

COMPARISON OF TECHNIQUES FOR ESTIMATION OF FOREST SOIL CARBON

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ABSTRACT

Soil organic carbon represents the largest constituent of the global C pool and carbon budgets are studied by researchers and modelers in C cycling, global climate change, and soil quality studies. Pedon and soil interpretation record databases are used with soil and ecological maps to estimate regional SOC even though these databases are rarely complete for surface litter and mineral subsurface horizons.

The first main objective of the project is to improve the ability to produce soil organic carbon estimates from existing spatial soils datasets, such as STATSGO. All records in the STATSGO *Layer* table that were incomplete or appeared to be incorrectly filled with a null or zero value were considered invalid. Data sorting procedures and texture lookup tables were used to identify exiting correct (valid) data entries that were used to substitute invalid records. STATSGO soil property data were grouped by soil order, MLRA, layer number, and texture to produce replacement values for all invalid data used to calculate mass SOC. Grouping criteria was specific to each variable and was based on texture designations. The resulting filled and unfilled tables were used with procedures assuming *Normal* and *Lognormal* distribution of parameters in order to analyze variation of mass SOC estimates caused by using different computation techniques.

We estimated mass SOC to 2 m in Maine and Minnesota using filled and unfilled STATSGO data tables. Up to 54% of the records in Maine and up to 80% of the records in Minnesota contained null or zero values (mostly in fields related to rock fragments) that were replaced. After filling, the database resulted in 1.5 times higher area-weighted SOC. SOC calculated using the *Normal* distribution assumption were 1.2 to 1.5 times higher than those using the *Lognormal* transformation. SOC maps using the filled tables had more logical geographic SOC distribution than those using unfilled tables.

The USDA Forest Service collects and maintains detailed inventory data for the condition and trends of all forested lands in the United States. A wide range of researchers and landowners use the resulting Forest Inventory and Analysis (FIA) database for analytical and decision making tasks. FIA data is available to the public in transformed or aggregate format in order to ensure confidentiality of data suppliers.

The second main objective of this project was to compute SOC (kg m^{-2}) results by FIA forest type and forest type group for three depth categories (25 cm, 1 m, and 2 m) at a regional scale for the 48 contiguous United States. There were four sets of results derived from the filled STATSGO and FIA datasets for each depth class by region: (1) SOC computed by the *Lognormal* distribution approach for (1a) all soil orders, (1b) without Histosols; and (2) SOC computed by the *Normal* distribution approach for (2a) all soil orders, (2b) without Histosols.

Two spatial forest cover datasets were relevant to this project, FIA and AVHRR. We investigated the effects of FIA inventory data masking for Maine and Minnesota, such as plot coordinates rounding to the nearest 100 arc-second, and the use of 1 km resolution satellite-derived forest cover classes from AVHRR data, on SOC estimates to 2 m by forest type group. SOC estimates by soil mapping unit were derived from fixed STATSGO database tables and were computed by the *Lognormal* distribution approach including all soil orders.

The methods in this study can be used for a variety of ecological and resource inventory assessments and the automated procedures can be easily updated and improved for future uses. The procedures in this study point out areas that could benefit the most during future revisions of STATSGO. The resulting SOC maps are dynamic and can be rapidly redrawn using GIS whenever STATSGO spatial or tabular data undergo updating. Use of pedon data to define representative values for all properties in all STATSGO layers and correlation of STATSGO layers to soil horizons will lead to vast improvement of the STATSGO *Layer* table and promote its use for mass SOC estimation over large regions.

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I am aware that Friday nights are specifically designed for parties and such (note my roommate), however success calls for sacrificing time and energy, even at a party level. I am looking forward to a grand celebration.

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CHAPTER 1: INTRODUCTION

BACKGROUND

The largest sink of terrestrial carbon in United States forests is the forest soil. Soil organic matter content and above ground leaf litter biomass accumulation in forests are a direct result from the *C* sequestration process that scientists are able to measure and monitor. Understanding the terrestrial carbon cycle is critical to understanding how greenhouse gas emissions may impact global climate. Related to land use and land cover change patterns soil organic carbon (SOC) data could help project terrestrial carbon budgets into the future and assess carbon sequestration potential of the U.S. forest. Knowledge of the relationship between forest type and soil carbon estimates will lead to further understanding of the effect of forest management practices on soil carbon fluctuations that may reduce the rate of increase of CO_2 concentrations in the atmosphere.

National-level estimates of SOC stocks are needed for scientific understanding and climate change modeling as well as soil quality assessment and mapping and natural resources policy considerations. As part of the United Nations Framework Convention on Climate Change (UNFCCC), the U.S. must report carbon budget estimates for all levels of terrestrial *C* cycle. The FORCARB model developed at the USDA Forest Service estimates and projects forest carbon budgets for the United States (Heath et al., 2002). Among all variables entered into the model the SOC levels by forest type group and fluxes are also considered.

The US Forest Service desires estimates of SOC by forest type group for three standard depths (0-25 cm, 0-100 cm, and 0-200 cm) in order to facilitate analysis and reporting. The methods for producing these SOC estimates should use existing soils and forest cover databases in a transparent, repeatable, rational and scientifically defensible approach that will be geographically comprehensive for the contiguous United States. Three such existing spatial datasets are STATSGO soils data, Advanced Very High Resolution Radiometer (AVHRR) satellite-derived maps for forest cover, and FIA forest inventory data.

The Natural Resources Conservation Service ([NRCS](#)) of the U.S. Department of Agriculture (USDA) manages the National Soil Survey Center ([NSSC](#)), which is responsible for gathering, compiling, storing, and distributing nationwide soils data at different levels of detail. There are three soils databases that are created from the collected data. The Soil Survey Geographic database (SSURGO, common scale is 1:24,000) is best suited for county and town level analysis, the State Soil Geographic database (STATSGO, common scale is 1:250,000) is best suited for statewide, basin level analysis, and the National Soil Geographic database (NATSGO, common scale is 1:2,000,000) is best suited for regional, nationwide analysis and data overlays.

The STATSGO database provides physical and chemical property data by a component phase for each delineated layer of all U.S. identified soil series. The data is represented by the minimum and the maximum value of the range of all measurements for each property. The data structure and tables in the database allow soil properties to be summarized and/or averaged for higher levels of a spatial data identifier that is called the mapping unit. Each map unit polygon contains a few soil components whose proportions are described by the *COMPPCT* variable in the *Comp* (component) table of the STATSGO database (National Soil Service Center, 1994).

The establishment and creation of the STATSGO database has benefited many natural resources researchers by providing comprehensive information on soils, land use, and other environmental parameters. Uses of the STATSGO soils database are numerous allowing data to be utilized in many studies where the objective is soil characterization, mapping, global climate change modeling (Bliss et al., 1995), soil organic carbon storage estimation (Homann et al., 1998; Davidson and Lefebvre, 1993) and mapping (Lacalle et al., 2001). Soils data analysis and modeling has become even easier and more efficient with the development of technologically advanced geographic information systems (GIS) that are compatible with data analysis software packages such as Microsoft Access, Excel, and SAS.

A general limitation of the STATSGO database is that it was first developed from agricultural soil series, where base maps of higher resolution were used to digitize the soil mapping unit boundaries. In a study of soil carbon densities for the state of South Carolina, Xu and Prisley (2000) indicate that the use of this data for forest soils analysis

yields results that may be highly variable. However, others show that soil carbon estimates from site specific studies published in the recent literature are found to be within one standard deviation of the mean STATSGO estimations (Heath et al., 2002).

The USDA Forest Service gathers detailed forest inventory data on all forested lands nationwide to provide the public, interested federal and state agencies, as well as the forest industry and research facilities with valuable and free information about the condition of the current forest cover. Data ranges from ownership information to detailed biomass estimates along with number of trees per acre and associated species, to understory assessment, species growth and mortality rates.

Beginning with the Multiple-Use Sustained-Yield Act of 1960, the FIA program has focused on inventorying and monitoring the resources and the values of the forestlands (Powell et al., 1994). Resulting inventory tables are used in broad-spectrum decision-making, planning, forest management and research projects, such as diameter growth modeling (Lessard et al., 2001), forest cover change (Dyer, 2001), timber inventory projection (Teeter and Zhou, 1998), and species growth and mortality rate variation caused by weather pattern change (Jenkins and Pallardy, 1995).

STATSGO SOILS DATABASE

STATSGO Data

STATSGO soils data is available on line and can be obtained free of charge at the STATSGO [webpage](#) that is maintained and updated regularly by the NRCS. The file type of the tabular data is in database format (dBASE) and is readable with some of the most common software packages, including GIS capable tools, such *ArcView 3.** and *ArcGIS 8.** by Environmental Systems Research Institute (ESRI, Inc., Redlands, Ca 92373).

For each state, there are fifteen different data tables that store information on various natural resources including soils, taxonomic classification, crop yield, forest understory, plant composition, wildlife, and woodlands. Soil parameter data is compiled in the *Layer* (layer) table and the number of records per state varies between 721 (Delaware) and 8327 (New York) or greater. Each record represents one soil layer (up to 6) and is assigned to a component (Figure 1.1); multiple components (up to 21) represent one mapping unit. A unique mapping unit identifier (*MUID*) relates each mapping unit to

a spatially allocated soils polygon. The *MUID* is used as a join field for linking the GIS files (ArcINFO format) and data tables in the STATSGO database in order to create custom soil maps.

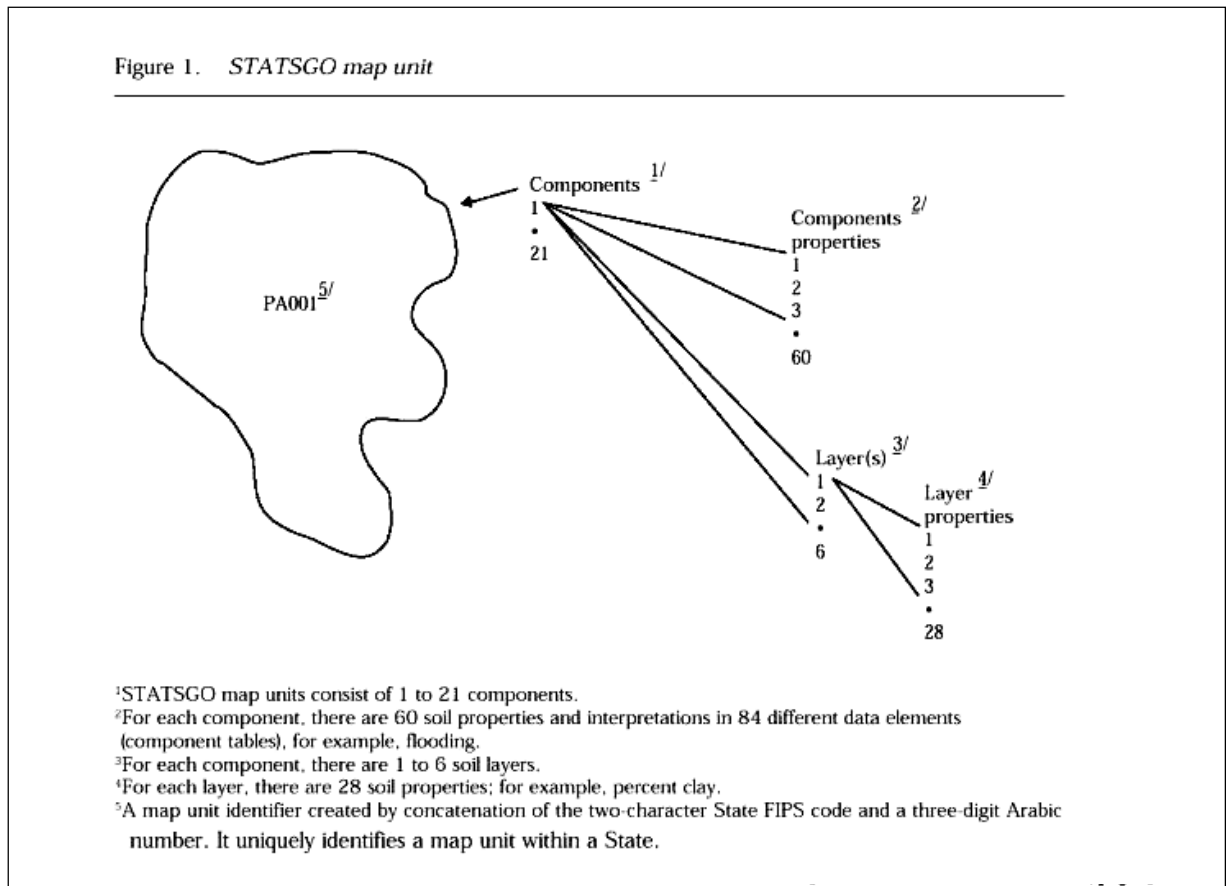


Figure 1.1. STATSGO data and relational structure between tabular and spatial variables, (Adapted from National Soil Survey Center. 1994; page 9).

Soil Property Distribution in the STATSGO Database

Layer properties in the STATSGO database are presented as numeric values and/or alphanumeric codes. All numeric variables are depicted in two fields representing the minimum and the maximum of the range of all measurement. For instance, the organic matter fields in the *Layer* table, *OML* and *OMH*, represent the minimum and the maximum value, respectively, for the range of organic matter (OM) content of that layer, expressed in percent by weight. Eventually only these two extreme values are used for any analysis and one must decide on the methods and/or approaches that should be used to compute a single representative estimate for the variable of interest; i.e. is it going to be the simple average, computed as $average = [min + max]/2$, or something else?

Many soil characteristics are skewed rather than symmetrically distributed (Grigal et al., 1991). Homann et al. (1998) state that the assumption of skewed rather than symmetrical distribution of soil properties reduce the STATSGO estimates for soil carbon content and the latter assumption yields results that better agree with other approaches. Modeling soil property distributions is a challenging task and most investigators find it satisfactory to use the simple average between the minimum and maximum values of the database, and therefore assuming a symmetrical distribution such as the *normal* distribution (Bliss et al., 1995; Davidson and Lefebvre, 1993).

Others disagree with that theory and have developed specific coefficients derived from local field studies for organic matter (OM) content, bulk density (BD), and rock fragment content (RFC) that can be used to compute representative values for each variable from the available minimum and maximum data (Homann et al., 1998). Attempting a step further, Brejda et al. (2000) demonstrate that \log_e transformed measurements (Figure 1.2,b) for most soil properties better approximate the normal distribution rather than that of the raw, non-transformed data (Figure 1.2,a). In addition, due to the fact that most soil properties are assigned only positive values and just a few of them appear as outliers, the \log_e transformation reduces variability two to threefold for most soil attributes (Brejda et al., 2000).

For *normal* distribution assumptions the mean of all measurements is found to be greater than the median due to the few outliers causing right skewness of the distribution graph (Brejda et al., 2000). Yet, not as strongly depicted for all soil parameters, the

lognormal distribution assumption produces very close or equal mean and median statistics for most of the soil properties at a regional scale of analysis (Brejda et al., 2000).

For the purpose of this study we adopt the method described by Brejda et al. (2000), which is referred to here as the *Lognormal* distribution approach. The *Normal* and *Lognormal* approaches differ in the method for computing a representative value for organic matter (OM) and bulk density (BD) from their respective minimum and maximum values, *OMH*, *OML*, and *BDH*, *BDL*. For example, the organic matter (OM) content by the *Lognormal* approach will be equal to the antilog of [(natural logarithm of *OMH* + natural logarithm of *OML*) *0.5], instead of being equal to the simple average of *OMH* and *OML* values that will be used in the *Normal* distribution approach. Results by both the *Lognormal* and *Normal* distribution approaches are computed in order to gain maximum benefit from this study and evaluate the sensitivity to these assumptions.

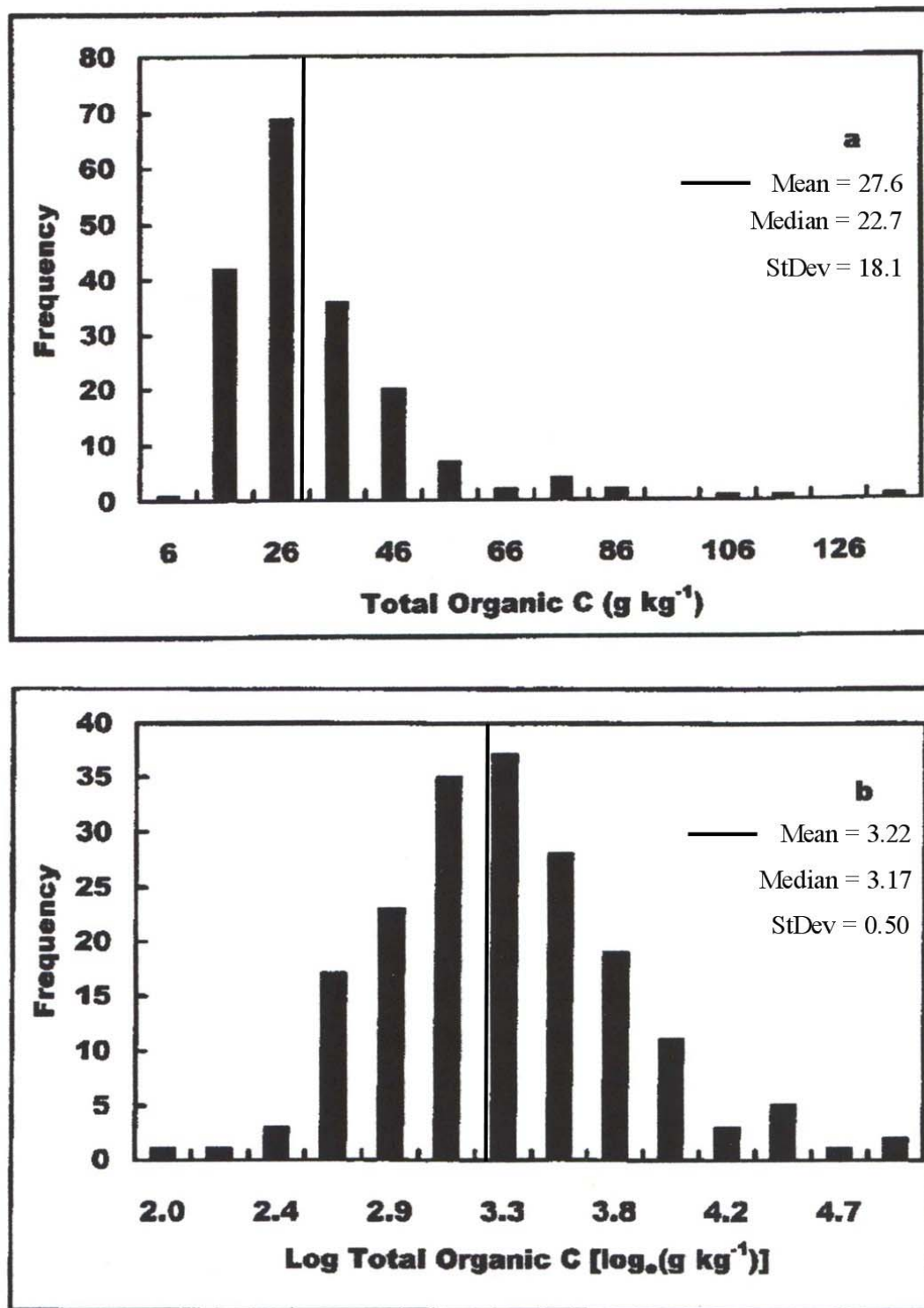


Figure 1.2. Frequency distribution of total organic C concentrations in MLRA 105, North Mississippi Valley Loess Hills: (a) nontransformed data and (b) \log_e transformed data. Vertical lines show means (Modified from Brejda et al., 2000, page 978).

Problems Identified

Numerous zeros and nulls for almost every soil variable (database field) are potential problems for any supplementary analysis and data manipulation. For example, in the Maine STATSGO database, 25% and 54% of the records contained zero values for *OMH* and *OML* (Table 1.1). Percent zero records were similar in Minnesota. The zero value was considered reasonable for *OML* in all except organic and mucky-modified mineral textures. Seven percent (Maine) and 2% (Minnesota) of all records that contained zero values in *BDH* or *BDL* fields for rock layers (weathered, *WB*, or unweathered, *UWB*, bedrock) were considered rational in terms of SOC computation.

The variables in the table are required for soil organic carbon computation and each null or zero record misleads the project investigator in the search for an accurate estimate. These data discrepancies may increase the variation and reduce the accuracy of the results by altering the final output of any environmental research study, such as SOC computation (Bliss et al., 1995; Lacalle et al., 2001).

So, there are a few problems that one encounters when using the STATSGO database. Table 1.2 lists the soil properties that are required for SOC estimation. All variables are soil properties that should always have a meaningful numeric entry for each soil layer including possibly zero for some unique textures. For example, *OML* and *OMH* can be zero for rock layers (weathered or unweathered bedrock) but cannot be zero for muck or peat layers.

Suggested Solution

The inventory results in Table 1.1 demonstrate the need for a scientific approach that will allow filling null and/or replacing zero record entries for all soil layers that meet certain criteria. The basic assumption in the development of such fixing methodology is that physical and chemical soil properties are affected by many external and internal processes, as well as they are interrelated between one other. Texture and parent material are considered to highly influence the organic matter (OM) content, bulk density (BD), and rock fragment content (RFC) parameter values.

Table 1.1. STATSGO variables used in the calculation of mass soil OC.

Variable	Nulls †	Zeros	Nulls †	Zeros
	Count			
	Maine (3649)		Minnesota (12318)	
INCH10 L	797	2280	2651	9665
INCH10 H	797	1045	2651	8515
INCH3 L	262	2389	236	11394
INCH3 H	262	902	236	6754
NO10 L	468	1	895	0
NO10 H	468	0	895	0
BD L	0	252	0	196
BD H	0	252	0	197
OM L	0	1975	0	6102
OM H	0	906	0	3383

‡ total number of records (soil layers) in parentheses.

† all null values are considered invalid and should be replaced with a reasonable estimate.

Table 1.2. STATSGO variables used in the calculation of mass soil OC.

Variable Code	Variable Name
<i>OMH</i>	organic matter high (maximum)
<i>OML</i>	organic matter low (minimum)
<i>BDH</i>	bulk density high (maximum)
<i>BDL</i>	bulk density low (minimum)
<i>INCH3H</i>	percent by weight of rock fragments with size greater than 25cm high (maximum)
<i>INCH3L</i>	percent by weight of rock fragments with size greater than 25cm low (minimum)
<i>INCH10H</i>	percent by weight of rock fragments with size greater than 7.5cm high (maximum)
<i>INCH10L</i>	percent by weight of rock fragments with size greater than 7.5cm low (minimum)
<i>NO10H</i>	percent by weight of rock fragments with size less than 7.5cm and which pass through a No.10 sieve (2 mm screen) high (maximum)
<i>NO10L</i>	percent by weight of rock fragments with size less than 7.5cm and which pass through a No.10 sieve (2 mm screen) low (minimum)

FOREST COVER DATA SOURCE

Forest Inventory and Analysis (FIA) Data

Prior to 1996 the FIA program at the USDA Forest Service conducted forest inventory on a state-by-state cycle that extended 7 to 10 years. Data analysis and publication appeared to be insufficient and did not meet the increasing customer needs (Gillespie, 1999). Vast forested areas of the Southeast region of the U.S. had been continuously affected by inclement weather (such as Hurricane Hugo in 1989) that was changing the forest landscape at such rates that required different monitoring approach and a shorter inventory cycle (Reams et al., 1999). In 1996, the FIA program launched a test cycle of the annually-based inventorying system in the South (Gillespie, 1999). The existing sets of sample sites were divided into five overlapping panels with the intent of measuring one panel each year. Due to the level of federal funding support of the FIA program, the transition from 7 to 10 year cycle to annual inventories in all states was expected to take some time (Gillespie, 1999).

Due to unequal transitioning stages of the FIA program among States data for this study was obtained from the new, annual-based Forest Inventory and Analysis Database (FIADB) and the old, 7 to 10 year cycle databases, the Eastwide (Hansen et al., 1992) and the Westwide (Woudenberg and Farrenkopf, 1994) Forest Inventory and Analysis Datasets, EWDB and WWDB respectively. Data was available in standard tabular formats and reflected forest condition for the most recent post-1988 inventory cycle (<http://fia.fs.fed.us/>).

Most of the variables from EWDB were transferred into FIADB database. However, the complexity of the FIADB data required two additional tables. The *County*, *Plot*, and *Tree* tables (EWDB) were separated into five tables of the FIABD database (*Survey*, *County*, *Plot*, *Cond*, and *Tree* tables) Table 1.3 shows the common variables that were used in the EWDB (column 3) and their corresponding item in FIADB datasets (column 2).

Table 1.3. ‘Crosswalk’ table between the EWDB and the FIADB datasets.

FIADB			EWDB		
(Tables) (Variables			[Table].[Variable]		
1	2		3		
Survey Table			Plot Table (continued)		
1	TABLENM		9	MEASMON	PLOT.MDATE
2	STATECD	COUNTY.STATE	10	MEASDAY	PLOT.MDATE
3	CYCLE	COUNTY.CYCLE	11	REMPER	PLOT.REMPER
4	SUBCYCLE		12	KINDCD	
5	STATEAB	COUNTY.STNAME	22	LAT	PLOT.LAT
6	STATENM		23	LON	PLOT.LONG
7	INVYR	COUNTY.DATE	24	ELEV	
8	MODDATE		25	EXPCURR	PLOT.EXPACR
9	CENSUSYR		26	EXPVOL	PLOT.EXPVOL
10	NFSYR		27	EXPGROW	PLOT.EXPGRO
11	RSCD		28	GROWCD	
12	NUMPANEL		29	EXPMORT	PLOT.EXPMOR
13	NOTES		30	MORTCD	
County Table			31	EXPREMV	PLOT.EXPREM
1	TABLENM		32	EXPCHNG	PLOT.EXPREM
2	STATECD	COUNTY.STATE	33	P2PANEL	
3	UNITCD	COUNTY.UNIT	34	P3PANEL	
4	COUNTYCD	COUNTY.COUNTY	35	ECOSUBCD	
5	COUNTYNM	COUNTY.CTYNAM	36	CONGCD	
6	UNITNM		37	MANUAL	
Plot Table			13	DESIGNCD	
1	TABLENM		14	RDCD	
2	STATECD	PLOT.STATE	15	RDDISTCD	
3	CYCLE		16	RDUSECD	
4	SUBCYCLE		17	PUBUSECD	
5	UNITCD	PLOT.UNIT	18	REUSECD1	
6	COUNTYCD	PLOT.COUNTY	19	REUSECD2	
7	PLOT	PLOT.PLTNUM	20	REUSECD3	
8	MEASYEAR	PLOT.MDATE	21	WATERCD	

Table 1.3 (continued) [2 of 3]

FIADB			EWDB		
(Tables) (Variables			[Table].[Variable]		
1	2	3	1	2	3
Cond Table			Cond Table (continued)		
1	TABLENM		32	ALSTKCD	PLOT.ALSTKPC
2	STATECD	PLOT.STATE	33	TRTOPCD	PLOT.TREATOP
3	CYCLE		34	DSTRBCD1	
4	SUBCYCLE		35	DSTRBYR1	
5	UNITCD	PLOT.UNIT	36	DSTRBCD2	
6	COUNTYCD	PLOT.COUNTY	37	DSTRBYR2	
7	PLOT	PLOT.PLTNUM	38	DSTRBCD3	
8	CONDID		39	DSTRBYR3	
9	CONDPROP		40	TRTCD1	
10	LANDCLCD	PLOT.GLUCUR	41	TRTYR1	
11	RESERVCD	PLOT.GLUCUR	42	TRTCD2	
12	OWNCD	PLOT.OWNER	43	TRTYR2	
13	OWNGRPCD	PLOT.OWNER	44	TRTCD3	
14	FORINDCD	PLOT.OWNER	45	TRTYR3	
15	ADFORCD	PLOT.ADFOR	46	PASTNFCD	
16	FORTYPCD	PLOT.TYPCUR	47	PRESNFCD	
17	FLDTYPCD		48	NFYEAR	
18	MAPDEN		Tree Table		
19	STDAGE	PLOT.STDAGE	1	TABLENM	
20	STDSZCD	PLOT.STDSIZE	2	STATECD	TREE.STATE
21	FLDSZCD		3	CYCLE	
22	SITECLCD	PLOT.SITECL	4	SUBCYCE	
23	SICOND	POLT.SI	5	UNITCD	TREE.UNIT
24	SIBASE	PLOT.SIAGE	6	COUNTYCD	TREE.COUNTY
25	SISP		7	PLOT	TREE.PLOT
26	STDORGCD	PLOT.STORCUR	8	SUBP	TREE.POINT
27	STDORGSP		9	TREE	TREE.TREE
28	SLOPE	PLOT.SLOPE	10	CONDID	
29	ASPECT	PLOT.ASPECT	11	AZIMUTH	
30	PHYSCLCD	PHYSIO	12	DIST	
31	GSSTKCD	PLOT.GRSTKPC			

Table 1.3 (continued) [3 of 3]

FIADB			EWDB		
(Tables) (Variables			[Table].[Variable]		
1	2	3	1	2	3
Tree Table (continued)			Tree Table (continued)		
13	PREVCOND		44	VOLCFNET	TREE.NETCFVL
14	PREVSUBC		45	VOLCFGRS	
15	STATUSCD	TREE.STATUS	46	VOLCSNET	TREE.NETCFSL
16	LEANCD		47	VOLCSGRS	
17	UTILCD		48	VOLBFNET	TREE.NETBFVL
18	SPCD	TREE.SPP	49	VOLBFGRS	
19	SPGRPCD	TREE.SPGRP	50	VOLCFSND	
20	DIA	TREE.DBHCUR	51	GROWCFGS	TREE.NETCFGR
21	DIAHTCD		52	GROWBFSL	TREE.NETBFGR
22	HT		53	GROWCFAL	
23	HTCD		54	MORTCFGS	TREE.NETCFVL
24	ACTUALHT		55	MORTBFSL	TREE.NETBFVL
25	TREECLCD	TREE.TCLASS	56	MORTCFAL	
26	CR	TREE.CRATIO	57	REMVCFGS	TREE.NETCFVL
27	CCLCD	TREE.CRCLS	58	REMBFSL	TREE.NETBFVL
28	TREEGRCD	TREE.TGRADE	59	REMVCFAL	
29	AGENTCD	TREE.DAMAGE	60	DRYBIOT	TREE.TOTBIO
30	CULL		61	DRYBIOM	TREE.MERBIO
31	DAMLOC1		62	DIACHECK	
32	DAMTYP1		63	MORTYR	
33	DAMSEV1				
34	DAMLOC2				
35	DAMTYP2				
36	DAMSEV2				
37	DECAYCD				
38	STOCKING				
39	WDLDSTEM				
40	TPACURR	TREE.VOLFAC			
41	TPAMORT	TREE.MORTFAC			
42	TPAREMV	TREE.REMVFAC			
43	TPAGROW	TREE.VOLFAC			

The forest industry and a variety of research organizations have a history of extensive utilization of the data. Using geographic information systems (GIS) technology and available map making tools applied to FIA data, one is able to quickly produce forest inventory reports on an area of interest anywhere in the United States. Joining it with other spatial data such information may become an essential part of one's decision making and planning. For example, soil carbon densities (Xu and Prisley, 2000) by land cover type can be estimated by allocating spatial soil *C* information with its associated forest or non-forest cover.

The FIA program uses permanent, re-measured plots to ensure consistency of data analyses and permit land cover change observations. The number of inventory plots varies per state and county such that each plot represents certain area of homogenous land cover on the ground. For example, each plot in Maine represents about 28 km² (*EXPACR* field) and the average area represented by an FIA plot in Minnesota is 5 km². Since the development of new technologies most FIA field personnel have adopted the use of global positioning system (GPS) devices to precisely locate inventory plots on the ground.

Very seldom is there a complete database to incorporate data of all environmental spheres at once, such as forest, hydrology, soils, and land use. Mostly due to independent funding sources, data collection is divided among agencies and one way to bring all these data together is by overlaying data layers according to their spatial location.

Until very recently, plot coordinates used to be distributed with rest of forest inventory data. Their location was available with 100 arc-second (approximately equal to 3 km distance for central Maine) rounding for both latitude and longitude coordinates to restrict unauthorized outside interference. Due to new security policies the distribution of inventory plot locations is no longer in effect and no one but authorized FIA agents have full access to all data.

AVHRR Land Cover Dataset

At the advent of space technology and the development of earth observation satellites, such as Landsat, the ability to produce up-to-date land cover information has greatly increased. Satellite imagery received from the Advanced Very High Resolution Radiometer (AVHRR) provides coarse spatial resolution with a short revisit time period,

i.e. high temporal resolution. These specifications of the AVHRR data allow imagery of the earth's surface with much reduced cloud cover to be prepared every 10-30 days (Townshend, 1994).

The Advanced Very High Resolution Radiometer (AVHRR) dataset depicts general forest cover types of the United States and is derived from AVHRR composite images from the 1991 growing season. The US Forest Service has defined the original forest type classes and Zhu and Evans (1994) describe the classification approach. A total of 25 classes are interpreted from AVHRR imagery. Data resolution is 1 km and can be obtained in GeoTIFF format from the [webpage](#) of the National Atlas of the United States. The scale of the data is 1:7,500,000 and is acquired in Lambert Azimuthal Equal Area projection.

The subject of this project is to compare different techniques for soil organic carbon estimation by forest type group. The study adopts SOC estimation methods described in Bliss et al. (1995) incorporating unique methodology for STATSGO soil data manipulation along with uncertainty analysis. We may not be able to conclude whether one approach is better than another, since there is no means to validate our results against an objective, true set of SOC estimates. However, we will compare results to previous similar work and explain differences.

RESEARCH QUESTIONS

Filling in and replacing uncertain records in the STATSGO database increases the data pool for SOC analysis and should increase the accuracy of the results in this study as well as help assess present SOC maps and regional SOC models. Using the mean of a lognormal distribution of values should provide a more representative estimate of soil properties than the simple arithmetic mean of minimum and maximum values by reducing the variation between extreme values.

Rounding inventory plot coordinates significantly affects SOC results by forest type group. SOC from STATSGO soil polygon overlay analysis with FIA data are more accurate and better agree with recently published estimates than these from raster (cell-based) STATSGO overlay with satellite-derived (AVHRR) forest cover data. The latter is

inspired by the fact that field verified forest cover data (FIA) is more accurate than remotely sensed satellite data.

OBJECTIVES

There are four objectives of this study that are organized in two main bodies of text in Chapter 4 (Part A and Part B of Results and Discussion) addressing specific research questions regarding soils and forest data uncertainty to allow effective comparison of SOC estimation techniques. The objectives are as follow:

- A. To improve the ability to produce soil organic carbon estimates from spatial soils and forest inventory datasets.
 - 1) To develop an automated tool for filling gaps in STATSGO and computing SOC (kg m^{-2}).
 - 2) To analyze SOC variation caused by using different computation techniques: (i) *Normal* and (ii) *Lognormal* approach; (iii) filled and (iv) unfilled STATSGO database.
- B. To produce nationwide SOC results at a regional scale.
 - 1) To produce SOC (kg m^{-2}) estimates for three layer depths (25 cm, 1 m, 2 m) by Forest Inventory and Analysis (FIA) program forest type and forest type group supported by STATSGO polygon based soil *C* storage maps.
 - 2) To calculate and compare SOC by forest type group computed from different forest cover datasets; (i) FIA and (ii) AVHRR.
- C. To compare results obtained using methods developed in *A* and *B* with other published sources of national SOC estimates.

In Part A, the goal is to calculate and compare mineral soil SOC to 2 m from STATSGO tables by four methods. Regional SOC stores for Maine and Minnesota will be calculated from unfilled and filled STATSGO databases using averages from untransformed and lognormal-transformed database values (*Normal* and *Lognormal* distribution approaches). The magnitude of variation in SOC estimates caused by the filling and transformation procedures will be presented along with mass SOC summarized by Forest Inventory Assessment (FIA) forest type groups.

In Part B, the goal is to calculate and compare soil organic carbon stocks to 2 m by forest type group from STATSGO soils and Forest Inventory and Analysis (FIA) data by three methods for Maine and Minnesota. Regional SOC estimates will be computed from spatial overlay of SOC values by mapping unit with FIA forest type group data presented in two formats: (i) when exact inventory plot locations are provided and (ii) when plot coordinates are rounded to the nearest 100 arc-second. SOC for the third method are derived from a raster-based GIS analysis of STATSGO soils and AVHRR forest type group datasets.

Soil organic carbon will be estimated by FIA forest type (forest type group) to three layer depths (25 cm, 1 m, and 2 m) for the 48 contiguous States summarized in nine regional units. There will be four sets of results for each depth class by region: (1) SOC computed by the *Lognormal distribution* approach for (1a) all soil orders and (1b) without the Histosols; (2) SOC computed by the *Normal distribution* approach for (2a) all soil orders and (2b) without the Histosols.

CHAPTER 2: LITERATURE REVIEW

SOC inventories and analyses are required for soil quality assessments (Sikora and Stott, 1996) and C cycling predictions (Ellert et al., 2002) and are used for state and larger regional planning by politicians, regulators, and agency employees. Modelers of global climate change need accurate and complete soil organic carbon inventories because the SOC pool represents the largest component of the global C pool (Jobbagy and Jackson, 2000) and acts as a regulator of atmospheric CO₂ levels (Amundson, 2001). Previous studies have attempted to extrapolate sources of SOC data available in pedon databases over large areas using small-scale digital soil maps (Franzmeier et al., 1985; Huntington et al., 1988; Davidson and Lefebvre, 1993; Kern, 1994; Homann et al., 1998; Galbraith et al., 2003). These researchers and modelers encountered consistent problems because of the incomplete nature of the soil databases.

Pedon databases seldom contain a complete inventory of the soil series used as map unit components, or they may fail to include organic C (OC) or organic matter (OM), bulk density (BD), and rock fragment content (RFC) values for surface litter and some mineral subsurface layers (Davidson and Lefebvre, 1993). USDA-NRCS Soil Interpretation Record (SIR) databases that accompany their digital soil surveys include all map unit components but do not include data from surface litter and are often missing OM from mineral subsurface horizons (Bliss et al., 1995). These omissions are critical limitations to producing accurate SOC estimates (Lacelle et al., 2001). For instance, Stone et al. (1993) reported that OC in the Bh horizons of Florida Spodosols contained about 17% of the solum OC. Franzmeier et al. (1985, Table 6) reported that up to half of the mass OC in Midwestern US Histosols was found in the subsoil below 1 m, and that on a regional basis the kg C m⁻² to 2 m was 1.07 times (7%) higher than the kg C m⁻² to 1 m. These studies show the potential impact on pedon OC totals when using database tables that are incomplete, especially if the missing data is OC or OM (Bliss et al., 1995).

The State Soil Geographic database (STATSGO) is a widely-used SIR database that provides a digital map and fifteen different tables for each state in the US. A complete description is given in Homann et al. (1998, p. 791) and in the STATSGO Data Users Guide (National Soil Survey Center 1994). STATSGO was first issued in 1991,

revised in 1993, and last revised in December 1994. Soil characterization, global climate change modeling (Bliss et al., 1995), soil organic carbon storage estimation (Homann et al., 1998; Davidson and Lefebvre, 1993) and mapping (Lacalle et al., 2001) projects have used STATSGO data. Modelers must calculate representative values for soil properties in STATSGO tables, unlike the databases currently used by USDA-NRCS that contain representative values assigned by soil scientists familiar with the soil resources.

STATSGO tables often contain empty (null) cells and zero values. The cells may have started out empty because a value had not been entered or null because the properties were not applicable, such as the OM content for a layer of bedrock. Zero values were valid in layers where the property values were immeasurably low or rounded down to a 0.0 value. However, blank cells may be converted to null or zero and null may be converted to zero during database conversions and file transfers, creating entries that are invalid. Null values are problematic because they cause calculation errors that result in loss of data from that layer and lower values for properties where mass is calculated. Inadvertent divisions by zero values also cause computation errors and loss of information.

Zero values in STATSGO tables that are invalid can be detected through expert knowledge, and should be replaced by estimated or calculated values. For example, Davidson and Lefebvre (1993) used results and data from technical bulletins to replace 0.0 OC concentration values with 0.2 values for lower layers in their STATSGO tables, based on the results of published research. Textures that have rock fragment modifiers but zero values in all rock fragment content fields are in evident error. Conversely, soil textures without a rock fragment modifier could possibly contain zero rock fragments. Zero would never be a reasonable value for minimum or maximum bulk density in a soil horizon and therefore, should be treated as invalid data.

A variety of methods have been used to fill null cells and replace inaccurate zero values in pedon and STATSGO databases. Davidson and Lefebvre (1993) and Galbraith et al. (2003) used expert judgment to fill missing data based on ancillary data and data from similar soil series. Davidson and Lefebvre (1993) also assigned minimum values for OM in subsoil layers to replace zero values based on studies that had shown that 0.1 to 0.3% OM actually occurred. Kern (1994) assigned OM concentration where it was

invalid by taking one-half the OM value from the horizon above, and adjusted bulk density data based on regressions from USDA lab data. Homann et al. (1995) replaced missing data with values from adjoining, genetically similar horizons in the same pedon, and by calculating replacement values from accessory sampling data. Lacelle et al. (2001, p. 489) filled missing bulk density data with replacement values from adjacent layers with similar clay and OM, and used a neural-net relationship to calculate bulk densities in six categories of soils. Unlike many other pedon and SIR databases, STATSGO contains records for each component of each map unit, and these records are nearly complete for properties in the upper 20 cm but have many missing values in lower layers. Homann et al. (1998) used ratios of volumetric SOC in the upper 20 cm to determine the relationship between soil map unit components, then applied that ratio to modify existing subsoil layer SOC for use in the subsoil layers of similar soils that had incomplete records. These methods prevented unreasonably low pedon SOC values while extrapolating incomplete SOC data to calculate regional SOC stocks.

Most investigators find it satisfactory to assume a symmetrical (normal) distribution of STATSGO data and use the simple average between the minimum and maximum values as a representative value (Davidson and Lefebvre, 1993; Kern, 1994; Bliss et al., 1995). However, many soil property distributions are skewed rather than symmetrical (Homann et al., 1998; Grigal et al., 1991; Brejda et al., 2000), as shown in Figure 1.2,a. If STATSGO values that are high and low estimates of soil properties are also not normally distributed, then some type of data transformation must be used to compute a representative value. Homann et al. (1998) used coefficient-transformed data assuming skewed distribution and untransformed data assuming normal distribution but chose the simple average of untransformed data because their coefficient-transformed representative C values (1998, Eq. 1) reduced regional SOC values from 13.8 to 12.9 kg C m⁻² in the upper 1 m. The higher SOC value was in closer agreement to the values calculated from arithmetic means of pedon data sets alone and area-weighted for four map units, but slightly higher than estimates from coarser-scale FAO soils map and ecosystem type maps (Olson et al., 1985). The authors stated that the accuracy and uncertainty of the regional mass SOC values cannot be objectively assessed (Homann et al., 1998), leaving an uncertainty as to whether or not the transformation improved

prediction accuracy. Recently, Brejda et al. (2000) demonstrated that \log_e (lognormal) transformed estimates for most soil properties approximated a normal distribution (Figure 1.2,b) more closely than the distribution of the non-transformed data (Figure 1.2,a). In addition, due to the fact that most soil properties are assigned only positive values and just a few of them appear as outliers, the \log_e transformation reduces variability twofold to threefold for most soil attributes (Brejda et al., 2000).

Cihlar et al. (1996) tested the classification accuracy of AVHRR (1 km) with the higher resolution Landsat TM (30m) imagery data for different land environments in the northern latitudes. They reported 45 to 60 % accuracy of the AVHRR data showing its limitations for higher resolution analysis on areas with significant patchiness of land cover distribution (Cihlar et al., 1996). Roderick et al. (1996) focused on the processing of AVHRR sensor data to get the final output of forest type layer, which was done through quantization error assessment. They suggested great caution of using satellite derived data for vegetation mapping purposes on areas with low reflectance (Roderick et al., 1996).

CHAPTER 3: METHODS AND MATERIALS

PROJECT ANALYSIS OVERVIEW

Figure 3.1 depicts the input data source and sequence of tasks and analysis that are used in this project. The STATSGO soils and the Forest Inventory and Analysis (FIA) databases provided all necessary tabular and spatial information to produce SOC (kg m^{-2}) values by forest type group for the contiguous United States.

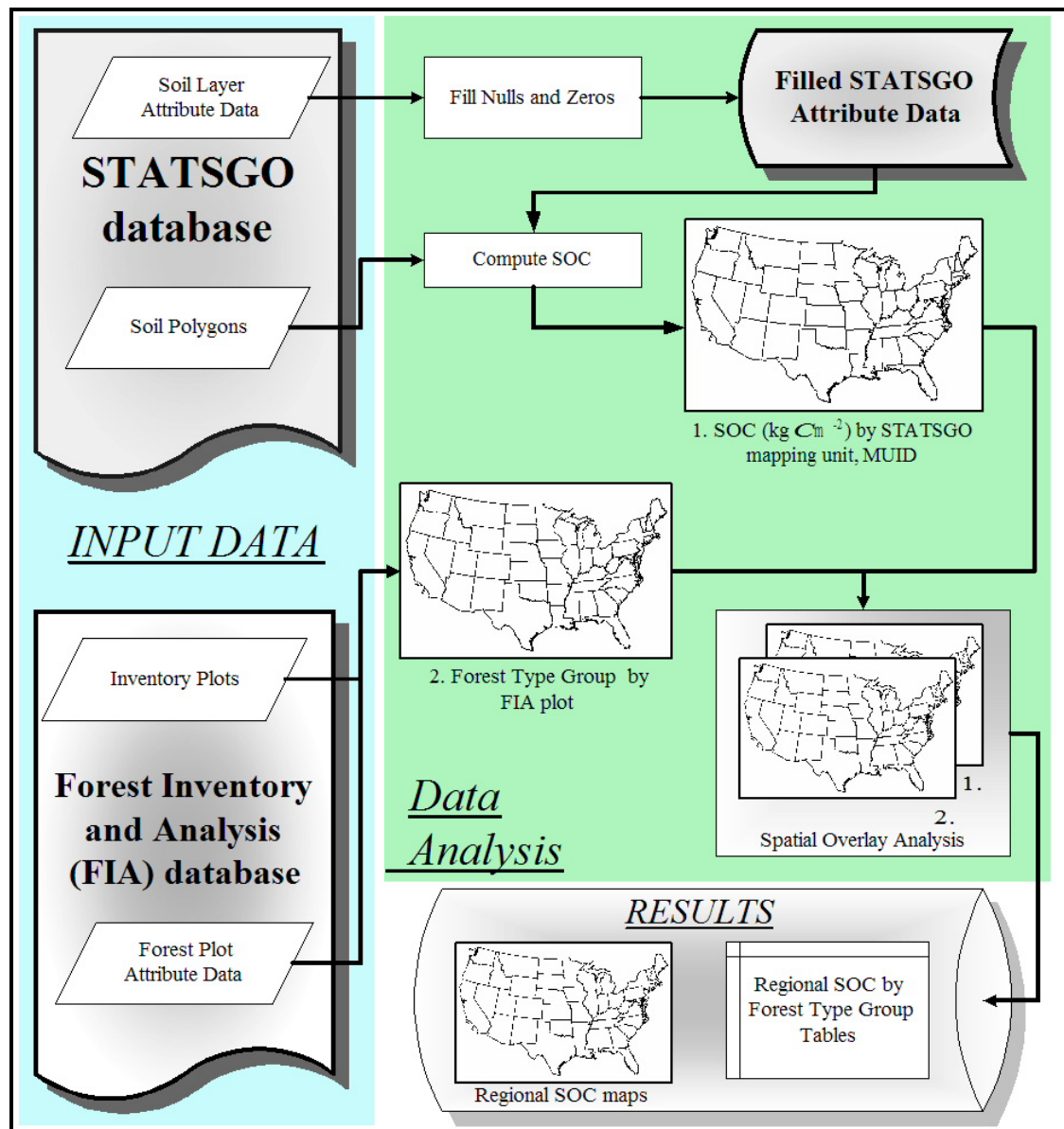


Figure 3.1. Data organization and project analysis flow.

STATSGO soil properties (organic matter content, OM; bulk density, BD; and rock fragment content, RFC) were checked for data consistency and all invalid layer entries were replaced (filled) with average estimates computed from valid records in similar soil layers. This resulted in a “filled” STATSGO database. The latter was used to compute SOC for each soil layer that was summarized by STATSGO mapping unit (Figure 3.1). The resultant SOC polygon layer was overlaid with the FIA inventory plot (point layer) and each forested plot was assigned SOC (kg m^{-2}) value of the STATSGO soil polygon that contained the plot. The overlay analysis produced tabular SOC estimates by forest type group at a regional scale that were associated with SOC distribution maps for the entire United States (Figure 3.1).

STATSGO DATA ANALYSIS

STATSGO spatial and tabular data were downloaded for Maine and Minnesota. Relationships between the STATSGO *Layer*, *Comp*, *Mapunit*, and *Taxclass* tables and the 19 variables of interest are depicted in Figure 3.2. The fields that held those 19 variables were integrated into one new table using the key fields *MUID*, *SEQNUM*, and *LAYERNUM* as indicated by the arrows. The properties used to calculate the mass SOC for each map unit component were found in the *Layer* (layer) table (Figure 3.2). The STATSGO tables from Maine and Minnesota were sorted and filtered to estimate the frequency and distribution of null and zero values. The intention in this study was to locate all incomplete and invalid records (database rows) for the variables (columns or fields) used to calculate mass SOC (Table 1.2).

The variables OM, BD, and RFC used to calculate SOC (Bliss et al., 1995) were assumed to be interrelated and variable by soil layer and texture. Therefore texture was used as the basis for calculating and assigning the averages to variables with invalid entries. The texture for any layer was represented by codes listed in the separate *TEXTURE 1*, *TEXTURE 2*, and *TEXTURE 3* fields. The texture entries were single codes unless the layer contained $\geq 15\%$ volume of rock fragments. In that case, there was an adjective (rock fragment modifier code) that preceded the texture code and was separated by a dash, such as *STV-FSL* (*STV* = “very stony”; *FSL* = “fine sandy loam”). These

separate codes are referred to as *TEXTUREx_LEFT* (rock fragment modifier code) and *TEXTUREx_RIGHT* (texture codes for < 15% volume of rock fragments).

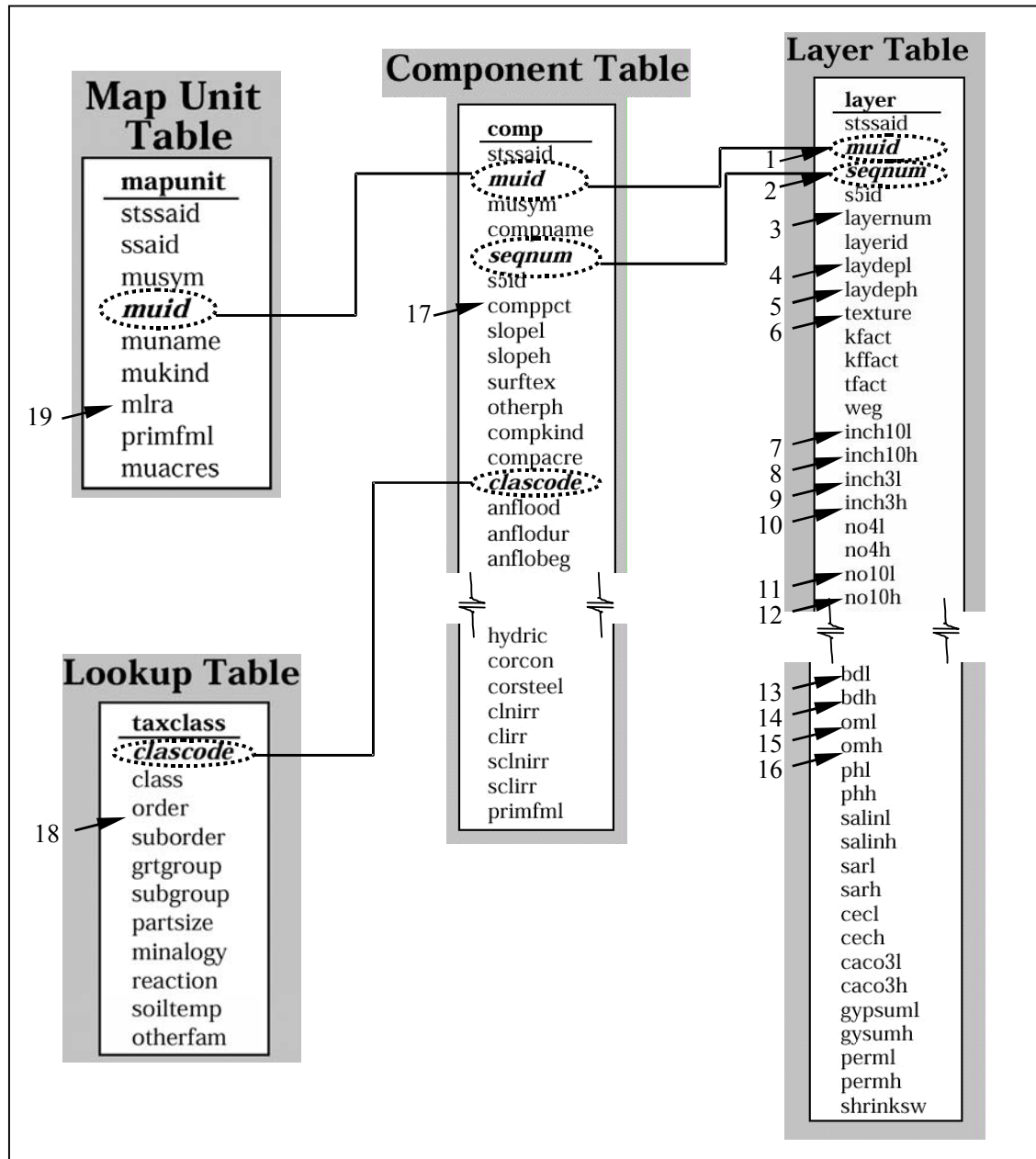


Figure 3.2. STATSGO attribute relational data tables used in the fixing process (Modified from National Soil Survey Center. 1994; page 33).

