

CRITERIA 4, INDICATOR 21.

AREA AND PERCENT OF FORESTLAND WITH SIGNIFICANTLY DIMINISHED SOIL ORGANIC MATTER AND/OR CHANGES IN OTHER SOIL CHEMICAL PROPERTIES

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A. RATIONALE

The health and productivity of forest ecosystems may be adversely affected by changes in soil chemical properties following disturbance or certain management practices. The purpose of this indicator is to quantify changes in soil chemical properties relative to long-term average values that may be sufficient to impact soil fertility and site productivity. However, because national level monitoring of forest soils is relatively new and baseline data are available only at the research or watershed scale, it is not currently possible to interpret the levels of soil chemical variables relative to long-term mean values. As a result, this analysis focuses solely on providing baseline information about the general distribution of soil organic matter and soil pH across the landscape.

Soil organic matter (SOM) was selected as an index of soil quality because of its importance as a regulator of soil chemical, biological, and physical properties. Forest ecosystems obtain most of

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their nutrients from the decomposition of litter, branches, and other organic materials near the soil surface. Soil organic matter contains a large number of exchange sites that increase the capacity of the soil to adsorb these nutrients and prevent them from leaching below the rooting zone. In addition to nutrient retention, SOM facilitates the transport of air and water through the soil by promoting the development of soil aggregates and increasing moisture holding capacity (Brady and Weil, 1996). Finally, SOM serves as a major reservoir for terrestrial carbon (Schlesinger, 1991). As concern about possible climatic responses to increased CO₂ emissions grows, an improved understanding of the capacity of forested systems to sequester carbon in soils is critical for developing national initiatives. This indicator shares cross-cutting issues with Criteria 5, Maintenance of Forest Contribution to Global Carbon Cycle.

Since SOM is concentrated at the soil surface, both the quantity and quality of SOM may change following certain forest operations and management practices. As with other soil indicators, the term “significant” needs to be defined with respect to variation among different landscapes and soil types. Both the impacts of organic matter loss on site productivity as well as the degree of change that is tolerable varies for different soil types and vegetation complexes. It is not within the scope of this data report to discuss the potential impacts of disturbance on SOM contents or the relationship between SOM content and forest health and productivity. Rather, the objective is limited strictly to: (1) identifying nationally-consistent sources of data that can be used to help quantify this indicator, either now or in the future, and (2) providing an initial analysis of key soil chemical parameters collected as part of the Forest Inventory and Analysis (FIA) and Forest Health Monitoring (FHM) programs.

B. DATA USED TO QUANTIFY THE INDICATOR

Although standard definitions and procedures exist for measuring soil organic matter, information on historical SOM levels in undisturbed stands are nearly non-existent. National level monitoring of forest soils is relatively new and baseline data are available only at the research or watershed scale. This lack of historical data makes it difficult to interpret the levels of SOM currently measured in forest systems relative to long-term mean values. The objective of this analysis is to assess baseline information about the general distribution of soil organic matter across the landscape.

Estimates of SOM content, C/N ratios, and pH were derived from two sources: the Natural Resource Conservation Service (NRCS) State Soil Geographic database (STATSGO) soil database and the FIA/FHM programs. Particular emphasis is placed on the spatial distribution of soil pH as an indicator of soil chemical status. Soil pH is often referred to as a “master variable” because it regulates nearly all biological and chemical reactions in the soil (Brady and Weil, 1996). Thus, the distribution of soil pH may provide a useful index of the weathering status, potential nutrient holding capacity, and fertility of different soil types. However, the relationships between soil chemical properties and forest health and productivity are complex and interpretation of these data should only be made within the context of a specific soil type and vegetation complex.

