FOREST DYNAMICS AT THE MISSOURI OZARK FOREST ECOSYSTEM PROJECT VIEWED THROUGH STOCKING DIAGRAMS

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Abstract.—Stocking diagrams come in two forms, the Gingrich diagram and the density management diagram. While they both present the same information about a forest stand, they each provide a different perspective on the data being displayed. Density management diagrams have been around since the 1930s and the Gingrich diagram has been around since the 1960s, but applications of the diagrams to investigate long-term forest dynamics have been rare. We apply both types of stocking diagrams to stands at the Missouri Ozark Forest Ecosystem Project to examine change over a 20-year period and to graphically illustrate the temporal trends.

INTRODUCTION

Stocking is a concept used in forestry to describe the space occupied by trees. This concept is similar to carrying capacity applied to animal populations. In a forest management context, stocking provides a tool for measuring and managing the growing space occupied by the trees in a stand. Stocking accounts for the number and size of trees of a given forest type that can partially fill, completely fill, or over-fill the available growing space.

There have been two prevailing approaches to examining stocking graphically. The first graphical approach published in the United States was by Reineke (1933). It used a log-log plot of the number of trees per acre (TPA) by their mean size (Fig. 1A). Reineke started by using mean tree diameter as the measure of tree size, although many other metrics of mean size have been tried. Today, quadratic mean tree diameter (QMD) is the commonly used metric of mean tree size because it is easy to apply to forest inventory data that are commonly available. In Reineke's original publication, the TPA variable was on the y-axis with QMD on the x-axis. It has become convention (Long 1985) to reverse these axes as it makes comparisons with other stocking charts more convenient. Besides the major axes, a Reineke stocking diagram includes a maximum stocking line defined as the maximum size density index (SDI) for the forest type in question (Larsen 2001). By convention, the maximum SDI applies for a given species or forest type, and it indicates the number of 10-inch diameter trees per acre that would occupy the entire growing space (or some given proportion of the growing space). The Reineke size density diagram translates the index for other combinations of mean QMD and TPA. Reineke published SDI parameters for species across the United States. The accepted SDI number for upland oaks in the Central Hardwood region is 230 10-inch diameter trees per acre (Schnur 1937).

The second graphical approach is a distillation of a sequence of papers by Gingrich (1967). In the Gingrich stocking diagram, the graph displays TPA on the x-axis and basal area per acre (BAa) on the y-axis. QMD is simply the diameter of the tree of average BAa which can be computed for any combination of basal area and number of trees per unit area (Fig. 1B).

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Included in the Gingrich stocking diagram are lines indicating threshold stocking levels. The basis for these thresholds originated from the tree area equation of Chisman and Schumacker (1940). In the Chisman and Schumacker paper, the authors proposed an equation to estimate area occupied by a tree, given its diameter at breast height (d.b.h.). They found that a quadratic equation predicted the relationship best. Because the independent variable in the stocking equation is diameter, this means the equation contains both d.b.h. and d.b.h.^{2}, which can be thought of as d.b.h. and basal area because basal area is simply the squared d.b.h. multiplied by a constant. At the time the Chisman and Schumacker paper was developed, people still used normal yield tables, which are tables showing change over time in basal area, volume, and number of trees for undisturbed stands. By using data from normal yield tables, Gingrich could determine the number of trees per acre of a given d.b.h. that would utilize all the growing space on a site. This information can be used to define the line of 100 percent stocking (sometimes called the A-line) on a Gingrich Diagram (see Gingrich 1967 or Larsen 2010 for details) (Fig. 1B).

Krajicek, a coworker of Gingrich in southern Illinois, wanted to develop an index of crowding in a forest. Kriajicek's solution was to measure open-grown trees, which represented trees with the largest possible crown area for a given d.b.h. This led to the concept of crown competition factor (CCF), a metric of the area that would be occupied if all trees on a site had maximum crown area (Krajicek et al. 1961). Crown competition factor is scaled so that a number of 100 indicates that the available space would be fully occupied if all trees were free to grow with their crowns at maximum area. If CCF is less than 100, there is unoccupied growing space on the site. If CCF is greater than 100, the tree crowns are competing with one another, and trees have smaller crowns than open-grown trees with an equivalent d.b.h.

Gingrich used the concept of crown competition factor to identify what is commonly referred to as the B-line on the Gingrich stocking chart. The B-line defines a threshold in stocking where stocking values above the B-line fully occupy the physical space and indicate crowding to some extent (i.e., CCF > 100). Stocking values below the B-line represent conditions where trees do not fully occupy the available growing space (i.e., CCF < 100).

