Quick Estimates of Carbon in Longleaf Pine Plantations Using Carbon-Basal Area Ratios (CBAR)

Forest carbon markets have once again become an opportunity for forest landowners to receive supplemental income. At a basic level, these markets allow industries that are emitting carbon during their production process to offset those emissions by purchasing carbon credits from others that are sequestering carbon beyond their usual practices. Carbon credits can be purchased from forest landowners who are sequestering carbon beyond what they normally would do without the presence of a forest carbon market—or their business-as-usual (BAU) forest management practices.

Increasingly, Mississippi nonindustrial private forest (NIPF) landowners, often referred to as family forest owners, who own smaller acreages (100 acres or less), have access to forest carbon markets that allow them to participate more actively. NIPF and larger public and private forest landowners alike will be interested in knowing how many metric tons of carbon and carbon dioxide equivalents (abbreviated as $MtCO_2e$) their longleaf pine (*Pinus palustris* Mill.) plantation is sequestering and storing.

This publication describes a quick and low-cost way to obtain a carbon-per-acre estimate. It then shows how carbon per acre is converted into metric tons and how carbon is converted into metric tons of CO_2 equivalents by using basic assumptions about the chemistry of wood. By using variable-radius sampling, we can take advantage of relationships between tree stem growth and carbon production to quickly estimate carbon per acre.

Estimating Carbon Using Variable-Radius Sampling and Carbon-Basal Area Ratios

Basal area per acre is a useful measure to estimate the site occupancy of trees in a forest. Using variable-radius sampling, you can quickly estimate basal area by simply counting the number of "in" trees, or sample trees, and then multiplying this number by the basal area factor (BAF) used to determine the number of sample trees.

Historically, volume-basal area ratios (VBARs) and weight-basal area ratios (WBARs) have been commonly associated with variable-radius sampling. This publication uses a carbon-basal area ratio (CBAR). We can assume that for each square foot increase in basal area, there is an associated increase in carbon.

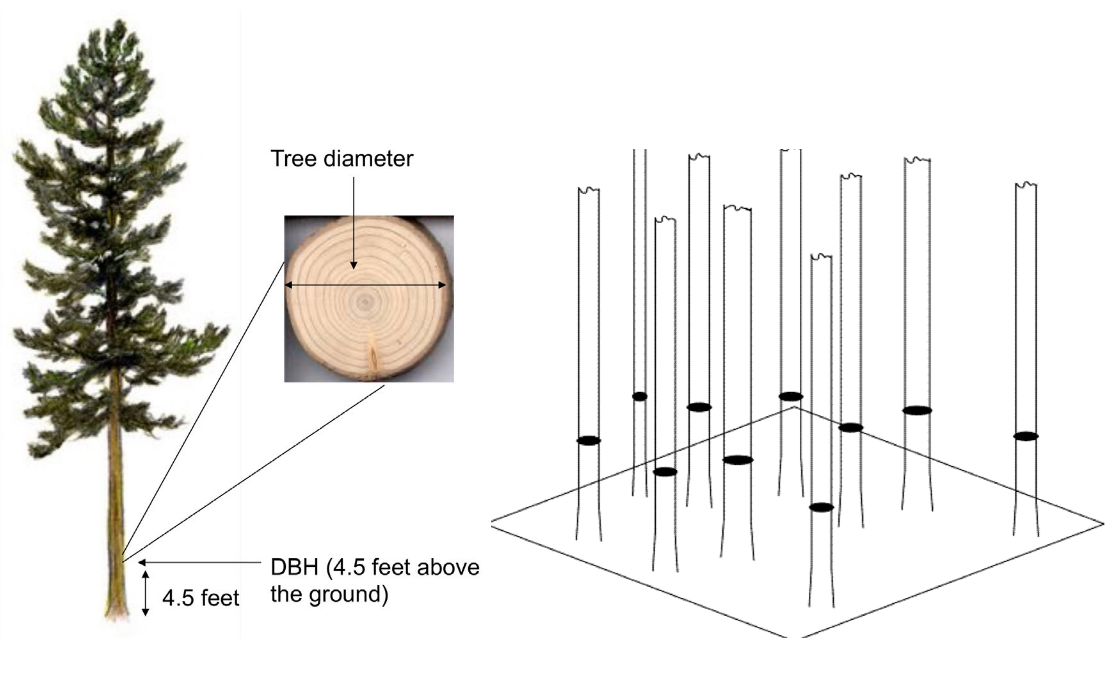

Figure 1. Basal area of a forest at a height of 4.5 feet above the ground (diameter at breast height or DBH) is a common measure used to quantify site occupancy of the overstory trees. It gives us an idea of the amount of competition for limited site resources of light, moisture, and nutrients. Subsequently, it is commonly used as a tool to determine when thinnings or other forest management techniques should be conducted. It is also an indirect measure of wildlife habitat structure.