NRCS STATSGO

The USDA Natural Resources Conservation Service (NRCS) is responsible for collecting, storing, maintaining, and distributing soil survey information for privately owned lands in the United States. The NRCS has established three soil geographic databases that are produced at different intensities and scales of mapping. Each database has a common link to an attribute data file for each map component. The State Soil Geographic database (STATSGO) is a 1:250,000 map that was designed primarily for resource planning and management at the regional, multistate, river basin, and multicounty levels (USDA NRCS, 1994). With the exception of Alaska, STATSGO provides national coverage of U.S. soils at a scale of 1:250,000; Alaskan soils are mapped at a scale of 1:2,000,000. Metadata for STATSGO data and compilation procedures can be obtained from the National Resource Conservation Service at http://www.ftw.nrcs.usda.gov/stat_data.html. Documentation and metadata for STATSGO may be found at: http://www.ftw.nrcs.usda.gov/stat_data.html.

FIA/FHM Soil Indicator Program

Parameters for monitoring changes in soil chemical properties were developed and initially measured by the Forest Health Monitoring program in the 1990's. In 1999, they were transferred to FIA and now are a subset of the FIA sample grid, with one forest health plot for every 16 standard plots (Stolte et al., 2002). When fully implemented, soil variables will be collected on

approximately 7,800 plots measured over a 5-year cycle. Variables used to assess soil erosion are based primarily on assessments of exposed bare soil, plant cover, forest floor thickness, soil texture, and slope. These field data are then combined with ancillary data on climate and landscape position to parameterize soil erosion model inputs. Documentation of the FIA/FHM sampling design and field methods may be found at <http://fia.fs.fed.us/library.htm>.

B.1 Soil Organic Matter

Estimates from NRCS STATSGO database

Estimates of SOM concentrations in the upper mineral layer of woodland soils were derived from the NRCS STATSGO database. In this analysis, mean values for SOM content in the upper soil layer were determined for each soil map unit based upon a spatially weighted average of component level data. The weighted data from each state were then compiled into a single national map (Figure 21.1). This analysis is limited only to the mineral soil and does not include information about SOM in forest floor materials. Details of the STATSGO database structure and the aggregation method employed in this analysis may be found in Appendix A.

In the context of soil survey, woodland ecological sites are separated from rangeland ecological sites based on the historic climax plant community that occupied the site before the arrival of European settlers. An Ecological Site Type of "woodland" is assigned where the historic vegetation was dominated by a 25 percent overstory canopy of trees, as determined by crown perimeter-vertical projection. A tree is defined as a woody-stemmed plant that can grow to 4

meters in height at maturity (National Soil Survey Handbook, NRCS). In this analysis, a map unit was considered a “woodland” soil if the NRCS identified any of its constituent components with a woodland Ecological Site Type.

The amount of carbon stored in the soil at any time represents the long-term balance between carbon inputs (from litter and roots) and carbon losses (by decomposition, fire, erosion, etc.). As a result, spatial patterns of SOM contents tend to be strongly correlated with gradients of climate and vegetation. In general, the highest concentrations of SOM are associated with regions where rates of decomposition are limited by environmental or chemical variables such as low temperature and high moisture content. As a result, STATSGO data indicates a rough latitudinal gradient in SOM contents with low SOM contents in the warmer southern portions of the country and higher SOM contents becoming more prevalent towards the northern U.S. The majority of woodland soils (57.9 percent) were characterized with an SOM content of between 1 and 3 percent. Nationally, only 3.8 percent of woodland soils were characterized as having a mean SOM concentration of less than 1 percent by weight (Table 21-1). More than 95 percent of these low SOM soils were located in the Rocky Mountain and Southern Resources Planning Act (RPA) regions. As a percentage of total area, the Southern region had the highest proportion of woodland soils categorized with less than 1 percent SOM (8.2 percent) compared to 6.4 percent in the Rocky Mountain region, and less than 1 percent in both the Northern and Pacific Coast regions.