The approach of this study was to create lookup tables from means of valid STATSGO values grouped by layer, MLRA (Soil Conservation Service, 1981), and Soil Taxonomy soil order (Soil Survey Staff, 1999) and use them to replace STATSGO data in the same groups that were invalid (Figure 3.3). All records that were incomplete or appeared to be incorrectly filled with a null or zero value were considered invalid. The example in Figure 3.3 shows the steps of checking for invalid layer entries and replacing (filling) of those that meet the definition for invalid records. In this example, 144 Virginia STATSGO *Layer* records were filtered as invalid. Replacement average values for all 144 records were computed from similar layers with existing valid entries (Figure 3.3).

Overview of Null and Zero Record Filling

Fixing procedures differ between targeted soil properties. The idea is that each of these parameters, (i) organic matter content (*OML*, *OMH*), (ii) bulk density (*BDL*, *BDH*), and (iii) rock fragments content (*INCH3L*, *INCH3H*; *INCH10L*, *INCH10H*; *NO10L*, *NO10H*) vary in their range of values according to the texture class of the soil layer and parent material. Hence, there are several grouping schemes that are specifically adjusted for each group of variables (i), (ii), and (iii).

Initially, all soil records are grouped into similar sets of layer records that have the same soil order (*Histosols*, *Spodosols*, etc), same major land resource area (*MLRA*, *MapUnit* table), same texture class (*loamy*, *sandy*, etc.), and same layer number ('layer number =1' for surface layers). Then all valid entries, non-zero and non-null, are used to compute an average value that is used to replace the problematic records by soil variable.

The purpose of the groupings is to modify the level of similarity between specific textures. Each fixing procedure is specific for OM, BD, and RFC variables and follows multiple phases of grouping valid records into subsets of data that are further used for average value estimation. The number of records in the subsets increases with each phase caused by intentional simplification of the grouping criteria. The trend is from multiple unique groups with small number of records, (phase I) to fewer groups with more records per group (phase IV). The efficacy of this grouping system enables replacement of most of the null and zero record entries detected in the *Layer* table.

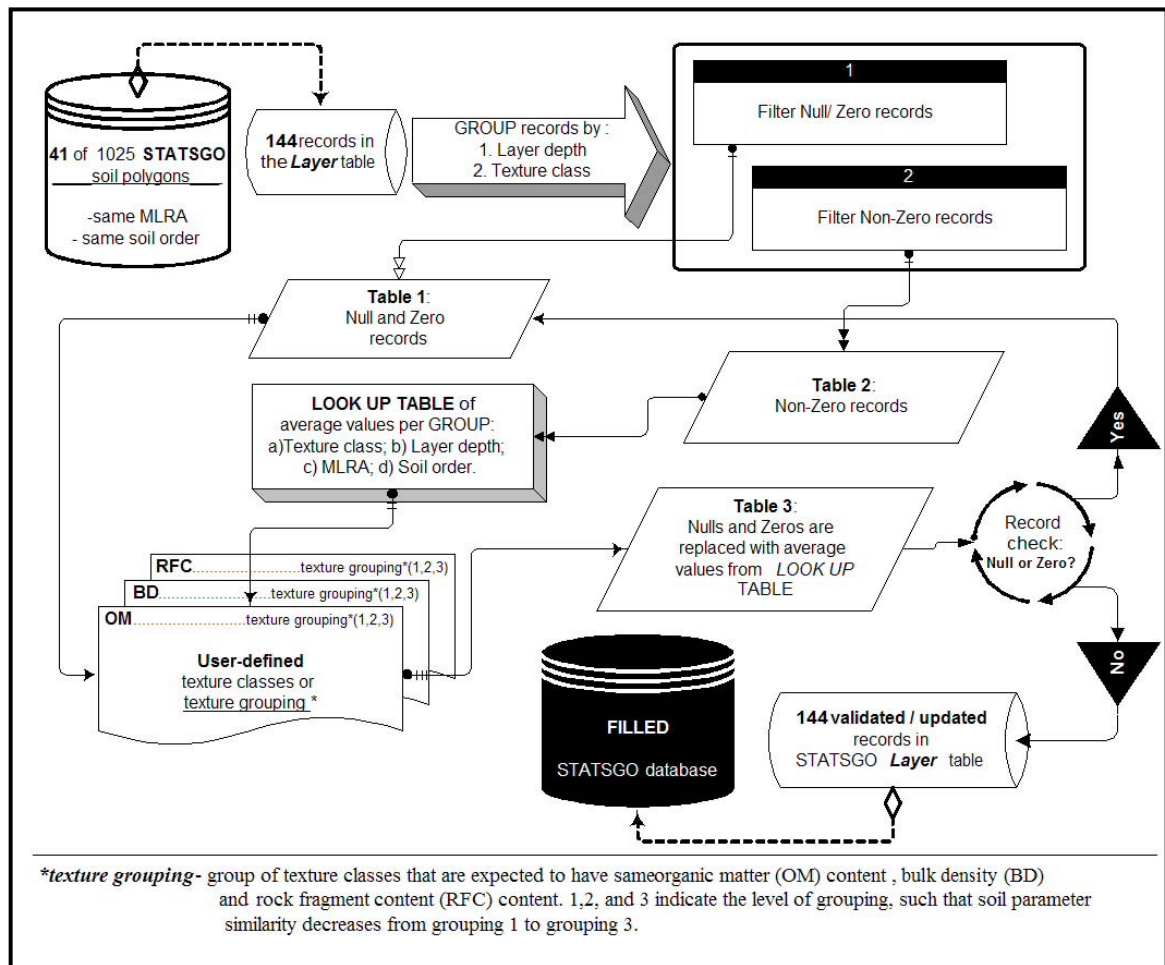


Figure 3.3. Schematics for replacing/filling null and zero values in the STATSGO *Layer* table.

In each grouping there is a limitation for the minimum number of non-zero and non-null records that is set by the user at the beginning of the fixing process. This limitation is required to establish reliability for the replacement values, i.e. how many valid entries are to be used to consider the new value as valid and reliable. The design is set to check for a sufficient valid data pool for each grouping. If the number of valid records is less than the assigned limit then the resulting average value is marked as unreliable and the fixing process continues to the next phase of fixing procedure. Subsequently, a greater number of valid entries are assigned to a less specific grouping class and are averaged to produce a reliable replacement value. At the completion of each phase all invalid entries (null and/or zero) are marked as fixed and are removed from the set of problematic records in order to increase speed of data processing and minimize computer memory use.

To increase efficiency the data manipulation is automated through a user-friendly software product allowing direct interaction of the researcher with the STATSGO data so that desired limitations and domains can be set. Intermediate tables can be exported in different formats, such as Microsoft Excel and dBASE format, so that original and fixed tables are compared and checked for consistency and rationale. The intention is to build a tool that provides an easy, timely, scientifically sound, transparent and repeatable way of fixing the above-mentioned STATSGO data discrepancies. This Microsoft Access-based product provides future STATSGO users with a quick and efficient tool for replacing invalid soil property entries with values in the expected range and brings together essential information from the database tables to estimate SOC (kg m^{-2} or metric tons ha^{-1}) by mapping unit identifier (*MUID*) for each state of interest.

The flexibility of the tool is achieved through a set of look-up tables that are incorporated in sequential macros. These tables can be studied and updated in a manner that fits user demands. Currently, all look-up tables provide soil variable grouping schemes that are based on soil scientist expertise in our team combined with consultation from USDA-NRCS specialists. The grouping of records in the *Layer* table is based on the texture class designation that is assigned by field crews. Provided the correct texture code in the *TEXTURE* field (*Layer* table) the automated tool filters records with valid entries and

computes the simple average of all that is then assigned to similar invalid (null and/or zero) records.

Currently this product is limited to fixing soil properties in the STATSGO *Layer* table that relate to SOC. The variables that are fixed are organic matter (OM) content, bulk density (BD), and rock fragment content (RFC).

The result of “fixing” the invalid entries was an original unfilled and a new filled database. Each fixing procedure followed multiple phases (I to IV) of grouping valid records prior to calculating average values by layer within MLRA and soil order groups. Grouping strategies for creating lookup tables were drafted with the joint effort of soil scientists involved with the project. The number of valid records increased with each phase caused by intentional generalization of the grouping criteria. The trend was from multiple specific groups with a small number of valid records [phase I] to fewer, more general groups that included greater number of valid records [phase IV]. The efficacy of this grouping system enabled replacement of most of the null and invalid zero record entries detected in the *Layer* table. In cases where the number of valid records in any group was less than three, the average value was considered unreliable and the null or zero value was left for fixing at the next more general phase. The fourth phase was designed to almost certainly produce groups of three or more valid records. At the completion of each phase, the fixed records were marked and removed from the set of problem records.

The texture for each layer within the MLRA and soil order groups was used as the basis for matching records and assigning lookup table averages to variables with invalid entries. *TEXTURE 1* was considered as the most likely and representative texture, and *TEXTURE 2* and *TEXTURE 3* as secondary and tertiary texture designations. *TEXTURE 1* was used primarily for record matching because it was more likely to be filled with valid codes than *TEXTURE 2* or *TEXTURE 3*. Therefore, only *TEXTURE 1* was used to compute replacement values that were stored in the lookup table. To insure full data utilization, there were three sequential procedures for exact matching in phase I: (i) invalid records from the *Layer* table were updated with representative values from a lookup table after joining both tables by *TEXTURE 1* field and filtering for exact record matching; (ii) remaining invalid nulls and zeros were replaced using *TEXTURE 2* as a

joining field; and (iii) remaining invalid nulls and zeros were replaced using *TEXTURE 3* as a joining field. Also, when codes *VAR* (“variable”), *SR* (“stratified”), and *UNK* (“unknown”) were used in *TEXTURE 1* to single out soil horizons with highly variable or unpredictable textures, the code in *TEXTURE 2* was used as a proxy to the code in *TEXTURE 1*. When *TEXTURE 1* contained *VAR*, *SR*, or *UNK* and the *TEXTURE 2* and *TEXTURE 3* fields were left blank or were null, the average of all valid records in that soil layer was used to represent the replacement value for the variable in question. In phases II to IV the groupings were assigned only by *TEXTURE 1* definition and *TEXTURE 2* and *TEXTURE 3* were not considered.

The sections that follow present the simplified description of the invalid STATSGO values replacement assumptions and methodology. The detailed version of the methodology is incorporated in [Appendix A](#).

Assumptions for Modifying Organic Matter Data

Layer number, parent material, soil order, and texture of the fine-earth (< 2 mm) were assumed to affect and/or reflect OM content, but RFC was not. Only *TEXTUREx_RIGHT* codes were used for OM computations and record matching. For example, textures with codes *STV-FSL* (*STV* = “very stony”; *FSL* = “fine sandy loam”) and *FSL* were grouped in the same set of records. The following assumptions were considered applicable for determining validity of *OMH* and *OML* records: (a) *OMH* and *OML* should be zero for the following textures: *WB* (“weathered bedrock”), *UWB* (“unweathered bedrock”), *CEM* (“cemented”), and *IND* (“indurated”); (b) zero value for *OML* is acceptable in mineral or inorganic layers but not for organic or mucky layers; (c) an average value of zero is acceptable for *OMH* for textures that are *ICE* (“ice or frozen soil”) layers or mostly rock fragments such as *FRAG* (“fragmental material”), *G* (“gravel”), and *CIND* (“cinders”).

The following assumptions were considered applicable for grouping valid *OMH* and *OML* records: (a) data were separated by MLRA; (b) within each MLRA group, data were separated into four specific soil order groups: Histosols, Spodosols, Andisols, and all others; (c) data was kept separate by layer in each MLRA and soil order group before averages were calculated by grouping in phases I to IV.

The following four phases were used for replacing invalid *OMH* and *OML* records (Table 3.1). In phase I, invalid records were matched with replacement values using an exact match in *TEXTURE 1_RIGHT* or its proxy *TEXTURE 2_RIGHT*. In phases II, III, and IV replacements were made based on the aggregated texture categories in groups 2 to 4 shown in Table 3.1. In phases II to IV replacements were made based on the aggregated texture categories in groups 2 to 4 shown in Table 3.1. Replacements continued until all invalid records were replaced. Zeros and nulls that were acceptable as zeros were marked as zero records in the new “fixed” table.

Assumptions for Modifying Bulk Density Data

Layer number, parent material, soil order, texture of the fine-earth, rock fragment size and content were assumed to affect the BD of the soil layer. Stones (*ST*, *STV*, and *STX* texture codes), flags (*FL*, *FLV*, and *FLX*), and boulders (*BY*, *BYV*, and *BYX*) were so large that they were assumed not to affect the BD of the fine-earth, but gravel (*G*, *GRC*, *GRF*, *GRV*, *GRX*), chert (*CR*, *CRC*, *CRV*, *CRX*), cinders (*CIND*), pumice (*PUM*, *APUM*, *HPUM*, *MPUM*), shale (*SH*, *SHV*, *SHX*), and channers (*CN*, *CNV*, *CNX*) were. Both *TEXTUREx_LEFT* and *TEXTUREx_RIGHT* codes were used for BD computations and record matching. The following assumptions were considered applicable for determining validity of *BDH* and *BDL* records: (a) *BDL* and *BDH* of zero was acceptable for textures *WB* (“weathered bedrock”), *UWB* (“unweathered bedrock”), *IND* (“indurated”), and *CEM* (“cemented”). The assumptions for grouping valid *BDH* and *BDL* records and for procedures for replacing invalid *BDH* and *BDL* records were the same described for *OMH* and *OML* above, with the following exceptions: (a) after fixing procedures, a value of 0.00 was used instead of null to prevent calculation errors, i.e. although 0.00 was not a reasonable value for bulk density, if the final result for 0.00 SOC is appropriate for these textures, then it can be accomplished by assigning 0.00 to BD; and (b) the grouping strategies were different as noted in Table 3.2.

Table 3.1. Texture-grouping for the organic matter content parameter (*OMH* and *OML*) fixing procedures.

Phase	I	II	III	IV
Texture Code	Texture Name (Group 1)	Group 2	Group 3	Group 4
APUM	ashy-pumiceous	fine ejecta	ejecta	mineral
ASHY	ashy	fine ejecta	ejecta	mineral
ASK	ashy-skeletal	fine ejecta	ejecta	mineral
BM	bouldery_mucky	mucky	O modified	organic
BVM	very_bouldery_mucky	mucky	O modified	organic
BXM	extremely_bouldery_mucky	mucky	O modified	organic
C	clay	clay	clayey loamy	mineral
CAM	angular_cobbly_mucky	mucky	O modified	organic
CE	coprogenous_earth	organic limnic	high Decomp O	organic modified
CEM	cemented	no carbon*1	no carbon*1	no carbon*1
CIND	cinders	no carbon*1	no carbon*1	no carbon*1
CL	clay_loam	clay loams	clayey loamy	mineral
CM	cobbly_mucky	mucky	O modified	organic
CNDY	cindery	coarse ejecta	ejecta	mineral
COS	coarse_sand	sands	sandy	mineral
COSL	coarse_sandy_loam	sandy loams	loamy	mineral
CVM	very_cobbly_mucky	mucky	O modified	organic
CXM	extremely_cobbly_mucky	mucky	O modified	organic
DE	diatomaceous_earth	inorganic limnic	inorganic limnic	inorganic limnic
FB	fibric_material	fibric	low Decomp O	organic modified
FRAG	fragmental_material	no carbon*1	no carbon*1	no carbon*1
FS	fine_sand	sands	sandy	mineral
FSL	fine_sandy_loam	sandy loams	loamy	mineral
G	gravel	no carbon*1	no carbon*1	no carbon*1
GCM	coarse_gravelly_mucky	mucky	O modified	organic
GFM	fine_gravelly_mucky	mucky	O modified	organic
GM	gravelly_mucky	mucky	O modified	organic
GVM	very_gravelly_mucky	mucky	O modified	organic
GXM	extremely_gravelly_mucky	mucky	O modified	organic
GYP	gypsiferous_material	loams	loamy	mineral
HM	hemic_material	hemic	high Decomp O	organic modified
HPUM	hydrous-pumiceous	hydrous	ejecta	mineral
HSK	hydrous-skeletal	hydrous	ejecta	mineral
HYDR	hydrous	hydrous	ejecta	mineral
ICE	ice_or_frozen_soil	no carbon*1	no carbon*1	no carbon*1
IND	indurated	no carbon*2	no carbon*2	no carbon*2
L	loam	loams	loamy	mineral
LCOS	loamy_coarse_sand	loamy sands	sandy	mineral

Table 3.1: (continued)

Phase	I	II	III	IV
Texture Code	Texture Name (Group 1)	Group 2	Group 3	Group 4
LFS	loamy_fine_sand	loamy sands	sandy	mineral
LS	loamy_sand	loamy sands	sandy	mineral
LVFS	loamy_very_fine_sand	sandy loams	loamy	mineral
MARL	marl	inorganic limnic	inorganic limnic	inorganic limnic
MEDL	medial	medium ejecta	ejecta	mineral
MK	mucky	mucky	O modified	organic
MPT	mucky-peat	hemic	high Decomp O	organic modified
MPUM	medial-pumiceous	medium ejecta	ejecta	mineral
MSK	medial-skeletal	medium ejecta	ejecta	mineral
MUCK	muck	sapric	high Decomp O	organic modified
PEAT	peat	fibric	low Decomp O	organic modified
PT	peaty	peaty	low Decomp O	organic modified
PUM	pumiceous	coarse ejecta	ejecta	mineral
S	sand	sands	sandy	mineral
SC	sandy_clay	clay	clayey loamy	mineral
SCL	sandy_clay_loam	clay loams	clayey loamy	mineral
SG	sand_and_gravel	sands	sandy	mineral
SI	silt	silty	loamy	mineral
SIC	silty_clay	clay	clayey loamy	mineral
SICL	silty_clay_loam	clay loams	clayey loamy	mineral
SIL	silt_loam	silty	loamy	mineral
SL	sandy_loam	sandy loams	loamy	mineral
SM	stony_mucky	mucky	O modified	organic
SP	sapric_material	sapric	high Decomp O	organic modified
SR	stratified	-	-	-
SVM	very_stony_mucky	mucky	O modified	organic
SXM	extremely_stony_mucky	mucky	O modified	organic
UNK	unknown	-	-	-
UWB	unweathered_bedrock	no carbon*2	no carbon*2	no carbon*2
VAR	variable	-	-	-
VFS	very_fine_sand	sands	sandy	mineral
VFSL	very_fine_sandy_loam	loams	loamy	mineral
WB	weathered_bedrock	no carbon*2	no carbon*2	no carbon*2

*1 there is carbon in some layers but is not available (use OMH of 0.0)

*2 use OMH of 0.0

Table 3.2. Texture-grouping for the bulk density parameter (*BDH* and *BDL*) fixing procedures.

Phase	I	II	III	IV
Texture Code	Texture Name (Group 1)	Group 2	Group 3	Group 4
APUM	ashy-pumiceous	ejecta w/rocks	ejecta	fine fragmental*1
ASHY	ashy	ejecta	ejecta	fine fragmental*1
ASK	ashy-skeletal	ejecta w/rocks	ejecta	fine fragmental*1
BM	bouldery_mucky	mucky	mucky	Inorganic + organic
BVM	very_bouldery_mucky	mucky	mucky	Inorganic + organic
BXM	extremely_bouldery_mucky	mucky	mucky	Inorganic + organic
C	clay	clayey	clayey	layer average
CAM	angular_cobbly_mucky	mucky w/rocks	mucky	Inorganic + organic
CE	coprogenous_earth	sapric	organic	organic
CEM	cemented	cemented	cemented	cemented*3
CIND	cinders	fine fragmental	fine fragmental	fine fragmental*1
CL	clay_loam	clayey	clayey	layer average
CM	cobbly_mucky	mucky w/rocks	mucky	Inorganic + organic
COS	coarse_sand	sandy	sandy	layer average
COSL	coarse_sandy_loam	loamy	loamy	layer average
CVM	very_cobbly_mucky	mucky w/rocks	mucky	Inorganic + organic
CXM	extremely_cobbly_mucky	mucky w/rocks	mucky	Inorganic + organic
DE	diatomaceous_earth	loamy	loamy	layer average
FB	fibric_material	fibric	organic	organic
FRAG	fragmental_material	fragmental	fragmental	fragmental*2
FS	fine_sand	sandy	sandy	layer average
FSL	fine_sandy_loam	loamy	loamy	layer average
G	gravel	fine fragmental	fine fragmental	fine fragmental*1
GCM	coarse_gravelly_mucky	mucky w/rocks	mucky	Inorganic + organic
GFM	fine_gravelly_mucky	mucky w/rocks	mucky	Inorganic + organic
GM	gravelly_mucky	mucky w/rocks	mucky	Inorganic + organic
GVM	very_gravelly_mucky	mucky w/rocks	mucky	Inorganic + organic
GXM	extremely_gravelly_mucky	mucky w/rocks	mucky	Inorganic + organic
GYP	gypsiferous_material	loamy	loamy	layer average
HM	hemic_material	hemic	organic	organic
HPUM	hydrous-pumiceous	ejecta w/rocks	ejecta	fine fragmental*1
HSK	hydrous-skeletal	ejecta w/rocks	ejecta	fine fragmental*1
HYDR	hydrous	ejecta	ejecta	fine fragmental*1
ICE	ice_or_frozen_soil	cemented	cemented	cemented*3
IND	indurated	cemented	cemented	cemented*3
L	loam	loamy	loamy	layer average
LCOS	loamy_coarse_sand	sandy	sandy	layer average
LFS	loamy_fine_sand	sandy	sandy	layer average

Table 3.2: (continued)

Phase	I	II	III	IV
Texture Code	Texture Name (Group 1)	Group 2	Group 3	Group 4
LS	loamy_sand	sandy	sandy	layer average
LVFS	loamy_very_fine_sand	loamy	loamy	layer average
MARL	marl	clayey	clayey	layer average
MEDL	medial	ejecta	ejecta	fine fragmental*1
MK	mucky	mucky	mucky	Inorganic + organic
MPT	mucky-peat	hemic	organic	organic
MPUM	medial-pumiceous	ejecta w/rocks	ejecta	fine fragmental*1
MSK	medial-skeletal	ejecta w/rocks	ejecta	fine fragmental*1
MUCK	muck	sapric	organic	organic
PEAT	peat	fibric	organic	organic
PT	peaty	mucky	mucky	Inorganic + organic
PUM	pumiceous	ejecta w/rocks	ejecta	fine fragmental*1
S	sand	sandy	sandy	layer average
SC	sandy_clay	clayey	clayey	layer average
SCL	sandy_clay_loam	clayey	clayey	layer average
SG	sand_and_gravel	fine fragmental	fine fragmental	fine fragmental*1
SI	silt	loamy	loamy	layer average
SIC	silty_clay	clayey	clayey	layer average
SICL	silty_clay_loam	clayey	clayey	layer average
SIL	silt_loam	loamy	loamy	layer average
SL	sandy_loam	loamy	loamy	layer average
SM	stony_mucky	mucky	mucky	Inorganic + organic
SP	sapric_material	sapric	organic	organic
SR	stratified	-	-	-
SVM	very_stony_mucky	mucky	mucky	Inorganic + organic
SXM	extremely_stony_mucky	mucky	mucky	Inorganic + organic
UNK	unknown	-	-	-
UWB	unweathered_bedrock	cemented	cemented	cemented*3
VAR	variable	-	-	-
VFS	very_fine_sand	sandy	sandy	layer average
VFSL	very_fine_sandy_loam	loamy	loamy	layer average
WB	weathered_bedrock	cemented	cemented	cemented*3

*1 use BDL of 0.7 and BDH of 0.85 (From Hawaii STATSGO)

*2 use BDL of 2.0 and BDH of 2.6 (From California STATSGO)

*3 use BDL of 1.5 and BDH of 2.0

Assumptions for Modifying Rock Fragment Data

Layer number, parent material, and texture were assumed to affect the RFC of the soil layer, but soil order was not. It was assumed that soil layers with stones would also contain smaller size rock fragments. The same concept was used when cobbles were present. However, it was not assumed that layers with gravel necessarily contained cobbles, or that layers with cobbles always contained stones. Gravel, cobble, and stone reference the hierarchy of rock fragment particle size in increasing order: gravel (from 0.2 to 7.5 cm) < cobble (from 7.5 to 25 cm) < stone (greater than 25 cm).

Both *TEXTURE_x_LEFT* and *TEXTURE_x_RIGHT* codes were used for RFC computations and record matching. The following assumptions were considered applicable for determining validity of RFC records: (a) zero values were acceptable for *INCH3L* and *INCH3H* (cobbles) and *INCH10L* and *INCH10H* (stones) if no rock fragment modifier was present; (b) zero values were not acceptable for *INCH3H* (cobbles) and *INCH10H* (stones) if any *TEXTURE_x_LEFT* code indicated RFC volume to be $\geq 15\%$; and (c) zero values were not acceptable for *NO10L* or *NO10H* because those variables represented the percent weight of rock fragments with size less than 7.5 cm plus those that passed through a No.10 sieve (2 mm screen), which means that a zero value would not be possible unless there was no fine earth in the layer at all, as in solid bedrock.

The following assumptions were considered applicable for grouping valid RFC records: (a) data were separated by MLRA; (b) data was kept separate by layer in each MLRA group before averages were calculated by grouping in phases I to IV. The procedure for replacing invalid RFC records were similar to those described for *OMH* and *OML* above, except that replacement was based on the presence of a code in any of *TEXTURE 1_LEFT*, *TEXTURE 2_LEFT*, or *TEXTURE 3_LEFT* rather than based on *TEXTURE 1_LEFT* alone. As before, replacement was based on the first *TEXTURE_x_LEFT* code found in the layer, checked in order from 1 to 3. The grouping strategies for RFC were different than for *OMH* and *OML* as noted in Table 3.3.

Table 3.3. Texture-grouping for rock fragment content parameter (*INCH3*, *INCH10*, and *NO10*) fixing procedures.

Phase	I	II	III	IV
Texture Code	Texture Name (Group 1)	Group 2	Group 3	Group 4
APUM ³	ashy-pumiceous	coarse ejecta	coarse	layer average
ASHY	ashy	nonrocky	fine	zero
ASK ^{2,3}	ashy-skeletal	coarse ejecta	coarse	layer average
BM ^{1,2,3}	bouldery_mucky	rocky	medium	layer average
BVM ^{1,2,3}	very_bouldery_mucky	very rocky	coarse	layer average
BXM ^{1,2,3}	extremely_bouldery_mucky	extremely rocky	coarse	layer average
BY ^{1,2,3}	bouldery	rocky	medium	layer average
BYV ^{1,2,3}	very_bouldery	very rocky	coarse	layer average
BYX ^{1,2,3}	extremely_bouldery	extremely rocky	coarse	layer average
C	clay	nonrocky	fine	zero
CAM ^{2,3}	angular_cobbly_mucky	rocky	medium	layer average
CB ^{2,3}	cobbly	rocky	medium	layer average
CBA ^{2,3}	angular_cobbly	rocky	medium	layer average
CBV ^{2,3}	very_cobbly	very rocky	coarse	layer average
CBX ^{2,3}	extremely_cobbly	extremely rocky	coarse	layer average
CE	coprogenous_earth	nonrocky	fine	zero
CEM ³	cemented	rock	rock	zero
CIND ³	cinders	coarse ejecta	coarse	layer average
CL	clay_loam	nonrocky	fine	zero
CM ^{2,3}	cobbly_mucky	rocky	medium	layer average
CN ^{2,3}	channery	rocky	medium	layer average
CNDY ³	cindery	rocky	medium	layer average
CNV ^{2,3}	very_channery	very rocky	coarse	layer average
CNX ^{2,3}	extremely_channery	extremely rocky	coarse	layer average
COS	coarse_sand	nonrocky	fine	zero
COSL	coarse_sandy_loam	nonrocky	fine	zero
CR ³	cherty	rocky	medium	layer average
CRC ³	coarse_cherty	rocky	medium	layer average
CRV ³	very_cherty	very rocky	coarse	layer average
CRX ³	extremely_cherty	extremely rocky	coarse	layer average
CVM ^{2,3}	very_cobbly_mucky	very rocky	coarse	layer average
CXM ^{2,3}	extremely_cobbly_mucky	extremely rocky	coarse	layer average
DE	diatomaceous_earth	nonrocky	fine	zero

Table 3.3: (continued) [2 of 4]

Phase	I	II	III	IV
Texture Code	Texture Name (Group 1)	Group 2	Group 3	Group 4
FB	fibric_material	nonrocky	fine	zero
FL ^{1,2,3}	flaggy	rocky	medium	layer average
FLV ^{1,2,3}	very_flaggy	very rocky	coarse	layer average
FLX ^{1,2,3}	extremely_flaggy	extremely rocky	coarse	layer average
FRAG ^{1,2,3}	fragmental_material	fragmental	coarse	layer average
FS	fine_sand	nonrocky	fine	zero
FSL	fine_sandy_loam	nonrocky	fine	zero
G ³	gravel	fragmental	coarse	layer average
GCM ³	coarse_gravelly_mucky	rocky	medium	layer average
GFM ³	fine_gravelly_mucky	rocky	medium	layer average
GM ³	gravelly_mucky	rocky	medium	layer average
GR ³	gravelly	rocky	medium	layer average
GRC ³	coarse_gravelly	rocky	medium	layer average
GRF ³	fine_gravelly	rocky	medium	layer average
GRV ³	very_gravelly	very rocky	coarse	layer average
GRX ³	extremely_gravelly	extremely rocky	coarse	layer average
GVM ³	very_gravelly_mucky	very rocky	coarse	layer average
GXM ³	extremely_gravelly_mucky	extremely rocky	coarse	layer average
GYP	gypsiferous_material	nonrocky	fine	zero
HM	hemic_material	nonrocky	fine	zero
HPUM ³	hydrous-pumiceous	coarse ejecta	coarse	layer average
HSK ³	hydrous-skeletal	coarse ejecta	coarse	layer average
HYDR	hydrous	nonrocky	fine	zero
ICE	ice_or_frozen_soil	nonrocky	fine	zero
IND ³	indurated	rock	rock	zero
L	loam	nonrocky	fine	zero
LCOS	loamy_coarse_sand	nonrocky	fine	zero
LFS	loamy_fine_sand	nonrocky	fine	zero
LS	loamy_sand	nonrocky	fine	zero
LVFS	loamy_very_fine_sand	nonrocky	fine	zero
MARL	marl	nonrocky	fine	zero
MEDL	medial	nonrocky	fine	zero
MK	mucky	nonrocky	fine	zero

Table 3.3: (continued) [3 of 4]

Phase	I	II	III	IV
Texture Code	Texture Name (Group 1)	Group 2	Group 3	Group 4
MPT	mucky-peat	nonrocky	fine	zero
MPUM ³	medial-pumiceous	coarse ejecta	coarse	layer average
MSK ^{2,3}	medial-skeletal	coarse ejecta	coarse	layer average
MUCK	muck	nonrocky	fine	zero
PEAT	peat	nonrocky	fine	zero
PT	peaty	nonrocky	fine	zero
PUM ³	pumiceous	coarse ejecta	coarse	layer average
RB ^{1,2,3}	rubby	rocky	medium	layer average
S	sand	nonrocky	fine	zero
SC	sandy_clay	nonrocky	fine	zero
SCL	sandy_clay_loam	nonrocky	fine	zero
SG ³	sand_and_gravel	fragmental	coarse	layer average
SH ³	shaly	rocky	medium	layer average
SHV ³	very_shaly	very rocky	coarse	layer average
SHX ³	extremely_shaly	extremely rocky	coarse	layer average
SI	silt	nonrocky	fine	zero
SIC	silty_clay	nonrocky	fine	zero
SICL	silty_clay_loam	nonrocky	fine	zero
SIL	silt_loam	nonrocky	fine	zero
SL	sandy_loam	nonrocky	fine	zero
SM ^{1,2,3}	stony_mucky	rocky	medium	layer average
SP	sapric_material	nonrocky	fine	zero
SR	stratified	nonrocky	fine	zero
ST ^{1,2,3}	stony	rocky	medium	layer average
STV ^{1,2,3}	very_stony	very rocky	coarse	layer average
STX ^{1,2,3}	extremely_stony	extremely rocky	coarse	layer average
SVM ^{1,2,3}	very_stony_mucky	very rocky	coarse	layer average
SXM ^{1,2,3}	extremely_stony_mucky	extremely rocky	coarse	layer average
SY ³	slaty	rocky	medium	layer average
SYV ³	very_slaty	very rocky	coarse	layer average
SYX ³	extremely_slaty	extremely rocky	coarse	layer average
UNK	unknown	nonrocky	fine	zero
UWB ³	unweathered_bedrock	rock	rock	zero

Table 3.3: (continued) [4 of 4]

Phase	I	II	III	IV
Texture Code	Texture Name (Group 1)	Group 2	Group 3	Group 4
VAR	variable	nonrocky	fine	zero
VFS	very_fine_sand	nonrocky	fine	zero
VFSL	very_fine_sandy_loam	nonrocky	fine	zero
WB ³	weathered_bedrock	rock	rock	zero

¹ indicates texture code to be analyzed for *INCH10H* and *INCH10L* variables

² indicates texture code to be analyzed for *INCH3H* and *INCH3L* variables

³ indicates texture code to be analyzed for *NO10H* and *NO10L* variables

SOC Computation: Formulae

The desired output units for SOC by forest type (forest type group) was kg C m^{-2} (or metric tons C ha^{-1}) derived for 3 different depths in order to match the USDA Forest Service database standards: 25 cm (10 inch) surface layer, 100 cm (39 inch) depth, and the entire profile (up to 200 cm). The results, summarized by region were computed by both the *Lognormal* and *Normal* approaches from two sets of the fixed STATSGO database tables, (i) including all soil orders and (ii) and excluding Histosols.

The procedures and formulae shown below were similar to the methods in Bliss et al. (1995) and should describe SOC estimation for both the *Normal* and *Lognormal* distribution approaches. Both approaches employed the same data attributes with the only difference being the formula for gaining a single representative value from available minimum and maximum measurements for organic matter (OM) content and bulk density (BD) soil properties.

Formulae

Each unique layer in the STATSGO *Layer* table, defined by the *LAYERNUM* variable, was treated as a separate entity and its layer organic carbon (LOC, kg C m^{-2}) was calculated as the product of organic carbon (OC), bulk density (BD), rock fragment conversion factor (R), and layer depth in equation [1] (Figure 3.4).

Organic carbon (OC, decimal number units) was estimated from organic matter content parameters, *OMH* and *OML* (percent by weight). 0.58 was the proportion of

organic matter content (OM) that was considered organic carbon (OC); 0.01 was used to convert percentage units to a decimal number.

The next two equations show the arithmetic means of computing OC by the *Normal* (Eq. 1.1a) and *Lognormal* (Eq. 1.1b) distribution approach:

$$OC = (OMH + OML) * 0.5 * 0.58 * 0.01 \quad \text{Eq. [1.1a]}$$

$$OC = \left[e^{([\ln OMH + \ln OML] * 0.5)} \right] * 0.58 * 0.01 \quad \text{Eq. [1.1b]}$$

Bulk density (BD, kg m⁻³ units) was estimated from *BDH* and *BDL* parameters (g cm⁻³ of fine soil fraction). A factor of a 1,000 (1000 = (1,000,000 cm³m⁻³) * (0.001 kg g⁻¹)) was used to convert g cm⁻³ to kg m⁻³ units.

The next two equations depict BD computation by the *Normal* (Eq. 1.2a) and *Lognormal* (Eq. 1.2b) distribution approach:

$$BD = (BDH + BDL) * 0.5 * 1,000 \quad \text{Eq. [1.2a]}$$

$$BD = \left[e^{([\ln BDH + \ln BDL] * 0.5)} \right] * 1,000 \quad \text{Eq. [1.2b]}$$

Soil layer thickness (LAYERDEPTH, meter units) was estimated as LAYERDEPTH = (LAYDEPH - LAYDEPL) * 0.0254, where *LAYDEPH* and *LAYDEPL* parameters represented the respective depths (in inches) to the lower and upper boundary of the layer, i.e. *LAYDEPH* > *LAYDEPL* for all layers. 0.0254 was used to convert inches to meters.

Rock fragment conversion factor (R, decimal number units) was estimated as $R = (V_{\text{fines}} / (V_{\text{fines}} + V_{\text{rock}}))^{-1}$ similar to the volume proportion of fine earth described in Bliss et al. (1995, page 298).

$$\text{LOC} = \text{OC} * \text{BD} * \text{LAYERDEPTH} * \text{R} * 10 \quad \text{Eq.[1]}$$

Some investigators preferred organic carbon results in metric tons ha^{-1} . Equation [2], below, provides the conversion from the original (kg C m^{-2}) estimates to metric tons C ha^{-1} . Note that $10 = (1 \text{ kg m}^{-2}) * (10,000 \text{ m}^2 \text{ ha}^{-1}) * (0.001 \text{ metric tons kg}^{-1})$

$$\text{LOC [metric tons C ha}^{-1}] = \text{LOC [kg C m}^{-2}] * 10 \quad \text{Eq.[2]}$$

Next, the values of LOC (kg C m^{-2}) were summed by map unit component (*SEQNUM* variable) in the *STATSGO Comp* table and stored as component organic carbon (*CompOC*) using equation [3]:

$$\text{CompOC} = \sum_{L=1}^n (\text{LOC}) \quad \text{Eq.[3]}$$

where *CompOC* = organic carbon estimate (kg C m^{-2}) by map unit component (*SEQNUM*). L = index number for layers with carbon data from the surface to standard depths, (L=1,2,3...n).

It was important that the specific summation procedures were individually applied on each layer organic carbon estimate to proportionally calculate LOC for the three standard depths: 0 to 25 cm (0 to 10 inch), 0 to 100 cm (0 to 39 inch), and lastly 0 to 200 cm (0 to 78 inch) or depth to bedrock, whichever was shallower.

The *STATSGO* map units may comprise of several different components identified by the unique *SEQNUM* variable in the *Comp* table. Each component was assigned a percentage, *COMPPCT* field, to depict its frequency within the map unit. The

total SOC value of the map unit, $MUID_OC$, was calculated as the sum of all component level results, $CompOC$, weighed by their respective percentage value within the mapping unit, as shown in equation [4] below:

$$MUID_OC = \sum_{M=1}^S (CompOC * COMPPCT * 0.01) \quad \text{Eq. [4]}$$

where $MUID_OC$ (kg C m^{-2}) = total SOC estimate by map unit identifier,
 $MUID.COMPPCT$ (percent) = component composition by $SEQNUM$ within each map unit.
 M = index number for number of components that are included in the map unit (M = 1,2,3...s).

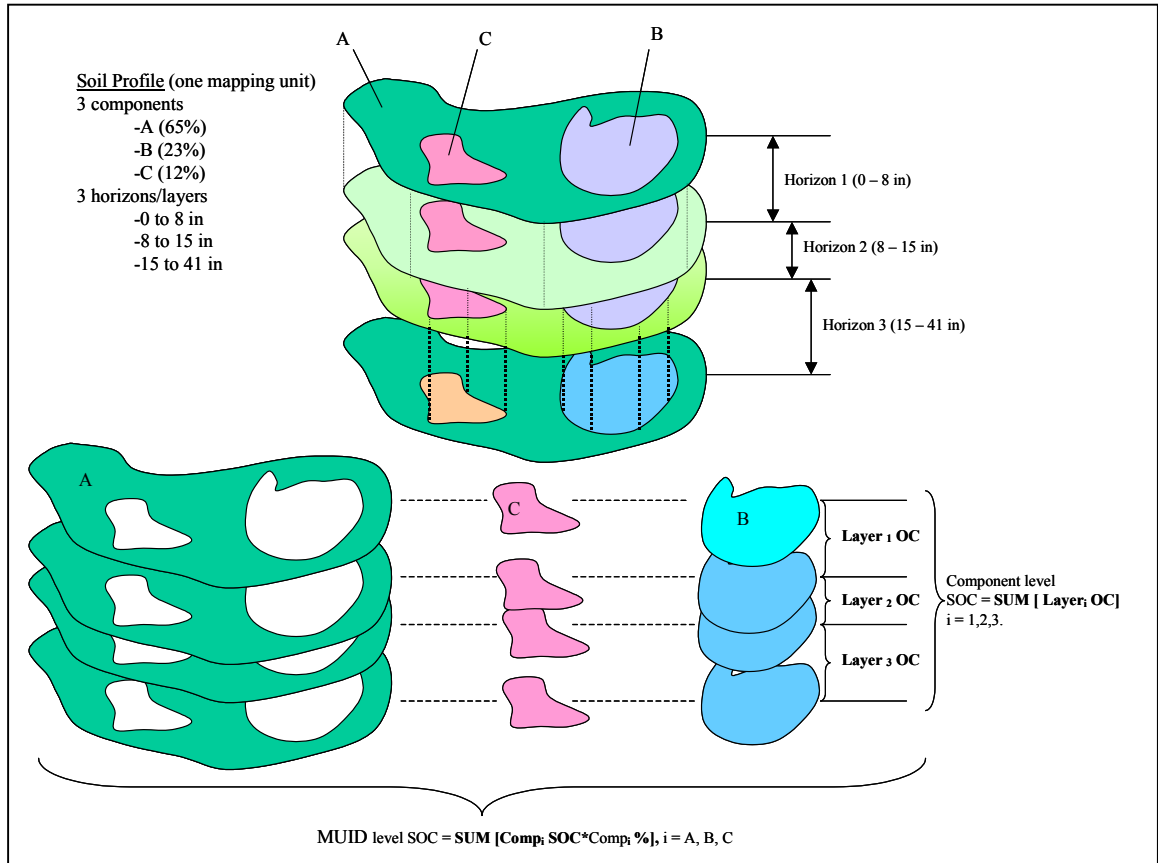


Figure 3.4. Example of levels for SOC computation showing the intermediate summations from layer level to MUID level, a.k.a. the ‘layer’ approach.

The final stage of SOC by forest type group estimation occurred after a spatial overlay was performed between STATSGO soil polygons and FIA inventory plots. Due to the ongoing FIA confidentiality policy debates we were unable to get FIA plot location coordinates. Instead, we requested all necessary tasks to be carried out at the National FIA Geospatial Service Center (NatFIAGSC) . The framework of the overlay analysis was sent to the NatFIAGSC along with soil *C* estimates by STATSGO mapping unit identifier, *MUID_OC*. Equation [5] described in the next section was used to combine *MUID_OC* data with forest inventory data in order to produce the desired output of SOC values by forest type group.

SOC Estimation by Four Methods

The kg C m^{-2} was determined for each unique layer (*LAYERNUM* variable) in the *Layer* table as layer organic carbon (LOC) from both unfilled and filled STATSGO databases for Maine and Minnesota. The LOC was summed for each map unit component (*SEQNUM*) and by map unit (*MUID*) to a depth of 2 m. STATSGO map units contained up to 21 components, and each map unit component contained up to six soil or rock layers. The lower boundary of the bottom layer was either extrapolated or truncated to 200 cm and the property values in that record (database row) were proportioned accordingly before the summation. Layers composed of bedrock or indurated materials were assigned 0 kg C m^{-2} . The LOC was calculated by two methods both before and after invalid records were fixed. The *normal* method assumed a normal distribution of non-transformed property values and $\text{LOC}_{\text{normal}}$ was calculated as described by Davidson and Lefebvre (1993) and Bliss et al. (1995). The *lognormal* method assumed a normal distribution of logarithmically transformed property values, such that $X_{\text{transformed}} = \ln(X)$, and $\text{LOC}_{\text{lognormal}}$ was calculated the same as $\text{LOC}_{\text{normal}}$ but with the following exceptions: (i) the antilog of [(natural logarithm of *OMH* + natural logarithm of *OML*) *0.5] was used in place of the simple average of the *OMH* and *OML* values, and (ii) the antilog of [(natural logarithm of *BDH* + natural logarithm of *BDL*) *0.5] was used in place of the simple average of the *BDH* and *BDL* values. The calculations of LOC were written such that average 0.0 OM or 0.0 BD would not result in calculation errors, but would result in 0.00 kg C m^{-2} , which would be true for layers with no organic matter.

For example, if *OMH* was equal to 0.5 (percent by weight) and *OML* was 0, then the logarithmic function used in the *lognormal* approach would produce an error, i.e. $\ln(OML)$ would be incomputable. We filtered all records that had organic matter content between 0 and 1% and assigned a 0.0 OM in order to avoid this computational error. Although we were intentionally changing the original STATSGO data by eliminating problematic records the impact of this procedure on SOC estimates was minimal due to the low amounts of OM in the layer.

The RFC variables were not converted to lognormal values because it was logical for many layers to have zero values for both *INCH3* and *INCH10* variables even after replacing invalid records. Within this range the logarithmic function, $X_{\text{transformed}} = \ln(X)$, yields negative values that decrease exponentially reaching negative infinity ($X_{\text{transformed}} \rightarrow -\infty$) as property values get smaller, i.e. $X \rightarrow 0$ (Figure 3.5). To avoid potential problems addressing these soil properties, the RFC variables were analyzed by the simple average method in both *Normal* and *Lognormal* distribution approaches. The calculations of LOC were written such that simple average values of zero for *INCH3* or *INCH10* variables would not result in 0.00 kg C m⁻² unless OM and BD were also zero (Bliss et al., 1995, p. 288).

STATSGO map units were comprised of several different components identified by unique MUID - *SEQNUM* variable combinations in the *Comp* (component) table (Figure 3.2). LOC_{normal} and $LOC_{\text{lognormal}}$ were summed for the upper 200 cm of each map unit component (*SEQNUM*) of each map unit (*MUID*) and stored as map unit component organic carbon ($CompOC_{\text{normal}}$ and $CompOC_{\text{lognormal}}$) values. $CompOC_{\text{normal}}$ and $CompOC_{\text{lognormal}}$ were calculated following methods described by Bliss et al. (1995) except that the lower boundary of the bottom layer was either extrapolated or truncated to 200 cm and the property values in that record (database row) were proportioned accordingly before the summation in order to get the SOC to the 2-m depth. Map unit components (*SEQNUM*) of water, rock outcrop, and other miscellaneous land types were assigned 0 kg C m⁻².

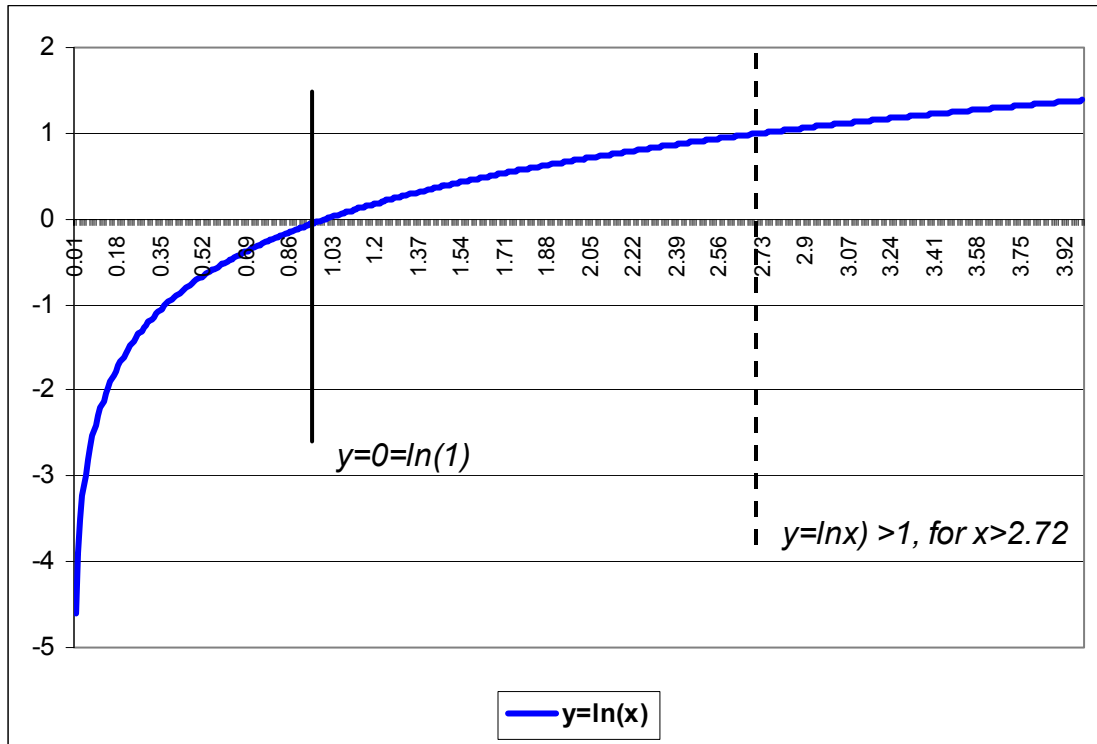


Figure 3.5. Graph of the logarithmic function, $y = \ln(x)$, showing change of values on the vertical axis, Y, as values of X, horizontal axis, increase from 0 to infinity; Special attention is brought to $X=1$ and $X=2.72$, where the transformed Y value is equal to 0 and 1, respectively.

Each map unit component was assigned a percentage in the *COMPPCT* field depicting its frequency within the map unit. The total SOC of each map unit (MUID) were calculated as the sum of all component SOC values weighted by their respective percentage within the mapping unit and stored as *MUID_OC_{normal}* and *MUID_OC_{lognormal}* values as kg C m^{-2} , following methods described by Bliss et al. (1995). The total mass of SOC for each polygon was calculated by multiplying *MUID_OC_{normal}* and *MUID_OC_{lognormal}* values times the area (from Albers Conical Equal Area projection) of each polygon with matching MUID. The total mass of SOC for each state was calculated by summing the mass SOC for each polygon in the spatial layer for that state. The result of these calculations was four STATSGO tables of mass SOC called Unfilled-Normal, Filled-Normal, Unfilled-Lognormal, and Filled-Lognormal data.

The next section summarizes the steps of SOC estimation that were used to produce SOC (kg m^{-2}) by STATSGO mapping unit

Summary of Steps

The first step was to compute organic carbon on a *layer* level (LOC, kg C m⁻²) using equation [1] for each record from the STATSGO *Layer* table.

The second step was to mark all layers in the *Layer* table that fell within each of the specific standard depths previously mentioned. Next, using separate procedures for each depth category all layers with *LAYDEPH* greater than or equal to the standard depth were excluded from the calculation of total LOC. All other layers were included in the analysis and were marked as such in the STATSGO database.

