Using Carbon-Basal Area Ratios (CBAR) for Quick Estimates of Carbon in Even-Aged Shortleaf Pine Forests

MISSISSIPPI STATE UNIVERSITY EXTENSION

Recently, 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 even-aged shortleaf pine (*Pinus echinata* Mill.) forest 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.

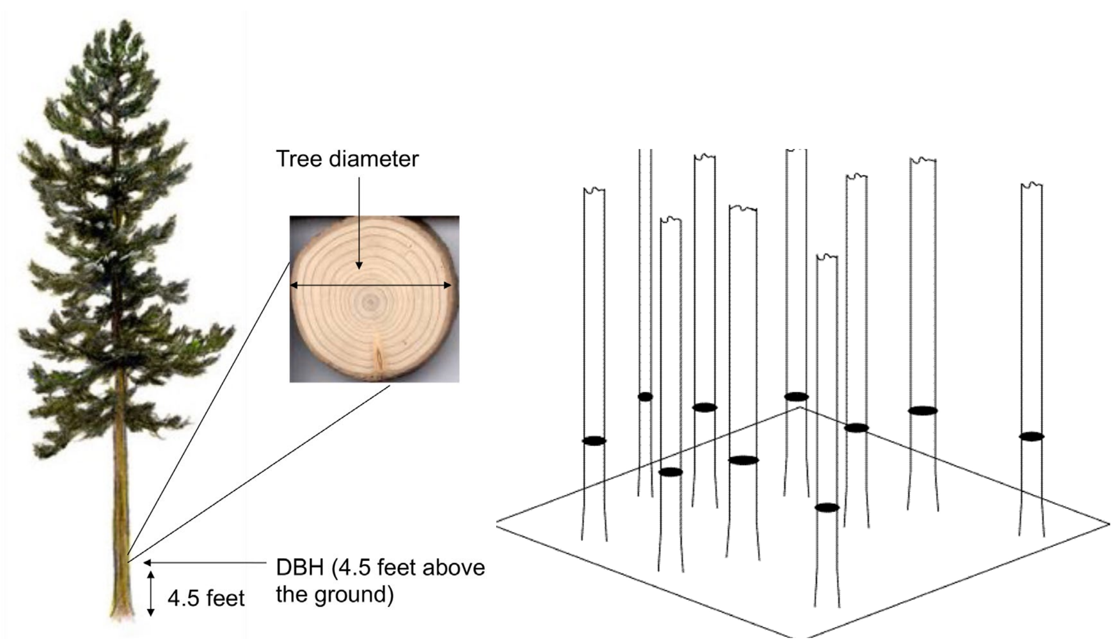

Figure 1. Basal area of a forest at a height of 4.5 feet above the ground (diameter at breast height or DBH) is a common measure used to quantify site occupancy of the overstory trees. It gives us an idea of the amount of competition for limited site resources of light, moisture, and nutrients. Subsequently, 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 an even-aged shortleaf pine forest 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.