Estimates from the Forest Health Monitoring Program

Organic carbon concentrations for the surface horizons collected as part of the FHM program from 1998-1999 are presented in Figure 21.2 (modified from the 2001 FHM National Technical Report; Conkling et al., in press). Total soil carbon was measured by dry combustion. In this method, a small sample of air-dried soil is combusted in a pure oxygen atmosphere. The combustion products are separated and quantified by passing them through a packed column. Results are expressed as a percent of air-dry sample weight. In high pH soils, some fraction of total carbon may be derived from inorganic carbonates in the soil parent material. In order to reflect changes in soil carbon due to biological responses, data are presented for organic carbon concentrations only.

Percent organic carbon data from each plot were aggregated by Bailey's ecoregion section and the mean value displayed as a shaded region on the map. Differences in mean values as shown on this map are not intended to represent statistical significance. Portions of ecoregion sections located in states for which no data were collected in 1998 and 1999 have been removed from this analysis.

Although, at present, there are insufficient data to summarize these data at the national level, general patterns of carbon distribution based on FHM data are similar to those derived from NRCS STATSGO data and indicate highest organic carbon concentrations in upper mineral soils of New England, upper Minnesota, and the Pacific Northwest. A key difference between these two approaches is that the FHM data differ from those based on the STATSGO database in that they represent percent carbon as opposed to soil organic matter. However, because carbon concentrations are proportional to SOM, the general spatial patterns are comparable.

B. 2 Soil pH.

Soil pH is a primary factor in determining the productivity of the soil through its regulation of soil nutrient availability, aggregate stability, and microbial activity. For this reason, maps of soil pH in relation to texture and forest type may provide a baseline index of the weathering status and potential nutrient holding capacity of soils. The ability of a particular soil to withstand changes in pH from both natural and human perturbations (e.g., acid deposition, fertilization) is primarily a function of the acid neutralizing capacity of the soil, the dominant clay mineralogy, and SOM content. In general, highly weathered clays are less able to buffer acidic inputs than less weathered clays. Because rainfall is naturally acidic, poorly buffered soils in regions receiving moderate rainfall are likely to have lower pH's than soils with higher acid neutralizing capacities.

Estimates from the NRCS STATSGO database

An estimate of soil acidity was derived from the STATSGO database following the procedure outlined for SOM (Appendix A). In general, soils in regions receiving higher precipitation, such as the eastern U.S. are more acidic (lower pH) than soils in arid regions (Fig. 21.4). In these areas, high rainfall tends to leach base cations (e.g., calcium, magnesium, potassium) from the surface of soil particles, resulting in increased acidity. Conversely, more arid regions, such the interior west, tend to have a neutral to slightly alkaline pH. Nationally, 18 percent of woodland soils are characterized as strongly acidic ($\text{pH} \leq 5.0$). Soils in forested regions of the Pacific Coast had the highest proportion of soils classified as strongly acidic, due primarily to the large

areas of organic soil in the interior of Alaska. Within the continental United States, strongly acidic soils were associated with the Coastal Plain and Appalachian regions of the eastern U.S. In contrast, 70 percent of woodland soils in the Rocky Mountain region were characterized in the neutral to alkaline category (pH > 6.5).

Estimates from FHM

The total acidity of a soil can be divided into three pools: (1) active acidity, a measure of the H^+ activity in the soil solution at a given time; (2) salt-replaceable acidity, which reflects the hydrogen and aluminum that are easily exchangeable by other cations in an unbuffered salt solution; and, (3) residual acidity. The FIA/FHM soils program measures the first two of these pools. Active acidity is measured by extraction of the soil with deionized water (water pH) and salt-replaceable acidity is measured in a solution of 0.01 M calcium chloride (salt pH). Salt pH values are lower than water pH values, because the calcium in the salt solution displaces H^+ ions sorbed to soil particles into solution.

Relative water pH values for the surface horizons are presented in Figure 21.4 (modified from FHM National Technical Report). Soil pH data from each plot were aggregated by Bailey's ecoregion section and the mean value displayed as a shaded region on the map. Differences in shading are not intended to represent statistical significance. Portions of ecoregion sections located in states for which no data were collected in 1998 and 1999 have been removed from this analysis. The distribution of strongly acidic soils generally supports the data derived from STATSGO and indicates that a greater proportion of acidic soils are associated with the eastern

and western coasts whereas higher pH values are more prevalent in the central U.S. and interior west. However, at present, there are insufficient data to summarize these data at the national level in a statistically meaningful way.

