Trott Brook Property - Ramsey, MN

Site Assessment for Significant Trees

FIGURES

1. Tree Survey Location & Overview
2. 1964 Historical Imagery
3. Fixed Radius Plots Method
4. Pre/Post Tree Planting Aerial Imagery

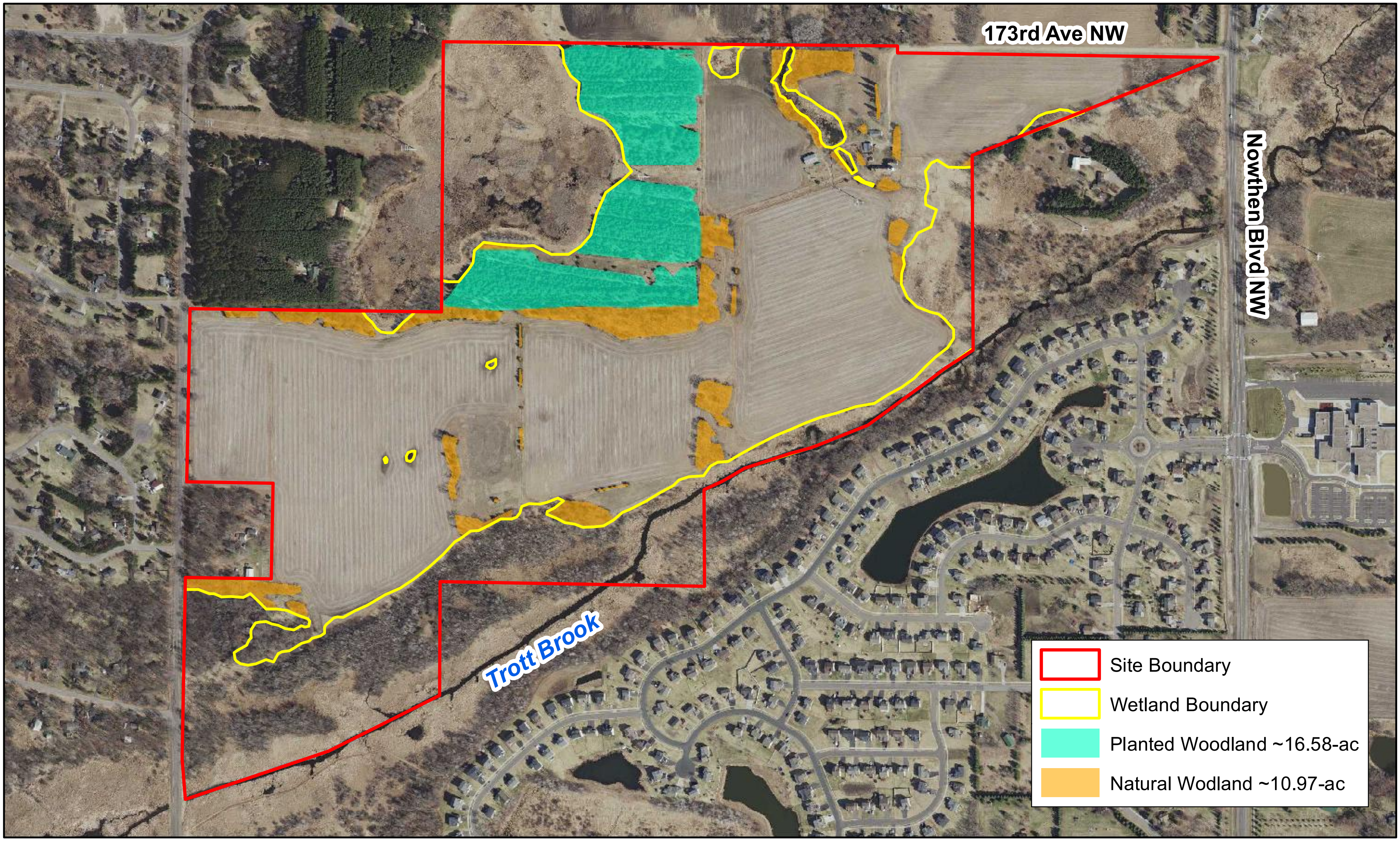

Figure 1 - Site location & Tree Survey Overview (2020 Imagery)

N

0 500

Feet

KJOLHAUG ENVIRONMENTAL SERVICES COMPANY

Source: MNGEO Spatial Commons

Trott Brook Property (KES 2021-108)
Ramsey, Minnesota

Note: Boundaries indicated on this figure are approximate and do not constitute an official survey product.

Figure 2 - 1964 Historical Aerial Imagery

N

0 500 Feet

Site Boundary

KJOLHAUG ENVIRONMENTAL SERVICES COMPANY

Source: MNHAPO

Trott Brook Property (KES 2021-108)
Ramsey, Minnesota

Note: Boundaries indicated on this figure are approximate and do not constitute an official survey product.

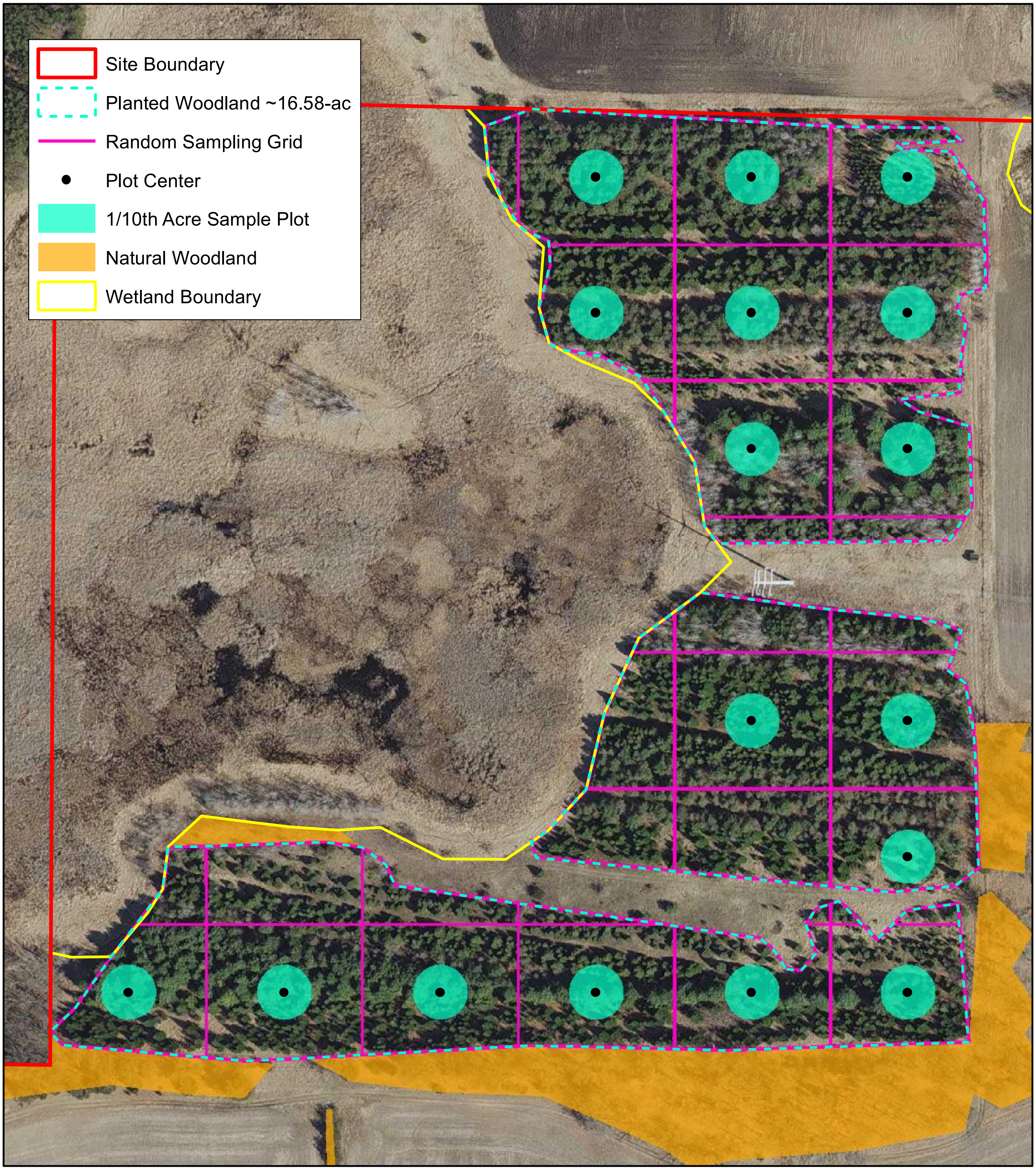

Figure 3 - Fixed Radius Plots Sampling Method (2020 Imagery)

N

0 185 Feet

KJOLHAUG ENVIRONMENTAL SERVICES COMPANY

Source: MNGEO Spatial Commons

Trott Brook Property (KES 2021-108)
Ramsey, Minnesota

Note: Boundaries indicated on this figure are approximate and do not constitute an official survey product.

Figure 4 - Pre/Post Tree Planting Aerial Imagery

N

0 500 Feet

Site Boundary

KJOLHAUG ENVIRONMENTAL SERVICES COMPANY

Source: USGS, FSA

Trott Brook Property (KES 2021-108)
Ramsey, Minnesota

Note: Boundaries indicated on this figure are approximate and do not constitute an official survey product.

Trott Brook Property - Ramsey, MN

Site Assessment for Significant Trees

Appendix A

Reference Documentation

United States Department of Agriculture

Natural Resources Conservation Service

July 2018

Forestry
Technical Note No. FOR–1

Forestry Inventory Methods

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FORESTRY INVENTORY METHODS

General Information

Title 180, National Planning Procedures Handbook (NPPH), Part 600, Subpart C, Section 600.23, "Inventory Resources," describes the resource inventory process used to collect information about a planning area's resources and related offsite information. Inventory information is used to determine the condition and trends of the resources, identify resource concerns and opportunities, and formulate and evaluate the effects of alternatives. The level of detail needed for an inventory depends on the level of planning—a forest management plan may utilize generalized information while a practice implementation plan will often require greater detail and statistical reliability.

This technical note provides a description of the common inventory methods and tools used in forestry and agroforestry applications and describes the methods used to conduct resource inventories that support planning processes for forestland.

Forest land is defined in Title 440, Conservation Programs Manual, Part 502, Subpart A, Section 502.0, "Definitions," as—

> "a land cover/use category that is at least 10 percent stocked by single-stemmed woody species of any size that will be at least 4 meters (13 feet) tall at maturity. Also included is land bearing evidence of natural regeneration of tree cover (cut over forest or abandoned farmland) that is not currently developed for nonforest use. Ten-percent stocked, when viewed from a vertical direction, equates to an aerial canopy cover of leaves and branches of 25 percent or greater. The minimum area for classification as forest land is 1 acre, and the area must be at least 100 feet wide."

Forest Stand Inventory

Stand Mapping

Prior to conducting an inventory, forested areas are mapped into relatively homogenous units (i.e., stands). Stands are relatively uniform with respect to aspect, dominant crown class, stocking density, species composition, landforms, etc. Information used for stand mapping includes using orthophotos, topographic images, soil maps, and ecological site descriptions. Information on geology, wetlands, and vegetation may also be useful. Refer to Web Soil Survey at website https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm for detailed soils information. Stand boundaries can be refined in the field with spatial data.