Third step was to calculate the total LOC within the constraining boundaries of each depth category. The subset of layer records that had *LAYDEPH* less than or equal to the standard depth was flagged and excluded from the *LOC-segment* analysis, explained below. Only marked layers with *LAYDEPH* and *LAYDEPL* that "bridged" the standard depth were subjected to the *LOC-segment* analysis (shown below) to allow estimation of LOC by depth category. The actual calculation process involved creating and joining series of intermediate tables in order to locate marked (flagged) layer records and to proceed with the *LOC-segment* analysis:

```
IF LAYDEPH <= StDt THEN LOCseg=LOC;
IF LAYDEPH => StDt AND LAYDEPL <= StDt
    THEN LOCseg=LOC* [ ( StDt-LAYDEPL ) / ( LAYDEPH-LAYDEPL ) ]
    ELSE IGNORE RECORD
END IF.
```

where *StDt* stands for standard depth, i.e. 25 cm, 100 cm, and *LOCseg* represents the portion of the layer organic carbon, that was found in the segment of soil mass constrained between the upper (*LAYDEPL*) and lower (*LAYDEPH*) boundaries of each depth category. Consequently, all segments for the total LOC were summarized by standard depth and were stored for further analysis (Figure 3.6).

The fourth Step was to summarize the total LOC for each component using equation [3]. The fifth step, equation [4], involved another summation that was accomplished on a higher level of analysis by mapping unit identifier, *MUID*, where each component's percentage value was used as a weighting factor that was populated in *COMPPCT* field of the *Comp* table.

In step six, we joined STATSGO and FIA datasets by spatial location in order to sum SOC stocks by FIA forest type group. We projected the STATSGO soil polygons from their native Albers Conical Equal Area projection based on North American Datum of 1927 (NAD'27) into decimal degrees of the same datum. Most FIA field crews were presently using and had recorded inventory data in that coordinate system, Geographic Coordinate System (GCS, NAD'27, decimal degrees). Upon completion of the overlay procedures all necessary data was available to proceed with equation [5] for SOC by forest type group analysis.

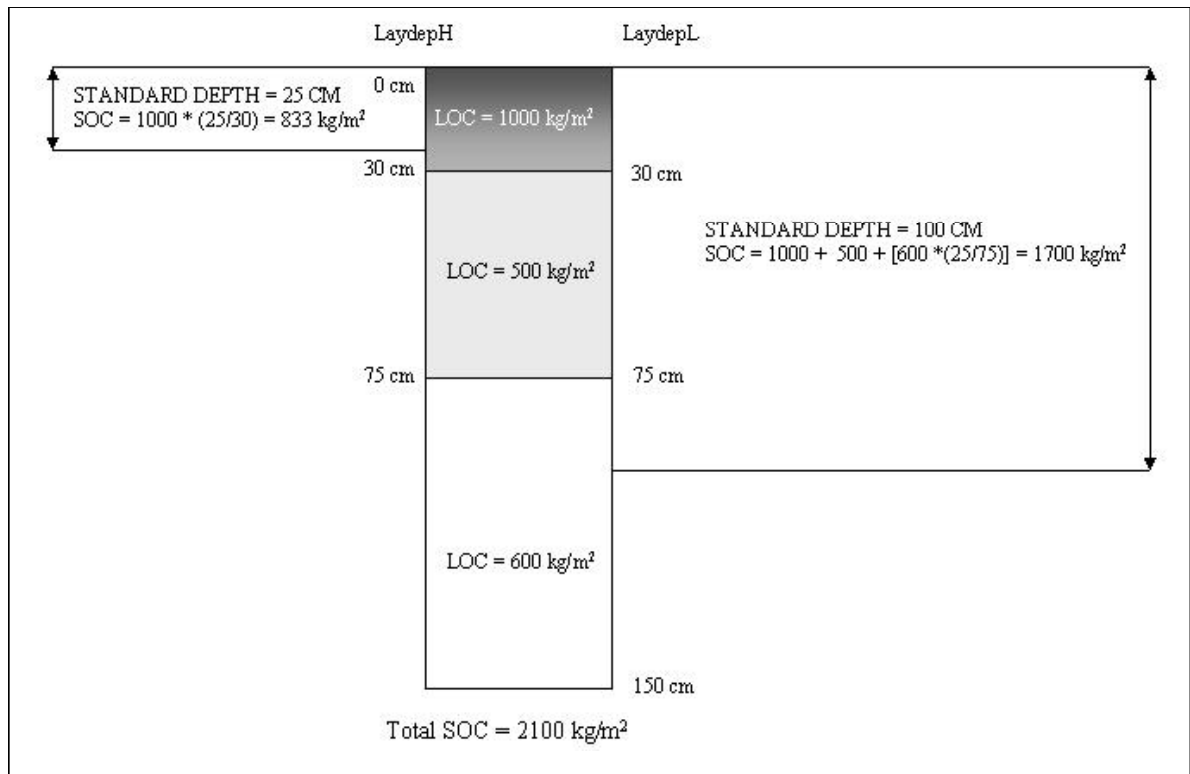


Figure 3.6. LOC (kg m^{-2}) proportion calculations for 0-25 cm and 0-100 cm standard depths based on real estimates.

FOREST COVER DATA SOURCE

To this stage of the analysis we had computed SOC (kg m^{-2}) values for the contiguous 48 United States by four different approaches, Filled-Lognormal, Filled-Normal, Unfilled-Lognormal, Unfilled-Normal. Next, we had to choose an appropriate forest cover data that should provide the desired forest type group information and should be spatially comprehensive for the entire U.S. There were two potential candidate data sources, the AVHRR and the FIA datasets.

We differentiated three possibilities to proceed with the analysis. One approach was to use satellite-derived AVHRR data. The other two options were to utilize field acquired forest data from the FIA program for two scenarios of plot location coordinates: (i) where the coordinates were rounded to the nearest 100 arc-second and (ii) where the exact location (Latitude and Longitude) was available. We hypothesized that AVHRR and rounded FIA plots would produce different results than the exact FIA plots.

AVHRR Land Cover Dataset

There was no report found on spatial accuracy for AVHRR forest type cover data. Due to very coarse resolution of the dataset we suspected its use and spatial applications to be limited to regional or national scales of analysis. We overlaid FIA inventory plot data for Maine and Minnesota with the AVHRR raster dataset to evaluate the accuracy of satellite-derived forest type group classes.

STATSGO soil polygons for Maine and Minnesota were projected to Lambert Azimuthal Equal Area Projection system to permit spatial data overlay with AVHRR data. We converted the AVHRR raster grid into shapefile feature class generating square vector polygon features with 1 km-by-1 km size. Next, each AVHRR forest type polygon was assigned a value for SOC (kg m^{-2}) to 2 m computed as area weighted average from SOC estimates of all soil polygons within AVHRR polygons. Following steps 1 to 6 discussed previously we produced SOC_{AVHRR} results to 2 m depth.

In previous attempts for producing soil *C* estimates by forest type group Heath et al. (2002) overlaid raster based STATSGO soil polygons with the AVHRR data. A general caveat of such analysis is that polygon to raster conversion algorithms often lose important data detail, especially at a 1 km resolution. For example, the *POLYGRID*

(ArcINFO®, ESRI, Inc.) function assigns the value of the largest polygon segment within the 1 km-by-1 km area extent to the output raster cell. Although *POLYGRID* works well in other spatial analysis, in the case of soil *C* distribution it is expected to lower the final SOC values due to the fact that large soil areas tend to have lower SOC stocks than small strips of concave landforms such as stream floodplains.

FIA Database. Data Structure

The Forest Inventory and Analysis (FIA) database includes three data tables, *County*, *Plot*, and *Tree* that are hierarchically related to one other. The most general, *County* table, contains plot-related county and regional unit information; at the next level is the *Plot* table, which provides extensive information on land ownership, current and previous forest type, number of acres that each plot represents on the ground (*EXPACR* variable), as well as unique plot identifier. The *Tree* table is the most detailed level of the FIA providing tree growth data, such as weight of biomass and mortality rates, which can be expanded into spatially related estimates (units per acre) using available expansion factors (Hansen et al., 1992).

The *Plot* table of the EWDB includes data for regional scale data summarization and analysis. Plot location coordinates (seconds of latitude and longitude rounded to the nearest 100 arc-second) were essential for spatial allocation of species type and timber volume results. The number of acres that each plot represented on the ground (*EXPACR*) was used in order to permit extrapolation of sample plot measurements to county and/or state levels.

For each inventory plot that is located in a forested area field crews describe forest type and forest type group. The numeric coding convention for the related variables, *TYPCUR* (EWDB) and *FTYPE* (FIADB), is set such that both forest type and forest type group are indicated in the record. For example, code 16 was used to indicate *white spruce* forest type (EWDB) and the 1 as the first digit referred to the forest type group ‘10’, a numeric code representing *Spruce-Fir*. All but four regions (Figure 3.7), South central (SC), Pacific Northwest (PNW), Rocky Mountains North (RMN), and Pacific Southwest (PSW), provided field crew descriptions for forest type and forest type group.

FIA- sample site-tree selection criteria and algorithms are used to determine forest type in areas where no field calls were made. An example algorithm for the Northeast is

described in Appendix 2 of the FIA field guide manual (FIA-NERS 2002). Field crew designation for forest type (*TYPCUR*) and that from algorithm (*FTYPE*) agreed 60-70% of the time, according to a report from the FIA GIS specialist involved in the project. Forest type data (*TYPCUR* variables) and area expansion factor (*EXPACR* or *EXPCURR*) can be extracted from the FIA database. Variable *FTYPE* (FIADB) is similar to *TYPCUR* but is computed by a statistical algorithm based on stocking of tree species found on the plot instead of being assigned by the field crew (FIA-NERS 2002). Both variables are available in the *Plot* table of the EWDB and FIADB datasets.

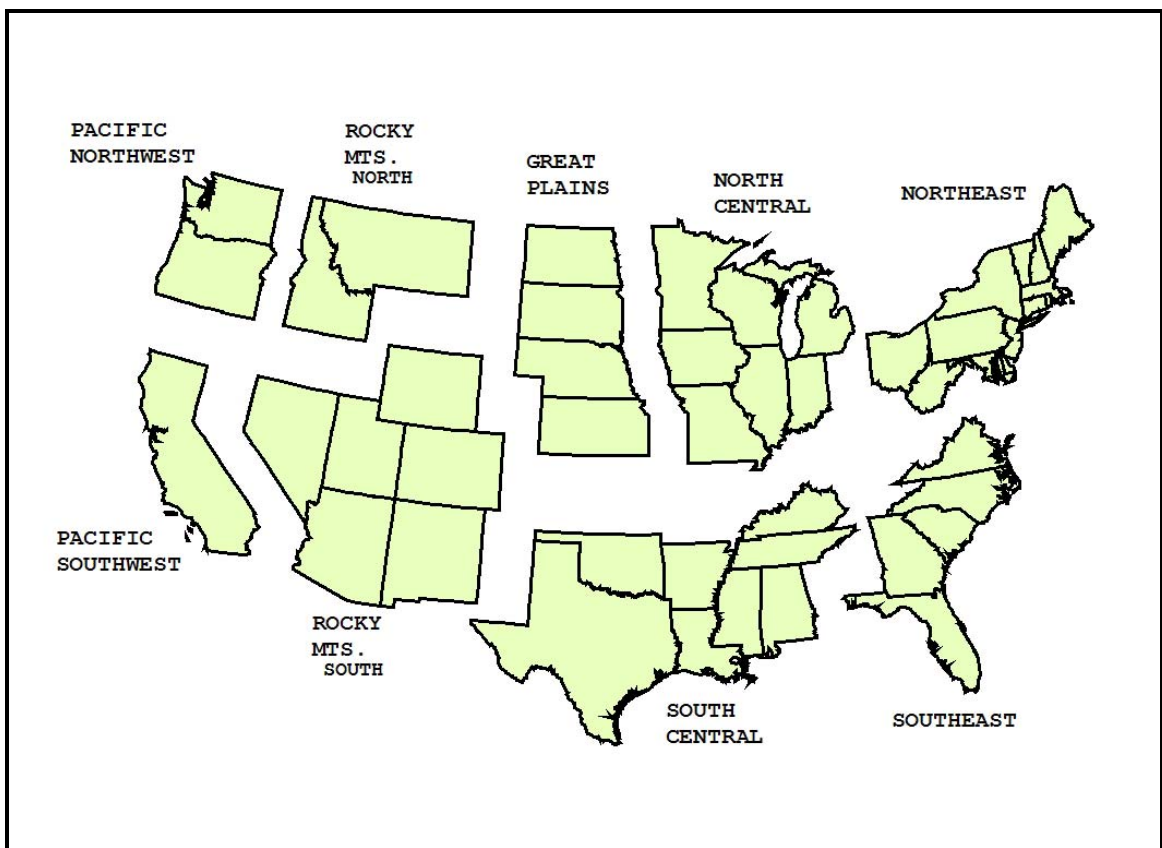


Figure 3.7. Regions of the contiguous 48 United States.

The *EXPACR* and *EXPCURR* variables indicate the expansion factor, or area represented by each plot on the ground (in acres) and are calculated per stratum in each county using the following equation: $EXPACR = ([\text{Census Land Area of county}] * [\text{Number PI points in stratum}] * [\text{Total Number PI within county}]^{-1}) * ([\text{Number plots in stratum}]^{-1})$, where number PI plots refers to photo interpretation plots designated from remotely sensed data. Essentially, *EXPACR* and *EXPCURR* field entries are used to indicate the influence (as a weighting factor) of each inventory plot in the estimation of mass soil *C* (kg m⁻²) by forest cover class.

We assume that each plot in the EWDB or FIADB databases has been assigned forest cover code (*TYPCUR* or *FTYPE*) indicating the best approximation for forest type and forest type group (*MFTYPE* variable). FIA data coding conventions for forest type (*TYPCUR*) allow easy forest type group classification for all inventory plots where *MFTYPE* codes are not provided.

Forest type group (*ForTypGr*) and area expansion factors (*Expacr*) were the variables extracted from the FIA *Plot* table. In the processes of spatial overlay of both the FIA and the STATSGO datasets we assigned SOC estimates by *MUID* to each forest inventory plot. The SOC data from the STATSGO map units were spatially related to FIA forest type group using the *ArcGIS 8.x Geoprocessing Tools*TM (Environmental Systems Research Institute, Inc., Redlands, California). Then, using equation [5] below we computed SOC estimates by forest type group.

$$ForTypGr\ SOC = \left(\sum_{F=1}^j (MUID_OC * Expacr) \right) / \left(\sum_{F=1}^j (Expacr) \right) \quad \text{Eq.[5]}$$

where *ForTypGr SOC* = soil organic carbon by forest type group (kg C m⁻²); *Expacr* = area represented by each FIA plot (acres); *F* = index number for number of FIA plot records with same forest type group (*F* = 1,2,3...*j*).

Problems Identified

The odds for ecological disasters, such as hurricanes and destructive tornados, to take place in a given year somewhere in the U.S. are very high (Saunders et al., 2000). If such occur, then all inventory data for affected regions will be immediately obsolete.

Permanent inventory plots are intended for long-term use. The precise location of these plots is not disclosed in order (i) to keep off the public and other institutions from intentional timber removal or other plot area interference, and (ii) to ensure landowners' privacy of information. By rounding location coordinates to the nearest 100 arc-second some plots appear as if they are set in water bodies and their number is proportional to the extent of open water body area. For example, the area of water polygons from the STATSGO database for Maine (260,854.3 ha) is 2.6 times less than that for Minnesota (666,453.9 ha) causing approximately 2.8 times less plots (as percent number of all FIA plots) to appear in water, 22 (0.7% of 3,001 total Maine FIA plots) and 903 (2.0% of 43,954 total Minnesota FIA plots). As a result FIA data pool is significantly reduced causing increased variation of any estimates and valuable inventory data becomes inadequate or unusable in GIS analyses.

Suggested Solution

Due to the nature of field data collection techniques and personnel efficiency there is very little to be done in order to establish better methodology for field measurements. Under normal conditions, expansion factors and coefficients treat all FIA data as equally recent allowing error within expected ranges (Hansen et al., 1992).

The National Forest Inventory and Analysis Geospatial Service Center in Newtown Square, PA, is a newly established (2002) FIA customer service center that provides users with most recent inventory data. In addition, their customer service GIS specialists readily offer spatial data overlays along with requested data analysis. Inventory data and subsequent results from this study are obtained, processed, analyzed, and reported from the National FIA Geospatial Service Center.

FIA Confidentiality Policy

One of the most critical items of information from the EWDB and FIADB datasets for use in GIS analysis is the inventory plot location coordinates. FIA field crews

in most US regions use decimal degrees in geographic coordinate system (GCS) based on the North American datum of 1927 (NAD27) in order to locate inventory plots on the ground. In addition, inventory plot coordinates are required element of any data analysis where spatial data overlays are part of the procedures such as overlaying STATSGO polygons and FIA plots.

However, FIA plot locations are intentionally displaced in publicly available inventory forest data in order to meet security policy issues regarding landowner confidentiality. This is an ongoing policy change and many affected agencies, both private and government, are involved in discussions about setting appropriate access for researchers that are in need of accurate inventory data. For the purpose of this project all spatial data overlays and analysis were performed at the National Forest Inventory and Analysis Geospatial Service Center at Newton Square, PA. Reported results for SOC by forest type and forest type group are computed from subsets of inventory plots that meet the current requirements of the new FIA policy (FIA Staff, 2002).

The USDA Forest Service has issued a draft of a new FIA data distribution policy (FIA Staff, 2002) in order to reflect new requirements, complying with the Food Security Act of 1985 (7 U.S.C. 2276(d)). The main principles of the new policy are privacy, integrity, and consistency. All three are based on suggested data transformations and aggregations in order ensure data supplier identity protection. The policy incorporates three methods of FIA data distribution (acquisition): (1) FIA authorized agents are granted full access and responsibility for confidentiality of all necessary data; (2) Data is masked for public and private sample plots by (2a) randomly changing the plot coordinates up to ½ mile from actual location in any direction (within the county) and by (2b) plot location swapping (for up to 25% of plots) in the same owner group and county (or supercounty); (3) FIA Geospatial Service Centers performs requested GIS tasks, where spatial specificity is crucial for the FIA data users (FIA Staff, 2002).

FIA Plot Location Uncertainty

We postulated that 100 arc-second rounding of plot location coordinates would affect SOC estimates at the forest type group level. We created 100 arc-second uncertainty zones (*epsilon band*) around each rounded FIA plot in order to spatially identify the potential true location of the plot. Due to the irregular latitude and longitude

distance change from the Equator to the North Pole the *epsilon band* resembled the shape of an ellipse (Figure 3.8,a). We used the *Geoprocessing Tool* of ArcGIS 8.1 software (ESRI, Inc.) to clip STATSGO polygons (linked with SOC summary table) with the *epsilon band* of each inventory plot in order to generate soil sub-polygons.

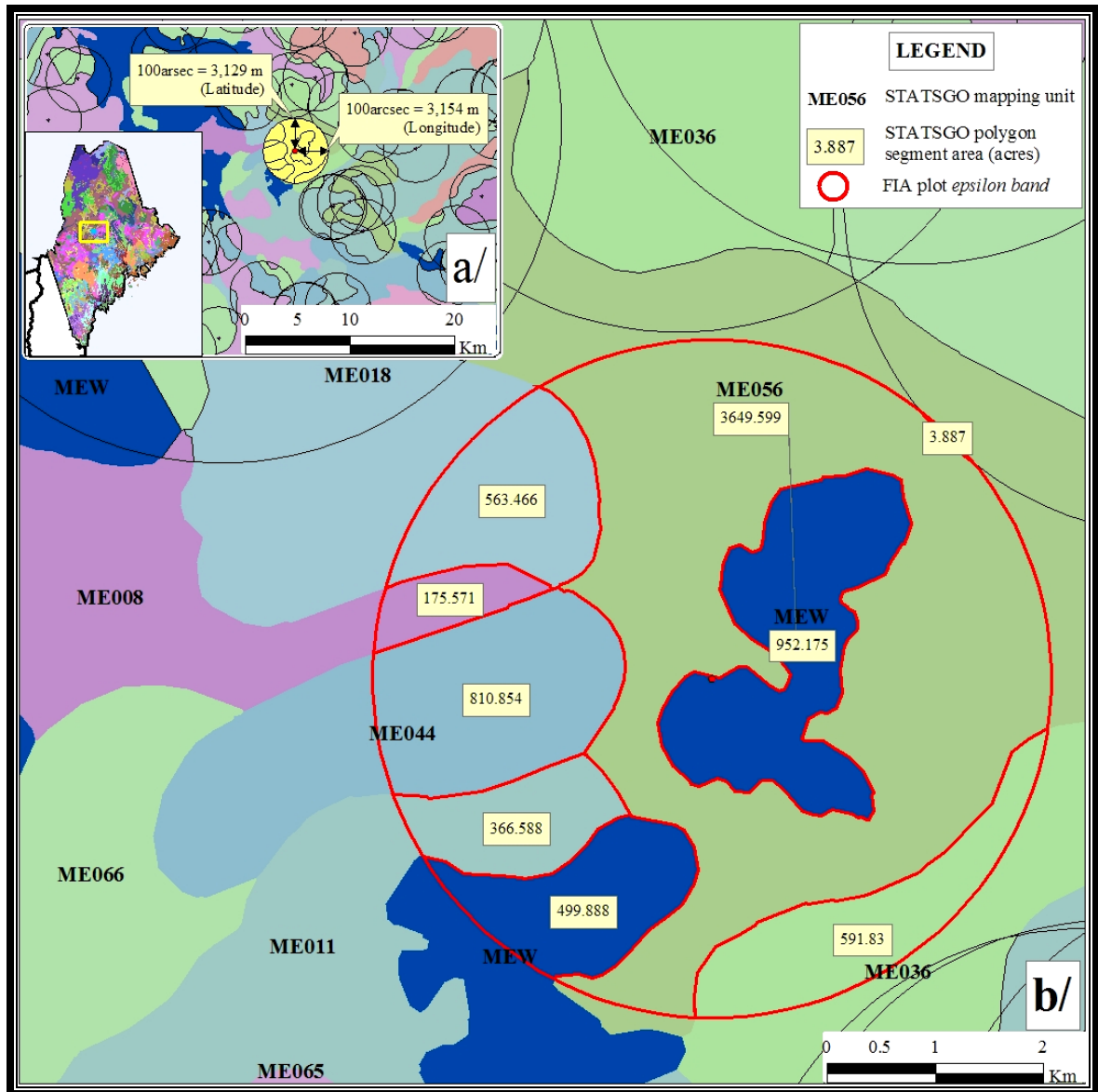


Figure 3.8 Example of Maine FIA plot 100 arc-second *epsilon band* (a/) overlay with STATSGO polygons in order to compute area weighted $SOC_{100arcsec}$ to 2 m (b/) from available SOC estimates for soil polygon segments within the uncertainty zone.

For each inventory plot we computed an *epsilon band* $SOC_{100acrsec}$ (kg C m⁻²) using data from all created soil sub-polygons and their area (m² in Albers Conical Equal Area Projection) as a weighting factor (Figure 3.8,b). For example, *epsilon band* soil C by *Lognormal* approach including Histosols was computed as follow: $SOC_{100acrsec} = \text{Sum} (SOC_{ME056} * 3,649.6 + SOC_{ME056} * 3.9 + SOC_{ME036} * 591.8 + SOC_{ME011} * 366.6 + SOC_{ME044} * 810.8 + SOC_{ME008} * 175.6 + SOC_{ME018} * 563.5) / \text{SUM} (3,649.6 + 3.9 + 591.8 + 366.6 + 810.8 + 175.6 + 563.5) = 5.91 \text{ kg C m}^{-2}$. Then, we assigned the $SOC_{100acrsec}$ estimates to their associated FIA plots, with unique *TYPCUR* and *EXPACR* designation, and finally, following steps 1 to 6, discussed earlier, we produced $SOC_{100acrsec}$ to 2 m by forest type.

CHAPTER 4: RESULTS AND DISCUSSION

PART A: STATSGO DATA ANALYSIS

STATSGO Layer Table Optimization Results

All null values were replaced by zero or replacement averages based on the assumptions above. There were few MLRA and soil order groups represented by fewer than 3 records with valid data in this study. In the Maine STATSGO database, 25% and 54% of the records contained zero values for *OMH* and *OML* (Table 4.1) before fixing. After fixing, only 7% valid zero values remained. The zero value was considered reasonable for *OML* in all except organic and mucky-modified mineral textures.

Seven (Maine) and 2% (Minnesota) of all records that contained zero values in *BDH* or *BDL* fields for rock layers (weathered, *WB*, or unweathered, *UWB*, bedrock) were considered acceptable for SOC computation (Table 4.1). Although 0.0 bulk density of rock layers (equal to particle density of rock, 2.65 g cm^{-3}) was not a valid estimate the assumption of this fact produced 0.0 kg C m^{-2} which was a reasonable output. The records where BD was zero also had zero OM, so the LOC was computed as 0.00 kg C m^{-2} in either case (Table 4.1).

The soils in Maine were dominantly glacial till over hard bedrock and there were many stony- and cobbly-modified textures that had zero values in *INCH3* and *INCH10* fields. The zero values were reduced to 30 and 7% for *INCH10L* and *INCH10H* and reduced to 23 and 2% for *INCH3L* and *INCH3H* after fixing (Table 4.1). The nulls in the *NO10* variables were replaced with nonzero averages.

The results for the Minnesota STATSGO database were similar for all except the rock fragment variables. The soils in Minnesota had fewer rock fragments (except in northern parts of the state) than the soils in Maine. The zero values were reduced to 78 and 11% for *INCH10L* and *INCH10H* and reduced to 37 and 6% for *INCH3L* and *INCH3H* after fixing. OM and BD values that were $0 < x < 0.5$ comprised between 2-7% of the total records after fixing (Table 4.1).

Elimination of the obviously problematic, invalid records (zeros and nulls) removed the main source of many computational faults. The remaining zeros were

assumed to be valid values as the procedures in this study were used to identify the obvious invalid zero or null entries. The output from these fixing procedures is a corrected, scientifically reasonable equivalent of the STATSGO *Layer* table. The procedures are reproducible for other states and may be used to improve the STATSGO databases before the next round of STATSGO maps are released by the USDA-NRCS.

Using MLRA as a grouping variable incorporates some of the soil, climate, vegetation, and geographic variation that influence OC sequestration in soils. The soil order variable conveyed some powerful soil morphology inferences that helped to group soils with unusual properties and materials, such as Histosols, Spodosols, and Andisols. These soil orders were the ones most likely to have significant accumulations or concentrations of OC in the subsoil layers that were often left blank for OM values. Mollisols are known to contain high amounts of OC as well but the OM data are usually complete for the surface layer of all mineral soils, decreasing the likelihood of finding invalid entries.

The MLRA and soil classification variables are commonly used in natural resources classification and distribution projects (Kern, 1994; Homann et al., 1998). Davidson and Lefebvre (1993, Table 1) showed that considerably more information was provided by grouping by suborder rather than order, but the number of soils in many of the suborder groups was very low. Kern (1994) reported that grouping pedon data by the great group level of Soil Taxonomy provided better estimates of SOC than grouping by soil order. He was able to generate meaningful averages by using thousands of pedons sampled from across the nation. That level of detail would not have been possible in this study because the low number of different map unit components of equal MLRA's within a State representing different great groups would not have provided enough data to generate meaningful averages, i.e. data generalization to a higher soil taxonomic level such as great group would require soil information input from area extent beyond any State's boundary, such as an MLRA or a geographic region. In future studies, grouping by drainage class as done by Davidson and Lefebvre (1993) might prove as useful as grouping by soil order.

Table 4.1. Inventory of STATSGO *Layer* tables before and after fixing procedures.

Variable	Nulls †	Zeros before fixing	Zeros after fixing	Nulls	Zeros before fixing	Zeros after fixing	Records with ≥ 1 variable fixed
----- Count -----				----- % of all records -----			
<u>Maine, 3649 records</u>							
INCH10 L	797	2280	1101	22	62	30	54
INCH10 H	797	1045	240	22	29	7	44
INCH3 L	262	2389	824	7	65	23	50
INCH3 H	262	902	65	7	25	2	30
NO10 L	468	1	0	13	< 1	-	13
NO10 H	468	0	0	13	-	-	13
BD L	0	252	246 [‡]	-	7	7	< 1
BD H	0	252	246 [‡]	-	7	7	< 1
OM L	0	1975	243	-	54	7	47
OM H	0	906	267	-	25	7	18
<u>Minnesota, 12318 records</u>							
INCH10 L	2651	9665	9663	22	78	78	22
INCH10 H	2651	8515	1372	22	69	11	80
INCH3 L	236	11394	4598	2	92	37	57
INCH3 H	236	6754	729	2	55	6	51
NO10 L	895	0	0	7	-	-	7
NO10 H	895	0	0	7	-	-	7
BD L	0	196	192 [‡]	-	2	2	< 1
BD H	0	197	192 [‡]	-	2	2	< 1
OM L	0	6102	193	-	50	2	48
OM H	0	3383	252	-	27	2	25

† All null values were considered invalid and changed to zero or larger number.

‡ 0.00 values were allowed to prevent computation errors.

Mass SOC Estimates

Table 4.2 shows the total mass SOC for Maine and Minnesota calculated by the Unfilled-Normal, Filled-Normal, Unfilled-Lognormal, and Filled-Lognormal procedures. The mass SOC estimates about twice as large when calculated from the filled rather than the unfilled *Layer* tables (Table 4.2). An exception was observed in Maine where the mass SOC was only about 1.5 times as large from the filled *Layer* table. In Maine, the mass SOC calculated using the *Normal* distribution approach was about 1.5 times higher than the *Lognormal* distribution approach SOC. The same relationships occurred in Minnesota, although the *Normal* mass SOC values were only about 1.2 times higher than the *Lognormal* SOC. Homann et al. (1988) reported a similar relationship but a smaller difference between the two methods. The mass SOC ranged between 1.2 and 2.2 times higher in Minnesota than in Maine. Franzmeier et al. (1985) reported mass SOC to 1 m ranging from 7.1 to 75 kg C m⁻² in Minnesota, but a weighted average by state was not reported. However, a visual estimate of the area percentage of each soil association in Minnesota (Franzmeier et al., 1985, Figure 1) times its average SOC resulted in a weighted average estimate of 15.5 kg C m⁻² to 1 m and 16.5 kg C m⁻² to 2 m. Those values were closest to but lower than the Filled-Lognormal value in this study. Davidson and Lefebvre (1993) reported an average mass SOC of 15.5 kg C m⁻² to about 1.65 m for Maine, using a Filled-Normal approach on the STATSGO database. Their mass SOC was higher than all of the estimates in this study for Maine, but was closest to and about 1.4 times higher than the Filled-Normal value (Table 4.2). The higher value in Davidson et al. (1993) could have resulted from higher OM replacement values in lower layers, because they used a slightly smaller soil area, or because of changes to STATSGO that occurred in 1993 and 1994 after they completed their study. Also, this study replaced many zero values for rock fragments and that lowered our mass SOC compared to the unaltered rock fragment data used by Davidson et al. (1993). The map of SOC produced by Kern (1994, Figure 6) from pedon data showed a range of 15.1 to 18.0 kg C m⁻² to 1 m in Maine, which is higher than the average in this study. Figure 6 in Kern's study shows a range of 9.1 to 57.6 kg C m⁻² to 1 m in Minnesota. Kerns averages were also higher than those reported by Davidson et al. (1993) in Maine and higher than reported by Franzmeier et al. (1985) in similar regions of Minnesota.

It remains unclear if the Normal or Lognormal distribution approach should be used for studies of this kind that involve averaging only two estimated soil properties rather than a measured population of soil properties. Further studies that compare these two approaches on randomly-collected pedon data may help resolve the question. Meanwhile, the Filled-Normal and Filled-Lognormal values in Table 4.2 could be considered as a range of reasonable values for each state.

Mass SOC was compared across calculation methods by forest type groups (Figure 4.1) and followed the same patterns as the statewide totals. The filling process affected the final results for both *Lognormal* and *Normal* distribution approaches and the change is summarized in Table 4.2. In general, the fixing procedures increased the mass SOC from 60 to 99% in the *Lognormal* and 28 to 79% in the *Normal* distribution approach in Maine. In Minnesota, the results were much different as the fixing procedures increased the mass SOC from <1 to 1241% in the *Lognormal* and -2 to 1022% in the *Normal* distribution approach. The magnitude of change was much higher in Minnesota because of the larger number of invalid values that were fixed during the filling procedures (Table 4.3). An exception occurred in Minnesota for the *Oak-Gum-Cypress (OGC)* forest type group, which did not appear to be affected by the filling procedures. This was caused by the fact that there was only one plot with that forest type group assignment for the entire state, as compared to 5887 plots for *Aspen-Birch (AB)* and 3675 for *Spruce-Fir (SF)*. The greater the number FIA plots per forest type group the more soil mapping units were intercepted, which in return carried greater changes from the filling procedures.

Table 4.2. SOC[†] weighted by STATSGO MUID[‡] area using Albers Conical Equal Area Projection.

	<i>Lognormal</i>		<i>Normal</i>	
	Filled	Unfilled	Filled	Unfilled
	----- kg C m ⁻² to 2m -----			
Maine	7.88 (3.96)	4.45 (2.81)	11.58 (5.10)	8.01 (3.91)
Minnesota	17.38 (8.85)	8.23 (7.64)	21.29 (10.64)	9.95 (8.29)

† kg C m⁻² to 2m depth with standard deviations in parentheses.

‡ Soil area for Maine = 81,457.1 km² and for Minnesota = 211,902.3 km²

Table 4.3. Change in SOC (kg m⁻²) to 2 m by FIA forest type group.

Forest Type Group	Area (Km ²)	<i>Lognormal</i>	<i>Normal</i>
		Unfilled/Filled Change % †	Unfilled/Filled Change % †
<u>Maine</u>			
Aspen/birch	8,749	+70	+41
Elm/ash/cottonwood	1,505	+89	+50
Loblolly/shortleaf pine	27	+99	+64
Maple/beech/birch	26,085	+82	+46
Oak/hickory	1,751	+65	+79
Oak/pine	422	+60	+62
Spruce/fir	24,671	+92	+43
White/red/jack pine	4,831	+80	+69
Nonstocked	170	+67	+28
Maine Average		+78	+54
<u>Minnesota</u>			
Aspen/birch	28,136	+381	+329
Oak/gum/cypress	4	+ <1	-2
Spruce/fir	18,569	+1241	+1022
White/red/jack pine	4,605	+388	+300
Nonstocked	854	+659	+564
Minnesota Average		+534	+443

† Percent change in SOC (kg m⁻²) was computed as [(Filled-Unfilled)/(Unfilled)*100, %]

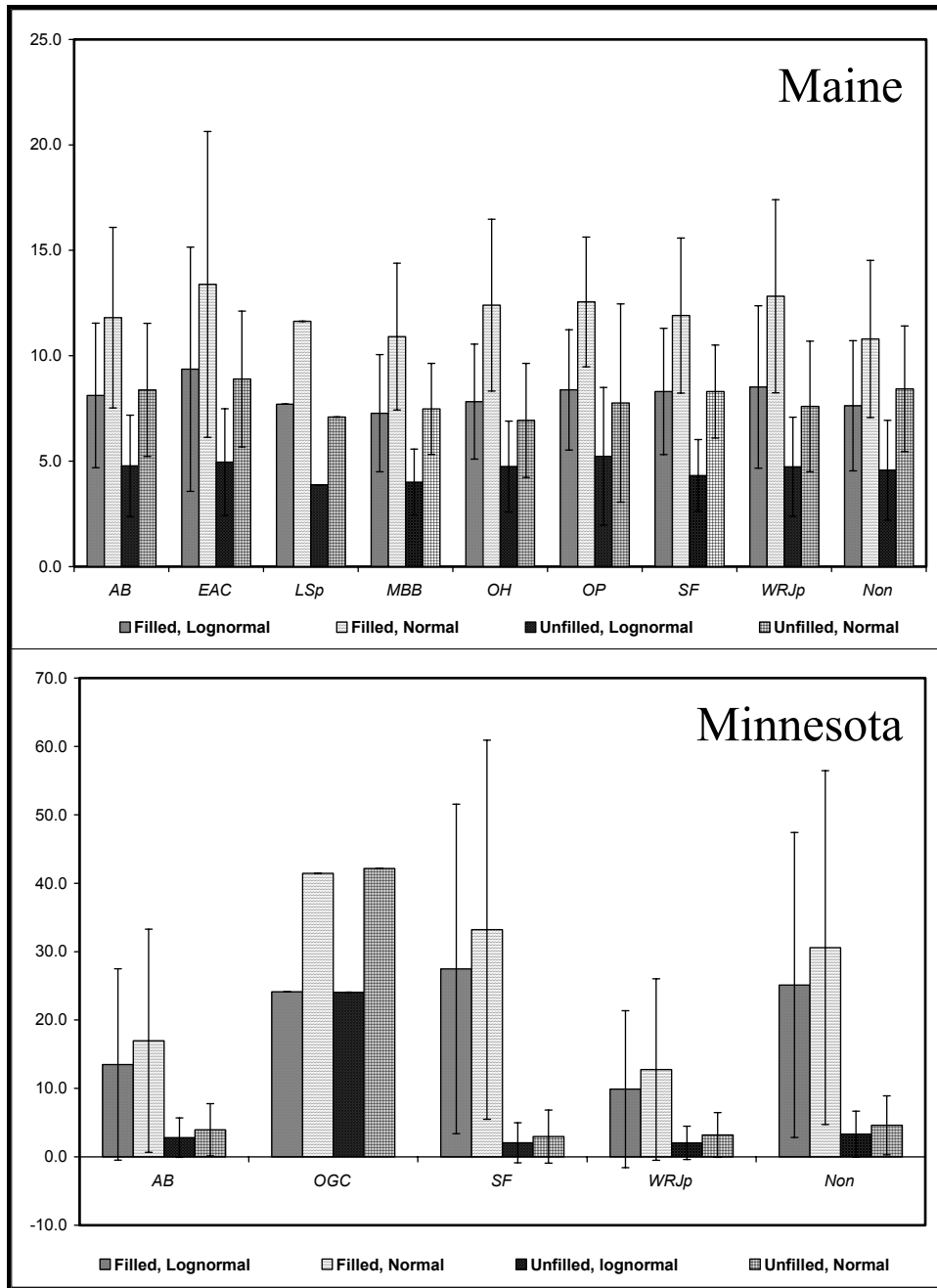


Figure 4.1. SOC (kg m^{-2}) estimates by forest type group along with associated error (StDev) for Maine and Minnesota computed by four different techniques (the forest type groups are Aspen-Birch (*AB*); Elm-Ash-Cottonwood (*EAC*); Loblolly-Shortleaf Pine (*LSp*); Maple-Beech-Birch (*MBB*); Oak-Gum-Cypress (*OGC*); Oak-Hickory (*OH*); Oak-Pine (*OP*); Spruce-Fir (*SF*); White-Red-Jack Pine (*WRJp*); Nonstocked (*Non*); Note: SOC results for *LSp* and *OGC* are computed from data derived from only one FIA plot and StDev was not assessed.

Spatial Comparison of Mass SOC Estimates

Figure 4.2 illustrates the differences in mass SOC distribution that occur as result from the filling and data transformation procedures. Open water bodies appear black on all four maps, regardless of mass SOC calculation method. As expected, the abundance of darker colored non-water areas (higher mass SOC) followed the sequence exhibited by Table 4.2 and Figure 4.2 where Filled-Normal > Unfilled-Normal = Filled-Lognormal > Unfilled-Lognormal.

Figure 4.3 combines the information for all thirteen states from the Northeast region of the United States illustrating the potential impact of the STATSGO database-fixing results, where the darkest-colored states indicate the highest percent of records with invalid values. There is no detectable spatial pattern among the affected states and there is no indication of STATSGO discrepancies to be related to any differences in state specific soil mapping techniques or database maintenance. The top three affected states from the Northeast region were RI (Rhode Island), MA (Massachusetts), CT (Connecticut) and the least three were MD (Maryland), ME (Maine), DE (Delaware).

Identification of the source(s) and cause(s) of zero and/or null records in the *Layer* table of the STATSGO database is not the objective of this research study and is not discussed in this paper. However, the methods described in this paper can be used to develop strategies for improving STATSGO and to find the map units with highest potential for improvement.

For example, using the Filled-Normal approach in Connecticut, the SOC was updated from 0.05 to 5.91 kg C m⁻² in the (*MUID*= CT012) map unit, accounting for 12,420% increase; in New York, the SOC was updated from 0.13 to 15.77 kg C m⁻² in the (*MUID*=NY100) map unit, accounting for an 11,805% increase; and in Massachusetts, the SOC was updated from 0.05 to 5.58 kg C m⁻² in the (*MUID*=MA036) map unit, accounting for an 11,712% increase. There were also map units where the Filled-Normal SOC was less than the one computed from the Unfilled-Normal approach and the change was identified as a decrease rather than an increase in soil organic carbon estimation. This could have occurred because of replacement of zero values for *INCH3* and *INCH10* variables with larger values that resulted in dilution of the mass SOC.

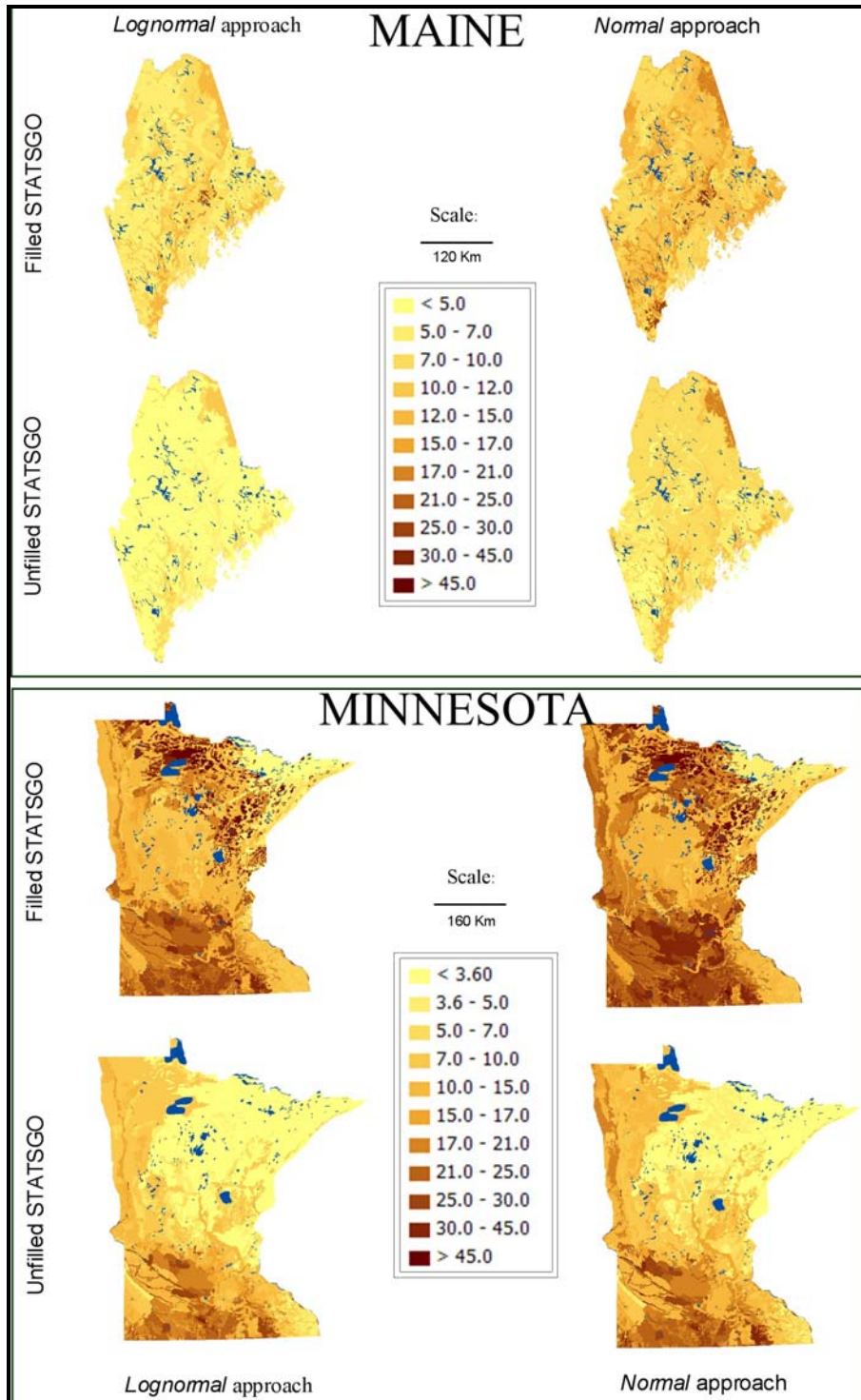


Figure 4.2. Total SOC (kg m^{-2}) maps for the states of Maine (top) and Minnesota (bottom) computed by four different techniques as a result of the combination of the filling methods and *Lognormal* versus *Normal* approach. Darker colors indicate higher *C* amounts (note: darkest spots that appear on same areas of all four maps per state indicate open water bodies).

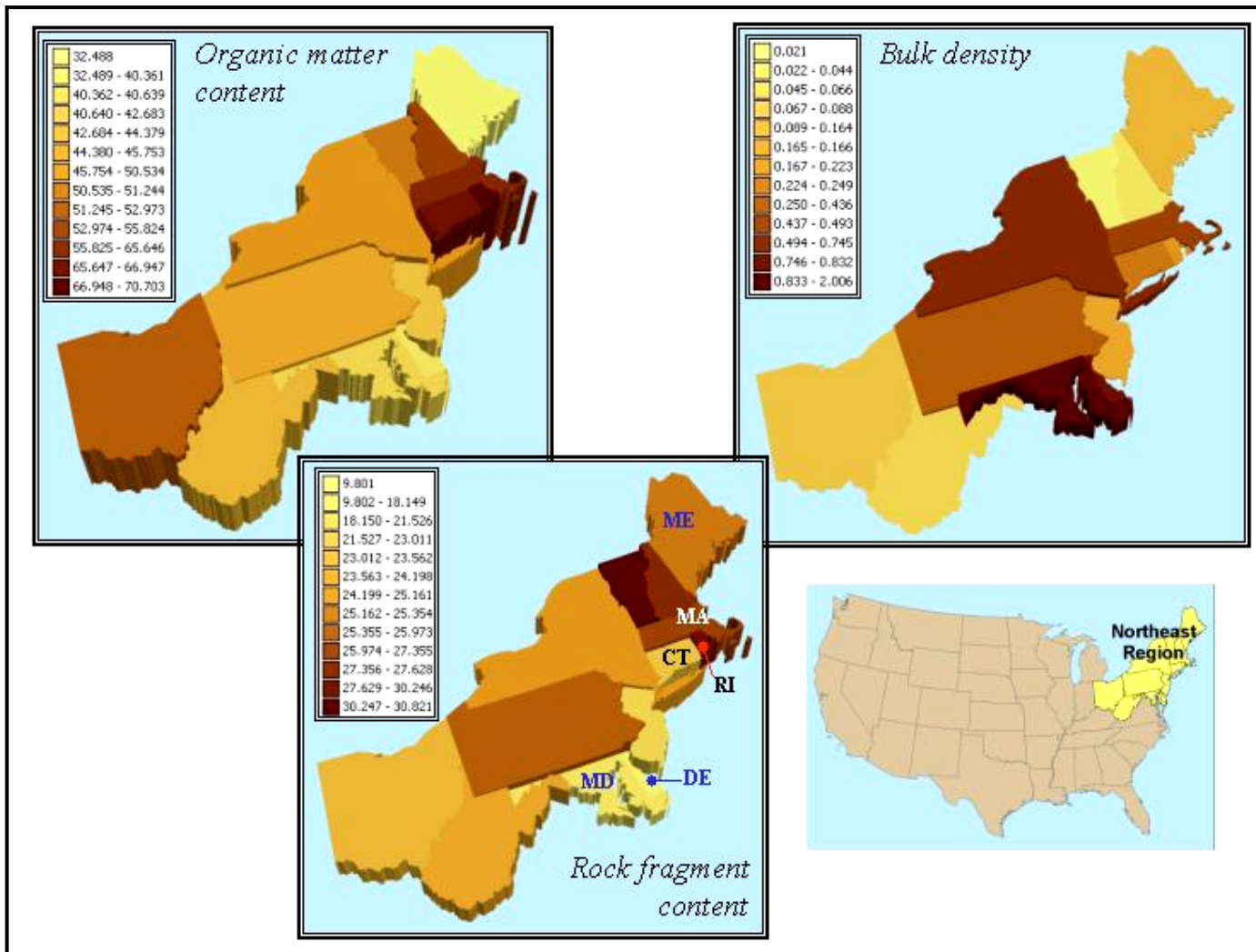


Figure 4.3. Layer table improvement rate (%) of valid records for organic matter, bulk density, and rock fragment content variables depicted by state for the Northeast region of the United States.

Changes in SOC estimates after STATSGO fixing

One of the major concerns of this project, along with producing SOC estimates by forest type group, was the issue of the null and zero records that existed in the *Layer* table of the STATSGO database. If any record was null for any of the soil parameters used in the calculation of layer organic carbon (LOC) in equation [1], then the result would be incomputable due to data insufficiency. Same common concept applied when MS Access software was used as a tool to proceed with division by a zero. In both cases the output was null and the discrepancies resulted in the waste of valuable soils data, i.e. if *NO10L* was the only variable with a null value the result would still be null no matter what was currently available in the property columns for the rest of the soil horizon, *OMH*, *OML*; *BDH*, *BDL*; *INCH3H*, *INCH3L*; *INCH10H*, *INCH10L* and *NO10H* values.

The changes that were inflicted to the STATSGO database resulted in a better utilization of all soils data so that a more accurate and scientifically defensible SOC results were produced for each state across the nation. Due to the fixing procedures, the Northeast region of the U.S. exhibited changes that ranged from 0 percent to 12,400 percent increase of SOC results mapped by *MUID* (Figure 4.4).

The variation of SOC (in percent) before and after the fix was estimated as the ratio of $\left(\frac{SOC_Fixed - SOC_Original}{SOC_Original} \right) * 100$, where *SOC_Fixed* and *SOC_Original* stand for the amount of SOC calculated from the fixed *Layer* table and the original STATSGO *Layer* table, respectively. Among all Northeast states the most influenced soil polygons were located in Connecticut (*MUID=CT012*) where SOC was updated from 0.05 to 5.91 kg C m⁻² accounting for 12,420% increase. Other significant results by state were as follow: New York (*MUID=NY100*; SOC changed from 0.13 to 15.77 kg C m⁻²; 11,805% increase), Massachusetts (*MUID=MA036*; SOC updated from 0.05 to 5.58 kg C m⁻²; 11,712% increase).

