Litter and Duff Bulk Densities in the Southern United States

Joint Fire Science Program Project #04-2-1-49

Final Report

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January 5, 2007

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Abstract

The organic layer (i.e., litter and duff) can represent the majority of the fuels in southeastern forest ecosystems. Measurements of organic layer mass (or loading) are critical for estimating fuel consumption in wildland fires and resulting fire effects, including smoke emissions and tree mortality. Managers generally only have time to measure the depth of the litter and duff layers. To convert depth measurements to mass, bulk density numbers are required for each layer. Previous field research to quantify organic layer bulk densities in the southeastern region of the United States has been generally confined to a small number of samples in very specific forest types.

In this study, litter and duff depths and bulk densities were quantified from 2280 samples collected in 5 forest types (slash pine, loblolly pine, hardwoods, shortleaf pine, and mixed pine and hardwoods) across 7 states in the southeastern United States. Average site litter depths ranged from 0.88 to 2.19 inches, with an average depth of 1.44 inches for all forest types. Litter bulk densities ranged from 0.95 to 3.29 t/ac/in, with an average of 1.91 t/ac/in. Duff depths ranged from 0.32 to 2.41 inches; average duff depth was 0.91 inches. Duff bulk densities ranged from 3.12 to 11.02 t/ac/in; average bulk density was 6.10 t/ac/in. Evaluating the data by forest type, the average litter and duff depths and bulk densities for pine sites were 1.44 and 0.91 inches and 2.04 and 6.41 t/ac/in. Average litter and duff depths and bulk densities for hardwood sites were 1.42 and 0.88 inches and 1.38 and 4.84 t/ac/in.

This study improved estimates of bulk density values for use in the Fuel Characteristic Classification System, consumption and fire effects software, including Consume 3.0 and the First Order Fire Effects, and the new DMM600 Duff Moisture Meter. They also provide improved estimates of carbon stores and of smoke produced during wildland fires in southern forests.

Introduction

Characterizing forest floor layers (i.e., litter and duff or Oi, Oe, and Oa soil horizons) in forests of the southeastern United States is becoming increasingly important in modeling fire effects. In some southeastern ecosystem types, forest floor material represents the majority of fuels consumed during prescribed and wildland fires and contributes to a range of fire effects including tree mortality, nutrient loss, soil erosion, and air pollution (Hardy et al. 2001, Fowler 2004, Johnston et al. 2004, Hiers et al. 2005).

Although the forest floor may contain a large proportion of a site's biomass (Nemeth 1973, Vogt et al. 1986), land managers rarely have the time and resources to adequately characterize its mass (tons). Instead, managers measure litter and duff depths for a specific site and need a mean bulk density estimate (tons/acre/inch) to allow conversion of forest floor depth to forest floor mass or loading.

Previous studies have reported forest floor bulk density values for the southern United States (Crosby and Loomis 1974, McNab et al. 1978, Scholl and Waldrop 1999, Ottmar et al. 2000, Ottmar et al. 2003). However, these studies were limited in scope or the data were collected and analyzed separately for specific projects at locations throughout the Southeast. No studies have compared forest floor depths and bulk densities using a standard methodology at different sites throughout the south. Comparing forest floor depths and bulk densities within forest types across the south will provide a better estimate of forest floor characteristics in southern forest types for use in various fire modeling software, emissions estimates, and management decision tools.

The primary objective of this study was to collect litter and duff samples from management agency ownerships (National Forests, National Wildlife Refuges, National Parks and The Nature Conservancy preserves) throughout the Southeast to adequately characterize forest floor depth and bulk density of 5 common forest types (loblolly pine, slash pine, shortleaf pine, mixed pine and hardwood, and upland hardwood). Adequate characterization of forest floor bulk densities (1) enables litter and duff depths from plots across the south to be converted to mass, (2) provides more precise values for estimating fuel loading and emissions for smoke management, (3) provides improved estimates of bulk densities for the Fuel Characteristic Classification System database (Ottmar et al. in press), and (4) provides users of the new DMM600 Duff Moisture Meter with a range of appropriate values for instrument calibration for gravimetric moisture outputs (Campbell Scientific 2002).

We also investigated the relationship of the percent of pine litter versus leaf litter to bulk density and depth. Finally, several hardwood stands were sampled in summer and winter to determine how season affects forest floor characteristic measurements and resulting biomass estimates.

Methods

Litter and Duff Definition

In this study, the litter is considered the top layer of the forest floor composed of loose debris of small diameter dead twigs, grass, recently fallen needles and leaves that is little altered by decomposition. It is referred to as the L (litter) layer or as the Oi horizon in U.S. soil taxonomy. The duff layer is considered to be partially decomposed material above the mineral soil and beneath the litter layer. It is often referred to as the F (fermentation) and H (humus) layer or as the Oe and Oa horizons in U.S. soil taxonomy.

Site Selection

After detailed discussions with over 20 land managers, a total of 74 sampling sites on 15 management agency lands in 7 southern states were selected to be included in the study (fig. 1, table 1). Sites were grouped by stand type (loblolly pine, slash pine, shortleaf pine, mixed pine [loblolly or pitch pine] and hardwood, and hardwood). We attempted to select pine sites with pure pine overstories and pure needle litter layers to reduce variability. However, in shortleaf pine sites, all sites contained a significant proportion of hardwoods and a mix of needle and hardwood leaf litter.

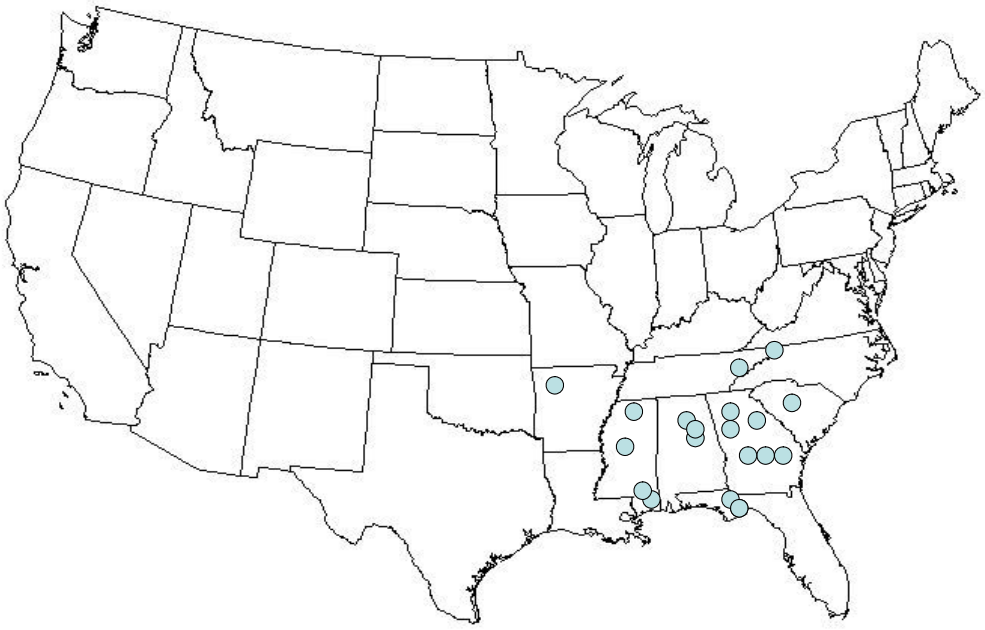

Figure 1. Location of bulk density study units.

Table 1. Summary of sample sites by management agency.

Management Agency	State	Overstory type
Apalachicola National Forest	Florida	Slash Pine
Bankhead National Forest	Alabama	Loblolly Pine, Mixed Pine and Hardwoods
Broxton Rocks The Nature Conservancy	Georgia	Loblolly Pine
Cherokee National Forest	Tennessee	Hardwood, Mixed Pine and Hardwood, Shortleaf Pine
Desoto National Forest	Mississippi	Slash Pine
Great Smokey Mountain National Park	Tennessee	Hardwood
Holly Springs National Forest	Mississippi	Shortleaf Pine
Mountain Longleaf National Wildlife Refuge	Alabama	Hardwood
Marshall Forest The Nature Conservancy	Georgia	Loblolly Pine
Mississippi Sandhill Crane National Wildlife Refuge	Mississippi	Slash Pine
Moody The Nature Conservancy	Georgia	Loblolly Pine, Slash Pine
Ouachita National Forest	Arkansa	Shortleaf Pine
St. Marks National Wildlife Refuge	Florida	Slash Pine
Sumter National Forest	South Carolina	Loblolly Pine, Mixed Pine and Hardwood
Talladega National Forest	Alabama	Hardwood

Litter and Duff Depth and Bulk Density Samples

Depth and bulk density sampling points were randomly selected within each of the 74 sampling sites. A total of 1272 litter and 1008 duff bulk density samples were collected for the study. Several sites were revisited in the winter to collect samples for seasonal comparison of forest floor depth and bulk density in hardwood stands.