In Gingrich (1967), a third line known as the C-line is displayed on the stocking diagram. The C-line represents stocking levels from which a stand could grow to reach the B-line in 10 years. Nowhere in the Gingrich's papers does he provide an equation or any statistics on this line. We view this as a bit of expert opinion.

STOCKING DYNAMICS

Stocking diagrams are routinely used to assess stand conditions at a single point in time, but most of us have not used stocking diagrams to examine changes over time for repeat-measurement data. With repeat-measurement data for large inventories, a stocking diagram can be produced for each stand or plot, resulting in hundreds or even thousands of individual stocking charts. Most people find viewing that many stocking charts to be tedious. Consequently, this approach is not well suited for a printed publication. This may be why there are so few papers on this subject. Additionally, two-dimensional descriptive statistics have not been well developed to describe subtle differences in stocking trajectories over time.

In general, repeat measurements for undisturbed plots show a trajectory over time of increasing quadratic mean diameter, increasing basal area, and decreasing number of trees per acre. In this paper we illustrate the utility of stocking diagrams for displaying stand development trajectories using repeat-measurements data sets.

METHODS

The data used in this study are from the Missouri Ozark Forest Ecosystem Project (MOFEP), which was implemented by the Missouri Department of Conservation, an agency responsible for natural resource management on state-owned lands as well as for providing landowner assistance. The MOFEP study was established on about 9,000 acres of state forest land along the Current River in Shannon, Reynolds, and Carter counties of Missouri (Shifley and Brookshire 2000). The study included nine sites ranging from 700 acres to 1,300 acres and grouped into three replicated blocks with three component treatments per block. The three treatments were no harvest management (NH), uneven-aged management (UAM), and even-aged management (EAM). On MOFEP sites, an overstory inventory was implemented on 648 1/2-acre, fixed-area plots. These plots were measured in 1992, 1995, 1997, 2001, 2005, 2009, and 2012.

In this paper, a sequence of stocking diagrams illustrates the effects on stocking for each treatment during the 20-year-period of the measurements. Each data set was graphed using both Reineke and Gingrich diagrams to compare the dynamics revealed by each graph type.

RESULTS AND DISSCUSSION

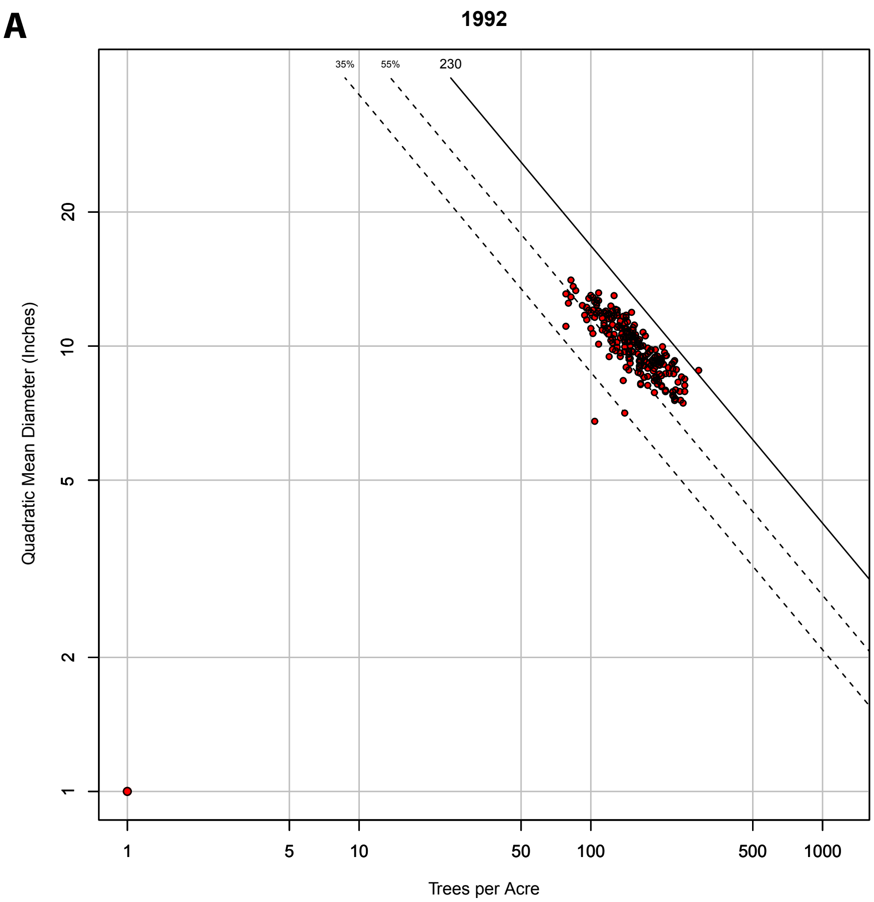
In general, the effect of the NH treatment was to reduce the range of the trees per acre and increase the range of basal area (Figs. 1 and 2), but the center of the plot cloud was at about 80 percent stocking. If we consider the Reineke diagrams (Figs. 1A and 2A), we have changed the trees per acre from about 120 to 150, and the quadratic mean diameter has increased from about 10 to about 12 inches.

