Variable-Density Yield Tables for Elm-Ash-Cottonwood Bottomland Hardwood Forests in Mississippi

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by
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Summary

Variable density yield tables are provided on a per acre basis for the elm-ash-cottonwood forest type residing in the flood plains and bottomlands of Mississippi. Data were obtained from the USDA Forest Service's Forest Inventory and Analysis program. Cubic foot volume yields per acre are supplied for total stems, to pulpwood upper diameter limits, and to sawlog upper diameter limits on both outside-bark and inside-bark bases. Doyle board foot volume per acre is also supplied for sawlogs. Yields are expressed in terms of stand age, site index, and basal area per acre. With emerald ash borer's increasing prevalence across the South, the information provided herein can be particularly timely for forest landowners, managers, and businesses to formulate management and utilization strategies for the resources of this forest type.

Introduction

Bottomland hardwood forests are some of the more productive forest types, yet little empirical information is available to describe their productive capability.

One predominant forest type found throughout the eastern United States that has particularly received little attention is elm/ash/cottonwood. While many of the species occupying these sites are often grouped together as “woods-run” or “mixed” hardwoods in the South, their collective value is far from trivial.

Since 1992, prices for both mixed hardwood sawtimber and hardwood pulpwood in Mississippi have been increasing at annual rates of 3.00 percent above inflation (McConnell et al. 2021). Mixed hardwood sawtimber prices from the Mississippi Timber Price Report have averaged from $25 to nearly $45 dollars per ton nominal over the past decade. Hardwood pulpwood prices have largely resided in a band between $5 and $12 per ton nominal over the past ten years (Mississippi State University Extension 2021). Although Mississippi is conspicuously absent from the US Department of Agriculture’s January 2021 emerald ash borer county detection map (USDA APHIS 2021), it is likely only a matter of time before that unfortunately changes (see inset 1). This emphasizes the need for better understanding of the 1.12 million acres and 2.01 billion cubic feet of timber inventory this forest type occupies in Mississippi.

This bulletin reports stand-level yields per acre for elm/ash/cottonwood residing in Mississippi bottomlands.

INSET 1

Emerald Ash Borer
(Agrilus planipennis)

Emerald ash borer (EAB) is a bright, metallic green beetle whose larvae feed on the inner bark of ash trees. It is believed EAB was brought to the United States in wood packaging materials sawn from infested trees in its native China. There, ash species have evolved to withstand EAB to varying degrees. The ash tree species in North America, however, do not possess host resistance. Millions of ash trees have succumbed to EAB since first being detected in Michigan in 2002. The ashes of Mississippi, green (*Fraxinus pennsylvanica*) and white (*Fraxinus americana*), will most likely suffer the same fate as those of the Midwest. Early detection, while not a cure, is critical to maintaining the ash species for as long as possible. This is true whether in the forest or your yard. If you notice unusual characteristics with your ash trees, such as branch dieback in the crown, new branch growth occurring near the tree's base, increased levels of woodpecker damage, or "D" shaped exit holes in the trunk, contact Mississippi State University Extension or the Mississippi Forestry Commission. Be mindful as well of moving wood from one locality to another, particularly if a tree was removed due to its poor health.