A 15-plot sampling grid was established 132 feet within each forest floor sampling unit from a randomly selected starting point located at the unit edge (fig. 2).

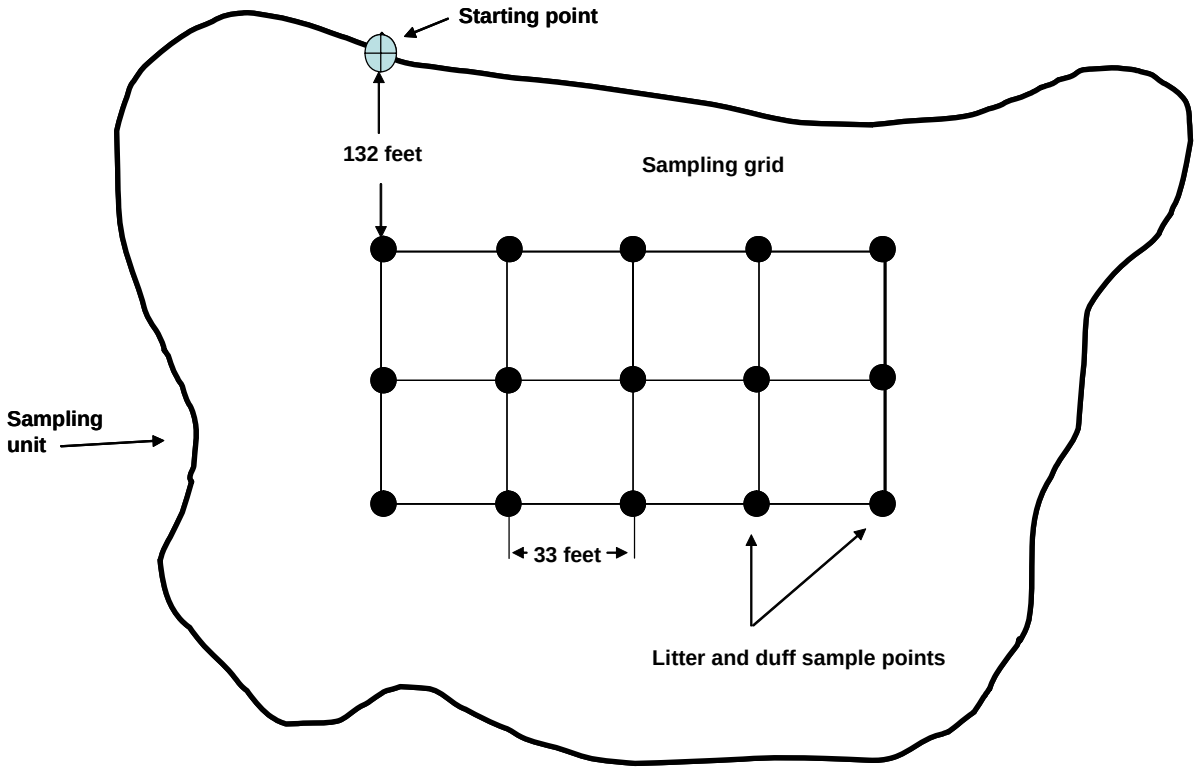

Figure 2. Litter and duff depth and bulk density sampling points.

At each sampling location, a 12-inch sharpened steel square was positioned on top of the litter and duff layer and inserted until the top of the square was flush with the litter layer, or the bottom of the square was embedded in mineral soil (figure 3). Twelve markers (6-inch gutter nails) were positioned within the square and inserted until flush with the top of the litter layer in a grid pattern (figure 3). The litter was carefully removed from the square and placed within a labeled bag. A visual estimate of the percent of pine in the litter layer was made during litter layer sample collection.

To measure the duff layer, each marker was inserted further until flush with the top of the duff layer. The duff layer was carefully removed from the square and place into a labeled plastic bag and sealed. The distance between the top of each marker and the top of the mineral soil was measured and recorded. These twelve depth measurements were averaged to represent the duff depth for the sample.

Samples were shipped back to Seattle to be oven-dried for 48 hours and weighed. Litter samples were dried at 70 degrees Celsius and duff samples at 100 degrees Celsius.

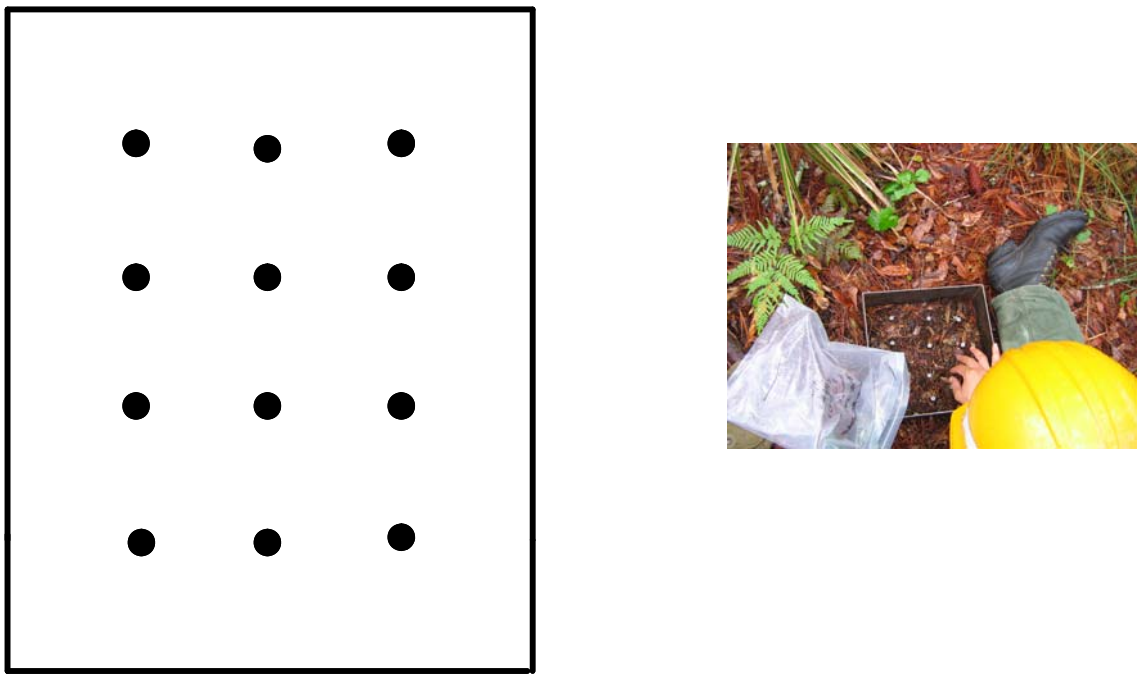

Figure 3. Diagram and photograph of the bulk density sampling square with depth marker locations.

Analysis

Determining Litter and Duff Depth

Forest floor litter and duff layer depth were determined for each sample by calculating the average of the twelve measurements taken for litter and duff within the sample square.

Calculating Bulk Density

The oven dry mass (lbs) of the litter and duff collected for each sample was divided by the area of the sampling square (144 in^2) divided by the average layer depth (in) to determine bulk density ($lbs/in^2/in$) for each sample. The results were converted to tons per acre per inch (t/ac/in).

Data Analysis

A total of 1262 litter samples and 804 duff samples were used for the analysis. These were measured from a total of 74 sampling sites on 15 management agency lands in 7 southern states (table 2). Litter samples with missing depth measurements were removed from the analysis; a total of 10 litter samples (of the 1272 collected) were omitted. In addition, for most of the analyses, only litter samples collected in the summer were used for hardwood stands. Pine stands and mixed pine and hardwood stands were sampled in summer or fall before leaves fell, so samples from both seasons from these forest types are included in the analyses. Winter samples were included in analysis of litter depth and bulk density by season for stands dominated by hardwoods. Litter data were normalized by natural log transformation of depth and bulk density values. Actual data values are reported in results tables.

Initial review of the duff data indicated duff samples collected with an average thickness of less than 0.2 inch (5 mm) were often contaminated with mineral soil, and these data were removed from the analysis. A total of 204 duff samples (of the 1008 collected) were removed from analysis. Samples from all times of year were included in duff analyses. Duff data were normalized by natural log transformation of depth values and square root transformation of bulk density values. Actual data values are reported in the results.

