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Using forest health monitoring data to integrate above and below ground carbon information

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"Capsule": *Field monitoring techniques for national scale characterization of forest carbon budgets have demonstrated the ability to detect a 20% change in total soil carbon and carbon content over 10 years.*

Abstract

The national Forest Health Monitoring (FHM) program conducted a remeasurement study in 1999 to evaluate the usefulness and feasibility of collecting data needed for investigating carbon budgets in forests. This study indicated that FHM data are adequate for detecting a 20% change over 10 years (2% change per year) in percent total carbon and carbon content (MgC/ha) when sampling by horizon, with greater than 80% probability that a change in carbon content will be determined when a change has truly occurred ($P \leqslant 0.33$). The data were also useful in producing estimates of forest floor and soil carbon stocks by depth that were somewhat lower than literature values used for comparison. The scale at which the data were collected lends itself to producing standing stock estimates needed for carbon budget development and carbon cycle modeling. The availability of site-specific forest mensuration data enables the exploration of above ground and below ground linkages.

Keywords: Carbon sequestration; Soils; Biomass; Carbon content; Modeling

1. Introduction

A national Forest Health Monitoring (FHM) program was initialed in 1990 to evaluate status and trends in the ecological condition of the nation's forests (Palmer et al., 1991; Stolte, 1997). Over the intervening years, several thousand plots have been established on a statistically based grid network across the United States (more information about the FHM program is available on the FHM web site: www.na.fs.fed.us/spfo/fhm). Due to recent interest in the potential of forests to sequester atmospheric carbon dioxide that is contributing to global climate changes (Huntington, 1995; Mcfee and Kelly, 1995; Birdscy, 1996; Lal et al., 1998), the FHM program was viewed as a potential data source for monitoring changes in above ground and below ground forest carbon.

The purpose of this study was to investigate using FHM data to detect changes over time in the amounts of carbon in soil and above ground standing biomass. These data were used along with published carbon sequestration models to compare predicted changes in carbon with measured changes (Birdsey, 1996). The soils indicator data and protocols used in this study have been modified and are part of the USDA Forest Service enhanced Forest Inventory and Analysis (FIA) Phase 3 program (US Department of Agriculture, Forest Service, 2001), but will be referred to in this paper as FHM data.

The objectives of the study addressed in this paper were to:

1. Determine if FHM data can be used to detect changes in carbon amounts in soil over time, and
2. Determine if FHM data can be used with carbon sequestration models to provide meaningful results.

For objective 1, the specific change targeted for evaluation was a 2% change per year over 5 years, or a 20% change over 10 years. The current FHM/FIA field sampling design divides the total number of ground plots into five rotating panels such that each panel contains

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one-fifth of the plots; each plot is visited every fifth year. For soils, a sampling scheme is being considered in which soils are measured once every other visit to plots, making the time between soil measurements on each plot 10 years.

The second objective was to test the usefulness of data gathered by foresters with the FHM program for producing carbon storage estimates necessary to conduct carbon sequestration assessments. One of the greatest difficulties in producing such estimates is the scarcity of consistently collected and analyzed soil and forest floor carbon data. The current enhanced FIA program is designed to collect nationally comparable soils and forest floor data as well as above ground biomass data.

2. Materials and methods

This study used FHM plots that were part of two earlier FHM studies in which soils had been sampled and analyzed from the FHM monitoring grid: the FHM 1991 Georgia Indicator Evaluation and Field Study (Alexander et al., 1993) and the FHM Southeast Loblolly/Shortleaf Pine Demonstration Project (SEDEMO) conducted in 1992 and 1993 (Lewis and Conkling, 1994; Hudson and Van Remortel, internal draft). Both above ground standing biomass (FHM mensuration indicator) and soil physical and chemical measurements (FHM soils indicator) were made on the Georgia Study and SEDEMO study plots. Remeasurement of those plots for the same variables provided the data needed to determine temporal changes in carbon content.

2.1. Site description

The FHM monitoring design divides the landscape into areas of approximately 40 km’ using a hexagon grid. Thirty hexagons in Georgia, each with one plot, were selected for remeasurement because they had been part of the studies conducted in 1991 1993 (Fig. 1).

Each 1 -ha plot had four fixed area subplots (r = 7.32 m) such that the centers of subplots 2, 3, and 4 were located 36.6 m from the center of subplot 1 at azimuths of 360 . 120 . and 240 , respectively. The soil types for the temporal carbon change evaluation were mostly ultisols, with one spodosol and one alfisol (Table 1).

2.2. Field sampling and laboratory analysis

Two sets of soil samples were collected from each plot. One set. for the temporal carbon change evaluation, was collected midway between the subplot centers along the azimuths listed above (USDA Forest Service, 1999). Samples for chemical analysis and bulk density were collected from each master horizon to a depth of 1 m if possible (horizon samples). The second set of Samples was collected approximately 18 m from each sampling site described above. at a prescribed distance from the subplot center (USDA Forest Service. 1999). These samples (depth samples) were collected by depth (O-5 cm. 5 10 cm, and 10 20 cm) using a known volume corer, and were used for both the chemical and bulk density analyses. All bulk density samples were collected using a known volume corer method (Blake and Hartge, 1986).

Fig. 1. Hexagons in Georgia chosen for the remeasurement study

Above ground vegetation measurements for each plot included tree growth, regeneration, and age (USDA Forest Service, 1999). Mensuration measurements were taken if currently available plot data had been collected more than a year prior to this study.

Forest floor material was sampled on an area basis (7.07×10^{-2} m^2) to estimate forest floor mass and express the results as a weight per unit area. A single forest floor sample per plot was collected adjacent to the horizon soil samples (Conkling and Byers, 1992). One forest floor sample was also collected from each depth sample soil-sampling site (USDA Forest Service, 1999).