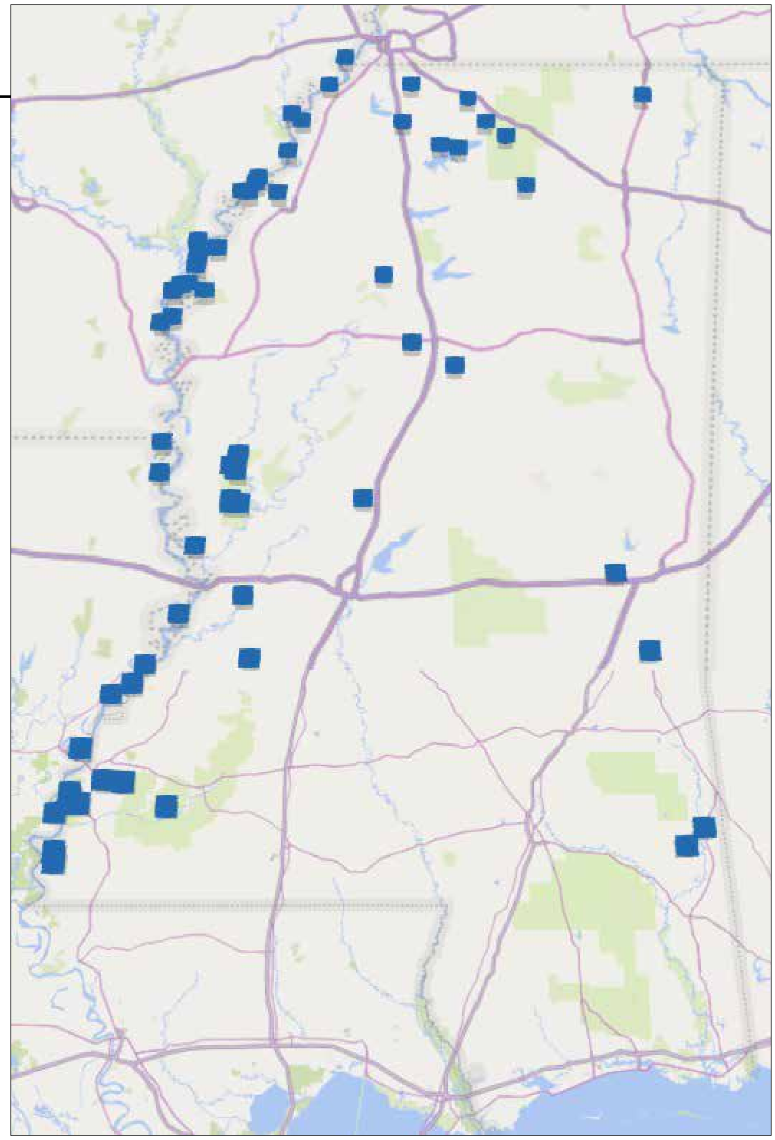
For more information, consult Mississippi State University Extension publication p2486, "Signs and Symptoms of Emerald Ash Borer," (Self and Layton 2019).

PHOTO: USDA APHIS

Methods

The data used to build the tables reported herein were obtained from the USDA Forest Service Forest Inventory and Analysis as part of the agency's forest survey program. Three tables for Mississippi were downloaded to Microsoft® Excel®: Condition, Plot, and Tree, which were then merged into a Microsoft® Access® database. Here, the data were queried for years 2009 to 2019. Plots were filtered based on their predominant forest type being elm/ash/cottonwood that resided in both narrow and wide floodplains and bottomlands. They must have been of natural origin, residing on forestland not continuously underwater or on steep slopes where timber harvesting would likely be deemed inoperable. A stand density index ratio, with the numerator being the sum of individual trees' SDIs and the denominator being the plot's SDI at its quadratic mean diameter (SDI_{sum}:SDI), was calculated following Shaw and Long (2007). The SDI ratio's minimum threshold was set to 0.90 to better ensure stands were at least nearly even aged. No records of past silvicultural treatments were allowed, but natural disturbances were included. Stand age was required to be at least 20 years, while a minimum basal area per acre of live trees was set at 60 ft^2/acre. Only living trees were recorded. The final number of plots meeting these criteria was n = 86 (Figure 1).

FIGURE 1. Approximate locations of USDA Forest Service study plots.



While the Mississippi timber inventory data does report site index for some plots, this was not the case for all. Moreover, site indexes were reported for several different species that happened to be the dominant resident on any one plot. Therefore, the site index equation for green ash (*Fraxinus pennsylvanica*) (Broadfoot 1969, reported in Carmean et al. 1989), was used across all plots, as it was the most prevalent species within the forest type (Walters and Ek 1993). The green ash site index equation was applied to all dominant and co-dominant trees and then averaged to the plot level at a base age of 50 years. Tree volumes were estimated using tree profile equations provided by the Mississippi State University Forest and Wildlife Research Center's Tree Volume Generator program. Volume equations were based on the "combined variable" D^2H, where D was diameter at breast height. Hardwood species' heights, H, were recorded for total tree height and merchantable heights to a 4-inch top for pulpwood and 9-inch top for sawtimber. Softwood species' heights were recorded for total height and merchantable heights to a 3-inch top for pulpwood and 7-inch top for sawtimber. Total cubic foot stem volumes were determined as were merchantable volumes to the designated top heights. Doyle board foot volumes were also calculated for sawlogs. These were then expanded to a per acre basis. The myriad of bulk density scaling factors across the species occupying the elm/ash/cottonwood forest type precluded reporting green weight yields, even though hardwood timber products are much more commonly scaled by weight in Mississippi.