Litter data were analyzed using analysis of variance (ANOVA) to determine how depth and bulk density differed by forest type and by states within forest types. Due to unequal variances, Games-Howell post hoc tests were used to determine differences among groups. In addition, the data were analyzed using linear regression to determine the relationship between litter depth and bulk density by forest type and whether litter depth or bulk density were related to percent of pine in the litter layer by forest type. Hardwood forest litter depth and bulk density were analyzed using T-tests to determine differences between samples collected in summer and winter.

Duff data were analyzed using ANOVA to determine how depth and bulk density differed by forest type and by states within forest types. Due to unequal variances, Games-Howell post hoc tests were used to determine differences among groups. In addition, the data were analyzed using linear regression to determine the relationships between duff depth and bulk density by forest type and between duff depth or bulk density and percent of pine in the litter layer by forest type.

Table 2 summarizes the number of samples used in the analyses by management agency. Statistical tests (ANOVA, linear regression and T-tests) were performed using SPSS 14.0 for Windows (5 Sept 2005).

Table 2. Analysis data summary by management agency. Litter samples missing bulk density or depth values were omitted from the analyses. Duff samples missing bulk density or depth values, or with depth values less than 5mm, were omitted from the analyses.

Management Agency	State	Overstory	Sample Date	Season Class	# Duff Samples	# Litter Samples
Apalachicola NF	FL	Slash Pine	Apr-05	None	72	103
				Total	72	103
Bankhead NF	AL	Loblolly Pine	Jun-05	None	15	15
		Mixed Pine & Hardwood	Jun-05	Summer	27	29
				Total	42	44
Broxton Rocks TNC	GA	Loblolly Pine	Apr-05		29	45
				Total	29	45
Cherokee NF	TN	Hardwood	Jul-05	Summer	43	88
		Mixed Pine & Hardwood	Jul-05	Summer	49	54
		Shortleaf Pine	Jul-05	Summer	14	15
				Total	106	157
Desoto NF	MS	Slash Pine	Feb-05	None	22	22
				Total	22	22
Great Smokey Mtn. NP	TN	Hardwood	Jul-05	Summer	78	99
			Nov-05	Winter		103
				Total	78	202
Holly Springs NF	MS	Shortleaf Pine	Oct-05	Fall	30	65
				Total	30	65
Mountain Longleaf NWR	AL	Hardwood	Jun-05	Summer	31	42
			Dec-05	Winter		42
				Total	31	84
Marshall Forest TNC	GA	Loblolly Pine	May-05	None	14	15
				Total	14	15
Mississippi Sandhill Crane NWR	MS	Slash Pine	Feb-05	None	75	75
				Total	75	75
Moody TNC	GA	Loblolly Pine	May-05	None	14	17
		Slash Pine	May-05	None	13	13
				Total	27	30
Ouachita NF	AR	Shortleaf Pine	Oct-05	Fall	87	96
				Total	87	96
St. Marks NWR	FL	Slash Pine	Jun-05	None	13	16
				Total	13	16
Sumter NF	SC	Loblolly Pine	May-05	None	61	74
		Mixed Pine & Hardwood	May-05	Summer	14	14
				Total	75	88
Talladega NF	AL	Hardwood	Jun-05	Summer	59	73
			Dec-05	Winter		73
		Mixed Pine & Hardwood	Jun-05	Summer	29	30
			Dec-05	Winter	15	44
				Total	103	220
			Grand Total		804	1262

Results

Forest Floor Litter Depth and Bulk Density

Forest floor litter depth and bulk density results are presented by forest type, state, and percent pine in litter, and season (tables 3-9).

Range of Forest Floor Litter Depth and Bulk Density Samples by Forest Type

Sample litter depths ranged from 0.44 to 3.41 in (table 3). Sample litter bulk densities ranged from 0.09 to 4.89 t/ac/in.

Table 3. Range of litter depth and bulk density samples for each forest overstory type (summer hardwood samples only).

Overstory Type	Min. Depth (in)	Max. Depth (in)	Min. Bulk Density (t/ac/in)	Max. Bulk Density (t/ac/in)
Loblolly Pine	0.44	2.38	0.84	4.89
Slash Pine	0.78	3.41	0.59	4.32
Shortleaf Pine	0.68	2.62	0.88	4.75
Mixed Pine & Hardwoods	0.50	2.65	0.94	3.42
Hardwood	0.53	2.80	0.09	2.91

Forest Floor Litter Depth and Bulk Density by Forest Type

Mixed pine and hardwood sites had the lowest range in litter depth (1.14-1.55 in) and litter bulk density (1.54-2.25 t/a/in; table 4). Hardwood sites had the widest range in average litter depth (0.88-1.87 in), and the loblolly pine sites had the widest range in average litter bulk density (1.63-3.29 t/a/in).

Table 4. Range of litter depth and bulk density site averages for each forest overstory type (summer hardwood samples only).

Overstory Type	N	Min. Depth (in)	Max. Depth (in)	Min. Bulk Density (t/ac/in)	Max. Bulk Density (t/ac/in)
Loblolly Pine	166	0.96	1.70	1.63	3.29
Slash Pine	229	1.09	2.19	1.47	2.68
Shortleaf Pine	176	1.13	1.78	1.63	2.38
Mixed Pine & Hardwoods	127	1.14	1.55	1.54	2.25
Hardwood	288	0.88	1.87	0.95	1.77

Among forest overstory types, average litter depths were significantly higher in slash pine stands (1.68 in; $p \leq 0.000$) than in all other forest overstory types sampled (table 5). Average litter bulk density in loblolly and slash pine stands was significantly higher (2.21 and

2.16 t/ac/in, respectively; $p \leq 0.013$) than shortleaf pine (1.94 t/ac/in), mixed pine and hardwoods (1.86 t/ac/in) and pure hardwood stands (1.38 t/ac/in).

Table 5. Average litter depth and bulk density for each overstory type (summer hardwood samples only). Values in each column with same superscript are not significantly different (p =0.05; Games-Howell post-hoc test).

Overstory Type	N	Average Depth (in)	Std. Deviation	Std. Error of Mean	Average Bulk Density (t/ac/in)	Std. Deviation	Std. Error of Mean
Loblolly Pine	166	1.35[a]	0.38	0.03	2.21[c]	0.78	0.06
Slash Pine	229	1.68[b]	0.48	0.03	2.16[c]	0.67	0.04
Shortleaf Pine	176	1.36[a]	0.33	0.02	1.94[b]	0.58	0.04
Pine & Hardwoods	127	1.37[a]	0.37	0.03	1.86[b]	0.53	0.05
Hardwood	288	1.42[a]	0.42	0.02	1.38[a]	0.46	0.03
All (average)		1.44			1.91		

Forest Floor Litter Depth and Bulk Density by Forest Type and State

Within loblolly and slash pine forest overstory types, none of the states had average litter bulk densities that were significantly different than any other states ($p \geq 0.508$; table 6). Average bulk density values among loblolly pine stands ranged from 2.15 t/ac/inches in Georgia to 2.47 t/ac/inches in Alabama; in slash pine stands bulk density ranged from 2.09 t/ac/inches in Mississippi to 2.22 t/ac/in in Florida and Georgia. Within the loblolly pine forest overstory type, Alabama had significantly higher average litter depth (1.70 in; $p \leq 0.015$) than the other two states sampled; South Carolina had the lowest average litter depth in loblolly stands (1.27 in). Average litter depth was significantly higher in slash pine stands in Florida (1.82 in) than in Mississippi (1.53 in; $p = 0.000$). Georgia (1.53 in) was not significantly different than either Florida ($p = 0.115$) or Mississippi ($p = 0.999$).

In shortleaf pine stands, Mississippi had significantly lower litter bulk density (1.79 t/ac/in; $p = 0.021$) than Tennessee (2.38 t/ac/in; $p = 0.021$) and Arkansas (1.97 t/ac/in; $p = 0.044$). Tennessee had an average litter depth (1.13 in) in shortleaf pine stands that was significantly lower than in Mississippi (1.45 in; $p = 0.006$) but not significantly different from Arkansas (1.34 in; $p = 0.051$).

Within the mixed pine and hardwood forest type, Alabama, South Carolina and Tennessee had similar litter depths ($p = 0.967$). South Carolina had the highest average litter bulk density (2.26 t/ac/in) of all states sampled; its bulk density was significantly higher than Tennessee (1.84 t/ac/in; $p = 0.004$) but not significantly higher than Alabama (1.91 t/ac/in; $p = 0.108$).