For the UAM sites (Figs. 3 and 4), the magnitude of the changes was less than that observed for the EAM sites. Uneven-aged management increased the range in basal area but decreased the range in trees per acre. It also reduced the range in quadratic mean diameter. It is important to note that prior to treatment, these sites were generally fully stocked forests and the densities were reduced by the treatments. This occurred because prior to treatment, the stands were mostly even-aged and harvesting was required to begin to convert them to uneven-aged stands, a process that will require five to six entries to be fully achieved.

On the EAM sites (Figs. 5 and 6), the plots exhibited a greater range of basal area than the other sites, largely because of the number of plots with a low basal area after regeneration harvests were implemented. The range in trees per acre was reduced by a small amount and the quadratic mean diameter increased because of growth following treatment.

Each of the treatments are readily identifiable in the pattern in each of the stocking diagrams. These patterns provide a visual means for understanding stand development patterns. Another trend more easily observed in the full temporal sequence is that the harvests are not removing all the forest growth, so the stands are accumulating growing stock.

A



B

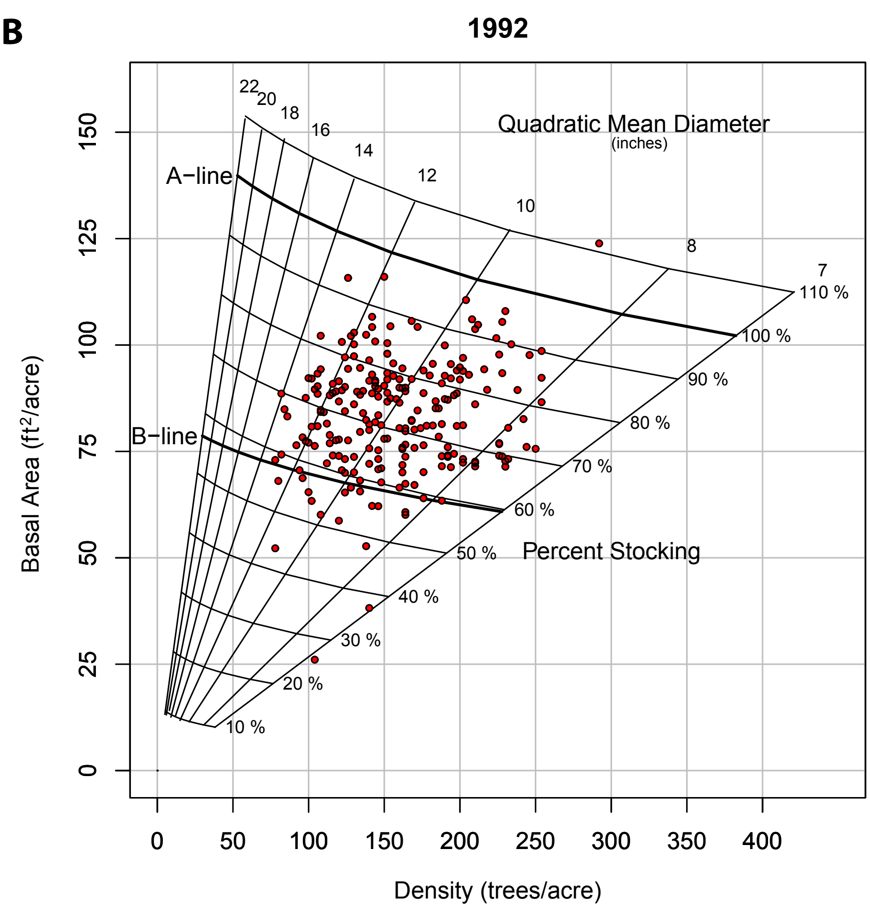


Figure 1.—Reineke (A) and Gingrich (B) stocking diagrams for the Missouri Ozark Forest Ecosystem Project no harvest (NH) sites in 1992.