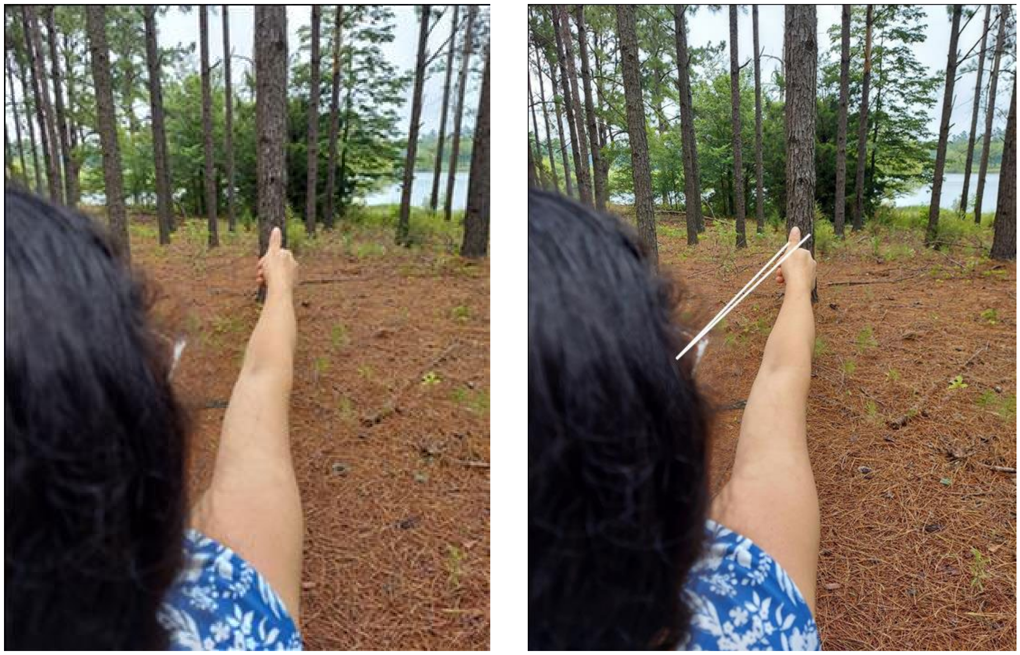

Figure 3. You can use your thumb to project an "imaginary" horizontal angle, which can be equated to a basal area factor (BAF). If you extend your thumb some distance from your eye, assuming the vertex of the angle (where the angle begins) is located in your eye, then an imaginary horizontal angle is 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 shortleaf pine forest, is it just the shortleaf 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 Shortleaf 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 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 × 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 317 pounds. They then multiply 317 by 104 square feet; this yields an estimate of around 32,968 pounds of carbon per acre being stored in their plantation.

Next, they convert the pounds of carbon per acre into metric tons by dividing 32,968 pounds per acre by 2,205 pounds. They estimate their 20-year-old plantation is sequestering around 14.95 metric tons per acre.

Further yet, 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 54.82 metric tons, or 54.82 $MtCO_2e$ (14.95 metric tons of carbon per acre × 3.667 = 54.82 $MtCO_2e$).

Example 2: Estimating Carbon per Acre of Shortleaf 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 an even-aged shortleaf pine forest that also contains some hardwoods. You are not sure of the age of the shortleaf 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 shortleaf 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 ÷ 3).

Since you don't know the age of the forest, and you want to estimate carbon for species other than shortleaf pine, you must use Table 3. If we knew the forest age, only for shortleaf 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 367 pounds per square foot of basal area. Therefore, your estimate is 1,222.11 pounds of carbon per acre in ash (367 pounds × 3.33 square feet of basal area per acre).

A similar procedure is used for the hickory and sweetgum, resulting in 4,390 and 9,200 pounds per acre of carbon in these trees, respectively. For shortleaf 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 shortleaf pine. And the number of pounds per square foot of basal area is 654. Therefore, your estimate is around 78,480 pounds per acre of carbon in these shortleaf pine trees.

Example 3: Estimating Carbon per Acre of Shortleaf 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 even-aged shortleaf pine forest. However, it includes some pine species other than shortleaf 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 shortleaf 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 19.15 metric tons per acre. Table 1 gives the same value (603 × 70 square feet per acre ÷ by 2,205).

In addition to the shortleaf 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 668 pounds per square foot of basal area. Therefore, we estimate there are around 10,020 pounds of carbon per acre (668 × 15 square feet of basal area). For metric tons, we can divide the 10,020 pounds by 2,205 (pounds per metric ton) and get 4.54 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 70.22 $MtCO_2e$ for the shortleaf pine and around 16.65 $MtCO_2e$ for the loblolly pine. These two values total to 86.87 $MtCO_2e$.