Figure 2. There is often a strong relationship between the basal area of a longleaf pine plantation and the amount of carbon being sequestered and stored within the overstory trees. Additionally, basal area is often a very good predictor of understory biomass. If there is a strong relationship (or strong correlation) between basal area and carbon, then by knowing basal area per acre, you essentially know carbon per acre. We can use this to our advantage. Basal area can be quickly obtained using variable-radius sampling protocols, and then a regionwide carbon-basal area ratio (CBAR) can be used to estimate carbon per acre in the trees.

Variable-radius sampling is known by a variety of names, including point sampling, horizontal-point sampling, angle-gauge sampling, horizontal-angle sampling, and prism sampling. Due to the protocol of variable-radius sampling, for a particular BAF, a sample tree always represents the same amount of basal area per acre. For example, if a 20 BAF is used, each "in" tree (each sampled tree) represents 20 square feet of basal area per acre. The most common BAF in this region is a 10 BAF, but often a 20 BAF is preferable, and a 5 BAF could be useful, as well. Remember, it is best to sample around six to ten trees per sampling point. For the sake of convention, the term "point" is used rather than "plot" since we are referring to inventories being conducted using variable-radius sampling and not fixed-radius plot sampling.

When conducting quick assessments, it is often sufficient to estimate carbon based upon the easily and quickly obtained basal area per acre. After obtaining an estimate of basal area per acre, the amount of carbon per acre can be calculated by simply multiplying that amount by an average CBAR. Individual tree diameters and heights do not need to be measured. To estimate carbon per acre, for example, use the following formula:

Carbon Per Acre = CBAR x BA

Where:

CBAR = average carbon-basal area ratio

BA = an estimate of basal area per acre from variable-radius points

There are several methods for obtaining an estimate of basal area per acre:

- Simply use your thumb (Figure 3).
- Use the MSU Basal Area Angle Gauge.
- Perform a quick prism sweep of the forest.
- Use a Jim-Gem Cruz-All.

Calculations can be as simple as establishing three or four sample points within a forest and then averaging the three or four basal area per acre estimates. Or you can perform a more extensive inventory—one point per acre or the number of points necessary to meet your desired level of precision. The sampling approach described here is for those cases when a relatively low intensity of sampling is sufficient. This inventory protocol will provide only basic information about a landowner's forested condition. Basal area often can be estimated in 2 minutes or less at an individual point using one of the methods listed above or any other method of projecting horizontal angles.