Hardwood stands in Alabama and Tennessee differed significantly in terms of average litter depth ($p = 0.000$) and bulk density ($p = 0.000$). Tennessee stands had higher average depth (1.50 in) than Alabama stands (1.28 in). Alabama stands had higher average bulk density (1.55 t/ac/in) than Tennessee stands (1.27 t/ac/in).

Table 6. Average litter bulk density and litter depth for each state within each forest overstory type (summer hardwood samples only). Average bulk density and depth values in each forest type with same superscript are not significantly different (p = 0.05; Games-Howell post-hoc test).

State	N	Average Bulk Density (t/ac/in)	Std. Deviation	Std. Error of Mean	Average Depth (in)	Std. Deviation	Std. Error of Mean
Loblolly Pine							
AL	15	2.47[a]	1.04	0.27	1.70[b]	0.40	0.10
GA	74	2.15[a]	0.68	0.08	1.36[a]	0.37	0.04
SC	77	2.21[a]	0.82	0.09	1.27[a]	0.36	0.04
Slash Pine							
FL	119	2.22[a]	0.75	0.07	1.82[b]	0.54	0.05
GA	13	2.22[a]	0.68	0.19	1.53[a,b]	0.38	0.11
MS	97	2.09[a]	0.57	0.06	1.53[a]	0.34	0.03
Shortleaf Pine							
AR	96	1.97[a]	0.52	0.05	1.34[a,b]	0.29	0.03
MS	65	1.79[b]	0.55	0.07	1.45[b]	0.36	0.05
TN	15	2.38[a]	0.88	0.23	1.13[a]	0.27	0.07
Pine & Hardwood							
AL	59	1.91[b]	0.50	0.07	1.39[a]	0.39	0.05
SC	14	2.26[b]	0.57	0.15	1.36[a]	0.37	0.10
TN	54	1.69[a]	0.50	0.07	1.36[a]	0.34	0.05
Hardwood							
AL	115	1.55[a]	.53	.05	1.28[a]	0.43	0.04
TN	173	1.27[b]	.36	.03	1.50[b]	0.39	0.03

Regression analysis shows a weak negative relationship between average litter bulk density and average litter depth within the southern states (all data) and within each forest type (table 7).

Table 7. Relationship of litter bulk density to litter depth by forest type.

Forest Type	P value	Relationship	R^2
All Data	0.000	Negative	0.049
Loblolly Pine	0.000	Negative	0.094
Slash Pine	0.000	Negative	0.138
Shortleaf Pine	0.000	Negative	0.152
Pine & Hardwoods	0.000	Negative	0.124
Hardwood	0.000	Negative	0.100

Forest Floor Litter Depth and Bulk Density by Percent Pine in the Litter

Regression analysis illustrates that average litter depth had a positive relationship with percent pine in the litter layer in loblolly, slash and shortleaf pine stands, however, the

relationships were very weak ($R^2 \leq 0.082$; table 8). There is no relationship between litter depth and percent pine in the litter layer in mixed pine and hardwood stands or pure hardwood stands ($p \geq 0.071$). There was a positive correlation between average litter bulk density and percent pine in the litter layer for loblolly pine, mixed pine and hardwood and pure hardwood stands, however the relationship was very weak ($R^2 \leq 0.045$). There was no relationship between litter bulk density and percent pine in the litter layer in slash pine or shortleaf pine stands ($p \geq 0.065$).

Table 8. Relationship of litter bulk density and depth to percent pine in the litter layer by forest overstory type.

	P value	Relationship	R^2
Loblolly Pine			
Litter depth	0.046	Positive	0.025
Litter bulk density	0.007	Positive	0.045
Slash Pine			
Litter depth	0.000	Positive	0.082
Litter bulk density	0.677	None	0.001
Shortleaf Pine			
Litter depth	0.028	Positive	0.029
Litter bulk density	0.065	None	0.020
Mixed Pine and Hardwood			
Litter depth	0.904	None	0.000
Litter bulk density	0.014	Positive	0.037
Hardwood			
Litter depth	0.071	None	0.008
Litter bulk density	0.034	Positive	0.010

Hardwood Forest Type Forest Floor Litter Depth and Bulk Density by Season

For hardwood forests, average litter depth differed significantly depending on the season in which it was measured (table 9), with samples collected in the winter (2.12 in) being deeper than those collected in the summer (1.43 in; $p = 0.000$). Average litter bulk density was also significantly different; samples collected in the summer had higher average bulk density (1.33 t/ac/in) than those collected in the winter (0.98; $p = 0.000$).

Table 9. Hardwood litter depth and bulk density by season. The data includes summer and winter samples from hardwood forest types that have pure hardwood litter. Average bulk density or depth values with same superscript are not significantly different ($p = 0.05$).

Season	N	Average Depth (in)	Std. Deviation	Std. Error of Mean	Average Bulk Density (t/ac/in)	Std. Deviation	Std. Error of Mean
Summer	149	1.43[a]	0.44	0.04	1.33[a]	0.49	0.04
Winter	158	2.12[b]	0.49	0.04	0.98[b]	0.23	0.02

Forest Floor Duff Depth and Bulk Density

The forest floor litter depth and bulk density are presented by forest type, state, percent pine in litter, and season (tables 10-15).

Range of Forest Floor Duff Depth and Bulk Density by Forest Types

Sample duff depths ranged from 0.20 to 4.8 inches; average duff depth was 0.98 in. (table 10). Sample duff bulk densities ranged from 0.44 to 20.27 t/ac/in; average bulk density was 6.03 t/ac/in.

Table 10. Range of duff depth and bulk density samples for each forest overstory type.

Overstory Type	Min. Depth (in)	Max. Depth (in)	Min. Bulk Density (t/ac/in)	Max. Bulk Density tons/ac/in
Loblolly Pine	0.21	2.77	0.52	16.17
Slash Pine	0.23	4.80	1.52	20.27
Shortleaf Pine	0.21	1.64	1.46	11.59
Pine & Hardwoods	0.20	3.29	1.83	18.21
Hardwood	0.20	3.62	0.44	18.03

Forest Floor Duff Bulk Density and Depth by Forest Type

Hardwood sites had the lowest range of bulk density values and shortleaf pine sites had the lowest range of depth values (table 11). Slash pine sites had the largest range in bulk density and depth value).

Table 11. Range of duff depth and bulk density site averages for each forest overstory type.

Overstory Type	N	Min. Depth (in)	Max. Depth (in)	Min. Bulk Density (t/ac/in)	Max. Bulk Density (tons/ac/in)
Loblolly Pine	133	0.32	1.24	5.09	9.34
Slash Pine	195	0.47	2.41	4.57	11.02
Shortleaf Pine	131	0.45	0.95	4.83	7.22
Pine & Hardwoods	134	0.46	1.64	4.37	8.38
Hardwood	211	0.39	2.21	3.12	7.04

Slash pine forests had significantly higher average duff depth (1.16 in; $p \leq 0.000$) than all forest types sampled, except mixed pine and hardwood forests (1.06 in; $p = 0.999$; table 12). Shortleaf pine had significantly lower (0.67 in; $p \leq 0.003$) average depth than the other forest types sampled, except loblolly (0.78 in; $p = 0.487$).

Slash pine forests had significantly higher duff bulk density than all other forest types sampled (6.88 t/ac/in; $p \leq 0.017$), except loblolly forests (6.80 t/ac/in; $p = 0.970$; table 12). Hardwood forests had significantly lower duff bulk density (4.84 t/ac/in; $p \leq 0.000$) than all of the pine forest types (slash 6.88 t/ac/in; loblolly 6.80 t/ac/in; shortleaf 6.05 t/ac/in) and mixed pine and hardwood forests (5.90 t/ac/in).

Table 12. Average duff depth and bulk density for each overstory type. Values in each column with the same superscript are not significantly different (p=0.05; Games-Howell post-hoc test).

Overstory Type	N	Average Depth (in)	Std. Deviation	Std. Error of Mean	Average Bulk Density (t/ac/in)	Std. Deviation	Std. Error of Mean
Loblolly Pine	133	0.78[a,b]	0.46	0.04	6.80[b,c]	2.97	0.26
Slash Pine	195	1.16[c]	0.80	0.06	6.88[c]	2.52	0.18
Shortleaf Pine	131	0.67[a]	0.33	0.03	6.05[b]	2.06	0.18
Pine & Hardwoods	134	1.06[c]	0.55	0.05	5.90[b]	2.44	0.21
Hardwood	211	0.88[b]	0.61	0.04	4.84[a]	2.73	0.19
All (average)		0.91			6.10		

Average duff depth in South Carolina's loblolly pine forests (0.64 in) was significantly lower than in both Georgia (0.89 in; p = 0.003) and Alabama (0.95 in; p = 0.003; table 13). Among loblolly pine stands, South Carolina had significantly higher average duff bulk density (7.56 t/ac/in) than Alabama (5.23 t/ac/in; p=0.012), but was not significantly different than Georgia (6.41 t/ac/in; p = 0.085).