C. INTERPRETATION

Changes in SOM and the chemical composition of soils may be expected in response to forest management regimes such as short rotation cropping, biomass harvesting or extreme forms of site preparation for plantation or natural forest regeneration. However, the effects of management practices on soil chemical properties have largely been monitored at the research or watershed scales and little is known about historical levels of SOM and nutrients in undisturbed forest ecosystems. This lack of historical data combined with the expense and logistical difficulty of monitoring soil properties over large spatial scales makes it difficult to interpret the degree to which soils may have already been impacted by management practices.

Soil organic matter content is characteristic of each forest ecosystem and is strongly associated with forest productivity because of the role it plays in regulating nutrient storage, soil physical and hydrological properties, and microbial activity. In some highly weathered soils, such as those typical of the Piedmont region in the southeastern United States, SOM may provide the dominant reservoir for soil nutrients (Brady and Weil, 1996). SOM concentrations in forest soils tend to be strongly correlated with climatic gradients, with higher concentrations associated with areas of poorer litter quality and cold or moist climates where rates of decomposition are reduced (Figs. 21.1 and 21.2). Following disturbance, SOM in soil horizons may decline in response to

either a decrease in carbon inputs to the system or an increase in the rate of decomposition caused by a change in environmental conditions or in the ability of the substrate to decompose. In interpreting this indicator, it is important to recognize that the effect of a loss in organic matter on site productivity as well as the degree of change that is tolerable varies for different soil types and vegetation complexes.

As with SOM concentrations, the distribution of acidic soils followed a climatic gradient with soils in regions of high precipitation having a larger proportion of acidic soils than arid regions. In general, strongly acidic soils were associated with highly weathered clays in the southeast and organic rich regions of New England and the upper Lake States. Given the levels of acidic deposition in industrialized areas of the northeastern U.S., there is increasing concern about whether these soils may be experiencing increases in acidity that correspond to a loss of essential nutrients and the release of ions such as aluminum and manganese in concentrations that may be toxic to some plants. It is important to emphasize that there are insufficient data at present to assess how a particular soil will respond to acidic inputs or whether the buffering capacity of these soils is sufficient to buffer the added acidity. However, in response to these concerns, the FIA/FHM soil indicator program has expanded chemical analysis of soil samples to include exchangeable aluminum and sulfur, which can be used in concert with soil pH and base cation status to indicate the effects of soil acidification. As this program becomes fully implemented, these repeated measurements can be used in concert with soil sensitivity maps to provide valuable insights into the relationships between acidic deposition, soil pH, and forest productivity on a regional basis.

Although the response of a given soil to a particular management practice depends upon a number of site-specific factors, regions that have SOM concentrations and pH values at the lower end of the range of reported values may have the potential to be more ecologically sensitive to future perturbations. It is important to recognize that this does not mean that these regions are more likely to experience a future decline in SOM. Only that an equivalent disturbance effect in these low SOM and pH soils might be more likely to negatively impact forest health and productivity. Under this model, forests in low SOM areas of the interior west and southeast may be more sensitive to reductions in SOM concentration than forested areas in more northern latitudes. Soils in the cold and moist regions of New England, the Lake States, and the Pacific Northwest have proportionately greater areas with a high SOM content that may correspond to a greater ability to withstand minor changes in SOM content following disturbance. Additional research is needed to assess the relative effects of perturbations in chemical properties for potentially sensitive regions.