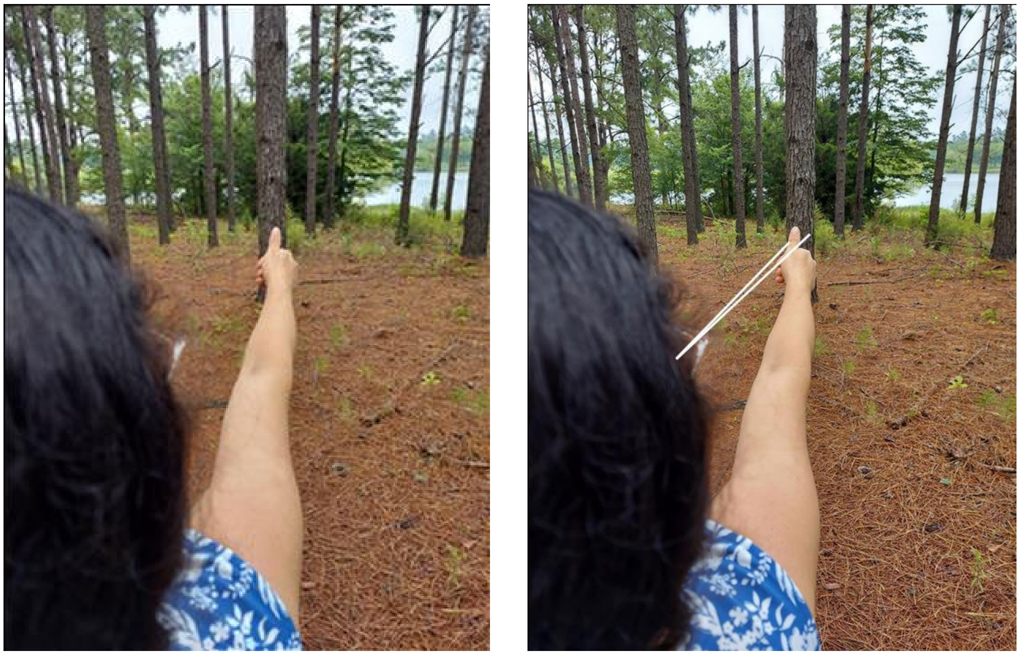

Figure 3. You can use your thumb to project an "imaginary" horizontal angle, which can be equated to a basal area factor (BAF). If you extend your thumb some distance from your eye, assuming the vertex of the angle (where the angle begins) is located in your eye, then an imaginary horizontal angle is projected out to your thumb and beyond (depicted on the right). This is the same approach used for stick angle-gauges, Cruz-All tools, etc. Depending on the width of your thumb and your arm distance, you can use this approach to generate your own BAF. Whenever the width of your thumb is smaller than the tree at DBH, the tree is "in." To obtain basal area per acre, just multiply the number of "in" trees at each point by your thumb-specific BAF.

The Importance of Knowing the Definition of Carbon

If you know about forest carbon or have participated in forest carbon markets, you know there is a wide range of interpretations, verbiage, definitions, units, and carbon pools that can be included or excluded from a particular analysis and carbon market. *Carbon pool* refers to the components of a forest that are sequestering carbon. From a forest carbon market perspective, it refers to the components of a forest that are being evaluated for their sequestration and storage.

When we talk about the amount of carbon being stored in a forest, there are terms that need definition. For instance, are we talking about the amount of carbon within tree stems, or are branches included? Are roots and foliage also included? Within a longleaf pine plantation, is it just the longleaf pine trees, or does it also include other pine species, or any hardwoods such as oak, hickory, or sweetgum? For the trees, is it only the living material or dead material as well? Is the understory vegetation carbon pool being considered? Carbon markets have also tried to monitor the amount of carbon sequestered and stored in harvested wood products obtained from forests, such as the long-term carbon stored in lumber, plywood, paper, or other products.

As you can see, it is essential that you know what carbon pools are being included in your estimate. Also, what units of measurement are you using—pounds, tons, or metric tons? Are you measuring basal area in square feet per acre or square meters per hectare?

For this publication, carbon estimates are only for the *living* trees sampled during the basal area inventory. Additionally, the amount of carbon being sequestered, or stored, includes only the woody components of a tree, so the foliage is not included in the carbon estimate. Both aboveground and belowground woody components are estimated, so roots are included. Therefore, the carbon estimates presented here are not exhaustive.

Converting Carbon into Metric Tons

Carbon is often reported, described, and discussed in terms of metric tons (about 2,205 pounds). To use the approach described in this publication, any carbon estimate must first be in pounds. After converting the estimate to pounds, divide it by 2,205 to convert to metric tons.

Users may also see carbon reported in metric units; one common unit is kilograms. To convert from kilograms to pounds, multiply the kilogram estimate by 2.205.

Occasionally carbon is reported in tons (not metric tons). In these instances, divide the carbon in pounds by 2,000.

Always make sure that you clearly understand the units of a carbon measurement.

Converting Carbon into Metric Tons of Carbon Dioxide Equivalents

Many people talk about metric tons of CO_2 equivalents (abbreviated as $MtCO_2e$). You can calculate a CO_2 equivalent based on the atomic weights (mass) of carbon and oxygen. Carbon has an atomic weight around 12, and oxygen has an atomic weight around 16 ($12 + [16 \times 2] = 44$). If we divide 44 from CO_2 by 12 from carbon, we get a multiplier for CO_2 equivalency of $44 \div 12 = 3.667$. To determine the amount of CO_2 being sequestered within a forest, multiply any carbon estimate by 3.667. This constant applies whether carbon is in pounds, kilograms, tons (2,000 pounds), or metric tons (about 2,205 pounds). For simplicity, we assume this exact multiplier applies to all tree species.