All soil samples were sent to the Soil Characterization Laboratory at the University of Missouri in Columbia, Missouri for analysis. Forest floor and mineral samples were stored in a freezer upon arrival at the laboratory until they could be processed. Moisture content was determined by oven drying overnight to 105 C. Roots and rock fragments greater than 2 mm were removed. Bulk density of the less than 2 mm fraction of the mineral soil was then calculated (Federer et al., 1993). Total carbon analysis was done by dry combustion using a LECO CR-12 Carbon analyzer.

Table 1
Plot characteristics

Forest group	Forest type	Stand age (years)	Soil type
Oak pine	Loblolly pine hardwood	9	Typic kandiudult
Planted slash pine	Slash pine	9	Aeric paleaquult
Planted loblolly pine	Loblolly pine	18	Grossarenic paleaquult
Natural Loblolly	Loblolly pine	41	Aquic paleudult
Oak pine	Slash pine hardwood	33	Arenic plinthaquic paleudult
Natural loblolly	Loblolly pine	66	Typic haplaquod
Natural loblolly	Loblolly pine	57	Grossarenic paleudult
Planted loblolly	Loblolly pine	16	Aquic arenic paleudult
Natural loblolly	Loblolly pine	67	Typic kandiudult
Planted loblolly	Loblolly pine	11	Rhodic kandiudult
Planted loblolly	Loblolly pine	4	Typic kandiudult
Oak gum cypress	Sweet bay swamp Tupelo red maple	23	Not characterized
Oak–hickory	Southern scrub oak	21	Aquic kandudult Aeric paleaquult
Planted loblolly	Loblolly pine	10	Aeric paleaquult
Planted loblolly	Loblolly pine	17	Vertic paleudalf
Oak pine	Loblolly pine hardwood	5	Arenic kandiudult
Shortleaf pine	Shortleaf pine	4	Typic kandiudult
Planted loblolly	Loblolly pine	9	Typic kandhapludult
Planted loblolly	Loblolly pine	21	Typic kandhapludult
Planted loblolly	Loblolly pine	12	Arenic plinthaquicudult
Planted loblolly	Loblolly pine	6	Grossarenic kandiudult Aeric kandhapludult
Planted loblolly	Loblolly pine	24	Typic kandhapludult
Planted loblolly	Loblolly pine	20	Typic kandhapludult
Planted loblolly	Loblolly pine	13	Typic kandhapludult
Oak pine	White oak red oak hickory	58	Typic paleudult Typic kandhapludult
Planted loblolly	Loblolly pine	16	Rhodic kandhapludult Typic rhodudult
Oak hickory	White oak red oak hickory	66	Typic kandhapludult
Natural loblolly	Loblolly pine	41	Kandhaplud[no order]
Natural loblolly	Loblolly pine	46	Fluvaquentic dystrochrept
Natural loblolly	Loblolly pine	19	Typic kandhapludult

2.3. Data analysis

To compare the bulk densities and carbon content (MTC/ha) measured in 1991–1993 (t_1) to those measured in 1999 (t_2), it was necessary to calculate one average bulk density and percent carbon for each master horizon on each plot. The t_1 samples were averaged prior to analysis using a weighting procedure to composite the soil (Byers et al., 1992). For t_2 samples, a comparable procedure was performed such that the weighted average was calculated after analysis. Master horizon thicknesses were calculated from the soil characterization data collected for each horizon sample profile. Since only one sample was collected for each master horizon in each profile, the master horizon thicknesses were calculated as the total of all diagnostic horizons in each profile horizon. The mean thicknesses for the plot were calculated similarly to the mean plot bulk densities. The forest floor sample is the litter sample along with any organic soil that may have been present. There were only seven plots that had values for the forest floor for both t_1 and t_2.

The first step in determining whether a 2% change in soil carbon per year can be detected using FHM data was to estimate the variance and correlation of the components of time and plot variability using the statistical procedure PROC MIXED (SAS, 1996).

The variance and correlation of percent total carbon with time were also estimated using PROC MIXED. A power analysis was performed for each master horizon and the forest floor for percent total carbon and carbon content. The power was estimated using 50 plots per year, the normal number of plots measured per year in Georgia. The power of the test is numerically 1 – Type II error. Since the Type II error is inferring there was no change when there really was a change, the power is the probability that a change will be detected when there truly is a change. This information along with the correlation coefficient is a good indication of whether or not a 2% change per year or 20% over 10 years can be detected, with a chosen confidence level in saying a change has really occurred (Steele et al., 1997).

For analyses done toward meeting the second objective, only data from the depth samples were used. The data were stratified by broad forest type (forest group) and lo-year age classes. The overall number of available plots was small, so the levels of data aggregation are coarse in scale.

The soil carbon by depth data and the accompanying forest floor data were combined with the forest mensuration data from the study plots and examined for possible predictive relationships between commonly measured above ground variables, such as stand age and basal area, and soil carbon concentration in the O-5 cm depth increment as well as soil carbon content in the O-5 cm and O-20 cm depths for the natural pine and planted pine plots only. Plot history was not taken into account for each of these analyses.

3. Results

3.1. Detection of changes in carbon over time

The variance and correlation of the components of time and plot variability, estimated using PROC MIXED (SAS, 1996) for percent total carbon, carbon content, bulk density, and horizon thickness are shown in Table 2. The intercept estimate is the estimate of the variable at t_1, which is set to 1991. The year estimate is the change in the variable per year. The estimates contain both measurement error and the within-plot variability. The Pr $>|t|$ is the probability that the estimated values are not due to random variability in the sample. With monitoring measurements, the probability of 0.33 used by FIA (Hansen et al., 1992) was considered to be a good starting point for circumstances that should be of interest or concern.