Mississippi slash pine stands had significantly higher average duff depth (1.52 in) than Florida (1.00 in; p = 0.000) but not Georgia (0.77 in; p = 0.047). Duff bulk density was not significantly different among sampled states within slash pine forests ($p \geq 0.062$). Mississippi had the highest bulk density (7.15 t/ac/in), while Georgia had the lowest (5.59 t/ac/in).

Both Arkansas and Tennessee had significantly higher depths (0.68 in and 0.95 in, respectively) than Mississippi (0.50 in; $p \leq 0.011$). In the shortleaf pine forest type, duff bulk density was significantly higher in Arkansas (6.52 t/ac/in) than in Mississippi (5.02 t/ac/in; p = 0.001) but not Tennessee (5.32 t/ac/in; p = 0.121). Mississippi had the lowest average duff depth (0.50 in).

Average duff depth in South Carolina (0.46 in) was significantly lower than Tennessee (1.23 in; p = 0.000) and Alabama (1.06 in; p = 0.000). South Carolina had the highest duff bulk density in mixed pine and hardwood forests (8.38 t/ac/in), which was significantly higher than Alabama (5.59 t/ac/in; p = 0.045) but not Tennessee (5.66 t/ac/in; p = 0.945).

Tennessee stands have higher average depth (1.08 in) than Alabama stands (0.61 in). Alabama stands have higher average bulk density (5.56 t/ac/in) than Tennessee stands (4.31 t/ac/in). Hardwood stands in Alabama and Tennessee differ significantly (p = 0.000) in terms of average duff depth and bulk density.

Table 13. Average bulk density and depth for each state within each forest overstory type. Mean bulk density and depth values in each forest type with same superscript are not significantly different (p = 0.05; Games-Howell post-hoc test).

State	N	Average Bulk Density (t/ac/in)	Std. Deviation	Std. Error of Mean	Average Depth (in)	Std. Deviation	Std. Error of Mean
Loblolly Pine							
AL	15	5.23[a]	2.22	0.57	0.95[b]	0.39	0.10
GA	57	6.41[a,b]	2.87	0.38	0.89[b]	0.49	0.07
SC	61	7.56[b]	3.03	0.39	0.64[a]	0.39	0.05
Slash Pine							
FL	85	6.77[a]	2.86	0.31	0.77[a]	0.46	0.05
GA	13	5.59[a]	1.83	0.51	1.00[a,b]	0.45	0.12
MS	97	7.15[a]	2.22	0.23	1.52[b]	0.90	0.09
Shortleaf Pine							
AR	87	6.52[b]	2.08	0.22	0.68[b]	0.33	0.04
MS	30	5.02[a]	1.64	0.30	0.50[a]	0.15	0.03
TN	14	5.32[a,b]	1.79	0.48	0.95[b]	0.42	0.11
Pine & Hardwood							
AL	71	5.59[a]	2.10	0.25	1.06[b]	0.43	0.05
SC	14	8.38[b]	3.99	1.07	0.46[a]	0.24	0.06
TN	49	5.66[a,b]	1.92	0.27	1.23[b]	0.64	0.09
Hardwood							
AL	90	5.56[a]	3.41	0.36	0.61[a]	0.30	0.03
TN	121	4.31[b]	1.94	0.18	1.08[b]	0.70	0.06

Regression analysis demonstrates that all loblolly pine, mixed pine and hardwood, and hardwood forests had very weak negative correlations between average duff bulk density and average duff depth (R^2 = 0.146, 0.076, and 0.039, respectively; table 14). There was no correlation between duff bulk density and depth for slash pine or shortleaf pine forests (p = 0.293 and 0.464, respectively).

Table 14. Relationship of duff bulk density to duff depth by forest overstory type.

Forest Type	P value	Relationship	R^2
All Data	0.000	Negative	0.024
Loblolly Pine	0.000	Negative	0.146
Slash Pine	0.293	None	0.006
Shortleaf Pine	0.464	None	0.004
Pine & Hardwoods	0.001	Negative	0.076
Hardwood	0.004	Negative	0.039

Forest Floor Duff Depth and Bulk Density by Percent Pine in the Litter

Regression analysis demonstrates that average duff depth had a weak positive relationship ($R^2 \leq 0.084$) with percent pine in the litter layer in slash and mixed pine and

hardwood stands (table 15). There was no relationship between duff depth and percent pine in the litter layer in loblolly pine, shortleaf pine or pure hardwood stands ($p \geq 0.241$). There was a positive correlation between average duff bulk density and percent pine in the litter layer for shortleaf pine stands, however the relationship was very weak ($R^2 = 0.068$). There was no relationship between duff bulk density and percent pine in the litter layer in loblolly pine, slash pine, mixed pine and hardwood stands or pure hardwood stands ($p \geq 0.083$).

Table 15. Relationship of duff bulk density and depth to percent pine in the litter layer by forest overstory type.

	P value	Relationship	R^2
Loblolly Pine			
Litter depth	0.264	None	0.010
Litter bulk density	0.083	None	0.024
Slash Pine			
Litter depth	0.000	Positive	0.084
Litter bulk density	0.284	None	0.000
Shortleaf Pine			
Litter depth	0.241	None	0.011
Litter bulk density	0.003	Positive	0.068
Mixed Pine and Hardwood			
Litter depth	0.001	Positive	0.083
Litter bulk density	0.338	None	0.007
Hardwood			
Litter depth	0.577	None	0.001
Litter bulk density	0.673	None	0.001

Discussion

This study reported litter and duff depth averages by forest type, state, and season. It also assessed if there is a significant relationship between depth and bulk density. The specifics to each relationship are discussed and a summary table provided for recommended litter depths and bulk density. The average depth and bulk densities will provide valuable inputs into modern fire effects and emission production models for fire management.

Litter Depth and Bulk Density by Forest Type

Litter depth was not significantly different between forest types with the exception of slash pine. Slash pine sites are generally drier with sandy soils, and less decay and compaction may take place than in the loblolly, shortleaf, pine and hardwood, and hardwood sites. Average bulk densities, however, were significantly different between the hardwoods, shortleaf pine and pine hardwoods, and loblolly and slash pine types. Leaf litter has a large surface area and often "curls" creating air spaces within the litter layer. This produces less mass per volume than a needled litter layer produced from a pine forest. The Fuel Characteristic Classification System (JFSP 98-1-1-06) and Consume 3.0 (JFSP 98-1-9-06) allow for distinctions between pine and hardwood litter bulk densities.

Duff Depth and Bulk Density by Forest Type

Duff depth and bulk densities were significantly different between the pine and hardwood forest types. Pine needle material decomposes differently than leaf material, thus creating denser duff over a shorter period of time than leaf derived duff.

Litter and Duff Bulk Density and Depth by Percent Pine in the Litter Layer

In the forest types that were sampled in this study, there is very little relationship between litter composition (percent of pine in the litter layer) and litter or duff depth or bulk density. Less than 10% of the variability among samples within each forest type was explained by the relationship of litter composition to depth or bulk density ($R^2 \leq 0.10$). This indicates that percent composition is not critical, and managers can designate litter and duff as either "hardwood" or "pine" and not need to designate a percent composition.

Litter Bulk Density and Depth by State

There were significant litter and duff depth and bulk densities differences by state within each forest type. However, sample data were limited for each state, and any assignment of litter and duff depth and bulk densities by state is not recommended based on the data from this study. We recommend managers use depth and bulk density based on all samples within each forest type (see Recommendation section).

Litter Bulk Density and Depth by Season in Hardwood Stands

Litter depth and bulk density for stands containing hardwoods were also analyzed by season. Litter depth in stands containing hardwoods was greater in winter than in summer, while litter bulk density was lower in winter than in summer. Since newly fallen deciduous hardwood

litter is present in hardwood and mixed pine hardwood stands in winter, the hardwood litter was typically fresher and less compact than in summer, leading to deeper and less dense litter layers in winter. The Fuel Characteristic Classification System (JFSP 98-1-9-06) accounts for seasonality in litter bulk density and the new bulk density values will be incorporated into the system for the southern hardwood fuelbed types.

