should this be accomplished? Second, roots are a significant carbon stock that varies across biomes (Jackson and others 1996), but they are not measured by the Soil Quality Indicator. Is there a method for measuring and/or estimating roots biomass on the plot network? Finally, what is the role of fire on soil carbon stocks? How does this vary across the many landscapes inventoried by the Soil Quality Indicator?

Five projects were reviewed to compile this summary. Of the five, the only projects with published outputs were those that included Indicator Advisors as collaborators. In fact, some funded projects did not submit posters to the annual Forest Health Monitoring Workshop. Clearly, the involvement of someone with a vested interest in EM increases the program's chances of receiving published research output. The ideas supported by EM funding are compelling and worthy of the resources dedicated to them. That said, the program frequently does not receive the outputs promised by investigators. Increased oversight from grant administrators might improve research output. In the absence of that, the collaboration of scientists with a professional interest in furthering the mission of the EM program results in published output.

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