The power test results for percent total carbon and carbon content (MTC/ha) are shown in Tables 3 and 4. Results for $\alpha=0.33$ are presented as well as the results for $\alpha = 0.10$, a more restrictive threshold commonly used by FHM. The initial estimate is the mean percent total carbon or mean carbon content at t_1. The standard deviation is the variation in the measured values of the 29 plots visited at t_1 and t_2. The correlation coefficient from the PROC MIXED procedure is the correlation of the variance due to time over the variance due to time, spatial differences, and crew differences. The standard error is the standard error of the change in measured plot values, based on measuring 50 plots per year in Georgia. The numbcr of plots used in the model as measured over the 10 years includes 50 plots per year from the first 5 years plus the 50 plots remeasured in year 11 (a total of 300 plots). The change over 10 years is the 20% change that is desired to be detected.

In Table 3, at $P>0.33$, the power of the tests in all cases is greater than 0.80; there is a greater than 80% probability that the 20% change over 10 years will be detected when sampling by horizon. For example, for the A horizon data in Table 3, the percent total carbon at t_1 is 2.18; a 20 percent change either positive or negative would be 0.44. If 50 plots were measured per year (normal number for Georgia) for 11 years (10 years of change), the standard error of change calculated from the standard deviation and correlation coefficient would be 0.16. Since 0.44 is approximately three times larger than the standard error of 0.16, there is a power of 0.99 to detect a 20% change if a Type 1 error of 0.33 is accepted. The Type I error (α) is rejecting the null hypothesis of no change. All powers decreased at $\alpha = 0.10$ indicating as expected that the choice of significance level affects the usefulness of the measurement in detecting change.

Table 2
Percent total carbon (by weight) (forest floor represents the seven plots that had measurements from time I and time 2)

Horizon	Effect	Estimate	S.E.	d.f.	t	Pr > $\|t\|$
Forest Floor	Intercept	45.16	2.187	6	20.93	0.0001
	Year	-1.271	0.262	5	-4.X6	0.0046
A	Intercept	2.116	0.369	2x	5.X9	0.000 1
	Year	-0.05x	0.030	2x	-1.93	0.0644
E	Intercept	0.287	0.044	16	6.53	0.000 1
	Year	0.006	0.005	9	1.10	0.2989
B	Intercept	0.457	0.097	26	4.70	0.0001
	Year	-0.017	0.010	26	1.66	0.109 1
Total carbon content[a]						
Forest Floor	Intercept	12.12	5.00	6	2.54	0.0438
	Year	0.248	0.705	5	0.35	0.7399
A	Intercept	35.X3	4.32	2x	X.29	0.000 1
	Year	-1.484	0.605	26	-2.45	0.0212
E	Intercept	17.06	4.398	14	3.89	0.0016
	Year	-0.058	0.373	9	-0.16	0.8798
B	Intercept	3X.76	8.269	26	4.69	0.000 1
	Year	-1.007	1.350	21	-0.75	0.4641
Bulk density (g/cm^3) in mineral horizons						
A	Intercept	1.33	0.041	2x	32.34	0.0001
	Year	-0.010	0.005	26	-2.10	0.0459
E	Intercept	1.65	0.029	14	57.51	0.0001
	Year	-0.014	0.004	9	-3.19	0.0109
n	Intercept	1.56	0.042	26	37.11	0.0001
	Year	-0.028	0.006	21	-4.X2	0.0001
Thickness (cm) in master horizons						
A	Intercept	13.64	1.203	2X	11.34	0.0001
	Year	0.165	0.179	2x	0.92	0.3653
E	Intercept	30.48	6.167	16	4.51	0.0004
	Year	0.466	0.626	9	0.74	0.4753
B	Intercept	60.63	5.560	26	10.91	0.0001
	Year	0.711	0.581	26	1.23	0.2314

[a] Metric tons/h; forest floor represents the seven plots that had measurements from time I and time 2.

3.2. Use of data in carbon sequestration models—forest floor carbon

Fig. 2 shows the mean forest floor carbon content in Mg/ha, aggregated by forest group across all ages. Fig. 3

Table 3
Change detection results for percent total carbon (by weight), 20% change over 10 years measuring 50 plots per year over IO years

Master horizon	Initial estimate	S.D.	Correlation coefficient	No. of plots measured over IO years	20% change over 10 years	S.E. of change in plot values	Power (a-0.33)	Power (a = 0.10)
Forest floor[a]	45.76	6.23	0.6941	300	9.15	0.67	0.9999	0.9999
A	2.18	1.93	0.8317	300	0.44	0.16	0.9907	0.9320
E	0.29	0.42	0.9525	300	0.06	0.02	0.9963	0.9648
B	0.46	0.48	0.6837	300	0.09	0.05	0.9048	0.6753

[a] Based on only the seven plots that had percent total carbon measured at time 1 and 2.

Table 4
Change detection results carbon content (MTC/ha), 20% change over IO years measuring SO plots per year over IO years

Master horizon	Initial estimate	S.D.	Correlation coefficient	No. of plots measured over IO years	20% change over 10 years	S.E. of change in plot values	Power ($\alpha = 0.33$)	Power ($\alpha = 0.10$)
Forest floor[a]	12.72	12.23	0.4687	300	2.54	1.68	0.8574	0.5854
A	35.83	21.26	0.4625	300	7.17	2.94	0.9769	0.8714
E	17.09	16.44	0.8609	300	3.42	1.21	0.9914	0.9360
B	3X.76	38.54	0.2884	300	7.75	6.01	0.8019	0.4989

[a] Based on only the seven plots that had percent total carbon measured at time I and 2.

shows the minimum, maximum, and mean carbon concentrations of the forest floor across the four broad forest groups. Forest floor carbon stocks were also aggregated by age class, although the number of plots was small for some age classes. When presented in this manner, values ranged from a low of 2.59 Mg/ha in the 0–10 age class to a high of 16.03 Mg/ha in the 51–60 year age class (Fig. 4). For Fig. 4 as well as the following analyses, only plots containing pine (*Pinus spp.*) were used. In this data set, the younger age classes are well represented, resulting in a more reliable estimate of forest floor carbon, while the older age classes are poorly represented.