Choice of Inventory Methods

Generally applied methods for inventorying forest stands include point sampling (also known as variable-radius plot sampling) and fixed plot sampling. Methods applicable to specific situations, depending on stand conditions and objectives of the inventory, include strip sampling, line transect sampling, crop-tree inventory, and the zig-zag transect. The method chosen must be appropriate for the geographic location and condition of the stand and efficient with regard to information collected in a given amount of time.

Point and fixed plot sampling methods are used to collect information for developing management plans and silvicultural prescriptions. The inventory typically includes plot-level measurements that are summarized to provide stand-level information including site index, basal area ((BA), sq.ft./acre), trees per acre (TPA), species present in each canopy class from dominants to ground vegetation, size class, wood or nontimber production potential, and other metrics needed to plan and schedule future management activities, or implement near-term activities.

There are a number of considerations in choosing between point and fixed plot methods. Fixed plots may be better suited to large stands with low variability; generally, in these situations, fewer plots are needed for an adequate sample size than if point sampling is used. In many stands, especially those with open understories, point sampling usually requires less time per plot which allows more plots to be sampled. A relatively larger number of plots is needed to provide statistically reliable estimates in stands with variable density and a diversity of tree species (Oderwald 1981).

Plot sampling and strip sampling methods are based on measuring a percentage of the stand. A proportion of the area is measured based on the assumption that the samples are representative of the entire stand. The percentage of the area sampled depends on how the information will be used as well as the uniformity of the stand and its size. For most planning purposes, a low intensity inventory is sufficient. Sampling percentages can range from as low as 0.2 percent using fixed-radius regeneration plots in homogeneous stands, up to 20 percent for variable-radius plots in diverse forests of a small acreage. As acreage increases, inventory intensity typically decreases. A complete discussion on statistical sampling intensity can be found in forest mensuration textbooks, such as Avery and Burkhart (1994).

Strip sampling is a form of fixed plot sampling using long, narrow plots. This method may be suitable for sites with variation due to environmental gradients.

Transect sampling is often used for seedling survival inventories. It is an efficient method when the number of entities is the main attribute of interest.

Crop tree inventory identifies desired trees to retain for objectives that may include wildlife habitat, visual quality, water quality, timber and nontimber products, and others. A crop-tree inventory is supplemented with a demonstration plot to illustrate forest management concepts and allow landowners to determine the desired intensity of management.

The zig-zag transect method was developed by NRCS, then known as the Soil Conservation Service (SCS), in the 1960s. It allowed SCS foresters to use a simplified process to quantify forest tree and stand characteristics and was useful in communicating information to landowners. Although the zig-zag transect method is no longer a common inventory technique, under certain stand conditions it is an efficient method to use and provides good estimates for stands that are dominated by one tree species, are even-aged, and have a narrow diameter range.

Purpose of Inventory

Forest inventories are conducted for different purposes, but in NRCS they usually support the development of a forest management plan (FMP) or a conservation plan.

Inventory methods are chosen to—

- Collect information that addresses client objectives.
- Suit site conditions.
- Provide efficiency and cost-effectiveness.

The inventory—

- Is the basis for identifying, assessing, and addressing resource concerns.
- Collects ancillary information needed for the forest management plan such as maps.

Some inventories meet multiple needs, such as qualifying landowners for State programs, and may require specific types of information.

The components of an FMP are listed in the Cooperative Forestry Assistance Act of 1978 (16 U.S.C. Sec. 2103a), Section 5(f)(1)(B), as referenced in the Food, Conservation, and Energy Act of 2008 (16 U.S.C. Sec. 3839aa), Section 2506(a)(4). An FMP "identifies and describes actions to be taken by the landowner to protect soil, water, range, aesthetic quality, recreation, timber, water, and fish and wildlife resources on such land in a manner that is compatible with the objectives of the landowner."

- Criteria for the NRCS FMP are included in Title 190, National Forestry Manual (NFM), Part 536, Subpart B, Section 536.10, "Forest Management Plan Criteria."
- As a general rule, FMPs should be reviewed and updated as necessary every 10 years, as recommended in the document "Understanding Your Plan: A Guide for Landowners using Managing Your Woodlands: A Template for Your Plans for the Future" (USDA NRCS, and USDA-Forest Service. 2015c (revised)).
- The NRCS State conservationist may publish supplemental guidance or information on how to complete an FMP.

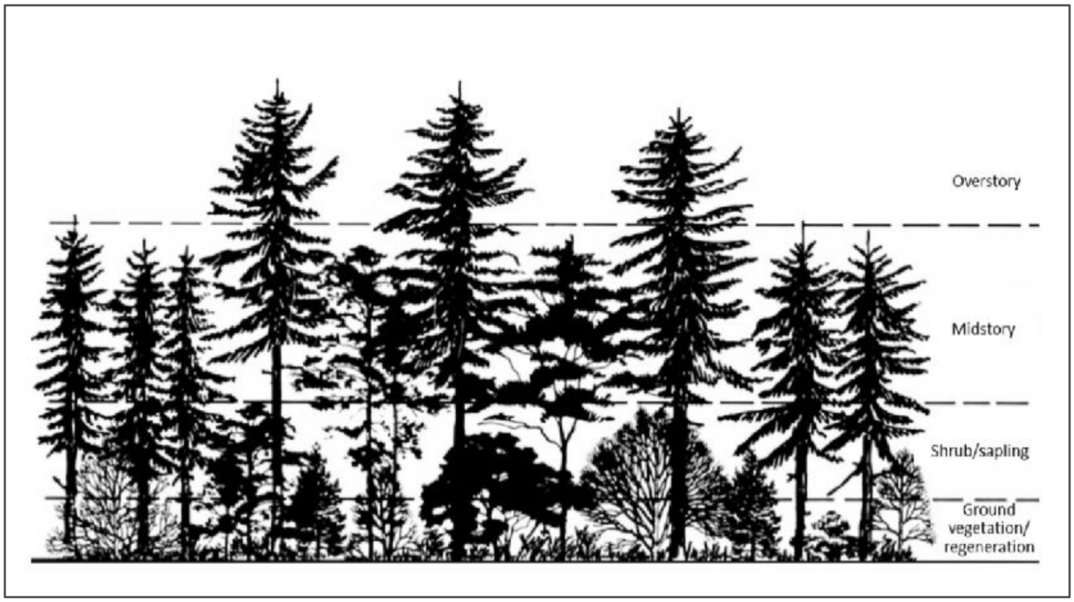
Stand Summary Information

Stand-level summaries provide information that allows foresters to describe current and potential future conditions to landowners, as an aid in setting goals for their property. Desired summaries may include stand-level information on structure by crown class and canopy stratification, average tree crown ratio, average tree growth rate, site index, diameter distribution, etc. Stand summaries are developed using various methods. Refer to State's "Resource Concern and Planning Criteria" document in the Field Office Technical Guide (FOTG), Section III, for guidance in selecting additional measurement and assessment tools.

- Stand Structure.—May be described by age classes or by canopy layers, from overstory to ground vegetation. Figure 1 shows the vegetation strata often found in a forest. Crown classes include dominants, codominants, intermediate, and overtopped.
- Crown Ratio.—Along with describing a stand by the different crown classes, crown ratio is a descriptive characteristic that conveys how well a tree is currently able to make use of available light for photosynthesis and how well it can be expected to respond to release. Crown ratio is simply what percentage of the total height of the tree includes live crown. An open grown tree may have nearly 100 percent crown ratio, while a suppressed tree has less than 25 percent.
- Tree Growth and Site Index

- Representative trees in the dominant crown class of each species in the stand are cored using an increment borer to determine tree age and growth. Choose a tree that is not growing close to a road or open area, as those trees express a growth advantage over trees deeper in the stand. Recording the radial growth for the past 10 years is a common practice. Noting the best 10 years growth is useful to understand potential growth and possible expectation of response to management activities.
- Site index trees, usually the same trees sampled for growth, are measured for age and height to determine stand growth potential. Site index curves are available from your forester. A cautionary note is that if the stand you are working in has been selectively harvested with numerous entries where the best lumber-producing trees were removed, the representative trees available may not offer an accurate site index.
- Site index information for a limited selection of tree species is often available by soil series from the Web Soil Survey at website https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

□□□□**r** □□□: Vertical Stratification in a Forest Stand



Graphic Adapted From Brown (1985)

Method

Point Sampling (or Variable-Radius Plot Sampling)

Point sampling, also known as variable-radius plot sampling, is a widely used forest inventory technique in which trees are selected and tallied based on their size relative to a preselected reference, either the BA prism or angle gauge. Results of point sampling can yield BA, TPA, and species composition depicted in a diameter distribution table if desired. Stand volume can also be estimated using point data.

- Determining the Number of Plots

- A low-intensity inventory is usually adequate for developing a forest management plan. The specific number of plots needed will vary, even for a low-intensity inventory. A stand that is relatively homogeneous in species composition and tree age can be represented with fewer plots, but as variability increases, so does the number of plots needed to provide adequate estimates of stand parameters.
- Table 1 offers minimum recommendations based on published sources and typical usage, but the optimal number of plots varies by forest type and other stand characteristics.

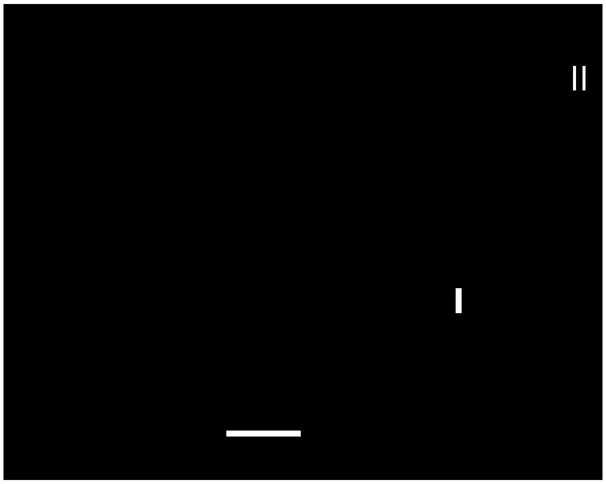
[illegible]: Recommended Minimum Number of Plots for Low-Intensity Forest Inventory in Stands of Various Sizes

[illegible]r[illegible]	M[illegible]
10 or less	3
11–20	6
21–40	10
41–150	15
>150	1 plot/10 acres

- The minimum guideline of three plots for stands of 10 acres or less follows USDA-Forest Service (2015), which notes this recommendation is for homogenous stands. Other sources recommend a larger number of plots (e.g., Wenger 1984). Stand variability will determine the number of plots needed. Consult an area or State forester for recommendations on optimal numbers of plots to use in your location.
- For situations where a known level of statistical reliability is desired, refer to methods for determining the number of plots needed to provide an acceptable sampling error. See, for example, the “Number of Plots” discussion in chapter 2 of the FSVeg Common Stand Exam User Guide, Version: 2.12.6. (USDA-Forest Service 2015).