D. LIMITATIONS TO DATA

Many of the data gathering, analysis, and extrapolation elements of this indicator are challenging and expensive both in terms of cost and labor. As a result, it may take many years to acquire sufficient data to fully address the temporal and spatial variability within this indicator. In addition, the lack of historical data on forest soil chemistry makes it difficult to characterize SOM dynamics in forest plantations and in degraded areas that have been reforested. In addition, analysis of chemical parameters is often highly dependent on the method used. These

differences in methodology limit the compilation of results from individual research projects into a unified assessment.

In this report, the distribution of low SOM and strongly acidic soils were used to provide a general baseline of the current status of forest soils for use in future trend analysis. The response of soils to a reduction in SOM or a change in soil chemistry depends upon a large number of site-specific factors (e.g., mineralogy, texture, acid neutralizing capacity, hydrology) and additional research is needed to establish the relationships between disturbance and soil response. For example, both the chemical speciation of organic compounds and the degree of physical protection within the soil matrix may reduce the degradability of organic matter irrespective of total SOM concentrations. Without this detailed knowledge, it is difficult to assess how the SOM in a given soil will respond to disturbance. Even for those systems where a change in soil chemistry from baseline levels has been established, the linkages between chemical variables, plant physiology, and forest health are complex and not fully understood.

Although the NRCS STATSGO database can provide some general insights into the distribution of SOM and soil chemical properties in forested soils, these data are static and cannot reflect responses to specific management practices. Soil survey data may also be more heavily weighted towards soils in agricultural systems, which can differ both in chemical and physical properties from their forested counterparts. Therefore, only SOM storage in the upper layer of the mineral soil was considered and not the much higher SOM concentrations typically associated with litter and forest floor layers. These surface organic horizons are likely to be more susceptible to the effects of management practices and natural disturbances than underlying

mineral horizons. In addition, both the scale of the STATSGO soil data (1:250,000) and the use of weighted averages to characterize soil mapping units preclude the use of this data at anything other than a national or regional scale. More detailed estimates should be based on the county-level State Survey Geographic Database (SSURGO) database at mapping scales ranging from 1:12,000 to 1:63,360.

The interpretation of STATSGO data is further complicated by the use of “woodland soils” as a base layer. In this analysis, a map unit is considered as a “woodland” soil if the NRCS identified one of its components with a woodland Ecological Site Type. Although the fraction of the map unit identified as “woodland” is provided in STATSGO, it is not possible to portray information at anything smaller than the size of an individual map unit. As a result the area represented in Figure 21.1 overestimates the actual area of woodland soils. For this reason, estimates of area and not provided and data are presented only as relative values. Future analyses could refine this approach by setting threshold values for the percentage of a map unit that must be designated as woodland.

Comparison of data from STATSGO and the FHM/FIA program may be useful in documenting general trends. However, these comparisons should be based on general spatial trends of relative values rather than comparison of absolute values. Many of the available soil maps and surveys are based largely upon analysis of agricultural soils and care must be taken when comparing pH values from forested soils with survey data. In general, forest soils tend to be naturally more acidic than agricultural soils due to the higher levels of organic acids produced by decomposition and leaching through the forest floor. For comparison with STATSGO and because of changes

in the sample collection protocols, we have restricted this report to discussing chemical variables within the 0-10 cm soil layer. In many systems, the majority of the chemical and biological functions in soil are related to clay and organic matter and, thus, the upper portion of the soil profile is likely to be more responsive to disturbance and can provide a useful index for monitoring changes in soil properties over time (Hudson, 1995). However, conclusive answers to some forest health questions may require additional analyses of samples taken from within the entire rooting zone. Finally, prior to 2000, the FHM program did not collect bulk density data to allow for calculation of carbon and nutrient storage on an areal basis. In the future, the full implementation of the soils program combined with the addition of bulk density, exchangeable aluminum, and sulfur (for soil acidity) to the sampling protocol will enhance the analysis of this indicator.