There is an excellent linear relationship between forest floor mass and carbon mass (Fig. 5) which may provide a more accurate way of estimating forest floor carbon than using a fixed carbon concentration for all forest floor material. When forest floor carbon content is plotted against stand age (Fig. 6), it appears there may be a linear relationship although it is not as strong in this case, mainly due to one plot with a very low forest floor mass and carbon content.

Forest floor carbon content was also plotted against total basal area (Fig. 7). A weak positive relationship existed (r = 0.26), but the lack of fit was driven primarily by five points that fell outside the range of the bulk of the data.

3.3. Soil carbon depth samples

As with the forest floor results, data were aggregated primarily at the level of broad forest group (Table 1) with the bulk of the plots falling on natural and plantation loblolly pine (*Pinus taeda*) forests, although three plots were located in oak-hickory and oak-pine groups, while shortleaf pine (*Pinus echinata*) and slash pine (*Pinus elliottii*) were represented by one plot each. Soil carbon concentrations ranged from a high of 3% (natural pine) to a low of 2.3% (oak-pine) in the 0–5 cm depth increment. Concentrations in the lower depth increments followed the same pattern (Fig. 8).

Bulk density values were lowest in the O-5 cm increment in the planted pine (0.94 g/cm') and natural pine (0.99 g/cm") groups and highest in the oak-hickory (1.29 g/cm") and oak-pine (1.36 g/cm") groups. The same pattern held for the 5–10 cm depth increment, but bulk densities were fairly similar in the 10–20 cm increment, ranging from 1.4 to 1.55 g/cm", with the lowest again in the planted pine plots. Soil carbon content was highest in the natural pine plots, 33 Mg C/ha, while the other types ranged between 28–29 Mg C/ha. Carbon content for each depth increment is given by forest type in Fig. 9, and by age class across forest types in Fig. 10.

4. Discussion

4.1. Detection of changes in carbon over time

This study was a preliminary look at detecting changes in carbon over time using data from a large-scale monitoring program. Sampling by horizon was done to utilize a baseline data set from the early 1990s. The results from the horizon data were promising for detecting a 2% change in carbon per year or a 20% change over 10 years. The challenge of collecting

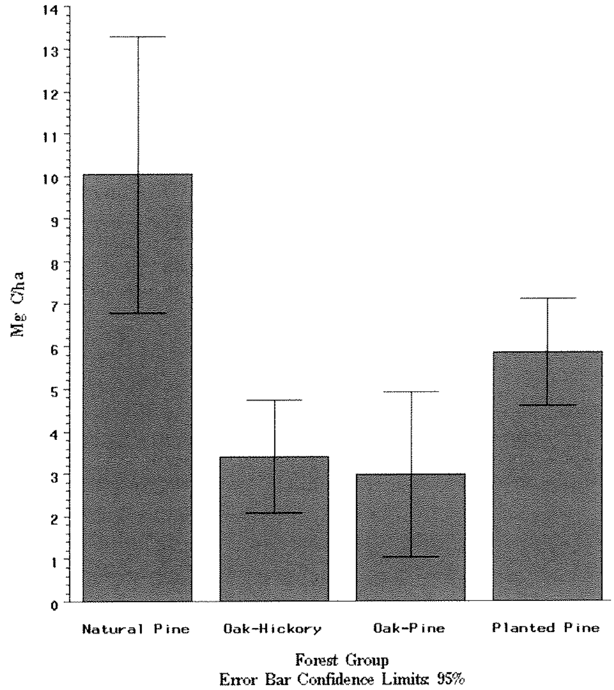

Fig. 2. Average carbon content of the forest floor by forest group

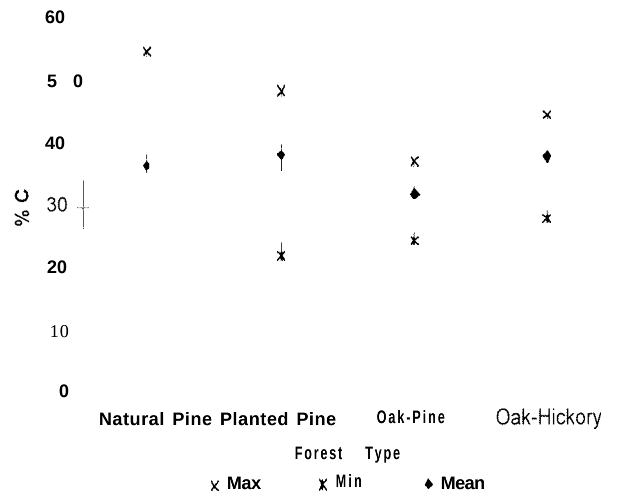

Fig. 3. Minimum, maximum, and mean C concentrations **of** forest floor material.

appropriate data in a cost-effective manner is, however, different for a monitoring program than for a controlled research study. Monitoring data must be aggregated to a regional scale, for example often resulting in combining soil types, landscape positions, and above-ground cover such as forest type. Additional analysis has been done to begin evaluating whether or not depth samples, which are more adaptable to a monitoring program, will yield similar results (Palmer et al., in review). Although detecting changes in soil carbon is important from a below ground standpoint, part of the application

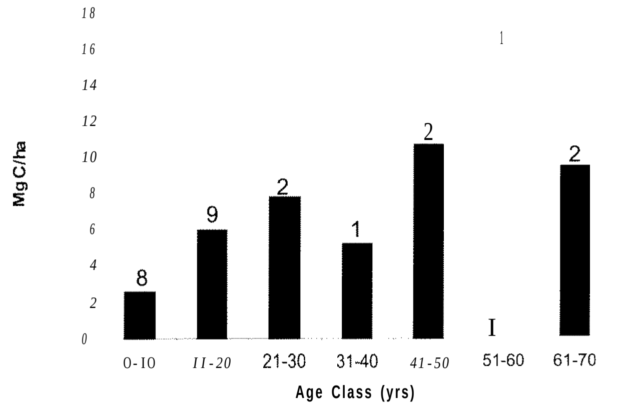

Fig. 4. Forest floor carbon by age class for pine and oak–pine plots. Numbers above bars indicate the number of plots included in the mean.