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 shortleaf 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 shortleaf 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	20	141	227	293	348	394	434	469	500	529	555	579	601	622	641	659
15	35	156	242	309	363	409	449	484	516	544	570	594	616	637	656	674
20	46	167	253	320	374	420	460	495	527	555	581	605	627	648	667	685
25	55	176	262	328	383	429	469	504	535	564	590	614	636	657	676	694
30	62	183	269	335	390	436	476	511	542	571	597	621	643	664	683	701
35	68	189	275	341	396	442	482	517	548	577	603	627	649	669	689	707
40	73	194	280	346	401	447	487	522	553	582	608	632	654	675	694	712
45	77	198	284	351	405	451	491	526	558	586	612	636	658	679	698	716
50	81	202	288	355	409	455	495	530	562	590	616	640	662	683	702	720
55	85	206	292	359	413	459	499	534	566	594	620	644	666	687	706	724
60	88	209	295	362	416	462	502	537	569	597	623	647	669	690	709	727
65	91	212	298	365	419	465	505	540	572	600	626	650	672	693	712	730
70	94	215	301	368	422	468	508	543	575	603	629	653	675	696	715	733
75	97	218	304	370	425	471	511	546	577	606	632	656	678	699	718	736
80	99	220	306	373	427	473	513	548	580	608	634	658	680	701	720	738
85		223	308	375	430	476	516	551	582	611	637	661	683	703	723	741
90		225	311	377	432	478	518	553	584	613	639	663	685	706	725	743
95		227	313	379	434	480	520	555	586	615	641	665	687	708	727	745
100		229	315	381	436	482	522	557	588	617	643	667	689	710	729	747
105		231	317	383	438	484	524	559	590	619	645	669	691	711	731	749
110		232	318	385	439	486	525	561	592	621	647	670	693	713	732	751
115		234	320	387	441	487	527	562	594	622	648	672	694	715	734	752
120		236	322	388	443	489	529	564	595	624	650	674	696	717	736	754
125		237	323	390	444	490	530	565	597	625	651	675	697	718	737	755
130			325	391	446	492	532	567	598	627	653	677	699	720	739	757
135			326	393	447	493	533	568	600	628	654	678	700	721	740	758
140			328	394	449	495	535	570	601	630	656	680	702	722	742	760
145			329	396	450	496	536	571	603	631	657	681	703	724	743	761
150			330	397	451	497	537	572	604	632	658	682	704	725	744	762
155			331	398	453	499	538	574	605	634	660	684	706	726	746	764
160			333	399	454	500	540	575	606	635	661	685	707	727	747	765
165			334	400	455	501	541	576	608	636	662	686	708	729	748	766
170			335	402	456	502	542	577	609	637	663	687	709	730	749	767
175			336	403	457	503	543	578	610	638	664	688	710	731	750	768
180				404	458	504	544	579	611	639	665	689	711	732	751	769
185				405	459	505	545	580	612	640	666	690	712	733	752	770
190				406	460	506	546	581	613	641	667	691	713	734	753	771
195				407	461	507	547	582	614	642	668	692	714	735	754	772
200				408	462	508	548	583	615	643	669	693	715	736	755	773
205				409	463	509	549	584	616	644	670	694	716	737	756	774
210				410	464	510	550	585	617	645	671	695	717	738	757	775

