Plot Size Recommendations for Biomass Estimation in a Midwestern Old-Growth Forest

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ABSTRACT: *We examine the relationship between disturbance regime and plot size for woody biomass estimation in a midwestern old-growth deciduousforestfrom* **1926** *to* **1992.** *Analysis was done on the core 19.6 ac of a 50. I ac forest in which every tree 4 in. dbh and greater has been tagged and mapped since 1926. Five windows of time are compared-1926, 1976, 1981, 1986 and 1992. The most efficient plot sizes requiring measurement of the least total area rangefrom 0.02 to 1.6 ac. A small plot size was recommended after grazing disturbance, and a large size was recommended when mortality was high andacceptable error was low. North. J. Appl.For. 15(4):165–168.*

Old-growth forests currently represent small forests and small numbers of forests throughout the region (Spetich 1995). However, these sites will continue to grow in area and numbers over the next century due to management strategies now in place (Shifley et al. 1995). For instance, Spetich et al. (1997) found that, over the next century in Indiana alone, old-growth forests will increase in area by a factor of 2,292 and in number by a factor of 7 based on management plans of public land holding agencies. In Missouri, old-growth forests will increase in area by a factor of 25 over the same time period (Shifley et al. 1995). The currently existing old-growth sites are important for the information they can provide us to develop as guidelines for monitoring these future old-growth sites. They will also provide us with data to better understand successional pathways and how those pathways change when sites are disturbed, forming the basis of management tools for other forests.

Little is known about the spatial variation of aboveground biomass and related sampling issues. Papers recommending plot size for Midwestern old-growth forests of the United States have not considered the size necessary to inventory biomass (Cain 1934, Shifley and Schlessinger 1994). Nor have these papers considered the type or level of disturbance that might affect variation and plot size decisions. The objective of this study was to recommend plot size for estimating biomass under two typical disturbance regimes that have occurred in Midwestern old-growth forests (exogenous and endogenous). The exogenous disturbance at our study site was grazing and the endogenous disturbances were two levels of mortality (high and low). These recommendations were based on the most efficient plot size and sample size combination that required the least total area.

Early in United States forest inventory history the 0.25 ac plot size was used extensively (Avery 1975). However, plots ≤ 0.1 ac are now more commonly used (Avery 1975). This change in size is partly due to the fact that second-growth forests are more homogenous than old-growth forests (Avery 1975). Today fixed-radius plots rarely exceed 0.25 ac in size due to the increasing number of borderline trees with increasing plot size (Loetsch et al. 1973). In a comparison of 144 sampling designs, Kulow (1966) found that sampling precision and accuracy were proportional to the size of sampling unit. He also found that 0.2 and 0.1 ac plots resulted in significantly better results than smaller sampling units by significantly reducing the difference between the true mean and the estimated mean.

Livestock grazing has influenced the structure of forests throughout most of the midwestern region (Barnes 1989, Parker 1989, Shifley et al. 1995). Many old-growth remnant forests have had grazing disturbance through the beginning of this century (Lindsey et al. 1969, McCune et al. 1988, Parker and Ward 1988, Barnes 1989, Parker 1989, Richards et al. 1995). A study of 20 yr of grazing in an old-growth forest in Pennsylvania found that, for the young trees (trees

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< 2.5 ft tall and > 1 in. in dbh), the grazed side of the forest had 59% less basal area than the ungrazed side (Lutz 1930). Steinbrenner (1951) found similar results for six woodlots in Wisconsin. Grazing by livestock can result in a more patchy distribution of small size class trees (Ward et al. 1996) and should be taken into account when sampling.

High rates of tree mortality have been noted in several midwestern old-growth forests (Barton and Schmelz 1987, McCune et al. 1988). The Barton and Schmelz study of a central Indiana old-growth forest from 1954 to 1984 indicated that mortality increased in almost every size class.