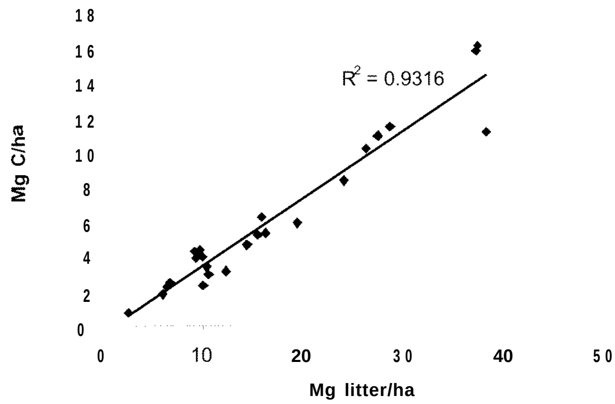

Fig. 5. Relationship between forest floor mass and forest floor carbon content.

value would be developing estimates of below ground carbon content that would be useful in regional carbon estimates. The following section discusses some possible applications of the FHM soil carbon data.

4.2. Use of FHM data in carbon sequestration models

Of the forest floor data available in the literature, few are organized strictly by age class, so few comparisons of the FHM data can be made to other data in this manner. In one example, a replicated field study using plantations of slash pine (*Pinus elliottii* var. *elliottii*) at seven ages from 2 to 34 years old, Gholz and Fisher (1982) reported an apparent linear increase in forest floor mass of 1.22 Mg/ha/year (ash-free dry wt.). A major difference in their method was including all fallen wood encountered in the forest floor values while the FHM forest floor values contain only wood less than about 0.64 cm in diameter. For example, the one FHM plot that was slash pine forest type had an average forest floor content of 0.098 Mg/ha with a stand age of 9

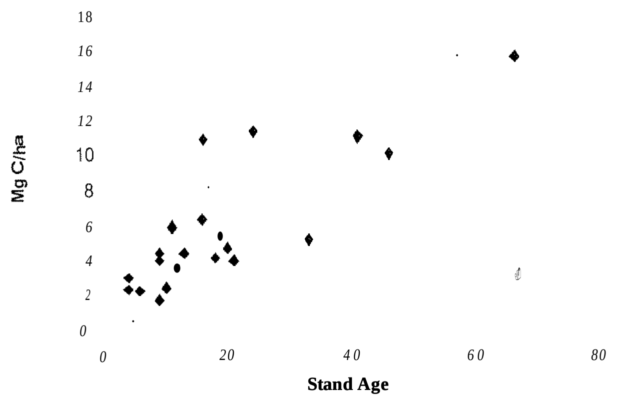

Fig. 6. Relationship between stand age and forest floor carbon content.

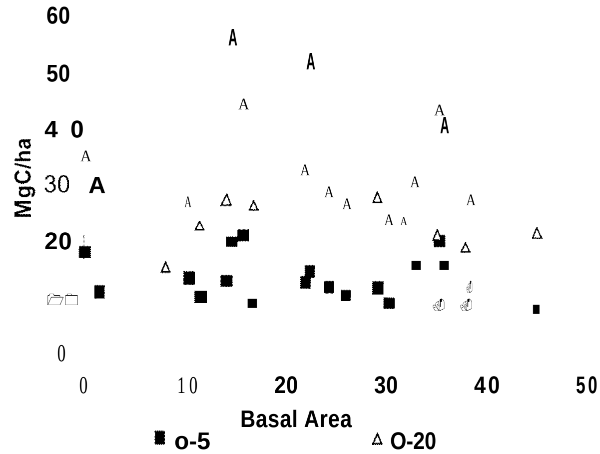

Fig. 7. Soil carbon content at two depths vs. basal area

years. Calculating the forest floor mass using 1.22 Mg/ha/year for 9 years results in 10.98 Mg/ha, highlighting differences that can be caused by different data collection protocols.

There are some collections of forest floor data organized by region and forest type. Birdsey (1996) assembled a collection of forest floor data that are used to estimate forest floor carbon storage; carbon content is calculated using a lixed carbon concentration of 58%. These numbers include leaves, twigs, and above ground woody debris while the current study's numbers do not include coarse woody debris, and both forest floor mass and carbon concentration were measured. Except for the pine type, where the forest floor mass measured by the FHM project was higher, the FHM measured values for forest floor mass and carbon content are less (Table 3), often considerably so, than those compiled by Birdsey. Van Lear et al. (1995) reported a similar carbon content to that of Birdsey for the forest floor under a 55-year old loblolly pine (*Pinus* taeda L.) plantation (Table 5).

A similar situation was seen when comparing the current study's values to forest floor carbon reported by Richter et al. (1995; Table 5). Richter et al. (1995) did not include coarse woody debris and calculated the carbon content as 50% of the ash-free mass of the forest floor. They acknowledged the carbon content was relatively high for a southern pine forest floor, perhaps because there was no evidence of fire.

