A Stocking Diagram for Midwestern Eastern Cottonwood-Silver Maple-American Sycamore Bottomland Forests

David R. Larsen, Daniel C. Dey, and Thomas Faust

ABSTRACT

A stocking diagram for Midwestern bottomland eastern cottonwood (*Populus deltoides* Bartram ex Marsh.)-silver maple (*Acer saccharinum* L.)-American sycamore (*Platanus occidentalis* L.) forests was developed following the methods of S.F. Gingrich (1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the Central States. *For. Sci.* 13:38–53). The stocking diagram was derived from forest inventory data from two different studies of bottomland forests that covered a wide range of soil and hydrologic site characteristics found throughout the central Midwest, including Missouri, Iowa, Illinois, and southern Wisconsin. The minimum of full stocking (B-level) was determined from measurements on open-grown trees. The maximum of full stocking (A-level) in our study was almost one-third higher in stand basal area than A-level stocking, as determined by J.C.G. Goelz (1995. A stocking guide for southern bottomland hardwoods. *South. J. Appl. For.* 19:103–104) for southern hardwood bottomlands dominated by cherrybark oak (*Quercus pagoda* Raf.), Nuttall oak (*Quercus nuttallii* Palmer), and sweetgum (*Liquidambar styraciflua* L.,), or by C.C. Myers and R.G. Buchman (1984. *Manager's handbook for elm-ash-cottonwood in the north central states.* GTR-98. US Forest Service, North Central For. Exp. Stn., St. Paul, MN. 11 p) for elm (*Ulmus* spp.), ash (*Fraxinus* spp.), and eastern cottonwood forests in the north central states. However, A-level stocking in this study was only slightly higher than guides developed for northern red oak (*Quercus rubra* L.) in Wisconsin (McGill, D.W., R. Rogers, A.J. Martin, and P.S. Johnson. 1999. Measuring stocking in northern red oak stands in Wisconsin. *North. J. Appl. For.* 16:144–150). Differences in stocking among these forest types are due to variation in species composition, species silvical characteristics, and possibly the data sources used to construct the stocking diagrams. This stocking diagram can be used by forest managers to make decisions related to stand stocking for management of eastern cottonwood, silver maple, and American sycamore bottomland forests in the Midwest.

Keywords: stand density, stocking diagram, silver maple, American sycamore, eastern cottonwood, average maximum density, bottomland forest, silviculture

In eastern North America, hardwood silviculturists commonly use Gingrich-style stocking diagrams (Gingrich 1967) to measure stocking percentage, a relative measure of stand density. Stocking diagrams are used to specify silvicultural prescriptions for stands by using stocking to allocate growing space to trees through thinning and other intermediate treatments relative to management goals and objectives (Ernst and Knapp 1985, Helms 1998, Johnson et al. 2002). Stocking diagrams have been produced for upland forests in the Central Hardwood Region (Gingrich 1967), northern red oak and sugar maple (*Acer saccharum* Marsh.) forests in Wisconsin (McGill et al. 1999), and eastern white pine (*Pinus strobus* L.) in New England (Philbrook et al. 1973, Seymour and Smith 1987).

Stocking diagrams for bottomland forest types are not widely available, although interest in bottomland forest management is high among managers and landowners. There are three published stocking guides for bottomland hardwood management in the eastern United States: (1) mixed southern bottomland hardwood forests of cherrybark oak, Nuttall oak, and sweetgum (Goelz 1995a); (2) water tupelo (*Nyssa aquatica* L.)–baldcypress (*Taxodium distichum* [L.] Rich.) (Goelz 1995b); and (3) American elm (*Ulmus americana* L.)–green ash (*Fraxinus pennsylvanica* Marsh.)–eastern cottonwood forests in the north central states (Myers and Buchman 1984). All three of these guides are based on data from either Table 6 or Table 8 in Putnam et al. (1960), which are hypothetical stocking and diameter distributions and estimated stand growth and yields for a rotation of managed southern bottomland forests. In addition, B-level stocking in Goelz (1995a, 1995b) and Myers and Buchman (1984) is based on John Putnam's expert opinion of what desirable stand density would be at that stocking level and is not defined by actual data from open-grown trees, which are modeled on the basis of the principles of tree growth, and tree and crown area relationships (Chisman and Schumacher 1940, Krajicek et al. 1961).

There is a critical need for stocking diagrams to be produced that are based on data from real inventories of normal, fully stocked stands and measures of open-grown trees, and modeling using proven allometric relationships. Additional stocking diagrams are needed also to account for variations in tree species composition, which is highly variable in bottomland forests. McGill et al. (1999) have emphasized the need for stocking diagrams for various species

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mixtures because of variations in the crown and basal area relationship among species that affect tree density for given levels of stocking. Tree species diversity in the Lower Mississippi Alluvial Valley is tremendously greater, with more than 60 endemic species (Putnam et al. 1960), compared with bottomland forests of more northern latitudes in the Upper Mississippi River Watershed.