Yield equations were built using multiple linear regression with two main goals: to be accurate and easy to use. Multiple linear regression is built upon assumptions that must be satisfied to facilitate its use. Rare is the case when forestry data can meet these assumptions. A flexible power transformation technique developed by Box and Cox (1964) was performed on only the dependent variable, volume per acre (see inset 2). The independent variables—stand age, green ash site index (base age of 50 years), and basal area per acre—were not manipulated. The assumptions of normality and constant variance were both verified. Back-transformation correction factors were applied to each regression's root mean square error as appropriate, $\frac{(RMSE)^2}{2}$ either for the logged volume or $(RMSE)^3$ for the cubic root transformation. The amount of variation accounted for by each equation was expressed as the adjusted coefficient of determination. A validation set of n = 33 plots from Louisiana's forest survey data was input into each equation to supply goodness of fit measures Mean Absolute Deviation and Mean Absolute Percent Error, which compared predicted values to those observed on the plots.

INSET 2

The Box-Cox Transformation

BOX AND COX (1964) INTRODUCED A DATA TRANSFORMATION TECHNIQUE WHEN no guiding protocol was present for specifying any one specific level.

$$y^{\lambda} = \frac{y^{\lambda} - 1}{\lambda}$$

THIS FORMULA ALLOWS THE DATA TO DETERMINE A PREFERRED FUNCTIONAL FORM FOR MEETING the normality assumption linear regression requires. Box-Cox power transformation levels for some specific functional forms are presented below and will be familiar to some readers.

Functional Form	λ
Natural Logarithm	0.00
Linear	1.00
Quadratic	2.00
Cubic	3.00
Square Root	0.50
Cubic Root	0.33
Inverse	-1.00

Results

THE STUDY STANDS (PLOTS) AVERAGED 52.5 YEARS OF AGE, WITH A BASAL area of 103 ft^2/acre (Table 1). They possessed a mean green ash site index of **82** feet at age 50. Outside (inside) bark yields averaged 3,082 (2,718) ft^3/acre, 3,023 (2,667) ft^3/acre, and 2,193 (1,942) ft^3/acre for total stem, to a pulpwood upper diameter limit, and to a sawlog upper diameter limit respectively. Doyle sawlog volume averaged 8,512 board feet per acre. Two plots possessed no measurable sawtimber trees.

TABLE 1. Descriptive statistics for the study plots.

Study Variables	Mean	Standard Deviation	99% Confidence Interval Lower Bound	99% Confidence Interval Upper Bound
Stand Age, years	52.5	15.8	48.1	57.0
Site Index (Green Ash, 50 years)	82	16	78	87
Basal Area, ft^2 per Acre	103.0	36.0	92.8	113.3
Total Stem Volume, ft^3, outside bark	3,082	1,671	2,606	3,556
Total Stem Volume, ft^3, inside bark	2,718	1,478	2,298	3,138
Volume to a pulpwood top, ft^3, outside bark	3,023	1,666	2,550	3,497
Volume to a pulpwood top, ft^3, inside bark	2,667	1,474	2,248	3,085
Volume to a sawlog top, ft^3, outside bark	2,193	1,653	1,724	2,663
Volume to a sawlog top, ft^3, inside bark	1,942	1,463	1,527	2,358
Doyle Board Feet Volume	8,512	7,232	6,457	10,567

Total stem volume and stem volume to a pulpwood upper diameter limit were best estimated when volume was transformed to its natural logarithm (Table 2). Sawlog volumes, both cubic foot and board foot, were better described when transformed to their cubic root. Between 75% and 80% of the variations in volume per acre were explained by including stand age, site index, and basal area per acre in the models. The deviation between predicted and observed yields in the Louisiana validation data ranged from 18% to 32%. Tables 3 to 9 present tabulated results using the coefficients found in Table 2.

TABLE 2. Regression equation coefficients and supplementary statistics for predicting per acre yields for bottomland elm/ash/cottonwood forests in Mississippi.

Coefficients	Total Cubic Foot Volume		Cubic Foot Volume to a Pulpwood Top		Cubic Foot Volume to a Sawlog Top		Doyle Board Feet
	Outside Bark	Inside bark	Outside Bark	Inside bark	Outside Bark	Inside bark	Inside bark
Volume Transformation	ln(V)	ln(V)	ln(V)	ln(V)	$\sqrt[3]{V}$	$\sqrt[3]{V}$	$\sqrt[3]{V}$
Intercept	5.8280	5.6905	5.7472	5.6106	-1.0086	-0.9524	-5.2582
Stand Age, years	0.0094	0.0095	0.0100	0.0101	0.0768	0.0737	0.1505
Site Index (Green Ash, 50 years)	0.0059	0.0059	0.0061	0.0061	0.0454	0.0435	0.0833
Basal Area, ft^2 per acre	0.0110	0.0110	0.0111	0.0112	0.0555	0.0533	0.0949
Root Mean Square Error	0.2009	0.2017	0.2053	0.2061	1.3031	1.2501	2.4568
Adjusted Coefficient of Determination	0.7908	0.7906	0.7890	0.7886	0.7827	0.7827	0.7541
Mean Absolute Deviation, ft^3 or BF	462	439	447	460	443	429	2,281
Mean Absolute Percent Error	19%	18%	18%	18%	25%	27%	32%