One of the benefits of a national monitoring program, such as the FIA/FHM soil indicator, is that it provides repeated, systematic sampling of soil chemical properties using standardized collection, preparation, and analytical techniques. When this program has been fully implemented, these data will provide critical information on the status of forest soils for use in future reporting. At present, however, these data are not evenly distributed across all forested regions and soil types and it is not possible to extrapolate to a national scale. Even when fully implemented, the spatial scale of the grid used in FIA soil sampling (1 plot per 96,000 acres) will limit estimates of change for anything smaller than the regional scale. An additional limitation of this data set is that the number of samples collected on each plot are limited and additional research is needed to assess how to address within-plot variability. Aggregation of plot-level data within larger units, such as ecoregion section (Figs. 21.2, 21.4) may mask trends in soil

chemical properties. In addition, depending upon the soil type, both the number of samples and the methods used in collecting these samples may vary between plots, complicating compilation and estimation procedures.

Soil chemistry data collected on FHM and FIA plots are intended to be interpreted as one part of a multi-tiered approach for detecting changes in soil properties across the landscape. FHM has five major activities: Detection Monitoring, Evaluation Monitoring, Intensive Site Monitoring, Research on Monitoring Techniques, and Analysis and Reporting (Tkacz, 2002). Detection Monitoring consists of nationally standardized aerial and ground surveys designed to collect baseline information on the current condition of forest ecosystems and to detect changes from those baselines over time. Data presented in this report were collected as part of this effort. The ground survey portion of the detection monitoring program has since been transferred to FIA. Evaluation Monitoring studies examine the extent, severity, and probable causes of changes in forest health identified through the Detection Monitoring surveys. Intensive Site Monitoring projects are conducted to enhance understanding of cause and effect relationships and assess specific issues at multiple spatial scales. Research on Monitoring Techniques focuses on developing and refining indicator measurements to improve the efficiency and reliability of data collection and analysis at all levels of the program (Rogers et al, 2001). Finally, Analysis and Reporting activities are designed to synthesize information from various data sources both within and external to the USDA Forest Service to produce reports on status and change at national, regional, and state levels. As such, soil chemistry data reported in this analysis should be viewed as an initial assessment to detect changes in the presence of reported compaction. More detailed

research collected under other portions of the FHM program is still needed to determine the extent and the ecological significance of these data.

E. IF CURRENT DATA ARE NOT ADEQUATE TO MEASURE THE INDICATOR, WHAT OPTIONS ARE AVAILABLE FOR REMEDY?

One of the primary difficulties in quantifying this indicator is that little information is available to quantify historical concentrations of SOM or other chemical variables in forest soils at anything larger than the research scale. As the FIA soil monitoring program becomes fully implemented across the U.S., SOM and other chemical data will form the baseline for future trend analyses. In addition, because these plot-level data will be collected as a subset of the national FIA forest inventory grid, changes in SOM and soil chemical variables can be directly correlated with changes in stand productivity across a range of soil and vegetation types.

As with other soil indicators, additional research is needed to quantify the impacts of changes in soil chemical variables on forest health and productivity. A mechanism for conducting this research already exists as part of the FHM Evaluation Monitoring and Intensive Site Monitoring programs. To the extent possible, additional process-level research should be used in combination with FIA plot data to improve the scaling and interpretation of data. Additional insight into temporal changes in soil chemical variables may be gained from long-term programs such as the NSF's Long-Term Ecological Research program (LTER). Data from research scale projects conducted over long periods of time may help establish the linkages between FIA monitoring data and the ecological effects of any observed deviations from baseline levels. In

particular, specific linkages between management practices and forest productivity are being investigated as part of the USFS long-term soil productivity research initiative (LTSP) (e.g., Powers and Fiddler, 1997). Fertilization and stand manipulation studies conducted as part of this program have produced localized data on changes in major soil nutrients and organic matter following management practices (for example, the loss of soil nitrogen, other nutrients, and organic matter after prescribed burns used to reduce logging slash). By combining changes in SOM and nutrient dynamics in these studies with statistical information on forest management practices within regional ecological units, relative estimates could be shown for the area of forestland associated with significantly diminished soil organic matter.