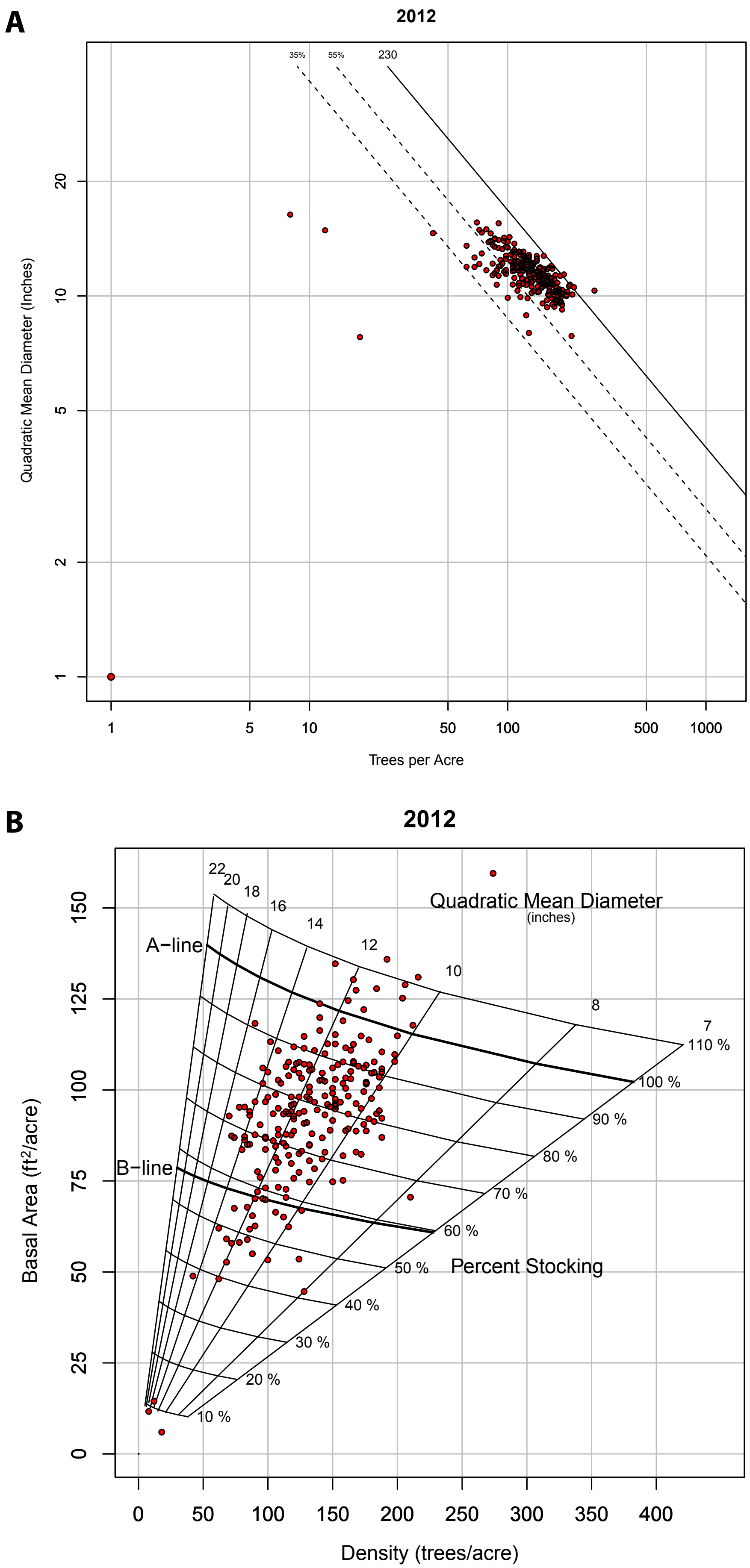


Figure 2.—Reineke (A) and Gingrich (B) stocking diagrams for the Missouri Ozark Forest Ecosystem Project no harvest (NH) sites in 2012.