[1]CBARs are calculated using CBAR = -756.089 + 38.1888 × ln(baacre) + 298.7314 × ln(Age), n = 135, Adj. R^2 = 0.3527. 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	0.09	0.64	1.03	1.33	1.58	1.79	1.97	2.13	2.27	2.40	2.52	2.63	2.73	2.82	2.91	2.99
15	0.24	1.06	1.65	2.10	2.47	2.79	3.06	3.30	3.51	3.70	3.88	4.04	4.19	4.33	4.47	4.59
20	0.42	1.52	2.30	2.90	3.40	3.81	4.18	4.49	4.78	5.04	5.27	5.49	5.69	5.88	6.05	6.22
25	0.62	1.99	2.97	3.72	4.34	4.86	5.32	5.71	6.07	6.39	6.69	6.96	7.21	7.44	7.66	7.87
30	0.84	2.49	3.66	4.56	5.30	5.93	6.47	6.95	7.38	7.77	8.12	8.45	8.75	9.03	9.29	9.54
35	1.07	2.99	4.36	5.42	6.28	7.01	7.65	8.20	8.70	9.16	9.57	9.95	10.30	10.63	10.93	11.22
40	1.32	3.52	5.07	6.28	7.27	8.11	8.83	9.47	10.04	10.56	11.03	11.46	11.86	12.24	12.59	12.92
45	1.57	4.05	5.80	7.16	8.27	9.21	10.03	10.74	11.39	11.97	12.50	12.99	13.44	13.86	14.25	14.62
50	1.84	4.59	6.54	8.05	9.28	10.33	11.23	12.03	12.74	13.39	13.98	14.52	15.02	15.49	15.93	16.34
55	2.12	5.14	7.28	8.94	10.30	11.45	12.44	13.32	14.11	14.82	15.47	16.06	16.61	17.13	17.61	18.06
60	2.40	5.69	8.03	9.85	11.33	12.58	13.67	14.62	15.48	16.26	16.96	17.61	18.22	18.78	19.30	19.79
65	2.69	6.26	8.79	10.76	12.36	13.72	14.90	15.93	16.86	17.70	18.47	19.17	19.82	20.43	21.00	21.53
70	2.98	6.83	9.56	11.67	13.40	14.87	16.13	17.25	18.25	19.15	19.98	20.74	21.44	22.09	22.70	23.28
75	3.29	7.41	10.33	12.60	14.45	16.02	17.37	18.57	19.64	20.61	21.49	22.31	23.06	23.76	24.42	25.03
80	3.60	7.99	11.11	13.53	15.50	17.17	18.62	19.90	21.04	22.07	23.02	23.88	24.69	25.43	26.13	26.79
85		8.58	11.89	14.46	16.56	18.34	19.87	21.23	22.44	23.54	24.54	25.46	26.32	27.11	27.86	28.55
90		9.17	12.68	15.40	17.62	19.50	21.13	22.57	23.85	25.02	26.08	27.05	27.96	28.80	29.58	30.32
95		9.77	13.47	16.35	18.69	20.68	22.40	23.91	25.27	26.49	27.61	28.64	29.60	30.49	31.32	32.10
100		10.37	14.27	17.30	19.77	21.85	23.66	25.26	26.69	27.98	29.16	30.24	31.24	32.18	33.05	33.87
105		10.98	15.07	18.25	20.84	23.03	24.93	26.61	28.11	29.46	30.70	31.84	32.90	33.88	34.79	35.66
110		11.59	15.88	19.21	21.92	24.22	26.21	27.97	29.54	30.96	32.25	33.45	34.55	35.58	36.54	37.44
115		12.21	16.69	20.17	23.01	25.41	27.49	29.33	30.97	32.45	33.81	35.05	36.21	37.28	38.29	39.23
120		12.83	17.51	21.13	24.10	26.60	28.77	30.69	32.40	33.95	35.37	36.67	37.87	38.99	40.04	41.03
125		13.45	18.32	22.10	25.19	27.80	30.06	32.06	33.84	35.45	36.93	38.28	39.54	40.71	41.80	42.83
130			19.14	23.07	26.29	29.00	31.35	33.43	35.28	36.96	38.49	39.90	41.21	42.42	43.56	44.63
135			19.97	24.05	27.38	30.20	32.65	34.80	36.73	38.47	40.06	41.53	42.88	44.14	45.32	46.43
140			20.80	25.03	28.49	31.41	33.94	36.18	38.18	39.98	41.63	43.15	44.56	45.87	47.09	48.24
145			21.63	26.01	29.59	32.62	35.24	37.56	39.63	41.50	43.21	44.78	46.24	47.59	48.86	50.05
150			22.46	27.00	30.70	33.83	36.55	38.94	41.08	43.02	44.79	46.41	47.92	49.32	50.63	51.87
155			23.30	27.98	31.81	35.05	37.85	40.33	42.54	44.54	46.37	48.05	49.61	51.05	52.41	53.68
160			24.14	28.97	32.93	36.27	39.16	41.72	44.00	46.07	47.95	49.69	51.29	52.79	54.19	55.50
165			24.98	29.97	34.04	37.49	40.47	43.11	45.46	47.59	49.54	51.33	52.98	54.53	55.97	57.32
170			25.82	30.96	35.16	38.71	41.79	44.50	46.93	49.12	51.13	52.97	54.68	56.27	57.75	59.15
175			26.67	31.96	36.29	39.94	43.11	45.90	48.40	50.66	52.72	54.62	56.37	58.01	59.54	60.98
180				32.96	37.41	41.17	44.43	47.30	49.87	52.19	54.31	56.26	58.07	59.75	61.33	62.81
185				33.97	38.54	42.40	45.75	48.70	51.34	53.73	55.91	57.92	59.77	61.50	63.12	64.64
190				34.97	39.67	43.63	47.07	50.10	52.82	55.27	57.51	59.57	61.48	63.25	64.91	66.47
195				35.98	40.80	44.87	48.40	51.51	54.29	56.81	59.11	61.22	63.18	65.00	66.71	68.31
200				36.99	41.93	46.11	49.73	52.92	55.77	58.35	60.71	62.88	64.89	66.76	68.51	70.15
205				38.00	43.07	47.35	51.06	54.33	57.25	59.90	62.32	64.54	66.60	68.52	70.31	71.99
210				39.02	44.21	48.59	52.39	55.74	58.74	61.45	63.93	66.20	68.31	70.27	72.11	73.84