Another promising approach for improving our understanding of the potential for changes in soil chemistry in response to atmospheric inputs is currently being developed by the New England Governors/Eastern Canadian Premiers Acid Rain Action Plan. The goal of this project is to identify those forest areas in the eastern US and Canada that are most sensitive to acidic deposition on the basis of clay mineralogy using a steady state mass balance approach (New England Governors, 2001). The inherent buffering capacity of these soils will then be combined with data on proximity to pollution sources to highlight areas where current or projected acidic deposition exceeds sustainable rates. This approach is similar to the mapping of critical soil acidification loads currently done by a number of European nations (Posch *et al.*, 1995), but differs through its quantification of sustainable deposition rates. Future analyses that combine these types of spatial and geochemical models with data from the FIA soils program would provide valuable insight into the potential effects of acid deposition on forest resources.

F. LITERATURE CITED

Brady, N.C. and Weil, R.R. 1996. The nature and properties of soils (11th Edition). New Jersey: Prentice-Hall, Inc. 740 pp.

Conkling, B.L.; Coulston, J.W.; Ambrose, M.J. (eds.). in press. 2001 Forest Health Monitoring national technical report. Gen Tech. Rep. Asheville, NC; U.S. Department of Agriculture, Forest Service, Southern Research Station.

New England Governors/ Eastern Canadian Premiers. 2001. Protocol for Assessment and mapping of forest sensitivity to atmospheric S and N deposition, Acid Rain Action Plan: Action Item 4: Forest Mapping Research Project.

Posch, M.; deSmet, P.A.M; Hettlingh, J-P.; and Downing, R.J. (eds.). 1995. Calculation and Mapping of Critical Thresholds in Europe: Status Report 1995. Report #259101004, RIVM Biltoven, the Netherlands.

Powers, R.F. and Fiddler, G.O. 1997. The North American Long-Term Soil Productivity Study: Progress through the first five years. In: Proceedings, Eighteenth Annual Forest Vegetation Management Conference; 1997 January 14-16; Sacramento, CA: Forest Vegetation Management Conference: 88-102.

Rogers, P.; Atkins, D.; Frank, M.; Parker, D. 2001. Forest Health Monitoring in the Interior West: A baseline summary of forest issues, 1996-1999. General Technical Report RMRS-GTR-75. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Schlesinger, W.H. 1991. Biogeochemistry: An analysis of global change. San Diego, CA: Academic Press, Inc. 443 pp.

Tkacz, B.M. 2002. Forest Health Monitoring. USDA Forest Service, State and Private Forestry, Forest Health Protection, <http://www.fs.fed.us/foresthealth/fhm/index.htm> .

USDA National Resources Conservation Service National Soil Survey Center, State Soil Geographic (STATSGO) Database Data Use Information. Miscellaneous Publication 1492, Fort Worth Texas. Available on-line at http://www.ftw.nrcs.usda.gov/pdf/statsgo_db.pdf.

APPENDIX A. STATSGO DATABASE STRUCTURE AND AGGREGATION PROCEDURE

In county-level soil maps, each map unit usually represents a single soil component (e.g., there is a 1:1 relationship between the soil mapping unit and the associated attribute data). In contrast, each map unit on a STATSGO map can contain up to 21 different soil components. Although attribute data is provided for each soil component, there is no visual distinction as to the location of these components within the mapping unit. For example, a mapping unit map contain a 10% inclusion of a wetland soil type; however, there is no way to determine which 10% of the mapping unit this wetland type represents. In addition, each component consists of multiple layers representing different soil horizons. Development of interpretive maps requires aggregating data from the lowest level in the schema (layer) up to the component level and then aggregating component level data up to the map unit level.