$Y = \beta_0 + \beta_1 Age + \beta_2 SI_{GrAsh} + \beta_3 BA + \varepsilon$, where Y was either ln($V$) or $\sqrt[3]{V}$, *Age* was stand age in years, SI_{GrAsh} was the averaged base age 50 years site index for green ash, and *BA* was the basal area per acre of live trees. ε was the model error term.

TABLE 3. Total cubic foot outside bark yield per acre for elm/ash/cottonwood forests in Mississippi.

Stand Age, years	Green Ash Site Index, feet at age 50 years	Basal Area, ft², per acre						
		60	70	80	90	100	110	120
20	60	1,152	1,287	1,436	1,604	1,790	1,999	2,232
	70	1,222	1,364	1,523	1,700	1,899	2,120	2,366
	80	1,296	1,447	1,615	1,803	2,013	2,248	2,509
	90	1,374	1,534	1,713	1,912	2,135	2,383	2,661
	100	1,457	1,626	1,816	2,027	2,263	2,527	2,821
30	60	1,266	1,414	1,579	1,762	1,968	2,197	2,453
	70	1,343	1,499	1,674	1,869	2,086	2,329	2,601
	80	1,424	1,590	1,775	1,982	2,212	2,470	2,758
	90	1,510	1,686	1,882	2,101	2,346	2,619	2,924
	100	1,601	1,787	1,996	2,228	2,488	2,777	3,101
40	60	1,392	1,554	1,735	1,937	2,162	2,414	2,695
	70	1,476	1,648	1,840	2,054	2,293	2,560	2,858
	80	1,565	1,747	1,951	2,178	2,431	2,715	3,031
	90	1,659	1,853	2,068	2,309	2,578	2,878	3,214
	100	1,759	1,964	2,193	2,449	2,734	3,052	3,408
50	60	1,530	1,708	1,907	2,129	2,377	2,653	2,962
	70	1,622	1,811	2,022	2,257	2,520	2,813	3,141
	80	1,720	1,920	2,144	2,393	2,672	2,983	3,331
	90	1,824	2,036	2,273	2,538	2,833	3,163	3,532
	100	1,934	2,159	2,410	2,691	3,004	3,354	3,745
60	60	1,681	1,877	2,095	2,339	2,612	2,916	3,256
	70	1,782	1,990	2,222	2,481	2,769	3,092	3,452
	80	1,890	2,110	2,356	2,630	2,937	3,279	3,660
	90	2,004	2,237	2,498	2,789	3,114	3,476	3,881
	100	2,125	2,373	2,649	2,957	3,302	3,686	4,116
70	60	1,847	2,062	2,303	2,571	2,870	3,205	3,578
	70	1,959	2,187	2,442	2,726	3,044	3,398	3,794
	80	2,077	2,319	2,589	2,891	3,227	3,603	4,023
	90	2,202	2,459	2,745	3,065	3,422	3,821	4,266
	100	2,335	2,607	2,911	3,250	3,629	4,051	4,523

TABLE 4. Total cubic foot inside bark yield per acre for elm/ash/cottonwood forests in Mississippi.