- Selecting Plot Locations
  - Plot locations are chosen without bias, so that all forested acres are equally represented in the sample. One way to locate plots is by using systematic sampling, which involves developing a parallel line pattern on a map with the plots evenly spaced along lines (fig. 2). Orienting the lines north-south or east-west makes it easier to establish on the ground, but other orientations may be used, such as aligning with a slope gradient. Make sure the sampling design places plots far enough away from property lines so that all the “in” trees are in the stand of interest. Plot locations can be preloaded into a device that uses spatial data (e.g., a data recorder, GPS navigation system, etc.). Alternatively, the distance between plots can be paced; in this case, bias will be reduced by stopping at the correctly paced distance even if the location is inconvenient.

□□□□**r**□□□ Example of a Systematic Line-Plot Sampling Layout



- Another sampling protocol that limits bias involves using random distances and azimuths to locate plots. Note that it is possible, even when plots are located correctly using random or systematic protocols, that the resulting sampling design may not represent all parts of a stand equally. Sample enough plots that these random effects will not significantly affect stand-level summary data.

- Using the Prism
  - A wedge prism is an angle-cut glass at a given basal area factor (BAF). Trees are sighted through the prism at 4.5 feet above ground, or diameter at breast height (DBH). Trees are counted as either “in” or “out.” If the bole displacement as viewed through the prism overlaps, the tree is in (fig. 3). Include every other borderline tree. At each sample point, keep the prism over the plot center and rotate around the prism in one direction only.
  - Note that a relatively small tree will need to be close to the plot center to be counted in, while a large tree can be quite far away.
- Using an Angle Gauge
  - An angle gauge works on the same principle as a prism. Unlike a prism, the eye is kept at plot center and the gauge is moved in a circle. An angle gauge such as the cruz-all has several BAFs in one tool. A tree is considered out if the bole is narrower than the sides of the chosen BAF (fig. 4).
  - A desirable number of trees per plot is between 5 and 12. If the number of trees in the plot tends to be fewer than 5, choose a prism or angle guage with a smaller BAF; if the plots routinely have more than 12 in trees, a larger BAF is appropriate. A stand of large trees requires a higher BAF and a stand of small trees a lower BAF. Keep the same BAF throughout the stand to simplify calculations later. As a recommendation, prior to conducting a forest cruise take a quick walk through the stand, using a prism or angle gauge occasionally to determine the appropriate BAF.

Figure 3: View of Tree Through Wedge Prism

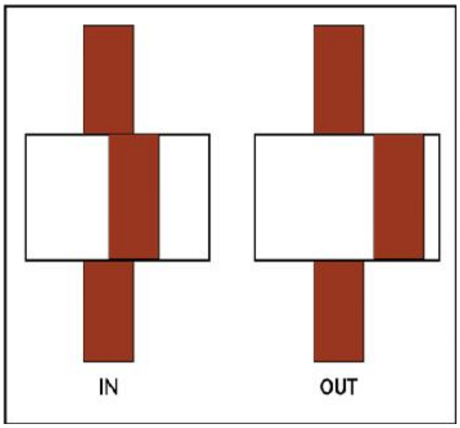
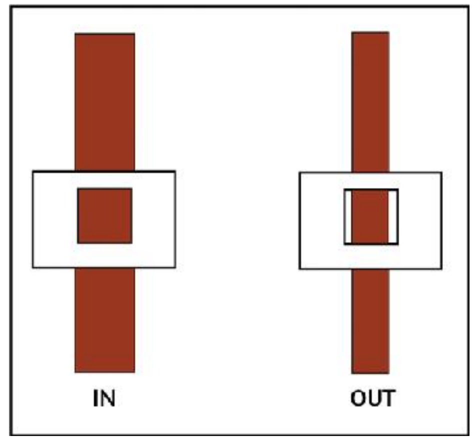
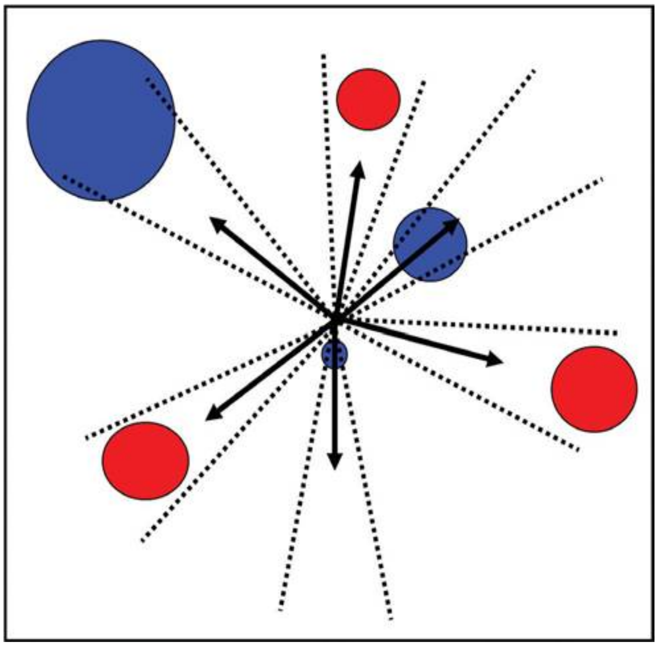


Figure 4: View of Tree Through Angle Gauge



- Establishing the Plot
  - At plot center, pivot in one direction, making a complete circle. Where to start the pivot is optional; some choose a cardinal direction, others simply the nearest tree. Use the wedge prism or angle gauge to identify trees that are in the plot. Inventory data will only be collected on the trees that are in the plot.
  - Note that each region will have a size threshold where trees below a certain diameter will not be included in a point sample; these trees will be sampled in regeneration plots. Consult with a forester on the lower size limit for point sampling.
  - If a tree is growing at an angle, tilt the prism or gauge to match. If the tree is obscured from view at DBH, either step away from plot center, maintaining the same distance to the tree in question, or target the tree above the obstruction. All trees counted in should be tallied by species and DBH within a 2-inch diameter class, at a minimum. Mark the plot center for reference if you need to physically measure the tree diameters; the eye quickly becomes calibrated and accurate ocular estimates of tree diameter can be achieved, but check your eye with actual measurements periodically.
  - Borderline trees are on the edge of the plot where it is difficult to determine whether they are in (fig. 5). The simplest approach is to count every other borderline tree as in; this approach provides an estimate of stand characteristics that is sufficient for most planning applications. If greater accuracy is desired, measure the distance from plot center to the borderline tree as per methods in appendix J of the FSVeg Common Stand Exam User Guide, Version: 2.12.6. (USDA-Forest Service 2015).

□□□r□□: Trees indicated by blue circles are within the variable-radius plot; trees in red are outside the plot. Images used by permission of Pacific Northwest extension.



- Collecting Plot Data
  - Utilize a “tally sheet” (also known as a “cruise sheet”), similar to the one shown in figure 6, for recording plot data. Field data recorders with programmed tally sheets may be used.
  - For each tree in the plot—
    - Determine and record tree species using standard codes. Codes used by the Forest Inventory and Assessment (FIA) program are recommended for consistency; see appendix F in O’Connell et al. (2016).
    - Measure the diameter at DBH (4.5 feet) using a diameter tape, and record the measurement to the nearest inch.
    - Rate the tree’s condition as vigorous, fair, or declining. A vigorous tree does not show signs of stress; it has a full healthy crown, no evidence of scars, wounds, or disease, and little or no epicormic branching. A declining tree may have a broken top, multiple forks, canker, wounds, scars, and disease; however, such trees may have high value for wildlife. Assign “fair” as an intermediate rating. Do not include species desirability in the condition rating; rate each tree on its merits, without regard to species. Record the condition rating in the field notes.
    - In the “notes” section, describe the reason for the tree’s rating. Note features of the tree that are important as wildlife habitat, aesthetics, economic value, etc.

[illegible]: Example Tally Sheet With Three Plots

Notes on filling out cruise sheet	Property:	Producer/Stand 1			BAF:	10		
Keep the same basal area factor **(BAF)** and fixed plot size	Date:				Fixed Plot Size:	1/100th ac		
for all plots in a stand.	Cruiser:	NRCS Planner			Field Office:			
In species column, record "in" trees as they occur while					GRTH/			
pivoting in one circular direction.	WyPt	Plot	SPECIES	DBH	AGE	20ths	HT	CR %
Use the dot grid tally to save space: DF alone is one tree,	256	1	DF	10		WEST ASPECT		
DF* is two trees, ect. The dot tally can include up to			DF*	12		30% SLOPE		
10 trees.			DF*	16				
Basal area "in" trees are 10" and greater Diameter Breast Height			DF**	14		OREGON GRAPE,		
(DBH) collected in 2" diameter classes.		R	LP**	8		KINNICKINICK,		
Trees 8" and smaller are recorded in nested fixed plot as			WL	6		PINE GRASS		
regeneration **(R)**; a 1/100th ac plot measures 11.8'			LP*	6				
and a 1/300th ac plot measures 6.8'								
Regeneration can be recorded by actual diameter or in	257	2	DF	16		SOME SPRUCE BUDWORM		
classes: 0-1, 2-3, 4-5, 6-7 and 8-9.			DF	14		NOT TOO BAD		
A growth tree **(GT)** is often a plot tree, however when it isn't,			WL*	12.4	75	10	62	40
record it on its own line.			WL*	10				
Measure and record growth of the last 10 yrs.			SNAG	18				
Age is total age; need to add how many years it took for		R	DF**	0-1				
tree to reach DBH. When in doubt, use 10 yrs.								
Crown ratio **(CR)** is % of tree with live crown.		GT	DF	16.2	96	12	75	50
Record a snag **(S)** as it occurs in the plot as if they were a separate								
species and you can determine snags per acre.	258	3	DF	14				
You can make additional notes recording insect or disease,			LP	10				
understory, aspect, or slope in unused space on right			LP	12				
side of cruise sheet.			DF	10				
			DF	12				
		R	DF*	0-1				

Note that this is only an example; consult a forester for a tally sheet adjusted to local forest types.

- Basic Inventory Calculations
  - A programmed spreadsheet is useful in making these calculations efficiently and consistently. Check with a local or State forester to see if a spreadsheet is available.
  - Determining BA
    - BA.—A measure of how much of an acre is occupied by trees. Each forest type has a BA range that is optimal for individual tree growth. Determining BA is fairly simple:

      BA = (total trees tallied ÷ total # of plots) × BAF
    - In the example, only BAs for trees 10 inches DBH and greater are determined. There are 19 trees 10 inches DBH and greater, so: 19÷3×10 BAF = 63 square feet of BA per acre.
  - Determining TPA

- TPA is a measure of stand density. Each tree size class has a recommended stocking level that can be expressed as TPA. Determining TPA in point sampling is more complicated than when using fixed plots. The tree tally must be expanded to a per acre basis and diameter classes summed for a total TPA. Again, a programmed worksheet simplifies this process.

  TPA = # of trees tallied × BAF ÷ BA per tree ÷ total number of plots

  Where BA per tree = $0.005454 \times DBH^2$

  The BA for a 10-inch DBH tree = $0.005454 \times 10^2 = 0.5454$

  The BAF in the cruise example is 10.

  Five trees are tallied in the 10-inch DBH class.