Eastern cottonwood–silver maple–American sycamore is a common bottomland association of the central Midwest. Although the association occupies a relatively small proportion of the land base, forests with this association are highly productive, with site index values commonly ranging from 80 to 150 ft (base age, 50 years) and are able to maintain high stand densities relative to the surrounding upland forests. However, there is little management information and no stocking diagram for the eastern cottonwood–silver maple–American sycamore bottomland association in the Midwest; and existing bottomland stocking diagrams are not appropriate for this species association.

Eastern cottonwood–silver maple–American sycamore forests occur in long narrow stands that have been shaped by fluvial geomorphic processes. Because of their limited areal extent and stand configuration, they are often poorly represented in area-based forest inventories. Sufficient stand data are lacking for developing stocking diagrams for these forests based on area-based inventories such as the Forest Inventory and Analysis (fia.fs.fed.us/). For example, in Missouri, there are only six plots in this forest association out of a total of 4,000 plots in the Forest Inventory and Analysis database. Therefore, we determined that it was necessary to conduct an inventory of eastern cottonwood-silver maple-American sycamore forests and measure open-grown trees of these species to have sufficient data to develop a stocking diagram according to the methods of Gingrich (1967).

The purpose of our study was to quantify stocking relationships to stand density and develop a stocking diagram for this forest association, which occurs in both the floodplains of larger rivers of the region, including the Mississippi, Missouri, Illinois, and De Moines rivers and their tributaries. This study is the first presentation of a stocking diagram for Midwestern bottomland forests that is based on field data, as opposed to idealized data used by others in the development of the existing stocking diagrams. This stocking diagram is also the first to be developed for the eastern cottonwood-silver maple-American sycamore association in the Midwest. We present, for the first time, the detailed procedure for deriving the equations necessary to construct the stocking diagram. Neither Gingrich (1967) nor any other developer of stocking diagrams has documented the method.

Methods

Developing Stocking Equations

The process of developing a stocking diagram according to Gingrich (1967) requires defining several points in the tree size-density space. Stocking diagrams have a clear objective of specifying the tree size-density space related to degrees of crowding for trees and full occupation of site by trees. To accomplish this, we need to define two key stocking curves: (1) when stands are at full-site occupancy, the average maximum density, which Gingrich (1967) labeled A-level stocking; and (2) the average minimum density, which he referred to as B-level stocking. Any point in the tree size-density space between A- and B-level stocking represents full stocking, i.e., all growing space in the stand is occupied by trees. The tree area equation is used to both model A- and B-level stocking.

Estimation for the Tree Area Relationships

The tree area (TA) equation developed by Chisman and Schumacher (1940) is

$$\mathrm{TA} = b_0 n + b_1 \sum d_i + b_2 \sum d_i^2, \tag{1}$$

where b_0, b_1, b_2 are parameters, n is the number of trees per acre, and d is tree dbh.

Students of Gingrich's stand stocking diagrams have long puzzled over his methods for constructing them, as the approach is unorthodox in the world of modeling. In many ways, the approach was a product of the technology and science available at the time Gingrich did his research. Unlike most regression modeling efforts, in which a dependent response, which has variable values or outcomes, is related to a set of independent variables associated with each unique outcome, the tree area response variable is set to the unit area (i.e., 1 ac). This means all TA values are equal to 1 for each of the plots taken in fully stocked normal stands. Equation 1 is estimated using linear regression procedures. To predict the average tree area given average diameter and average squared diameter, Equation 1 is divided by n. In addition, tree area is expressed in millacres (1/1,000 of an acre, or 43.56 ft^2) to reduce the number of leading zeros in the parameters. Thus,

$$\frac{\mathrm{TA}}{n \cdot 1000} = b_0 1 + b_1 \frac{\sum d_i}{n} + b_2 \frac{\sum d_i^2}{n} \tag{2}$$

is used to estimate A- and B-level stocking. Equation 2 states that the inverse of the number of trees is a function of average diameter and average squared diameter.

Average Maximum Density for Full-Site Occupancy (A-Level Stocking)

A-level stocking is defined as the average maximum number of trees that can grow on an acre in such a way that all growing space is used by the trees, while minimizing mortality. It is the level of stand stocking that a forest moves toward over time without any management. Initially understocked stands increase in density and individual trees grow larger, increasing stocking to the A-level. Overstocked stands undergo self-thinning to reduce density and stocking to the A-level. At this level, mortality due to competition is in equilibrium and trees have enough resources to survive with minimal growth. A-level stocking is determined by regression modeling of data from normally stocked stands, which are undisturbed, even-aged stands that have no gaps in the canopy, uniform spacing of trees, and near maximum basal area and volume for that given stand age and site quality (Johnson et al. 2002).

Average Minimum Density for Full-Site Occupancy (B-Level Stocking)

The second major relationship described in Gingrich stocking diagrams is the level of average minimum density for full-site occupancy (B-Level). It is the minimum number of trees, if all were open grown without competition, that it would take to "fill," or use, all the growing space on an acre. This level of stocking is estimated with the same tree area relationship proposed by Chisman and Schumacher (1940), but the nature of the data and the estimations procedure are quite different from those used to model A-level stocking. We need to estimate the minimum number of trees for each given diameter that will use all the growing space on an acre. This relationship depends on the work of Krajicek et al. (1961).

Table 1. Data summary table for the small and large river datasets used in the construction of the average maximum density (or A-level stocking) equation.