A

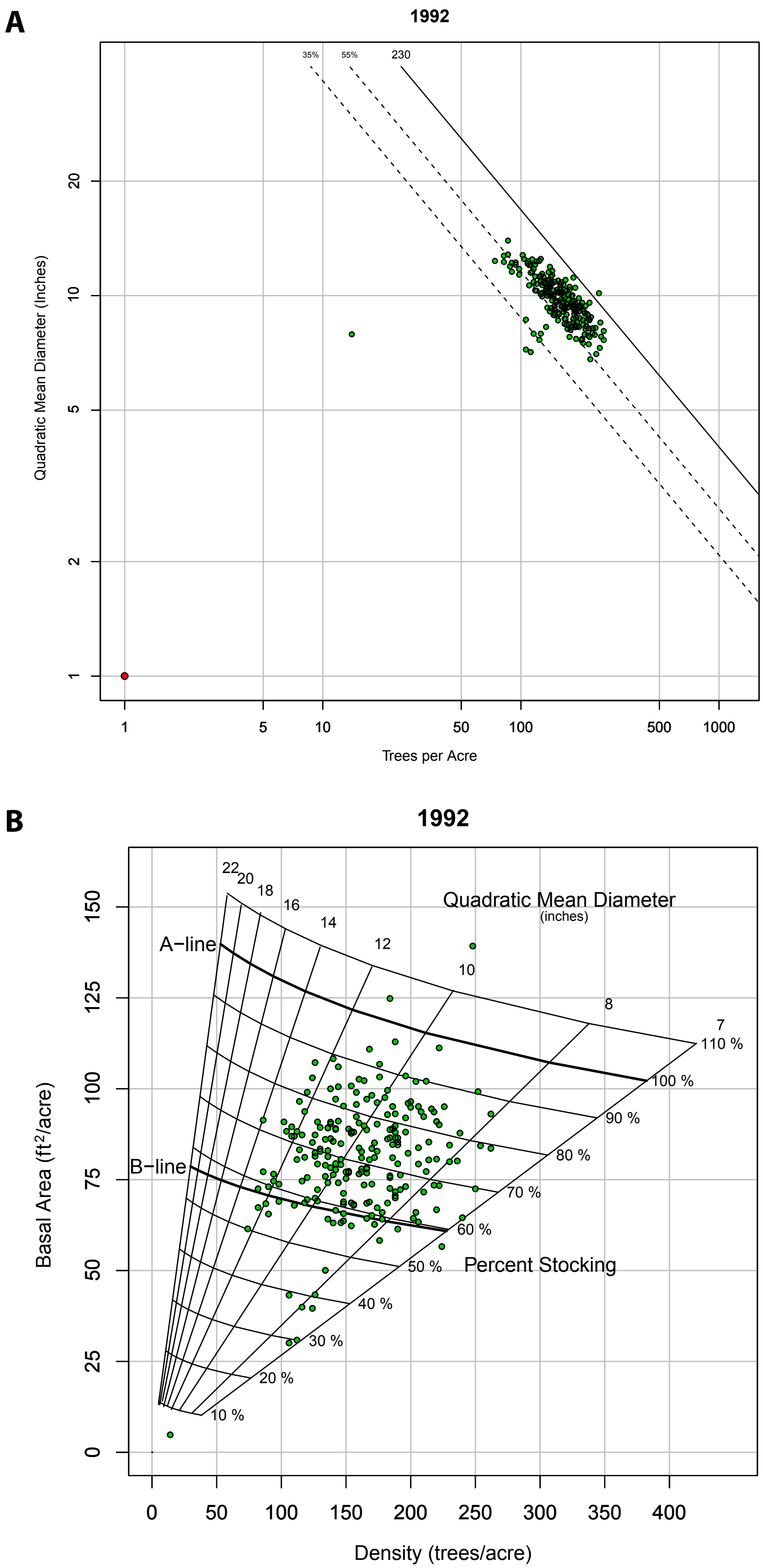


Figure 3.—Reineke (A) and Gingrich (B) stocking diagrams for the Missouri Ozark Forest Ecosystem Project uneven-aged management (UAM) sites in 1992.