  TPA for 10-inch DBH class = 5 tallied trees × 10 BAF ÷ 0.5454÷3 plots = 31 trees per acre

  If this calculation is carried out for the remaining diameter classes found in the cruise:

  TPA for 12-inch DBH class = 6×10÷0.7853÷3=25 TPA

  TPA for 14-inch DBH class = 5×10÷1.068÷3=16 TPA

  TPA for 16-inch DBH class = 3×10÷1.396÷3=7 TPA

  Total = 79 TPA 10-inch DBH and greater

- Diameter Distribution Table
  A diameter distribution table is a useful visual to help with the decision-making process for possible management options. Using a programmed worksheet or applications such as the Forest Vegetation Simulator (FVS), a diameter distribution table can be developed for each stand, broken down by species (see table 2).
- Volume of merchantable and nonmerchantable timber and biomass
  It is possible to develop timber volume estimates using information collected during point sampling; however, the accuracy of a volume estimate depends on attributes such as tree form and defect. Collecting this type of information requires specialized training. In instances where volume estimates are desired, consult an area or State forester.

[illegible]: Example Stand-Level Diameter Distribution Table Using 2-Inch Size Classes Between 10 and 18 Inches DBH

[illegible]	[illegible]		[illegible]		[illegible]	
DBH	TPA	BA	TPA	BA	TPA	BA
10	12	7	6	3	12	7
12	13	10	4	3	8	7
14	16	16	0	0	0	0
16	7	10	0	0	0	0
18	0	0	0	0	0	0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

- Tree Regeneration Sampling in Conjunction With Point Sampling
  - To obtain a complete stand description, consider collecting nested fixed-radius plots for trees in the seedling, sapling, or pole size at the same time as conducting point sampling of the stand overstory. A fixed-radius plot with the same plot center as the point sample can yield useful information for either a forest management plan or a conservation practice job sheet. Plot size is dependent on tree density.
  - Choose a plot size that will capture stocking without having to count more trees than necessary; a cursory walk through the stand will help determine an appropriate plot size. If tree density appears low enough that a 1/300th acre plot will often be empty, where a 1/100th acre plot will capture regeneration, then utilize the larger plot. Conversely, when surveying an extremely dense stand, the smaller plot is better to avoid missing stems. As with the BA factor, keep the same plot size for the entire stand to make expansion calculations easier.
  - Calculating Regeneration TPA

    Using the example tally sheet in figure 6, the fixed area plots are 1/100th acre in size (11.8 feet).

    There were 11 trees tallied in the 8-inch diameter class and smaller. So,

    TPA = 11 counted trees × 100 / 3 = 366 trees per acre
  - Again, a diameter distribution table is very useful to help target treatment options (table 3).

[illegible] 3: Example Stand-Level Conifer Regeneration Table Showing Number of Trees in Seedling, Sapling, and Pole Size Classes

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0–1	167	0	0	167
2–3	0	0	0	0
4–5	0	0	0	0
6–7	0	66	33	99
8–9	0	100	0	100
[illegible]	[illegible]	[illegible]	**33**	**3**[illegible]

Note that in different geographic areas and forest types, size classes are defined differently, so that some of the DBH classes shown in this table would be part of overstory tallies.

Fixed Plot Sampling

In fixed plot sampling, a set of plots, generally all the same size, are located throughout the area. Plots can be any shape; circular plots are commonly used because it is convenient to set up a plot of this shape from a single center point, but rectangular plots are equally acceptable. The number and size of plots is determined by the desired inventory intensity, stand variability, and stand size.

An adequate total sampled area is needed for accurate estimates of stand-level characteristics. A standard size for fixed plots may have been established regionally; in this case the number of plots sampled may be varied to reach the desired total sampled area.

A smaller number of plots is often acceptable in locations where there is relatively low variability in stand density and composition; more plots are needed in stands with high variability. The number of plots along with plot sizes determines the total area sampled, generally expressed as a percentage of the stand area. Consult a local forestry expert for optimal sampling percentages.

Sample plots may be located throughout the area in a number of ways.

- One method is to locate the plots systematically, at predetermined intervals on lines that are a set distance apart (fig. 7).
- Other methods utilize randomly generated distances and azimuths to select random plots, sometimes using rejection criteria for unnatural disturbances or nonforested locations.
- Ecological site descriptions often use deliberate placement of plots to capture a reference state, however a forest inventory requires an unbiased sample.

Nested subplots, all sharing the same center, are often used to capture sequentially smaller size classes (e.g., 1/5th acre plot for sawtimber, 1/10th acre for pole class, and 1/300th for seedling/saplings).

Refer to table 4 for the radii commonly used to construct plots of various sizes. See also the discussion in the section “Point Sampling” on page 4 of this TN. To calculate sampling percentage, the formula is—

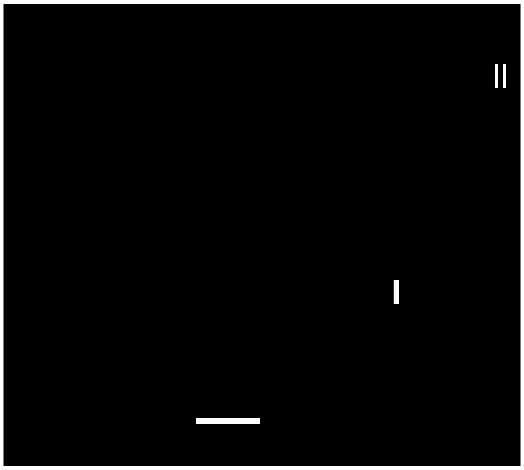
(total plot size in acres/acres represented) × 100 = % inventory

Using the systematic 1/4 acre plot sampling scenario shown in figure 7 as an example:

Total the number of plots.
Multiply by the area of each plot.
Divide by area of the stand.
Convert the figure to a percentage.

This percentage is the amount of the total stand area included in the sample.
((17 plots × 0.25 ac) / 40 ac) × 100 = 10.6% inventory

□□□r □□: Example of a Systematic Line-Plot Sampling Layout for a 10-Percent Sample Using Fixed Plots in a 40-Acre Stand



Many features of point sampling and fixed plot sampling are identical.

- The number and location of plot centers are determined in the same manner.
- Methods for determining which borderline trees to sample are the same.
- Tree measurements (diameter, height, defects, etc.) are also measured or estimated by methods similar to those used in point sampling.
- The primary difference between the two methods is that fixed plot sampling requires measurement of plot dimensions. Also, fixed plots may be less efficient in stands with a large number of small trees, because of the additional time required to measure them.

□□□□□: Commonly Utilized Dimensions for Fixed Plot Sampling, Showing Radii for Circular Plots

□□□□ □□ □□□□□
1/1000-acre plot = 3.7-foot radius or 6.6 feet × 6.6 feet
1/500-acre plot = 5.3-foot radius or 9.3 feet × 9.3 feet
1/250-acre plot = 7.4-foot radius or 13.2 feet × 13.2 feet
1/100-acre plot = 11.8-foot radius or 20.9 feet × 20.9 feet
1/300 –acre plot = 6.8-foot radius or 12 feet × 12 feet
1/20-acre plot = 26.3-foot radius or 46.7 feet × 46.7 feet
1/10-acre plot = 37.2-foot radius or 66 feet × 66 feet
1/4-acre plot = 58.9-foot radius or 104.4 feet × 104.4 feet
1/5-acre plot = 52.7-foot radius or 93.3 feet × 93.3 feet
1/2-acre plot = 83.3-foot radius or 147.6 feet × 147.6 feet
1-acre plot = 118-foot radius or 208.7 feet × 208.7 feet

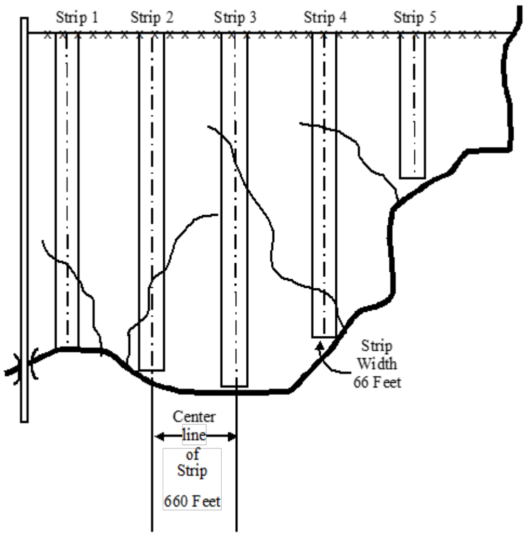
Strip Sampling

In strip sampling, the sample units are continuous strips of uniform width, spaced at a predetermined distance apart. The width of the strips and the distance between the centerline of the strips determines the percentage of the area sampled.

Strips are often used in tropical forests where there is such a dense understory that point sampling is limited by visibility.

These designs may also be useful in areas with strong environmental gradients, usually due to steep slopes, where they are oriented perpendiculuar to the slope. See figure 8 for an example of a strip sampling design.

Figure 8: Example Strip Sampling Layout



Tree Planting Inventory

Many factors can affect the postplanting success of tree and shrub establishment projects. Negative factors may include adverse weather conditions or livestock trampling, or other biotic and abiotic causes of mortality.

Regular inspections of tree planting sites or direct seeding sites are necessary to identify the many factors affecting survival and growth. Inspections help determine whether there are needs for replanting; additional weed control; moisture management; protection from deer, rabbits, or other herbivores; management of insect or disease problems; etc.

It is important to note that factors such as improper seedling shipping, handling, onsite storage, or planting procedures are elements of the actual tree planting project.

- These issues must be addressed in a properly designed job sheet, combined with the oversight of an experienced tree planting supervisor during the time of planting.
- These causes for failure are not the same as the ones that are the focus of tree planting inventories.
- The methods described in this section can be used to evaluate most newly planted tree and shrub establishment practices and very young plantations.

Timing for Inspections

Generally, survival should be assessed at 4 to 5 months after the initial planting and at least once a year until the trees and shrubs are established. This typically occurs within the first 3 years, but establishment may take longer in some geographic areas.

- For evergreen plantations, it may be easier to see small trees in the late fall or winter, when the brown ground cover or snow provides more contrast to their green foliage.
- For deciduous trees and shrubs, growing season (leaf-on) inspections may allow for better and easier species identification.
- If very adverse conditions, such as dry weather, high predation, or heavy weed competition, are noted, a second inspection in the fall may be recommended. End of the growing season (early fall) inspections can also make it easier to locate trees and shrubs with contrasting fall foliage colors.
- If deciduous trees and shrubs are inspected during dormancy, confirm survival by assessing the "suppleness" of the twig with presence of soft, current-year buds, or by scraping a very small patch to reveal green inner bark. Limit the number of scrapings by developing a general "feel" for which trees are alive.

Plot Sampling Methods for Tree Planting Inventory

- Circular Plots
  - This method is appropriate for all planting arrangements, including linear plantings, random spacing layouts, and direct seeding plantings.
    - Generally, a 1/100th acre circular plot will work for most typical tree and shrub plantings.
    - Larger 1/20th- and 1/5th-acre circular plots work well when tree plantings exceed a 10-foot by 10-foot spacing or for even wider spaced trees, such as those used in fruit and nut tree plantations (40-foot by 40-foot spacing).
    - Refer to table 4 for the radii commonly used to construct plots of various sizes. Choose a plot size large enough to inventory several planted trees per plot.
  - Count and inspect all seedlings within the plot. If desirable natural tree and shrub regeneration help meet planting objectives, include those plants in the tally. Count every other seedling that falls directly on the edge of the plot.
  - To calculate the average number of seedlings per acre, total the number of live seedlings in all plots, then divide by the total number of plots. Multiply the average number of seedlings per plot by 100 (for a 1/100th-acre plot) to obtain the average number of seedlings per acre.
- Linear Plots
  - Linear plots can be used for plantings that were installed with uniform row widths and evenly spaced trees and shrubs, (for example windbreaks, hedgerows, and other linear plantings). This method is often preferred in narrow plantings or under dense vegetation conditions, when a planting slit (or furrow) can be located.
  - Several variations of linear plots may be used depending on field conditions and planting scenarios. The two most common types of linear plots are assessing 10 consecutive seedlings in a row and assessing a row of seedlings over a distance of

100 feet. Variations of these two methods can be created by adjusting the number of seedlings counted in a row or the distance used within the row.