Study Site

The Davis Research Forest is a 50.1 ac old-growth deciduous forest located in Randolph Co. in east-central Indiana, in the SE quarter of Section 23, Township 21 North, Range 12 East. The forest canopy is dominated by oak-hickory with a range of tree species that typically occur on mesic to wet mesic sites. The site is in the Blufton Till Plain Section of the Central Till Plain Natural Region (Homoya et al. 1985). Topography of the area is gently rolling with 10 ft of relief. The four soils in this forest are Blount (fine, illitic, mesic Aeric Ochraqualfs), Glynwood (fine, illitic, mesic Apuic Hapludalfs), Pewamo (fine, mixed, mesic Typic Argiaquolls) and Saranac (fine, mixed, mesic Fluvaquentic Hapluquoll). The site is vegetatively classified as a lowland depressional forest (Lindsey and Schmelz 1970) but is physiographically located on upland. Subcanopy species are dominated by maple-elm. Density was greater in 1992 than in 1926 due to ingrowth of small diameter trees, which resulted in a lower arithmetic average dbh. A more detailed site description can be found in Parker et al. (1985).

Davis Research Forest was privately owned until 1917 when it was donated to Purdue University. Livestock grazing occurred from the mid 1800s until 1917. Other human disturbances included the cutting of up to 50 dead, dying and storm damaged trees in the 1940s and 1950s and the theft of 3 to 4 black walnut trees in the 1960s. Dutch elm disease and phloem necrosis continue to alter the structural status of both American elm and slippery elm. American elm was once a large dominant tree in this forest, but now is relegated to the understory due to the disease. Other minor disturbances have occurred outside the core area of forest examined during this research.

Methods

Past Inventories and Layout of the Study Area

The Davis Research Forest data set is probably the most spatially and temporally extensive old-growth data on the continent (i.e., a 100% census spanning 66 yr), which gave us a unique opportunity to investigate biomass sampling issues. The first inventory of this tract was in 1926 when the area was divided into 55 plots and every tree 4 in. or larger in diameter was measured. Species and diameter at breast height (dbh) to the nearest inch were recorded, a metal ID tag was placed on each tree at dbh, and each tree's location was plotted on a large-scale map (Bur M. Prentice 1927, unpublished report).

The 1926 plot corners were relocated in 1976. In a new inventory of the core 19.6 ac study area, species and dbh were recorded for all trees greater than 4 in. dbh, and trees were retagged at knee height. Cartesian coordinates for each tree were determined to the nearest yard. In 1981, ingrowth trees (less than 4 in. diameter in 1976 but greater than 4 in. by 1981) were measured and retagged. In 1986, the study area was gridded into 32.8 x 32.8 ft plots, all trees ≥ 4 in (including ingrowth) were remeasured, and all trees were tagged at the base. In 1992, the study area was inventoried on the 32.8 x 32.8 ft plot grid including ingrowth.

This research is based on the core 19.6 ac of the forest where data are most consistent across all inventories and edge influence is minimized. Because only ingrowth trees were measured in 1981, diameters of all other trees within the study area for that year were estimated from differences between the 1986 and 1976 diameters for each tree. The average growth rate by species was used to establish the 1981 dbh for trees that died after 1981 and before 1986.

Biomass Equations

Equations of Smith (1985) and Hahn and Hansen (1991) were used to estimate biomass of each tree by location within the study site in 1926, 1976, 1981[1], 1986 and 1992. Two sets of equations were utilized to calculate biomass for tree species of this forest, one for the bole of each tree and one for the tree top and branches excluding leaves. These are the only biomass equations available for Indiana and have been accepted in the literature (Jose and Gillespie 1997a, Jose and Gillespie 1997b, Kaczmarek et al. 1995). Fewer than 0.2% of the trees in Davis exceed the dbh range of the equations at any of the five inventory dates. The estimate of bole volume was combined with the tree top and branch volume to compute overall dry weight biomass for each tree.