Estimating Carbon

Example 1: Estimating Carbon per Acre of Longleaf Pine

A landowner has heard a lot about forest carbon markets and the benefits of carbon sequestration for the environment. They are curious about how much carbon is "sequestered" in the longleaf pine trees in their 20-year-old plantation.

This example assumes that they use the thumb method to obtain an estimate of basal area per acre. For this example, assume that their thumb has a BAF of 8. They establish three points and have a total of 39 sample trees. Across the three points, the average basal area per acre is 104 square feet (8 BAF $\times$ 13 sample trees per point on average = 104 square feet). For simplicity and to use Table 1, they round the 104 square feet per acre to 105 square feet. Based on Table 1, they obtain a CBAR of 578 pounds. They then multiply 578 by 104 square feet; this yields an estimate of around 60,112 pounds of carbon per acre being stored in their plantation.

Next, they convert the pounds of carbon per acre into metric tons by dividing 60,112 pounds per acre by 2,205 pounds. They estimate their 20-year-old plantation is sequestering around 27.26 metric tons per acre.

Further, many people talk about metric tons of CO_2 equivalents ($MtCO_2e$). When using the multiplier of 3.667 as described earlier, this landowner's forest has a CO_2 equivalent of around 99.96 metric tons, or 99.96 $MtCO_2e$ (27.26 metric tons of carbon per acre $\times$ 3.667 = 99.96 $MtCO_2e$).

Example 2: Estimating Carbon per Acre of Longleaf Pine and Hardwoods

Let's assume that you are meeting with an Extension specialist or consulting forester and decide to "walk" your property, which is a longleaf pine plantation that also contains some hardwoods. You are not sure of the age of the plantation because you recently inherited the property.

Out of curiosity, the consultant decides to quickly measure three variable-radius sampling points by using a 10 BAF prism. Across the three points, the average longleaf pine basal area per acre is estimated to be 120 square feet per acre. In addition, the hickory basal area per acre is 10 square feet, sweetgum is 20 square feet, and ash is 3.33 square feet. How do you get 3.33 square feet when using three points? Remember, the average basal area per acre estimate is across the three points. Thus, at two points, there were no "in," or sample, ash trees; at one point, there was one ash tree sampled. Since the consultant used a 10 BAF prism, across the three points, on average, there are 3.33 square feet per acre ($10 \div 3$).

Since you don't know the age of the forest, and you want to estimate carbon for species other than longleaf pine, you must use Table 3. If we knew the forest age, only for longleaf pine, we could first use Tables 1 or 2 and then use Table 3 to estimate carbon for all other species. Also, notice in Table 3 that there is no CBAR specifically for ash trees. Ash is lumped into the "other hardwood" category, and you will use a CBAR of 403 pounds per square foot of basal area. Therefore, your estimate is 1,341.99 pounds of carbon per acre in ash (403 pounds $\times$ 3.33 square feet of basal area per acre).

A similar procedure is used for the hickory and sweetgum, resulting in 6,240 and 6,860 pounds per acre of carbon in these trees, respectively. For longleaf pine, since you don't know the age, you cannot use Tables 1 and 2, so you need to use Table 3. In this example, you have 120 square feet per acre of basal area of longleaf pine. And the number of pounds per square foot of basal area is 710. Therefore, your estimate is 85,200 pounds per acre of carbon in these longleaf pine trees.

Example 3: Estimating Carbon per Acre of Longleaf Pine and Other Pine Species

In this example, let's assume you want to find out how much carbon is sequestered in the pine trees of a 55-year-old longleaf pine plantation. However, it includes some pine species other than longleaf pine. In this case, you establish two points using the MSU Basal Area Angle Gauge, which has a BAF of 10. Across the two points, there are 14 sampled longleaf pine trees, or "in" trees, resulting in 140 square feet of basal area; since there are two points, you must divide that number by two to obtain an average basal area per acre of 70 square feet (10 BAF × 14 "in" trees on two points; average = 70 square feet). Table 2 estimates that the forest is sequestering 24.53 metric tons per acre. Table 1 gives the same value (773 × 70 square feet per acre ÷ 2,205).