- Ten Consecutive Seedling Count Method
  - The 10 consecutive seedling count method is best used when all planted seedlings (live and dead) are present, planted at the original planned spacing, and natural tree and shrub regeneration will not be assessed.
  - For a 10 consecutive seedling row plot—
    - Follow one row and assess 10 consecutive (live and dead) planted trees and shrubs in that row.
    - After 10 planted plants have been inspected within that row, move over one or more rows and repeat the procedure until the required number of plots has been assessed.
  - To determine total number of surviving seedlings per acre—

    (# of live seedlings tallied ÷ # of plots) × 10 = % survival rate

    => (% survival rate × # of planted seedlings per acre) ÷ 100 = surviving seedlings per acre
- 100-Foot Row Seedling Count Method

  The 100-foot row seedling count method is best used when individual seedling spacing varies within a row but spacing between rows is relatively consistent. Much like the circular plot, this type of linear plot can be used to assess natural regeneration that may be occurring within planted rows. Include natural regeneration tallies only if it helps meet planting objectives. To use this method—
    - Count the number of seedlings in a 100-foot distance along the row. If desirable natural tree and shrub regeneration help meet planting objectives, include those plants in the tally.
    - Measure the width between rows.
    - After the 100-foot distance has been inspected, move over one or more rows and repeat the procedure until the required number of plots has been assessed.
    - To determine average number of surviving seedlings per acre—

      Average distance between rows, feet × 100 feet ÷ 43560 sq ft/acre = area sampled, acres—

      => total # of live seedlings tallied ÷ # of plots = average # of seedlings per plot

      => average seedlings per plot ÷ area sampled, acre = surviving seedlings per acre.

- Sampling Procedures
  - For any of the circular or linear plot methods, select plot locations in the planting area that best represent the variation of soils, topography, aspect, etc. Select a random starting spot (roughly 100 feet from the edge) in one corner of the planted area and install plots diagonally through the plantation. Alternatively, use two diagonals forming an "X" pattern. Record data on the "Tree and Shrub Planting Evaluation

Form," or a similar data collection form adapated to the setting (see fig. 9 in this section).

- To collect enough data for a reliable survival estimate, use at least the number of plots shown in table 5. For windbreaks and sites with highly variable soils, hydrology, etc., consider increasing the number of plots per acre, to increase the confidence level of the data collected.

Table 5: Minimum Number of Circular or Linear Plots Needed for Reliable Seedling Survival Estimates in Planted Areas of Different Sizes

[illegible]	
Minimum number of circular plots needed	
≤ 5 ac.	5 plots
6 to 10 ac.	1 plot per ac.
> 10 ac.	10 plots + 1 plot/additional 5 ac.
[illegible]	
Minimum number of linear plots needed*	
≤ 5 ac.	3 plots
6 to 10 ac.	1 plot per every 2 ac.
> 11 ac.	5 plots + 1 plot/additional 10 ac.
*Double the number of plots for windbreaks.	

[illegible]: Example Form for Recording Data During Tree or Shrub Survival Surveys

[illegible]

Client:			Total acres in unit:		County:		Evaluation date:	
Tract #:		Field #:		Planned trees/ac. (a):		Planned spacing (ft.):	____X____	Evaluation by:	

Conservation practice:	☐Tree/Shrub Establishment (612); ☐Windbreak/Shelterbelt Establishment (380); ☐Riparian Forest Buffer (391); ☐Windbreak/Shelterbelt Renovation; ☐Other (specify):________________

[illegible]

☐ Circular Plots (1/100th ac.; radius 11.8 ft. (11’, 9½”))

☐ Linear Plots assessing 10 consecutive seedlings plot

☐ Linear Plots assessing 100 ft. row seedling plot

[illegible] Be sure to inspect several areas or rows in the plantation to ensure the sampled area is representative of the site.

Plot Number	# of Live	Spacing between rows	Additional Field Notes (species observed, improper planting technique, deer and rodent damage, weed competition, O&M needs, etc. Include plot numbers if note does not apply to the whole planting unit):
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
Totals # plots (b)	Total # live (c)	Average ft. (d)	

Circular 1/100th Plot Summary:

	÷		× 100 =		÷		=	%
Total # of live (c)		Total # of plots (b)		**Surviving trees/ac.**		Original # trees/ac. (a)		**Survival Rate**

Linear 10 Consecutive Seedling Plot Summary:

	÷		× 10 =	%	×		÷ 100 =	
Total # of live (c)		Total # of plots (b)		**Survival Rate**		Original # trees/ac. (a)		**Surviving trees/ac.**

Linear 100 ft. Row Seedling Plot Summary:

	× 100ft. ÷ 43,560 sq ft/ac =			÷		=	
Average row width, ft (d)		**Plot size in ac.**	Total # live (c)		Plot size in ac.		**Surviving trees/ac.**

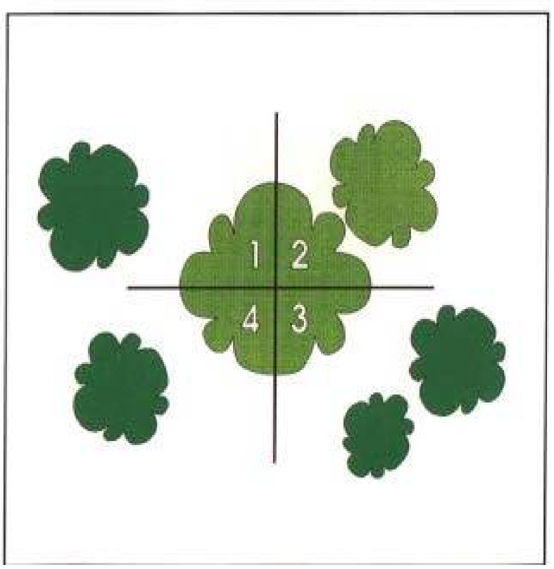
This form is adapted from Michigan Technical Note Forestry #30, Evaluation of Tree and Shrub Establishment Practices, December 2011, developed by Tom Ward, NRCS retired.

Crop Tree Inventory and Demonstration

- Crop Tree Inventory
  - Crop tree management is a forest stand improvement treatment, also known as release, that provides potential crop trees with additional growing space, light, and air through opening the area around their crowns. It reduces competition from adjacent trees to promote survivial and more rapid growth of the desired crop trees, and in some cases can be used to increase seed production.
  - A crop tree can be any tree that has been identified as desirable and worth retaining, and may be selected for the purposes of wildlife habitat, economic value, water quality, aesthetics, etc., depending on landowner objectives.
  - Crop tree management is typically applied in multispecies forest stands, such as eastern and northern hardwoods (maple, oak, hickory, etc.), and bottomland hardwoods (elm, ash, cottonwood, silver maple, red maple, etc.).
  - Multiple purposes can be addressed through crop tree management. It can be used to create desired forest structure in stands that are primarily even-aged. See Perkey et al. (1994) for information on silvicultural aspects of crop tree selection and management.
  - Trees that are relatively young for their life spans, around 25 feet tall with large healthy crowns, are often good candidates for crop tree management.
  - Trees selected for economic value will have a desirable growth form.
  - Before commencing an inventory and demonstration, discuss crop tree management with the landowners to gauge interest and identify purposes.
  - Conduct a reconnaissance survey of the stand to determine whether crop trees that meet landowner objectives are present, and to identify representative stand conditions. Take point samples as described in the section "Point Sampling" on page 4 in this TN. At each point, use a tally sheet such as the one shown in figure 11 to record species and DBH (for all trees of 4 inches DBH or larger), and codes indicating whether the tree is a potential crop tree for one or more purposes. (e.g., "W" for wildlife, "T" for timber, "V" for visual quality, etc.). Also use codes to identify trees that compete with potential crop trees ("cut trees").
- Crop Tree Demonstration
  - A demonstration plot is used to assist the landowners in deciding whether to manage for crop trees, and if so, how intensively.
  - One or more demonstration plots are located in representative portions of the forest stand.
    - A 1/5-acre plot is recommended; the plot may be circular with a radius of 53 feet or a square of 93 feet on a side.
    - Flag the plot boundaries sufficiently to allow the landowners to visualize plot dimensions. Within the plot—
      - Identify and flag high-value crop trees using criteria selected by the landowners.
      - Identify trees that are competing with crop trees for light (i.e., those with a crown that touches the crop tree crown).

    - Flag these competing trees with flagging of a different color; they are the “cut trees” that will be cut or killed to release the crowns of crop trees. Trees that do not contact a crop tree crown, or that are growing below a crop tree crown, are disregarded since they do not compete with crop trees.
    - Identify and flag competing trees on at least three out of four quadrats around the crop tree (fig. 10).
- Determine whether the landowners are satisfied with the amount of cutting. If less cutting is desired, first reduce the number of crop trees and then reduce the cut trees associated with those crop trees. This ensures that all remaining crop trees are fully released.
- Utilize information from the reconnaissance survey to calculate the number and average diameter of crop trees and cut trees, and the residual BA of the stand.
- The average number of crop trees and cut trees per acre, and the average diameter of these trees, will help the landowners or forestry contractor determine the potential for a timber sale and estimate the workload to cut or kill competing trees. In typical cases, 20–75 crop trees will be released per acre (4–15 crop trees per 1/5-acre plot).
- The calculation of residual BA will ensure that the stand remains fully stocked after crop tree management. See Perkey et al. (1994) for more information on crop tree management.

Figure 10: The crop tree crown in the center of this illustration has been separated into four quardrants. A free-to-grow rating is determined by evaluating each side for competition from neighboring crowns. This crop tree is free to grow on three sides (Wilkens 1994).



□□□□r □□□: Example of a Crop Tree Tally Sheet, to be Adapted as Needed for Different Geographic Areas

CROP TREE TALLY SHEET

(Eastern Hardwoods and Bottomland Hardwoods)

LANDOWNER:		**DATE:**	
STAND HISTORY:			
STAND NUMBER:	**TYPE:**	**APPROX. AGE:**	**ACRES:**
LANDOWNER OBJECTIVES:			

Plot No.	Species	DBH	Crop Tree [1] T,W, V, WQ	Cut Tree x

				AVG.
Basal Area - "leave" trees [4]				
Basal Area - cut trees				
TOTAL Basal Area [5]				

Crop Tree Totals				
			Avg. No.	**Avg.**
Category	**Total [2]**	**# Plots**	**Trees/Ac. [3]**	**DBH**
Timber (T)				
Wildlife (W)				
Visual Quality (V)				
Water Quality (WQ)				
Total All Categories				
Cut Tree Totals				
Cut Trees (x)				

[1] **Crop Tree Categories**

T - Timber
W - Wildlife
V - Visual Quality
WQ - Water Quality

x - Cut Tree

1/5 acre plot radius = 53 feet

DBH - diameter breast height

[2] If a tree qualifies in more than one category (example: T & W) count it only once in the category where it makes the greatest contribution to to accomplishing the primary landowner objective.