Litter Bulk Density and Depth Relationship

Less than 20% of the variability among samples within each forest type was explained by the relationship of litter bulk density to litter depth ($R^2 \leq 0.20$). The relationship provides little predictive capability. The data indicate that in some cases a forest type with a high average depth also had a higher average bulk density, which does not follow the negative relationship indicated by the regression analysis (e.g. slash pine southwide [table 5] or loblolly pine in Alabama [table 6]).

Duff Bulk Density and Depth Relationship

Duff bulk density and depth were more weakly correlated than litter bulk density and depth in all forest types sampled except loblolly pine. Again, less than 20% of the variability among samples within each forest type was explained by the relationship of bulk density to depth ($R^2 \leq 0.2$). There was no correlation detected for slash pine or shortleaf pine stands.

Recommendations

The litter and duff depth and bulk density comparisons indicate there are minimal differences between forest types, weak relationships between litter depth and bulk densities, and minimal differences based on percent pine litter versus hardwood litter. Table 16 provides a simple list indicating depths and bulk densities to use based on comparison significance. For example, the loblolly, shortleaf pine, pine hardwoods, and hardwood litter depths were not significantly different (table 5). The litter depth for those forest types and season were averaged together and assigned.

If managers have only differentiated between pine and hardwood forest types, a simpler table has been produced (table 17). In this table all forest types dominated or co-dominated by pines were averaged together.

Table 16. Average litter and duff bulk density and depth for forest types and for the summer and winter season.

Forest Type	Litter Depth (in)	Litter Bulk Density (t/ac/in)	Duff Depth (in)	Duff Bulk Density (t/ac/in)
Loblolly	1.38	2.19	0.73	6.25
Slash Pine	1.68	2.19	1.11	6.88
Shortleaf Pine	1.38	1.90	0.73	6.25
Pine and Hardwoods	1.38	1.90	1.11	6.25
Hardwoods	1.38	1.38	0.88	4.84
Hardwood (Summer)	1.38	1.38	-	-
Hardwood (Winter)	2.17	0.93	-	-

Table 17. Litter and duff depths and bulk densities for pine and hardwood forest types.

Forest Type	Litter Depth (in)	Litter Bulk Density (t/ac/in)	Duff Depth (in)	Duff Bulk Density (t/ac/in)
Pine	1.44	2.04	0.91	6.41
Hardwood	1.42	1.38	0.88	4.84

Application

The organic layer (i.e., litter and duff) can represent the majority of the fuels in southern forest ecosystems. Measurements of organic layer mass (or loading) are critical for estimating fuel consumption in wildland fires and resulting fire effects, including smoke emissions, tree mortality, and for carbon accounting. Managers often only have time to measure the depth of the litter and duff layers. To convert depth measurements to mass, bulk density numbers are required for each layer. The average estimates of litter and duff depths and bulk densities for forested areas in the south presented allows managers to better estimate total mass of the forest floor. The average fuelbed depths and bulk density values will be entered into the Fuel Characteristic Classification System to improve characterization of southern fuelbeds. The values will also be implemented into fire effects software, including Consume 3.0 to better estimate total loading of the forest floor and to improve fuel consumption and emission production estimates. Finally, the new bulk density values will assist in calibrating the DMM600 Duff Moisture Meter to better represent the Southern States.

Deliverables

The primary deliverable product for this project is this final report of results and incorporation of the bulk density results into various fuel characteristic, fuel consumption, and emission production models such as the Fuel Characteristic Classification System and Consume 3.0. A proceedings paper and peer-reviewed journal article are in preparation. Additional data analysis at the request of managers that was not proposed was completed and is included in this report (see tables 18 and 19). We also have been incorporating the results into training curricula and distributing the results to modelers and instrument developers.

Table 18. Comparison of proposed and actual deliverables.

Proposed	Delivered	Status
Forest floor data collection 576 samples southwide	Collected 1272 litter samples and 1008 duff samples from 15 management agency lands in 7 southern states.	Done
Progress reports	Two progress reports were completed for the JFSP in 2005 and 2006.	Done
Incorporation of new bulk density data into Consume 3. 0 software	Southern bulk densities values have been provided to the Consume 3.0 software manager, and will be incorporated into the next release.	In progress (planned for February 2007)
Incorporation of new bulk density data into the Fuel Characteristic Classification System (FCCS) software	Southern bulk densities values have been distributed to the FCCS software manager and will be incorporated into the next release.	In progress (planned for February 2007)
Incorporating bulk density data into the DMM600 Duff Moisture Meter	A bulk density report will be distributed to Dr. Pete Robichaud for development of DMM600 Duff Moisture Meter calibration curves for the southern states.	In progress
Final report	Ottmar, R.D.; Andreu, A. **2007**. Litter and duff bulk densities in the southern United States. Final Report.	Done
Proceedings paper	Ottmar, R.D.; Vihnanek, R.E. **2007**. Litter and duff depths and bulk densities in the southern United States. Proceedings. 2nd Fire Behavior and Fuels Conference, March 27-30, 2007, Destin, FL.	In progress (submitted)
Journal article	In preparation for submittal to the Southern Journal of Applied Forestry.	In progress

Table 19. Items delivered which were not in the original proposal.

Ottmar, R.D. **2006**. Southern bulk density data results. Ohio Regional Fuels Workshop, 2006 November 30, West Portsmouth, OH. (Workshop funded by JFSP #05-4-1-14).	Done
Bulk density data results have been incorporated into the Fuel consumption and emissions sections in Smoke management RX -410 training curriculum.	Done
Bulk density data have been incorporated into the Fire Emissions Production Simulator (JFSP-98-1-9-05)	In progress
Bulk density data have been used to update litter and duff loading values for: Ottmar, R.D.; Vihnanek, R.E. **1999.** Stereo photo series for quantifying natural fuels. Volume V: Midwest red and white pine, northern tallgrass prairie, and mixed oak types in the Central and Lake States. PMS 834. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 99 p. (JFSP-98-1-1-05) Ottmar, R.D.; Vihnanek, R.E**. 2000.** Stereo photo series for quantifying natural fuels. Volume VI: Longleaf pine, pocosin, and marshgrass types in the Southeast United States. PMS 835. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 56 p. (JFSP-98-1-1-05) Ottmar, Roger D.; Vihnanek, Robert E.; Mathey, Jared W. **2003**. Stereo photo series for quantifying natural fuels. Volume VIa: sand hill, sand pine scrub, and hardwoods with white pine types in the Southeast United States with supplemental sites for volume VI. PMS 838. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 78 p. (JFSP-01-1-7-02)	In progress

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Appendix A
Site Summary Data

Table A.1. Site summary of loblolly pine litter depth samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Litter Avg Depth (in)
Loblolly Pine	Bank 04	6/15/2005	15	1.70
	BR 02	4/23/2005	4	1.70
	BR 02 (02)	5/17/2005	13	1.63
	BR 03	4/23/2005	13	1.23
	BR 04	4/23/2005	15	1.23
	MF 01	5/23/2005	15	1.33
	MO 02	5/18/2005	3	1.39
	MO 03	5/18/2005	14	1.28
	SUM 01	5/19/2005	15	1.43
	SUM 02	5/21/2005	15	0.96
	SUM 03	5/21/2005	14	1.24
	SUM 04	5/21/2005	15	1.36
	SUM 06	5/22/2005	15	1.34
Loblolly Pine Total			166	1.35

Table A.2. Site summary of loblolly pine duff depth samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Duff Avg Depth (in)
Loblolly Pine	Bank 04	06/15/05	15	0.95
	BR 02	04/23/05	4	0.58
	BR 02 (02)	05/17/05	13	1.04
	BR 03	04/23/05	9	0.60
	BR 04	04/23/05	3	0.38
	MF 01	05/23/05	14	1.24
	MO 02	05/18/05	3	1.09
	MO 03	05/18/05	11	0.68
	SUM 01	05/19/05	15	0.80
	SUM 02	05/21/05	13	0.58
	SUM 03	05/21/05	6	0.32
	SUM 04	05/21/05	14	0.83
	SUM 06	05/22/05	13	0.44
Loblolly Pine Total			133	0.78

Table A.3. Site summary of slash pine litter depth samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Litter Avg Depth (in)
Slash Pine	AP-338	4/18/2005	15	1.57
	AP-348	4/19/2005	15	1.99
	AP4A	4/21/2005	14	2.12
	AP-70	4/21/2005	15	2.18
	AP-85	4/21/2005	15	1.37
	AP-94	4/16/2005	15	2.19
	APAL-04	4/19/2005	14	1.86
	Desoto 01	2/21/2005	8	1.18
	Desoto 03	2/20/2005	14	1.51
	MO 01	5/18/2005	13	1.53
	Sandhill 01	2/22/2005	15	1.41
	Sandhill 02	2/21/2005	15	1.76
	Sandhill 03	2/21/2005	15	1.61
	Sandhill 04	2/22/2005	15	1.66
	Sandhill 05	2/23/2005	15	1.38
	SM 01	6/10/2005	2	1.55
	SM 02	6/10/2005	3	1.09
	SM 03		3	1.22
	SM 05		8	1.43
Slash Pine Total			229	1.68

Table A.4. Site summary of slash pine duff depth samples site ID.