In addition to the longleaf pine trees, there are also three "in" trees of loblolly pine, across the two points. Thus, three trees multiplied by 10 square feet of basal area equals 30 square feet; when divided by two points, we obtain an estimate of 15 square feet of basal area per acre. We can use the "other pine" category in Table 3 for these loblolly pine trees. For the "other pine" category, the amount of carbon is estimated to be 600 pounds per square foot of basal area. Therefore, we estimate there are around 9,000 pounds of carbon per acre (600 × 15 square feet of basal area). For metric tons, we can divide the 9,000 pounds by 2,205 (pounds per metric ton) and get 4.08 metric tons per acre.

For $MtCO_2e$, the CO_2 equivalency multiplier of 44 ÷ 12 = 3.667 should be used. Remember that, in forestry, we often make simplifying assumptions given the costs of obtaining more detailed measurements, so we assume across all species that the 3.667 constant is applicable. Thus, this forest has a CO_2 equivalent of around 89.95 $MtCO_2e$ for the longleaf pine and around 14.96 $MtCO_2e$ for the loblolly pine. These two values total to 104.91 $MtCO_2e$.

Other Potential Applications

Carbon estimates obtained using this CBAR approach can also be used to quickly validate carbon estimates obtained through other sampling protocols. For example, inexperienced foresters could quickly double-check their estimates using another approach. Consulting foresters can provide a quick estimate of carbon per acre when initially meeting with landowners.

There are likely other applications of the presented average CBARs. For instance, LiDAR (light detection and ranging, a remote sensing method) often provides an acceptable estimate of basal area per acre, but the approach currently does not directly provide estimates of sufficient quality for carbon. The CBAR approach described here could be used to provide estimates of carbon per acre when using LiDAR to conduct inventories. Alternatively, for longleaf pine, the per-acre values in Table 2, based on the CBARs in Table 1, could be used along with the LiDAR basal area estimate.

Table 1. CBARs (in pounds) presented below can be used for longleaf pine based on the basal area per acre estimate (at DBH, 4.5 feet above the ground) and when stand age is known.[1]

Basal Area Per Acre (sq ft)	Stand Age (years)															
	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
10	104	203	273	327	372	409	442	471	497	520	541	561	579	596	611	626
15	156	255	326	380	425	462	495	524	549	573	594	613	631	648	664	679
20	194	293	363	417	462	500	532	561	587	610	631	651	669	686	701	716
25	223	322	392	446	491	529	561	590	616	639	660	680	698	715	730	745
30	246	345	416	470	515	552	585	614	639	663	684	703	721	738	754	769
35	266	365	436	490	535	572	605	634	659	683	704	723	742	758	774	789
40	284	383	453	507	552	590	622	651	677	700	721	741	759	776	791	806
45	299	398	468	523	567	605	638	666	692	715	737	756	774	791	807	822
50	313	412	482	536	581	619	651	680	706	729	750	770	788	805	820	835
55	325	424	494	549	593	631	664	692	718	741	763	782	800	817	833	848
60	336	435	506	560	605	642	675	704	729	753	774	793	812	828	844	859
65	347	446	516	571	615	653	685	714	740	763	784	804	822	839	855	869
70	356	455	526	580	625	662	695	724	749	773	794	813	832	848	864	879
75	365	464	535	589	634	671	704	733	758	782	803	822	841	857	873	888
80	374	473	543	598	642	680	712	741	767	790	811	831	849	866	882	896
85		481	551	605	650	688	720	749	775	798	819	839	857	874	889	904
90		488	558	613	657	695	728	756	782	805	827	846	864	881	897	912
95		495	565	620	664	702	735	763	789	812	834	853	871	888	904	919
100		502	572	627	671	709	741	770	796	819	840	860	878	895	911	925
105		508	578	633	677	715	748	776	802	825	847	866	884	901	917	932
110		514	584	639	683	721	754	782	808	831	853	872	890	907	923	938
115		520	590	645	689	727	759	788	814	837	858	878	896	913	929	943
120		526	596	650	695	732	765	794	819	843	864	884	902	918	934	949
125		531	601	656	700	738	770	799	825	848	869	889	907	924	940	954
130			606	661	705	743	775	804	830	853	874	894	912	929	945	959
135			611	666	710	748	780	809	835	858	879	899	917	934	950	964
140			616	670	715	752	785	814	840	863	884	904	922	938	954	969
145			620	675	719	757	790	818	844	867	889	908	926	943	959	974
150			625	679	724	761	794	823	848	872	893	913	931	947	963	978
155			629	683	728	766	798	827	853	876	897	917	935	952	967	982
160			633	688	732	770	802	831	857	880	901	921	939	956	972	986
165			637	692	736	774	806	835	861	884	905	925	943	960	976	990
170			641	696	740	778	810	839	865	888	909	929	947	964	979	994
175			645	699	744	781	814	843	869	892	913	933	951	967	983	998
180				703	747	785	818	846	872	895	917	936	954	971	987	1002
185				706	751	789	821	850	876	899	920	940	958	975	990	1005
190				710	754	792	825	853	879	902	924	943	961	978	994	1009
195				713	758	795	828	857	883	906	927	947	965	982	997	1012
200				717	761	799	831	860	886	909	930	950	968	985	1001	1015
205				720	764	802	835	863	889	912	934	953	971	988	1004	1019
210				723	767	805	838	866	892	915	937	956	974	991	1007	1022