Variable	n	Mean	Standard deviation	Minimum	Maximum
Small River data set					
TPA	21	302	91.66	125	465
BA (ft^2/ac)	21	176	35.283	118	245
dbh (in.)	21	9.5	2.198	6.5	14.7
Large River data set					
TPA	10	320	195.541	75	711
BA (ft^2/ac)	10	158	27.919	124	201
dbh (in.)	10	6.7	5.36	3.0	20.1
Combined data set					
TPA	31	307	130.954	75.3	711
BA (ft^2/ac)	31	171	33.729	118	245
dbh (in.)	31	9.2	3.475	3	20.1

TPA, trees per acre; BA, basal area.

B-level stocking, defined by Krajicek et al. (1961) as a crown competition factor of 100, is an estimate of the fewest number of trees of a given size that can fully occupy the growing space in a stand. They reasoned that since crown area represents the ground area occupied by a tree, and open-grown trees are able to reach the limits of branch length growth, which varies by species and tree size, then tree size could be used to predict the maximum area used by a single tree of a given size when it grows without competition. Collectively then, the total number of trees that are needed to occupy all the growing space on an acre defines B-level stocking, and this varies by tree size. Theoretically, trees are arranged on the acre so that their fully developed crowns would just be touching each other and the site would be fully occupied with the minimum number of trees for that species. To estimate this relationship, we need a data set of open-grown trees of all size classes for the target species of management. The data necessary for this analysis are dbh and crown width measurements of individual open-grown trees for each species. From these individual tree data, tree area functions are estimated.

Data for Modeling A-Level Stocking

Data for production of the stocking diagrams were derived from several sources. To determine A-level stocking, we used data from 31 fully stocked plots (Table 1): (1) 10 plots from an inventory of big river floodplain forests along the Missouri, Mississippi, Illinois, and De Moines rivers (Colbert et al. 2002) in 1994 and 1995; and (2) the remainder from a study of forests in secondary flood plains in northern Missouri (Faust 2006).

The big river plot data (study 1 above) came from a study designed to investigate stand dynamics and tree mortality in eastern cottonwood-silver maple-American sycamore stands following floods along the (1) Mississippi River between Muscatine, IA, and St. Louis, MO; (2) Missouri River between Omaha, NE, and St. Louis, MO; (3) Illinois River between Peoria, IL, and Grafton, IL; and (4) De Moines River between De Moines, IA, and Keokuk, IA. Forest inventory plots were established in these stands that were located outside levees, i.e., they were on the river side of the levees and exposed to seasonal flooding. This forest inventory was acceptable for developing the stocking chart because tree mortality was confined to minor tree species and small diameter trees less than 8 in. in dbh, and the plots had substantial stocking in trees greater than 8 in., i.e., the plots were fully stocked with normal mortality. Each plot was a cluster of 11 1/20-ac fixed-area circular plots. The 11 subplot averages were used as a single observation in this analysis. These plots covered a sample area of 0.55 ac and were usually within 100 ft of the river's edge (Colbert et al. 2002). From the plot data, we used all live trees greater than 3 in. dbh.

The small river plot data (study 2 above) came from a study of the structure and stand development of eastern cottonwood-silver maple-American sycamore bottomland forests on tributaries to the lower Missouri river such as the Grand River, Locust Creek, and other lower-order headwater streams in northern Missouri (Faust 2006). The plots were fixed-area rectangular plots 65.6 by 164.0 ft, approximately 0.25 ac. Again, we used all live trees greater than 3 in. dbh. These plots were between 45 ft and 2,500 ft from the river, with an average distance of 460 ft (Faust 2006).

The big and small river data sets were combined (Table 1 and Figure 1) for developing the bottomland stocking chart. In the big river data (study 1), the cluster plot, i.e., all 11 1/20-ac subplots, was rejected if the average density (basal area and trees per acre) of the cluster was well below the highest values found in the data set. Selecting the threshold density was difficult because there was no clear break in the data set to indicate which plots to include or exclude. Our rational for selection was to evaluate each plot, reject those that had low stand density, typically less than two-thirds of the stocking of the plot included in the analysis. These plots occurred in Figure 2 between the graphed points and the origin. In selecting plots this way, we can reasonably expect that some of the highest plot density values may cause over estimates in A-level stocking. So, the guiding principle in compiling a data set for developing stocking relationships is to assemble one that has a sufficient number of plots that represent the highest values found in the data set. Thus, if one or two plots are inordinately high density, their influence on the regression will be minimized. Figure 2 illustrates the highest density values in our data set that we chose to include in estimating A-level stocking.

Although these two data sets have different sampling systems, we realized that they represented a major Midwestern bottomland type for which there is minimal quantitative research published. These data provided an opportunity to explore the tree size-density space useful in estimating stand stocking. However, a problem that quickly confronted us was that both of these data sets included plots that could not be considered fully stocked. Determination of the A-level stocking curve following Gingrich (1967) and Chisman and Schumacher (1940) require that stands be normal and fully stocked. It is somewhat subjective to determine which plots are fully stocked in the field and appropriate to use in the determination of A-level stocking. We assessed the study data sets by considering the location of individual plots in the size-density space (Figure 2). Obviously, the plots on the upper side of the size-density space were included, but the question was how far down the size-density space should we go before considering plots as being less than fully stocked. This decision has a large effect on the magnitude and shape of the resulting A-level stocking estimate. By choosing fewer plots, more weight is given to the highest density plots in the size-density space. By the criteria described above, we included the top 62% of the plots, yielding 31 stands, 10 from the large rivers data set and 21 from the smaller rivers data set (Table 1).