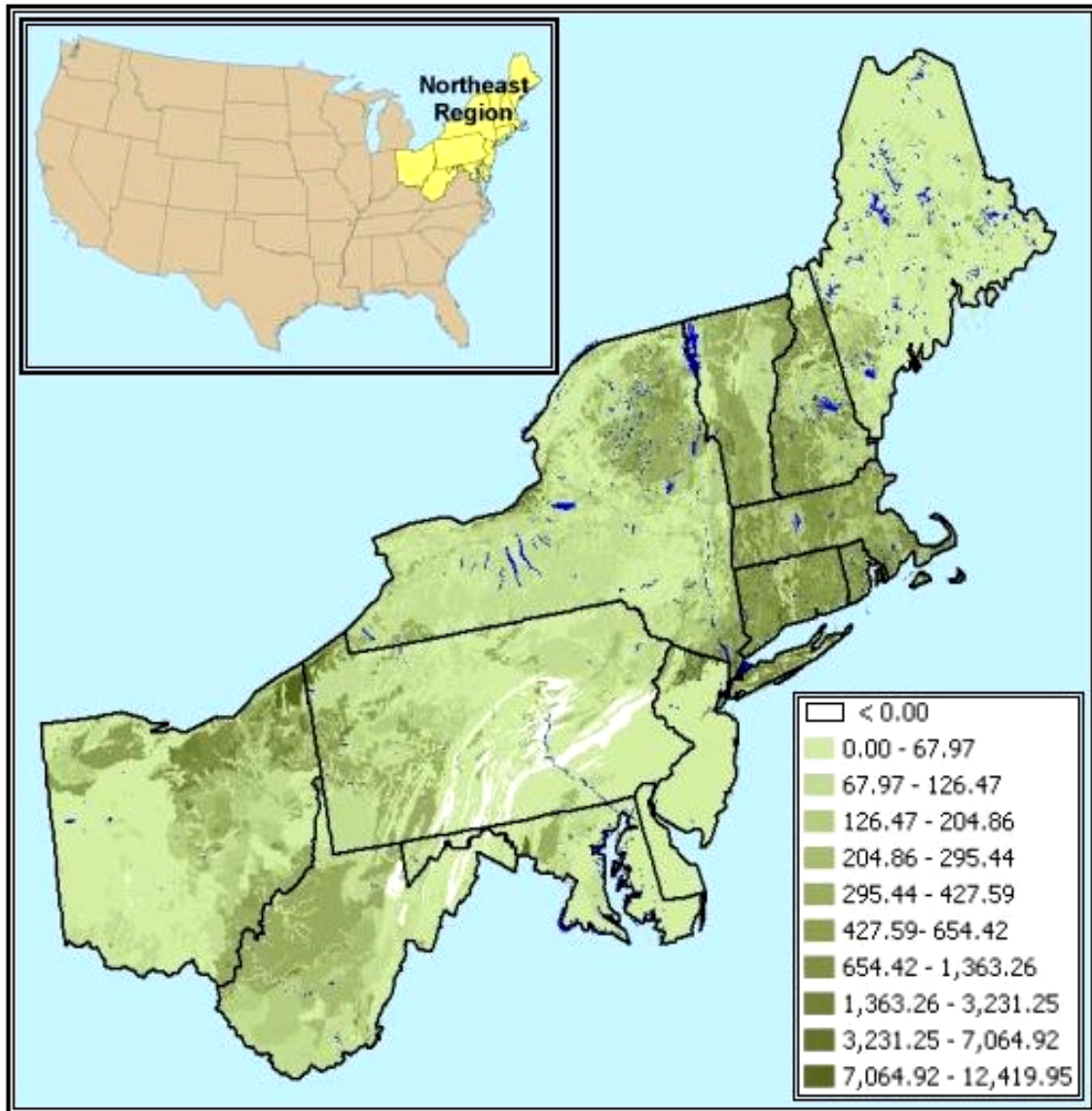


Figure 4.4. SOC change (in percent) for the Northeast region of the U.S. manipulated through the STATSGO *Layer* table fixing procedures.

There were areas in Pennsylvania (*PA033; PA103*), West Virginia (*WV079, WV111*), Ohio (*OH167*), New Hampshire (*NH043*), Maine (*ME025*), and Maryland (*MD028; MD056*) where the new SOC estimate was less than the one computed from the original *Layer* table and the change was a decrease rather than an increase in estimated soil organic carbon. The reasons for that were embedded in the relationship between the parameters that were used in SOC mapping. For instance, if the amount of cobbles would have been revised and updated to a greater value (e.g. [*Layer-fixed*]*_INCH3H* >

[*Layer*]_{INCH3H}), then the amount of fine earth was proportionally reduced. Since SOC was found only in fine earth and not in rock substances the actual result for SOC was lowered from its original estimate.

Results in the Northeast US showing areas by *MUID* with gains and losses in mass SOC resulting from the “fixing” methods and assumptions are shown in Figure 4.5, to illustrate the effect of filling the STATSGO database. The two maps depict the spatial distribution of the total SOC computed for the entire depth of the soil profile by *MUID*, i.e. all horizons that lay between the zero inch depth and the underlying bedrock are included. The color-schemes of the maps allow easier assessment and comparison between the two sets of results: light colors depict areas with less SOC and darker zones indicate high SOC values.

The results from the original STATSGO *Layer* (Figure 4.5, left-hand map) table indicated that the richest states in SOC ($>21.00 \text{ kg C m}^{-2}$) were New Jersey ($NJ036=33.04 \text{ kg C m}^{-2}$), Ohio ($OH030=24.75 \text{ kg C m}^{-2}$) and Maine ($ME025=21.01 \text{ kg C m}^{-2}$). The same statistics derived from the *Layer-fixed* table (Figure 4.5, right-hand map), SOC results ($>21.00 \text{ kg C m}^{-2}$), was as follow: New Jersey ($NJ036=52.94 \text{ kg C m}^{-2}$), Maine ($ME006=36.96 \text{ kg C m}^{-2}$; $ME047=25.63 \text{ kg C m}^{-2}$; $ME061$), Ohio ($OH013=28.56 \text{ kg C m}^{-2}$; $OH030=24.86 \text{ kg C m}^{-2}$; $OH018$), New York ($NY107=26.61 \text{ kg C m}^{-2}$; $NY083=24.62 \text{ kg C m}^{-2}$; $NY139$; $NY081$), Rhode Island ($RI012 = 26.15 \text{ kg C m}^{-2}$), Massachusetts ($MA008=23.24 \text{ kg C m}^{-2}$; $MA061=23.24 \text{ kg C m}^{-2}$), New Hampshire ($NH035=23.24 \text{ kg C m}^{-2}$; $NH007=21.49 \text{ kg C m}^{-2}$), and Vermont ($VT027=22.74 \text{ kg C m}^{-2}$; $VT067=21.89 \text{ kg C m}^{-2}$).

The elimination of nulls and zeros in the STATSGO database leads to changes in SOC results that may be considered significant in certain States. The use of the original instead of the fixed STATSGO database for SOC computations in future projects may cause significant analysis error. Also, due to soil property inconsistencies in the original STATSGO database, such as inadequacies between stony textures and rock fragment content in individual soil layers, SOC estimates will be expected to be highly variable.

Although using the original STATSGO data, existing non-zero and non-null records in the *Layer* table, to fill data gaps yields better SOC results there could be potential errors involved in the fixing methodology. Using only STATSGO data for the

lookup tables could lead to filling most of the invalid records with averages from only few series that are present numerous times in many mapping units. Combining STATSGO with some data from other pedon datasets, such as the National Soil Survey Laboratory (NSSL) database, to fill the OM, BD, and RFC records for the soils of major extent within a MLRA unit would improve the soil property database and SOC maps.

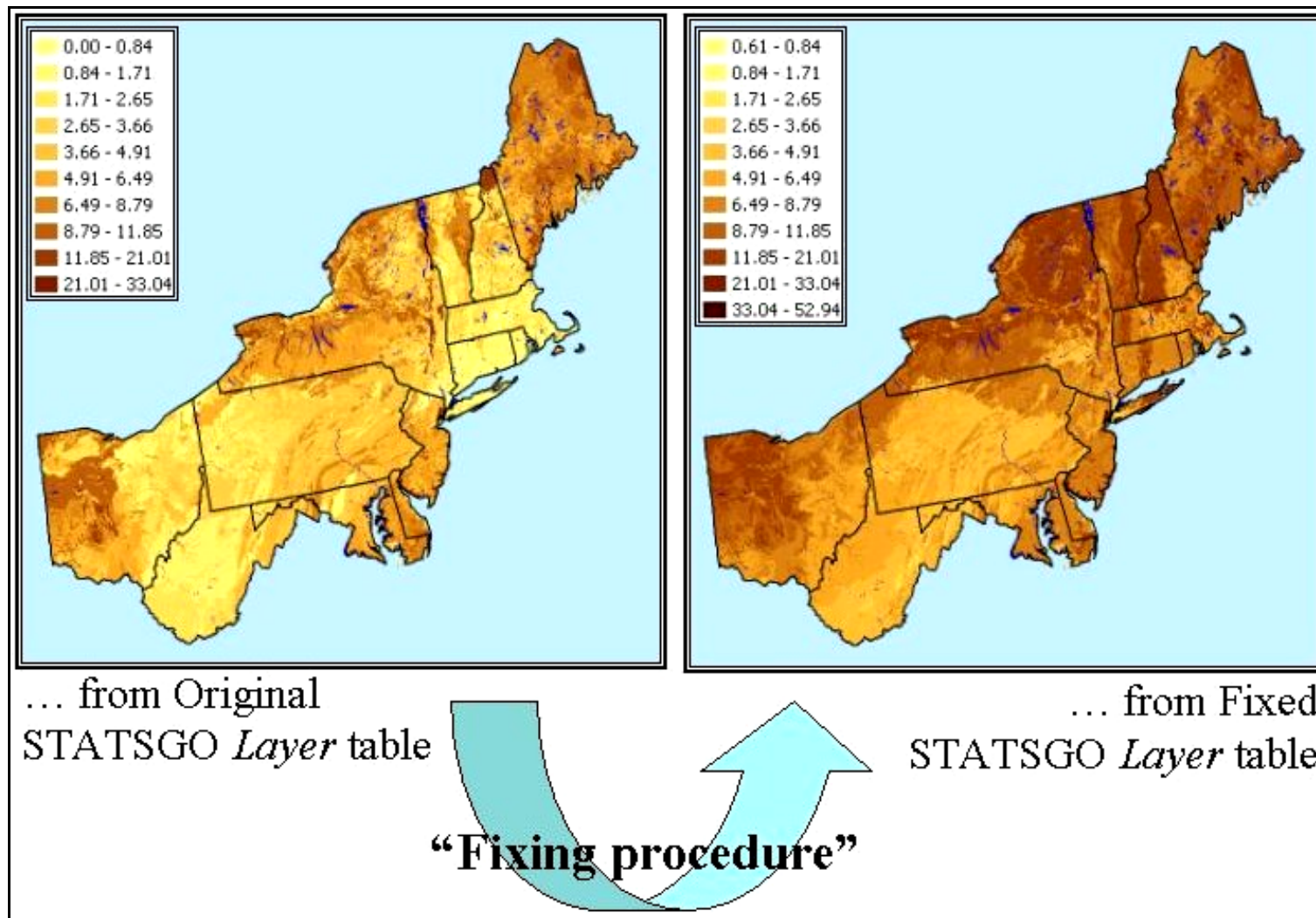


Figure 4.5. Preliminary SOC (kg m^{-2}) results for the entire soil profile (depth to bedrock or 2 m) by STATSGO *MUID* from the original *Layer* table (Unfilled-Normal database at left) and after the fixing procedure (Filled-Normal database at right).

PART B: FOREST COVER DATA UNCERTAINTY ANALYSIS

Effects of Forest Data Source on SOC results

Satellite derived forest cover data from the AVHRR sensor was found to have low agreement with FIA field inventory data. Tables 4.3a and 4.3b summarize the results of an accuracy assessment of subsets of AVHRR data for the States of Maine and Minnesota. Overall accuracy for Maine was 34.8% (Table 4.4a) and 67.2% for Minnesota (Table 4.4b). Highest accuracy for Maine, computed as percent of the diagonal cells from column total, was observed in *Spruce-Fir* (53.7%), followed by *Maple-Beech-Birch* (38.1%) and *White-Red-Jack Pine* (25.3%) forest type groups. For example, 53.7% accuracy for *Spruce-Fir* (SF) forest cover in Maine meant that a little over half of the area with SF forest type group (as identified on the ground) was correctly classified as SF by the AVHRR sensor, while the rest of the SF covered regions, i.e. 48.3% of all SF lands, were assigned to other cover types resulting in classification error. Highest classification accuracy for Minnesota forest covers was observed in *Aspen-Birch* (50.6%) and *Spruce-Fir* (24.7%) forest type groups. The accuracy for non forest areas was 83.8%.

Loblolly-Shortleaf Pine (LSp) and *Elm-Ash-Cottonwood* (EAC) forest types were not included in the AVHRR data although FIA inventory plots reported their existence in Maine. Similar to LSp and EAC forest covers, *Oak-Gum-Cypress* (OGC) forest type group was not classified by AVHRR in any area of Minnesota. Not depicting these forest type groups could very well be due to the patchiness of LSp, EAC, and OGC forest type groups that limited forest cover classification accuracy at a 1 km resolution of the AVHRR dataset (Cihlar et al., 1996). (Tables 4.3a and 4.3b, Figure 4.6,c,d). In addition, 102 (of 3,001 total) and 613 (of 43,954 total) FIA plots for Maine and Minnesota, respectively, appeared either outside the boundaries of the AVHRR dataset or overlaid with open water body raster cells.

The accuracy of the AVHRR data for Minnesota was twice greater than that for Maine. The high overall accuracy of 67.2% for Minnesota could be due to the fact that forest patchiness and land cover reflectance properties could greatly affect image classification accuracy. Results in Table 4.4b suggested that a major factor in Minnesota was the forest distribution pattern in the State. The AVHRR dataset reported dense

forested regions located in the Northeast part and vast non forest areas in the Southern and Southwestern parts of the State (Figure 4.6,d) showing that only one third of the State was forested. Although the accuracy ranged from 4.6% (*Oak - hickory*) up to 50.6% (*Aspen – Birch*) the overall accuracy was improved dramatically by the percent correct non forest grid cells. About 90.5% of the non forest cells were verified to be non forest, representing 83.8% of the true non forest lands in Minnesota (Table 4.4b).

Poor accuracy of forest cover data affects the accuracy of SOC estimates by forest type group and increases variation of results. Since forest and soils datasets are spatially registered to each other, i.e. they occupy the same space on the surface of the planet, the only concern is the methodology of combining both datasets with least amount of processing error.

There are numerous methods to accomplish the task but only two are suggested as potentially best: (i) Using the AVHRR dataset: clip soil polygons (STATGO or other soils database) with AVHRR grid cells and assign area-weighted SOC estimate to the forest type group of the AVHRR cell, such that the area-weighted SOC is computed from all soil segments within the boundary extent of the clipping AVHRR grid cell, similar to the estimation of $SOC_{100arcsec}$ in Figure 3.8, b; (ii) Using the FIA data with exact plot coordinates: perform spatial overlay (point-in-polygon scenario) of the FIA plot data with soil polygons and assign the SOC value of the polygon that includes the sample site to the forest type cover of the inventory dataset.

Other methods, such as intersecting the centroid of the AVHRR data with the soil layer and using the SOC value of the polygon that contains the centroid without considering other soil polygon segments within the AVHRR dataset would produce biased results. SOC distribution maps indicated that larger soil polygons contained much less SOC than small, concave landforms. In addition, upon data overlay the probability of the centroid to fall within a large polygon was much greater than the probability of occurrence in a small polygon thus reducing the SOC estimates for the region. Similarly, when using FIA data with rounded plot coordinates one is advised to consider plot location uncertainty by applying the *epsilon band* approach discussed in previous chapters (Figure 3.8, a, b).

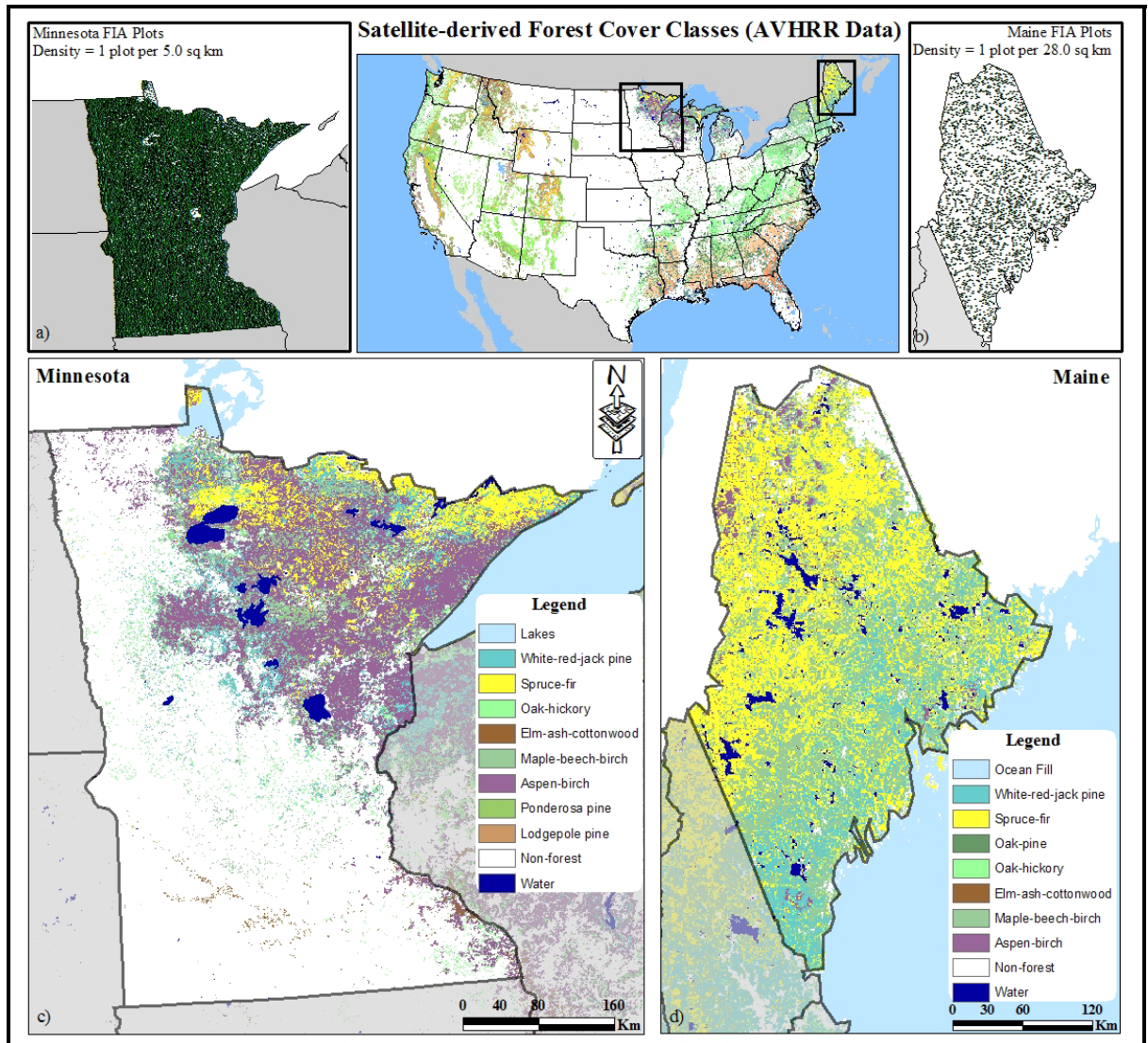


Figure 4.6. FIA inventory sampling density maps (a, b) plotted beside forest type group classifications for Maine (d) and Minnesota (c) acquired from satellite (AVHRR) imagery.

Table 4.4a. Accuracy assessment (AA) matrix showing levels of agreement (number inventory plots) between field (FIA data) and satellite-derived (AVHRR data) forest type group for Maine. Correctly classified plots are shown in colored cells along the diagonals.

MAINE	Satellite [AVHRR] Forest Type Group	Field [FIA Plots] Forest Type Group									Percent Correct
		WRJp	SF	LISlp †	OP	OH	EAC ‡	MBB	AB	NF	
	White-red-jack pine (WRJp)	132	94	1	7	24	9	110	39		31.7%
	Spruce-fir (SF)	136	495		4	13	26	389	130	4	41.4%
	Loblolly-shortleaf pine (LISlp) †										N/A
	Oak-pine (OP)	2	4				1	4			0.0%
	Oak-hickory (OH)	27	21			5	3	24	12		5.4%
	Elm-ash-cottonwood (EAC) ‡										N/A
	Maple-beech-birch (MBB)	151	239		6	24	14	370	114	4	40.1%
	Aspen-birch (AB)	5	31				2	36	7		8.6%
	Nonforest (NF)	69	38				3	38	32		0.0%
AVHRR Accuracy (%)		25.3%	53.7%	0.0%	0.0%	7.6%	0.0%	38.1%	2.1%	0.0%	34.81%

† There was no AVHRR data for Loblolly-shortleaf pine (LSp) forest cover class.

‡ No FIA plots overlaid with Elm-ash-cottonwood (EAC) forest cover class from the AVHRR dataset.

Table 4.4b. Accuracy assessment (AA) matrix showing levels of agreement (number inventory plots) between field (FIA data) and satellite-derived (AVHRR data) forest type group for Minnesota. Correctly classified plots are shown in colored cells along the diagonals.

MINNESOTA	Satellite [AVHRR] Forest Type Group	Field [FIA Plots] Forest Type Group									Percent Correct	
		WRJp	SF	OH	OGC *†	EAC	MBB	AB	PP *‡	LP *‡	NF	
	White-red-jack pine (WRJp)	161	346	42		64	67	552			727	8.2%
	Spruce-fir (SF)	124	907	2		41	16	464			555	43.0%
	Oak-hickory (OH)	11	47	43		28	36	129			531	5.2%
	Oak-gum-cypress (OGC) *†											N/A
	Elm-ash-cottonwood (EAC)			23		5	6	1			88	4.1%
	Maple-beech-birch (MBB)	63	271	45		122	133	828			824	5.8%
	Aspen-birch (AB)	350	1906	254		484	452	2984			2099	35.0%
	Ponderosa pine (PP) *‡										2	0.0%
	Lodgepole pine (LP) *‡										3	0.0%
	Nonforest (NF)	146	192	533	1	350	448	938			24897	90.5%
AVHRR Accuracy (%)	18.8%	24.7%	4.6%	0.0%	0.5%	11.5%	50.6%	N/A	N/A	83.8%	67.21%	

*† Oak-gum-cypress (OGC) forest cover class was not identified in the AVHRR dataset.

*‡ Ponderosa pine (PP) and Lodgepole pine (LP) forest type groups were not identified in FIA data.

Estimates for total area by forest type group for the states of Maine and Minnesota are reported in Table 4.5. The total forested area (excluding *Nonstocked* sites) for Maine (71,400 km²) covered 89.4% of the land surface area (where water bodies not included) in the state according to the FIA inventory dataset. The data from the AVHRR dataset for Maine showed that 73,100 km² (93.4%) were forested (Table 4.5). Estimates from the Maine FIA dataset (1994 – 1996 data) showed that the largest portion of the forested area was in *Maple-Beech-Birch* (34.5 %) and *Spruce-Fir* (32.7%), followed by *White-Red-Jack-Pine* (16.1%) and *Aspen-Birch* (11.7%). The relative proportions of different forest type groups as percent of total forested area from the AVHRR data were lower from the FIA-derived values for all forest type groups except for *Spruce-Fir* (45.0%) and *Oak-Hickory* (2.9%) confirming the pattern of agreement between the two datasets depicted in Table 4.4a.

Differences in total forest area estimates from the FIA and AVHRR datasets for Minnesota were similar to these computed for Maine (Table 4.5). The total estimate of forested area (excluding *Nonstocked* sites) for Minnesota was 66,600 km² and 78,800 km² derived from the FIA and AVHRR datasets respectively (Table 4.5). Although 18% overestimation of forested area by AVHRR could seem acceptable for Minnesota the results may differ significantly for other States where the ratio between forest and nonforest area was greater.

According to the AVHRR dataset 63.0% of the land in Minnesota was nonforest which was very close to the FIA estimate, 67.2 percent (Table 4.5). The majority of the forested area of the state was in *Aspen-Birch* (41.6%), and *Spruce-Fir* (27.2%) forest type group as it was reported in FIA field crew data gathered between 1982 and 1991 (Minnesota FIA *Plot* table).

Table 4.5. Area estimates by forest type group from the FIA and AVHRR datasets.

Forest Type Group	FIA		AVHRR	
	Area, Km ²	% ‡	Area, Km ²	% ‡
MAINE				
White - Red - Jack Pine	11,512	14.4	10,933	14.0
Spruce - Fir	23,407	29.3	32,971	42.1
Oak - Pine	447	0.6	292	0.4
Oak - Hickory	1,643	2.1	2,153	2.7
Elm - Ash - Cottonwood	1,437	1.8	5	0.0
Maple - Beech - Birch	24,667	30.8	24,438	31.2
Aspen - Birch	8,376	10.5	2,397	3.1
Nonstocked	170	0.2	--	--
Nonforest	8,316	10.4	5,175	6.6
Maine total †	79,974	100.00	78,364	100.00
MINNESOTA				
White - Red - Jack Pine	4,522	2.2	9,917	4.7
Spruce - Fir	18,129	8.8	11,111	5.2
Oak - Hickory	4,871	2.4	4,126	1.9
Elm - Ash - Cottonwood	5,620	2.7	664	0.3
Maple - Beech - Birch	5,817	2.8	11,012	5.2
Aspen - Birch	27,722	13.4	42,048	19.7
Nonstocked	854	0.4	--	--
Nonforest	138,582	67.2	134,046	63.0
Minnesota total †	206,117	100.00	212,924	100.00

† Land area estimates exclude areas classified as 'water'.

‡ Percent of total land surface area.

SOC results (kg C m⁻²) by forest type group are depicted in Table 4.6. Generally, estimates from the AVHRR (SOC_{AVHRR}) data were higher than these from FIA (SOC_{BASE} , and $SOC_{100arcsec}$). The FIA data with rounded plot locations, $SOC_{100arcsec}$, produced results that were associated with the lowest variation between all test scenarios. The highest amount of SOC in Maine was observed under *Elm-Ash-Cottonwood* (9.29 kg C m⁻², +/- 5.337) and *White-Red-Jack-Pine* (8.49 kg C m⁻², +/-3.873). Similar for Minnesota, *Spruce-Fir* (27.52 kg C m⁻², +/-24.106), and *Elm-Ash-Cottonwood* (17.00 kg C m⁻², +/- 15.555) were the forest type groups with highest accumulation of SOC (Table

4.6). The average soil C budget for Minnesota was 2.2 times higher than that in Maine most certainly due to the generally less rock fragment content of the soils in Minnesota and the large areas of Histosols located in the Northeastern parts of the State.

SOC by Forest Type and Forest Type group

For each region in Figure 3.7 SOC (kg m^{-2}) was computed to three depths by the *Lognormal* and *Normal* approach. The results were summarized by FIADB forest type group and forest type (Appendix C and Appendix D).

Figure 4.7 summarizes the SOC to 2 m depth computed by forest type group as area weighted average for all forested regions of the 49 contiguous United States. The results showed that SOC (kg m^{-2}) stocks were the highest for *Spruce / Fir* (from 16.1 to 20.2 kg C m^{-2}), *Hemlock / Sitka Spruce* (from 14.6 to 17.8 kg C m^{-2}), *Alder / Maple* (from 12.2 to 15.6 kg C m^{-2}), and *Longleaf / Slash Pine* (from 9.6 to 13.4 kg C m^{-2}); the range in the parentheses was bound by the respective *Lognormal* (lower value) and *Normal* (higher value) estimates (Figure 4.7). The lowest SOC estimates were computed for *Pinyon / Juniper* (5.1 to 6.4 kg C m^{-2}), *Lodgepole Pine* (from 5.6 to 6.7 kg C m^{-2}), and *Western Oak* (from 6.2 to 7.8 kg C m^{-2}). *Tropical Hardwoods* (from 9.0 to 14.3 kg C m^{-2}) were not expected to have such high carbon stocks due to the high rates of organic matter decomposition by microorganisms in the soils. These results were caused by the small sample size of FIA plots that were in *Tropical Hardwoods*.

Data about the proportion of each forest type group within the forested regions of the nation was computed in order to relate SOC stocks that were sequestered by the particular tree species and their abundance within the forested ecosystems. This relationship should help landowners, foresters, and politicians to better plan and manage future forests of the United States that would sequester and hold larger quantities of atmospheric C in the soils. Also, related to land use change patterns this data could help project SOC budgets into the future and assess carbon sequestration potential of the U.S. forest. Oak / Hickory (26.3%), Maple / Beech / Birch (14.2%), and Loblolly / Shortleaf Pine (7.2%) were the most common forest type groups (Figure 4.7). About 18.3 percent of the forests were reported as Nonstocked that represented productive forests that were less than 10% stocked with trees of minimum size (Figure 4.7).

Table 4.6. SOC* by forest type group from three forest cover datasets.

Forest Type Group	FIA †		FIA-100arcsec ‡		AVHRR	
	SOC _{BASE}	StDev	SOC _{100ARCSEC}	StDev	SOC _{AVHRR}	StDev
kg C m ⁻² to 2m						
MAINE						
White - Red - Jack						
Pine	8.49	3.873	8.28	2.477	8.40	3.720
Spruce - Fir	8.29	2.939	8.20	2.296	7.68	3.669
Oak - Pine	8.74	3.216	8.17	2.042	8.26	3.348
Oak - Hickory	7.71	2.713	8.01	1.947	8.32	3.317
Elm - Ash -						
Cottonwood	9.29	5.337	8.90	2.997	11.50	1.852
Maple - Beech - Birch	7.27	2.790	7.41	2.128	7.63	3.450
Aspen - Birch	8.12	3.463	8.04	2.505	7.53	2.386
Nonstocked	7.63	3.088	7.46	2.120	--	--
Nonforest	9.20	3.512	9.05	2.515	9.51	2.744
Maine average ††	7.96	3.144	7.93	2.296	7.79	3.550
MINNESOTA						
White - Red - Jack						
Pine	11.88	11.108	13.09	9.220	15.86	17.855
Spruce - Fir	27.52	24.106	24.38	15.878	20.04	21.674
Oak - Hickory	12.20	8.336	12.54	5.713	14.41	12.543
Elm - Ash -						
Cottonwood	17.00	15.555	17.95	9.888	16.59	7.671
Maple - Beech - Birch	14.32	12.434	15.83	8.720	17.14	17.715
Aspen - Birch	13.52	14.034	14.87	9.790	18.40	17.683
Nonstocked	25.11	22.127	22.23	14.305	--	--
Nonforest	17.51	9.218	17.56	7.083	17.11	16.559
Minnesota average ††	17.58	16.222	17.56	11.065	17.91	17.918

* kg C m⁻² to 2m depth computed by the *Lognormal approach* from filled STATSGO database and overlaid with forest cover dataset.

† FIA dataset provided exact inventory plot location coordinates

‡ FIA dataset provided plot location with 100 arc-second rounding of coordinates

†† Area-weighted average computed from values for all categories excluding 'Nonforest'

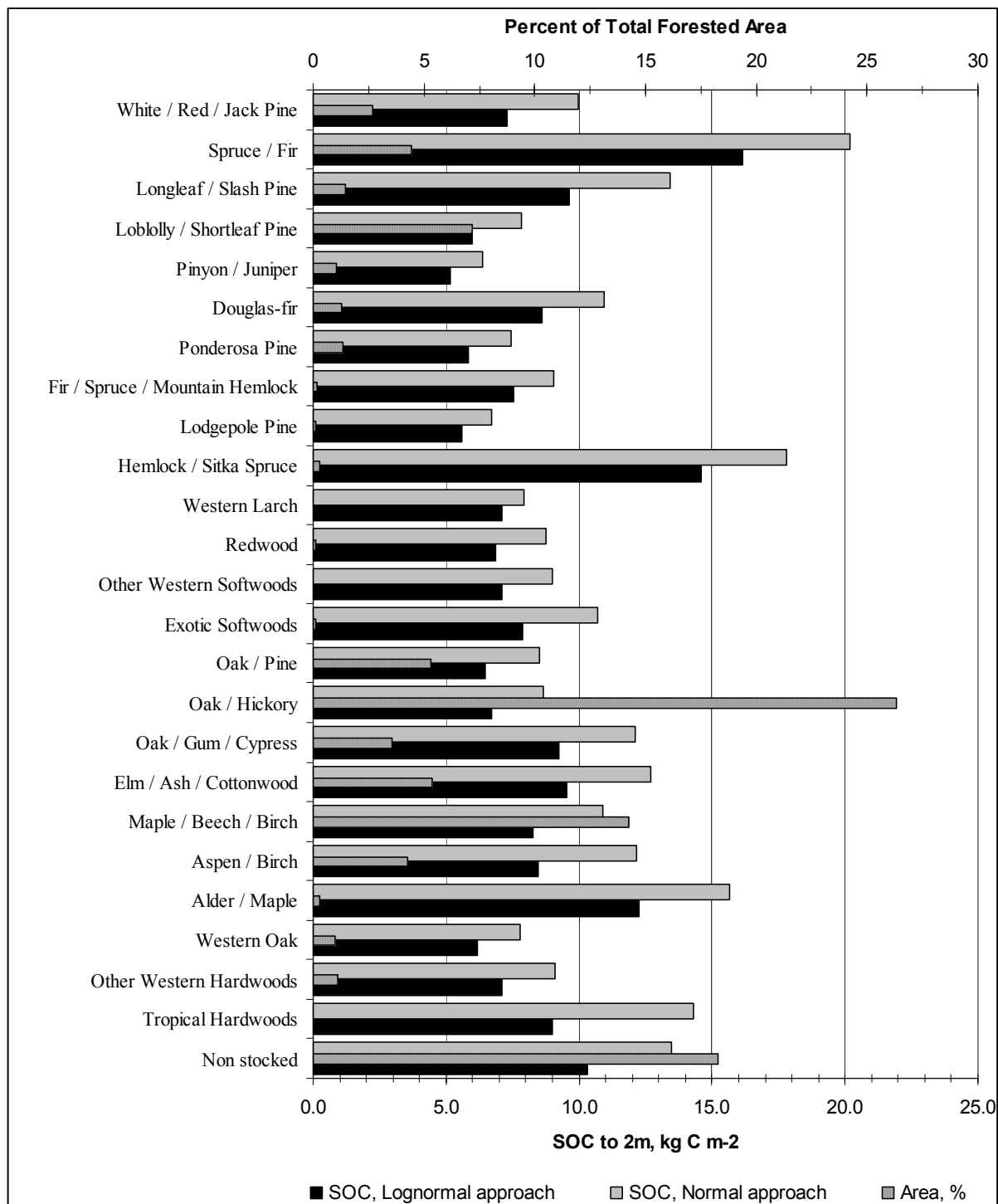


Figure 4.7. SOC to 2 m depth by forest type group computed from the filled STATSGO by the Lognormal and Normal approach.

Spatial Distribution of SOC

In certain occasions maps that showed the spatial distribution of SOC (kg m^{-2}) could improve one's perception of C stock relations to geographic regions across the contiguous 48 United States. The maps shown in Figure 4.8 complemented the understanding of the tabular estimates by forest type and forest type group. For example, there was about 250 km swath of continuous area stretching from Virginia to Alabama including the entire state of Florida (Figure 4.8, e, f) that had higher SOC than the inner land surface following a distinctive boundary between the Appalachian Ridges and Valleys and the Coastal Plain ecoregion of the eastern states. However, without spatial representation in the form of SOC maps this phenomena should not have been noted, which may induce alternative perception of soil organic C sequestration.

The maps were created in the STATSGO native projection system, Albers Conical Equal Area. STATSGO mapping units (*MUID*) were color-coded according to the amount of SOC computed from the filled *Layer* table for three depths (25 cm, 1 m, and 2 m, Figure 4.8), darker colors indicate higher SOC. Open water body features appear as dark gray polygons at one and same area of all six maps and should be considered as regions with 0.0 SOC.

Results from the *Lognormal* and *Normal* approach were mapped parallel to each other in order to show the differences of SOC estimates at STATSGO soil series level from both approaches. The magnitude of SOC difference between *Lognormal* and *Normal* approaches varied between 15 and 30 % with a peak mostly observed in surface soil layers where the concentrations of soil organic matter were the greatest causing the *lognormal* average OM and BD values to be lower than the *normal* ones. Larger versions of all six maps from Figure 4.8 are included in Appendix B.

Generally, SOC estimates were the highest for regions located east from the Rocky Mountains with a peak in the Great Lakes region (Minnesota, Wisconsin, Iowa), the Atlantic coast region (the Northeast and Southeast), the Great Plains States, and the Coastline of the Gulf of Mexico. Very narrow areas in the Norwest (Washington and Oregon states) were also observed to hold relatively high amounts of SOC. The lowest values of SOC were observed in the Appalachian region and the entire extent of the Rocky Mountains (Figure 4.8). One should be advised that isolated pockets of area with

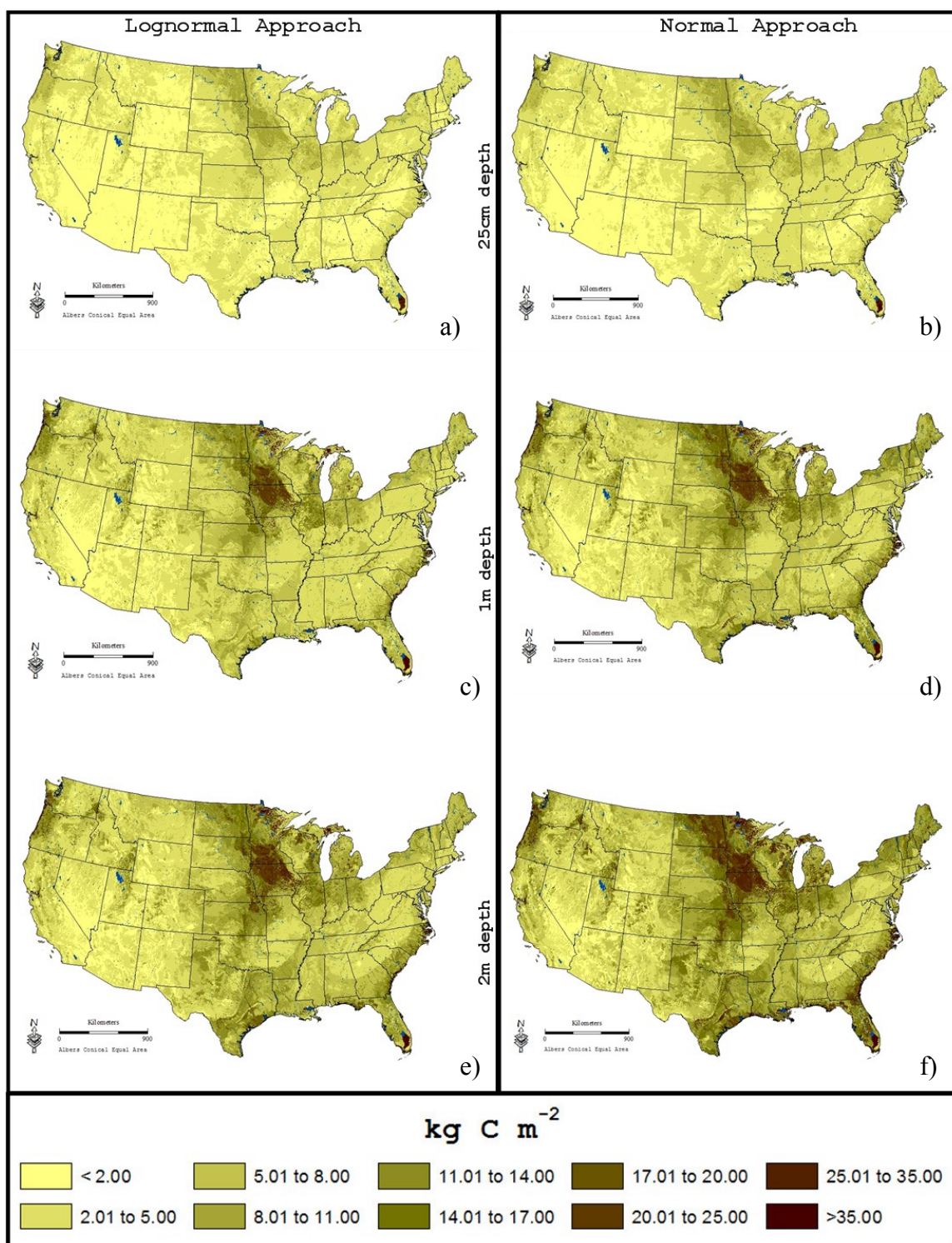


Figure 4.8. SOC by STATSGO mapping unit to 25 cm- (a, b), 1m- (c, d), and 2 m-depth (e, f) computed by *Lognormal* and *Normal* approach.

high SOC values were generally narrow strips of concave land surface, usually around stream flood plains or standing water (as the Histosols) and vegetation, that were not depicted on the maps due to mapping scale.

SOC Results Validation

Very few studies from the recent literature were found to report SOC estimates (for depths ≥ 1 m) by forest type encompassing all 48 states of the contiguous United States. In their attempt to draw soils data from available soils databases (STATSGO, NSSL, and the National Resources Inventory (NRI) database from the USDA-NRCS) researchers identified numerous data format and data availability issues, such as missing values for rock fragment content (RFC), organic matter (OM), and bulk density (BD), soil properties presented as a range of minimum and maximum values, insufficient depth of available soil pedons, and the lack of scientific methodology for replacing and modeling missing soils data. Difficulties were also encountered with nationwide forest cover datasets (AVHRR and FIA). SOC results differed between different scenarios of spatial data overlay of the forest coverage and soils layer mostly due to the underlying principles of data aggregation to a forest type group level.

Kern (1994) produced soil organic carbon estimates by three approaches one of which computed SOC values by soil order, suborder, and great group. SOC data from the NSSL database was summed to a great group level and then was geographically distributed nationwide by MLRA region designation of the NRI dataset (Kern, 1994). Although NSSL pedon data provided only one measurement of SOC, as opposed to range of values similar to the STATSGO database, Kern made an assumption that each pedon equally represented the SOC of the taxonomic unit that it was assigned to. Therefore, when data was summarized to a great group, or higher soil taxonomic level, data was manipulated in a manner that resembled the *normal* approach thus treating the outliers of the sample pool of pedons with equal weight resulting increased SOC values.

Important note for this study was that Kern did not account for rock fragment content (RFC) and SOC by volume were computed as the product of SOC by weight, bulk density and soil depth (Kern, 1994, page 441). As a result, one should expect higher SOC values with no predictable overestimation pattern among soil classification levels due to irregularities of soil property distribution. Nevertheless, keeping in mind the above

assumption about the relation between RFC and SOC values the results by soil order (Kern, 1994, page 446:Table 3) and by great group class (Kern, 1994, page 448-449:Table 5) were used as one of the SOC sources in the literature in order to validate our results.

Figures 4.9a and 4.9b depict the SOC results to 1 m depth from Kern (1994, Table 5) and from the *lognormal* approach of the current study, noted as Amichev. The results from both studies were closest for great groups in the Alfisols, Mollisols, Ultisols, and Vertisols orders. The differences were greatest for most great groups in the Spodosols, Inceptisols, and Histosols orders (Figures 4.9a and Figure 4.9b). Kern (1994) reported 3.4 times higher SOC results for great groups in the Histosols order which was due to poor data of such soil layers in the STATSGO database.

As expected, the estimates from Kern (1994) were consistently higher than these from Amichev except for 9 great groups. The explanation for these 9 great groups was based on the fact that Amichev modified the STATSGO *Layer* table by filling missing values for organic matter (OM), bulk density (BD) and RFC. Filling for and replacing invalid records had resulted in a larger relative SOC increase from OM records input than the relative decrease caused by adjusting RFC values.

The average difference between Kern and Amichev results was 5.9 kg C m^{-2} computed as the average of $\text{SOC}_{\text{Kern}} - \text{SOC}_{\text{Amichev}}$ (Figures 4.9a and Figure 4.9b). Generally, for half of the great groups (Kern 1994, Table.5) the differences in SOC were less than 5.9 kg C m^{-2} , and for a third of the population the differences were less than 3.0 kg C m^{-2} (half of average SOC difference). The STATGO database did not provide equally sufficient data for all soil taxa resulting in ‘no-data’ values for all great groups in the Oxisols order, *hydrandepts* and *eutrandepts* in the Inceptisols, and *natralbolls* in the Mollisols order.

The next phase of validation of SOC estimates targeted results at higher levels of aggregation, soil order and State. Published SOC estimates by soil order were reported in Johnson and Kern (2003) and Kern (1994). Area weighted mass SOC values by State were produced by Bliss et al. (1995).

Johnson and Kern (2003) used two independent sources for soil properties: (i) the STATSGO database to obtain coarse fragment and soil depth information as well as the

STATSGO soil polygons to spatially distribute nationwide SOC values, and (i) the NSSL pedon database to extract SOC estimates similar to Kern (1994). Unlike Kern (1994), Johnson and Kern (2003) adjusted the SOC estimates by great group for rock fragment content and replaced missing data from similar taxa within a study region. An important detail that was observed was the extent of their study areas. The contiguous United States was considered a region by itself, then Alaska, Hawaii, and Puerto Rico were treated as separate entities. Johnson and Kern (2003) used one SOC value per soil order within a region implying the assumption that soils from the same soil taxonomic order across the contiguous United States would have equal SOC content. However, differences in intensity and effects of soil forming factors across the nation could result in different soil properties, therefore different SOC content per soil order, classifying the above assumption as partially or fully inaccurate.

Amichev produced SOC estimates at the soil order level for the 9 regions analyzed in this project (Figure 3.7). The objective was to test homogeneity of SOC stocks by soil order among the regions within the contiguous United States. If results were found to be similar then one would be able to apply a single SOC by soil order value for that particular soil order anywhere in the contiguous United States. Figure 4.10 showed the extent of SOC homogeneity between the regions. The coefficient of variation ($CV = \text{standard deviation} * \text{mean}^{-1} * 100$) ranged from 44 to 165% and results by soil order were as follow: Andisols (165%), Histosols (161%), Aridisols (85%), Ultisols (79%), Spodosols (68%), Vertisols (67%), Entisols (59%), Mollisols (50%), Alfisols (48%), and Inceptisols (44%). The conclusion of Amichev's homogeneity test showed that SOC estimates by soil order differed within regions. If only one value per order was assigned to each occurrence of mapping units in the particular soil order, over- or underestimation of SOC could occur.

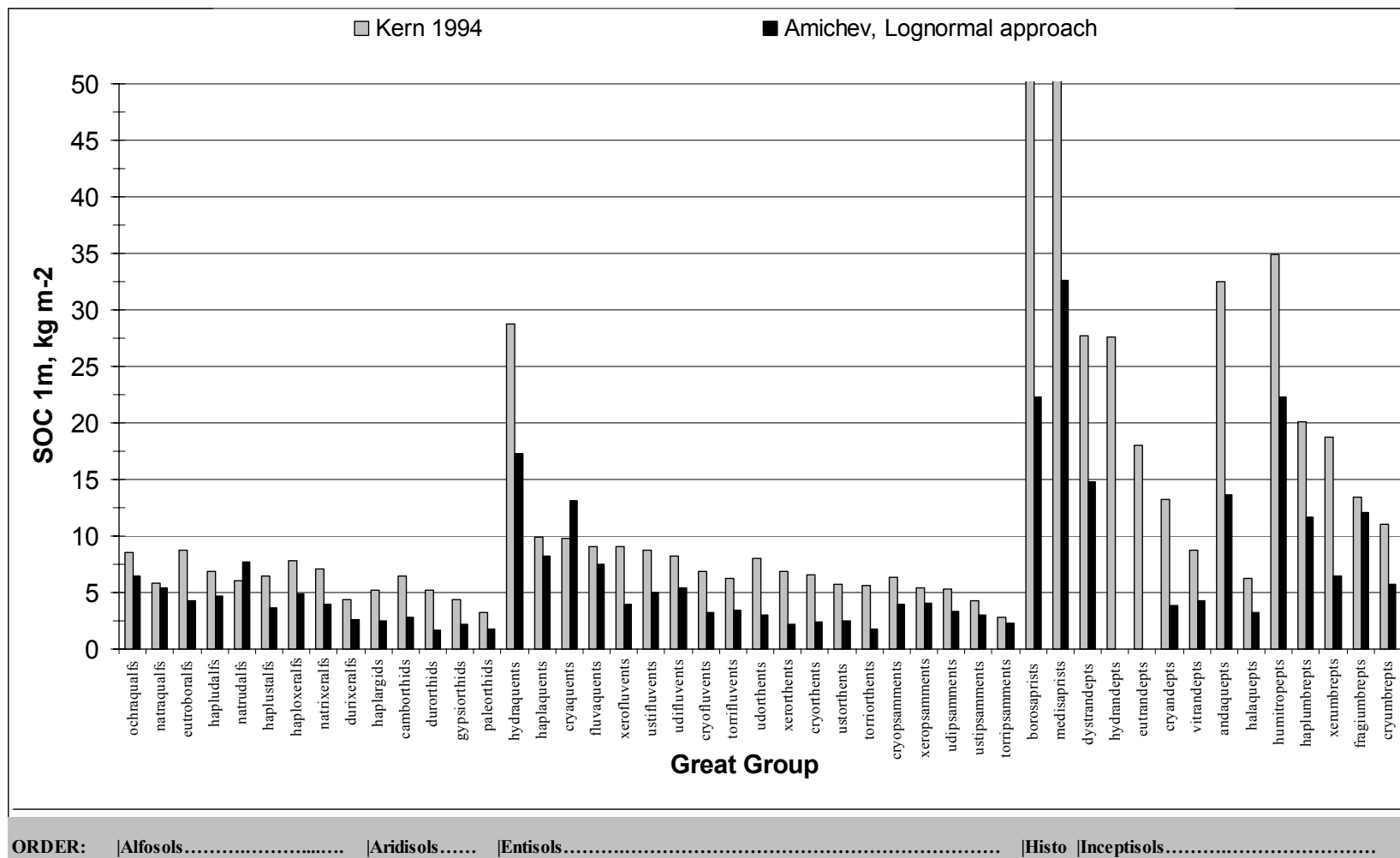


Figure 4.9a. SOC estimates to 1 m by great group summarized from mapping unit data for the 48 contiguous United States. Note: SOC for Histosols, *borosapristis* and *medisapristis* from Kern (1994) should be read as 97.2 and 80.1 kg C m⁻² respectively.

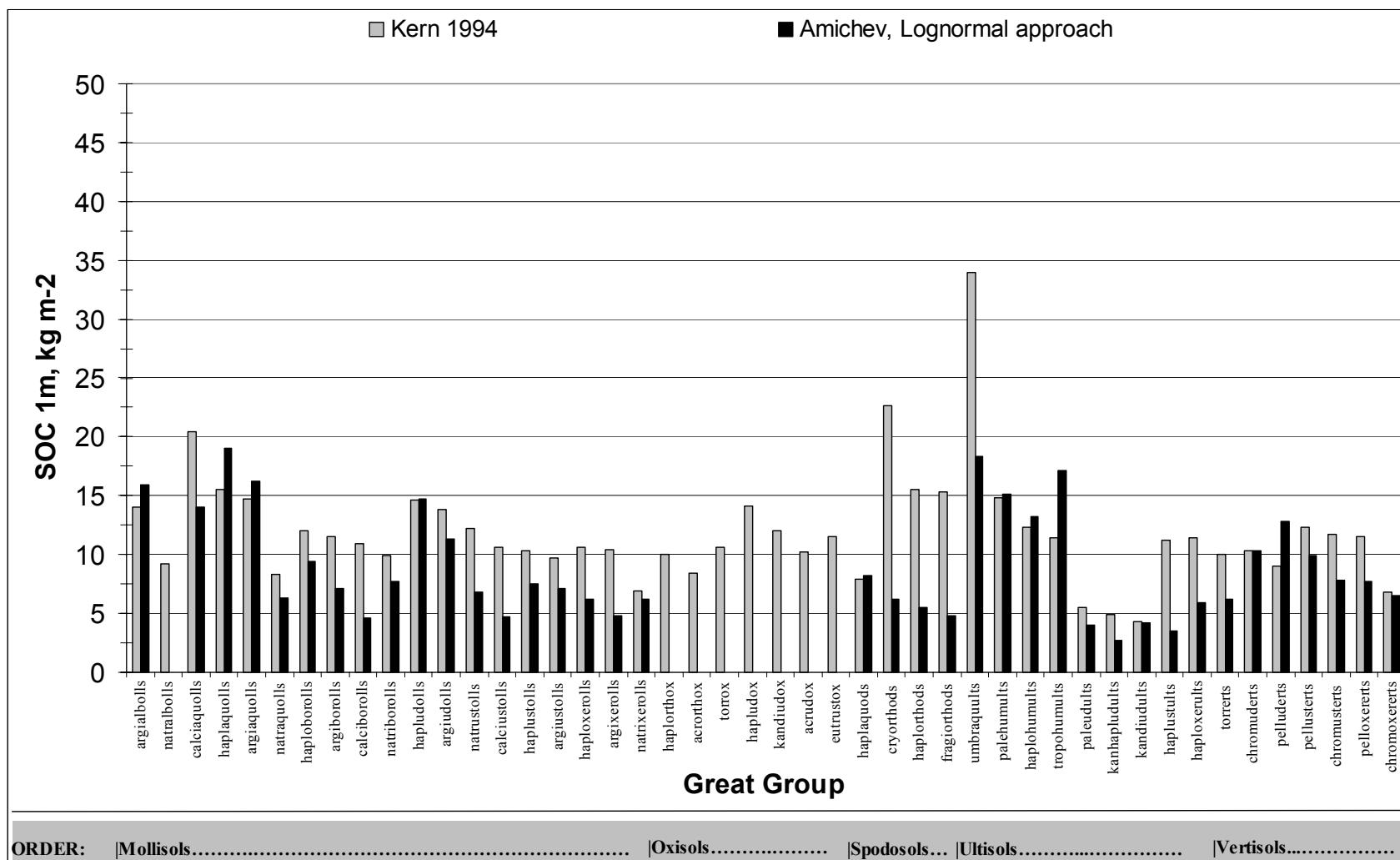


Figure 4.9b. SOC estimates to 1 m by great group summarized from mapping unit data for the 48 contiguous United States.