[3] Ave. Number of Trees Per Acre = Total # Trees / # Plots X 0.2 acre

[4] "leave" trees are all trees that are not marked to be cut or killed, that is BOTH Crop Trees AND trees that are neither Crop Trees nor cut trees. BA reported in this space represents the total post-treatment BA. BA measurements should be made at 2 or 3 points near plot center.

[5] Total pre-treatment BA

NRCS-Michigan
11/22/2006

Zig-Zag Transect Method

The zig-zag transect is best suited for even-aged, single-layer, and single-species forest stands of a uniform nature. These conditions would likely be encountered in a plantation type of stand. However, experienced users are also able to apply this method in measuring multilayered stands with a diversity of tree species.

The zig-zag method can be used to determine—

- Average tree diameter.
- Range of tree diameters.
- Stocking rates (TPA).
- Stand composition.
- Stand condition (health).

Information from the zig-zag transect can be used to derive an estimate of the BA of the sampled stand.

The zig-zag transect is performed by selecting a point in the stand where the transit will begin, along with determining a direction of travel (a general route which will best capture the stand attributes) (fig. 12). A compass and bearing are used to guide the route. The transect will normally be conducted along the contour when stands are on sloping topography.

A “starter tree” anchors the transect and is not measured. An imaginary 90^o quadrant, bisected by the direction of travel, is used to determine the area where the first sample tree will be selected.

- From the starter tree, select the next closest sample tree from within the 90^o quadrant. This provides a degree of randomness. Measure the distance from the starter tree to the first tree. Species, DBH, height, tree condition and other attributes of this first sample tree are recorded.
- The first tree that was sampled serves as the reference point in selecting the second tree. The same process that was used with the starter tree is repeated in order to select the next sample tree. Continue in this manner until 20 or more trees have been sampled.
- Be careful to exclude uncharacteristic openings. The true tree-to-tree distances will reveal the general stand density only if openings are excluded. The same logic applies to clumps of trees or other configurations that obviously do not represent the general stand structure. Figure 13 illustrates this concept.
- Collectively, these “atypical” conditions should occur infrequently within the stand. If they don’t, and if these areas become significant in cumulative size, then the overall stand description must be revised to account for the openings or clumps.
- See Montana’s Technical Note MT-22 for additional detail on the zig-zag transect method (Logar and Wiersum 2003).

Figure 2: Configuration of a Zig-Zag Transect Showing Tree Selection Sequence and Direction of Travel

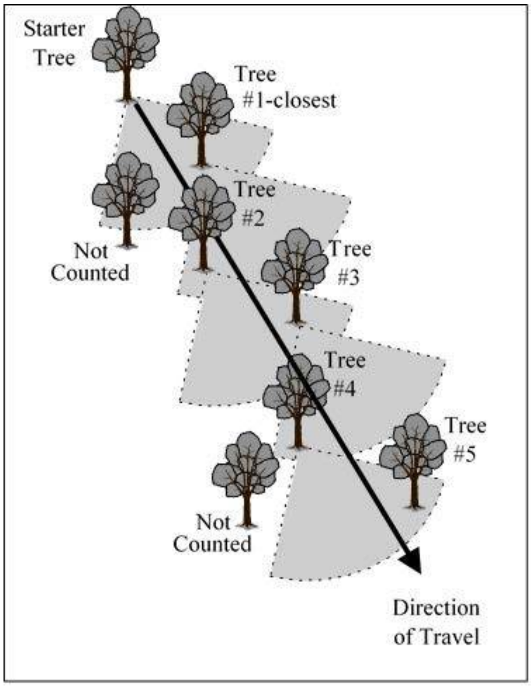
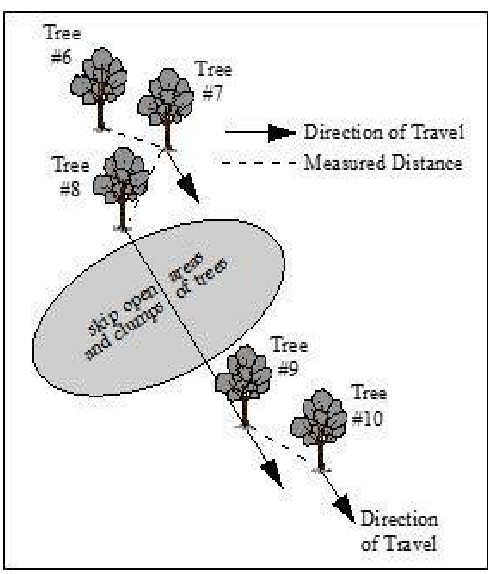


Figure 3: Using the Zig-Zag Method When Encountering Forest Openings or Clumps of Trees



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Effect of Plot and Sample Size on Timing and Precision of Urban Forest Assessments

David J. Nowak, Jeffrey T. Walton, Jack C. Stevens, Daniel E. Crane, and Robert E. Hoehn

Abstract. Accurate field data can be used to assess ecosystem services from trees and to improve urban forest management, yet little is known about the optimization of field data collection in the urban environment. Various field and Geographic Information System (GIS) tests were performed to help understand how time costs and precision of tree population estimates change with varying plot and sample sizes in urban areas using random sampling approaches. Using one-tenth acre (0.04 ha) plots, it is estimated that, on average, approximately three plots per day can be measured with plot data collected on several variables for all trees greater than 1 in (2.54 cm) in diameter along with general plot, ground cover, and shrub data. A field crew of two people can gather approximately 200 one-tenth acre (0.04 ha) plots during a 14 week summer field season depending on city traffic, city area, and tree cover conditions. These 200 plots typically yield approximately a 12% relative standard error on the total number of trees.

Key Words. Tree measurement; urban forest monitoring; urban forest sampling.

Measuring the urban forest structure (i.e., species composition, number of trees, tree sizes and locations, tree health) can give managers and planners a basis with which to develop and evaluate programs for managing urban trees and forests throughout a city. In addition, long-term monitoring of urban forest structure can provide essential data related to rates and factors of change affecting population totals, tree mortality, tree planting and natural regeneration, tree health, and species changes.

An accurate quantification of urban forest structure is also needed to assess the various ecosystem services and values provided by the urban forest. Urban vegetation, particularly trees, provides numerous benefits that can improve environmental quality and human health in and around urban areas. These benefits include improvements in air and water quality, building energy conservation, cooler air temperatures, reductions in ultraviolet radiation, and many other environmental and social benefits (Nowak and Dwyer 2007). By having accurate information on urban forest structure, managers can understand what the current urban forest provides in terms of various environmental benefits and also alter the structure of the urban forest (e.g., tree plantings, species and site selections, and tree maintenance and removals) to enhance these benefits in the future.

One of the best ways to assess the entire urban forest is through sampling procedures. However, varying sample and plot sizes affect total cost (time) of data collection and the precision of the urban forest estimate. The purpose of this article is to illustrate, based on field data collection tests, how plot and sample size of randomly located circular plots in urban areas can affect data collection time, number of permissions needed to access plots, and precision of tree cover and total tree population estimates. These types of data have been lacking related to urban forest sampling and can be useful in developing sampling schemes to help provide desired precision of estimates and understand the costs associated with obtaining that precision.

METHODS

Effect of Plot Size on Data Collection Time and Total Population Estimate Precision

To estimate the effect of plot size on time needed to collect field data and on total population estimates, a random sample of 26 residential plots (from a total of 100 residential plots that were measured and analyzed using the Urban Forest Effects [UFORE] model in Syracuse, NY, U.S. [Nowak and Crane 2000; Nowak and O'Connor 2001]) were measured and timed using a field crew of two people. Crews were trained before field data collection and were experienced in urban forest field data collection. For each plot, permission was obtained from the lot owner (where the plot center was located) by knocking on the front door of the lot residence. If the plot encompassed more than one lot, additional lot owners were contacted for permission if trees in those additional lots were located within the plot boundary.

On each plot, all UFORE variables (i-Tree 2007) were collected on concentric one-twenty-fourth acre (24 ft radius circle), one-tenth (37.2 ft radius), and one-sixth acre plots (48.1 ft radius) (0.0168 ha [7.3 m radius], 0.04 ha [11.3 m radius], and 0.067 ha [14.7 m radius] plots, respectively). These variables include several tree variables (e.g., species, diameter at breast height, crown, and health parameters) on all trees greater than 1 in (2.54 cm) in diameter at breast height (4.5 ft [1.37 m]) and general plot information (e.g., location, plot center, tree and shrub cover), ground cover types, and general shrub types and dimensions. Electronic distance measuring devices were used to record trees distances from plot center and tree heights. Data collection also included measures of general plot slope and aspect.

Data collection was cumulatively timed moving from the smallest to largest plot and number of access permissions needed was recorded. Average measurement time, number of lots accessed, and number of trees along with associated standard errors were assessed for each plot design. In addition, an estimated total number of trees in the residential area was calculated and compared with an estimate using 100 one-tenth acre (0.04 ha) plots to illustrate how plot size affects the total tree and standard error estimate. Average plot time for field plot setup, cover estimates, and measurements per tree were used to estimate how average field measurement time would likely vary as tree cover changes.

In a separate analysis, an additional test of plot size and plot design was conducted using GIS tree cover, land use, and parcel data for the city of Syracuse. Five hundred points were randomly distributed throughout the city. At each point, the following seven different plot sizes or designs were constructed around the point using GIS: 1) one-twenty-fourth acre (0.017 ha) circular plot; 2) one-twelfth acre (0.034 ha) circular plot; 3) one-tenth (0.04 ha) circular plot; 4) one-eight acre (0.05 ha) circular plot; 5) one-sixth acre (0.067 ha) circular plot; 6) one-fourth acre (0.1 ha) circular plot; and 7) four one-twenty-fourth acre (0.017 ha) circular plots (cluster plot) using the USDA Forest Service Forest Inventory and Analysis (FIA) plot design (USDA Forest Service 2000). With this cluster plot design, three subplots were established 120 ft (36.6 m) from the center subplot at 120°, 240°, and 360° azimuths.

For each of the plot sizes and designs, total amount of tree cover within the plot was assessed using a 2 ft (0.61 m) resolution tree cover map (Myeong et al. 2003), and the number of parcels and associated number and area of land uses in each parcel within the plot design was recorded using a digital land use parcel map. The average amount of permissions required for each plot design was categorized among three classes: 1) permission required (residential land use parcels); 2) permission questionable—uncertain if crew would need to obtain permission (commercial/industrial, institutional, utility/transportation parcels); and 3) no permission needed (greenspace, street right-of-ways, and vacant parcels) to assess how permissions would vary based on plot size and design. The average percent of plot area within the parcel that contained the plot center was also calculated. This calculation was done to help determine how much of the plot area would require the crew to move to an additional parcel and how much of that extra plot space would require additional permissions. Mean tree cover and standard error for each plot design were calculated and compared with the actual tree cover as classified by the tree cover map.