[1]CBARs are calculated using CBAR = -757.771 + 129.9496 × ln(baacre) + 244.1472 × ln(Age), n = 508, Adj. R^2 = 0.6141. After calculating the amount of carbon per acre in pounds based on the CBAR and basal area, divide by 2,000 for tons of carbon or 2,205 for metric tons of carbon.

Table 2. Metric tons of carbon per acre (2,205 pounds per metric ton) estimates based on the CBARs presented in Table 1.

Basal Area Per Acre (sq ft)	Stand Age (years)															
	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
10	0.47	0.92	1.24	1.48	1.69	1.86	2.00	2.14	2.25	2.36	2.45	2.54	2.62	2.70	2.77	2.84
15	1.06	1.74	2.21	2.59	2.89	3.14	3.37	3.56	3.74	3.89	4.04	4.17	4.30	4.41	4.52	4.62
20	1.76	2.65	3.29	3.79	4.19	4.53	4.83	5.09	5.32	5.53	5.72	5.90	6.07	6.22	6.36	6.50
25	2.52	3.65	4.44	5.06	5.57	5.99	6.36	6.69	6.98	7.24	7.48	7.71	7.91	8.10	8.28	8.45
30	3.35	4.70	5.65	6.40	7.00	7.51	7.96	8.35	8.70	9.01	9.30	9.57	9.82	10.05	10.26	10.46
35	4.23	5.80	6.91	7.78	8.49	9.08	9.60	10.06	10.47	10.84	11.17	11.48	11.77	12.04	12.29	12.52
40	5.15	6.94	8.22	9.21	10.01	10.70	11.29	11.81	12.28	12.70	13.08	13.44	13.77	14.07	14.36	14.63
45	6.10	8.12	9.56	10.67	11.58	12.35	13.01	13.60	14.12	14.60	15.03	15.43	15.80	16.14	16.46	16.77
50	7.09	9.34	10.93	12.16	13.17	14.03	14.77	15.42	16.00	16.53	17.01	17.45	17.87	18.25	18.60	18.94
55	8.11	10.58	12.33	13.69	14.80	15.74	16.55	17.27	17.91	18.49	19.02	19.51	19.96	20.38	20.77	21.14
60	9.16	11.85	13.76	15.24	16.45	17.48	18.37	19.15	19.85	20.48	21.06	21.59	22.08	22.54	22.97	23.37
65	10.22	13.14	15.21	16.82	18.13	19.24	20.20	21.05	21.81	22.49	23.12	23.70	24.23	24.73	25.19	25.63
70	11.32	14.46	16.69	18.42	19.83	21.03	22.06	22.97	23.79	24.53	25.20	25.82	26.40	26.93	27.43	27.90
75	12.43	15.80	18.19	20.04	21.55	22.83	23.94	24.92	25.80	26.59	27.31	27.97	28.59	29.16	29.70	30.20
80	13.56	17.15	19.70	21.68	23.29	24.66	25.84	26.89	27.82	28.66	29.43	30.14	30.80	31.41	31.98	32.52
85		18.53	21.24	23.34	25.05	26.51	27.76	28.87	29.86	30.76	31.58	32.33	33.03	33.68	34.29	34.86
90		19.92	22.79	25.01	26.83	28.37	29.70	30.87	31.92	32.87	33.74	34.54	35.27	35.96	36.61	37.21
95		21.33	24.36	26.71	28.62	30.25	31.65	32.89	34.00	35.00	35.92	36.76	37.54	38.26	38.94	39.58
100		22.76	25.94	28.41	30.43	32.14	33.62	34.92	36.09	37.15	38.11	38.99	39.82	40.58	41.29	41.97
105		24.20	27.54	30.14	32.26	34.05	35.60	36.97	38.20	39.30	40.32	41.25	42.11	42.91	43.66	44.37
110		25.65	29.16	31.87	34.09	35.97	37.60	39.03	40.32	41.48	42.54	43.51	44.41	45.26	46.04	46.78