Figure 4.11 represents SOC values to 1 m depth from three sources. Although Johnson and Kern (2003, page 56: Table 4.2) adjusted their SOC values by STATSGO rock fragment content their estimates were close but consistently higher the results from Kern (1994, page 446: Table 3). Both studies based their analysis on SOC data from the NSSL pedon database and both used different methods of compensating for missing SOC and bulk density values. Yet, Johnson and Kern (2003) did not mention the vast number of missing records in the rock fragment fields of the STATSGO database, which would affect SOC estimates.

Amichev's SOC results were consistently lower from both Kern (1994) and Johnson and Kern (2003) results by an average difference of 5.0 and 5.9 kg C m⁻² respectively that was computed as $(SOC_{Kern} - SOC_{Amichev})$ and $(SOC_{JohnsonandKern} - SOC_{Amichev})$.

Amichev's estimates were computed from the filled STATSGO database by the *Lognormal* approach. The filling procedure filled in and replaced invalid entries for OM, BD, and RFC that were used in the equation for SOC computation. If RFC data was left unaccounted for in the original STATSGO database then coarse fragments volume for each layer should have been considered as fine earth that could overestimate the SOC results.

Another explanation for SOC differences in Figure 4.11 was based on the methods of adjusting SOC values for 'no-data' layers within a pedon. For example, Johnson and Kern (2003) used the half of the SOC value from the 30-100 cm increment and then assigned it to the 100-150 cm. On the other hand, Amichev used available layer data in the STATSGO database and computed the average of all values by soil layer within the same soil order, texture classifications, and MLRA region that was assigned to layers with missing data.

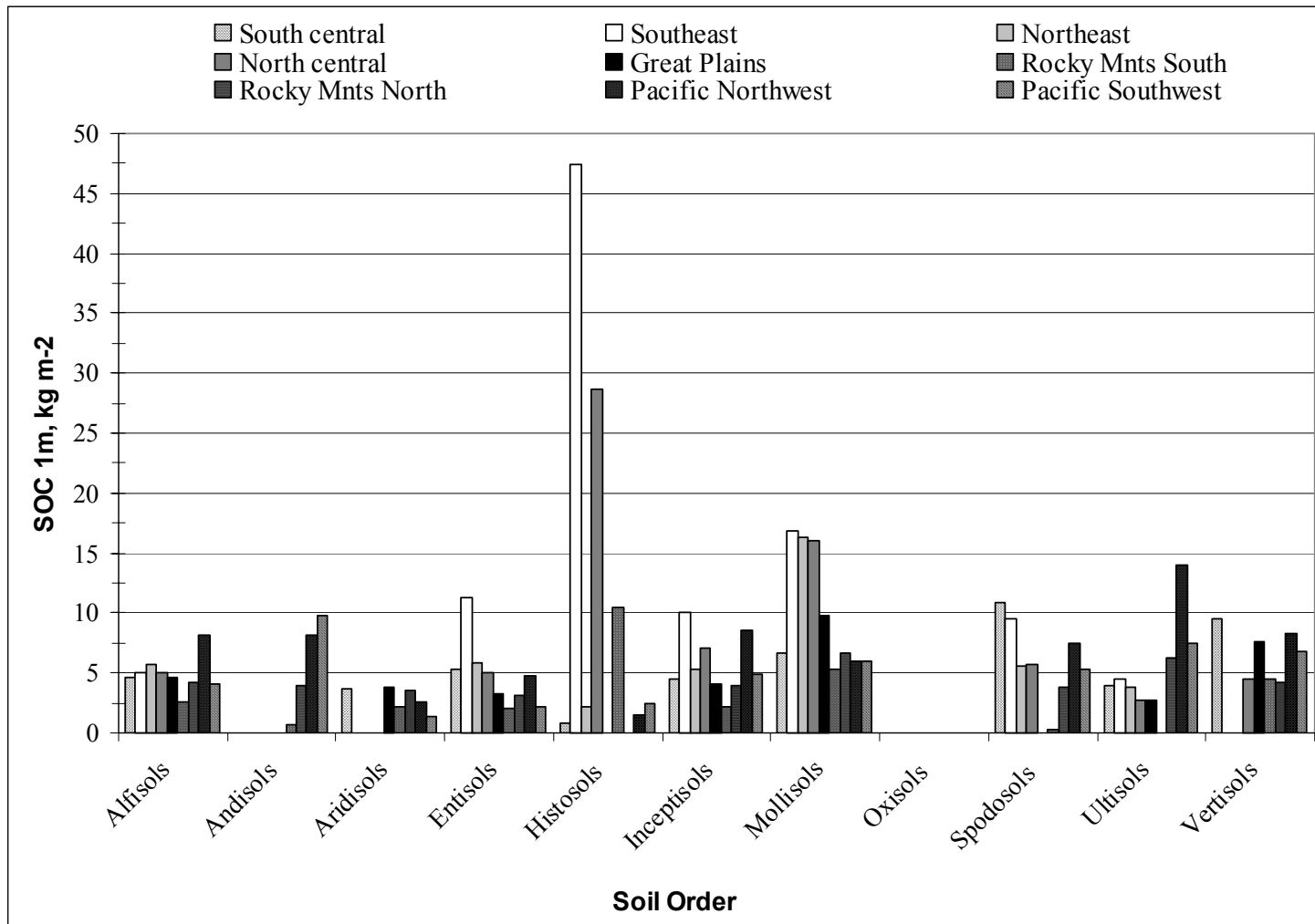


Figure 4.10. SOC to 1m depth by regions in the U.S. computed from filled STATSGO database using the *Lognormal* approach.

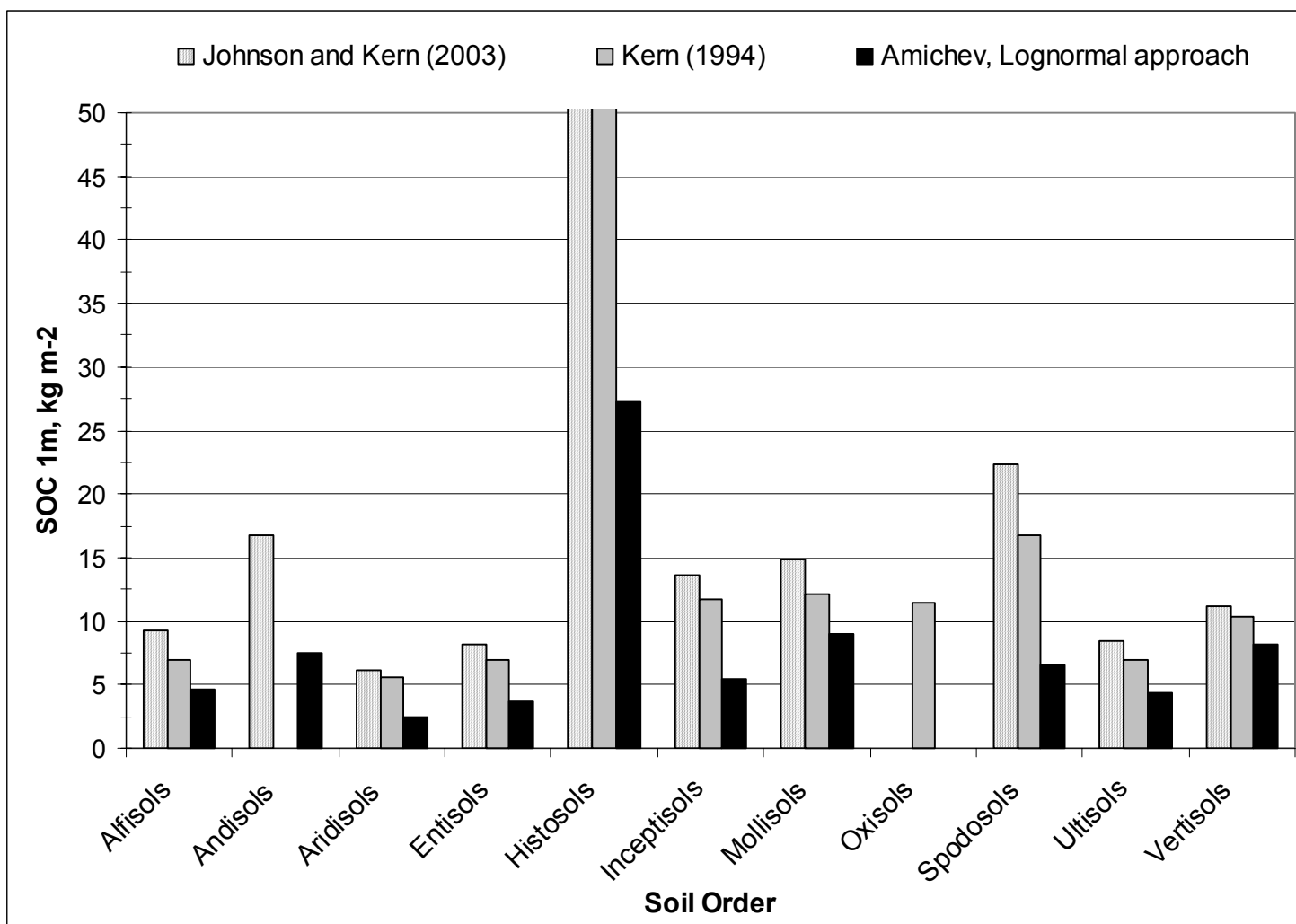


Figure 4.11. SOC estimates to 1m by soil order summarized from available soils data of the 48 contiguous United States. Note, SOC for Histosols should be read as 83.20 and 84.30 kg C m⁻² from their respective Johnson and Kern (2003) and Kern (1994) sources.

Bliss and other (1995) described an extensive methodology of using the minimum and maximum values per soil property from the STATSGO database in order to produce nationwide C inventory maps and results. They used all available layer data, including OM, BD, rock fragment content (RFC) and layer depth in order to compute soil organic stocks that were adjusted for RFC. An important detail of their study was that SOC results within a soil component were only summed for contiguous layers from the surface that had data (Bliss et al., 1995). For example, if a component with 4 layers had data for all three but layer 2 (second from the surface) then the SOC for that component was equal to the SOC of layer 1 (surface layer); if layer 3 was missing data then component SOC was computed as the sum of SOC values of layer 1 and layer 2 (Bliss et al., 1995). Although this method of SOC computation did not define the exact depth of analysis Bliss et al. (1995, page 293: Table 2) identified each State's data availability status and reported percent area with reported data along with their mass SOC.

Figure 4.12 represents the SOC estimates agreement between Bliss et al. (1995) and Amichev (*Lognormal* approach to 2 m depth). The per State results were very close with average difference of 1.5 kg C m^{-2} , computed as the Absolute value of $(\text{SOC}_{\text{BlissandOthers}} - \text{SOC}_{\text{Amichev}})$ and the average SOC ratio, $(\text{SOC}_{\text{BlissandOthers}} * \text{SOC}_{\text{Amichev}}^{-1})$ average was equal to 0.94 that ranged from 0.4 (Montana) to 1.5 (Delaware).

Amichev adopted the methodology and equations for SOC estimation from Bliss et al. (1995) and applied the filling methodology to the STATSGO *Layer* table. The filled STATSGO was then used to compute area weighted SOC stocks for the those States that Bliss et al. (1995, page 293: Table 2) indicated >80% of percent area with reported data. Since both sets of results were derived from the same data source, the objective of this validation case was to assess the consistency and effect of STATSGO database filling procedures. The results from this comparison were accepted as reasonable.

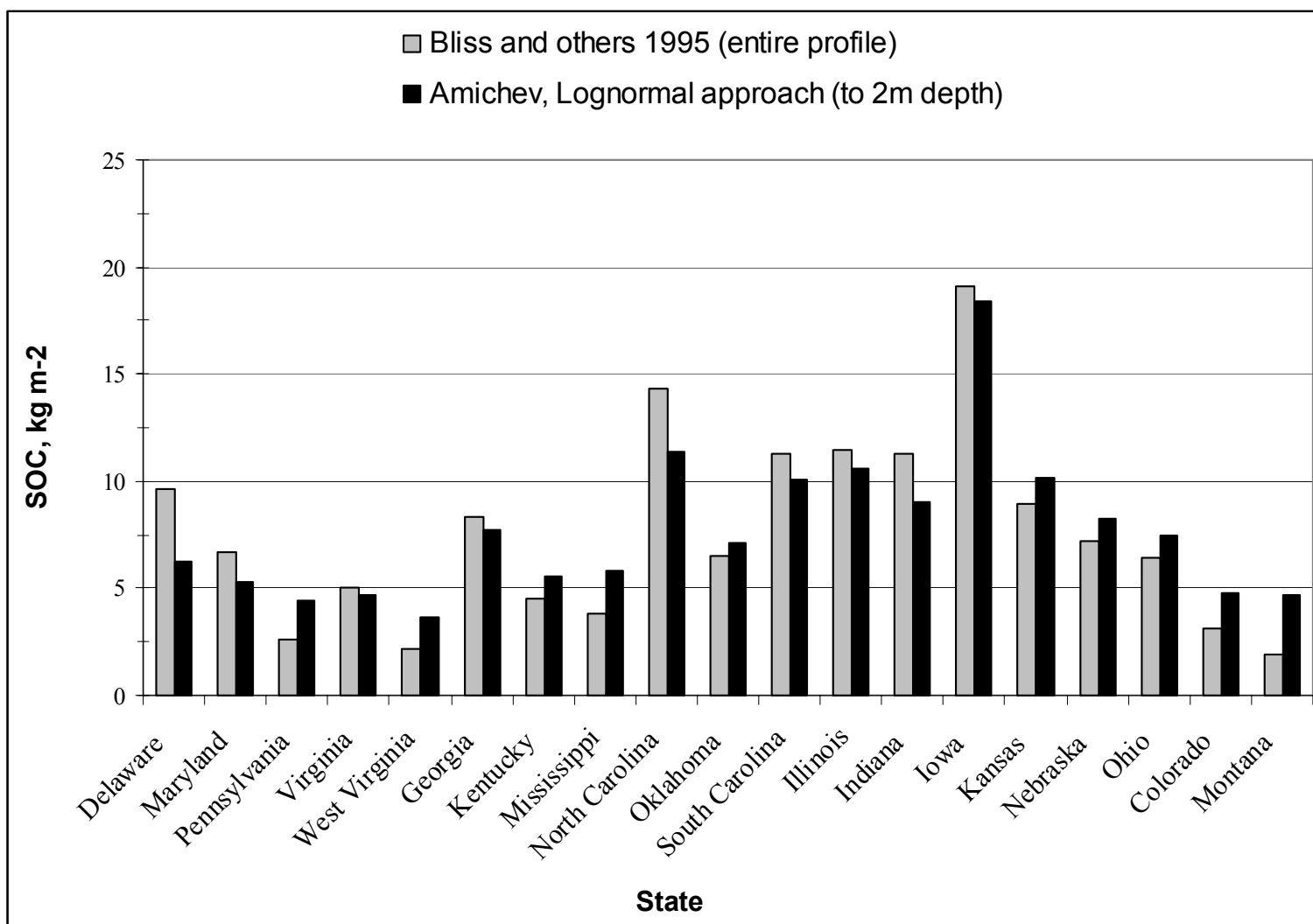


Figure 4.12. SOC by selected States derived from the STATSGO database.

CHAPTER 5: CONCLUSIONS

The current averaging and replacing methods are unique and provide flexible, user-defined, rapid procedures and tools for dealing with the STATSGO null and zero records. The advantage of such a system is that multiple states can be processed quickly using automated procedures and simple software. This study was conducted as a preliminary effort to automate and critique the procedures and rules and will be continuously updated and improved. The resulting SOC maps are dynamic and can be rapidly redrawn using GIS whenever STATSGO spatial or tabular data undergo updating.

The procedures in this study can be improved in future efforts. Primarily, research is needed to determine whether the data in STATSGO should be transformed before mass SOC is calculated. Possible shortfall of using only STATSGO data for the lookup tables could lead to filling most of the invalid records with averages from only few series that are present numerous times in many mapping units. Replacement averages would be improved if the data from different states were combined before calculation of average values by MLRA because several MLRAs occur in five adjacent states. Soil classification to the suborder or great group level rather than soil order could be used in areas where there are sufficient numbers of map unit components to produce meaningful averages. Also, combining STATSGO with some data from other pedon datasets, such as NSSL, to fill inaccurately entered records for the soils of major extent within a MLRA unit would improve the soil property database and SOC maps.

The USDA-NRCS has reorganized and now deals with soil correlation by MLRA rather than by state. Therefore, future STATSGO products will remove some spatial and map unit composition disagreements along state borders and promote regionally-specific values to be entered into the tables.

The procedures in this study point out areas that could benefit the most during future revisions of STATSGO. Addition of surface litter horizons as suggested by Homann et al. (1998) and Galbraith et al. (2003), OM values specific to land use or vegetation group, use of pedon data to define representative values for all properties in all STATSGO layers and correlation of STATSGO layers to soil horizons will lead to vast improvement of the STATSGO *Layer* table and promote its use for mass SOC estimation

over large regions. STATSGO can be easily joined with FIA data to produced SOC averages by forest type group, making the FIA database more complete and leading the way to producing total ecosystem C estimates in the forests that include C from standing biomass, surface litter, dead roots, and soil.

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APPENDICES

APPENDIX A: STATSGO NULL AND ZERO RECORD FIXING

Fixing procedures differ between targeted soil properties. The idea is that each of these parameters, (i) organic matter content (*OML*, *OMH*), (ii) bulk density (*BDL*, *BDH*), and (iii) rock fragments content (*INCH3L*, *INCH3H*; *INCH10L*, *INCH10H*; *NO10L*, *NO10H*) vary in their range of values according to the texture class of the soil layer and parent material. Hence, there are several grouping schemes that are specifically adjusted for each group of variables (i), (ii), and (iii) (Tables 3.1, 3.2, and 3.3). The purpose of the groupings is to modify the level of similarity between specific textures. Each fixing procedure is different for (i), (ii), and (iii) variables and each follows multiple phases of grouping valid records into sets of data to be used for average value estimation. The number of records in the data sets increases with each phase caused by intentional simplification of the grouping criteria. The trend is from multiple, small number records, unique groups [phase I] to less number of groups including greater number of texture entries [phase IV]. The efficacy of such grouping system enables replacement of most of the null and zero record entries detected in the *Layer* table. In each grouping there is limitation for a minimum number of non-zero and non-null records that is set at the beginning of the fixing process. Such limitation is required to establish credibility for the replacement average values, i.e. how many valid entries are to be used to consider the new value as valid and reliable. In cases when the data pool of valid records in any grouping is less than the assigned limit the value is unreliable and the fixing process continues to the next phase of fixing. Then, a greater number of valid entries that are assigned to a less discrete and less specific grouping class are averaged and used as a replacement value. At the completion of each phase each null and invalid zero record entry, is marked as fixed and is removed from the set of problem records. By doing so, the speed of data processing is increased and the use of computer memory is minimized.

A. Organic matter content

Before proceeding with any grouping analysis we need the parameters of interest, i.e. the *group by* variables must be available in appropriate fields in the *Layer* table. The strategy is to extract available data from different STATSGO tables so that each soil layer

record in the *Layer* table is assigned a legitimate soil order code (from *Taxclass* table) and MLRA code (from *Mapunit* table). Table relationships in the STATSGO database are depicted in Figure 3.2. *Layer*, *Comp*, *Mapunit*, and *Taxclass* tables can be joined using common fields as depicted in bold. With the means of Microsoft Access relational queries all nineteen variables of interest (marked with arrow) are integrated into the *Layer* table so that the key fields, *MUID*, *SEQNUM*, and *LAYERNUM* uniquely identify each soil layer.

A.1. Assumptions

Record grouping criteria and fixing procedure techniques are appropriate under some basic assumptions. The following are applicable for both organic matter high, *OMH*, and organic matter low, *OML*, parameters: (a) parent material and texture of fine-earth affect and/or reflect organic matter (OM) content, but rock fragment content does not; (b) *OMH*; *OML* should be zero for the following textures: *WB* (“weathered bedrock”), *UWB* (“unweathered bedrock”), *CEM* (“cemented”), and *IND* (“indurated”); (c) some texture layers are mostly rock fragments, *FRAG* = “fragmental material”, *G* = “gravel”, *CIND* = “cinders”, and *OMH* can be set to zero only if all other records yield average of zero; (d) *ICE* (“ice or frozen soil”) layers occur in frozen soils that often do contain organic matter, so an average is computed and used as a replacement value even if it is zero. *OMH* should only be set to zero if all values are null; (e) zero value for *OML* is acceptable in mineral or inorganic layers but not organic or mucky layers (Tables 3.1, column II and IV). *OML* for organic and mucky layers should be replaced with an average replacement value, using the same grouping scheme as for *OMH*. If nulls/zero records are still present, the rest of organic and mucky *OML* nulls/zeros are set to 0.1, which is assumed to be the lower end of OM concentration range of variability (Davidson and Lefebvre 1993); (f) there are four grouping variables – texture class (texture-grouping code), layer number, MLRA, and soil order. There are three specific soil orders that are treated separately from all others – *H* (“Histosols”), *S* (“Spodosols”), and *C* (“Andisols”).

A.2. Procedure

Most of the texture class entries are single-code words, while many others contain an additional adjective (rock fragment modifier code) that is separated by a dash from the main texture definition. Since only the texture code is the required parameter, the part before the dash is not used for any further computations or record matching. For example, *STV-FSL* (*STV* = “very stony”; *FSL* = “fine sandy loam”) and *FSL* textures are considered one and the same and such soil layers will be grouped in the same set of records, given all other grouping variables are equal. Next step is to compute average *OMH*; *OML* for each texture designation from all soil horizons with valid record entries, grouped by soil order, MLRA, and layer number. Table 3.1 (‘Texture Code’ field) lists the texture classes that are potential targets for record value verification and replacement. Important aspect of the STATSGO *Layer* table is the existence of multiple texture definitions split into three separate fields, *TEXTURE 1*, *TEXTURE 2*, and *TEXTURE 3*, which is the result from data format conversion as described in the STATSGO user’s guide. This can be interpreted as the frequency of texture class occurrence by soil type considering *TEXTURE 1* as the main texture, and *TEXTURE 2*, *TEXTURE 3* as secondary texture designations.

For example, the following random record from the *Layer* table for the state of Connecticut has three valid entries in each texture field:

ORDER	I
MLRA	144A
MUNAME	CHARLTON-CANTON-PAXTON (CT001)
MUIDSEQNUM	CT001 1
LAYERNUM	2
TEXTURE1	FSL
TEXTURE2	GR-FSL
TEXTURE3	GR-L

This means that the texture of the soil listed in *MUNAME* field (“Charlton-Canton-Paxton” soil) with *MUID* = CT001 and *LAYERNUM* = 2 is mostly observed as *FSL* (“fine sandy loam”), and for the rest of the pedons it is classified as either *GR-FSL* (“gravelly-fine sandy loam”) or *GR-L* (“gravelly-loam”). These additional data fields are used for secondary record matching within the same grouping if null/zeros still exist.

Yet, this is not the only occasion when secondary texture fields, *TEXTURE 2* and *TEXTURE 3*, are populated with valid codes. Special attention is brought to texture codes *VAR* (“variable”), *SR* (“stratified”), and *UNK* (“unknown”), which are used to single out soil horizons with unclear and indiscrete textures. In this case the secondary texture fields are the ones that may contain meaningful texture codes or be left as blank. In cases where the texture fields following *VAR*, *SR*, and *UNK* are left blank, average *OMH;OML* values for each layer are computed from all valid record entries grouped by soil order and MLRA, regardless of primary or secondary texture designation.

A.3. Phases in *OMH;OML* nulls and zeros fixing

There are five phases of the *OMH;OML* fixing procedure. Figure A.1 depicts the steps and methodology of valid entry grouping showing consequent null/zero records replacement with average *OMH;OML* estimates. In order to show the computational sequence of producing average values, an imaginary *Layer* table has been created (Figure A.1, a) with total of 3,000 records, among which only fifty percent are valid entries and the rest are nulls or zeros. Ultimate objective of the fixing technique is to populate all null records and replace the zeros with values that are scientifically justified by texture class (texture-grouping code), layer number, soil order, and MLRA.

In *Phase I*, all valid records, for each soil layer, are grouped by their soil order definition and MLRA code so that one single, average *OMH;OML* value is calculated for each original texture code. It is important to understand the limitation for the minimum number of valid records per grouping set. The process of updating nulls/zeros will be applicable only if the replacement value is the result of sufficient number valid records. The default limit is three (user-defined) and it is considered the lowest threshold of replacement value reliability. Then, the number of valid records per texture code is queried and such replacement values that are obtained from less than three valid records are removed from the look-up table. Next, newly created *replacement-values I* look-up table is joined with the original STATSGO *Layer* table by their common fields (*ORDER*, *MLRA*, *LAYERNUM*, and *TEXTURE 1*) to transfer replacement values to all records with *OMH;OML* fields that are nulls or zeros.

In the illustrated example of a subset of 20 records (Figure A.1, b), half of the records are valid and half are zeros/nulls. Record numbers 1; 2; 4; 6; 7; 9; 10 and 3000

are marked as 'a' for their equal texture class, same layer number, soil order, and same MLRA code. From these, records 2; 4; 9; and 3000 are nulls/zeros and are assigned the same average value computed from the rest of the 'a' - marked valid records, i.e. the average of 2; 6; 7 and 10 records. The same procedure is applied to all 'b' - marked records, the average of records 3; 8 and 2991 is assigned to records 5 and 2992. Both, the valid record sets for 'a' - and 'b' - marked records contain three or more original *Layer* records and meet the minimum fixing limitation.

On the other hand, valid entries that are marked as 'e', records 2995 and 2998, are the only two that are found in the whole table and this is the reason why there is no replacement value produced for 'e'-marked null/zero records. Still, if 'e'-marked nulls/zeros have different texture definitions assigned in *TEXTURE 2* or *TEXTURE 3* fields, then these records are fixed using a new secondary texture classification. Record marked as 'a' is any record with the following key fields: *ORDER* = *H* ("histosols"), *MLRA* = *144A* ("New England and Eastern New York Upland, Southern Part"), *LAYERNUM* = *3*, and *TEXTURE 1* = *SIL* ("silt loam"). Record marked as 'b' is any record that has: *ORDER* = *H* ("histosols"), *MLRA* = *144A* ("New England and Eastern New York Upland, Southern Part"), *LAYERNUM* = *3*, and *TEXTURE 1* = *SL* ("sandy loam"), i.e. 'a' and 'b' marked records differ only by their *TEXTURE 1* definition.

These records meet the limitation for minimum number valid records and the nulls/zeros in their respective sets of records are fixed with estimated averages. For instance, suppose record marked as 'e' has the following key field entries: *ORDER* = *H* ("histosols"), *MLRA* = *144A* ("New England and Eastern New York Upland, Southern Part"), *LAYERNUM* = *3*, *TEXTURE 1* = *VFSL* ("very fine sandy loam"), *TEXTURE 2* = *SIL* ("silt loam"), and *TEXTURE 3* = *SL* ("sandy loam"). Then 'e'-marked records are considered as a combination between the 'a' - and 'b' -marked, referred to as 'a-b' type, as *TEXTURE 2* and *TEXTURE 3* fields suggest. In such cases 'e'-marked, 'a-b' type, invalid records are replaced with a new average value that is computed as

$$[AverageFor' a_b'] = \left(\frac{[AverageFor' a'] + [AverageFor' b']}{2} \right),$$

Grouping Scheme for OMH/OML fixing procedure with 3 as **required** minimum number of valid records

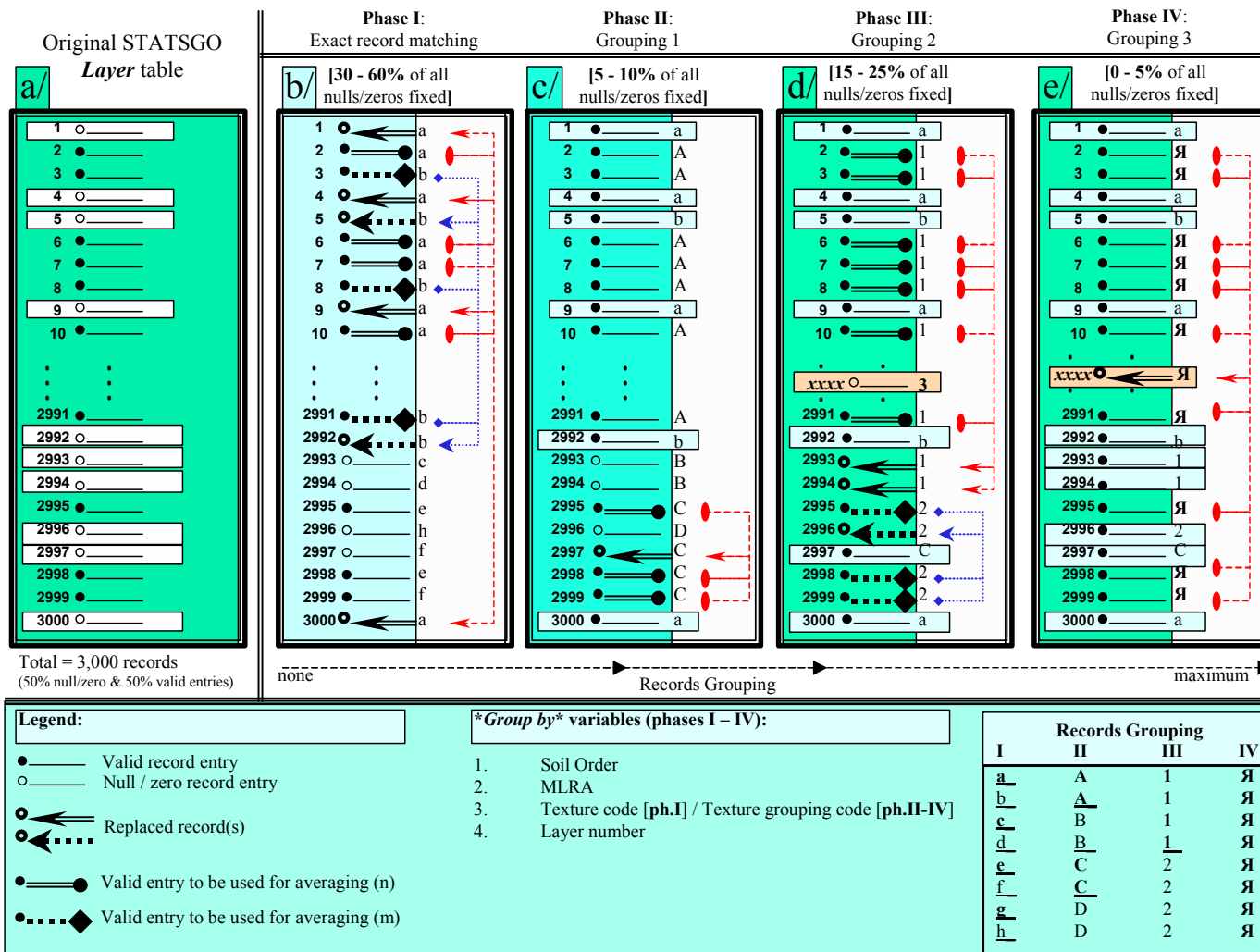


Figure A.1. Phases in fixing OMH;OML nulls and zeros using similar texture groupings of minimum of three valid records.

where *AverageFor* 'a' is the simple average of all valid entries from original *Layer* table marked as 'a', given their count is greater or equal to the assigned limitation, e.g. [count \Rightarrow 3]; *AverageFor* 'b' is the simple average of all valid entries from original *Layer* table marked as 'b', given their count is greater or equal to the assigned limitation; *AverageFor* 'a_b' is the new replacement value for records of 'a_b' type which have TEXTURE 2 and/or TEXTURE 3 for 'a_b' equal to TEXTURE 1 code for 'a' and/or 'b'-marked records.

The nulls and/or zeros for some special texture codes that are detected in *TEXTURE 1* field, such as *VAR*, *SR*, and *UNK* are updated at the end of *Phase I*. There are two possibilities to proceed with replacement value computation: (1) if *TEXTURE 2* and/or *TEXTURE 3* fields are populated and there are exact record matches that are found in the *replacement-values1* look-up table, then a new replacement value, computed by the above equation, is filled in for nulls/zeros, as in the scenario with the 'e'-marked records; or (2) if both *TEXTURE 2* and *TEXTURE 3* fields are blank, then a special replacement value is computed as an average of all valid records with *TEXTURE 1* field containing either of the codes *VAR*, *SR*, *UNK*, *ICE*, *G*, *CIND*, and *FRAG*. The last four texture codes are included in the set of special textures as they occur in special topological settings and environmental conditions as *VAR*, *SR*, and *UNK* (see assumptions, c

Depending on the ratio between valid and invalid records, as well as on the similarity between soil horizons, the rate of fixing in *Phase I* may vary between 30 and 60 percent of all detected null/zero records in the STATSGO *Layer* table. The rest of the invalid records are updated during the next steps of the fixing procedure.

In *Phase II* each record is assigned a texture-grouping code introduced by a predefined texture look-up table, named "*LU_Texture_Grouping_2*" (Table 3.1, column II). The latter consists of all possible texture codes and names as described in the STATSGO Data Use Information (1995) and an additional field with self-descriptive alphanumeric grouping codes that fuse the primary texture classes into fewer sets of similar textures. All look-up tables are created with the joined effort of soil scientist expertise in our team combined with consultation from NRCS professionals. The purpose of such look-up tables, used in *Phases II* through *IV*, is to increase valid data pools for each texture-grouping so that the limitation for minimum number valid records is met. This is done

with the expense of reduced texture similarity between valid records, which allows a greater number of original *OMH;OML* entries to be used in the computation of replacement values.

Similar to *Phase I*, the grouping variables here are *SOIL ORDER*, *MLRA*, and *LAYER NUMBER*, and *texture-grouping code* is the only new property. Same for each set of similar records, an average replacement value for each texture-grouping code, *GROUP_2*, is computed from all valid records in the *Layer* table. An important rule is that all valid records that are used to compute an average value are from the original *Layer* table entries and none are previously replaced records. For example, records 1; 4; 5; 9; 2992 and 3000 are marked as fixed, accomplished in *Phase I*, and they have no further effect on fixing the rest of the null/zero records, such as records 2993; 2994 and 2996 (Figure A.1, c).

The efficiency of the texture-grouping codes from *LU_Texture_Grouping_2* look-up table is shown with the fixing of record 2997. The target record is ‘C’-marked, which corresponds to some specific settings of texture-grouping code, soil order, MLRA, and layer number. In *Phase I* of the procedure this record was ‘f’-marked and there were insufficient number of valid records resulting in failure to compute a replacement value. In *Phase II*, both ‘e’- and ‘f’-marked records are assigned in the same group of similar record sets and combined together provide sufficient number of valid records to compute an average. As a result, the average of all three records 2995, 2998, and 2999 is assigned for record 2997.

To make this procedure automated, as in *Phase I*, a new look-up table, *replacement-values2*, is created from all texture-grouping codes that have sufficient number of valid entries and therefore can be used to update existing nulls and zeros. Next, *replacement-values2* look-up table is joined with the original *Layer* table by common fields, *ORDER*, *MLRA*, *LAYERNUM*, and *TEXTURE 1* to transfer average values into null/zero records. The same is repeated twice with switching the texture-joining field to the secondary *TEXTURE 2* and *TEXTURE 3* fields instead of the primary *TEXTURE 1* one. Lastly, the average of both is assigned to the null/zero record from the same texture-grouping. The fixing efficiency in this phase of the procedure is between 5 and 10 percent of all detected nulls and zeros in *Layer* table.

Phases III and IV are very identical to all actions performed in *Phase II* with the only difference being the introduction of new, more generalized, texture-grouping look-up tables, *LU_Texture_Grouping_3* and *LU_Texture_Grouping_4* respectively (Tables 3.1, column III and IV). Once again, by using greater and greater generalization between original texture codes the valid data pool is increased and much more records are used to produce one replacement value per texture group code. Eventually all records that have been identified as unique in *Phase I* will be included in more common texture group sets and those that carry invalid entries will be assigned a new valid one.

It is arguable what should be considered as more reliable replacement value: (i) the average of only n records, $3 < n < 10$ in *Phase I*, or the average of m original valid entries in *Phases II* through *IV*, $m > 10$ (20). An imaginary unique record, *xxxx*, is used to demonstrate the power of the texture-grouping look-up tables that allow even the most unique invalid record, such as *xxxx*, to be replaced with a reasonable value estimated from original *Layer* valid entries for *OMH;OML* (Figure A.1, d, e). With no answer to this question the structure of the fixing procedure follows the trend of a gradual generalization between layer records. This is realized with the introduction of texture-grouping look-up tables in a specific order starting with exact record matching queries in *Phase I* (21 texture codes, Connecticut, total of 1605 *Layer* records), then proceeding with 19 texture-groupings in *Phase II*, 12 in the next *Phase III*, and gradually ending with fewer, greatly generalized texture-groupings (5) in *Phase IV*.

In the last *Phase V* the fixing procedures are applied to the rest of null/zero records that have not been managed in the previous phases. The chances that nulls/zeros will still exist at this stage of the fixing procedure are very low and if so, then all these records are treated as one group of records with special textures. Data manipulation in *Phase V* filters down to two main steps – (1) create a *replacement-value5* table look-up with replacement values for each unique set of records grouped by soil order, MLRA, and layer number, and then (2) transfer replacement values into their corresponding null/zero records matching them by common joining fields: *ORDER*, *MLRA*, and *LAYERNUM*. In these final queries, texture field is not used as **group by** variable because of the texture uniqueness of these records.

Bottom line of the fixing methodology is that (i) each replaced value is generated from original *Layer* table soil property entries; (ii) one is given the opportunity to interactively change the minimum number of original valid records, i.e. non-zero and non-null, to be used in the process of producing replacement average values; (iii) levels of grouping permit control over the extent of similarity between textures, allowing maximum fixing efficacy that complies with the requirement for minimum number valid entries; and (iv) all possible scenarios of texture uniqueness and/or similarity are encompassed within the queries and procedures of the STATSGO *Layer* table fixing product within a user-friendly interface using the ACCESS software (Microsoft Corporation ®).

B. Bulk density

The sequential character of the fixing queries permits the use of grouping fields, such as *SOIL ORDER* and *MLRA*. The latter have been assigned to each record in the *Layer* table during the initial procedures associated with *organic matter content* fixing. Although, the key variables are the same, soil order, MLRA, layer number, texture class, there are some differences between organic matter content and bulk density soil properties. Bulk density variables are dependant on different sets of factors and require different set of assumptions, fixing procedure, unique phases, and new look-up tables that best reflect bulk density variation.

B.1. Assumptions

The following are applicable for both bulk density high, *BDH*, and bulk density low, *BDL*, parameters: (a) parent material, texture of fine-earth, rock fragment size, and rock fragment content affect the *bulk density* of the soil layer or soil horizon; (b) stones (*ST*, *STV*, and *STX* texture codes), flags (*FL*, *FLV*, and *FLX*), and boulders (*BY*, *BYV*, and *BYX*) are so large that they do not affect *bulk density* of fine-earth, but gravel (*G*, *GRC*, *GRF*, *GRV*, and *GRX*), chert (*CR*, *CRC*, *CRV*, and *CRX*), cinders (*CIND*), pumice (*PUM*, *APUM*, *HPUM*, and *MPUM*), shale (*SH*, *SHV*, and *SHX*), and channers (*CN*, *CNV*, and *CNX*) do so; (c) zero value for *BDL*; *BDH* is acceptable for four textures: *WB* (“weathered bedrock”), *UWB* (“unweathered bedrock”), *IND* (“indurated”), and *CEM* (“cemented”); (d) there are four grouping variables – texture class (texture-grouping code), layer

number, MLRA, and soil order. There are three specific soil orders that are treated separately from all others – *H* (“Histosols”), *S* (“Spodosols”), and *C* (“Andisols”); (e) if a texture class starts with *VAR*, *SR* or *UNK* or is separated by a dash, the texture code that follows is used when supplying missing values. If there are no other textures given besides *VAR*, *SR* or *UNK*, then an overall average is computed for that layer using valid data for all textures; (f) *ICE* (“ice or frozen soil”) texture class records are set to 1.0 for both *BDH* and *BDL*.

B.2. Procedure

Record grouping is done by *TEXTURE 1* field and follows similar rules that have been applied during the *organic matter content* fixing procedure. Yet again, most of the texture entries that include adjectives, recognized as rock fragment modifiers are subjected to preliminary modifications. This part of the texture class that is separated from the main texture definition with a dash, is isolated into a separate field, named *TEXTURE1_LEFT*, representing the appropriate rock fragment modifier entry for each unique record. The separation of records is made by the *TEXTURE 1* entry because it is considered to be the primary observation for texture class. For example, any record with *STV-FSL* (*STV* = “very stony”, *FSL* = “fine sandy loam”) texture class will be included in the *very rocky* group of records (Table 3.2, column II); records with texture class *GR-FSL* (*GR* = “gravelly”, *FSL* = “fine sandy loam”) are included in the *rocky* group, and lastly records with *FSL* (“fine sandy loam”), i.e. with no rock fragment modifier, are assigned into *nonrocky* group of records.

The designation of each texture class by group is facilitated through the use of *LU_Texture_BD_Grouping* look-up table (Table 3.2). The technique of locating these sets of records is the same as in the *OMH;OML* procedure where *TEXTURE 1*, *TEXTURE 2*, and *TEXTURE 3* field entries are used in sequential fixing queries. For instance, the following four records from the *Layer* table for the state of Connecticut have valid entries for each texture field that differ from one other.

For example, records *CT00213* and *CT012 1* in Table A.1 are included in *rocky* group because of the *GR* (“gravelly”) rock modifier contained in their *TEXTURE 1* code, and records *CT01014* and *CT008 3* are incorporated in the *very rocky* group, because of their *GRV* (“very_gravelly”) texture modifier. Furthermore Table A.1 depicts the

subgroups that are indicated by the texture codes found after the dash of the original texture field, *Texture1_Right*, *Texture2_Right* and *Texture3_Right* fields. The fixing procedure is designed to use all available information from these three fields with priority given to the texture class in *TEXTURE 1* field. The additional data fields are used only for secondary record matching within the same grouping sets if null/zeros still exist.

Table A.1. Example of texture grouping for BDH and BDL by texture modifier for four random records from the *Layer* table for the state of Connecticut.

<u>Variable \ Record</u>	<u>CT00213</u>	<u>CT01014</u>	<u>CT008 3</u>	<u>CT012 1</u>
<i>ORDER</i>	I	I	I	I
<i>MLRA</i>	144A	145	144A	144A
<i>MUIDSEQNUM</i>	CT00213	CT01014	CT008 3	CT012 1
<i>LAYERNUM</i>	3	4	3	3
<i>Texture1_Left</i>	<i>rocky</i>	<i>very rocky</i>	<i>very rocky</i>	<i>rocky</i>
<i>TEXTURE1</i>	GR-LS	GRV-LS	GRV-SL	GR-SL
<i>TEXTURE2</i>	LFS	GR-SL	GRV-LS	GR-FSL
<i>TEXTURE3</i>	GR-LCOS	GR-FSL	GR-LS	FSL
<i>Texture1_Right</i>	LS	LS	SL	SL
<i>Texture2_Right</i>	LFS	SL	LS	FSL
<i>Texture3_Right</i>	LCOS	FSL	LS	FSL

B.3. *Phases in BDL; BDH null and zero fixing*

There are total of four phases of *BDH* and *BDL* parameter fixing procedure. In *Phase I* the null/zero records are replaced with average values computed from valid *BDH;BDL* records that are originally present in the *Layer* table. These records are required to match exactly the set of targeted zero/null entries by their common *group-by* variables: soil order, MLRA, layer number, and texture class. In the same way as it was discussed for *organic matter content* fixing, record matching is a key technique for locating, extracting, and averaging valid record entries associated with the soil property of interest, i.e. bulk density. All action queries are arranged into two sub-steps of updating null/zero data (Figure A.2). Each replacement value in *LU_average_T1* table (sub-step one) is computed from valid record entries for bulk density, *BDH; BDL*,

grouped by *SOIL ORDER*, *MLRA*, *LAYERNUM*, and *TEXTURE 1* fields in the *Layer* table. The rule for minimum number of valid records is also enforced in the same way as it was applied in the process of dealing with *OMH;OML* discrepancies. The essence of exact matching by soil layer, *exact record matching*, is that all valid records that have equal texture class, same soil order and MLRA are expected to have similar or equal soil properties. Identically, all invalid records, nulls and zeros, are anticipated to have similar soil properties given the above conditions are equal.

The first update query (*Update1_Query*) in Figure A.2 is the first sub-step where matching null/zero records in the *Layer* table are updated with average replacements from valid records that have the same primary texture class. Following this is a set of queries that make possible the use of additional secondary texture data, *TEXTURE 2* and *TEXTURE 3*. The latter fields are used in the second sub-step of record matching with queries (*Update2_Query*) that follow the logic behind and ‘e’-marked record fixing that was previously discussed.

Phases II to IV are identical to the procedures applied for organic matter (OM) fixing except that new and unique grouping schemes are used from *Lu_Texture_BD_Grouping* look-up table (Table 3.2, columns II to IV). The grouping variables are soil order, MLRA, layer number, and texture code (texture grouping class).

C. Rock fragment content

The three variables that are considered important for rock fragment determination by soil layer are *INCH3L*, *INCH3H* (low and high values, respectively); *INCH10L*, *INCH10H*; and *NO10L*, *NO10H*. The definition of each one depicts the size of the rocks they represent; (i) *INCH10* stands for percent by weight of rock fragments (cobbles) with size greater than 25 cm (10 inch); (ii) *INCH3* stands for percent by weight of rock fragments (stones) with size between 7.5 cm (3 inch) and 25 cm (10 inch); and (iii) *NO10* stands for percent by weight of rock fragments (gravel) with size less than 7.5 cm (3 inch), which pass through No.10 sieve (rock size greater than 2mm). Because of the apparent differences in rock fragment arrangement, there are new adjustments and assumptions that will help describe the relationship between these three variables. It is logical that soil layers with stones (*INCH10* > 0%) will also contain smaller size rock fragments, i.e. *INCH3* and *NO10* variables are expected to be greater than zero, too.

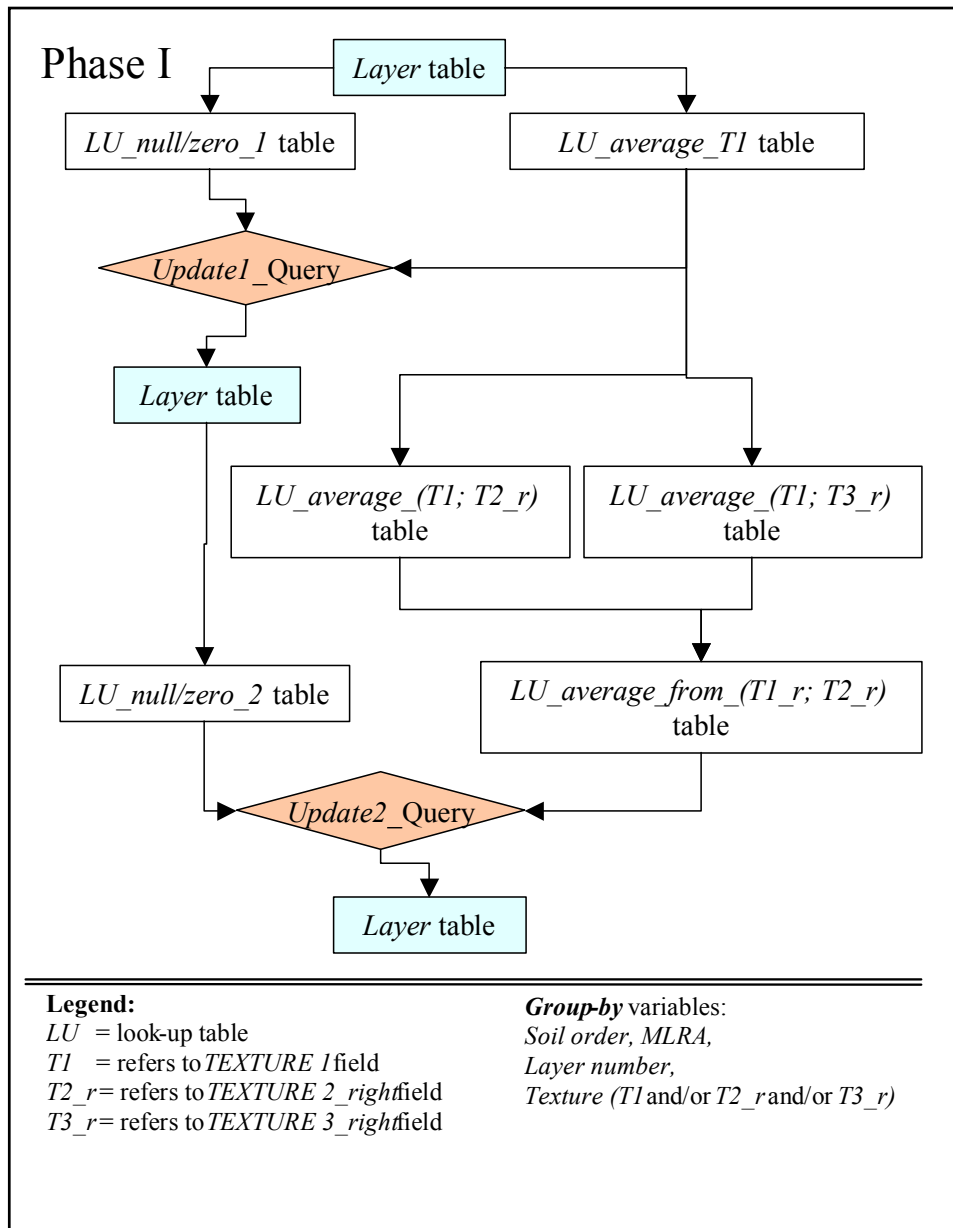


Figure A.2. Phase I of the procedure for fixing BDH and BDL variable null and zero records.

The same concept is valid when cobbles are present (*INCH3* > 0%) in the soil layer. In this case, it is very likely for one to find gravel (*NO10* > 0%), but this does not imply that stones will also be available in that very same layer (*INCH10* = 0% or *INCH10* > 0%).

C.1. Assumptions

The following are applicable both for low and high property values for *INCH3*, *INCH310*, and *NO10*: (a) The following group of rock fragment modifier adjectives, *GR* (“gravelly”), *CR* (“cherty”), *CNDY* (“cindery”), *PUM* (“pumiceous”), *SH* (“shaly”), *CN* (“channery”), *FL* (“flaggy”), and *ST* (“stony”) that are part of any texture code indicate 15 to 35% volume of rock fragments; (b) when the *very* modifier is added to the texture definition, e.g. *GRV-LS* (“very gravelly-loamy sand”) there is an indication that 35 to 65% volume of rock fragments is present; the *skeletal* modifier, *ASK* (“ashy-skeletal”), indicates greater than 35% volume; (c) The *extremely* modifier, *GRX-LS* (“extremely gravelly-loamy sand”), indicates volume of rock fragments greater than 65% and the *fragmental* modifier, *FRAG* (“fragmental material”), indicates greater than 90% volume of rocks; (d) if a texture class starts with *VAR*, *SR* or *UNK* or is separated by a dash, the texture code that follows the dash is used when supplying missing values. If there are no other textures given besides *VAR*, *SR* or *UNK*, then an overall average is computed for that layer using valid data from all textures; (e) grouping variables that affect the rock fragment content are MLRA, layer number, and texture class modifier. Soil order is assumed to have no effect on any of the rock fragment variables; (f) any texture class modifier that indicates rock fragment volume (of the particular size) to be greater than 15% subjects the associated records to analysis and if found to be null or zero the latter are replaced with an average estimate. This is applicable for the three rock fragment variables, *INCH3* (cobbles), *INCH10* (stones), and *NO10* (gravel) and their respective high and low measurements; (g) the texture class modifier refers to the part of the texture code that is located before the dash of the entries in either *TEXTURE 1*, *TEXTURE 2*, or *TEXTURE 3* columns of the STATSGO *Layer* table.