Effect of Sample Size on Total Population Estimate Precision

To determine the effect of sample size on the standard error estimate for the total tree population, sample data from 14 cities were analyzed using the UFORE model (Nowak and Crane 2000; Nowak et al. 2002) (Table 1). For each city, population total, standard error (SE), and relative SE were calculated. The relative SE is a measure of estimated reliability and is the ratio of SE to the estimate, in this case, population total (SE/total × 100) (US Department of Health and Human Services, Centers for Disease Control and Prevention 2007). Eleven of the cities were sampled using a stratified random sampling approach, and three using a randomized grid approach, which was used to facilitate long-term monitoring of urban forest change. Standard error for each city was standardized to a population size of 200 plots using the formula: SE = standard deviation/$\sqrt{n}$. The average SE using 200 plots was calculated for the 14 cities and used to illustrate how SE of the total tree population estimate will vary as sample size varies between 10 and 500 plots.

RESULTS

Effect of Plot Size on Data Collection Time and Total Population Estimate Precision

Increasing plot size from a one-twenty-fourth acre (0.017 ha) plot to a one-sixth acre (0.067 ha) plot nearly doubled the amount of time needed to measure the plot variables, but also nearly cut in half the relative standard error for the total popu-

Table 1. Estimates of total number of trees and standard errors from 14 cities analyzed using the UFORE model.[z]

	Number of trees				200 plot[y]		
City	Total	SE	Year	No. plots	SE	RSE	Sample[x]
Atlanta, GA[w]	9,415,000	749,000	1997	205	758,000	8.1	Str. random
Baltimore, MD[v]	2,571,000	494,000	2004	200	494,000	19.2	Str. random
Boston, MA[w]	1,183,000	109,000	1996	217	114,000	9.6	Str. random
Freehold, NJ[u]	48,000	6,000	1998	144	5,000	10.1	Str. random
Jersey City, NJ[u]	136,000	22,000	1998	220	23,000	16.7	Str. random
Minneapolis, MN[t]	979,000	165,000	2004	110	122,000	12.5	Random grid
Moorestown, NJ[u]	583,000	53,000	2000	206	54,000	9.3	Str. random
Morgantown, WV[s]	658,000	79,000	2004	136	65,000	9.9	Str. random
New York, NY[w]	5,212,000	719,000	1996	206	729,000	14.0	Str. random
Philadelphia, PA[w]	2,113,000	211,000	1996	210	216,000	10.2	Str. random
San Francisco, CA[r]	668,000	98,000	2004	194	97,000	14.5	Random grid
Syracuse, NY[v]	876,000	119,000	2001	197	119,000	13.5	Str. random
Washington DC[q]	1,928,000	224,000	2004	201	224,000	11.6	Random grid
Woodbridge, NJ[u]	986,000	97,000	2000	215	100,000	10.2	Str. random

[z]Average relative standard error = 12.1%.
[y]Estimated standard error (SE) and relative standard error (SE/total × 100; RSE) using a sample of 200 one-tenth acre (0.04 ha) plots.
[x]Str. random = stratified random sample; random grid = randomized grid sample.
[w]Data collection by ACRT, Inc.
[v]Data collection by U.S. Forest Service.
[u]Data collection by New Jersey Department of Environmental Protection.
[t]Data collection by Davey Resource Group.
[s]Data collection by West Virginia University.
[r]Data collection by city personnel.
[q]Data collection by Casey Trees Endowment Fund.

lation estimate (Table 2). Average time per plot increased from approximately 62 min (SE = 7.4) for a one-twenty-fourth acre plot (0.017 ha) to 106 min (SE = 14.0) for a one-sixth acre (0.067 ha) plot. Number of permissions (lots) also increased from an average 1.9 (SE = 0.1) to 3.1 (SE = 0.2), and number of trees measured per plot increased from 2.6 (SE = 1.1) to 6.5 (SE = 1.5). All three plot sizes produced total population estimates with a sampling error within 1 SE of the estimated population total of 251,000 trees, but as plot size increased, the total estimate moved closer to the 251,000 estimate and SE decreased (Table 2). The trend of the overall estimate decreasing with plot size (Table 2) suggests that the sample size was not large enough for the two smaller plot sizes. The effect of increasing the number of plots for the smaller plots sizes such that the total sample area remains the same among all plots sizes remains to be investigated.

A similar pattern occurred when accessing tree cover from digital maps using plot sizes that ranged from one-twenty-fourth acre (0.017 ha) to one-fourth acre (0.1 ha), including an FIA cluster plot. Number of permissions increased and percent of plot in parcel with plot center decreased as plot size increased (Table 3). The one-fourth acre (0.1 ha) plot produced the closest estimate of actual tree cover value and had the lowest SE and relative SE. The one-twenty-fourth acre (0.017 ha) plot produced the estimate farthest from the actual tree cover value, although it was still within 1 SE from the true mean and had the highest SE and relative SE. The FIA cluster design, which is being used in the urban forest health monitoring program (Cumming et al. 2008), produced estimates of tree cover with a slightly higher SE and relative SE than a one-sixth acre (0.067 ha) single plot design. The FIA plot design also required nearly double the permissions of the one-sixth acre (0.067 ha) plot design (Table 3).

Average time to set up a residential plot (e.g., gain permission and establish plot center) was 15.6 min (SE = 1.9); average time needed to estimate cover types was 12.8 min per plot (SE = 1.1). Thus, the average fixed time per plot was approximately 30 min. The average time to record all measurements on one tree was 12.2 min (SE = 0.9).

Effect of Sample Size on Total Population Estimate Precision

The relative standard error (RSE) of total number of trees drops significantly with the first 50 to 100 one-tenth acre (0.04 ha) plots established, from 54.1% RSE with 10 plots to 17.1% RSE at 100 plots. After approximately 100 plots, the RSE continues to drop, but a reduced rate per additional plot (Figure 1). The average RSE for 200 plots is 12.1% (Table 1).

DISCUSSION

The key to assessing urban forests is to determine the optimal number of plots and plot size needed to gain the desired precision of an estimate at minimal cost. Unfortunately, there is not much information in the literature on costs of urban field plots and structural variability across the urban forest. A general rule of sampling is increasing the plot size and number of plots tends to increase precision, but at increased cost. Data presented in this article begin to reveal the increases in precision and time costs associated with different sample designs for sampling trees in urban areas.

Assuming an average tree density of 204 trees per acre of urban tree cover (504 trees/ha cover) (Dwyer et al. 2000) and a national average tree cover of 27.1% (Nowak et al. 2001), the average time to set up and measure a one-tenth acre (0.04 ha) urban plot in the United States would be approximately 95 min (five plots per 8 hr day). However, this estimate does not include travel time. The longer the distance between plots and the slower the traffic, the fewer the number of plots that can be measured per day. This estimate also includes plot permissions; however, plots on several land uses often do not require permission and access setup time could be reduced. Also, the fewer the trees per plot or fewer variables measured, the more plots can be measured per day. A reasonable estimate of average number of one-tenth acre (0.04 ha) plots per day for a field crew of two people would be approximately three plots per day for a full suite of tree and plot measurements in a midsized city.

Number of plots per day will vary by the amount of tree cover in a region because when tree cover increases, the amount of time measuring trees increases. In desert regions, urban tree cover averages 9.3% (Nowak et al. 2001) and average plot setup and measurement time would be approximately 51 min. In grasslands (urban tree cover averages 17.8%), average plot time would be approximately 72 min. In forested areas (urban tree cover averages 34.4%), average plot time would be approximately 113 min. Again, these estimates do not include travel time or office time needed to establish plot locations and maps.

The standard UFORE model sampling approach establishes approximately 200 one-tenth acre (0.04 ha) circular plots in randomized grid or stratified random sample. The selection of 200 plots was based on an estimated amount of plots that could be surveyed by field crew of two people during a summer season (14 weeks), given an average data collection rate of three plots per day. In some cities with high tree cover and/or traffic volumes, data collection will take longer than 14 weeks. In addition to data collection time, there are also costs associated with establishing the locations of the plots, transportation, equipment, data entry or data transfer, and data analysis and reporting costs.

The use of 200 one-tenth acre (0.04 ha) plots produces a reasonable population estimate if a 12% RSE is acceptable to the user. Depending on the desired precision, a smaller sample size may provide adequate estimates of the urban forest population.

Table 2. Average time, number of lots accessed, trees per plot, and total population estimate from 26 residential plots measured in Syracuse, New York, U.S. using different plot sizes.

	Time (min)		No. of lots		No. trees per plot			No. of residential trees		
Plot size (ac)	Mean	SE[z]	Mean	SE[z]	Mean	SE[z]	Range	Estimate[y]	SE[z]	RSE[x]
1/24 (0.017 ha)	61.8	7.4	1.9	0.1	2.6	1.1	0–27	429,998	178,366	41.5
1/10 (0.04 ha)	84.1	9.9	2.8	0.2	4.6	1.3	0–33	316,968	90,708	28.6
1/6 (0.067 ha)	106.1	14.0	3.1	0.2	6.5	1.5	0–34	267,922	61,220	22.8

[z]Standard error.
[y]Actual estimated number based on 100 one-tenth acre (0.04 ha) plots is 251,000 trees (SE = 35,000).
[x]Relative standard error.

Table 3. Effect of plot size and design on number of parcels per plot, number of access permissions required, and percent tree cover in Syracuse, NY, using 2 ft resolution tree cover and land use/parcel boundary maps of 500 randomly located plots.

	Number of parcels				Percent of plot area				Percent tree cover		
						Additional parcels					
Plot size (ac)[z]	Total	Perm. req.[y]	Perm. quest.[x]	No perm.[w]	First parcel[v]	Perm. req.[y]	Perm. quest.[x]	No perm.[w]	Mean[u]	SE[t]	RSE[s]
1/24	1.9	0.9	0.4	0.6	84	9	2	5	25.8	1.1	4.1
1/12	2.3	1.2	0.4	0.7	78	13	3	7	26.1	0.9	3.3
1/10	2.4	1.3	0.4	0.7	76	14	3	7	26.2	0.8	3.1
1/8	2.6	1.4	0.4	0.8	74	15	4	7	26.3	0.8	2.9
1/6	2.9	1.6	0.5	0.8	70	17	4	8	26.4	0.7	2.6
1/4	3.4	2.0	0.5	0.9	65	20	5	8	26.6	0.6	2.2
FIA[r]	5.3	3.2	0.8	1.3	48	27	8	17	26.2	0.8	3.0

[z]1/24 ac = 0.017 ha; 1/12 ac = 0.034 ha; 1/10 ac = 0.04 ha; 1/8 ac = 0.05 ha; 1/6 ac = 0.067 ha; 1/4 ac = 0.1 ha.
[y]Permission required (residential land).
[x]Permission requirement is questionable; uncertain if crew would need to obtain permission (commercial/industrial; institutional; utility/transportation).
[w]No permission needed (greenspace; street right-of-way; vacant).
[v]Average percent of plot within parcel where plot center is located.
[u]Average tree cover in Syracuse = 26.6%.
[t]Standard error.
[s]Relative standard error (SE/mean × 100).
[r]USDA Forest Service, Forest Inventory and Analysis plot design of four 1/24 ac (0.067 ha) subplots.