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 (MtCO2e) CBAR ÷ 2,205 × 3.667
Shortleaf pine	135	654	0.2967	1.0881
Hickory	66	439	0.1993	0.7308
Oak	115	538	0.2442	0.8954
Sweetgum	26	460	0.2086	0.7649
Other pine	11	668	0.3031	1.1115
Other hardwood	79	367	0.1664	0.6101
Other softwood (includes eastern redcedar)	26	286	0.1295	0.4750
All hardwood species	286*	461	0.2091	0.7668

* Exceeds *n* = 135 because some FIA plots have more than one hardwood species or species group.

Appendix

Development of Carbon-Basal Area Ratios

For this publication, average CBARs were calculated using USDA Forest Inventory and Analysis (FIA) inventories of shortleaf pine forests in Arkansas, Mississippi, Oklahoma, and Texas (no FIA plots from Louisiana met the inclusion requirements). Within FIA, only those plots classified as shortleaf pine (FORTYPCD = 162 in the FIA database) were selected. Only plots of 6 years or older were included. Plots with site indexes (base age 25) less than 30 and greater than 90 were deleted. All FIA plots with a basal area per acre (across all species) less than 10 square feet and greater than 290 square feet were deleted. Site index at base age 25 used the FIA-reported site index at base age 50 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 67 years old, and the youngest and oldest forests included were 17 and 96 years old, respectively.

In addition to the CBAR for shortleaf 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**
Shortleaf pine	135	76	30	187	88	23	211	2,462	194	7,173	59.3	5.9	236.7
Hickory	52	12	6	60	4	1	30	67	3	777	1.6	0.1	7.6
Oak	107	32	6	120	17	1	55	279	10	1,411	7.9	0.2	48.0
Sweetgum	22	13	6	36	7	1	18	149	9	365	3.7	0.3	10.0
Other pine	10	11	6	30	15	2	43	489	27	1,907	12.8	0.9	47.2
Other hardwood	50	14	6	48	5	1	23	91	12	598	2.2	0.2	17.9
Other softwood	24	12	6	36	8	1	33	108	7	424	1.8	0.2	7.6
All species	135	116	36	259	109	32	227	2,823	255	8,424	69.0	6.6	275.9

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**
Shortleaf pine	135	156	36	2,879	93	31	211	28	6	79
Hickory	66	55	6	375	6	1	30	1	0	12
Oak	115	111	6	798	18	1	55	5	0	21
Sweetgum	26	66	6	375	8	1	18	2	0	4
Other pine	11	31	6	168	15	2	43	5	0	21
Other hardwood	79	142	6	600	9	1	53	2	0	9
Other softwood	26	49	6	306	9	1	33	1	0	5
All species	135	385	36	2,879	121	46	260	34	8	95

For these shortleaf pine even-aged forests, site index (base age 25) averaged 45 feet and ranged from 30 feet to 79 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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