Stand Age, years	Green Ash Site Index, feet at age 50 years	Basal Area, ft², per acre						
		60	70	80	90	100	110	120
20	60	1,010	1,128	1,260	1,407	1,571	1,755	1,960
	70	1,072	1,197	1,337	1,493	1,667	1,861	2,079
	80	1,137	1,270	1,418	1,583	1,768	1,975	2,205
	90	1,206	1,347	1,504	1,680	1,876	2,095	2,339
	100	1,279	1,429	1,595	1,782	1,990	2,222	2,481
30	60	1,112	1,241	1,386	1,548	1,729	1,930	2,156
	70	1,179	1,317	1,470	1,642	1,834	2,048	2,287
	80	1,251	1,397	1,560	1,742	1,945	2,172	2,426
	90	1,327	1,482	1,655	1,848	2,063	2,304	2,573
	100	1,407	1,572	1,755	1,960	2,189	2,444	2,730
40	60	1,223	1,366	1,525	1,703	1,902	2,124	2,372
	70	1,297	1,449	1,618	1,807	2,017	2,253	2,516
	80	1,376	1,537	1,716	1,916	2,140	2,390	2,669
	90	1,460	1,630	1,820	2,033	2,270	2,535	2,831
	100	1,548	1,729	1,931	2,156	2,408	2,689	3,003
50	60	1,345	1,502	1,678	1,874	2,092	2,336	2,609
	70	1,427	1,594	1,780	1,987	2,219	2,478	2,768
	80	1,514	1,690	1,888	2,108	2,354	2,629	2,936
	90	1,606	1,793	2,003	2,236	2,497	2,789	3,114
	100	1,703	1,902	2,124	2,372	2,649	2,958	3,304
60	60	1,480	1,653	1,846	2,061	2,302	2,570	2,870
	70	1,570	1,753	1,958	2,186	2,442	2,727	3,045
	80	1,665	1,860	2,077	2,319	2,590	2,892	3,230
	90	1,767	1,973	2,203	2,460	2,747	3,068	3,426
	100	1,874	2,093	2,337	2,610	2,914	3,255	3,634
70	60	1,628	1,818	2,030	2,267	2,532	2,828	3,158
	70	1,727	1,929	2,154	2,405	2,686	3,000	3,350
	80	1,832	2,046	2,285	2,551	2,849	3,182	3,553
	90	1,943	2,170	2,424	2,707	3,022	3,375	3,769
	100	2,062	2,302	2,571	2,871	3,206	3,580	3,998

TABLE 5. Cubic foot outside bark yield per acre to a pulpwood upper diameter limit (either 3.0 inches for softwoods or 4.0 inches for hardwoods) for elm/ash/cottonwood forests in Mississippi.

Stand Age, years	Green Ash Site Index, feet at age 50 years	Basal Area, ft^2, per acre						
		60	70	80	90	100	110	120
20	60	1,097	1,226	1,371	1,532	1,713	1,914	2,140
	70	1,165	1,303	1,456	1,628	1,820	2,034	2,274
	80	1,238	1,384	1,547	1,730	1,933	2,161	2,416
	90	1,315	1,471	1,644	1,838	2,054	2,296	2,567
	100	1,398	1,562	1,747	1,952	2,182	2,440	2,727
30	60	1,212	1,355	1,514	1,693	1,892	2,115	2,365
	70	1,288	1,439	1,609	1,799	2,011	2,248	2,513
	80	1,368	1,529	1,710	1,911	2,136	2,388	2,670
	90	1,454	1,625	1,816	2,030	2,270	2,537	2,836
	100	1,544	1,726	1,930	2,157	2,412	2,696	3,014
40	60	1,339	1,497	1,673	1,871	2,091	2,338	2,613
	70	1,423	1,590	1,778	1,988	2,222	2,484	2,776
	80	1,512	1,690	1,889	2,112	2,361	2,639	2,950
	90	1,606	1,795	2,007	2,244	2,508	2,804	3,134
	100	1,707	1,908	2,132	2,384	2,665	2,979	3,330
50	60	1,480	1,654	1,849	2,067	2,311	2,583	2,887
	70	1,572	1,757	1,965	2,196	2,455	2,744	3,068
	80	1,670	1,867	2,087	2,333	2,608	2,916	3,259
	90	1,775	1,984	2,218	2,479	2,771	3,098	3,463
	100	1,886	2,108	2,356	2,634	2,945	3,292	3,680
60	60	1,635	1,828	2,043	2,284	2,553	2,854	3,190
	70	1,737	1,942	2,171	2,427	2,713	3,032	3,390
	80	1,846	2,063	2,306	2,578	2,882	3,222	3,602
	90	1,961	2,192	2,451	2,739	3,062	3,423	3,827
	100	2,084	2,329	2,604	2,911	3,254	3,637	4,066
70	60	1,807	2,020	2,258	2,524	2,821	3,154	3,525
	70	1,920	2,146	2,399	2,681	2,997	3,351	3,746
	80	2,040	2,280	2,549	2,849	3,185	3,560	3,980
	90	2,167	2,422	2,708	3,027	3,384	3,783	4,228
	100	2,302	2,574	2,877	3,216	3,595	4,019	4,493

TABLE 6. Cubic foot inside bark yield per acre to a pulpwood upper diameter limit (either 3.0 inches for softwoods or 4.0 inches for hardwoods) for elm/ash/cottonwood forests in Mississippi.