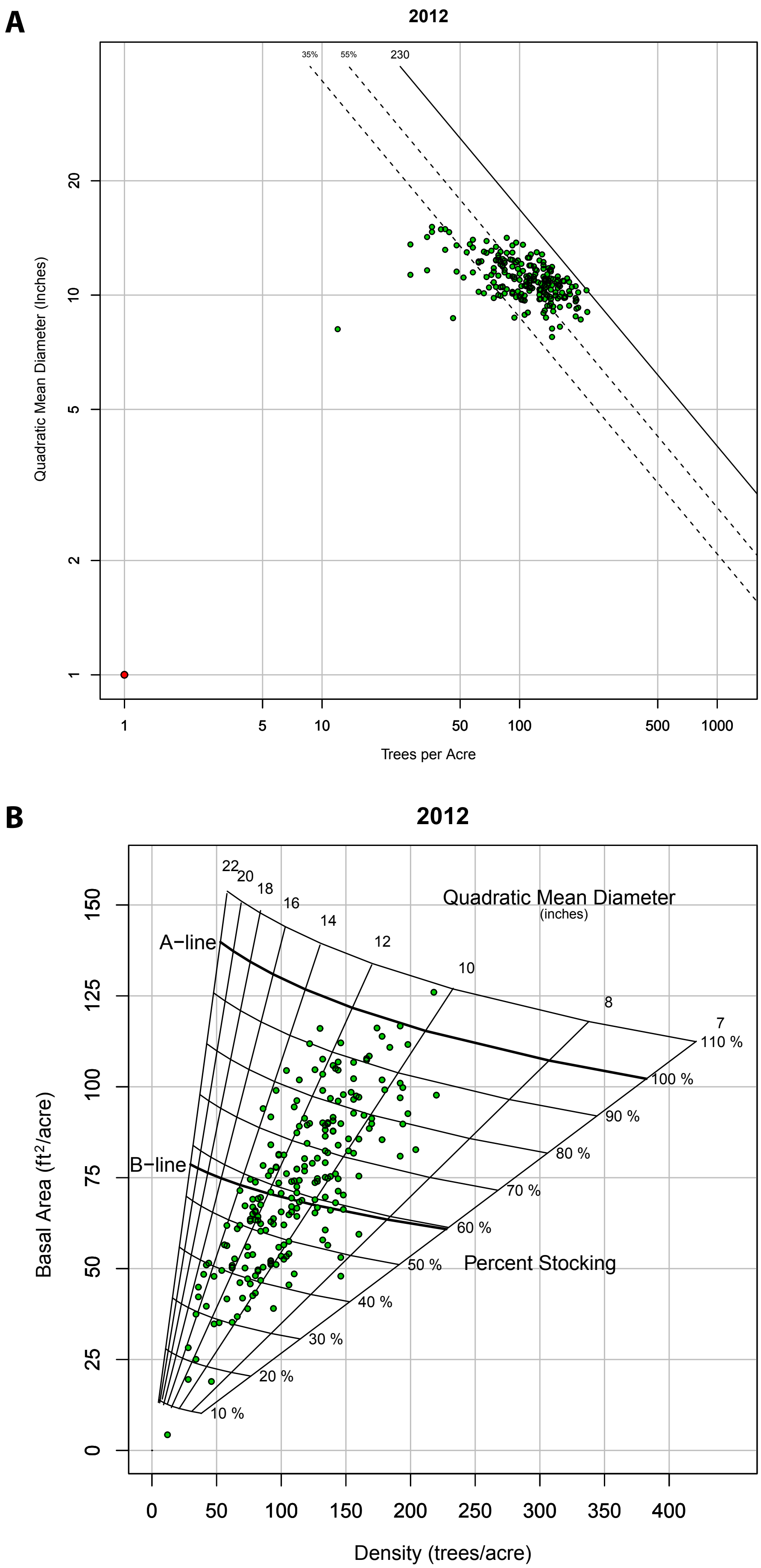
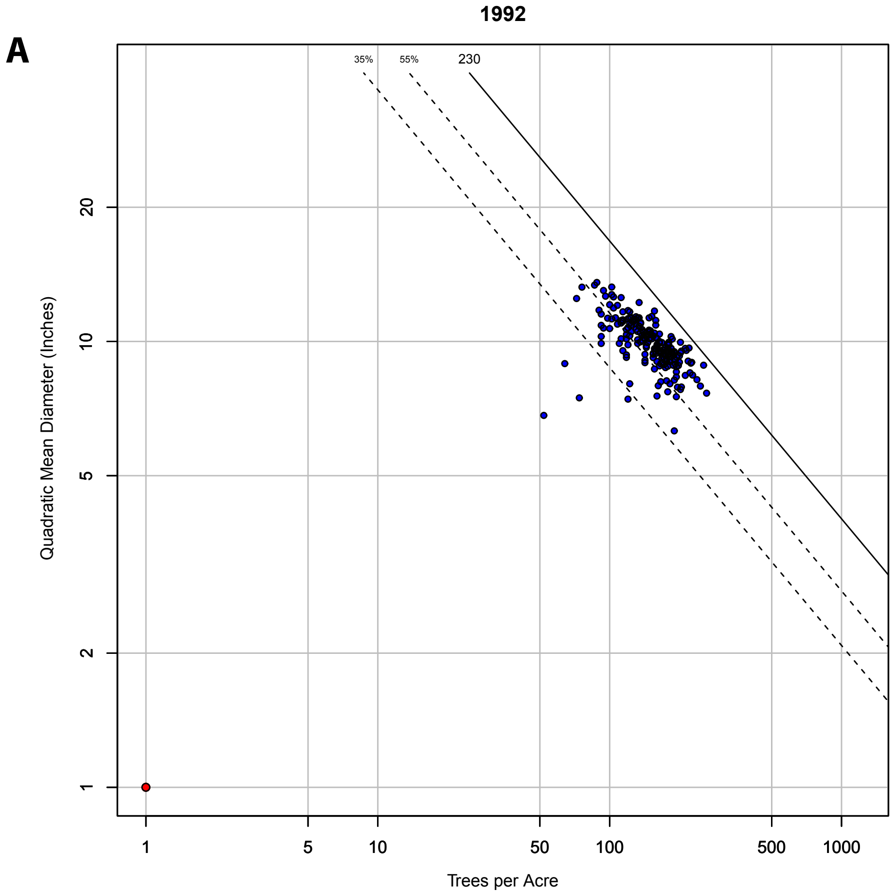


Figure 4.—Reineke (A) and Gingrich (B) stocking diagrams for the Missouri Ozark Forest Ecosystem Project uneven-aged management (UAM) sites in 2012.