Forest Type	Site ID	Sample Date	#Samples	Duff Avg Depth (in)
Slash Pine	AP-338	04/18/05	9	0.74
	AP-348	04/19/05	10	1.00
	AP4A	04/21/05	13	0.96
	AP-70	04/21/05	8	0.79
	AP-85	04/21/05	11	0.55
	AP-94	04/16/05	13	0.75
	APAL-04	04/19/05	8	0.51
	Desoto 01	02/21/05	8	1.24
	Desoto 03	02/20/05	14	1.71
	MO 01	05/18/05	13	1.00
	Sandhill 01	02/22/05	15	0.82
	Sandhill 02	02/21/05	15	2.06
	Sandhill 03	02/21/05	15	2.41
	Sandhill 04	02/22/05	15	1.09
	Sandhill 05	02/23/05	15	1.21
	SM 01	06/10/05	2	1.25
	SM 02	06/10/05	3	1.09
	SM 03	(blank)	3	0.74
	SM 05	(blank)	5	0.47
Slash Pine Total			195	1.16

Table A.5. Site summary of shortleaf pine litter depth samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Litter Avg Depth (in)
Shortleaf Pine	CNF 01B	7/24/2005	15	1.13
	HS-02	10/24/2005	14	1.47
	HS-03	10/25/2005	6	1.47
	HS-04	10/25/2005	15	1.42
	HS-05	10/24/2005	15	1.14
	HS-06	10/24/2005	15	1.78
	Ouch 01	10/21/2005	12	1.49
	Ouch 02	10/22/2005	15	1.22
	Ouch 03	10/23/2005	14	1.32
	Ouch 04	10/23/2005	12	1.36
	Ouch 06	10/22/2005	14	1.27
	Ouch 07	10/23/2005	14	1.28
	Ouch 09	10/22/2005	15	1.47
Shortleaf Pine Total			176	1.37

Table A.6. Site summary of shortleaf pine duff depth samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Duff Avg Depth (in)
Shortleaf Pine	CNF 01B	07/24/05	14	0.95
	HS-02	10/24/05	6	0.46
	HS-03	10/25/05	2	0.55
	HS-04	10/25/05	4	0.45
	HS-05	10/24/05	13	0.54
	HS-06	10/24/05	5	0.47
	Ouch 01	10/21/05	12	0.52
	Ouch 02	10/22/05	15	0.79
	Ouch 03	10/23/05	11	0.66
	Ouch 04	10/23/05	11	0.80
	Ouch 06	10/22/05	13	0.88
	Ouch 07	10/23/05	10	0.62
	Ouch 09	10/22/05	15	0.47
Shortleaf Pine Total			131	0.67

Table A.7. Site summary of mixed pine and hardwood litter depth samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Litter Avg Depth (in)
Mixed Pine & HW	Bank 01	6/15/2005	14	1.14
	Bank 03	6/15/2005	15	1.55
	CNF 02A	7/25/2005	15	1.39
	CNF 03	7/23/2005	14	1.17
	CNF 04	7/23/2005	12	1.41
	CNF 06	7/22/2005	13	1.49
	SUM 05	5/22/2005	14	1.36
	TAL 06B	12/3/2005	15	2.35
	TAL 07	6/17/2005	15	1.37
	TAL 07B	12/3/2005	29	2.06
	TAL 08	6/17/2005	15	1.47
Mixed Pine & HW Total			171	1.57

Table A.8. Site summary of mixed pine and hardwood duff depth samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Duff Avg Depth (in)
Mixed Pine & HW	Bank 01	06/15/05	12	0.83
	Bank 03	06/15/05	15	0.95
	CNF 02A	07/25/05	13	0.88
	CNF 03	07/23/05	11	0.98
	CNF 04	07/23/05	12	1.38
	CNF 06	07/22/05	13	1.64
	SUM 05	05/22/05	14	0.46
	TAL 06B	12/03/05	15	1.06
	TAL 07	06/17/05	15	1.49
	TAL 08	06/17/05	14	0.93
Mixed Pine & HW Total			134	1.06

Table A.9. Site summary of hardwood litter depth samples site ID.

Forest Type	Site ID	Sample Date	#Samples	Litter Avg Depth (in)
Hardwood	CNF 01A	7/24/2005	14	1.51
	CNF 01A/B	12/1/2005	14	2.18
	CNF 02B	7/23/2005	13	1.55
	CNF 05	7/22/2005	12	1.39
	CNF 07	7/22/2005	10	1.54
	CNF 08	7/22/2005	25	1.40
	LLP 01	6/12/2005	12	0.98
	LLP 01B	12/2/2005	13	2.27
	LLP 02	6/13/2005	15	1.32
	LLP 02B	12/2/2005	15	2.25
	LLP 04	6/12/2005	15	0.88
	LLP 04B	12/2/2005	14	2.16
	NP 01	7/20/2005	14	1.49
	NP 01B	11/30/2005	15	2.38
	NP 02	7/20/2005	15	1.38
	NP 02B	11/30/2005	14	2.05
	NP 03	7/20/2005	13	1.27
	NP 03B	11/30/2005	15	2.03
	NP 04	7/21/2005	15	1.41
	NP 04B	11/30/2005	30	1.96
	NP 05	7/20/2005	13	1.70
	NP 06	7/20/2005	15	1.87
	NP 06B	11/30/2005	15	2.40
	NP 07	7/19/2005	14	1.59
	NP 07B	11/30/2005	14	2.36
	TAL 01	6/13/2005	15	1.23
	TAL 01B	12/3/2005	15	1.60
	TAL 02	6/14/2005	14	1.47
	TAL 02B	12/3/2005	14	1.83
	TAL 03	6/14/2005	15	1.30
	TAL 03B	12/3/2005	15	1.87
	TAL 04	6/16/2005	14	1.67
	TAL 04B	12/4/2005	14	1.94
	TAL 05	6/16/2005	15	1.39
	TAL 05B	12/3/2005	15	2.13
Hardwood Total			520	1.71

Table A.10. Site summary of hardwood duff depth samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Duff Avg Depth (in)
Hardwood	CNF 01A	07/24/05	13	0.57
	CNF 02B	07/23/05	12	0.92
	CNF 05	07/22/05	9	0.75
	CNF 07	07/22/05	9	0.76
	LLP 01	06/12/05	5	0.39
	LLP 02	6/13/05	13	0.73
	LLP 04	6/12/05	13	0.53
	NP 01	07/20/05	13	0.95
	NP 02	07/20/05	15	1.09
	NP 03	07/20/05	13	1.76
	NP 04	07/21/05	13	0.65
	NP 05	07/20/05	9	0.80
	NP 06	07/20/05	1	0.95
	NP 07	07/19/05	14	2.21
	TAL 01	06/13/05	11	0.47
	TAL 02	06/14/05	9	0.42
	TAL 03	06/14/05	12	0.70
	TAL 04	06/16/05	13	0.67
	TAL 05	06/16/05	14	0.77
Hardwood Total			211	0.88

Table A.11. Site summary of loblolly pine litter bulk density samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Litter Avg BD (t/ac/in)
Loblolly Pine	Bank 04	6/15/2005	15	2.47
	BR 02	4/23/2005	4	3.29
	BR 02 (02)	5/17/2005	13	2.08
	BR 03	4/23/2005	13	2.60
	BR 04	4/23/2005	15	2.15
	MF 01	5/23/2005	15	1.89
	MO 02	5/18/2005	3	2.66
	MO 03	5/18/2005	14	1.97
	SUM 01	5/19/2005	15	1.63
	SUM 02	5/21/2005	15	2.03
	SUM 03	5/21/2005	14	3.03
	SUM 04	5/21/2005	15	2.11
	SUM 06	5/22/2005	15	2.03
Loblolly Pine Total			166	2.21