C.2. Procedure

Significant role for rock fragment content classification is given to the modifier that characterizes any given texture class. In cases when such modifier code is absent it is concluded that the lack of rock fragments with size greater than 2mm (passing No.10 sieve) or their insufficient volume is the underlying reason. There are three sets (one per variable) of texture classes that are differentiated among all possible texture entries,

which are to be used to isolate, check, and replace null and zero records. The tables below show the respective lists of texture codes utilized for null and zero record fixing.

There are 17 texture codes that if part of any of the texture names (STATSGO Data Use Information 1995) should not be associated with null or zero values for the *INCH10H* and *INCH10L* fields (Table A.2). Same concept is applied for *INCH3H* and *INCH3L* fields (30 texture codes) and *NO10H* and *NO10L* fields (63 codes) and the list of texture codes are shown in Tables A.3 and A.4 below. The codes that are bolded on darker background indicate the unique codes that have been added to the previous table, i.e. colored records in Table A.3 are not found in Table A.2 but are found in Table A.4.

As indicated in the tables above many texture codes are shared between the three sets. This is a result of the rock fragments' relational structure between size and volume, i.e. affected by weathering and erosion processes the bigger rocks wear away and produce smaller rocks. Eventually, some texture classes lack stones and/or cobbles and are consisted of smaller rocks alone ($2\text{mm} < \text{rock fragment size} < 7.5\text{ cm}$) that are intermixed with fine earth material (fragment size less than 2mm).

Upon isolation, each null or zero record from the above texture sets is replaced with an average estimate of all non-zero values grouped by rock fragment modifier code. The procedure is repeated for each variable separately (*INCH3*, *INCH10*, and *NO10*) and the records are grouped by MLRA and layer number. Special attention is aimed at records with *VAR*, *SR*, and *UNK* texture codes that do not have any additional data in either one of the three texture fields, *TEXTURE 1*, *TEXTURE 2*, and *TEXTURE 3*. These are replaced with a corresponding average value estimated from all non-zero records grouped by MLRA, layer number, and soil order, regardless of texture definition. Finally, if nulls and/or zeros are still present in the *Layer* table, a fixing technique similar to the *OMH;OML* one is applied utilizing the texture class groupings provided in the new, rock fragment specific texture look-up table, *LU_Rocks_Grouping* (Table 3.3)

Table A.2. Texture codes for the *INCH10H* and *INCH10L* fields (representing stones) that should not be associated with null and/or zero entries in the STATSGO *Layer* table.

BM	BY	FL	FRAG	ST	SVM
BVM	BYV	FLV	RB	STV	SXM
BXM	BYX	FLX	SM	STX	

Table A.3. Texture codes for the *INCH3H* and *INCH3L* fields (representing cobbles) that should not be associated with null and/or zero entries in the STATSGO *Layer* table. The Shaded cells indicate texture codes that are unique for cobbles.

ASK	BYV	CBV	CNX	FLX	ST
BM	BYX	CBX	CVM	FRAG	STV
BVM	CAM	CM	CXM	MSK	STX
BXM	CB	CN	FL	RB	SVM
BY	CBA	CNV	FLV	SM	SXM

Table A.4. Texture codes for the *NO10H* and *NO10L* fields (representing gravel) that should not be associated with null and/or zero. Shaded cells indicate texture codes that are unique for gravel.

APUM	CAM	CN	CVM	GFM	GXM	SG	SVM
ASK	CB	CNDY	CXM	GM	HPUM	SH	SXM
BM	CBA	CNV	FL	GR	HSK	SHV	SY
BVM	CBV	CNX	FLV	GRC	IND	SHX	SYV
BXM	CBX	CR	FLX	GRF	MPUM	SM	SYX
BY	CEM	CRC	FRAG	GRV	MSK	ST	UWB
BYV	CIND	CRV	G	GRX	PUM	STV	WB
BYX	CM	CRX	GCM	GVM	RB	STX	

C.3. Phases in rock fragment content fixing

There are five phases of the fixing procedure and they are specifically adapted to manage and fix nulls and zeros found in *INCH3L*, *INCH3H*; *INCH10L*, *INCH10H*; *NO10L*, and *NO10H* rock fragment fields.

Phase I is unique for each variable, *INCH3*, *INCH10*, and *NO10*. The key procedure is to locate and isolate all records that contain any one of the specific codes [see previous section: 2. *Procedure*, (i), (ii), and (iii)] in their texture classes. Rock fragment modifiers are extracted from the existing texture codes in any of the three fields, *TEXTURE 1*, *TEXTURE 2*, and *TEXTURE 3*, in a way that priority is given to the first occurrence of a valid modifier code. For instance, if a record has the following entries for texture, *GR-FSL* (“gravelly-fine sandy loam”), *FSL*, and *GRV-SL* (“very gravelly-sandy loam”) provided in the *TEXTURE 1*, *TEXTURE 2*, and *TEXTURE 3* respectively, then *GR* will be the modifier assigned to it, i.e. *TEXTURE 1* supplies a valid modifier code for this record. Suppose, the entry codes for *TEXTURE 1* and *TEXTURE 3* fields are reversed, i.e. *GRV-SL* was in the *TEXTURE 1* column, then the record should have been assigned *GRV* code to be the modifier. In cases when *TEXTURE 1* does not contain any valid code, *TEXTURE 2* and *TEXTURE 3* fields are queried for one and the first occurrence of rock modifier is used.

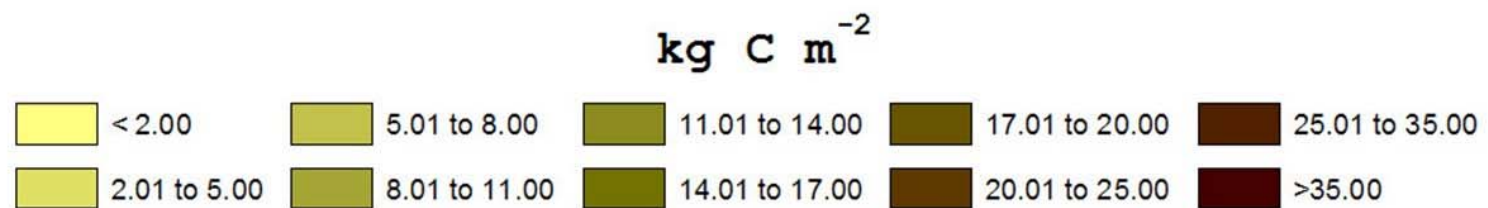
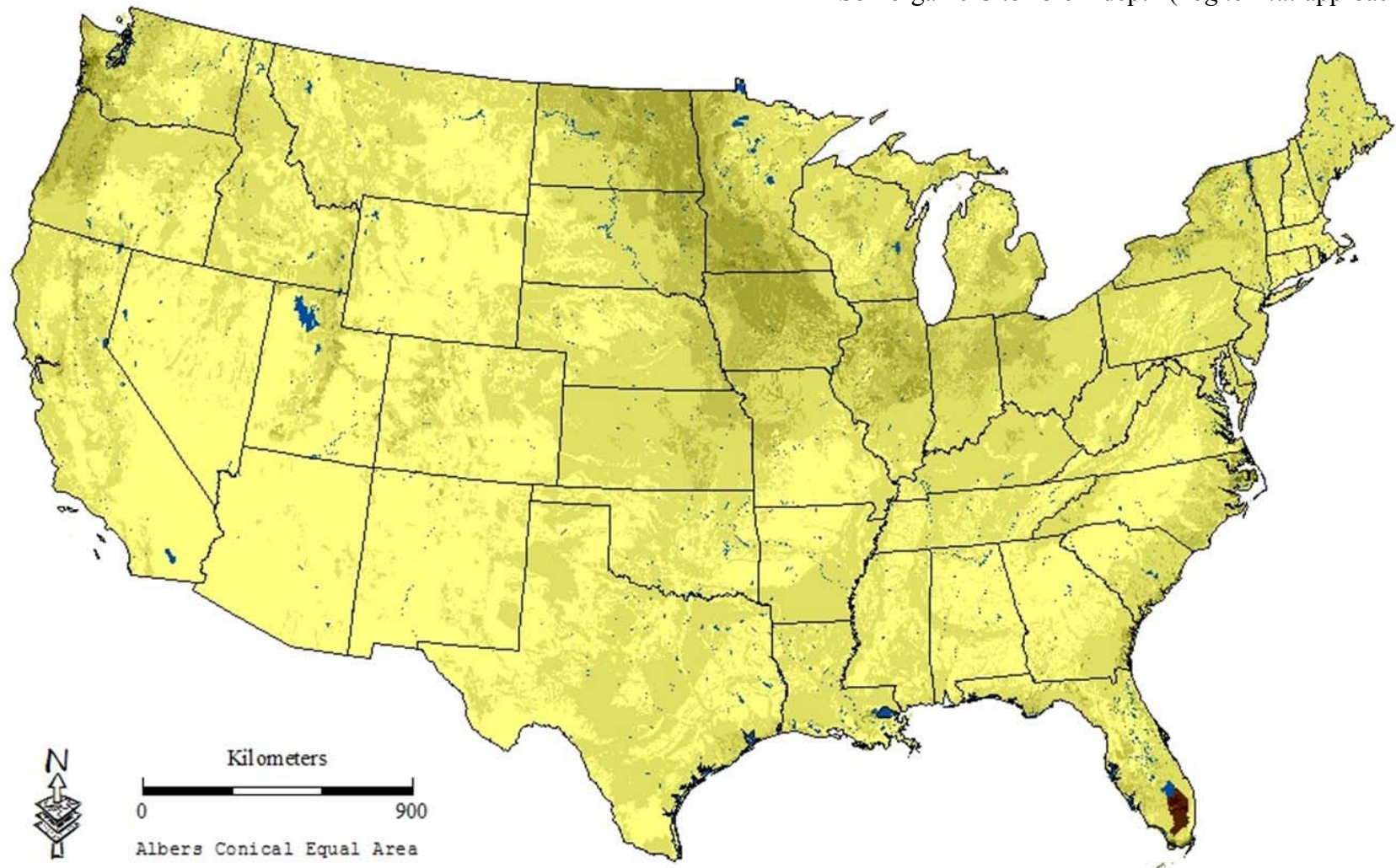
Next, the records that match any rock fragment code from the texture sets above are queried for nulls and zeros and the results are designated into a *locator-null* table. This procedure allows the user to group the invalid records for each of the three rock variables by their common fields – MLRA, layer number, and modifier code. Then, using all present non-zero values from the original *Layer* table, joined with the *locator-null* table, average estimates are produced for each set of records, which are filled in for the null/zero records to complete the first phase of the fixing procedure. The effectiveness of this step varies among rock variables and is mainly dependant on the extent of null/zero discrepancies detected in *Layer* table, as well as the availability of valid records that are used for replacement value computation. To ensure credibility of the replacement values, the rule for minimum non-zero records is enforced intentionally through a user-defined control embedded in the fixing form.

Phases II through V are identical to the procedures applied for *OMH;OML* fixing. However, because of the differences in the nature of these soil variables, *organic matter*, *bulk density*, and *rock fragment content* there are unique texture look-up tables that are used for record matching and record grouping.

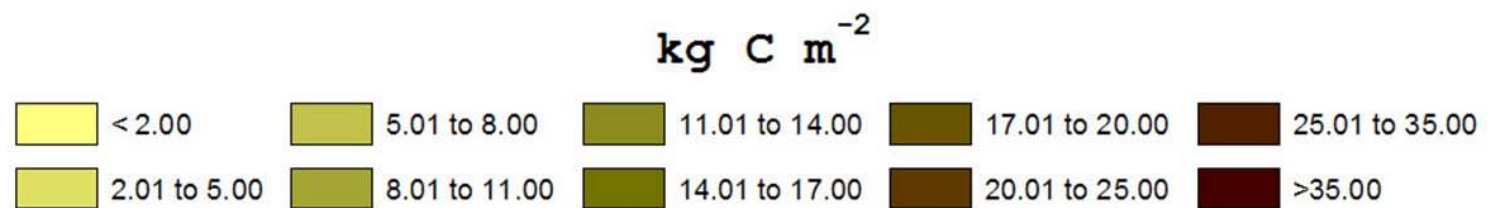
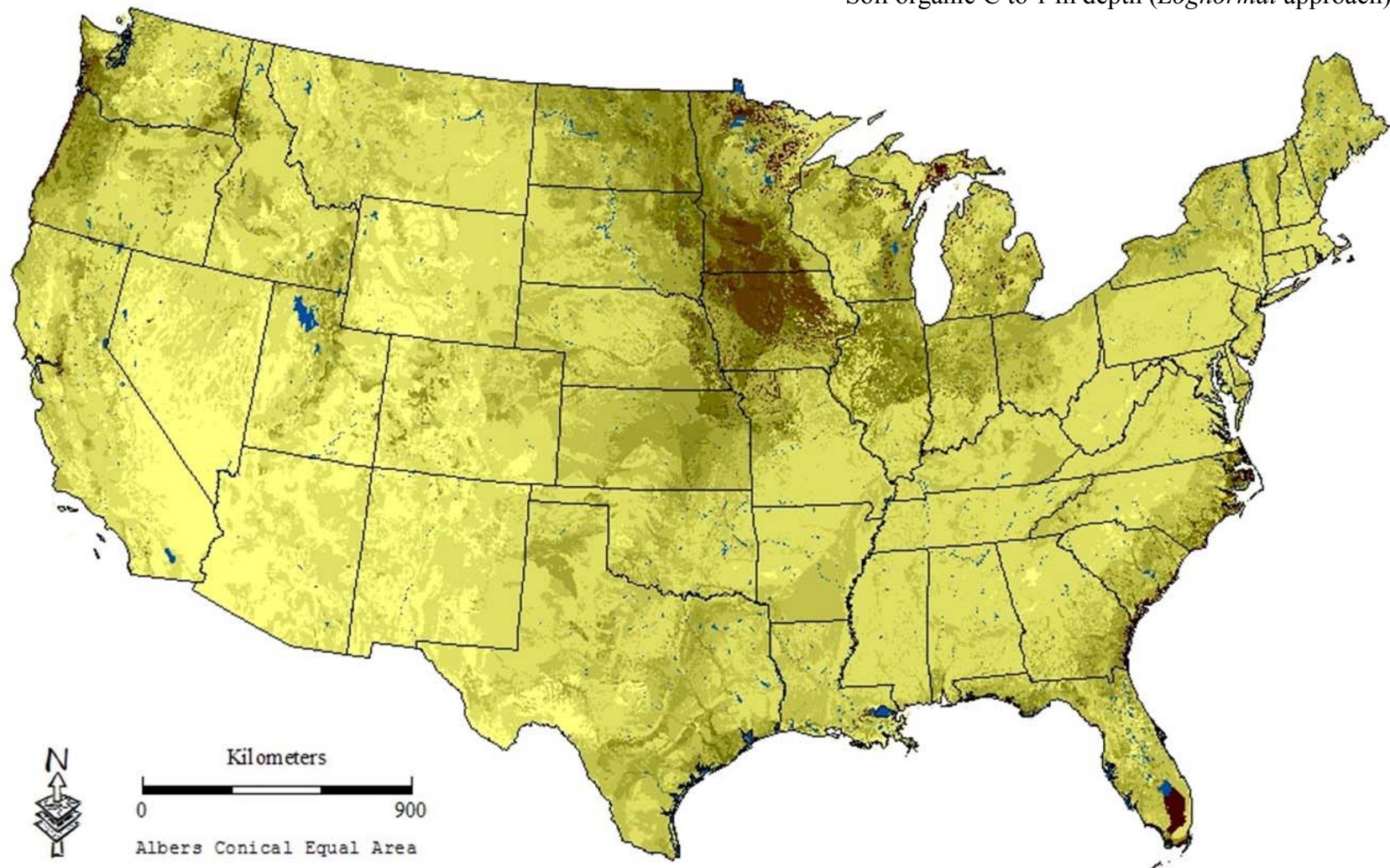
As mentioned before, the technique of gradual generalization of the matching criteria between the records provides a reasonable way of utilizing all available information into a very efficient computation process of replacement values even for the most unique texture classes that may possibly be observed. For the three rock content variables, *INCH10L*, *INCH10H*; *INCH3L*, *INCH3H*, and *NO10L*, *NO10H* the generalization is accomplished through a three-level grouping code matching, provided in a texture look-up table (Table 3.3, columns II to IV). The *group-by* variables that are used to perform the analysis are MLRA, layer number, texture, and soil order. The last two variables are added to the fixing procedure, as compared with phase I, at the expense of the modifier code classification.

The last step, *Phase V*, is designed to compute the overall layer average values from record entries with equal MLRA and soil order. These estimates are then assigned to all null/zero records that have not been yet updated due to insufficient number valid records or because of the unique character of the texture class.

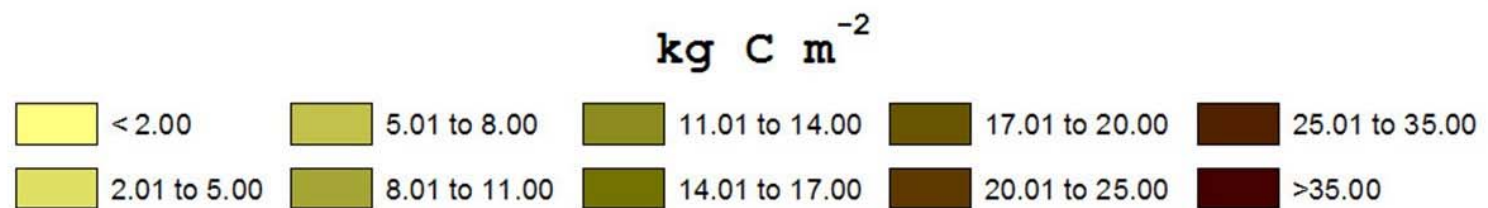
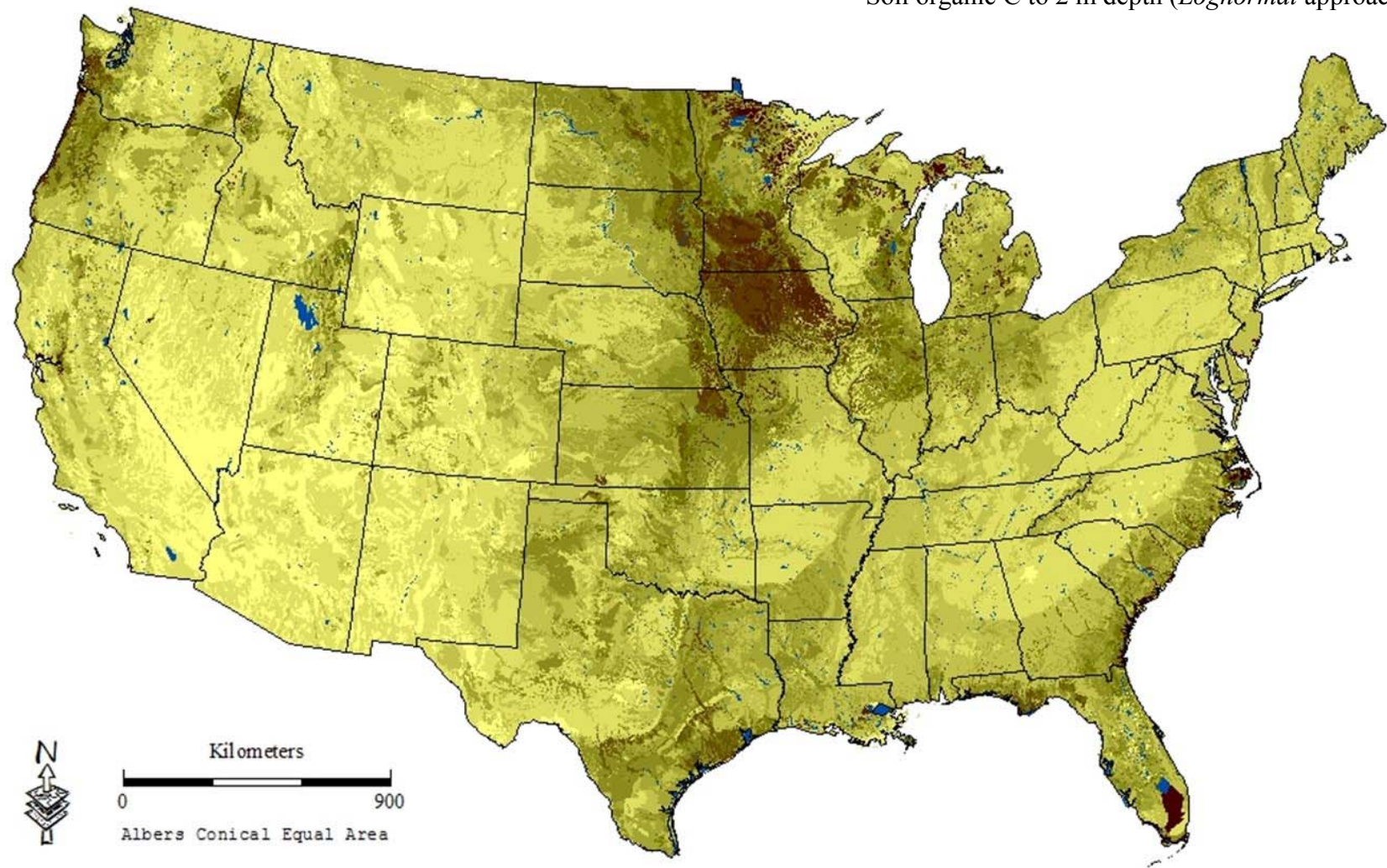
APPENDIX B: SOC MAPS

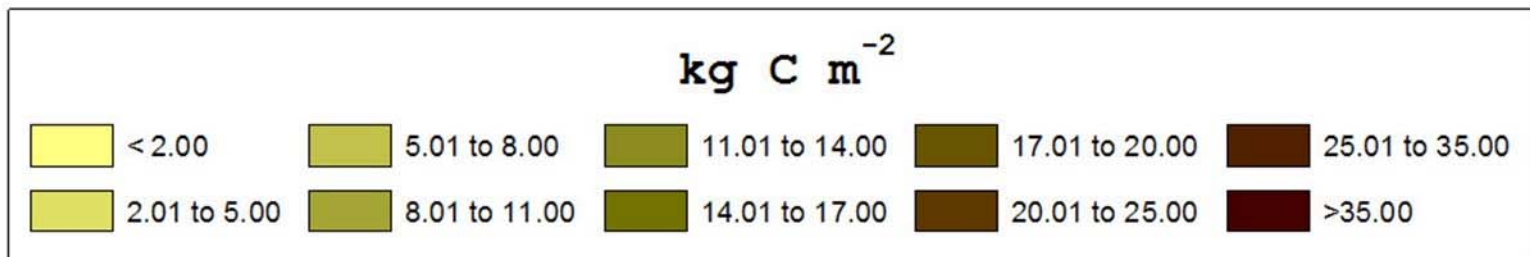
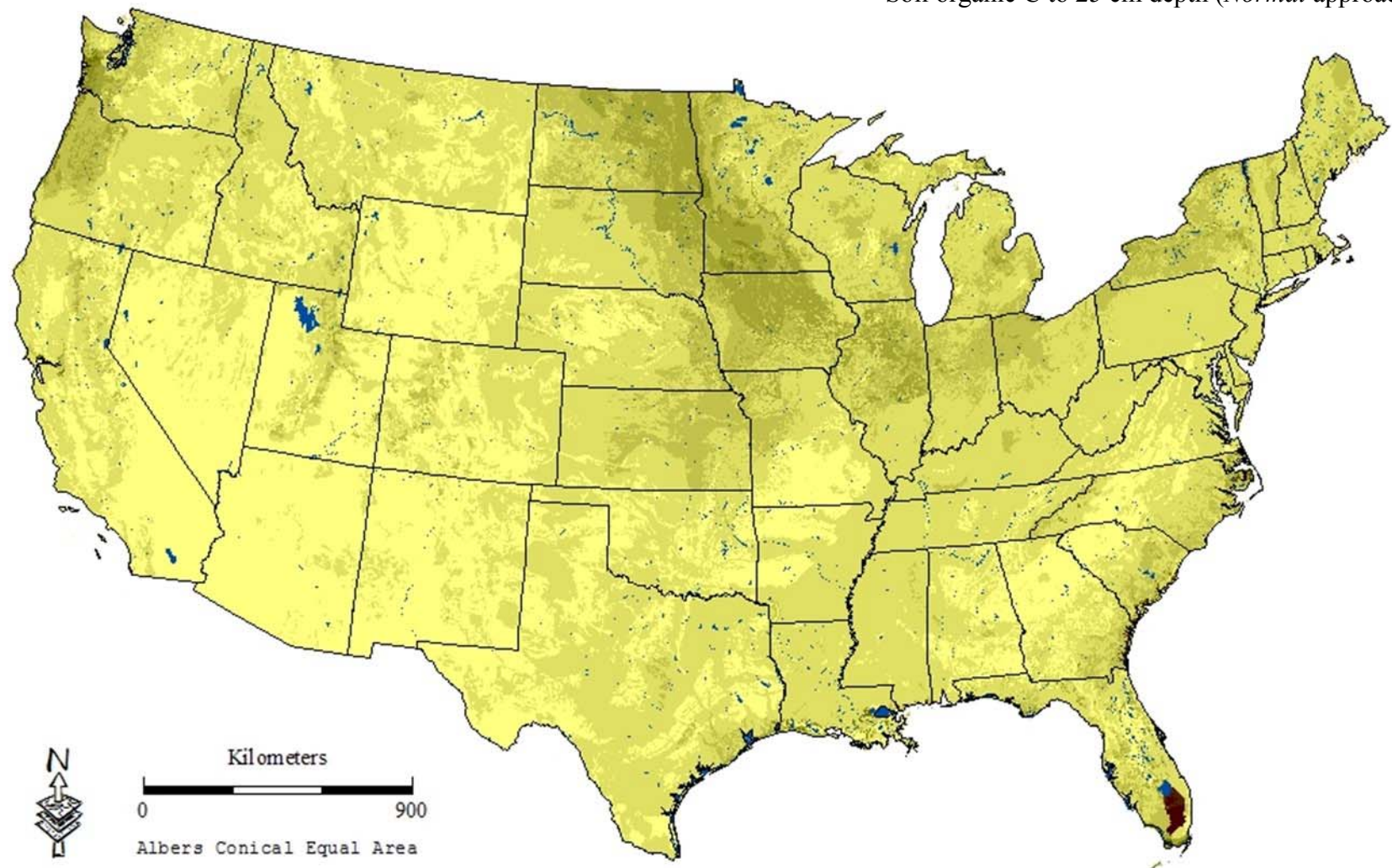


Soil organic C to 1 m depth (*Lognormal* approach)

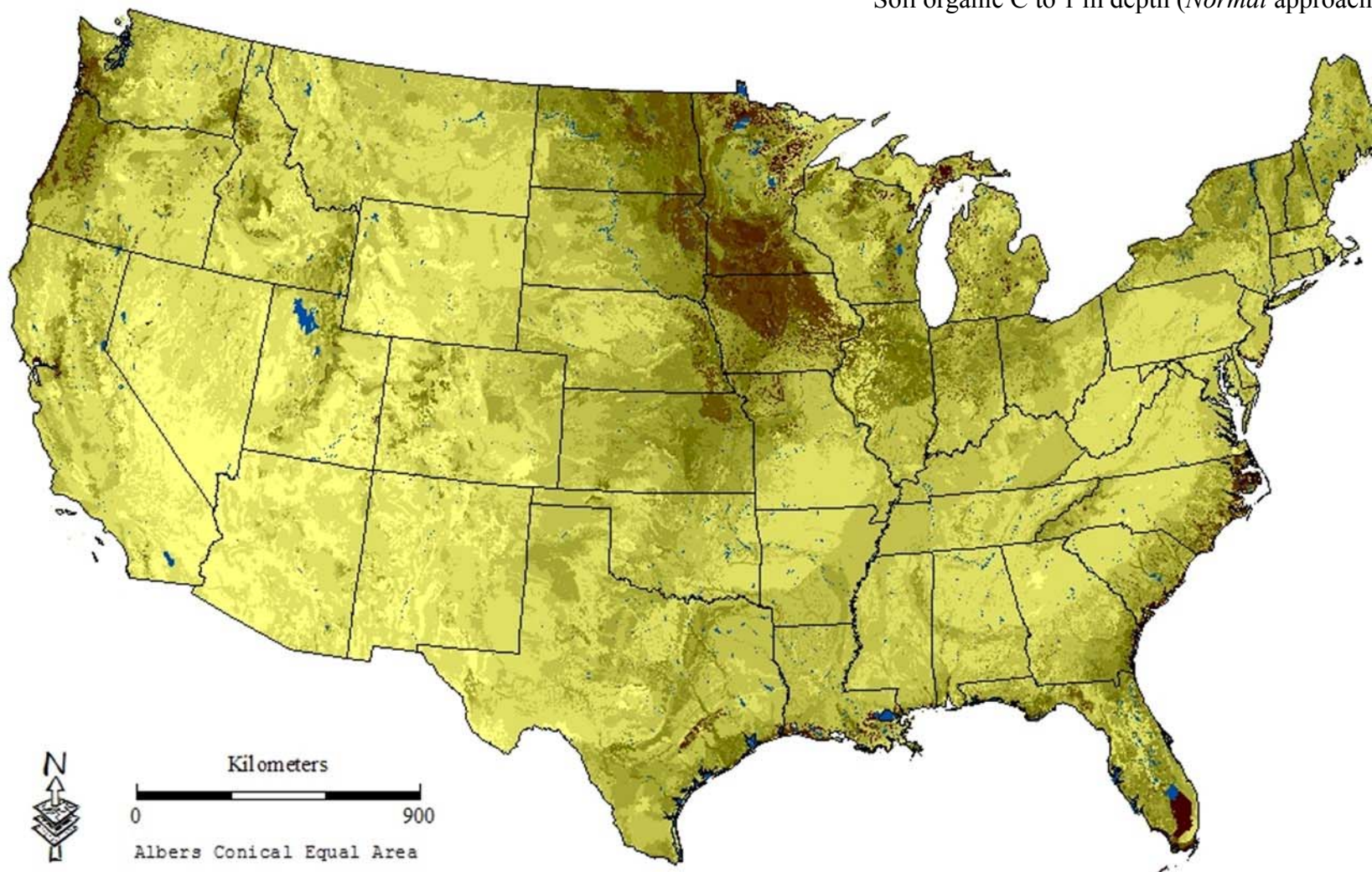


Soil organic C to 2 m depth (*Lognormal* approach)

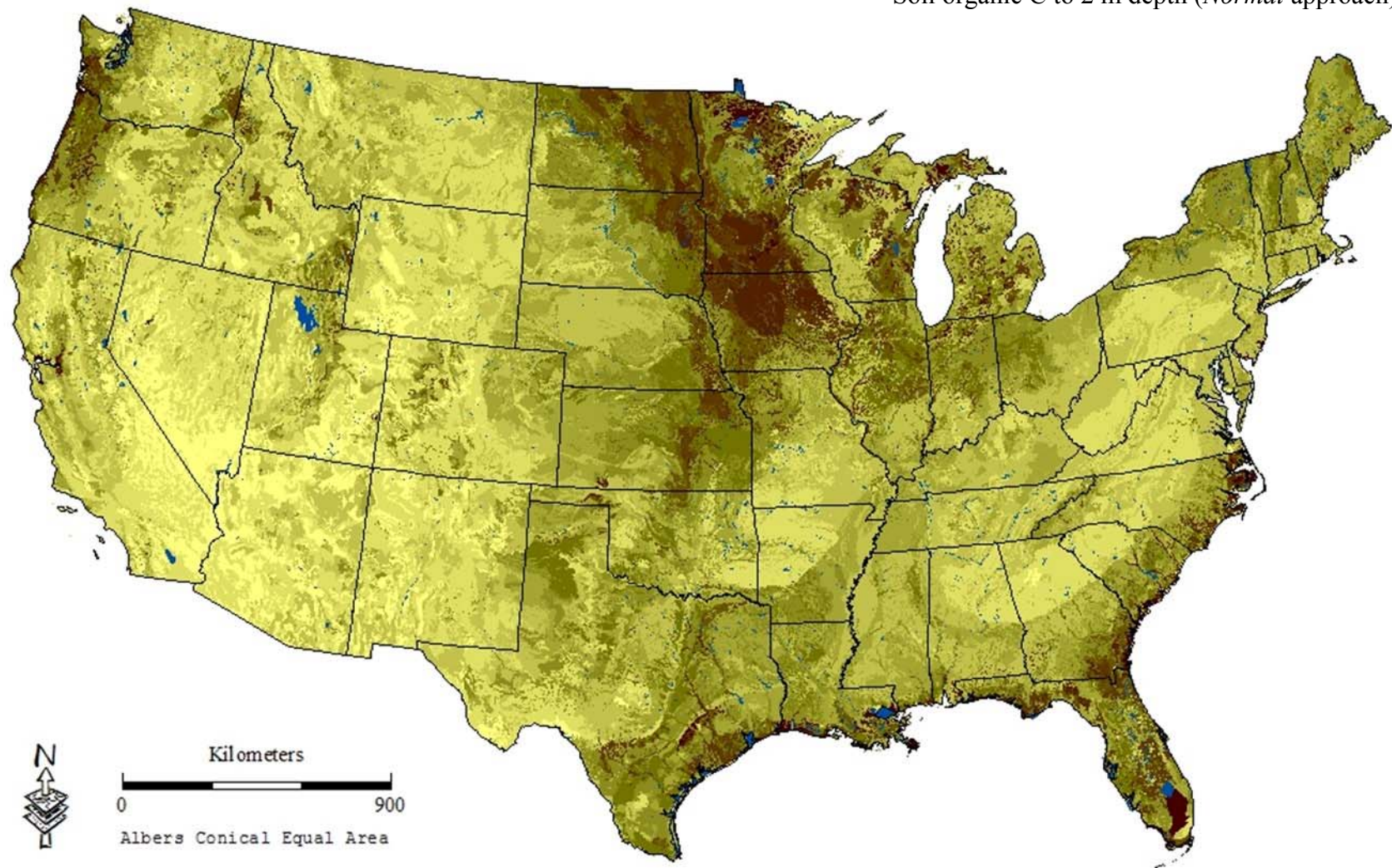




Soil organic C to 1 m depth (*Normal* approach)



Soil organic C to 2 m depth (*Normal* approach)



APPENDIX C: SOC (KG M⁻²) ESTIMATES PER FOREST TYPE GROUP BY (A) LOGNORMAL AND (B) NORMAL
APPROACHES FOR 9 REGIONS OF THE CONTIGUOUS 48 UNITED STATES.

(A)

Geographic region	FIADB code Δ	Forest Type GROUP ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
<i>Lognormal approach</i>															
Northeast (13 states: ME, VT, NH, MA, CT, RI, PA, NJ, MD, DE, WV, OH, NY)	100 White / Red / Jack Pine	3,591	3.44	5.70	6.92	1.715	2.542	3.284	3.44	5.59	6.53	1.716	2.444	2.737	
	120 Spruce / Fir	3,533	3.40	6.47	8.23	1.253	2.076	3.301	3.40	6.02	6.92	1.250	1.853	2.067	
	160 Loblolly / Shortleaf Pine	742	2.88	4.66	5.51	1.029	1.980	2.902	2.86	4.64	5.43	1.023	1.966	2.863	
	180 Pinyon / Juniper	81	3.28	5.03	5.88	1.416	3.738	6.412	3.25	4.99	5.82	1.410	3.733	6.406	
	380 Exotic Softwoods	216	4.35	5.88	6.72	2.025	2.688	3.020	4.35	5.87	6.71	2.026	2.688	3.010	
	400 Oak / Pine	1,527	2.95	4.65	5.53	1.347	2.090	2.802	2.94	4.64	5.47	1.347	2.087	2.731	
	500 Oak / Hickory	17,759	2.59	3.84	4.49	0.958	1.458	1.846	2.59	3.83	4.46	0.955	1.443	1.794	
	600 Oak / Gum / Cypress	139	3.12	5.37	6.78	1.069	1.408	1.550	3.10	5.34	6.65	1.060	1.394	1.509	
	700 Elm / Ash / Cottonwood	3,258	3.77	5.90	7.08	1.781	2.883	3.915	3.77	5.83	6.89	1.779	2.842	3.721	
	800 Maple / Beech / Birch	19,938	3.09	5.04	6.03	1.426	2.052	2.599	3.09	4.96	5.79	1.426	2.009	2.371	
	900 Aspen / Birch	2,504	3.45	6.17	7.55	1.608	2.518	3.524	3.45	5.93	6.84	1.602	2.381	2.783	
	999 Non stocked	159	3.59	5.43	6.49	1.632	2.743	3.780	3.59	5.41	6.42	1.631	2.730	3.722	
	Northeast Average			3.03	4.87	5.84	1.303	1.967	2.583	3.02	4.79	5.58	1.301	1.915	2.313
North central (7 states: IL, IN, IA, MI, MN, MO, WI)	100 White / Red / Jack Pine	2,667	3.15	7.73	9.93	1.935	7.155	9.008	3.06	6.38	7.77	1.952	6.850	8.211	
	120 Spruce / Fir	4,216	3.23	13.92	20.81	1.612	12.259	17.098	2.49	5.73	7.34	1.705	10.307	12.471	
	160 Loblolly / Shortleaf Pine	162	1.81	3.60	4.67	0.480	0.655	0.972	1.81	3.60	4.67	0.480	0.655	0.972	
	180 Pinyon / Juniper	333	2.05	3.74	4.58	0.862	1.207	1.408	2.05	3.74	4.58	0.862	1.207	1.408	
	380 Exotic Softwoods	132	3.33	7.20	9.01	1.325	5.385	7.972	3.31	6.86	8.48	1.324	5.364	7.939	
	400 Oak / Pine	713	1.91	3.70	4.80	1.048	1.983	2.392	1.91	3.68	4.76	1.045	1.890	2.190	
	500 Oak / Hickory	11,745	3.49	6.71	8.14	2.393	4.730	5.528	3.47	6.32	7.52	2.403	4.536	4.936	
	600 Oak / Gum / Cypress	187	3.53	6.83	8.54	1.588	3.402	3.827	3.53	6.83	8.54	1.588	3.402	3.827	
	700 Elm / Ash / Cottonwood	5,094	4.59	9.76	12.16	2.337	6.421	8.718	4.51	8.61	10.31	2.366	6.038	7.692	
	800 Maple / Beech / Birch	10,213	4.11	8.65	10.75	2.168	5.991	7.518	4.06	7.71	9.25	2.178	5.801	7.079	
900 Aspen / Birch	7,960	3.17	8.93	12.25	1.670	8.247	11.724	2.94	5.48	6.68	1.724	6.574	8.114		

Appendix C (A): (continued) [2 of 5]

Geographic region	FIADB code Δ	Forest Type GROUP ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
				<i>Lognormal approach</i>											
		999 Non stocked	432	3.19	10.93	15.75	1.668	10.513	15.410	2.88	5.59	6.76	1.753	8.361	9.966
		North central Average		3.61	8.64	11.27	2.046	6.696	8.809	3.47	6.63	8.01	2.074	6.023	7.223
Southeast (5 states: FL, GA, NC, SC, VA)		100 White / Red / Jack Pine	264	2.37	5.21	7.04	1.999	16.514	33.335	2.23	4.10	4.81	0.937	1.716	1.968
		120 Spruce / Fir	5	11.82	18.53	19.37	0.000	0.000	0.000	11.82	18.53	19.37	0.000	0.000	0.000
		140 Longleaf / Slash Pine	5,054	3.32	8.55	11.70	1.470	3.690	4.657	3.32	8.43	11.47	1.469	3.683	4.639
		160 Loblolly / Shortleaf Pine	11,313	2.47	5.66	7.69	1.973	9.600	17.655	2.41	5.14	6.71	1.774	4.985	6.237
		180 Pinyon / Juniper	65	1.95	3.27	3.87	0.719	1.108	1.506	1.95	3.27	3.87	0.719	1.108	1.506
		400 Oak / Pine	5,581	2.39	5.24	7.03	1.648	7.513	13.985	2.36	4.95	6.45	1.497	3.746	4.782
		500 Oak / Hickory	12,447	2.23	4.24	5.28	1.364	3.731	4.734	2.23	4.23	5.26	1.364	3.704	4.695
		600 Oak / Gum / Cypress	6,467	3.88	9.93	13.81	2.480	14.067	27.035	3.73	8.52	11.05	2.138	6.075	7.586
		700 Elm / Ash / Cottonwood	776	2.43	5.38	7.56	1.545	5.071	7.139	2.43	5.33	7.47	1.545	5.041	7.074
		800 Maple / Beech / Birch	136	4.16	6.61	7.27	3.345	5.203	5.316	4.16	6.61	7.27	3.345	5.203	5.316
		980 Tropical Hardwoods	148	3.67	7.23	8.98	1.861	4.060	4.621	3.65	7.18	8.89	1.861	4.049	4.589
		999 Non stocked	125	3.68	9.61	12.59	6.310	23.719	30.722	2.52	5.35	6.96	1.942	5.744	7.141
	Southeast Average		2.72	6.19	8.31	1.776	7.533	13.090	2.67	5.76	7.49	1.631	4.431	5.583	
South central (8 states: AL, AR, KY, LA, MS, OK, TN, TX)		100 White / Red / Jack Pine	139	2.32	4.34	5.23	1.016	2.366	2.575	2.32	4.34	5.23	1.016	2.366	2.575
		140 Longleaf / Slash Pine	1,715	2.23	5.11	7.53	0.626	1.801	2.643	2.22	5.06	7.43	0.631	1.807	2.658
		160 Loblolly / Shortleaf Pine	14,692	1.96	4.20	6.12	0.600	1.410	2.549	1.96	4.19	6.11	0.600	1.409	2.546
		180 Pinyon / Juniper	901	2.18	4.16	5.14	0.764	1.272	1.697	2.18	4.16	5.14	0.764	1.272	1.697
		400 Oak / Pine	10,582	2.01	4.18	5.84	0.649	1.467	2.468	2.01	4.17	5.83	0.650	1.464	2.461
		500 Oak / Hickory	33,327	2.13	4.07	5.36	0.748	1.385	2.077	2.13	4.07	5.36	0.748	1.384	2.075
		600 Oak / Gum / Cypress	7,099	2.51	5.50	7.84	1.134	2.578	3.900	2.51	5.49	7.82	1.134	2.577	3.897
		700 Elm / Ash / Cottonwood	3,696	2.58	5.14	6.86	0.782	1.704	2.483	2.58	5.14	6.85	0.782	1.705	2.484

Appendix C (A): (continued) [3 of 5]

Geographic region	FIADB code Δ	Forest Type GROUP ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
				<i>Lognormal approach</i>											
	800 Maple / Beech / Birch	669	3.08	4.96	5.68	1.085	1.711	2.037	3.08	4.96	5.68	1.085	1.711	2.037	
	999 Non stocked	579	2.27	4.66	6.16	0.659	1.653	2.433	2.24	4.56	6.05	0.689	1.651	2.464	
	South central Average		2.15	4.34	5.95	0.743	1.548	2.436	2.15	4.34	5.94	0.744	1.547	2.434	
Great Plains (4 states: ND, SD, NE,KS)	180 Pinyon / Juniper	206	3.17	6.89	8.44	1.516	3.808	4.815	3.17	6.89	8.43	1.518	3.814	4.825	
	220 Ponderosa Pine	733	2.93	4.84	5.27	0.602	0.780	0.836	2.93	4.83	5.24	0.601	0.779	0.824	
	400 Oak / Pine	90	3.79	7.76	9.21	1.427	3.421	3.773	3.79	7.76	9.21	1.427	3.421	3.773	
	500 Oak / Hickory	681	4.27	8.60	10.24	1.746	3.348	4.101	4.27	8.60	10.24	1.746	3.349	4.101	
	700 Elm / Ash / Cottonwood	839	4.02	9.16	11.35	1.835	5.373	6.316	4.02	9.16	11.35	1.835	5.373	6.316	
	800 Maple / Beech / Birch	830	4.58	9.46	11.64	1.508	3.441	4.361	4.58	9.46	11.64	1.508	3.441	4.361	
	900 Aspen / Birch	112	4.40	7.46	8.85	1.107	1.867	2.312	4.40	7.46	8.85	1.108	1.869	2.316	
	999 Non stocked	136	3.35	6.48	8.08	1.814	3.010	3.544	3.35	6.46	8.04	1.817	3.020	3.556	
	Great Plains Average		3.91	7.93	9.56	1.443	3.288	3.970	3.91	7.93	9.55	1.443	3.289	3.968	
Pacific NW (2 states: WA, OR)	180 Pinyon / Juniper	130	2.16	4.36	4.84	0.963	2.495	3.085	2.16	4.36	4.85	0.963	2.495	3.084	
	200 Douglas-fir	6,103	5.97	10.78	11.94	2.652	4.894	5.398	5.97	10.78	11.92	2.652	4.894	5.396	
	220 Ponderosa Pine	1,560	2.66	5.70	6.54	0.836	1.874	2.157	2.66	5.70	6.55	0.836	1.873	2.156	
	Fir / Spruce / Mountain														
	260 Hemlock	3,119	3.57	6.83	7.67	1.705	2.538	2.785	3.57	6.83	7.67	1.705	2.538	2.784	
	280 Lodgepole Pine	1,082	2.19	5.05	6.21	1.937	2.788	2.700	2.19	5.05	6.21	1.937	2.788	2.702	
	300 Hemlock / Sitka Spruce	4,494	7.99	14.40	15.51	3.250	6.870	7.345	7.98	14.37	15.46	3.253	6.874	7.341	
	320 Western Larch	159	2.65	6.24	7.12	0.140	0.917	1.287	2.65	6.24	7.12	0.140	0.917	1.287	
	700 Elm / Ash / Cottonwood	108	5.34	8.97	10.13	2.009	3.426	4.242	5.33	8.77	9.87	2.009	3.563	4.391	
	900 Aspen / Birch	80	3.06	4.86	5.14	1.067	1.732	1.932	3.06	4.86	5.14	1.067	1.732	1.932	
	910 Alder / Maple	1,462	6.87	12.72	13.93	3.022	6.208	6.650	6.87	12.69	13.87	3.022	6.221	6.665	
	920 Western Oak	417	4.06	7.43	8.14	1.489	2.778	3.129	4.06	7.43	8.14	1.489	2.778	3.129	

Appendix C (A): (continued) [4 of 5]

Geographic region	FIADB code Δ	Forest Type GROUP ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
				<i>Lognormal approach</i>											
		950 Other Western Hardwoods	565	5.00	9.22	10.26	2.488	5.368	5.852	4.99	9.19	10.22	2.492	5.389	5.878
		999 Non stocked	149	6.24	11.60	12.85	3.231	6.293	6.881	6.23	11.57	12.79	3.242	6.268	6.825
		Pacific Northwest Average		5.51	10.18	11.23	2.413	4.621	5.019	5.51	10.16	11.20	2.414	4.624	5.019
Pacific SW (1 state: CA)		180 Pinyon / Juniper	5,883	1.57	2.91	3.19	0.933	1.817	2.048	1.57	2.91	3.19	0.933	1.814	2.041
		200 Douglas-fir	399	3.11	4.82	5.26	0.916	1.460	1.647	2.94	4.54	4.98	0.973	1.397	1.543
		220 Ponderosa Pine	3,470	3.00	5.15	5.70	1.440	2.630	3.020	3.00	5.15	5.70	1.441	2.632	3.022
		Fir / Spruce / Mountain													
		260 Hemlock	961	3.84	6.82	7.40	1.578	3.003	3.031	3.84	6.82	7.40	1.578	3.002	3.030
		280 Lodgepole Pine	373	2.43	4.35	4.95	1.501	2.577	3.145	2.37	4.22	4.83	1.567	2.732	3.295
		300 Hemlock / Sitka Spruce	63	6.75	12.88	13.70	0.617	2.864	3.321	6.75	12.88	13.70	0.617	2.864	3.321
		340 Redwood	798	3.87	6.27	6.85	1.296	3.087	3.335	3.67	5.94	6.51	1.429	3.196	3.413
		360 Other Western Softwoods	269	3.64	6.06	7.11	1.867	3.233	4.146	3.35	5.56	6.62	1.864	3.144	4.065
		700 Elm / Ash / Cottonwood	1,994	4.44	9.72	11.65	0.212	3.180	4.548	4.43	9.66	11.56	0.198	3.121	4.456
		910 Alder / Maple	50	5.29	9.68	10.58	2.479	5.103	5.361	4.71	8.70	9.60	2.901	5.765	6.003
		920 Western Oak	7,157	2.28	3.89	4.17	1.017	1.872	2.125	2.28	3.88	4.17	1.017	1.870	2.123
		950 Other Western Hardwoods	6,226	2.19	3.62	3.91	1.115	2.104	2.342	2.16	3.57	3.85	1.103	2.079	2.308
	Pacific Southwest Average		2.50	4.44	4.91	1.059	2.201	2.546	2.48	4.40	4.87	1.061	2.195	2.533	
Rocky Mts North (2 states: MT, ID)		200 Douglas-fir	13,546	2.64	4.67	5.34	1.221	2.583	3.074	2.64	4.67	5.34	1.220	2.581	3.070
		220 Ponderosa Pine	16,335	2.20	4.21	4.90	0.850	1.899	2.341	2.20	4.21	4.90	0.850	1.899	2.341
		240 Western White Pine	56	1.86	3.88	4.41	1.001	2.200	2.676	1.84	3.65	4.18	1.037	2.491	2.956
		Fir / Spruce / Mountain													
		260 Hemlock	5,060	1.90	3.23	3.64	1.107	2.131	2.532	1.90	3.24	3.66	1.105	2.122	2.519
		280 Lodgepole Pine	5,176	2.25	4.02	4.64	1.005	1.817	2.154	2.26	4.03	4.65	1.003	1.811	2.146
		300 Hemlock / Sitka Spruce	930	2.82	5.40	6.16	1.324	3.718	4.357	2.82	5.39	6.16	1.324	3.720	4.358
		360 Other Western Softwoods	1,972	2.14	3.68	4.16	1.150	2.051	2.433	2.15	3.68	4.17	1.148	2.043	2.421

Appendix C (A): (continued) [5 of 5]

Appendix C (1): (Continued) [5 of 5]

Geographic region	FIADB code Δ	Forest Type GROUP ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Lognormal approach															
		700 Elm / Ash / Cottonwood	3,721	2.25	4.52	5.49	0.778	1.732	2.236	2.24	4.52	5.48	0.778	1.732	2.236
		900 Aspen / Birch	5,115	2.54	4.96	5.73	1.404	2.993	3.515	2.54	4.95	5.71	1.405	3.000	3.524
		Rocky Mountains North Average		2.34	4.31	4.99	1.057	2.226	2.681	2.34	4.31	4.99	1.056	2.225	2.678
Rocky Mts South (6 states: WY, CO, NM, AZ, UT, NV)		180 Pinyon / Juniper	20,881	1.26	2.34	2.76	0.743	1.461	1.784	1.26	2.33	2.76	0.734	1.453	1.776
		200 Douglas-fir	3,062	2.15	4.05	4.75	1.480	2.604	2.934	2.11	3.99	4.68	1.412	2.535	2.872
		220 Ponderosa Pine	5,394	1.76	3.23	3.79	1.076	1.913	2.304	1.75	3.23	3.78	1.076	1.912	2.302
		Fir / Spruce / Mountain													
		260 Hemlock	3,557	1.94	3.48	3.94	1.573	2.727	2.973	1.92	3.46	3.92	1.513	2.666	2.912
		280 Lodgepole Pine	1,980	2.07	3.58	4.05	1.180	2.110	2.383	2.07	3.59	4.06	1.179	2.105	2.375
		360 Other Western Softwoods	695	1.90	3.31	3.74	1.195	2.193	2.421	1.89	3.30	3.73	1.151	2.147	2.375
		500 Oak / Hickory	11	2.90	3.41	3.41	0.000	0.000	0.000	2.90	3.41	3.41	0.000	0.000	0.000
		700 Elm / Ash / Cottonwood	126	1.51	3.44	4.60	0.805	1.659	2.349	1.51	3.42	4.55	0.808	1.661	2.270
		900 Aspen / Birch	3,232	2.84	5.28	6.03	2.009	3.842	4.157	2.77	5.19	5.93	1.945	3.801	4.126
		920 Western Oak	2,856	1.89	3.62	4.23	1.492	2.872	3.251	1.88	3.60	4.22	1.479	2.859	3.239
		950 Other Western Hardwoods	1,149	1.36	2.63	3.19	1.247	2.126	2.343	1.34	2.60	3.16	1.226	2.101	2.324
		999 Non stocked	981	1.23	2.29	2.64	0.952	1.801	1.998	1.23	2.29	2.65	0.952	1.800	1.995
	Rocky Mountains South Average		1.64	3.04	3.55	1.089	2.032	2.352	1.63	3.02	3.53	1.068	2.013	2.334	