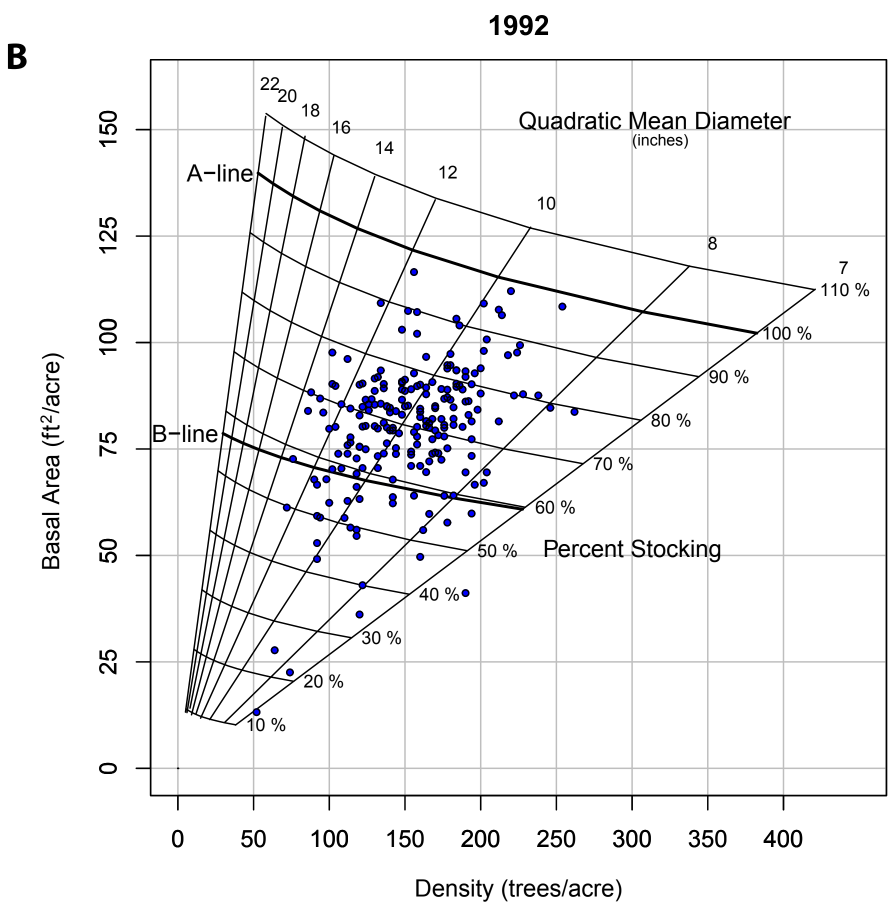


Figure 5.—Reineke (A) and Gingrich (B) stocking diagrams for the Missouri Ozark Forest Ecosystem Project even-aged management (EAM) sites in 1992.