Data for Modeling B-Level Stocking

As stated above, B-level stocking represents the fewest number of trees of a given size that can fully occupy the available space. Open-grown trees are used as surrogates for trees unencumbered by space competition. To determine B-level stocking, we used data from a set

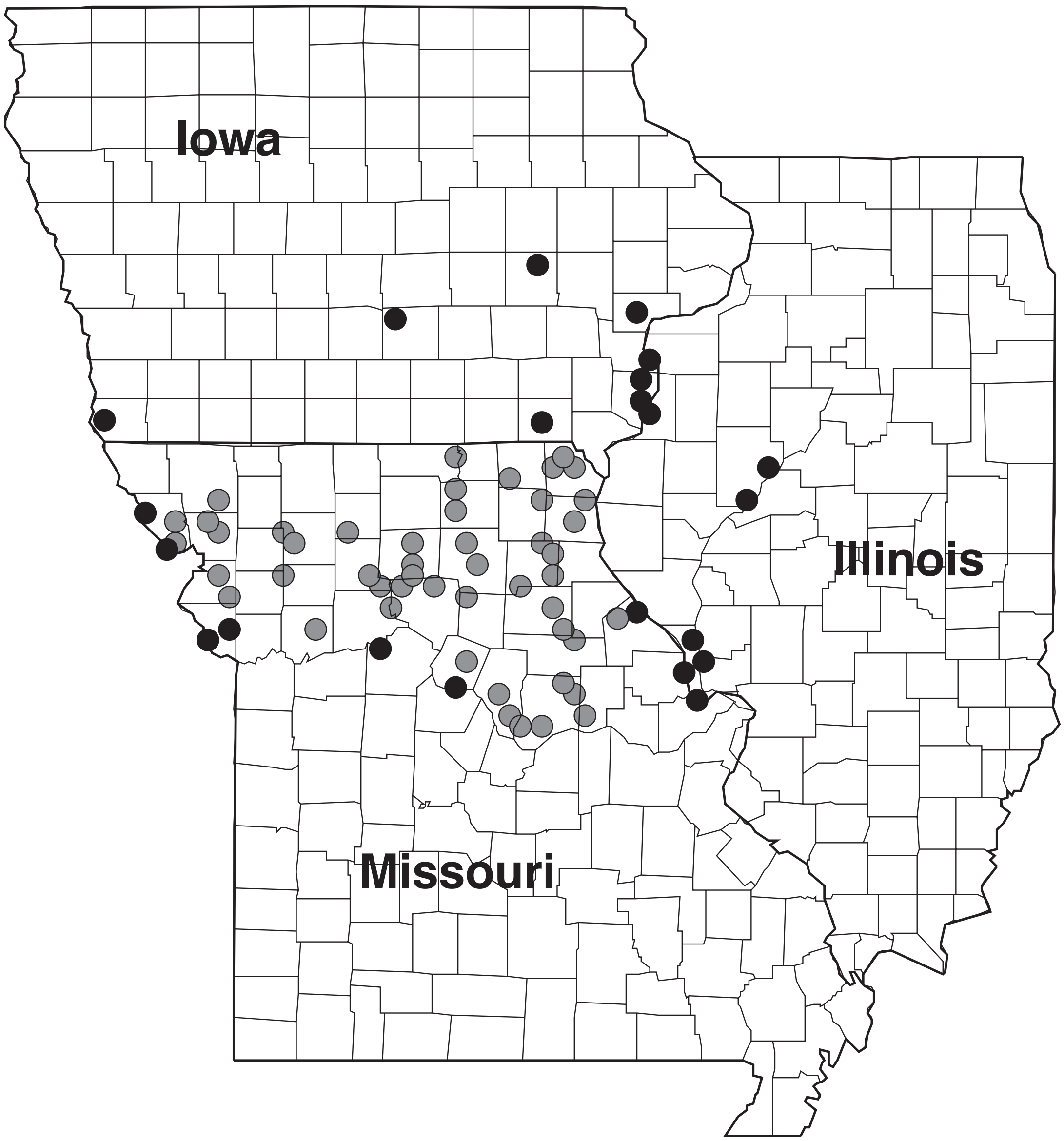

Figure 1. Map of the data plot locations in Missouri, Illinois, and Iowa. Black dots represent plots from the big river study (Colbert et al. 2002), and gray dots represent plots from the small river study (Faust 2006).

of individual open-grown silver maple, eastern cottonwood, and American sycamore trees from two sources: (1) trees ($n = 109$) in north Missouri flood plains that were measured by the authors, and (2) trees ($n = 126$) in southern Illinois and eastern Iowa that were recorded by Krajicek in the late 1950s (Krajicek et al. 1961). The open-grown trees measured in this study had no apparent damage or external indicators that past damage had occurred from mechanical, weather, insect, disease, or other sources that would limit their growth. The trees measured included the range of tree sizes from 0.3 to 55 in. dbh (Table 2). We assumed that the trees occupied the maximum possible growing space that an individual tree of that given size could when grown in the open without competition from other trees. Trees were selected by traveling through river bottoms to find single, open-grown trees of the desired species. Tree measurements included dbh, species, and four crown radii (our inventory) or one crown width (Krajicek inventory). Krajicek's data were compared with the authors' data for each subject species to confirm that our data were reasonable for species common to the two data sets. No data collected were considered outliers, so all were used in this analysis.