The carbon values obtained from the current study are substantially lower than those from Birdsey's compilation. It is common practice for investigators to simply measure forest floor mass and then convert to carbon using a fixed value for forest floor carbon concentration; although forest floor carbon content is not technically difficult to measure, sample preparation and analysis is time consuming and can become expensive if many samples are processed. These fixed values for- carbon concentration vary somewhat from study to study. but are typically in the range of 46–48% C. Since different tree species have varying leaf chemistry and carbon concentration in leaf forest floor changes during the decomposition process, these fixed values may not accurately represent the carbon concentration of the entire forest floor, which contains well-decomposed material in addition to fresh litter. The mean carbon concentration across all forest floor samples in the FHM study was 37%, with a range across forest types of 32–38%. This could account for the large differences seen in Table 5 and highlights the need for accurate measurement of forest floor carbon content as well as mass.

If relationships exist between commonly measured forcst mensuration variables and forest floor variables, then it may be possible to obtain reliable information without extensive sampling and analysis, or reliance on fixed carbon concentrations that may not be accurate. Several different relationships were investigated. Since the focus of this study was the pine type, only the pine and oak–pine plots were considered in this portion of the analysis. There is an excellent linear relationship between forest floor mass and carbon mass (Fig. 5). which may provide a more accurate way of estimating forest floor carbon than using a fixed carbon concentration for all forest floor material. When forest floor carbon content is plotted against stand age as in Fig. 6, it appears that there may also be a linear relationship although it is not as strong in this case. mainly due to one plot with a very low forest floor mass and carbon content. In this study plot history was not taken into account, so it is possible that forest floor raking or other management practices that disturb the forest floor could have occurred. When a larger dataset is available. this relationship will be reexamined.

Forest floor carbon content was also plotted against total basal area. A weak positive relationship existed ($r^2 = 0.26$), but the lack of fit was driven primarily by 5 points that fell outside the range of the bulk of the data. Again, this relationship can be more thoroughly

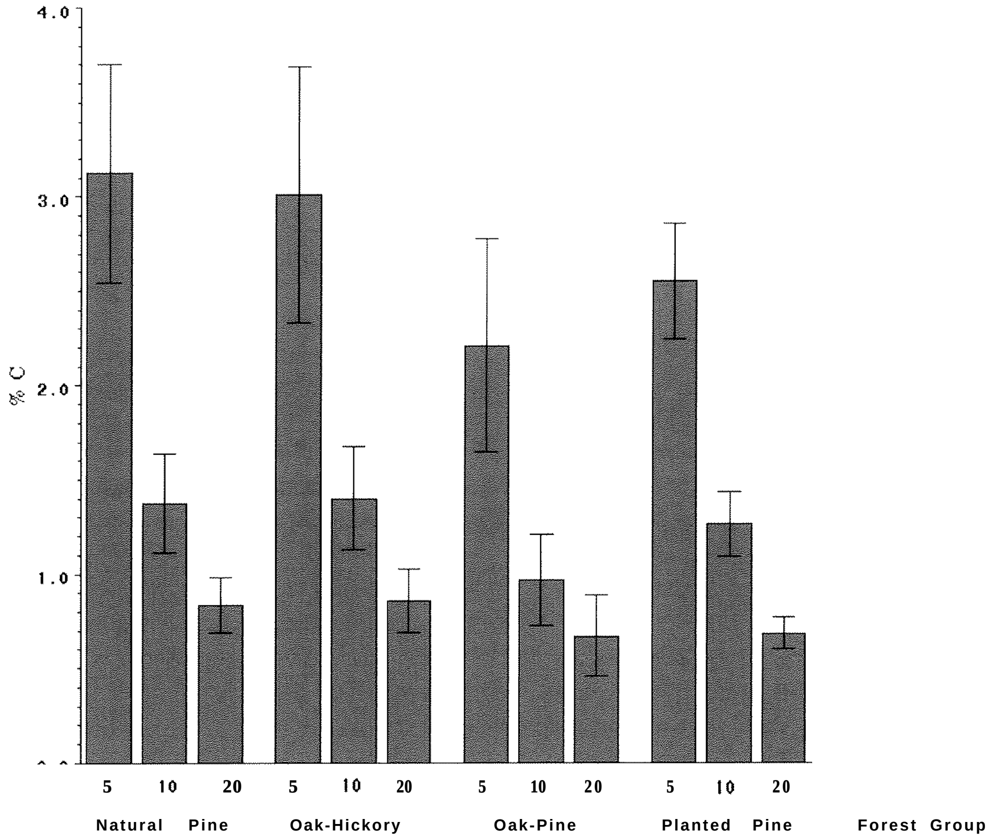

Fig. X. Soil carbon concentration **by** forest **group** and depth increment (5 = 0 5, 10 = 5 10, and **20 10 20 cm**)

evaluated when more data are available and individual plot characteristics will not carry as much weight. In addition, follow-up should include examining these relationships for other forest types as data become available.

Part of the value of the data generated by the FHM program is the manner in which it is collected, which enables pairing of above ground and below ground data, and aggregation of the data by different criteria. With a sufficient number of plots, data could be compared by age class, forest type, or forest type and age class, or any combination of factors. Little is known about the rate of soil carbon accumulation, the age at which maximum storage is reached, or whether accumulation is linear or follows some other pattern, mainly because sufficient data to answer these questions are not available. At this point, FHM is just beginning to accumulate sufficient data from plots in all age classes to be able to draw conclusions about the questions posed above. However, it seems clear that this type of data will allow questions of this nature to be answered.