Sample Size Estimation

Sixteen plot sizes ranging from 0.02 to 4.98 ac (Spetich and Parker 1998) were used for comparisons of sample size for biomass estimation. All plots were aggregations of the 32.8 x 32.8 ft plots, resulting in a grid of plots across the 100% inventoried study area. The mean and standard deviation of the biomass were calculated for each plot size. These results were used to estimate sample sizes required to estimate biomass within 5, 10, and 20% of the observed mean (where observed mean is based on the 100% inventory). Freese's 1962 sample size equation was used. The sample size, n, was determined for all 16 plot sizes at error levels of 5, 10, and 20%. Plot and sample size values were computed for each of the five inventory dates to develop plot and sample size recommendations for biomass estimation in a Midwestern old-growth forest under endogenous and exogenous disturbance regimes.

In each case, we selected as most efficient the plot size that required measurement of least total area (plot size x n) at a specified error level. To simplify comparison of alternatives, we assumed that efficiency was directly related to total area sampled to achieve a given allowable

[1] Noningrowth tree diameters based on estimated dbh

error (i.e., travel cost between plots and plot establishment costs were zero). In Indiana there are a total of 26 old-growth sites scattered throughout the state with an average tract size of 36 ac. The major travel cost is going to and from each site. Within these small stands, travel costs from plot to plot are negligible. The major cost within each site is in terms of the total area sampled.

Results

Most efficient plot sizes for biomass estimation range from 0.02 to 1.58 ac and differ by disturbance regime (Table 1). The smallest plot size was most efficient in 1926 shortly after the grazing disturbance; the largest size was most efficient at the 1992 measurement when allowable error was 5%.

In 1926, grazing from earlier times reduced the number and biomass of small diameter trees. The 0.02 ac plot size was most efficient in 1926, but required only slightly less total area than the 0.1 ac plot size. For the 1926 dataset, samples based on the 0.1 ac plot size required measurement of no more than 0.22 ac total area more than the 0.02 ac plot size. Conversely, the 0.02 ac size required 3.8 to 4.0 times more plots (depending on error level) than the 0.1 ac size. Even a small difference in cost of travel between plots, plot establishment and measurement would favor the 0.1 ac plot size in this case (Table 1).

In 1976 through 1986 the most efficient plot size was 0.22 ac (Table 1). By 1992, high mortality rates had occurred for 10 yr. In the 1992 measurement, a plot size of 1.58 ac appeared to be the most efficient when the allowable error was 5%. However, the 1.58 ac plot size was only marginally more efficient than plot sizes of 0.22 ac, 0.40 ac, and 0.62 ac. With the exception of the 1.58 ac plot size, the general trend was for decreasing sampling efficiency for plot sizes larger than 0.62 ac when the acceptable error rate was 5%. At 10 and 20% error rates, the 0.22 ac plot size was still the recommended size (Table 1). At the 5% level of acceptable error, increasing plot size up to 0.62 ac is recommended.

Discussion/Application

Sampling recommendations for biomass of Midwestern old-growth forests have not been previously published. We present sampling recommendations based on what is probably the most extensive data set for an old-growth forest on the continent due to the 66 yr time span of data sampling and detail of the inventories.

Recommended plot sizes from 1976 to 1992 were larger than typically used in most second-growth forest inventories of IO.1 ac (Avery 1975). However, most of these plot sizes are consistent with recommendations for measuring Midwestern old-growth basal area and number of trees to within ± 10% of the mean (Shifley and Schlesinger 1994). Most plot size recommendations are also comparable to the 0.25 ac plot size used extensively in early forest inventories (Avery 1975) when old-growth forests were likely more prevalent. Kulow (1966) supports the use of larger plot sizes to increase precision and accuracy.

Note also that the 0.02 ac plot size is the smallest plot size in this study. In 1926 trees had the largest average diameter at 15 in. versus 11 in. for the other four inventory years. Forest sampling techniques for fixed-radius plots would normally recommend larger plots when inventorying large trees (Schreuder et al. 1993). Although small plots are more variable than large plots leading to a larger number of small plots, their total area is less.