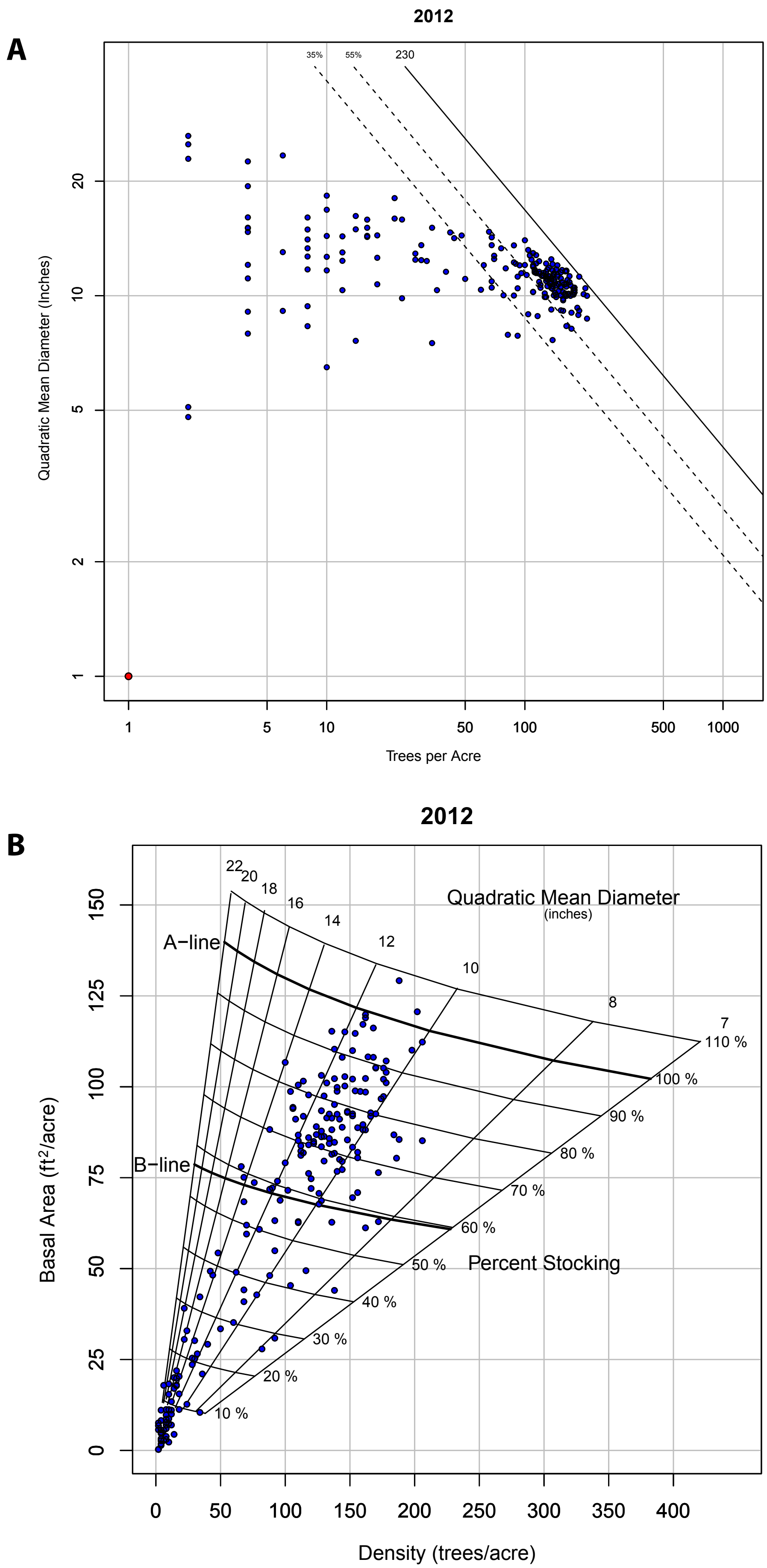


Figure 6.—Reineke (A) and Gingrich (B) stocking diagrams for the Missouri Ozark Forest Ecosystem Project even-aged management (EAM) sites in 2012.

CONCLUSIONS

Stand development patterns can be tracked on stocking diagrams using repeat-measurement plots. Stocking diagrams are helpful for interpreting changes caused by management treatments or other disturbances. The diagrams presented here provide a picture of the relative impact of three forest management practices applied over two decades for a large, forested landscape.

LITERATURE CITATIONS

Chisman, H.H.; Schumacker, F.X. 1940. **On the tree-area ratio and certain of its applications**. Journal of Forestry. 38: 311-317.

Gingrich, S.F. 1967. **Measuring and evaluating stocking and stand density in upland hardwood forests in the central states.** Forest Science. 13: 38-53. (Note: Gingrich was misspelled as Ginrich in the Journal).

Krajicek, J.E.; Brinkman, K.A.; Gingrich, S.F. 1961**. Crown competition: a measure of density**. Forest Science. 7: 35-42.

Larsen, D.R. 2001. **Reineke stocking diagrams.** http://oak.snr.missouri.edu/nr3110/topics/density.php (accessed June 2016).

Larsen, D.R.; Dey, D.C.; Faust, T. 2010. **A stocking diagram for midwestern eastern cottonwood-silver maple-American sycamore bottomland forests.** Northern Journal of Applied Forestry. 27(4): 132-139.

Long, J.N. 1985. **A practical approach to density management.** Forestry Chronicle. 61: 23-27.

Reineke, L.H. 1933. **Perfecting a stand density index for even-aged forests.** Journal of Agricultural Research. 46: 627-638.

Schnur, L. 1937. **Yield, stand, and volume tables for even-aged upland oak forests.** Technical Bulletin No. 560. Washington, DC: U.S. Department of Agriculture, Forest Service. 87 p.

Shifley, S.R.; Brookshire, B.L., eds. 2000. **Missouri Ozark forest ecosystem project: site history, soils, landforms, woody and herbaceous vegetation, down wood, and inventory methods for the landscape experiment.** Gen. Tech. Rep. NC-208. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 314 p.