Stand Age, years	Green Ash Site Index, feet at age 50 years	Basal Area, ft^2, per acre						
		60	70	80	90	100	110	120
20	60	962	1,076	1,203	1,345	1,504	1,681	1,880
	70	1,023	1,143	1,278	1,429	1,598	1,787	1,998
	80	1,087	1,215	1,359	1,519	1,699	1,899	2,124
	90	1,155	1,292	1,444	1,615	1,806	2,019	2,257
	100	1,228	1,373	1,535	1,716	1,919	2,146	2,399
30	60	1,064	1,190	1,330	1,488	1,663	1,860	2,079
	70	1,131	1,265	1,414	1,581	1,768	1,977	2,210
	80	1,202	1,344	1,503	1,680	1,879	2,101	2,349
	90	1,278	1,429	1,597	1,786	1,997	2,233	2,497
	100	1,358	1,519	1,698	1,898	2,123	2,373	2,654
40	60	1,177	1,316	1,472	1,645	1,840	2,057	2,300
	70	1,251	1,399	1,564	1,749	1,955	2,186	2,445
	80	1,330	1,487	1,662	1,859	2,078	2,324	2,598
	90	1,413	1,580	1,767	1,976	2,209	2,470	2,762
	100	1,502	1,680	1,878	2,100	2,348	2,625	2,935
50	60	1,302	1,456	1,628	1,820	2,035	2,275	2,544
	70	1,384	1,547	1,730	1,934	2,163	2,418	2,704
	80	1,471	1,644	1,839	2,056	2,299	2,570	2,874
	90	1,563	1,748	1,954	2,185	2,443	2,732	3,054
	100	1,661	1,858	2,077	2,322	2,597	2,904	3,246
60	60	1,440	1,610	1,800	2,013	2,251	2,516	2,814
	70	1,531	1,711	1,913	2,139	2,392	2,675	2,991
	80	1,627	1,819	2,034	2,274	2,543	2,843	3,179
	90	1,729	1,933	2,162	2,417	2,702	3,022	3,378
	100	1,838	2,055	2,297	2,569	2,872	3,211	3,591
70	60	1,593	1,781	1,991	2,226	2,489	2,783	3,112
	70	1,693	1,893	2,116	2,366	2,646	2,958	3,308
	80	1,799	2,012	2,249	2,515	2,812	3,144	3,516
	90	1,912	2,138	2,391	2,673	2,989	3,342	3,737
	100	2,033	2,273	2,541	2,841	3,177	3,552	3,972

TABLE 7. Cubic foot outside bark yield per acre to a sawlog upper diameter limit (either 7.0 inches for softwoods or 9.0 inches for hardwoods) for elm/ash/cottonwood forests in Mississippi.

Stand Age, years	Green Ash Site Index, feet at age 50 years	Basal Area, ft², per acre						
		60	70	80	90	100	110	120
20	60	484	594	719	861	1,020	1,198	1,395
	70	640	771	920	1,086	1,271	1,477	1,703
	80	826	982	1,155	1,348	1,561	1,796	2,053
	90	1,046	1,227	1,427	1,649	1,892	2,158	2,448
	100	1,302	1,510	1,740	1,992	2,267	2,566	2,891
30	60	573	695	834	990	1,164	1,358	1,572
	70	746	892	1,055	1,236	1,438	1,660	1,905
	80	952	1,122	1,312	1,521	1,752	2,005	2,281
	90	1,193	1,390	1,607	1,846	2,108	2,394	2,704
	100	1,471	1,697	1,944	2,215	2,510	2,830	3,176
40	60	672	807	960	1,131	1,321	1,532	1,764
	70	864	1,024	1,202	1,400	1,618	1,859	2,122
	80	1,090	1,276	1,482	1,708	1,957	2,229	2,525
	90	1,353	1,566	1,801	2,059	2,340	2,646	2,977
	100	1,654	1,898	2,164	2,455	2,770	3,111	3,480
50	60	782	931	1,099	1,285	1,492	1,720	1,970
	70	993	1,168	1,363	1,577	1,814	2,072	2,355
	80	1,241	1,443	1,666	1,910	2,178	2,470	2,786
	90	1,526	1,757	2,011	2,288	2,589	2,915	3,268
	100	1,852	2,114	2,400	2,711	3,048	3,411	3,802
60	60	903	1,067	1,250	1,453	1,677	1,923	2,192
	70	1,135	1,326	1,537	1,769	2,024	2,302	2,604
	80	1,405	1,624	1,865	2,128	2,415	2,727	3,065
	90	1,714	1,963	2,236	2,532	2,854	3,202	3,577
	100	2,065	2,347	2,653	2,985	3,343	3,729	4,144
70	60	1,036	1,216	1,415	1,635	1,877	2,142	2,430
	70	1,290	1,497	1,726	1,976	2,250	2,548	2,871
	80	1,583	1,819	2,079	2,361	2,669	3,002	3,362
	90	1,916	2,185	2,477	2,794	3,137	3,507	3,906
	100	2,294	2,596	2,923	3,276	3,657	4,067	4,505