4.3. Soil carbon depths samples

How the data obtained from the FHM study compare to other data and current estimates can be a difficult question to answer since sampling and analysis protocols vary widely, with the most common problem being the use of different sampling depths and depth increments. Table 6 presents the values from this study, the current estimates derived from STATSGO data and regional estimates derived by Birdsey (1996) using the regression method of Burke et al. (1989) which relies on climate and soil texture data rather than vegetation type. Since the depth increments vary, direct comparisons cannot be made. In an attempt to address this difficulty, the third row in the table contains the data from this study extrapolated to 25 cm for purposes of comparison to the STATSGO estimates. These **values** may be slight overestimates, since they assume that the carbon concentration in the 20-25 cm depth increment is the same as that in the IO-20 cm increment.

The agreement between data sources in the upper portion is fairly good (Table 6), although the **values** from the SEDEMO study adjusted to 25 cm depth are somewhat higher than those derived from the STATSGO database. Selection of FHM plots is based on stringent criteria, while STATSGO uses the soil series approach and encompasses mainly agricultural lands. As data continue to become available for more regions and forest types, the estimates from different data sources should continue to be compared.

The soil carbon by depth data were combined with the forest mensuration data from the study plots, and

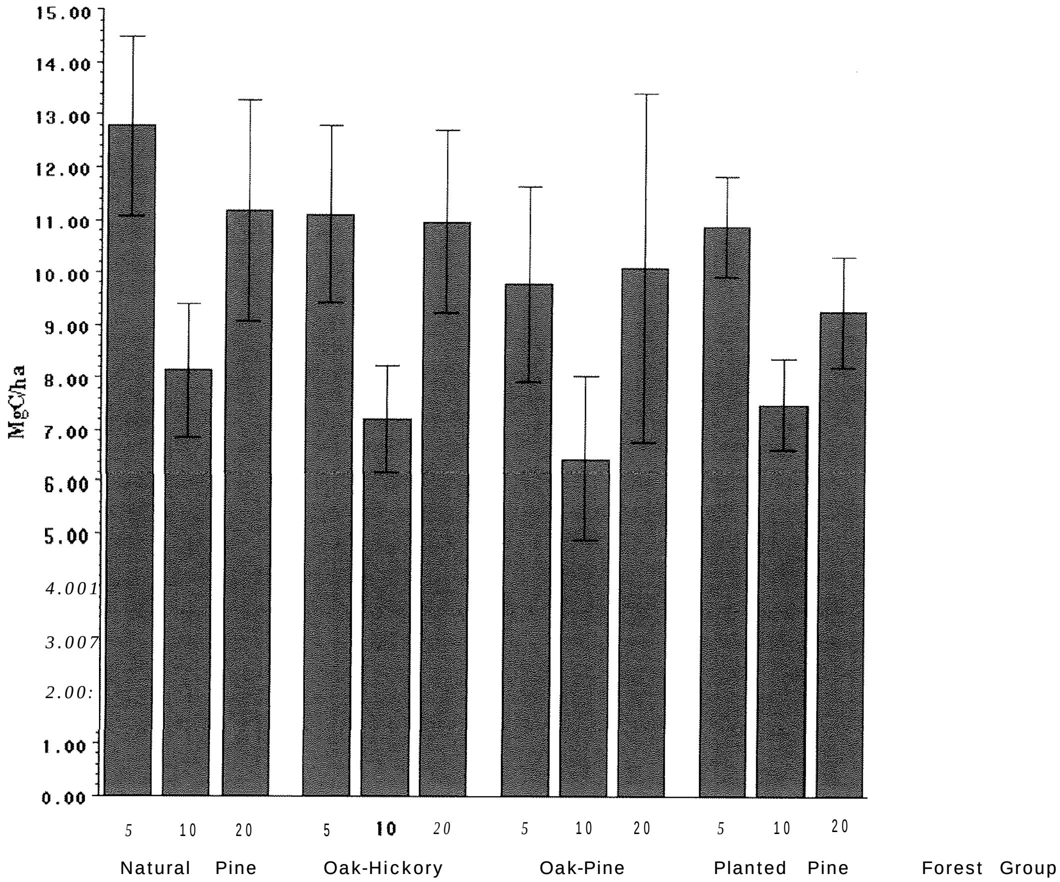

Fig. 9. Soil carbon content by forest group and depth increment (5 = 0 5, 10 = 5 10, and 20 = 10 20 cm). The number of plots included in each forest type was Natural Pine, 8; Oak Hickory, 3; Oak Pine. 3; Planted Pine, 16.

Table 5
Forest floor and carbon mass values for the FHM study and other compiled data

Forest type	Data source	Mg/ha forest floor	Mg/ha carbon
Pines	FHM	21.41	7.95
	Birdsey (1996)	20.03	11.61
	Richter et al. (1995)	65.6	32.8
	Van Lear et al. (1995)		11.9
	Jorgensen et ill. (1975)	2x	
Oak pine'	FHM	9.16	2.98
	Birdsey (1996)	15.13	8.74
Oak hickory[a]	FHM	8.82	3.41
	Birdsey (1996)	10.24	5.94

[a] Oak pine and oak hickory values for FHM were based on only three plots.

examined for possible predictive relationships between commonly measured above ground variables and soil carbon concentration in the 0–5 cm depth increment as well as soil carbon content in the 0–5 cm and 0–20 cm depths, for the natural pine and planted pine plots only. Plot history was not considered in these analyses. The following variables were tested against carbon concentration and carbon content: stand age, basal area per acre, total green weight per acre, and quadratic mean diameter. No relationships were found between carbon content or concentration and any of the four test variables, nor did multiple regression reveal any relationships that explained a substantial quantity of the variation. Fig. 7 shows the plot of soil carbon content against basal area; the other variables produced similar plots. Before ruling out the possibility of predicting soil carbon from above ground information, this analysis should be repeated when a larger dataset is available; these results are based on data from 23 plots for which land-use history is not known.