* Area summarized from the FIADB *Plot* table

‡ Forest type group assigned by FIA approved algorithm

† Indicates depth to 2 m or bedrock

Δ three digit FIADB code for forest type group

Appendix C (B): (continued) [2 of 5]

Geographic region		FIADB code Δ	Forest Type GROUP ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
					SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
					25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Normal approach																
		999 Non stocked		432	3.61	13.18	19.70	1.785	11.919	18.411	3.25	6.84	8.48	1.889	9.423	11.587
		North central Average			4.04	10.34	13.98	2.071	7.427	10.724	3.86	7.92	9.95	2.106	6.620	8.925
Southeast (5 states: FL, GA, NC, SC, VA)	100 White / Red / Jack Pine		264	2.95	6.64	8.91	2.316	18.492	37.351	2.79	5.39	6.40	1.259	2.345	2.685	
	120 Spruce / Fir		5	13.32	21.77	22.96	0.000	0.000	0.000	13.32	21.77	22.96	0.000	0.000	0.000	
	140 Longleaf / Slash Pine		5,054	4.05	11.03	16.06	1.744	4.743	6.667	4.04	10.54	15.02	1.736	4.496	6.057	
	160 Loblolly / Shortleaf Pine		11,313	3.01	7.04	9.69	2.387	11.240	20.257	2.95	6.38	8.46	2.182	6.322	8.031	
	180 Pinyon / Juniper		65	2.29	3.98	4.77	0.817	1.452	2.073	2.29	3.98	4.77	0.817	1.452	2.073	
	400 Oak / Pine		5,581	2.91	6.60	9.07	1.977	8.762	16.121	2.88	6.20	8.26	1.819	4.689	6.213	
	500 Oak / Hickory		12,447	2.76	5.50	6.94	1.729	4.865	6.324	2.76	5.46	6.88	1.728	4.782	6.150	
	600 Oak / Gum / Cypress		6,467	4.76	12.52	17.98	2.986	16.149	30.627	4.58	10.63	14.16	2.648	7.696	9.731	
	700 Elm / Ash / Cottonwood		776	2.99	6.80	9.64	1.935	6.460	9.118	2.99	6.60	9.26	1.935	6.341	8.779	
	800 Maple / Beech / Birch		136	5.06	8.79	9.83	3.694	5.883	6.016	5.06	8.79	9.83	3.694	5.883	6.016	
	980 Tropical Hardwoods		148	4.77	10.69	14.32	2.448	5.680	6.859	4.74	10.62	14.19	2.427	5.628	6.842	
	999 Non stocked		125	4.56	12.43	16.71	7.957	30.089	38.679	3.12	7.06	9.58	2.507	7.507	9.641	
		Southeast Average			3.33	7.87	10.85	2.164	8.976	15.416	3.28	7.25	9.65	2.013	5.613	7.228
South central (8 states: AL, AR, KY, LA, MS, OK, TN, TX)	100 White / Red / Jack Pine		139	3.38	6.32	7.66	1.313	2.892	3.177	3.38	6.32	7.66	1.313	2.892	3.177	
	140 Longleaf / Slash Pine		1,715	2.88	7.09	10.74	1.138	3.417	5.222	2.81	6.80	10.26	0.852	2.825	4.835	
	160 Loblolly / Shortleaf Pine		14,692	2.49	5.55	8.15	0.806	1.974	3.470	2.49	5.54	8.12	0.806	1.965	3.444	
	180 Pinyon / Juniper		901	2.64	5.38	6.84	0.880	1.820	2.671	2.64	5.38	6.84	0.880	1.820	2.671	
	400 Oak / Pine		10,582	2.53	5.51	7.78	0.890	2.111	3.397	2.52	5.47	7.71	0.826	1.917	3.235	
	500 Oak / Hickory		33,327	2.64	5.37	7.18	0.919	1.937	2.967	2.64	5.36	7.17	0.919	1.933	2.953	
	600 Oak / Gum / Cypress		7,099	3.32	7.81	11.33	1.701	5.040	7.992	3.31	7.77	11.22	1.700	5.025	7.949	
	700 Elm / Ash / Cottonwood		3,696	3.35	7.23	9.91	1.038	3.391	6.180	3.35	7.23	9.89	1.038	3.390	6.170	

Appendix C (B): (continued) [3 of 5]

Geographic region	FIADB code Δ	Forest Type GROUP ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
				Normal approach											
	800 Maple / Beech / Birch	669	3.78	6.51	7.57	1.410	2.557	3.030	3.78	6.51	7.57	1.410	2.557	3.030	
	999 Non stocked	579	3.10	6.90	9.13	2.079	5.372	6.260	2.79	6.13	8.34	0.840	2.320	4.196	
	South central Average		2.72	5.82	8.10	0.993	2.410	3.853	2.71	5.79	8.05	0.967	2.339	3.789	
Great Plains (4 states: ND, SD, NE,KS)	180 Pinyon / Juniper	206	3.57	8.22	10.20	1.555	4.150	5.358	3.57	8.22	10.19	1.557	4.156	5.369	
	220 Ponderosa Pine	733	3.40	6.95	7.79	0.754	1.468	1.556	3.40	6.94	7.76	0.754	1.471	1.552	
	400 Oak / Pine	90	4.18	9.22	11.32	1.420	3.349	3.595	4.18	9.22	11.32	1.420	3.349	3.595	
	500 Oak / Hickory	681	4.80	10.65	13.05	1.877	3.946	5.007	4.80	10.65	13.05	1.877	3.946	5.007	
	700 Elm / Ash / Cottonwood	839	4.49	11.24	14.41	1.958	5.683	6.714	4.49	11.24	14.41	1.958	5.683	6.714	
	800 Maple / Beech / Birch	830	5.11	11.65	14.68	1.612	3.831	5.001	5.11	11.65	14.68	1.612	3.831	5.002	
	900 Aspen / Birch	112	5.08	11.66	14.69	1.186	2.789	4.101	5.08	11.66	14.69	1.187	2.792	4.105	
	999 Non stocked	136	3.85	8.31	10.38	2.040	4.060	4.629	3.85	8.28	10.35	2.043	4.066	4.633	
	Great Plains Average		4.41	10.04	12.42	1.563	3.786	4.646	4.41	10.03	12.42	1.563	3.787	4.646	
Pacific NW (2 states: WA, OR)	180 Pinyon / Juniper	130	2.39	4.97	5.56	1.050	2.825	3.530	2.39	4.97	5.56	1.050	2.825	3.529	
	200 Douglas-fir	6,103	6.50	13.27	15.10	2.698	5.662	6.599	6.50	13.25	15.06	2.696	5.653	6.584	
	220 Ponderosa Pine	1,560	2.96	6.46	7.44	0.888	2.032	2.371	2.96	6.46	7.44	0.888	2.031	2.369	
	Fir / Spruce / Mountain														
	260 Hemlock	3,119	3.93	7.98	9.07	1.801	3.022	3.449	3.93	7.98	9.07	1.801	3.022	3.449	
	280 Lodgepole Pine	1,082	2.45	5.88	7.29	1.976	3.381	3.396	2.45	5.88	7.29	1.976	3.381	3.399	
	300 Hemlock / Sitka Spruce	4,494	8.58	17.27	19.03	3.201	7.371	8.069	8.57	17.17	18.85	3.208	7.376	8.045	
	320 Western Larch	159	2.90	6.96	7.93	0.107	1.237	1.661	2.90	6.96	7.93	0.107	1.237	1.661	
	700 Elm / Ash / Cottonwood	108	6.11	11.40	13.18	2.055	4.131	5.476	6.11	11.19	12.91	2.055	4.304	5.653	
	900 Aspen / Birch	80	3.71	6.75	7.29	1.393	2.946	3.387	3.71	6.75	7.29	1.393	2.946	3.387	
	910 Alder / Maple	1,462	7.48	15.84	17.84	2.993	6.631	7.380	7.47	15.79	17.74	2.991	6.628	7.367	
	920 Western Oak	417	4.55	9.21	10.32	1.567	3.430	4.062	4.55	9.21	10.32	1.567	3.430	4.062	

Appendix C (B): (continued) [4 of 5]

Geographic region	FIADB code Δ	Forest Type GROUP ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
				<i>Normal approach</i>											
		950 Other Western Hardwoods	565	5.50	11.61	13.28	2.538	5.890	6.705	5.49	11.57	13.21	2.545	5.926	6.736
		999 Non stocked	149	6.76	14.16	16.12	3.315	7.154	8.198	6.74	14.06	15.94	3.319	7.028	7.963
		Pacific Northwest Average		6.00	12.31	13.88	2.442	5.183	5.854	5.99	12.27	13.82	2.443	5.182	5.843
Pacific SW (1 state: CA)		180 Pinyon / Juniper	5,883	1.80	3.61	4.04	1.034	2.179	2.568	1.80	3.61	4.05	1.033	2.169	2.550
		200 Douglas-fir	399	3.60	6.12	6.81	1.049	2.007	2.345	3.41	5.78	6.46	1.049	1.733	2.040
		220 Ponderosa Pine	3,470	3.56	6.41	7.17	1.825	3.351	3.836	3.56	6.41	7.17	1.826	3.354	3.839
		Fir / Spruce / Mountain													
		260 Hemlock	961	4.56	8.24	9.07	2.031	3.626	3.650	4.56	8.24	9.07	2.031	3.626	3.650
		280 Lodgepole Pine	373	2.74	5.33	6.17	1.697	2.897	3.537	2.67	5.18	6.02	1.772	3.094	3.732
		300 Hemlock / Sitka Spruce	63	7.56	15.22	16.57	1.740	7.486	8.704	7.56	15.22	16.57	1.740	7.486	8.704
		340 Redwood	798	4.47	7.81	8.75	1.447	3.966	4.493	4.24	7.39	8.32	1.554	3.993	4.473
		360 Other Western Softwoods	269	4.28	7.59	8.98	2.117	3.908	5.025	3.95	6.98	8.38	2.071	3.638	4.781
		700 Elm / Ash / Cottonwood	1,994	4.82	12.67	16.87	0.224	5.395	8.962	4.79	12.53	16.65	0.200	5.255	8.739
		910 Alder / Maple	50	6.04	12.05	13.44	2.407	5.373	5.683	5.37	10.83	12.21	2.874	6.129	6.407
		920 Western Oak	7,157	2.70	4.81	5.22	1.244	2.349	2.694	2.69	4.81	5.21	1.243	2.345	2.689
		950 Other Western Hardwoods	6,226	2.56	4.50	4.92	1.305	2.586	2.957	2.53	4.44	4.86	1.285	2.532	2.887
	Pacific Southwest Average		2.90	5.55	6.34	1.261	2.838	3.455	2.87	5.50	6.28	1.259	2.811	3.415	
Rocky Mts North (2 states: MT, ID)		200 Douglas-fir	13,546	2.99	5.77	6.75	1.313	3.007	3.762	2.99	5.77	6.75	1.313	3.006	3.759
		220 Ponderosa Pine	16,335	2.52	5.02	5.93	0.916	2.146	2.710	2.52	5.02	5.92	0.916	2.146	2.710
		240 Western White Pine	56	2.20	5.31	6.20	1.190	2.759	3.728	2.18	4.79	5.67	1.227	3.374	4.301
		Fir / Spruce / Mountain													
		260 Hemlock	5,060	2.20	4.22	4.90	1.216	2.715	3.424	2.21	4.23	4.92	1.214	2.706	3.410
		280 Lodgepole Pine	5,176	2.61	5.07	6.00	1.086	2.184	2.745	2.61	5.07	6.00	1.083	2.179	2.738
		300 Hemlock / Sitka Spruce	930	3.15	6.41	7.52	1.394	4.099	5.066	3.15	6.40	7.51	1.394	4.105	5.071
		360 Other Western Softwoods	1,972	2.44	4.57	5.27	1.257	2.476	3.028	2.44	4.57	5.28	1.255	2.469	3.017

Appendix C (B): (continued) [5 of 5]

Appendix C (B): (Continued) [C-615]

Geographic region	FIADB code Δ	Forest Type GROUP ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
				<i>Normal approach</i>											
		700 Elm / Ash / Cottonwood	3,721	2.58	5.41	6.65	0.853	1.952	2.545	2.57	5.40	6.64	0.854	1.953	2.545
		900 Aspen / Birch	5,115	2.83	5.89	6.94	1.526	3.497	4.211	2.83	5.87	6.91	1.528	3.507	4.222
		Rocky Mountains North Average		2.66	5.26	6.20	1.143	2.597	3.249	2.66	5.26	6.20	1.143	2.597	3.248
Rocky Mts South (6 states: WY, CO, NM, AZ, UT, NV)		180 Pinyon / Juniper	20,881	1.49	3.08	3.71	0.819	1.953	2.457	1.48	3.07	3.70	0.810	1.944	2.448
		200 Douglas-fir	3,062	2.47	5.29	6.38	1.541	2.960	3.512	2.43	5.21	6.29	1.465	2.881	3.433
		220 Ponderosa Pine	5,394	2.09	4.46	5.36	1.135	2.323	2.951	2.09	4.46	5.35	1.135	2.321	2.946
		Fir / Spruce / Mountain													
		260 Hemlock	3,557	2.22	4.52	5.28	1.660	3.195	3.632	2.20	4.49	5.26	1.596	3.128	3.566
		280 Lodgepole Pine	1,980	2.35	4.69	5.46	1.287	2.597	3.048	2.36	4.69	5.47	1.285	2.592	3.040
		360 Other Western Softwoods	695	2.13	4.09	4.72	1.269	2.568	2.906	2.11	4.07	4.71	1.219	2.515	2.855
		500 Oak / Hickory	11	3.11	3.85	3.97	0.000	0.000	0.000	3.11	3.85	3.97	0.000	0.000	0.000
		700 Elm / Ash / Cottonwood	126	1.77	4.68	6.47	0.913	2.241	3.328	1.76	4.66	6.40	0.916	2.242	3.203
		900 Aspen / Birch	3,232	3.19	6.56	7.66	2.117	4.325	4.818	3.11	6.45	7.54	2.045	4.278	4.784
		920 Western Oak	2,856	2.22	4.79	5.72	1.577	3.321	3.888	2.21	4.77	5.70	1.563	3.309	3.879
		950 Other Western Hardwoods	1,149	1.57	3.34	4.14	1.301	2.453	2.846	1.55	3.31	4.11	1.277	2.431	2.834
		999 Non stocked	981	1.48	3.17	3.74	1.031	2.242	2.605	1.48	3.17	3.74	1.031	2.240	2.602
	Rocky Mountains South Average		1.91	3.99	4.76	1.167	2.491	3.002	1.90	3.97	4.74	1.144	2.470	2.981	

* Area summarized from the FIADB *Plot* table

‡ Forest type group assigned by FIA approved algorithm

† Indicates depth to 2 m or bedrock

Δ three digit FIADB code for forest type group

APPENDIX D: SOC (KG M⁻²) ESTIMATES PER FOREST TYPE BY (A) LOGNORMAL AND (B) NORMAL APPROACHES FOR
9 REGIONS OF THE CONTIGUOUS 48 UNITED STATES.

(A)

Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
<i>Lognormal approach</i>															
Northeast (13 states: ME, VT, NH, MA, CT, RI, PA, NJ, MD, DE, WV, OH, NY)	101 Jack pine	6	3.41	6.62	9.34	2.199	2.938	3.560	3.41	5.59	6.33	2.199	3.029	3.326	
	102 Red pine	235	3.91	5.75	6.82	1.966	2.695	3.159	3.91	5.65	6.54	1.966	2.684	3.056	
	103 Eastern white pine	1,729	3.51	5.74	6.95	1.690	2.517	3.103	3.51	5.66	6.59	1.691	2.472	2.747	
	104 White pine / hemlock	412	3.57	6.26	7.86	2.052	3.190	4.962	3.57	5.99	7.02	2.052	2.743	2.987	
	105 Eastern hemlock	1,209	3.25	5.43	6.53	1.556	2.257	2.703	3.25	5.35	6.27	1.556	2.230	2.556	
	121 Balsam fir	1,118	3.42	6.59	8.43	1.157	2.099	3.588	3.41	6.10	7.01	1.153	1.768	1.974	
	122 White spruce	152	3.58	6.57	8.45	1.257	1.897	2.406	3.58	6.05	6.95	1.253	1.931	2.218	
	123 Red spruce	860	3.10	5.98	7.63	1.156	1.771	2.515	3.10	5.57	6.43	1.157	1.677	1.878	
	124 Red spruce / balsam fir	469	3.26	6.20	7.82	1.175	1.887	2.897	3.26	5.81	6.68	1.175	1.697	1.890	
	125 Black spruce	269	3.31	6.42	8.39	1.398	2.020	2.710	3.31	5.85	6.72	1.395	2.032	2.231	
	126 Tamarack	74	4.14	7.70	9.84	1.360	2.618	4.670	4.14	7.15	8.25	1.353	2.155	2.445	
	127 Northern white-cedar	591	3.71	6.88	8.65	1.403	2.321	3.799	3.71	6.43	7.36	1.398	2.064	2.297	
	161 Loblolly pine	146	3.58	5.92	7.35	1.362	1.921	2.172	3.58	5.92	7.34	1.362	1.921	2.159	
	162 Shortleaf pine	18	2.38	4.15	4.97	0.093	0.441	0.477	2.36	4.12	4.86	0.078	0.415	0.389	
	163 Virginia pine	210	2.59	3.73	4.27	0.631	2.221	4.008	2.59	3.73	4.27	0.631	2.221	4.008	
	165 Table-mountain pine	10	1.65	2.33	2.49	0.966	0.959	0.935	1.65	2.33	2.49	0.966	0.959	0.935	
	167 Pitch pine	358	2.78	4.73	5.52	0.992	1.570	1.766	2.76	4.67	5.37	0.976	1.535	1.629	
	181 Eastern redcedar	81	3.28	5.03	5.88	1.416	3.738	6.412	3.25	4.99	5.82	1.410	3.733	6.406	
	381 Scotch pine	116	4.54	6.20	7.06	2.460	3.224	3.545	4.54	6.20	7.05	2.462	3.223	3.529	
	383 Other exotic softwoods	100	4.17	5.55	6.38	1.525	2.055	2.427	4.17	5.55	6.38	1.525	2.054	2.427	
	401 White pine / red oak / white ash	832	3.25	5.12	6.04	1.639	2.256	2.673	3.25	5.11	5.96	1.639	2.255	2.545	
	402 Eastern redcedar / hardwood	74	3.48	4.95	5.83	1.181	1.468	1.959	3.48	4.95	5.81	1.179	1.464	1.956	
	404 Shortleaf pine / oak	7	2.36	4.37	5.33	0.354	1.047	1.125	2.36	4.37	5.33	0.354	1.047	1.125	
	405 Virginia pine / southern red oak	178	2.39	3.52	4.13	0.479	0.748	1.055	2.39	3.52	4.13	0.479	0.748	1.054	
	406 Loblolly pine / hardwood	104	3.13	5.22	6.55	1.055	1.430	1.604	3.13	5.22	6.54	1.055	1.430	1.595	

Appendix D (A): (continued) [2 of 12]

Appendix B (Continued) [2 of 12]

Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Lognormal approach															
	409	Other pine / hardwood	330	2.42	4.03	4.81	0.940	2.385	3.931	2.40	4.00	4.73	0.930	2.370	3.899
	501	Post oak / blackjack oak	310	2.42	3.75	4.43	0.814	1.253	1.503	2.41	3.74	4.41	0.811	1.241	1.475
	502	Chestnut oak	867	2.30	3.18	3.63	0.535	0.727	0.876	2.30	3.19	3.63	0.535	0.726	0.875
	503	White oak / red oak / hickory	2,306	2.72	3.98	4.64	1.031	1.438	1.732	2.72	3.98	4.63	1.030	1.433	1.721
	504	White oak	616	2.57	3.82	4.50	0.770	1.070	1.354	2.57	3.82	4.50	0.770	1.067	1.346
	505	Northern red oak	1,108	2.73	4.21	4.95	1.174	1.751	2.147	2.73	4.18	4.86	1.173	1.710	1.976
	506	Yellow-poplar / white oak / red oak	792	2.48	3.66	4.20	0.579	0.887	1.100	2.48	3.66	4.20	0.579	0.885	1.096
	507	Sassafras / persimmon	22	2.25	3.64	4.49	0.534	1.011	1.422	2.23	3.60	4.44	0.511	0.957	1.344
	508	Sweetgum / yellow -poplar	87	3.09	5.36	7.01	0.918	1.861	2.937	3.04	5.26	6.84	0.840	1.678	2.581
	510	Scarlet oak	108	2.38	3.85	4.66	0.967	1.447	1.730	2.36	3.83	4.59	0.953	1.419	1.654
	511	Yellow-poplar	150	2.33	3.37	3.90	0.492	0.781	1.112	2.33	3.37	3.90	0.491	0.776	1.101
	512	Black walnut	126	3.10	4.49	5.15	1.092	1.633	1.830	3.10	4.49	5.15	1.092	1.627	1.820
	513	Black locust	193	2.82	4.10	4.80	1.051	1.388	1.719	2.82	4.10	4.79	1.051	1.382	1.700
	519	Red maple / oak	298	2.57	4.18	5.06	1.064	1.845	2.317	2.57	4.13	4.89	1.060	1.788	2.078
	520	Mixed upland hardwoods	8,028	2.59	3.84	4.49	0.980	1.517	1.940	2.59	3.84	4.47	0.978	1.505	1.900
	601	Swamp chestnut oak / cherrybark oak	16	3.33	5.66	7.25	1.028	1.321	1.438	3.33	5.66	7.20	1.028	1.321	1.417
	602	Sweetgum / Nuttall oak / willow oak	44	2.86	5.04	6.58	0.485	0.694	0.857	2.86	5.04	6.55	0.485	0.694	0.826
	606	Atlantic white -cedar	28	3.42	5.72	6.78	1.359	1.941	2.113	3.37	5.63	6.50	1.339	1.915	2.025
	607	Baldcypress / water tupelo	6	3.31	5.88	7.83	1.597	1.816	1.729	3.31	5.88	7.69	1.597	1.816	1.747
	608	Sweetbay / swamp tupelo / red maple	45	3.07	5.30	6.65	1.205	1.501	1.679	3.05	5.27	6.50	1.196	1.487	1.633
	701	Black ash / American elm / red maple	1,611	3.87	5.95	7.09	1.886	2.741	3.512	3.87	5.90	6.95	1.885	2.736	3.459
	702	River birch / sycamore	116	2.77	3.97	4.62	0.863	1.119	1.457	2.77	3.97	4.62	0.863	1.118	1.457
	703	Cottonwood	182	4.20	6.29	7.46	2.017	3.291	3.857	4.20	6.28	7.46	2.017	3.293	3.859
	704	Willow	361	4.47	7.09	8.52	1.550	2.826	4.146	4.46	6.97	8.22	1.544	2.836	4.115
	705	Sycamore / pecan / American elm	228	3.10	5.05	5.99	1.282	2.826	3.463	3.10	5.05	5.99	1.282	2.826	3.461

Appendix D (A): (continued) [3 of 12]

Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Lognormal approach															
		706 Sugarberry / hackberry / elm / green ash	248	4.19	6.07	7.13	1.729	2.884	3.458	4.17	6.04	7.09	1.742	2.893	3.457
		708 Red maple / lowland	507	3.15	5.38	6.80	1.604	3.104	5.002	3.14	5.23	6.32	1.600	2.876	4.176
		801 Sugar maple / beech / yellow birch	10,252	3.07	5.04	6.02	1.378	1.918	2.361	3.06	4.97	5.82	1.378	1.906	2.255
		802 Black cherry	1,718	2.99	4.36	5.09	1.284	2.002	2.464	2.99	4.33	4.98	1.284	1.958	2.304
		809 Red maple / upland	3,799	3.18	5.26	6.38	1.601	2.402	3.206	3.18	5.13	5.97	1.601	2.288	2.684
		901 Aspen	1,508	3.72	6.44	7.83	1.814	2.839	3.876	3.72	6.21	7.18	1.808	2.717	3.211
		902 Paper birch	869	2.96	5.64	6.90	1.065	1.658	2.128	2.95	5.41	6.22	1.059	1.631	1.815
		^903 Gray Birch	187	3.62	6.54	8.37	1.308	2.648	4.947	3.62	6.06	6.98	1.308	1.947	2.192
		999 Non stocked	159	3.59	5.43	6.49	1.632	2.743	3.780	3.59	5.41	6.42	1.631	2.730	3.722
		Northeast Average		3.05	4.92	5.90	1.290	1.952	2.548	3.05	4.83	5.63	1.289	1.902	2.287
North central (7 states: IL, IN, IA, MI, MN, MO, WI)		101 Jack pine	956	2.49	7.05	9.45	1.250	8.238	10.564	2.39	5.49	6.95	1.258	7.968	9.916
		102 Red pine	1,214	2.83	7.28	9.52	1.480	6.737	8.404	2.73	5.79	7.15	1.497	6.480	7.744
		103 Eastern white pine	493	4.44	9.22	11.14	2.546	5.910	7.363	4.38	8.33	9.69	2.577	5.408	5.903
		121 Balsam fir	789	3.09	8.75	12.35	1.623	8.776	11.808	2.84	5.53	7.15	1.660	7.646	9.316
		122 White spruce	246	3.21	8.80	12.01	1.551	8.462	11.409	3.02	5.85	7.42	1.568	7.189	8.839
		125 Black spruce	1,341	3.27	17.49	27.06	1.386	13.811	20.652	2.05	4.75	5.99	1.547	10.337	12.735
		126 Tamarack	618	3.47	18.93	29.08	1.498	13.992	21.594	2.24	4.42	5.51	1.759	8.905	10.816
		127 Northern white-cedar	1,222	3.15	11.28	16.05	1.763	12.199	15.291	2.83	7.55	9.86	1.793	11.725	13.991
		162 Shortleaf pine	144	1.81	3.60	4.67	0.480	0.655	0.972	1.81	3.60	4.67	0.480	0.655	0.972
		181 Eastern redcedar	333	2.05	3.74	4.58	0.862	1.207	1.408	2.05	3.74	4.58	0.862	1.207	1.408
		381 Scotch pine	51	3.14	7.07	8.88	1.343	5.559	8.228	3.14	7.07	8.88	1.343	5.559	8.228
		402 Eastern redcedar / hardwood	458	2.06	3.93	5.05	1.104	2.094	2.416	2.06	3.93	5.05	1.104	2.094	2.416
		404 Shortleaf pine / oak	191	1.60	3.20	4.24	0.745	1.184	1.451	1.60	3.20	4.24	0.745	1.184	1.451
		409 Other pine / hardwood	21	2.55	4.67	5.97	0.672	2.141	3.464	2.53	3.97	4.60	0.621	0.610	0.733

Appendix D (A): (continued) [4 of 12]

Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Lognormal approach															
		501 Post oak / blackjack oak	706	2.47	4.52	5.50	2.291	3.971	4.191	2.47	4.52	5.50	2.291	3.971	4.191
		502 Chestnut oak	249	4.30	8.39	10.04	2.393	5.000	5.418	4.30	8.22	9.77	2.394	4.983	5.362
		503 White oak / red oak / hickory	5,382	3.72	6.75	8.00	2.430	4.533	4.739	3.72	6.74	7.98	2.430	4.535	4.738
		504 White oak	1,155	3.28	5.98	7.17	2.403	4.422	4.634	3.28	5.97	7.16	2.403	4.424	4.635
		509 Bur oak	130	5.38	11.79	14.01	1.643	5.762	7.309	5.38	11.71	13.93	1.643	5.898	7.457
		514 Southern scrub oak	118	3.22	5.74	7.20	1.334	2.838	3.126	3.22	5.74	7.20	1.334	2.838	3.126
		515 Chestnut oak / black oak / scarlet oak	966	1.34	2.64	3.40	0.543	1.103	1.370	1.34	2.64	3.40	0.543	1.103	1.370
		520 Mixed upland hardwoods	910	4.87	8.62	9.69	2.164	3.780	3.867	4.87	8.50	9.43	2.169	3.940	4.123
		601 Swamp chestnut oak / cherrybark oak	111	3.45	6.94	8.79	0.732	2.123	2.683	3.45	6.94	8.79	0.732	2.123	2.683
		701 Black ash / American elm / red maple	2,123	4.96	9.37	11.00	2.419	4.740	5.201	4.96	9.30	10.88	2.424	4.705	5.006
		703 Cottonwood	168	4.64	9.14	10.73	2.333	4.621	5.036	4.64	9.14	10.73	2.333	4.621	5.036
		704 Willow	83	4.82	9.54	11.49	2.381	5.029	6.802	4.78	8.93	10.29	2.430	4.917	5.395
		801 Sugar maple / beech / yellow birch	40	5.67	10.22	11.65	2.484	4.583	4.723	5.67	10.20	11.62	2.484	4.589	4.724
		802 Black cherry	764	6.17	11.16	12.61	2.155	4.075	4.228	6.16	11.12	12.53	2.156	4.103	4.275
		803 Cherry / ash / yellow -poplar	607	2.33	4.66	5.93	1.373	3.746	4.592	2.33	4.66	5.93	1.373	3.746	4.592
		805 Hard maple / basswood	2,209	3.46	6.67	8.23	1.909	5.223	6.474	3.45	6.52	7.95	1.917	5.128	6.141
		901 Aspen	6,180	3.19	8.96	12.30	1.679	7.923	11.429	2.96	5.48	6.67	1.732	6.129	7.608
		902 Paper birch	1,209	2.83	8.15	11.07	1.461	9.211	12.494	2.61	5.06	6.11	1.514	7.949	9.574
		904 Balsam poplar	477	3.93	11.36	15.70	1.872	10.117	13.711	3.65	6.97	8.66	1.947	8.778	10.815
		999 Non stocked	432	3.19	10.93	15.75	1.668	10.513	15.410	2.88	5.59	6.76	1.753	8.361	9.966
		North central Average		3.42	8.37	11.02	1.845	6.520	8.468	3.26	6.25	7.56	1.876	5.750	6.737
Southeast (5 states: FL, GA, NC, SC, VA)		103 Eastern white pine	165	2.27	4.30	5.09	0.996	1.789	2.005	2.27	4.30	5.09	0.996	1.789	2.005
		104 White pine / hemlock	50	2.01	3.34	3.75	0.558	1.193	1.457	2.01	3.34	3.75	0.558	1.193	1.457
		105 Eastern hemlock	12	2.67	4.51	5.34	0.884	1.657	1.172	2.67	4.51	5.34	0.884	1.657	1.172

Appendix D (A): (continued) [5 of 12]

Appendix B (Continued)

Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Lognormal approach															
		141 Longleaf pine	977	2.68	7.14	9.99	1.236	3.403	4.222	2.68	7.08	9.90	1.236	3.298	4.122
		142 Slash pine	4,077	3.48	8.88	12.10	1.486	3.705	4.698	3.47	8.75	11.84	1.486	3.715	4.699
		161 Loblolly pine	9,242	2.52	5.45	7.15	1.884	5.921	8.554	2.51	5.33	6.96	1.862	5.167	6.462
		162 Shortleaf pine	436	1.67	3.18	4.03	0.618	1.281	1.688	1.67	3.18	4.03	0.618	1.281	1.688
		163 Virginia pine	842	1.68	3.14	3.93	0.587	1.183	1.523	1.68	3.14	3.93	0.587	1.183	1.523
		164 Sand pine	278	1.97	5.44	8.60	1.086	3.986	4.967	1.96	5.43	8.57	1.081	3.982	4.970
		165 Table-mountain pine	33	2.27	2.96	3.11	0.809	0.915	0.941	2.27	2.96	3.11	0.809	0.915	0.941
		166 Pond pine	418	5.87	24.10	39.40	3.991	37.314	76.827	4.36	10.42	12.96	1.997	6.754	8.162
		167 Pitch pine	57	2.49	4.18	4.73	0.815	1.932	2.438	2.49	4.18	4.73	0.815	1.932	2.438
		181 Eastern redcedar	65	1.95	3.27	3.87	0.719	1.108	1.506	1.95	3.27	3.87	0.719	1.108	1.506
		401 White pine / red oak / white ash	237	2.40	4.10	4.79	0.984	1.777	1.990	2.40	4.10	4.79	0.984	1.775	1.987
		402 Eastern redcedar / hardwood	89	1.90	3.22	3.94	0.654	1.384	1.725	1.90	3.22	3.94	0.655	1.387	1.726
		403 Longleaf pine / oak	231	2.22	6.05	8.77	1.268	2.906	3.687	2.22	6.03	8.72	1.268	2.900	3.673
		404 Shortleaf pine / oak	425	1.68	3.11	3.92	0.634	1.303	1.758	1.68	3.11	3.92	0.634	1.303	1.758
		405 Virginia pine / southern red oak	530	1.94	3.36	4.11	0.713	1.217	1.525	1.94	3.36	4.11	0.713	1.217	1.525
		406 Loblolly pine / hardwood	2,760	2.51	5.72	7.79	1.978	9.499	17.814	2.45	5.24	6.83	1.769	4.535	5.585
		407 Slash pine / hardwood	444	3.13	7.72	10.59	1.442	3.112	3.981	3.13	7.59	10.33	1.442	3.152	4.059
		409 Other pine / hardwood	369	2.69	6.07	8.22	1.824	12.640	24.958	2.60	5.06	6.40	1.302	2.714	3.626
		501 Post oak / blackjack oak	184	1.84	3.37	4.30	0.639	1.302	1.617	1.84	3.37	4.30	0.639	1.302	1.617
		502 Chestnut oak	897	2.32	3.79	4.36	1.310	2.198	2.465	2.32	3.79	4.36	1.310	2.197	2.464
		503 White oak / red oak / hickory	2,686	2.03	3.57	4.35	0.979	1.684	2.046	2.03	3.57	4.35	0.979	1.683	2.044
		504 White oak	145	1.83	3.33	4.14	0.534	1.277	1.954	1.83	3.33	4.14	0.534	1.277	1.954
		505 Northern red oak	46	3.27	5.43	6.01	3.349	5.235	5.429	3.27	5.43	6.01	3.349	5.235	5.429
		506 Yellow-poplar / white oak / red oak	1,835	2.15	3.85	4.62	1.200	3.389	4.184	2.15	3.85	4.62	1.200	3.388	4.184
		508 Sweetgum / yellow -poplar	2,165	2.12	4.42	5.70	1.654	4.947	6.168	2.12	4.36	5.63	1.653	4.831	6.037

Appendix D (A): (continued) [6 of 12]

Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
<i>Lognormal approach</i>															
	514 Southern scrub oak	523	2.12	5.79	8.58	0.867	2.960	3.726	2.12	5.78	8.55	0.867	2.950	3.687	
	520 Mixed upland hardwoods	1,893	2.45	4.83	6.07	1.510	4.385	5.609	2.45	4.82	6.05	1.510	4.380	5.591	
	601 Swamp chestnut oak / cherrybark oak	106	4.10	8.79	10.91	2.881	11.406	14.238	4.10	8.79	10.91	2.881	11.406	14.238	
	602 Sweetgum / Nuttall oak / willow oak	1,910	3.71	8.71	11.69	2.148	9.781	17.869	3.67	8.28	10.84	1.992	5.561	7.051	
	605 Overcup oak / water hickory	44	4.58	10.70	16.14	1.337	2.310	5.495	4.58	10.36	15.69	1.337	2.357	5.609	
	606 Atlantic white -cedar	14	3.91	9.41	12.13	2.478	5.924	6.828	3.91	8.60	11.13	2.478	5.540	6.605	
	607 Baldcypress / water tupelo	660	4.38	10.68	14.24	2.398	11.613	21.623	4.28	9.73	12.35	2.206	6.211	7.773	
	608 Sweetbay / swamp tupelo / red maple	2,064	3.74	10.58	15.44	2.700	17.371	34.092	3.47	8.07	10.50	2.157	6.131	7.568	
	702 River birch / sycamore	200	2.01	3.77	4.71	1.070	2.246	2.981	2.01	3.76	4.70	1.070	2.209	2.945	
	703 Cottonwood	6	3.79	12.04	20.46	0.272	2.879	7.846	3.79	11.87	20.13	0.272	2.723	7.554	
	704 Willow	86	1.96	4.05	5.30	2.489	11.988	15.128	1.96	4.05	5.30	2.489	11.988	15.128	
	705 Sycamore / pecan / American elm	112	2.06	4.93	7.33	0.861	3.147	5.565	2.06	4.91	7.29	0.861	3.119	5.507	
	706 Sugarberry / hackberry / elm / green ash	339	2.77	6.38	9.16	1.574	3.971	6.260	2.77	6.29	9.00	1.574	3.922	6.161	
	801 Sugar maple / beech / yellow birch	136	4.16	6.61	7.27	3.345	5.203	5.316	4.16	6.61	7.27	3.345	5.203	5.316	
	999 Non stocked	125	3.68	9.61	12.59	6.310	23.719	30.722	2.52	5.35	6.96	1.942	5.744	7.141	
	Southeast Average		2.69	6.17	8.31	1.660	6.096	9.858	2.65	5.74	7.48	1.557	4.129	5.172	
South central (8 states: AL, AR, KY, LA, MS, OK, TN, TX)	103 Eastern white pine	70	2.11	3.75	4.74	0.923	2.265	2.437	2.11	3.75	4.74	0.923	2.265	2.437	
	104 White pine / hemlock	27	2.31	5.02	5.64	0.706	2.522	2.791	2.31	5.02	5.64	0.706	2.522	2.791	
	105 Eastern hemlock	39	3.33	6.01	6.92	1.269	2.380	2.666	3.33	6.01	6.92	1.269	2.380	2.666	
	141 Longleaf pine	670	2.17	4.90	7.03	0.653	1.978	2.805	2.16	4.87	6.97	0.653	1.981	2.809	
	142 Slash pine	1,045	2.27	5.25	7.84	0.603	1.643	2.471	2.26	5.18	7.72	0.612	1.653	2.502	
	161 Loblolly pine	11,906	2.02	4.38	6.49	0.578	1.388	2.493	2.02	4.37	6.48	0.578	1.387	2.491	
	162 Shortleaf pine	1,780	1.58	3.31	4.40	0.601	1.223	2.324	1.58	3.31	4.40	0.600	1.222	2.322	
	163 Virginia pine	926	1.89	3.42	4.17	0.624	1.211	1.630	1.89	3.42	4.17	0.624	1.211	1.630	

Appendix D (A): (continued) [7 of 12]

Appendix B (Continued) [7 of 12]

Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Lognormal approach															
	165	Table-mountain pine	19	2.36	4.13	4.77	1.470	2.812	3.185	2.36	4.13	4.77	1.470	2.812	3.185
	167	Pitch pine	51	1.78	4.04	4.32	1.112	3.923	4.375	1.78	4.04	4.32	1.112	3.923	4.375
	168	Spruce pine	9	1.78	4.60	7.28	0.311	1.141	1.884	1.78	4.60	7.27	0.309	1.132	1.864
	181	Eastern redcedar	901	2.18	4.16	5.14	0.764	1.272	1.697	2.18	4.16	5.14	0.764	1.272	1.697
	401	White pine / red oak / white ash	78	2.67	4.91	5.70	0.966	2.460	2.686	2.67	4.91	5.70	0.966	2.460	2.686
	402	Eastern redcedar / hardwood	1,662	2.22	4.07	4.96	0.773	1.254	1.679	2.22	4.07	4.96	0.773	1.254	1.679
	403	Longleaf pine / oak	236	2.13	4.80	6.80	0.757	2.189	2.936	2.13	4.75	6.69	0.758	2.193	2.930
	404	Shortleaf pine / oak	1,696	1.62	3.39	4.52	0.590	1.163	2.140	1.62	3.39	4.52	0.590	1.161	2.137
	405	Virginia pine / southern red oak	727	2.09	3.61	4.26	0.760	1.211	1.501	2.09	3.61	4.26	0.760	1.211	1.501
	406	Loblolly pine / hardwood	5,485	2.02	4.40	6.53	0.543	1.367	2.475	2.02	4.40	6.52	0.543	1.366	2.472
	407	Slash pine / hardwood	432	2.34	5.44	7.76	0.668	1.902	2.492	2.32	5.30	7.54	0.694	1.929	2.550
	409	Other pine / hardwood	265	2.26	4.70	6.15	0.778	1.945	2.414	2.26	4.70	6.14	0.778	1.945	2.413
	501	Post oak / blackjack oak	1,908	1.79	3.71	4.74	0.677	1.247	1.962	1.79	3.71	4.74	0.677	1.247	1.962
	502	Chestnut oak	1,111	2.21	3.96	4.80	0.785	1.820	2.031	2.21	3.96	4.80	0.785	1.820	2.031
	503	White oak / red oak / hickory	10,759	1.99	3.99	5.50	0.682	1.339	2.297	1.99	3.99	5.49	0.682	1.338	2.294
	504	White oak	660	1.98	3.55	4.38	0.753	0.986	1.402	1.98	3.55	4.38	0.753	0.986	1.402
	505	Northern red oak	30	2.04	3.32	3.72	0.534	0.851	0.930	2.04	3.32	3.72	0.534	0.851	0.930
	506	Yellow-poplar / white oak / red oak	1,579	2.29	4.06	5.11	0.805	1.580	1.932	2.29	4.06	5.11	0.805	1.580	1.932
	508	Sweetgum / yellow -poplar	2,034	2.15	4.14	5.55	0.759	1.382	1.997	2.15	4.14	5.55	0.759	1.381	1.995
	512	Black walnut	16	2.20	3.34	3.66	0.292	0.396	0.508	2.20	3.34	3.66	0.292	0.396	0.508
	514	Southern scrub oak	193	1.63	3.92	5.07	0.775	2.321	3.287	1.63	3.92	5.07	0.775	2.321	3.287
	520	Mixed upland hardwoods	7,440	2.31	4.19	5.32	0.783	1.345	1.791	2.31	4.19	5.32	0.783	1.345	1.790
	601	Swamp chestnut oak / cherrybark oak	260	2.26	4.67	6.43	0.532	1.058	1.613	2.26	4.67	6.43	0.532	1.058	1.613
	602	Sweetgum / Nuttall oak / willow oak	3,055	2.37	5.10	7.21	0.585	1.462	2.334	2.37	5.10	7.20	0.584	1.460	2.329
	605	Overcup oak / water hickory	432	2.49	5.44	7.62	0.509	1.480	2.462	2.49	5.44	7.62	0.509	1.480	2.460

Appendix D (A): (continued) [8 of 12]

Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Lognormal approach															
		607 Baldcypress / water tupelo	837	3.52	7.75	11.00	2.640	5.705	8.514	3.51	7.73	10.96	2.639	5.708	8.523
		608 Sweetbay / swamp tupelo / red maple	957	2.35	5.16	7.40	0.906	2.064	2.900	2.35	5.14	7.35	0.906	2.060	2.887
		701 Black ash / American elm / red maple	152	3.27	5.46	6.52	1.135	1.483	1.895	3.27	5.46	6.52	1.135	1.483	1.895
		702 River birch / sycamore	368	2.61	4.79	6.02	0.679	1.213	1.574	2.61	4.79	6.02	0.679	1.213	1.574
		703 Cottonwood	166	2.37	5.13	6.89	0.285	0.981	1.548	2.37	5.13	6.89	0.285	0.981	1.548
		704 Willow	467	2.22	4.91	6.61	0.587	1.308	1.937	2.22	4.91	6.61	0.588	1.312	1.940
		705 Sycamore / pecan / American elm	509	2.45	4.95	6.60	0.691	1.402	2.113	2.45	4.94	6.60	0.691	1.402	2.113
		706 Sugarberry / hackberry / elm / green ash	2,031	2.65	5.26	7.08	0.829	1.908	2.775	2.65	5.26	7.07	0.829	1.909	2.776
		801 Sugar maple / beech / yellow birch	347	3.33	5.37	6.07	1.208	1.827	1.993	3.33	5.37	6.07	1.208	1.827	1.993
		802 Black cherry	28	3.30	5.25	6.37	1.045	1.664	2.297	3.30	5.25	6.37	1.045	1.664	2.297
		809 Red maple / upland	9	2.92	5.33	6.72	0.526	0.859	1.468	2.92	5.33	6.72	0.526	0.859	1.468
		999 Non stocked	579	2.27	4.66	6.16	0.659	1.653	2.433	2.24	4.56	6.05	0.689	1.651	2.464
		South central Average		2.14	4.33	5.95	0.699	1.472	2.312	2.14	4.33	5.94	0.700	1.472	2.312
Great Plains (4 states: ND, SD, NE,KS)		181 Eastern redcedar	131	3.75	8.20	10.33	1.411	3.798	4.490	3.75	8.20	10.33	1.411	3.798	4.490
		182 Rocky Mountain juniper	75	1.92	4.04	4.31	0.932	1.367	1.317	1.92	4.03	4.30	0.933	1.373	1.331
		221 Ponderosa pine	733	2.93	4.84	5.27	0.602	0.780	0.836	2.93	4.83	5.24	0.601	0.779	0.824
		402 Eastern redcedar / hardwood	90	3.79	7.76	9.21	1.427	3.421	3.773	3.79	7.76	9.21	1.427	3.421	3.773
		501 Post oak / blackjack oak	64	2.48	5.29	6.30	1.076	1.989	2.817	2.48	5.29	6.30	1.076	1.989	2.817
		503 White oak / red oak / hickory	288	4.33	9.52	11.65	1.180	3.235	4.010	4.33	9.52	11.65	1.180	3.235	4.010
		509 Bur oak	329	4.68	8.61	9.96	2.028	3.193	3.728	4.68	8.61	9.96	2.028	3.193	3.728
		701 Black ash / American elm / red maple	553	4.04	9.39	11.57	1.944	5.673	6.477	4.04	9.39	11.57	1.944	5.673	6.478
		703 Cottonwood	192	3.93	8.64	10.91	1.918	5.639	7.112	3.93	8.64	10.91	1.918	5.639	7.112
		704 Willow	46	4.17	8.13	10.06	0.841	0.639	1.112	4.17	8.13	10.06	0.841	0.639	1.112
		805 Hard maple / basswood	220	4.30	9.19	11.94	1.024	2.902	4.093	4.30	9.19	11.94	1.024	2.902	4.093

Appendix D (A): (continued) [9 of 12]

			Area*			Include all soil orders						Exclude <i>Histosols</i>					
Geographic region	FIADB code Δ	Forest Type ‡	(ha x 1000)	SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev				
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†		
<i>Lognormal approach</i>																	
		807 Elm / ash / locust	610	4.69	9.56	11.53	1.639	3.639	4.485	4.69	9.56	11.53	1.639	3.639	4.486		
		999 Non stocked	136	3.35	6.48	8.08	1.814	3.010	3.544	3.35	6.46	8.04	1.817	3.020	3.556		
		Great Plains Average		3.90	7.93	9.55	1.400	3.203	3.841	3.90	7.93	9.54	1.400	3.203	3.840		
Pacific NW (2 states: WA, OR)		201 Douglas-fir	6,090	5.96	10.75	11.91	2.645	4.856	5.360	5.96	10.75	11.89	2.645	4.857	5.359		
		202 Port -Orford-cedar	13	9.15	19.74	21.39	3.915	9.709	10.272	9.13	19.61	21.18	3.916	9.725	10.285		
		221 Ponderosa pine	1,558	2.65	5.70	6.56	0.836	1.882	2.164	2.65	5.70	6.56	0.836	1.881	2.163		
		264 Pacific silver fir	571	5.11	8.08	8.78	1.329	2.106	2.254	5.11	8.08	8.78	1.329	2.106	2.254		
		270 Mountain hemlock	17	3.71	6.69	7.48	1.903	2.074	1.993	3.71	6.69	7.48	1.903	2.074	1.993		
		281 Lodgepole pine	1,082	2.19	5.05	6.21	1.937	2.788	2.700	2.19	5.05	6.21	1.937	2.788	2.702		
		301 Western hemlock	2,738	8.13	14.51	15.57	3.321	6.918	7.389	8.12	14.48	15.51	3.326	6.926	7.388		
		304 Western redcedar	874	6.23	10.83	11.95	1.898	3.620	4.165	6.23	10.83	11.94	1.898	3.620	4.179		
		305 Sitka spruce	441	9.86	20.25	21.89	2.905	7.903	8.368	9.85	20.15	21.74	2.909	7.920	8.387		
		709 Cottonwood / willow	44	5.34	8.97	10.13	2.009	3.426	4.242	5.33	8.77	9.87	2.009	3.563	4.391		
		911 Red alder	1,347	6.87	12.72	13.93	3.022	6.208	6.650	6.87	12.69	13.87	3.022	6.221	6.665		
		922 California black oak	43	4.38	8.30	9.37	1.289	2.737	2.994	4.38	8.30	9.37	1.289	2.737	2.994		
		Canyon live oak / interior live															
		932 oak	21	3.27	5.86	6.78	0.027	0.561	1.020	3.27	5.86	6.78	0.027	0.561	1.020		
		951 Pacific madrone	155	3.52	6.16	6.92	0.574	1.411	1.726	3.52	6.16	6.92	0.574	1.411	1.726		
		999 Non stocked	149	6.24	11.60	12.85	3.231	6.293	6.881	6.23	11.57	12.79	3.242	6.268	6.825		
		Pacific Northwest Average		5.89	10.81	11.91	2.454	4.773	5.187	5.89	10.79	11.88	2.455	4.776	5.189		
Pacific SW (1 state: CA)		201 Douglas-fir	399	3.11	4.82	5.26	0.916	1.460	1.647	2.94	4.54	4.98	0.973	1.397	1.543		
		221 Ponderosa pine	293	3.28	5.89	6.84	1.395	2.651	3.299	3.28	5.89	6.84	1.396	2.656	3.306		
		Jeffrey pine / Coulter pine / 223 bigcone Douglas-fir	1,417	2.07	3.68	3.92	0.941	1.921	2.091	2.07	3.68	3.92	0.941	1.921	2.092		

Appendix D (A): (continued) [10 of 12]