Modeling Tree Area Relationships and Stand Stocking

Initially, we estimated the tree size and area relationships using modern nonlinear fitting techniques. When viewed in tree area versus diameter space, the lines produced by the traditional (e.g., Gingrich 1967) and the modern methods were similar (Figure 3). However, when tree area equations were converted to stocking by expanding individual tree areas to stand area measures of stocking on a trees per acre basis, which is then plotted on the Gingrich stocking diagram, the differences between modern nonlinear and traditional regression approaches were quite noticeable. We concluded that the quadratic model form and using the traditional transformed fitting methods minimized a different error space than the nonlinear methods and hence produced different stocking curves when plotted as a Gingrich stocking diagram.

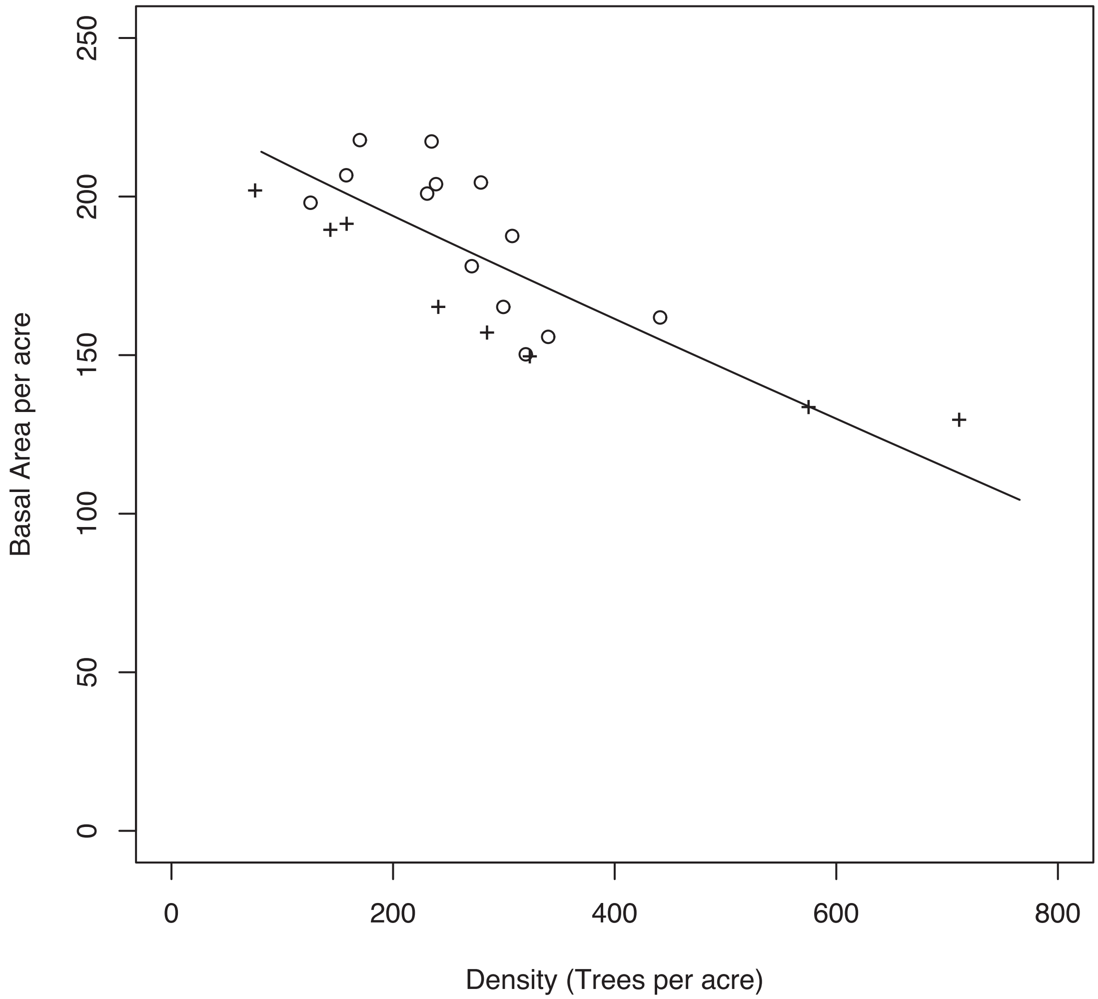

Figure 2. Graph of the sample data used in the fit of the A-level stocking with the fit equation plotted. The line is plotted in Gingrich space (basal area per acre versus trees per acre). Sources of the data are indicated by symbols: +, Colbert et al. (2002); ○ Faust (2006).