There was little disturbance between 1926 to 198 1. Up to 50 dead and dying trees were harvested throughout the forest in the 1940s and 1950s, some from this study area. Dutch elm disease and phloem necrosis eliminated most American elm from the overstory. These disturbances, however, were minor compared to disturbance before (grazing) or after (mortality) these dates. With over 20 yr between the harvesting disturbance and the next inventory, other woody vegetation had filled in these disturbance sites.

For a given percent allowable error, total area required to inventory at those levels was comparable for all inventories from 1976 to 1992. Although total area was similar to the previous three measurement years, in 1992 alargerplot size resulted in the

Table 1. Size and number of plots necessary to inventory total biomass while measuring the least total area at $a = 0.05$ and three percentage error levels. Based on data from Davis Research Forest, Randolph Co., IN.

	Disturbance regime														
	Grazing			Low mortality[a]						High mortality[b]					
	Year of Measurement														
	1926[c]			1976			1981			1986[d]			1992[e]		
% error	Plot size (ac)	No. of plots	Total area (size × no.)	Plot size (ac)	No. of plots	Total area (size × no.)	Plot size (ac)	No. of plots	Total area (size × no.)	Plot size (ac)	No. of plots	Total area (size × no.)	Plot size (ac)	No. of plots	Total area (size × no.)
5	0.02	564	13.9	0.22	50	11.1	0.22	50	11.1	0.22	47	10.5	1.58	6	9.5
10	0.02	303	7.5	0.22	23	5.1	0.22	23	5.1	0.22	21	4.7	0.22	22	4.9
20	0.02	109	2.7	0.22	9	2.0	0.22	9	2.0	0.22	8	1.8	0.22	9	2.0

[a] Low mortality = 0.6 tons/ac/yr from 1977 to 1981.
[b] High mortality = 1.6 tons/ac/yr from 1982 to 1992.
[c] NOTE: In 1926 even a small difference in cost of travel between plots would favor the 0.1 ac plot size. The 0.1 ac plots required measurement of no more than 0.22 ac total area than the 0.02 ac plot size.
[d] NOTE: In 1986 there was only a difference in total area of 0.05 ac between the 0.22 and 0.62 ha plot size.
[e] NOTE: In 1992 the 1.58 ac plot size was only marginally more efficient than the 0.62 ac plot size at the 5% error level. At that level of error increasing plot size up to 0.62 ac is recommenced (see Results).

least total area at the 5% error rate. However, trends in total area measured are much more variable for larger plots due to the amount of area an addition or subtraction of one large plot makes relative to one small plot. In 1992, at 5% error the relatively small total area for the 1.58 ac plot size was likely an anomaly contradicting the general trend of increasing inefficiency with increasing plot sizes > 0.62 ac (Table 1).

The difference between the 1926 disturbance and the 1992 mortality is that grazing was selectively creating a patchy understory (Ward et al. 1996) in 1926 (leading to a larger recommended total sample area) (Table 1) and the 1977 to 1992 mortality was more evenly distributed. For instance, northern red oak is a uniformly distributed species in this forest (Leopold et al. 1985) and accounted for 40% of deadwood biomass from 1977 to 1981, 52% from 1982 to 1986 and 46% from 1987 to 1992.

These results should be useful to both scientists and practitioners. With increased interest in ecosystem management it will become increasingly important to monitor a wide variety of habitats including remnant old-growth forests. Due tocurrent management strategies on public lands, old-growth forests will become a greater proportion of the forested landscape (Shifley et al. 1995). In Indiana alone, old-growth forests will increase in area by a factor of 2,292 (Spetich 1997).

Biomass is a useful measure of a tree's ability to compete for and store resources. To make meaningful estimates of aboveground biomass, we should consider the disturbance regime and its relationship to sampling. Table 1 addresses types and levels of disturbance typically found in Midwestern old-growth forests. After choosing a desirable percent error level, it should be possible to make meaningful decisions about plot size and number for the most efficient sampling scheme of aboveground biomass.

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