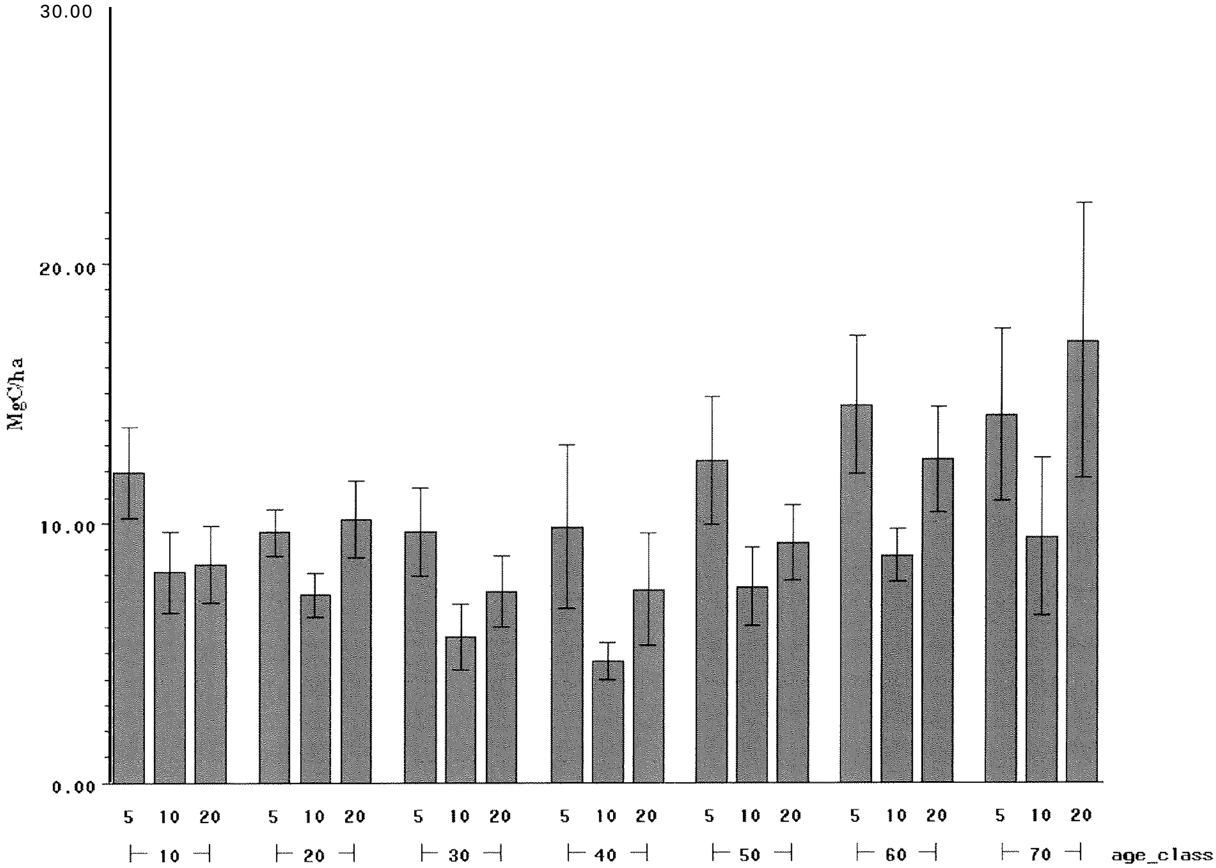

Fig. 10. Soil carbon content by age class (10 = 0–10 years, 20 = 11–20 years, 30 = 21–30 years, etc.) and depth increment (5 = 0–5, 10 = 5–10, and 20 = 10–20cm). The number of plots included in each age class was 0–10 (eight plots), 11–20 (nine plots), 21–30 (three plots), 31–40 (one plot), 41–50 (three plots), 51–60 (two plots), and 61–70 (three plots).

Table 6
Soil carbon contents from various data sources

Data source	Depth (cm)	Carbon content (kg/m^2)		
		Loblolly–shortleaf pine	Oak–pine	Oak–hickory
FHM	0–20 (measured)	3.1	2.9	2.8
STATSGO	0–25	3.0	3.0	2.8
FHM	0–25 (estimate)	3.7	3.5	3.6
STATSGO	0–100	7.5	6.1	4.5
Birdsey (1996)[a]	0–100	7.7	7.7	7.7

[a] Values from Birdsey (1996) represent a regional mean across forest types, based on climate and soil texture.

5. Conclusions

The data from this study indicate that FHM data are adequate for detecting a 20% change over 10 years (equal to a 2% change per year) in percent total carbon and carbon content (MTC ha) when sampling by horizon. At a significance level of 0.33 (the level commonly used by FIA), for all depth increments there is a greater than 80% probability that a change in carbon content will be determined when a change has truly occurred, when sampling by depth, at the rate of change of 20% over 10 years. Additional plot data will be used to investigate the power of change detection over a wider variety of soils.

The data gathered during the FHM project were readily usable to produce estimates of forest floor and soil carbon stocks. The structure of the data facilitates post-stratification by various methods. and the consistent collection procedures will enable cross-site and through-time comparisons. The scale at which the data are collected lends itself to producing the type of standing stock estimates needed for carbon budget development and carbon cycle modeling, and the availability of site-specific forest mensuration data enables the exploration of aboveground and belowground linkages. This is a first step in data analysis with follow-up work planned such as inclusion of a wider variety of forest types. continued post-stratificatioii on larger data sets to examine the effect of stand age and forest type on forest floor and soil carbon stocks, production of statewide and region-wide (if appropriate) estimates of soil and forest floor carbon by appropriately defined categories, and continued exploration of possible predictive relationships between soil and forest floor carbon and common forest mensuration variables.

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