Table 2. Tree dbh (in inches) summary for open grown trees used to estimate minimum full site occupancy (B-level stocking).

Variable	n	Mean	Standard deviation	Minimum	Maximum
Faust					
SM Larsen	19	18.9	11.2658	2.3	42.1
CW	46	9.5	9.1921	0.6	55
SM	18	21.6	14.0954	0.3	47.7
SYC	26	8.9	8.3302	1.3	39.1
Krajicek					
CW	61	11.6	8.0792	0.7	31.8
SYC	65	13.8	9.7849	0.4	47
Combined					
CW	107	10.7	8.5998	0.6	55
SM	37	20.2	12.6149	0.3	47.7
SYC	91	12.4	9.6115	0.4	47

Three sources of these data were used: Colbert et al. (2002) from the Missouri River Bottoms, Faust (2006) from smaller river bottoms in northern Missouri, and Krajicek et al. (1961) from southern Illinois and southeastern Iowa. Species codes: CW, eastern cottonwood; SM, silver maple; SYC, American sycamore.

It is not self-evident how to construct a stocking chart following the procedures given in Gingrich (1967), but by using the methods of Krajicek et al. (1961) in the context of Gingrich's discussion, it becomes easy to develop Gingrich stocking diagrams for other species or forest types. The key missing information in the Gingrich article is the following procedure from Krajicek's article; this method estimates parameters for the linear function,

$$\mathrm{CW} = b_0 + b_1\mathrm{dbh}. \tag{3}$$

where CW is the average crown width of an individual tree, b_0 and b_1 are parameters, and dbh is the dbh of an individual tree. On the basis of this function, the result is transformed to predict crown area as

$$\mathrm{MCA} = \left(\frac{\pi(\mathrm{CW})^2}{4/435.6}\right), \tag{4}$$

$$\mathrm{MCA} = 0.0018(\mathrm{CW})^2, \tag{5}$$

$$(\mathrm{CW})^2 = (b_0 + b_1\mathrm{dbh})^2, \tag{6}$$

$$\mathrm{MCA} = \left(\frac{b_0' + b_1' \cdot \mathrm{dbh} + b_2' \cdot \mathrm{dbh}^2}{0.0018 * 1000}\right), \tag{7}$$

$$\mathrm{MCA} = b_0'' + b_1'' \cdot \mathrm{dbh} + b_2'' \cdot \mathrm{dbh}^2, \tag{8}$$

where MCA is maximum crown area, π is the math constant 3.1416, CW is the crown width from Equation 3, and dbh. Please note that a number of different parameters, specified as b_0, b'_0, and