115		27.12	30.78	33.62	35.95	37.91	39.61	41.11	42.45	43.66	44.77	45.79	46.73	47.61	48.44	49.21
120		28.60	32.42	35.39	37.81	39.86	41.63	43.20	44.60	45.86	47.02	48.08	49.07	49.98	50.84	51.65
125		30.09	34.07	37.16	39.69	41.82	43.67	45.30	46.76	48.08	49.28	50.39	51.41	52.37	53.26	54.10
130			35.74	38.95	41.57	43.79	45.71	47.41	48.93	50.30	51.55	52.70	53.77	54.76	55.69	56.56
135			37.41	40.75	43.47	45.78	47.77	49.53	51.11	52.53	53.83	55.03	56.14	57.17	58.13	59.04
140			39.10	42.56	45.38	47.77	49.84	51.67	53.30	54.78	56.13	57.37	58.52	59.59	60.59	61.53
145			40.79	44.38	47.30	49.78	51.92	53.81	55.51	57.04	58.43	59.72	60.91	62.02	63.05	64.02
150			42.50	46.21	49.23	51.80	54.01	55.97	57.72	59.30	60.75	62.08	63.31	64.45	65.53	66.53
155			44.22	48.05	51.18	53.82	56.11	58.13	59.94	61.58	63.07	64.45	65.72	66.90	68.01	69.05
160			45.94	49.90	53.13	55.86	58.22	60.31	62.18	63.86	65.41	66.82	68.14	69.36	70.50	71.58
165			47.68	51.75	55.09	57.90	60.34	62.49	64.42	66.16	67.75	69.21	70.56	71.83	73.00	74.11
170			49.42	53.62	57.05	59.96	62.47	64.69	66.67	68.46	70.10	71.61	73.00	74.30	75.52	76.66
175			51.17	55.50	59.03	62.02	64.60	66.89	68.93	70.78	72.46	74.01	75.45	76.79	78.04	79.21
180				57.38	61.02	64.09	66.75	69.10	71.20	73.10	74.83	76.43	77.90	79.28	80.56	81.77
185				59.27	63.01	66.17	68.90	71.32	73.47	75.43	77.21	78.85	80.37	81.78	83.10	84.34
190				61.18	65.01	68.25	71.06	73.54	75.76	77.76	79.59	81.28	82.84	84.29	85.65	86.92
195				63.08	67.02	70.35	73.23	75.77	78.05	80.11	81.99	83.71	85.31	86.80	88.20	89.51
200				65.00	69.04	72.45	75.41	78.02	80.35	82.46	84.39	86.16	87.80	89.33	90.76	92.10
205				66.92	71.06	74.56	77.59	80.26	82.66	84.82	86.79	88.61	90.29	91.86	93.32	94.70
210				68.85	73.09	76.68	79.78	82.52	84.97	87.19	89.21	91.07	92.79	94.40	95.90	97.31

Table 3. Average CBARs by species or species group. *n* refers to the sample size used to estimate the species-specific CBAR. Carbon is only for living trees with DBH of 1 inch or greater and for the entire woody component of a tree, both aboveground and belowground, but excluding foliage.

Species/Species Group	*n*	CBAR (pounds)	CBAR (metric tons) CBAR ÷ 2,205	CBAR ($MtCO_2e$) CBAR ÷ 2,205 × 3.667
Longleaf pine	508	710	0.3218	1.1800
Hickory	11	624	0.2831	1.0382
Oak	255	549	0.2491	0.9135
Sweetgum	49	343	0.1554	0.5697
Other pine	184	600	0.2719	0.9972
Other hardwood	151	403	0.1828	0.6702
Other softwood (includes eastern redcedar and cypress)	4	356	0.1613	0.5916
All hardwood species	466	482	0.2184	0.8010