Table A.12. Site summary of loblolly pine duff bulk density samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Duff Avg BD (t/ac/in)
Loblolly Pine	Bank 04	06/15/05	15	5.23
	BR 02	04/23/05	4	9.34
	BR 02 (02)	05/17/05	13	5.65
	BR 03	04/23/05	9	6.55
	BR 04	04/23/05	3	5.09
	MF 01	05/23/05	14	6.35
	MO 02	05/18/05	3	7.27
	MO 03	05/18/05	11	6.30
	SUM 01	05/19/05	15	8.81
	SUM 02	05/21/05	13	6.82
	SUM 03	05/21/05	6	7.35
	SUM 04	05/21/05	14	6.59
	SUM 06	05/22/05	13	7.98
Loblolly Pine Total			133	6.80

Table A.13. Site summary of slash pine litter bulk density samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Litter Avg BD (t/ac/in)
Slash Pine	AP-338	4/18/2005	15	2.24
	AP-348	4/19/2005	15	1.97
	AP4A	4/21/2005	14	2.68
	AP-70	4/21/2005	15	1.88
	AP-85	4/21/2005	15	2.16
	AP-94	4/16/2005	15	2.19
	APAL-04	4/19/2005	14	2.61
	Desoto 01	2/21/2005	8	2.48
	Desoto 03	2/20/2005	14	2.16
	MO 01	5/18/2005	13	2.22
	Sandhill 01	2/22/2005	15	1.86
	Sandhill 02	2/21/2005	15	2.32
	Sandhill 03	2/21/2005	15	2.22
	Sandhill 04	2/22/2005	15	1.47
	Sandhill 05	2/23/2005	15	2.33
	SM 01	6/10/2005	2	1.50
	SM 02	6/10/2005	3	2.21
	SM 03		3	2.04
	SM 05		8	2.15
Slash Pine Total			229	2.16

Table A.14. Site summary of slash pine duff bulk density samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Duff Avg BD (t/ac/in)
Slash Pine	AP-338	04/18/05	9	5.99
	AP-348	04/19/05	10	5.88
	AP4A	04/21/05	13	7.88
	AP-70	04/21/05	8	9.45
	AP-85	04/21/05	11	7.16
	AP-94	04/16/05	13	5.13
	APAL-04	04/19/05	8	6.37
	Desoto 01	02/21/05	8	9.21
	Desoto 03	02/20/05	14	7.49
	MO 01	05/18/05	13	5.59
	Sandhill 01	02/22/05	15	6.50
	Sandhill 02	02/21/05	15	6.77
	Sandhill 03	02/21/05	15	6.36
	Sandhill 04	02/22/05	15	5.78
	Sandhill 05	02/23/05	15	8.91
	SM 01	06/10/05	2	4.57
	SM 02	06/10/05	3	5.51
	SM 03	(blank)	3	11.02
	SM 05	(blank)	5	5.98
Slash Pine Total			195	6.88

Table A.15. Site summary of shortleaf pine litter bulk density samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Litter Avg BD (t/ac/in)
Shortleaf Pine	CNF 01B	7/24/2005	15	2.38
	HS-02	10/24/2005	14	1.63
	HS-03	10/25/2005	6	1.75
	HS-04	10/25/2005	15	1.72
	HS-05	10/24/2005	15	1.88
	HS-06	10/24/2005	15	1.92
	Ouch 01	10/21/2005	12	1.82
	Ouch 02	10/22/2005	15	2.25
	Ouch 03	10/23/2005	14	2.03
	Ouch 04	10/23/2005	12	2.00
	Ouch 06	10/22/2005	14	2.18
	Ouch 07	10/23/2005	14	1.68
	Ouch 09	10/22/2005	15	1.84
Shortleaf Pine Total			176	1.94

Table A.16. Site summary of shortleaf pine duff bulk density samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Duff Avg BD (t/ac/in)
Shortleaf Pine	CNF 01B	07/24/05	14	5.32
	HS-02	10/24/05	6	5.21
	HS-03	10/25/05	2	6.33
	HS-04	10/25/05	4	4.88
	HS-05	10/24/05	13	4.83
	HS-06	10/24/05	5	4.89
	Ouch 01	10/21/05	12	6.16
	Ouch 02	10/22/05	15	6.22
	Ouch 03	10/23/05	11	6.03
	Ouch 04	10/23/05	11	6.61
	Ouch 06	10/22/05	13	7.22
	Ouch 07	10/23/05	10	6.13
	Ouch 09	10/22/05	15	7.04
Shortleaf Pine Total			131	6.05

Table A.17. Site summary of mixed pine and hardwood litter bulk density samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Litter Avg BD (t/ac/in)
Mixed Pine & HW	Bank 01	6/15/2005	14	2.20
	Bank 03	6/15/2005	15	1.92
	CNF 02A	7/25/2005	15	1.77
	CNF 03	7/23/2005	14	1.54
	CNF 04	7/23/2005	12	1.80
	CNF 06	7/22/2005	13	1.68
	SUM 05	5/22/2005	14	2.26
	TAL 06B	12/3/2005	15	1.77
	TAL 07	6/17/2005	15	1.74
	TAL 07B	12/3/2005	29	1.31
	TAL 08	6/17/2005	15	1.80
Mixed Pine & HW Total			171	1.76

Table A.18. Site summary of mixed pine and hardwood duff bulk density samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Duff Avg BD (t/ac/in)
Mixed Pine & HW	Bank 01	06/15/05	12	7.67
	Bank 03	06/15/05	15	4.95
	CNF 02A	07/25/05	13	5.64
	CNF 03	07/23/05	11	6.03
	CNF 04	07/23/05	12	5.19
	CNF 06	07/22/05	13	5.80
	SUM 05	05/22/05	14	8.38
	TAL 06B	12/03/05	15	4.37
	TAL 07	06/17/05	15	5.45
	TAL 08	06/17/05	14	5.92
Mixed Pine & HW Total			134	5.90

Table A.19. Site summary of hardwood litter bulk density samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Litter Avg BD (t/ac/in)
Hardwood	CNF 01A	7/24/2005	14	1.10
	CNF 01A/B	12/1/2005	14	1.10
	CNF 02B	7/23/2005	13	1.36
	CNF 05	7/22/2005	12	1.17
	CNF 07	7/22/2005	10	1.26
	CNF 08	7/22/2005	25	1.48
	LLP 01	6/12/2005	12	1.57
	LLP 01B	12/2/2005	13	0.85
	LLP 02	6/13/2005	15	1.76
	LLP 02B	12/2/2005	15	0.91
	LLP 04	6/12/2005	15	1.76
	LLP 04B	12/2/2005	14	0.89
	NP 01	7/20/2005	14	1.06
	NP 01B	11/30/2005	15	0.87
	NP 02	7/20/2005	15	1.26
	NP 02B	11/30/2005	14	1.00
	NP 03	7/20/2005	13	1.24
	NP 03B	11/30/2005	15	1.06
	NP 04	7/21/2005	15	1.06
	NP 04B	11/30/2005	30	0.84
	NP 05	7/20/2005	13	1.34
	NP 06	7/20/2005	15	1.22
	NP 06B	11/30/2005	15	1.00
	NP 07	7/19/2005	14	1.52
	NP 07B	11/30/2005	14	1.16
	TAL 01	6/13/2005	15	1.76
	TAL 01B	12/3/2005	15	1.02
	TAL 02	6/14/2005	14	1.58
	TAL 02B	12/3/2005	14	1.14
	TAL 03	6/14/2005	15	1.77
	TAL 03B	12/3/2005	15	1.20
	TAL 04	6/16/2005	14	0.95
	TAL 04B	12/4/2005	14	1.09
	TAL 05	6/16/2005	15	1.18
	TAL 05B	12/3/2005	15	0.97
Hardwood Total			520	1.21

Table A.20. Site summary of hardwood duff bulk density samples by site ID.

Forest Type	Site ID	Sample Date	#Samples	Duff Avg BD (t/ac/in)
Hardwood	CNF 01A	07/24/05	13	4.05
	CNF 02B	07/23/05	12	4.83
	CNF 05	07/22/05	9	4.39
	CNF 07	07/22/05	9	3.12
	LLP 01	06/12/05	5	4.12
	LLP 02	6/13/05	13	4.71
	LLP 04	6/12/05	13	5.82
	NP 01	07/20/05	13	3.35
	NP 02	07/20/05	15	4.45
	NP 03	07/20/05	13	4.96
	NP 04	07/21/05	13	3.46
	NP 05	07/20/05	9	4.39
	NP 06	07/20/05	1	4.31
	NP 07	07/19/05	14	5.69
	TAL 01	06/13/05	11	7.02
	TAL 02	06/14/05	9	7.04
	TAL 03	06/14/05	12	6.21
	TAL 04	06/16/05	13	4.37
	TAL 05	06/16/05	14	5.08
Hardwood Total			211	4.84