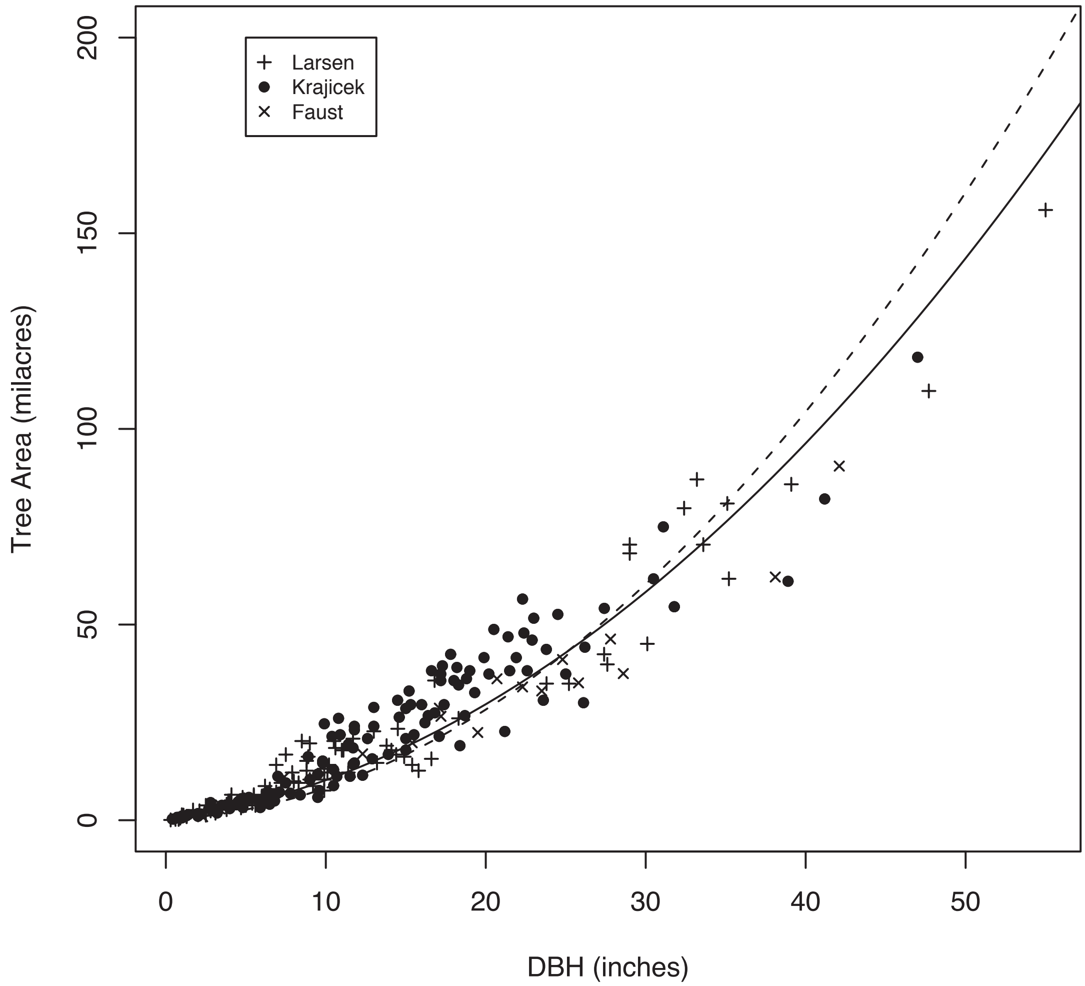

Figure 3. Graph of the data used to define B-level stocking in tree area space (tree area in millacres versus dbh in inches). Sources of the data are indicated by symbols: +, Larson; ●, Krajicek et al. (1961); ×, Faust (2006). The solid line is the equation fit to this data. The dashed line is from Gingrich (1967) for comparison.

b''_0, are different parameters, but they can be derived from the transformation described above. The end result is Equation 8, the familiar tree area equation.

This method of algebraic manipulation of the simple linear crown width equation into the tree area equation would make logical sense in the 1960s. Today, most researchers would approach the problem of fitting Equation 8 differently. In fitting the equation directly, we are minimizing a different error space than Gingrich. These methods produce curves with only minor difference in the tree area versus dbh graph space. In the Gingrich diagram space, the transformations accentuate small differences that, when transformed, produce different shaped curves. Krajicek's method described here was used to produce the average minimum full stocking functions used in this report.

Results and Discussion

After going through this exercise of learning how Gingrich fit the original equation, we used his method to determine the average maximum density line (A-line) and the minimum full stocking line (B-line). Multiple linear regression was used to model A-level stocking using the tree area ratio Equation 1 (adjusted $R^2 = 0.93$) (Figure 2) and to model B-level stocking with crown width Equation 3 (adjusted $R^2 = 0.91$) (Figure 3). The parameter estimates are shown in Table 3, and the stocking lines generated from these parameters are shown in Figure 4.

Table 3. Parameter estimates for tree area ratio equations for A-level and B-level stocking in eastern cottonwood–silver maple–American sycamore bottomland forests in the Midwest.

Parameter	A-level	B-level
b_1	0.685724	0.159
b_2	0.010125	0.544
b_3	0.023656	0.0465

Comparisons between this stocking guide and other bottomland stocking guides are limited because each guide has a slightly different set of dominant species, varying site conditions, and different methods used to develop the guides. Clearly, stocking guides developed for a particular species community are relevant only for that forest composition, even though average tree area for a given diameter and species is the same regardless of tree age or site quality according to Gingrich (1967).

A-level stocking in this study is almost 33% higher than A-level values published by Myers and Buchman (1984) and Goelz (1995a). The stocking charts produced by Myers and Buchman (1984) and Goelz (1995a) were developed from an inventory of

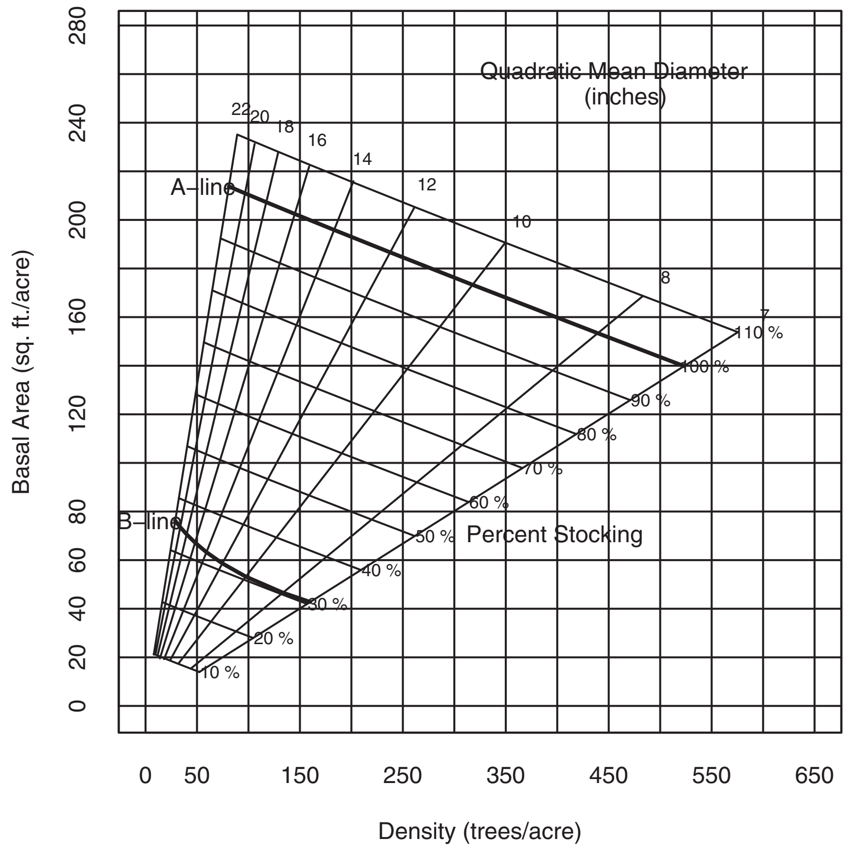

Figure 4. Gingrich stocking diagram for Midwest bottomland hardwood species (eastern cottonwood, silver maple, and American sycamore).