			Include all soil orders						Exclude <i>Histosols</i>						
Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Lognormal approach															
	224 Sugar pine		1,743	3.49	5.88	6.54	1.460	2.692	3.035	3.49	5.88	6.54	1.462	2.695	3.038
	262 Red fir		371	4.95	8.19	8.71	2.068	3.043	2.857	4.95	8.20	8.71	2.068	3.042	2.856
	281 Lodgepole pine		373	2.43	4.35	4.95	1.501	2.577	3.145	2.37	4.22	4.83	1.567	2.732	3.295
	305 Sitka spruce		63	6.75	12.88	13.70	0.617	2.864	3.321	6.75	12.88	13.70	0.617	2.864	3.321
	341 Redwood		558	3.87	6.27	6.85	1.296	3.087	3.335	3.67	5.94	6.51	1.429	3.196	3.413
	361 Knobcone pine		27	3.64	6.06	7.11	1.867	3.233	4.146	3.35	5.56	6.62	1.864	3.144	4.065
	709 Cottonwood / willow		1,994	4.44	9.72	11.65	0.212	3.180	4.548	4.43	9.66	11.56	0.198	3.121	4.456
	911 Red alder		50	5.29	9.68	10.58	2.479	5.103	5.361	4.71	8.70	9.60	2.901	5.765	6.003
	922 California black oak		317	2.91	4.90	5.46	1.301	2.464	2.934	2.90	4.89	5.44	1.304	2.463	2.932
	Canyon live oak / interior live														
	932 oak		255	2.68	4.39	4.74	1.404	2.391	2.550	2.68	4.38	4.72	1.413	2.406	2.570
	951 Pacific madrone		116	3.14	4.98	5.45	0.964	2.119	2.387	3.09	4.90	5.37	0.981	2.110	2.370
	Pacific Southwest Average			3.48	6.44	7.31	1.031	2.644	3.195	3.44	6.37	7.24	1.046	2.646	3.185
Rocky Mts North (2 states: MT, ID)	201 Douglas-fir		13,546	2.64	4.67	5.34	1.221	2.583	3.074	2.64	4.67	5.34	1.220	2.581	3.070
	221 Ponderosa pine		16,335	2.20	4.21	4.90	0.850	1.899	2.341	2.20	4.21	4.90	0.850	1.899	2.341
	241 Western white pine		56	1.86	3.88	4.41	1.001	2.200	2.676	1.84	3.65	4.18	1.037	2.491	2.956
	265 Engelmann spruce		733	2.11	3.59	4.03	1.150	2.113	2.399	2.12	3.60	4.05	1.148	2.103	2.385
	266 Engelmann spruce / subalpine fir		2,906	1.83	3.09	3.50	1.064	2.043	2.463	1.83	3.10	3.52	1.062	2.034	2.449
	270 Mountain hemlock		66	2.38	4.36	4.87	1.700	3.904	4.645	2.38	4.39	4.92	1.697	3.893	4.628
	281 Lodgepole pine		5,176	2.25	4.02	4.64	1.005	1.817	2.154	2.26	4.03	4.65	1.003	1.811	2.146
	301 Western hemlock		158	2.25	3.90	4.37	0.771	1.321	1.559	2.25	3.88	4.35	0.775	1.365	1.599
	304 Western redcedar		772	2.92	5.65	6.47	1.375	3.932	4.604	2.92	5.65	6.47	1.375	3.930	4.601
	366 Limber pine		1,054	2.30	4.08	4.62	1.105	2.100	2.517	2.30	4.08	4.62	1.105	2.100	2.517
	367 Whitebark pine		918	1.90	3.06	3.45	1.179	1.837	2.146	1.90	3.08	3.47	1.175	1.821	2.122
		709 Cottonwood / willow		3,721	2.25	4.52	5.49	0.778	1.732	2.236	2.24	4.52	5.48	0.778	1.732

Appendix D (A): (continued) [11 of 12]

			Include all soil orders						Exclude <i>Histosols</i>						
Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
<i>Lognormal approach</i>															
	901 Aspen		5,059	2.55	4.97	5.74	1.407	3.001	3.524	2.54	4.96	5.73	1.408	3.008	3.533
	902 Paper birch		56	2.16	3.70	4.18	0.979	1.636	1.817	2.16	3.70	4.18	0.979	1.636	1.817
	Rocky Mountains North Average			2.35	4.34	5.02	1.053	2.218	2.672	2.34	4.34	5.02	1.052	2.217	2.670
Rocky Mts South (6 states: WY, CO, NM, AZ, UT, NV)	182 Rocky Mountain juniper		12	2.79	5.24	5.79	1.700	3.953	4.432	2.79	5.24	5.79	1.700	3.953	4.432
	184 Juniper woodland		1,801	1.08	2.11	2.54	0.524	1.051	1.383	1.08	2.11	2.53	0.524	1.051	1.383
	185 Pinyon juniper woodland		7,047	1.10	2.04	2.41	0.629	1.244	1.565	1.10	2.05	2.41	0.629	1.244	1.565
	201 Douglas-fir		2,932	2.15	4.05	4.75	1.480	2.604	2.934	2.11	3.99	4.68	1.412	2.535	2.872
	221 Ponderosa pine		5,349	1.76	3.24	3.79	1.077	1.915	2.306	1.75	3.23	3.78	1.077	1.914	2.304
	223 Jeffrey p/ Coulter pine / Douglas fir		25	1.84	3.10	3.23	0.202	0.653	0.640	1.84	3.10	3.23	0.202	0.653	0.640
	261 White fir		244	1.23	2.24	2.62	1.067	1.658	1.931	1.23	2.24	2.62	1.067	1.658	1.931
	265 Engelmann spruce		1,297	1.80	3.17	3.57	1.329	2.438	2.653	1.78	3.16	3.57	1.267	2.372	2.587
	266 Engelmann spruce / subalpine fir		1,240	2.08	3.80	4.34	1.887	3.149	3.429	2.05	3.76	4.30	1.814	3.077	3.358
	268 Subalpine fir		346	1.96	3.50	3.87	0.977	2.053	2.215	1.96	3.52	3.89	0.974	2.038	2.191
	269 Blue spruce		43	1.36	2.95	3.58	1.146	1.857	2.091	1.36	2.95	3.58	1.146	1.856	2.089
	281 Lodgepole pine		1,407	2.07	3.58	4.05	1.180	2.110	2.383	2.07	3.59	4.06	1.179	2.105	2.375
	365 Foxtail pine / bristlecone pine		104	1.84	3.30	3.87	0.858	1.603	1.874	1.84	3.30	3.86	0.857	1.601	1.873
	366 Limber pine		324	2.44	4.29	4.84	1.236	2.211	2.425	2.41	4.25	4.79	1.174	2.160	2.385
	367 Whitebark pine		210	1.31	2.25	2.49	0.937	1.852	1.979	1.31	2.27	2.52	0.935	1.839	1.959
	368 Misc. western softwoods		57	1.24	1.90	2.05	0.606	0.973	1.061	1.24	1.90	2.05	0.606	0.973	1.061
	509 Bur oak		9	2.90	3.41	3.41	0.000	0.000	0.000	2.90	3.41	3.41	0.000	0.000	0.000
	703 Cottonwood		23	0.89	1.90	2.40	0.449	1.006	1.392	0.89	1.90	2.40	0.449	1.005	1.391
709 Cottonwood / willow		102	1.67	3.82	5.15	0.799	1.551	2.206	1.67	3.80	5.09	0.804	1.561	2.115	
901 Aspen		3,222	2.84	5.29	6.03	2.011	3.845	4.160	2.77	5.19	5.93	1.947	3.804	4.129	
902 Paper birch		4	2.90	3.41	3.41	0.000	0.000	0.000	2.90	3.41	3.41	0.000	0.000	0.000	

Appendix D (A): (continued) [12 of 12]

Appendix B (1): (Continued) [12 of 12]

Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
				<i>Lognormal approach</i>											
	925	Deciduous oak woodland	615	1.68	3.28	3.87	1.240	2.436	2.906	1.68	3.28	3.87	1.240	2.436	2.905
	952	Mesquite woodland	625	0.83	1.92	2.58	0.462	1.112	1.486	0.83	1.92	2.58	0.462	1.112	1.486
	954	Intermountain maple woodland	20	1.74	3.28	3.70	1.030	2.128	2.328	1.74	3.29	3.71	1.028	2.120	2.315
	955	Misc. western hardwood woodlands	79	0.65	1.43	1.97	0.731	1.090	1.317	0.65	1.43	1.97	0.731	1.090	1.317
	999	Non stocked	981	1.23	2.29	2.64	0.952	1.801	1.998	1.23	2.29	2.65	0.952	1.800	1.995
		Rocky Mountains South Average		1.70	3.16	3.67	1.111	2.056	2.377	1.69	3.14	3.65	1.089	2.037	2.359

* Area summarized from the FIADB *Plot* table

\ddagger Forest type assigned by FIA approved algorithm

† Indicates depth to 2 m or bedrock

Δ three digit FIADB code for forest type

Appendix D:
(B)

Geographic region

FIADB code Δ

Forest Type ‡

Area*
(ha x 1000)

Include all soil orders

SOC, kg C m⁻²

StDev

Exclude *Histosols*

SOC, kg C m⁻²

StDev

25 cm 100cm Total†

25 cm 100cm Total†

25 cm 100cm Total†

25cm 100cm Total†

Normal approach

Northeast

(13 states: ME, VT, NH, MA, CT, RI, PA, NJ, MD, DE, WV, OH, NY)

101 Jack pine

102 Red pine

103 Eastern white pine

104 White pine / hemlock

105 Eastern hemlock

121 Balsam fir

122 White spruce

123 Red spruce

124 Red spruce / balsam fir

125 Black spruce

126 Tamarack

127 Northern white-cedar

161 Loblolly pine

162 Shortleaf pine

163 Virginia pine

165 Table-mountain pine

167 Pitch pine

181 Eastern redcedar

381 Scotch pine

383 Other exotic softwoods

401 White pine / red oak / white ash

402 Eastern redcedar / hardwood

404 Shortleaf pine / oak

405 Virginia pine / southern red oak

406 Loblolly pine / hardwood

6

235

1,729

412

1,209

1,118

152

860

469

269

74

591

146

18

210

10

358

81

116

100

832

74

7

178

104

4.63

4.67

4.56

4.84

4.35

4.78

4.74

4.41

4.61

4.64

5.45

5.02

4.30

2.81

3.13

2.13

3.36

3.85

5.27

4.86

4.30

4.17

3.18

2.96

3.81

9.35

7.69

8.59

9.81

8.29

9.78

9.43

9.04

9.24

9.44

10.87

9.90

7.22

5.19

4.73

3.35

6.63

6.41

7.91

7.26

7.86

6.52

6.07

4.63

6.46

12.88

9.39

10.74

12.51

10.15

12.35

12.06

11.38

11.46

12.07

13.76

12.32

9.15

6.30

5.44

3.59

7.78

7.59

9.28

8.68

9.50

7.86

7.37

5.45

8.23

2.236

2.043

1.699

2.035

1.590

1.205

1.249

1.245

1.243

1.508

1.406

1.442

1.743

0.029

0.759

0.912

1.146

1.621

2.558

1.618

1.659

1.235

0.630

0.945

1.362

3.565

3.454

3.323

3.880

3.198

2.538

2.410

2.201

2.335

2.333

3.174

2.821

2.397

0.286

2.731

0.756

3.034

4.694

3.799

2.866

3.279

1.905

1.566

0.945

1.761

4.704

4.259

4.567

6.112

4.070

4.392

3.215

3.186

3.592

3.161

5.696

4.678

2.673

0.378

4.745

0.718

3.178

7.660

4.463

3.769

4.069

2.627

1.508

1.392

1.974

4.63

4.67

4.55

4.83

4.35

4.78

4.74

4.41

4.61

4.64

5.44

5.01

4.30

2.80

3.13

2.13

3.33

3.82

5.27

4.86

4.30

4.16

3.18

2.96

3.81

8.12

7.58

8.41

9.47

8.17

9.19

8.81

8.54

8.77

8.74

10.22

9.36

7.22

5.15

4.73

3.35

6.56

6.36

7.91

7.26

7.82

6.50

6.07

4.63

6.46

9.25

9.05

10.02

11.37

9.76

10.59

10.25

9.87

10.06

10.01

11.84

10.74

9.12

6.18

5.44

3.59

7.59

7.52

9.27

8.68

9.27

7.81

7.37

5.45

8.22

2.236

2.043

1.703

2.035

1.590

1.202

1.245

1.247

1.244

1.507

1.400

1.439

1.743

0.013

0.759

0.912

1.131

1.617

2.560

1.618

1.657

1.221

0.630

0.443

1.362

3.497

3.450

3.239

3.379

3.171

2.190

2.448

2.158

2.174

2.399

2.562

2.510

2.396

0.253

2.731

0.756

3.010

4.691

3.796

2.866

3.257

1.842

1.566

0.945

1.761

4.091

4.168

3.835

3.955

3.905

2.674

3.114

2.624

2.601

2.718

2.961

2.927

2.713

0.275

4.745

0.718

3.099

7.657

4.438

3.768

3.889

2.515

1.508

1.390

1.987

Appendix D (B): (continued) [2 of 12]

Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Normal approach															
		409 Other pine / hardwood	330	3.00	5.52	6.62	1.150	3.418	4.978	2.98	5.47	6.50	1.139	3.374	4.917
		501 Post oak / blackjack oak	310	3.17	5.56	6.68	0.932	2.714	3.210	3.16	5.54	6.65	0.929	2.694	3.181
		502 Chestnut oak	867	2.76	4.04	4.67	0.659	1.081	1.335	2.76	4.04	4.67	0.659	1.079	1.333
		503 White oak / red oak / hickory	2,306	3.45	5.46	6.48	1.059	1.918	2.559	3.45	5.45	6.44	1.057	1.898	2.468
		504 White oak	616	3.19	5.03	5.99	0.826	1.349	1.775	3.19	5.03	5.98	0.826	1.340	1.756
		505 Northern red oak	1,108	3.56	6.26	7.68	1.268	2.914	4.050	3.56	6.19	7.36	1.267	2.815	3.502
		506 Yellow-poplar / white oak / red oak	792	3.07	4.77	5.51	0.595	1.156	1.438	3.07	4.77	5.51	0.595	1.154	1.434
		507 Sassafras / persimmon	22	2.92	4.91	6.08	0.504	1.102	1.632	2.90	4.87	6.02	0.484	1.051	1.555
		508 Sweetgum / yellow -poplar	87	3.68	6.50	8.60	1.132	2.168	3.261	3.62	6.39	8.40	1.039	1.958	2.893
		510 Scarlet oak	108	3.09	5.26	6.45	1.020	1.737	2.157	3.07	5.19	6.30	0.992	1.625	1.953
		511 Yellow-poplar	150	2.99	4.44	5.17	0.493	0.850	1.312	2.99	4.44	5.17	0.492	0.845	1.301
		512 Black walnut	126	3.68	5.77	6.74	1.097	2.030	2.397	3.68	5.77	6.73	1.097	2.025	2.387
		513 Black locust	193	3.45	5.44	6.48	1.137	2.081	2.616	3.45	5.43	6.45	1.136	2.067	2.557
		519 Red maple / oak	298	3.44	6.18	8.10	1.110	2.773	4.614	3.44	6.01	7.29	1.106	2.538	3.245
		520 Mixed upland hardwoods	8,028	3.23	5.18	6.13	1.064	2.144	2.791	3.23	5.17	6.09	1.061	2.117	2.710
		601 Swamp chestnut oak / cherrybark oak	16	3.98	6.85	8.90	1.328	1.682	1.802	3.98	6.85	8.84	1.328	1.682	1.796
		602 Sweetgum / Nuttall oak / willow oak	44	3.34	6.05	8.05	0.586	0.789	0.933	3.34	6.05	8.01	0.586	0.789	0.906
		606 Atlantic white -cedar	28	4.09	7.18	8.60	1.378	2.227	2.359	4.04	7.04	8.22	1.359	2.126	2.197
		607 Baldcypress / water tupelo	6	4.03	7.05	9.37	2.080	2.393	2.326	4.03	7.05	9.21	2.080	2.393	2.379
		608 Sweetbay / swamp tupelo / red maple	45	3.64	6.44	8.18	1.492	1.849	2.045	3.61	6.39	8.00	1.486	1.840	2.031
		701 Black ash / American elm / red maple	1,611	4.70	8.04	9.82	2.000	3.544	4.676	4.70	7.97	9.61	1.998	3.523	4.577
		702 River birch / sycamore	116	3.43	5.31	6.34	0.914	1.799	2.873	3.43	5.31	6.34	0.914	1.799	2.873
		703 Cottonwood	182	4.87	8.19	10.06	2.207	4.128	5.199	4.87	8.17	10.04	2.206	4.131	5.206
		704 Willow	361	5.35	9.53	11.73	1.650	3.676	5.254	5.34	9.39	11.35	1.644	3.671	5.199
		705 Sycamore / pecan / American elm	228	3.76	6.43	7.75	1.296	3.102	4.026	3.76	6.43	7.75	1.296	3.102	4.025

Appendix D (B): (continued) [3 of 12]

Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Normal approach															
		706 Sugarberry / hackberry / elm / green ash	248	4.88	7.85	9.56	1.983	3.964	5.244	4.86	7.80	9.49	1.989	3.956	5.207
		708 Red maple / lowland	507	4.22	8.03	10.24	1.619	3.860	6.112	4.20	7.79	9.48	1.613	3.543	4.980
		801 Sugar maple / beech / yellow birch	10,252	4.15	7.67	9.28	1.421	2.862	3.662	4.15	7.58	9.01	1.421	2.844	3.551
		802 Black cherry	1,718	3.64	5.77	6.84	1.417	2.742	3.526	3.64	5.73	6.71	1.417	2.680	3.321
		809 Red maple / upland	3,799	4.24	7.87	9.63	1.656	3.283	4.462	4.24	7.70	9.11	1.655	3.147	3.881
		901 Aspen	1,508	4.85	9.28	11.38	1.848	3.550	4.993	4.84	9.00	10.57	1.845	3.417	4.193
		902 Paper birch	869	4.21	8.67	10.51	1.134	2.203	2.808	4.20	8.39	9.66	1.131	2.233	2.665
		^903 Gray Birch	187	4.68	9.31	12.02	1.358	3.351	6.233	4.68	8.72	10.15	1.358	2.520	2.906
		999 Non stocked	159	4.24	7.07	8.65	1.751	3.507	4.865	4.24	7.04	8.54	1.750	3.479	4.746
		Northeast Average		3.96	7.08	8.62	1.356	2.694	3.624	3.96	6.96	8.24	1.354	2.630	3.297
North central (7 states: IL, IN, IA, MI, MN, MO, WI)		101 Jack pine	956	2.99	8.73	12.02	1.378	9.428	12.671	2.87	6.82	8.88	1.390	9.112	11.959
		102 Red pine	1,214	3.34	9.01	12.31	1.579	7.585	10.322	3.22	7.19	9.25	1.601	7.272	9.542
		103 Eastern white pine	493	4.82	10.81	13.93	2.520	6.352	8.598	4.74	9.66	11.68	2.558	5.698	6.718
		121 Balsam fir	789	3.65	10.84	15.56	1.845	9.968	13.761	3.35	6.98	9.27	1.887	8.643	10.956
		122 White spruce	246	3.80	10.97	15.35	1.821	9.626	13.336	3.57	7.46	9.84	1.841	8.150	10.489
		125 Black spruce	1,341	3.83	20.90	32.68	1.542	15.598	23.581	2.41	5.99	7.82	1.738	11.706	14.926
		126 Tamarack	618	3.99	22.49	35.13	1.637	15.865	24.607	2.56	5.38	6.99	1.931	10.087	12.800
		127 Northern white-cedar	1,222	3.64	13.74	20.51	1.944	13.629	17.763	3.27	9.33	13.12	1.978	13.094	16.434
		162 Shortleaf pine	144	2.17	4.64	6.20	0.460	0.978	1.613	2.17	4.64	6.20	0.460	0.978	1.613
		181 Eastern redcedar	333	2.31	4.48	5.65	0.861	1.315	1.711	2.31	4.48	5.65	0.861	1.315	1.711
		381 Scotch pine	51	3.74	8.88	12.34	1.378	6.523	12.781	3.74	8.88	12.34	1.378	6.523	12.781
		402 Eastern redcedar / hardwood	458	2.37	4.83	6.37	1.081	2.348	2.920	2.37	4.83	6.37	1.081	2.348	2.920
		404 Shortleaf pine / oak	191	1.88	4.06	5.55	0.814	1.661	2.217	1.88	4.06	5.55	0.814	1.661	2.217
		409 Other pine / hardwood	21	3.03	6.02	8.28	0.737	2.612	5.608	3.01	5.12	5.94	0.683	0.676	1.164

Appendix D (B): (continued) [4 of 12]

Appendix B (B): (Continued) [1 of 12]															
Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
				Normal approach											
		501 Post oak / blackjack oak	706	2.73	5.31	6.66	2.218	4.044	4.355	2.73	5.31	6.66	2.218	4.044	4.355
		502 Chestnut oak	249	4.62	9.68	11.91	2.345	5.219	5.838	4.62	9.49	11.59	2.345	5.197	5.764
		503 White oak / red oak / hickory	5,382	4.00	7.78	9.49	2.352	4.652	4.975	4.00	7.77	9.45	2.352	4.649	4.948
		504 White oak	1,155	3.58	6.99	8.62	2.342	4.589	4.916	3.58	6.98	8.60	2.342	4.590	4.907
		509 Bur oak	130	5.62	12.77	15.46	1.712	5.786	7.364	5.62	12.68	15.38	1.712	5.917	7.511
		514 Southern scrub oak	118	3.63	7.26	9.44	1.262	3.050	3.557	3.63	7.26	9.44	1.262	3.050	3.557
		515 Chestnut oak / black oak / scarlet oak	966	1.59	3.28	4.38	0.576	1.149	1.518	1.59	3.28	4.38	0.576	1.149	1.518
		520 Mixed upland hardwoods	910	5.09	9.62	11.14	2.139	3.916	4.142	5.09	9.45	10.69	2.144	4.086	4.298
		601 Swamp chestnut oak / cherrybark oak	111	3.87	8.42	10.97	0.705	2.447	3.296	3.87	8.42	10.97	0.705	2.447	3.296
		701 Black ash / American elm / red maple	2,123	5.26	10.63	12.87	2.346	4.901	5.803	5.25	10.54	12.65	2.352	4.823	5.254
		703 Cottonwood	168	4.87	10.19	12.30	2.284	4.848	5.464	4.87	10.19	12.30	2.284	4.848	5.464
		704 Willow	83	5.11	10.84	13.88	2.336	5.716	10.537	5.07	9.99	11.77	2.401	5.183	5.896
		801 Sugar maple / beech / yellow birch	40	5.93	11.41	13.36	2.416	4.719	5.006	5.93	11.38	13.26	2.416	4.711	4.921
		802 Black cherry	764	6.41	12.34	14.25	2.076	4.136	4.345	6.41	12.29	14.14	2.077	4.166	4.386
		803 Cherry / ash / yellow -poplar	607	2.68	5.59	7.34	1.322	3.743	4.713	2.68	5.59	7.34	1.322	3.743	4.713
		805 Hard maple / basswood	2,209	3.79	7.76	10.21	1.902	5.506	9.911	3.78	7.48	9.31	1.910	5.216	6.412
		901 Aspen	6,180	3.74	11.12	15.66	1.890	9.008	13.838	3.46	6.89	8.67	1.954	6.910	9.727
		902 Paper birch	1,209	3.35	10.16	14.00	1.599	10.310	14.402	3.10	6.47	8.01	1.667	8.877	11.195
		904 Balsam poplar	477	4.55	13.92	19.82	2.179	11.491	16.519	4.21	8.63	11.21	2.264	9.959	13.525
		999 Non stocked	432	3.61	13.18	19.70	1.785	11.919	18.411	3.25	6.84	8.48	1.889	9.423	11.587
		North central Average		3.83	9.99	13.57	1.902	7.169	9.970	3.63	7.45	9.31	1.939	6.263	7.820
Southeast (5 states: FL, GA, NC, SC, VA)		103 Eastern white pine	165	2.82	5.55	6.66	1.348	2.481	2.786	2.82	5.55	6.66	1.348	2.481	2.786
		104 White pine / hemlock	50	2.56	4.62	5.23	0.689	1.431	1.799	2.56	4.62	5.23	0.689	1.431	1.799
		105 Eastern hemlock	12	3.55	6.48	7.85	1.465	3.030	2.657	3.55	6.48	7.85	1.465	3.030	2.657

Appendix D (B): (continued) [5 of 12]

Appendix D (D): (Continued) [5 of 12]

Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Normal approach															
	141 Longleaf pine	977	3.25	8.92	12.97	1.501	4.347	5.869	3.25	8.75	12.68	1.501	4.062	5.464	
	142 Slash pine	4,077	4.24	11.52	16.78	1.756	4.749	6.713	4.22	10.96	15.57	1.747	4.524	6.107	
	161 Loblolly pine	9,242	3.08	6.79	9.05	2.334	7.436	10.574	3.07	6.59	8.72	2.307	6.579	8.319	
	162 Shortleaf pine	436	2.05	4.04	5.16	0.800	1.761	2.302	2.05	4.04	5.16	0.800	1.761	2.302	
	163 Virginia pine	842	2.03	3.90	4.92	0.721	1.506	1.970	2.03	3.90	4.92	0.721	1.506	1.970	
	164 Sand pine	278	2.45	7.05	11.42	1.313	4.856	6.164	2.43	6.97	11.23	1.232	4.745	6.024	
	165 Table-mountain pine	33	2.70	3.83	4.04	0.902	1.201	1.267	2.70	3.83	4.04	0.902	1.201	1.267	
	166 Pond pine	418	6.94	29.37	47.83	4.415	41.410	85.303	5.25	13.11	16.90	2.306	8.522	10.601	
	167 Pitch pine	57	3.11	5.63	6.42	1.012	2.400	3.018	3.11	5.63	6.42	1.012	2.400	3.018	
	181 Eastern redcedar	65	2.29	3.98	4.77	0.817	1.452	2.073	2.29	3.98	4.77	0.817	1.452	2.073	
	401 White pine / red oak / white ash	237	2.97	5.42	6.43	1.283	2.563	2.960	2.97	5.43	6.43	1.283	2.562	2.958	
	402 Eastern redcedar / hardwood	89	2.27	3.98	4.92	0.766	1.752	2.252	2.27	3.98	4.92	0.766	1.753	2.252	
	403 Longleaf pine / oak	231	2.67	7.44	11.15	1.441	3.455	4.865	2.67	7.37	10.93	1.441	3.376	4.548	
	404 Shortleaf pine / oak	425	2.06	3.93	4.98	0.809	1.724	2.300	2.06	3.93	4.98	0.809	1.724	2.299	
	405 Virginia pine / southern red oak	530	2.34	4.22	5.20	0.850	1.548	1.950	2.34	4.22	5.20	0.850	1.548	1.950	
	406 Loblolly pine / hardwood	2,760	3.04	7.04	9.77	2.369	10.982	20.327	2.97	6.45	8.60	2.153	5.702	7.204	
	407 Slash pine / hardwood	444	3.85	9.98	14.67	1.775	4.105	6.066	3.84	9.52	13.51	1.769	3.904	5.362	
	409 Other pine / hardwood	369	3.35	8.08	11.13	2.093	14.514	28.250	3.25	6.75	8.76	1.549	3.487	5.040	
	501 Post oak / blackjack oak	184	2.20	4.18	5.42	0.797	1.658	2.084	2.20	4.18	5.42	0.797	1.658	2.083	
	502 Chestnut oak	897	2.86	5.01	5.80	1.516	2.675	3.034	2.86	5.01	5.81	1.516	2.675	3.033	
	503 White oak / red oak / hickory	2,686	2.51	4.61	5.65	1.225	2.257	2.756	2.51	4.61	5.65	1.224	2.248	2.739	
	504 White oak	145	2.24	4.21	5.28	0.648	1.604	2.487	2.24	4.21	5.28	0.648	1.604	2.487	
	505 Northern red oak	46	3.88	6.77	7.60	3.716	6.019	6.286	3.88	6.77	7.60	3.716	6.019	6.286	
	506 Yellow-poplar / white oak / red oak	1,835	2.66	5.02	6.07	1.578	4.506	5.533	2.66	5.02	6.07	1.578	4.505	5.533	
	508 Sweetgum / yellow -poplar	2,165	2.59	5.56	7.27	2.090	6.517	8.295	2.59	5.44	7.10	2.088	6.260	7.962	

Appendix D (B): (continued) [6 of 12]

Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Normal approach															
	514 Southern scrub oak	523	2.59	7.45	11.53	1.049	3.755	5.256	2.59	7.37	11.38	1.049	3.635	4.990	
	520 Mixed upland hardwoods	1,893	3.04	6.31	8.08	1.940	5.674	7.463	3.04	6.27	7.99	1.941	5.617	7.254	
	601 Swamp chestnut oak / cherrybark oak	106	5.13	10.97	13.76	3.892	14.994	18.596	5.13	10.97	13.75	3.892	14.994	18.596	
	602 Sweetgum / Nuttall oak / willow oak	1,910	4.57	10.81	14.79	2.645	11.419	20.466	4.51	10.20	13.58	2.497	6.981	8.840	
	605 Overcup oak / water hickory	44	5.59	13.36	20.02	1.400	2.901	6.737	5.59	12.62	18.93	1.400	2.813	6.452	
	606 Atlantic white -cedar	14	4.58	11.42	14.87	2.663	6.937	7.998	4.58	10.16	13.32	2.663	6.215	7.565	
	607 Baldcypress / water tupelo	660	5.42	13.84	19.33	2.880	13.413	24.623	5.29	12.43	16.44	2.680	7.735	9.865	
	608 Sweetbay / swamp tupelo / red maple	2,064	4.56	13.32	20.07	3.206	19.768	38.395	4.24	10.02	13.43	2.663	7.817	9.817	
	702 River birch / sycamore	200	2.45	4.67	5.90	1.310	2.806	3.784	2.45	4.65	5.88	1.310	2.752	3.733	
	703 Cottonwood	6	4.79	15.12	25.37	0.205	3.425	9.397	4.79	14.36	23.94	0.205	2.736	8.111	
	704 Willow	86	2.35	4.94	6.51	3.271	15.262	19.198	2.35	4.93	6.50	3.271	15.263	19.201	
	705 Sycamore / pecan / American elm	112	2.57	6.16	9.11	1.120	3.908	6.769	2.57	6.08	8.96	1.120	3.787	6.516	
	706 Sugarberry / hackberry / elm / green ash	339	3.43	8.16	11.85	1.925	5.062	8.044	3.42	7.83	11.18	1.928	4.857	7.472	
	801 Sugar maple / beech / yellow birch	136	5.06	8.79	9.83	3.694	5.883	6.016	5.06	8.79	9.83	3.694	5.883	6.016	
	999 Non stocked	125	4.56	12.43	16.71	7.957	30.089	38.679	3.12	7.06	9.58	2.507	7.507	9.641	
	Southeast Average		3.29	7.81	10.80	2.030	7.403	11.864	3.24	7.19	9.60	1.919	5.234	6.686	
South central (8 states: AL, AR, KY, LA, MS, OK, TN, TX)	103 Eastern white pine	70	3.04	5.59	7.13	1.122	2.853	3.224	3.04	5.59	7.13	1.122	2.853	3.224	
	104 White pine / hemlock	27	3.32	6.83	7.61	0.548	2.197	2.348	3.32	6.83	7.61	0.548	2.197	2.348	
	105 Eastern hemlock	39	5.04	8.93	10.16	1.726	3.135	3.438	5.04	8.93	10.16	1.726	3.135	3.438	
	141 Longleaf pine	670	2.68	6.36	9.44	0.800	2.409	4.046	2.67	6.24	9.18	0.801	2.387	3.975	
	142 Slash pine	1,045	3.00	7.55	11.56	1.329	3.968	5.846	2.90	7.15	10.93	0.881	3.080	5.315	
	161 Loblolly pine	11,906	2.57	5.80	8.66	0.777	1.957	3.418	2.57	5.78	8.62	0.777	1.948	3.392	
	162 Shortleaf pine	1,780	1.96	4.30	5.78	0.785	1.650	3.041	1.96	4.29	5.76	0.783	1.643	3.020	
	163 Virginia pine	926	2.50	4.65	5.73	0.859	1.723	2.314	2.50	4.65	5.73	0.859	1.723	2.314	

Appendix D (B): (continued) [7 of 12]

Appendix D (B): (Continued) [7 of 12]

Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Normal approach															
	165 Table-mountain pine	19	4.18	7.46	8.85	1.422	3.980	5.167	4.18	7.46	8.85	1.422	3.980	5.167	
	167 Pitch pine	51	3.70	6.95	7.30	0.001	2.647	3.144	3.70	6.95	7.30	0.001	2.647	3.144	
	168 Spruce pine	9	2.10	5.57	8.93	0.426	1.439	2.230	2.09	5.56	8.92	0.422	1.426	2.203	
	181 Eastern redcedar	901	2.64	5.38	6.84	0.880	1.820	2.671	2.64	5.38	6.84	0.880	1.820	2.671	
	401 White pine / red oak / white ash	78	3.58	6.71	7.90	1.149	2.821	3.190	3.58	6.71	7.90	1.149	2.821	3.190	
	402 Eastern redcedar / hardwood	1,662	2.66	5.11	6.35	0.868	1.590	2.242	2.66	5.11	6.35	0.868	1.590	2.242	
	403 Longleaf pine / oak	236	2.62	6.38	9.35	0.892	2.649	3.869	2.60	6.15	8.82	0.899	2.572	3.486	
	404 Shortleaf pine / oak	1,696	2.04	4.44	5.96	0.785	1.593	2.843	2.04	4.43	5.96	0.784	1.578	2.818	
	405 Virginia pine / southern red oak	727	2.78	4.98	5.93	1.013	1.800	2.225	2.78	4.98	5.93	1.013	1.800	2.225	
	406 Loblolly pine / hardwood	5,485	2.56	5.81	8.66	0.714	1.827	3.165	2.56	5.79	8.63	0.714	1.821	3.150	
	407 Slash pine / hardwood	432	3.10	7.87	11.74	1.854	4.819	5.985	2.84	6.99	10.40	0.824	2.383	4.345	
	409 Other pine / hardwood	265	2.94	6.26	8.29	1.085	2.372	2.957	2.94	6.25	8.26	1.085	2.372	2.953	
	501 Post oak / blackjack oak	1,908	2.17	4.77	6.20	0.788	1.548	2.465	2.17	4.77	6.20	0.788	1.547	2.460	
	502 Chestnut oak	1,111	2.80	5.19	6.38	1.025	2.325	2.671	2.80	5.19	6.38	1.025	2.325	2.671	
	503 White oak / red oak / hickory	10,759	2.49	5.29	7.36	0.856	1.893	3.146	2.49	5.28	7.34	0.856	1.887	3.129	
	504 White oak	660	2.43	4.62	5.80	0.854	1.285	1.809	2.43	4.62	5.80	0.854	1.285	1.809	
	505 Northern red oak	30	2.70	4.65	5.27	0.562	1.120	1.257	2.70	4.65	5.27	0.562	1.120	1.257	
	506 Yellow-poplar / white oak / red oak	1,579	2.89	5.37	6.85	1.098	2.184	2.644	2.89	5.37	6.85	1.098	2.184	2.644	
	508 Sweetgum / yellow -poplar	2,034	2.64	5.52	7.57	0.943	2.197	3.401	2.64	5.52	7.57	0.943	2.193	3.393	
	512 Black walnut	16	2.78	4.42	4.88	0.192	0.477	0.644	2.78	4.42	4.88	0.192	0.477	0.644	
	514 Southern scrub oak	193	1.93	4.88	6.39	0.851	2.569	3.843	1.93	4.88	6.39	0.851	2.569	3.842	
	520 Mixed upland hardwoods	7,440	2.84	5.50	7.11	0.921	1.734	2.440	2.84	5.50	7.11	0.921	1.733	2.436	
	601 Swamp chestnut oak / cherrybark oak	260	2.82	6.37	8.94	0.664	1.457	2.316	2.82	6.37	8.94	0.664	1.457	2.315	
	602 Sweetgum / Nuttall oak / willow oak	3,055	3.08	6.90	9.79	0.769	2.015	3.076	3.08	6.88	9.74	0.766	2.004	3.043	
	605 Overcup oak / water hickory	432	3.46	7.56	10.62	0.743	2.413	4.649	3.46	7.56	10.61	0.743	2.408	4.621	

Appendix D (B): (continued) [8 of 12]

			Include all soil orders						Exclude <i>Histosols</i>						
Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
				Normal approach											
		607 Baldcypress / water tupelo	837	5.03	13.32	19.84	4.042	12.068	19.208	5.02	13.23	19.62	4.040	12.077	19.230
		608 Sweetbay / swamp tupelo / red maple	957	2.94	7.07	10.56	1.233	3.443	5.580	2.93	6.95	10.26	1.233	3.391	5.418
		701 Black ash / American elm / red maple	152	3.84	7.05	8.54	1.140	1.746	2.464	3.84	7.05	8.54	1.140	1.746	2.464
		702 River birch / sycamore	368	3.20	6.33	8.12	0.784	1.480	2.087	3.20	6.33	8.12	0.784	1.480	2.087
		703 Cottonwood	166	3.15	7.40	9.92	0.416	1.895	2.667	3.15	7.40	9.92	0.416	1.895	2.667
		704 Willow	467	3.02	7.64	10.43	0.825	3.099	4.494	3.02	7.61	10.38	0.825	3.098	4.465
		705 Sycamore / pecan / American elm	509	3.06	6.81	9.29	0.798	1.925	2.874	3.06	6.81	9.29	0.798	1.925	2.874
		706 Sugarberry / hackberry / elm / green ash	2,031	3.49	7.36	10.25	1.140	3.917	7.416	3.49	7.35	10.23	1.140	3.917	7.408
		801 Sugar maple / beech / yellow birch	347	4.15	7.19	8.26	1.687	2.919	3.178	4.15	7.19	8.26	1.687	2.919	3.178
		802 Black cherry	28	3.87	6.83	8.66	1.022	2.113	3.351	3.87	6.83	8.66	1.022	2.113	3.351
		809 Red maple / upland	9	3.50	6.85	8.77	0.577	1.668	2.891	3.50	6.85	8.77	0.577	1.668	2.891
		999 Non stocked	579	3.10	6.90	9.13	2.079	5.372	6.260	2.79	6.13	8.34	0.840	2.320	4.196
		South central Average		2.71	5.82	8.11	0.925	2.202	3.494	2.70	5.78	8.05	0.899	2.138	3.438
Great Plains (4 states: ND, SD, NE,KS)		181 Eastern redcedar	131	4.17	9.74	12.43	1.417	3.993	4.768	4.17	9.74	12.43	1.417	3.993	4.768
		182 Rocky Mountain juniper	75	2.26	4.92	5.33	1.053	1.653	1.571	2.26	4.91	5.31	1.053	1.655	1.580
		221 Ponderosa pine	733	3.40	6.95	7.79	0.754	1.468	1.556	3.40	6.94	7.76	0.754	1.471	1.552
		402 Eastern redcedar / hardwood	90	4.18	9.22	11.32	1.420	3.349	3.595	4.18	9.22	11.32	1.420	3.349	3.595
		501 Post oak / blackjack oak	64	2.87	7.03	9.13	1.314	3.125	4.725	2.87	7.03	9.13	1.314	3.125	4.725
		503 White oak / red oak / hickory	288	4.88	11.19	13.91	1.152	3.215	4.318	4.88	11.19	13.91	1.152	3.215	4.319
		509 Bur oak	329	5.23	11.08	13.28	2.227	4.332	5.320	5.23	11.08	13.28	2.227	4.332	5.320
		701 Black ash / American elm / red maple	553	4.54	11.63	14.85	2.067	6.029	6.934	4.54	11.63	14.85	2.067	6.029	6.934
		703 Cottonwood	192	4.31	10.30	13.42	2.060	5.753	7.223	4.31	10.30	13.42	2.060	5.753	7.223
		704 Willow	46	4.68	10.43	13.18	0.894	1.476	2.179	4.68	10.43	13.18	0.894	1.476	2.179
		805 Hard maple / basswood	220	4.71	10.81	14.38	1.000	3.086	4.814	4.71	10.81	14.38	1.000	3.086	4.814

Appendix D (B): (continued) [9 of 12]

Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Normal approach															
		807 Elm / ash / locust	610	5.25	11.95	14.79	1.764	4.066	5.115	5.25	11.95	14.79	1.764	4.066	5.116
		999 Non stocked	136	3.85	8.31	10.38	2.040	4.060	4.629	3.85	8.28	10.35	2.043	4.066	4.633
		Great Plains Average		4.39	9.98	12.32	1.513	3.690	4.509	4.39	9.97	12.31	1.513	3.691	4.509
Pacific NW (2 states: WA, OR)		201 Douglas-fir	6,090	6.49	13.24	15.07	2.690	5.630	6.568	6.49	13.23	15.03	2.689	5.622	6.556
		202 Port -Orford-cedar	13	9.72	22.33	24.85	3.978	10.130	10.883	9.66	21.88	24.11	3.978	10.116	10.762
		221 Ponderosa pine	1,558	2.95	6.46	7.44	0.887	2.041	2.380	2.95	6.46	7.44	0.887	2.040	2.379
		264 Pacific silver fir	571	5.70	9.79	10.74	1.225	1.913	2.056	5.70	9.79	10.74	1.225	1.913	2.056
		270 Mountain hemlock	17	4.08	7.73	8.69	1.999	2.402	2.318	4.08	7.73	8.69	1.999	2.402	2.318
		281 Lodgepole pine	1,082	2.45	5.88	7.29	1.976	3.381	3.396	2.45	5.88	7.29	1.976	3.381	3.399
		301 Western hemlock	2,738	8.72	17.36	19.04	3.265	7.438	8.132	8.71	17.26	18.86	3.273	7.456	8.123
		304 Western redcedar	874	6.82	13.79	15.68	1.931	4.374	5.334	6.82	13.79	15.67	1.931	4.374	5.350
		305 Sitka spruce	441	10.42	23.12	25.55	2.882	8.038	8.504	10.37	22.79	25.01	2.891	8.070	8.493
		709 Cottonwood / willow	44	6.11	11.40	13.18	2.055	4.131	5.476	6.11	11.19	12.91	2.055	4.304	5.653
		911 Red alder	1,347	7.48	15.84	17.84	2.993	6.631	7.380	7.47	15.79	17.74	2.991	6.628	7.367
		922 California black oak	43	4.94	10.41	12.13	1.321	2.961	3.387	4.94	10.41	12.13	1.321	2.961	3.387
		Canyon live oak / interior live													
		932 oak	21	3.60	7.19	8.50	0.061	0.064	0.209	3.60	7.19	8.50	0.061	0.064	0.209
		951 Pacific madrone	155	3.94	8.16	9.51	0.596	2.069	2.663	3.94	8.16	9.51	0.596	2.069	2.663
	999 Non stocked	149	6.76	14.16	16.12	3.315	7.154	8.198	6.74	14.06	15.94	3.319	7.028	7.963	
		Pacific Northwest Average		6.40	13.12	14.80	2.467	5.333	6.035	6.40	13.08	14.72	2.468	5.333	6.026
Pacific SW (1 state: CA)		201 Douglas-fir	399	3.60	6.12	6.81	1.049	2.007	2.345	3.41	5.78	6.46	1.049	1.733	2.040
		221 Ponderosa pine	293	3.87	7.23	8.52	1.772	3.240	3.892	3.87	7.23	8.52	1.774	3.251	3.907
		Jeffrey pine / Coulter pine /													
		223 bigcone Douglas-fir	1,417	2.41	4.52	4.87	1.142	2.388	2.656	2.41	4.52	4.87	1.142	2.389	2.656
		224 Sugar pine	1,743	4.18	7.36	8.26	1.893	3.493	3.915	4.18	7.36	8.26	1.895	3.498	3.920

Appendix D (B): (continued) [10 of 12]

			Include all soil orders						Exclude <i>Histosols</i>						
Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Normal approach															
	262 Red fir		371	5.76	9.66	10.25	2.458	3.646	3.396	5.76	9.66	10.25	2.458	3.645	3.395
	281 Lodgepole pine		373	2.74	5.33	6.17	1.697	2.897	3.537	2.67	5.18	6.02	1.772	3.094	3.732
	305 Sitka spruce		63	7.56	15.22	16.57	1.740	7.486	8.704	7.56	15.22	16.57	1.740	7.486	8.704
	341 Redwood		558	4.47	7.81	8.75	1.447	3.966	4.493	4.24	7.39	8.32	1.554	3.993	4.473
	361 Knobcone pine		27	4.28	7.59	8.98	2.117	3.908	5.025	3.95	6.98	8.38	2.071	3.638	4.781
	709 Cottonwood / willow		1,994	4.82	12.67	16.87	0.224	5.395	8.962	4.79	12.53	16.65	0.200	5.255	8.739
	911 Red alder		50	6.04	12.05	13.44	2.407	5.373	5.683	5.37	10.83	12.21	2.874	6.129	6.407
	922 California black oak		317	3.51	6.17	6.94	1.680	3.191	3.736	3.49	6.15	6.92	1.680	3.180	3.724
	Canyon live oak / interior live														
	932 oak		255	3.19	5.46	5.95	1.680	2.914	3.141	3.18	5.44	5.93	1.691	2.936	3.169
	951 Pacific madrone		116	3.64	6.28	7.04	1.047	2.572	3.130	3.59	6.18	6.94	1.049	2.517	3.071
	Pacific Southwest Average			3.98	8.13	9.73	1.257	3.702	4.882	3.94	8.03	9.61	1.265	3.669	4.823
Rocky Mts North	201 Douglas-fir		13,546	2.99	5.77	6.75	1.313	3.007	3.762	2.99	5.77	6.75	1.313	3.006	3.759
(2 states: MT, ID)	221 Ponderosa pine		16,335	2.52	5.02	5.93	0.916	2.146	2.710	2.52	5.02	5.92	0.916	2.146	2.710
	241 Western white pine		56	2.20	5.31	6.20	1.190	2.759	3.728	2.18	4.79	5.67	1.227	3.374	4.301
	265 Engelmann spruce		733	2.44	4.64	5.34	1.223	2.509	2.924	2.44	4.65	5.36	1.220	2.498	2.908
	266 Engelmann spruce / subalpine fir		2,906	2.13	4.08	4.75	1.187	2.695	3.459	2.13	4.09	4.76	1.185	2.686	3.446
	270 Mountain hemlock		66	2.63	5.11	5.88	1.764	4.342	5.518	2.64	5.14	5.92	1.761	4.331	5.500
	281 Lodgepole pine		5,176	2.61	5.07	6.00	1.086	2.184	2.745	2.61	5.07	6.00	1.083	2.179	2.738
	301 Western hemlock		158	2.61	5.03	5.74	0.839	1.530	1.878	2.60	4.97	5.69	0.844	1.629	1.972
	304 Western redcedar		772	3.24	6.64	7.82	1.450	4.349	5.371	3.24	6.65	7.83	1.449	4.348	5.369
	366 Limber pine		1,054	2.60	4.95	5.72	1.214	2.503	3.050	2.60	4.95	5.72	1.214	2.504	3.051
	367 Whitebark pine		918	2.18	3.97	4.59	1.282	2.333	2.887	2.19	3.99	4.62	1.278	2.318	2.865
	709 Cottonwood / willow		3,721	2.58	5.41	6.65	0.853	1.952	2.545	2.57	5.40	6.64	0.854	1.953	2.545
	901 Aspen		5,059	2.83	5.90	6.95	1.529	3.506	4.221	2.83	5.88	6.92	1.532	3.516	4.232

Appendix D (B): (continued) [11 of 12]

			Include all soil orders						Exclude <i>Histosols</i>						
Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
Normal approach															
	902 Paper birch		56	2.50	4.88	5.66	1.002	2.053	2.659	2.50	4.88	5.66	1.002	2.053	2.659
	Rocky Mountains North Average			2.67	5.29	6.23	1.139	2.585	3.234	2.67	5.28	6.23	1.139	2.585	3.233
Rocky Mts South (6 states: WY, CO, NM, AZ, UT, NV)	182 Rocky Mountain juniper		12	3.12	6.18	6.93	1.725	4.326	5.084	3.12	6.18	6.93	1.725	4.326	5.084
	184 Juniper woodland		1,801	1.31	2.99	3.65	0.612	1.690	2.247	1.31	2.99	3.65	0.612	1.690	2.247
	185 Pinyon juniper woodland		7,047	1.35	2.92	3.48	0.734	1.879	2.353	1.35	2.92	3.49	0.733	1.880	2.353
	201 Douglas-fir		2,932	2.47	5.29	6.38	1.541	2.960	3.512	2.43	5.21	6.29	1.465	2.881	3.433
	221 Ponderosa pine		5,349	2.09	4.46	5.36	1.136	2.325	2.953	2.09	4.46	5.35	1.136	2.323	2.948
	223 Jeffrey p/ Coulter pine / Douglas-fir		25	2.22	4.23	4.45	0.360	1.358	1.386	2.22	4.23	4.45	0.360	1.358	1.386
	261 White fir		244	1.52	3.35	3.99	1.182	2.283	2.726	1.52	3.35	3.99	1.182	2.283	2.726
	265 Engelmann spruce		1,297	2.08	4.12	4.81	1.425	2.901	3.304	2.06	4.11	4.80	1.359	2.829	3.235
	266 Engelmann spruce / subalpine fir		1,240	2.39	4.95	5.84	1.979	3.673	4.167	2.35	4.91	5.79	1.902	3.599	4.093
	268 Subalpine fir		346	2.16	4.28	4.91	1.020	2.322	2.618	2.17	4.30	4.93	1.016	2.305	2.592
	269 Blue spruce		43	1.91	5.05	6.30	1.509	3.310	3.882	1.92	5.05	6.30	1.508	3.308	3.879
	281 Lodgepole pine		1,407	2.35	4.69	5.46	1.287	2.597	3.048	2.36	4.69	5.47	1.285	2.592	3.040
	365 Foxtail pine / bristlecone pine		104	2.09	4.08	4.89	0.925	1.833	2.243	2.09	4.08	4.89	0.924	1.829	2.238
	366 Limber pine		324	2.69	5.16	5.94	1.313	2.617	2.952	2.65	5.11	5.89	1.240	2.559	2.908
	367 Whitebark pine		210	1.49	2.83	3.22	0.997	2.184	2.406	1.49	2.85	3.26	0.995	2.171	2.384
	368 Misc. western softwoods		57	1.53	2.96	3.28	0.707	1.633	1.810	1.53	2.96	3.28	0.707	1.633	1.810
	509 Bur oak		9	3.11	3.85	3.97	0.000	0.000	0.000	3.11	3.85	3.97	0.000	0.000	0.000
	703 Cottonwood		23	1.13	2.89	3.70	0.605	1.640	2.109	1.13	2.89	3.70	0.605	1.639	2.108
	709 Cottonwood / willow		102	1.92	5.13	7.16	0.908	2.196	3.324	1.92	5.10	7.07	0.916	2.205	3.176
901 Aspen		3,222	3.19	6.56	7.67	2.120	4.327	4.820	3.11	6.45	7.54	2.048	4.281	4.786	
902 Paper birch		4	3.11	3.85	3.97	0.000	0.000	0.000	3.11	3.85	3.97	0.000	0.000	0.000	
925 Deciduous oak woodland		615	2.03	4.54	5.44	1.409	2.979	3.570	2.03	4.55	5.44	1.409	2.978	3.569	

Appendix D (B): (continued) [12 of 12]

Geographic region	FIADB code Δ	Forest Type ‡	Area* (ha x 1000)	Include all soil orders						Exclude <i>Histosols</i>					
				SOC, kg C m ⁻²			StDev			SOC, kg C m ⁻²			StDev		
				25 cm	100cm	Total†	25 cm	100cm	Total†	25 cm	100cm	Total†	25cm	100cm	Total†
				<i>Normal approach</i>											
	952 Mesquite woodland	625	1.03	2.66	3.61	0.564	1.662	2.221	1.03	2.66	3.61	0.564	1.662	2.221	
	954 Intermountain maple woodland	20	1.91	4.00	4.72	1.078	2.473	2.861	1.92	4.00	4.73	1.076	2.464	2.847	
	955 Misc. western hardwood woodlands	79	0.80	2.07	2.84	0.866	1.932	2.388	0.80	2.07	2.84	0.866	1.932	2.388	
	999 Non stocked	981	1.48	3.17	3.74	1.031	2.242	2.605	1.48	3.17	3.74	1.031	2.240	2.602	
	Rocky Mountains South Average		1.99	4.22	5.02	1.200	2.562	3.073	1.98	4.19	5.00	1.176	2.540	3.051	

* Area summarized from the FIADB *Plot* table

\ddagger Forest type assigned by FIA approved algorithm

† Indicates depth to 2 m or bedrock

Δ three digit FIADB code for forest type

VITA

Beyhan Amichev was born in 1976 in Bulgaria (the town of Devin) to a family of high school teachers, Yousmen and Gulfye Amishev. He graduated from an accredited Mathematics High School in 1994 with specialization in Mathematics and English language. In the Fall of that year he started his higher level of education at the University of Forestry in Sofia, Bulgaria. In his fourth year of university, late 1997 (one year before graduation) Beyhan Amichev won the *Green Card* lottery that granted him a permanent resident status of the United States. In May 1998 he immigrated to the United States.

In the Fall of 2000, after being in the U.S. for over two years Beyhan transferred his Bulgarian university transcripts towards the degree of Bachelor of Science in Forestry to Virginia Tech. Beyhan obtained his bachelor's degree in May 2001 from the Forestry department at Virginia Tech. In the Fall of that year he enrolled as a graduate student working towards the degree of Master of Science in Forestry.

Beyhan is a national member of the Society of American Foresters (SAF) and the American Society for Photogrammetry and Remote Sensing (ASPRS), Virginia Tech chapter, where he holds the treasurer position.