In this report, interpretive maps were developed by limiting analyses to the upper soil layer of each map component. A weighted average of component data was then determined for each map unit by multiplying the mean value for a given soil component by the percent of the mapping unit represented by that component and then summing across all components. For example, estimates of soil pH were derived as follows:

$$\text{Weighted pH} = (\text{High pH} + \text{Low pH})/2 * \text{Component percent}$$

$$\text{Map Unit Weighted pH} = \sum \text{Weighted pH}$$

Null values for pH and SOM within the STATSGO database are assigned a value of "0". To limit the downward bias that inclusion of these values would cause in estimation, null values were removed from the database and replaced with the mean pH and SOM values for the state in which the map unit occurred. However, this also has the effect of masking out regions of the landscape with

FIGURE CAPTIONS

Figure 21.1 Mean soil organic matter content in the upper mineral layer of woodland soils. The aggregation scheme used to generate this map is provided in Appendix A. Data from Natural Resource Conservation Service STATSGO database.

Figure 21.2 Organic carbon concentration in upper mineral soil horizons measured on FHM detection monitoring plots (1998-1999). Symbols represent the organic carbon content in the upper soil horizon on a plot. Mean plot values were then aggregated by Bailey's ecoregion and the mean value of each ecosystem used for classification. Differences in shading are not intended to represent statistical significance. Portions of ecoregion sections falling in states for which no data were collected have been removed from this analysis. Figure modified from the 2001 FHM National Technical Report (Conkling et al, in press).

Figure 21.3 Mean pH in the upper mineral layer of woodland soils. The aggregation scheme used to generate this map is provided in Appendix A. Data from Natural Resource Conservation Service STATSGO database.

Figure 21.4 Soil acidity (salt pH) in upper mineral soil horizons measured on FHM soil indicator detection monitoring plots (1998-1999). Symbols represent the pH for a plot. Mean plot values were then aggregated by Bailey's ecoregion and the mean value of each ecosystem used for classification. Differences in shading are

not intended to represent statistical significance. Portions of ecoregion sections falling in states for which no data were collected have been removed from this analysis. Figure modified from the 2001 FHM National Technical Report (Conkling et al, in press).

Table 21.1. - SOM content summarized by Research Planning Act (RPA) regions. Values represent the percentage of the area shaded in Fig. 21.1 that fall within a range of SOM values. See Appendix A for details of this aggregation approach and model limitations. Note that the definition of “woodland soils” used in STATSGO differs from the definitions used in FIA and data from these two sources are not directly comparable. For the purposes of this report, a soil mapping unit was characterized as a woodland soils if one of its component soils was characterized with a woodland ecological site type. As a result, the shaded area in Fig. 21.1 overestimates the actual area of woodland soils. For this reason, data are provided as relative values only.

Region	Soil Organic Matter Content			
	< 1%	1-3%	3-5%	> 5%
North	0.2%	42.2%	21.4%	36.2%
Rocky Mountain	6.4%	76.7%	13.8%	3.2%
Pacific Coast	0.4%	29.4%	17.8%	52.4%
South	8.2%	78.7%	7.8%	5.2%
Total	3.8%	57.9%	15.2%	23.0%

Table 21.2.- pH content summarized by Research Planning Act (RPA) regions. Values represent the percentage of the area shaded in Fig. 21.3 that fall within a range of pH values. See Appendix A for details of this aggregation approach and model limitations. Note that the definition of “woodland soils” used in STATSGO differs from the definitions used in FIA and data from these two sources are not directly comparable. For the purposes of this report, a soil mapping unit was characterized as a woodland soils if one of its component soils was characterized with a woodland ecological site type. As a result, the shaded area in Fig. 21.1 overestimates the actual area of woodland soils. For this reason, data are provided as relative values only.

Region	Strongly Acidic (pH < 5.0)	Acidic (5.0 < pH < 6.5)	Neutral (6.5 < pH < 7.3)	Alkaline (pH > 7.3)
North	18.9%	71.7%	8.8%	0.6%
Rocky Mountain	0.2%	29.6%	36.5%	33.7%
Pacific Coast	26.1%	58.6%	14.9%	0.4%
South	22.0%	72.4%	4.0%	1.6%
Total	18.0%	63.6%	12.3%	6.0%