TABLE 8. Cubic foot inside bark yield per acre to a sawlog upper diameter limit (either 7.0 inches for softwoods or 9.0 inches for hardwoods) for elm/ash/cottonwood forests in Mississippi.

Stand Age, years	Green Ash Site Index, feet at age 50 years	Basal Area, ft², per acre						
		60	70	80	90	100	110	120
20	60	255	325	406	500	607	729	866
	70	312	391	482	587	706	840	990
	80	375	464	567	683	814	961	1,125
	90	447	547	661	789	933	1,094	1,272
	100	528	639	765	906	1,064	1,239	1,432
30	60	355	441	540	652	780	923	1,082
	70	424	521	631	755	895	1,052	1,226
	80	502	609	731	869	1,022	1,193	1,382
	90	589	708	843	993	1,160	1,346	1,550
	100	685	817	964	1,129	1,311	1,511	1,731
40	60	477	581	699	833	982	1,148	1,332
	70	561	677	807	954	1,117	1,297	1,497
	80	655	782	926	1,086	1,263	1,459	1,674
	90	758	898	1,055	1,229	1,422	1,633	1,865
	100	872	1,025	1,196	1,385	1,593	1,821	2,070
50	60	625	749	888	1,044	1,217	1,408	1,618
	70	725	861	1,014	1,184	1,372	1,578	1,805
	80	835	985	1,152	1,336	1,539	1,762	2,005
	90	956	1,120	1,301	1,501	1,720	1,959	2,220
	100	1,089	1,267	1,463	1,678	1,914	2,171	2,450
60	60	800	946	1,108	1,288	1,486	1,704	1,942
	70	918	1,077	1,254	1,448	1,663	1,897	2,152
	80	1,047	1,220	1,412	1,622	1,853	2,104	2,377
	90	1,187	1,375	1,582	1,809	2,057	2,326	2,617
	100	1,340	1,543	1,766	2,010	2,275	2,563	2,873
70	60	1,006	1,175	1,362	1,567	1,793	2,039	2,306
	70	1,143	1,326	1,528	1,750	1,992	2,256	2,542
	80	1,291	1,490	1,708	1,947	2,206	2,488	2,793
	90	1,452	1,667	1,902	2,157	2,435	2,736	3,060
	100	1,626	1,857	2,109	2,383	2,679	2,999	3,344

TABLE 9. Doyle board foot yield per acre to a sawlog upper diameter limit (either 7.0 inches for softwoods or 9.0 inches for hardwoods) for elm/ash/cottonwood forests in Mississippi.

Stand Age, years	Green Ash Site Index, feet at age 50 years	Basal Area, ft², per acre						
		60	70	80	90	100	110	120
20	60	617	844	1,121	1,455	1,849	2,310	2,842
	70	813	1,084	1,411	1,797	2,250	2,773	3,372
	80	1,048	1,367	1,747	2,191	2,705	3,294	3,963
	90	1,325	1,697	2,132	2,638	3,217	3,877	4,621
	100	1,648	2,075	2,572	3,142	3,791	4,525	5,348
30	60	1,000	1,309	1,678	2,111	2,613	3,189	3,844
	70	1,268	1,629	2,054	2,547	3,114	3,760	4,489
	80	1,582	1,998	2,483	3,040	3,676	4,395	5,202
	90	1,944	2,419	2,968	3,593	4,302	5,098	5,988
	100	2,357	2,896	3,512	4,210	4,996	5,873	6,848
40	60	1,518	1,923	2,396	2,941	3,563	4,267	5,059
	70	1,870	2,334	2,870	3,482	4,176	4,957	5,831
	80	2,273	2,800	3,403	4,086	4,857	5,718	6,677
	90	2,731	3,324	3,998	4,757	5,607	6,554	7,601
	100	3,247	3,911	4,659	5,498	6,432	7,467	8,607
50	60	2,192	2,706	3,295	3,965	4,720	5,566	6,508
	70	2,639	3,219	3,878	4,623	5,457	6,387	7,416
	80	3,143	3,793	4,527	5,350	6,267	7,284	8,406
	90	3,709	4,432	5,244	6,149	7,154	8,263	9,481
	100	4,338	5,139	6,033	7,025	8,121	9,325	10,644
60	60	3,041	3,677	4,396	5,204	6,105	7,105	8,209
	70	3,595	4,304	5,100	5,990	6,977	8,068	9,267
	80	4,212	4,997	5,875	6,850	7,928	9,114	10,413
	90	4,896	5,762	6,725	7,790	8,963	10,247	11,649
	100	5,651	6,602	7,654	8,813	10,083	11,470	12,979
70	60	4,088	4,858	5,720	6,679	7,739	8,906	10,185
	70	4,759	5,609	6,556	7,603	8,757	10,022	11,403
	80	5,500	6,434	7,469	8,609	9,860	11,227	12,715
	90	6,314	7,336	8,463	9,701	11,053	12,526	14,125
	100	7,205	8,319	9,543	10,881	12,339	13,921	15,634