mixed-species southern bottomland hardwood stands on good to excellent sites (i.e., ≥90 ft site index for cherrybark oak) presented by Putnam et al. (1960). It was assumed by Goelz (1995a) that the unthinned stands in Putnam's work represented fully stocked stands that were at A-level stocking. Goelz (1995b) also used Putnam's stand data from thinned stands to determine B-level stocking, which he recognized did not follow the concept of minimum full stocking (see Krajicek et al. 1961), but he thought it illustrated desired stand density after thinning as determined by an expert. Forest-grown trees thinned to what an expert deems desirable density for promoting growth and yield may not represent the same minimum density as full-site occupancy defined by open-grown trees. Myers and Buchman (1984) did not give any methods on how they used Putnam's data to construct their stocking chart. A-level stocking represents stand density when growth and mortality are in "balance" in fully stocked stands. Our stocking equations indicate that the study stands had substantially higher stocking for given levels of stand density than those reported by others using the data of Putnam et al. (1960). We found several bottomland hardwood forests with much higher basal area per acre than would be expected using either Myers and Buchman's or Goelz's stocking diagrams

The stocking guides of Myers and Buchman (1984) and Goelz (1995a, 1995b) are based on data from the southern bottomlands in the Lower Mississippi Alluvial Valley. Southern bottomlands are generally considered more productive areas than upland oak used by Gingrich (1967) or the Midwestern eastern cottonwood/silver maple forests used in this study, in part because of the shorter growing seasons at these more northerly latitudes. Thus, we would expect their stocking guides to show higher basal areas at A-level stocking for the given tree densities compared with upland stocking guides or our Midwestern bottomland guide based only on regional differences in forest composition and climate. However, they show lower basal areas compared with our Midwestern forest sites for similar combinations of density and stocking. Thus, we suggest that the perceived ability of bottomlands in Midwestern states of Missouri, Illinois, and Iowa to support higher basal areas than more southern bottomland forests over the range of stocking and density is related to factors other than stand or site conditions, and perhaps more related to the methods used in constructing the stocking diagrams.

We suggest that differences in tree structure, shade tolerance, and mortality rates of silver maple and eastern cottonwood may also allow for the higher basal areas at A-level stocking found in our study compared with other bottomland stocking studies described in this article. The structure of eastern cottonwood-silver maple-American sycamore associations may be characterized by smaller crown widths, primarily because of the dominance of eastern cottonwood, which would allow for higher basal areas in the fully stocked condition compared with a diverse mixture of southern hardwoods including oak species. Another possible explanation is that silver maple is considered shade tolerant on good sites (Burns and Honkala 1990), and a subcanopy of silver maple that is recruiting into the dominant crown classes of the overstory could result in higher stand basal areas at given stocking levels.

B-level stocking in our diagram is lower than the other bottomland stocking charts (Myers and Buchman 1984, Goelz 1995a). Direct comparisons are tenuous, however, because their B-level stocking curves are based on the Putnam et al. (1960) "desired" stocking after thinning rather than actual data on open-grown trees.

Conclusion

We developed a stocking diagram for Midwestern bottomland forests of the eastern cottonwood-silver maple-American sycamore association. A-level stocking was developed from normal, fully stocked, mixed-hardwood Midwestern bottomland forests, located in the floodplains of the big rivers and their tributaries. We found that A-level stocking was about 33% higher than previously published bottomland hardwood stocking guides. B-level stocking was developed from open-grown trees for the three study species collected in Missouri, Illinois, and Iowa. This stocking diagram is a significant contribution to forest management of Midwestern bottomlands, as none existed before; it is based on actual forest inventories and was determined following the principles and methods of Chisman and Schumacher (1940), Krajicek et al. (1961), and Gingrich (1967). We have also documented in detail the procedure necessary for constructing a stocking diagram, which should be followed to develop stocking diagrams for other forest compositions in other regions.

Stocking guides are an estimate of average tree space occupancy for a restricted set of species in a particular region. Species and regional differences are to be expected when comparing stocking charts from widely different ecoregions. We found that shape and magnitude of the stocking lines are dependent on the source data, the procedures, and modeler's assumptions. Given these caveats, stocking charts are useful tools for managers attempting to fully use available growing space to achieve a variety of resource management objectives, including providing for regeneration, sustaining timber production, creating wildlife habitat, restoring woodlands and savannas, and maintaining aesthetic values. This stocking chart can be used to guide management decisions for Midwest bottomland forests dominated by eastern cottonwood and silver maple, with minor ($<$10%) amounts of American sycamore.

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