Appendix

Development of Carbon-Basal Area Ratios

For this publication, average CBARs were calculated using USDA Forest Inventory and Analysis (FIA) inventories of longleaf pine plantations in Alabama, northwestern Florida (UNITCD = 2 within the FIA database), Louisiana, Mississippi, and Texas. Within FIA, only those plots classified as longleaf pine (FORTYPCD = 141 within the FIA database) and planted (STDORGCD = 1) were selected. Only plots of 6 years or older were included. Plots with site indexes (base age 25) less than 30 feet and greater than 90 feet were deleted. All FIA plots with a basal area per acre (across all species) less than 10 square feet and greater than 275 square feet were deleted. Site index at base age 25 years used the FIA-reported site index at base age 50 years along with the appropriate equation from *Growth and Yields of Natural Stands of the Southern Pines* by F.X. Schumacher and T.S. Coile (1960). After meeting these criteria, the average forest age was 53 years old, and the youngest and oldest forests included were 7 and 99 years old, respectively.

In addition to the CBAR for longleaf pine itself, a CBAR was also calculated for all other species within these forests. CBARs were calculated for sweetgum (*Liquidambar styraciflua* L.) and select groups of several species. Select groups were oaks (*Quercus* spp.), hickories (*Carya* spp.), other pine (*Pinus* spp.) species ("other pine"), all other softwood species ("other softwood"), and then all other hardwood species ("other hardwood"). Finally, for those who just want an estimate when grouping together all hardwood species, use "all hardwood species," Table 3.

Summary of Data Used to Produce CBARs

Following is a summary of the data used to produce the CBARs presented in Tables 1, 2, and 3.

*Please note that carbon estimates in this publication are only for the **living** trees sampled during the basal area inventory. Additionally, the amount of carbon being sequestered, or stored, is **only** of the woody component, so the foliage is not included in the carbon estimate. Both aboveground and belowground components are estimated. However, forests contain many more carbon pools, such as dead trees, understory vegetation, and mushrooms. For these other carbon pools, there are both the aboveground and belowground components. Thus, the carbon estimates presented here are not exhaustive.

Table A1. Summary of the USDA Forest Service Forest Inventory and Analysis (FIA) plot data for those trees classified as merchantable—living trees with a minimum DBH of 5 inches. Volume and tons per acre are based on a 1-foot stump to a 4-inch top diameter outside-bark (DOB) limit. Tons per acre is based on 2,000 pounds per ton.

		Trees Per Acre			Basal Area Per Acre			Volume Per Acre			Tons Per Acre		
Species/Species Group	***n***	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Longleaf pine	501	80	6	313	60	2	252	1,729	17	9,584	42.7	0.5	174.0
Hickory	9	9	6	24	5	2	10	108	22	209	1.9	0.5	4.9
Oak	216	17	6	102	7	1	45	122	5	803	3.3	0.2	21.1
Sweetgum	32	8	6	18	5	1	29	116	5	727	2.4	0.2	10.6
Other pine	170	16	6	138	10	1	46	263	5	1,805	7.1	0.1	30.7
Other hardwood	116	14	6	102	6	1	38	110	6	777	2.8	0.1	23.3
Other softwood	2	6	6	6	1	1	1	11	9	12	0.3	0.3	0.4
All species	501	97	6	367	69	2	252	1,904	17	9,584	47.4	0.5	174.0

Table A2. Summary of the FIA plot data for all living trees of DBH 1 inch and greater. Carbon is metric tons (2,205 pounds) per acre.

		Trees Per Acre			Basal Area Per Acre			Carbon Per Acre		
Species/Species Group	***n***	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Longleaf pine	508	170	6	1,452	66	10	252	22	1	121
Hickory	11	28	6	81	5	0	12	2	0	4
Oak	255	116	6	831	10	0	64	3	0	17
Sweetgum	49	85	6	618	6	0	30	1	0	8
Other pine	184	32	6	375	10	1	46	3	0	19
Other hardwood	151	87	6	750	7	0	43	1	0	10
Other softwood	4	40	6	75	2	1	4	0.3	0	1
All species	508	274	6	1,806	77	11	252	25	1	121

For these longleaf pine plantations, site index (base age 25) averaged 48 feet and ranged from 30 feet to 80 feet. Site index at base age 25 used the reported site index at base age 50 along with the appropriate equation from *Growth and Yields of Natural Stands of the Southern Pines* (Schumacher and Coile, 1960).

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