Using the Equations

Example 1: Outside-bark total stem yield to a pulpwood top is desired on a natural, even-aged elm/ash/cottonwood bottomland stand being considered for thinning in Marshall County. The stand is 37 years old, and it resides on a green ash site index of 75 feet. It possesses a basal area of 115 ft²/acre. Our regression equation can be estimated by:

> At 128 ft³ per standard cord, there are 20.5 standard cords per acre on the site.

$$\ln(V)=b_0+b_1Age+b_2SI_{GrAsh}+b_3BA,6$$

$$\ln(V)=5.7472+(0.0100*6\!\!7)+(0.00616*75)+(0.0111*115)=7.8525,6$$

$$V=e\left(7.8525+\frac{RMSEa}{}\right),6$$

$$V=e\left(7.8525+6\frac{3a}{}\right),6$$

$$V=e^{7.6\!7356}=2,627\frac{6^3}{acrea}$$

Example 2: A forest manager seeks to determine an average number of board feet per acre on a natural, even-aged elm/ash/cottonwood bottomland stand in Warren County. The stand is 64 years old, possesses a basal area of 106 ft²/acre, and green ash site index was estimated to be 88 feet. Our regression equation can be estimated by:

$$\sqrt[3]{V}=b_0+b_1Age+b_2SI_{GrAsh}+b_3BA$$

$$\sqrt[3]{V}=-5.2582+(0.1505*64) + (0.0833*88) + (0.0949*106) = 21.7656,$$

$$v = 21.7656^3 + RMSE^3,$$

$$v = 21.5117^3 + 2.4568^3 = 10,326\frac{BF}{acre}$$

If we further assumed mixed hardwood sawtimber stumpage was valued at $250/MBF on the Doyle scale, the per acre value of the hardwood sawtimber would be:

$$\frac{\$}{Acre}=\frac{10,326BF}{Acre}*\frac{1MBF}{1,000BF}*\frac{\$250}{MBF} = \$2,581.51\ per\ acre$$

Closing Remarks

THE MODELS SELECTED PROVIDED A GOOD SYNOPSIS OF a timber stand as it develops and performed reasonably well compared with other regional whole stand yield equations (e.g., Walters and Ek 1993). By using only one transformation on the dependent variable—volume per acre—the assumptions required by linear regression were met, and model complexity was significantly reduced. The flexibility of the Box-Cox technique allowed the data to determine the level of transformation needed. As we observed, a singular level of transformation across all volume classes was not appropriate.

The tradeoff with this line of thought, though, was a potential loss of accuracy. For example, whole stand yield models will often use the inverse of age, Age^{-1}, as an independent variable to better account for the "leveling off" of stand volume as age progresses (Avery and Burkhart 1994). The rationale here was that transforming multiple variables would in turn lead to potentially numerous solutions that would be relatively equivalent. For example, "increasing" the transformation level for sawlog volumes from the cubic root ($Y^{0.33}$) to the square root ($Y^{0.50}$) could be the same as decreasing the power to which age is raised. The equations and tables in this bulletin should only be used to gain insight on current stand conditions. Extrapolating from the present to the future is not advised, because the equations were not constructed to account for stand growth, survival, and mortality over varying time periods. Doing so would most likely result in an over-estimation of future yield. The equations should perform reasonably well within the ranges of the data, particularly older, well-stocked stands in Mississippi.

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