However, when subdividing the analysis into smaller units (e.g., species, land use), the RSE will tend to increase. To increase precision for various estimates, more crews could be used to collect more plot data by either increasing plot size and/or increase the number of plots. In addition, stratification of plots in similar groups (e.g., land use classes, as done in the UFORE analyses) tends to increase precision. Increasing the number of plots from 200 to 500 will likely reduce the RSE on the total number of trees to 7.7% (a 36% reduction). Thus, increasing the number of plots enhances the precision of the estimate, but at an increased cost.

A sampling of 150 to 200 plots is a reasonable sample size given the costs associated with measuring field plots during a summer season and a goal of maximizing reduction in SE of the estimates per unit cost. If sample size increases to greater than 200 plots, it is likely a second field crew will be needed to collect the additional plot data. Thus, increasing sample size to greater than 200 plots increases costs (adding an additional crew) with relatively minimal gains in the reduction in SE as compared with the first 200 plots sampled. Increasing the plot size from one-tenth acre (0.04 ha) to one-sixth acre (0.067 ha) will also likely reduce the RSE by approximately 16% to 20%. However, increasing the plot size will increase the number of permissions needing to be obtained for the sample and thus the overall project time required.

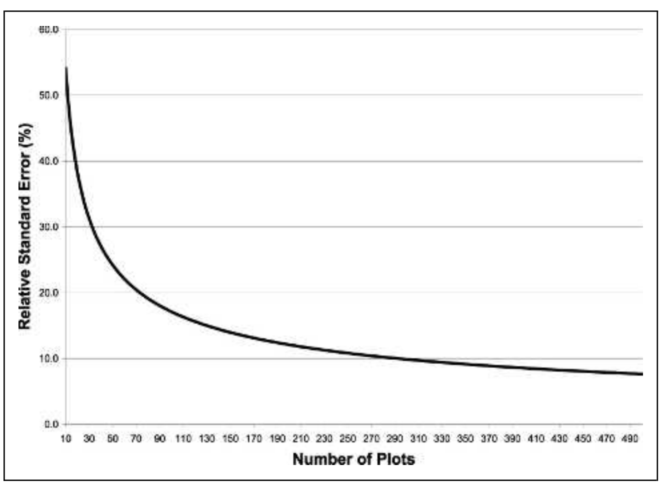

Figure 1. Estimated relative standard error (SE/total × 100) of total number of trees based on varying number of total one-tenth acre (0.04 ha) field plots.

CONCLUSION

Data gathered on urban forest structure is essential to improve urban forest management. Random sampling offers a relatively easy means to accurately assess urban forest structure and subsequently estimate its ecosystem services and values. The precision and cost of the estimate is dependent on sample and plot size. Managers need to plan their data collection procedures properly to ensure a desired precision of the estimate and adequately plan for data collection costs. Ensuring that the proper variables are collected will help guarantee that the data are useful for urban forest management. Incorporating these data within models to assess ecosystem services and values, and within long-term management and monitoring plans, can help improve urban forest health and sustain or increase urban tree cover and consequently environmental and human health in urban and urbanizing areas.

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Résumé. Des données de terrain précises peuvent être utilisées pour évaluer les bénéfices que procurent les arbres à un écosystème et pour améliorer la gestion de la forêt urbaine, encore que peu soit connu à propos de l'optimisation de la collecte des données de terrain dans un environnement urbain. Divers tests de terrains et de système d'informations géographiques ont été employés pour aider à comprendre comment les coûts en temps et le degré de précision des estimations de la population d'arbres peuvent changer en fonction de la variation des échantillons et de la taille de ces derniers en milieux urbains, et ce en utilisant des approches par échantillonnage aléatoire. Au moyen d'unités d'échantillonnage de 0,04 ha, il a été estimé qu'en moyenne trois unités d'échantillonnage pouvaient être mesurées par jour avec diverses données colligées pour les arbres de plus de 2,5 cm de D.H.P. en plus de données générales sur l'unité d'échantillonnage, le couvert au sol et les arbustes. Une équipe de deux personnes peut ainsi couvrir environ 200 unités d'échantillonnage en 14 semaines en été, et ce dépendant du degré de circulation de la ville, de la superficie de la ville et des conditions du couvert arboré. Ces 200 unités d'échantillonnage ont résulté en une erreur standard relative d'environ 12% par rapport au nombre total d'arbres.

Zusammenfassung. Akkurate Felddaten können dazu verwendet werden, den Beitrag von Bäumen in ihrem Ökosystem zu bewerten und das urbane Forstmanagement zu verbessern. Dennoch ist wenig bekannt über die Optimierung der Datenerhebung in urbanen Räumen. Verschiedene Feld- und GIS-Tests wurden ausgeführt, um ein besseres Verständnis dafür zu erlangen, wie Zeitkosten und Schätzungen der Baumpopulation bei zufälligen Probenahmen mit der Größe der Fläche und der Probenmenge variieren können. Bei Probeflächen von 0,4 ha wird geschätzt, dass durchschnittlich ca. 3 Flächen pro Tag gemessen werden können, wobei zusammen mit allgemeinen Daten zur Fläche, Bodenbedeckung und Unterpflanzung die Daten von allen Bäumen über 2,5 cm Durchmesser gesammelt wurden. Ein Team von 2 Leuten kann während einer 14wöchigen Sommersaison und in Abhängigkeit von Verkehr, Stadtbereich und Bedeckungsgrad ca. 200 Flächen á 0,4 ha erfassen. Diese 200 Flächen bergen durchschnittlich in Bezug auf die Gesamtzahl der Bäume pro Einheit ca. 12 % Fehler.

Resumen. Pueden utilizarse datos precisos para evaluar los servicios ambientales de los árboles y mejorar el manejo del bosque urbano, aunque aún no se conoce lo suficiente sobre la optimización de la colección de los datos de campo en el ambiente urbano. **Se** realizaron varias pruebas de campo y GIS para ayudar a entender cómo los costos en tiempo y precisión de la estimación de la población de árboles cambia con la variación de del tamaño y forma de la parcela en áreas urbanas usando aproximaciones por muestreo al azar. Con el uso de parcelas de una décima de acre (0.04 ha), se estima que, en promedio, aproximadamente tres parcelas por día pueden ser medidas con los datos colectados en varias variables para todos los árboles mayores a 2.5 cm (1 pulg) en diámetro junto con la parcela general, cobertura y datos de arbustos. Un equipo de campo de dos personas puede levantar aproximadamente 200 parcelas de una décima de acre durante una estación de verano de 14 semanas dependiendo del tráfico de la ciudad, área de la ciudad y condiciones de cobertura. Estas 200 parcelas típicamente rinden aproximadamente un 12% de error relativo estándar sobre el número total de árboles.

Comparative Evaluation of Accuracy and Efficiency of Six Forest Sampling Methods

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We compared estimates of woody stem density with known stem densities in three forest stands in southeast Oklahoma by using fixed-radius plots 3.64 m radius (0.01 acre; FRPs-AC), fixed-radius plots 5.64 m radius (0.01 ha; FRPs-HA); 10 m X 10 m quadrat (0.01 ha; QUAD), variable-radius plot (VRP), point-centered quarter (PCQ), and belt transect (BT) sampling techniques. These stands varied in stem density and were categorized as high, moderate, and low density stands. We found that FRPs were the most time-efficient and produced the most accurate estimates regardless of stem size. The VRP and PCQ methods were also time-efficient, but tended to underestimate actual stem density. Although FRPs of suitable size are accurate for large diameter stems in dense forest, time constraints limit applicability. We recommend using FRPs for small stems [(2.54–11.42 cm diameter breast height (DBH)] and VRPs for large stems (≥11.43 cm DBH). These methods with appropriate sample sizes should be applied after pre-sampling has been completed to determine sampling variance. This combination of methodologies provides a quick and relatively accurate manner to characterize or monitor change in the wide range of forest conditions found in Oklahoma.

INTRODUCTION

Quantitative data are essential to adequately characterize the woody component of forest communities (*1,2*). Some form of sampling is required because total counts of individuals in naturally occurring plant populations are generally impractical without an exhaustive expenditure of energy and resources (*3*). A number of sampling techniques are available to quantify forest communities. These techniques vary in quantitative capabilities, equipment required, and time necessary to obtain an adequate sample for statistical analysis (*4,5*). Obtaining adequate information with minimum effort and time is a major concern when sampling vegetation (*4,5*).

Variable radius plot (VRP), fixed radius plot (FRP), point-centered quarter (PCQ), belt transect (BT), and 10 m X 10 m plots (QUAD) are sampling methods commonly used to quantify forest vegetation (*2–6*). The purpose of this study was to determine the best sampling method for use in widely varying forest conditions that would adequately characterize forest communities in Oklahoma for the purpose of monitoring change in the woody component following either experimental manipulation or land use change. Our primary objective was to compare the accuracy of estimates of woody stem density for six forest sampling techniques under widely varying stand densities. A second objective was to compare the time required by these methods to obtain a 10% sample (by area).

STUDY AREA

We conducted this study on the Pushmataha Forest Habitat Research Area (PFHRA) on the 7395 ha Pushmataha Wildlife Management Area, approximately 6 km southeast of Clayton, Oklahoma (*7*). The PFHRA was protected from logging, grazing, and fire until 1984 when a comprehensive study on the effects of fire and timber harvest began (*7–10*).

We selected three different stands in the research area to represent varying stand densities in both understory and overstory. Stands included

1. High density stand—unmanaged stand, no fire or timber harvest, 0.92 ha in size.
2. Moderate density stand—removal of 1/2 of the hardwood basal area, annual winter burn since 1985, 0.56 ha in size.
3. Low density stand—harvest all merchantable pine, annual winter burn since 1985, 1 ha in size.

The high density stand was dominated by post oak (*Quercus stellata*), shortleaf pine (*Pinus echinata*), with occasional blackjack oaks (*Q. marilandica*) and mockernut hickory (*Carya tomentosa*) (*7*). Shortleaf pine dominated the moderate density stand while the low density stand was dominated by post oak with occasional blackjack oak and mockernut hickory. Study area soils and vegetation on these sites were previously described by Masters and Masters et al. (*7–10*).

METHODS

We delineated the area to be sampled in each stand by using a compass and hip chain. We sampled experimental stands $\geq$20 m from stand boundaries to minimize edge effects from adjacent stands. After stand boundaries were surveyed and marked, we obtained a total count of stem density from each stand. We recorded species and diameter at breast height (DBH) of all stems with a DBH $\geq$2.54 cm. After a stem was tallied we marked the bark or foliage with paint to ensure that all trees were counted accurately.

We selected sampling points at random distances along a base line through the long axis of the stand after the method of Beason and Haucke (*3*). We then selected a random distance from the random point on the base line for location of plot center. This process continued until the desired number of samples had been taken (Table 1).

Sampling Methods: The six sampling methods compared with total census counts included VRPs, 3.64 m fixed-radius plot (FRP-AC), 5.64 m fixed-radius plot (0.01 ha; FRP-HA), QUAD, PCQ, and BT. We practiced each sampling method prior to sampling to familiarize ourselves with the methods. We performed only one sampling technique on a plot at a time. Sampling time was recorded with a stopwatch.

We sampled approximately 10% of the area of each experimental unit using all methods except VRP. For VRP, we used the same plot centers as those used in the PCQ method. We tallied all woody species with a DBH $\geq$2.54 cm, except when applying the PCQ, for which only stems $\geq$11.43 cm were tallied. We recorded species and DBH for all sampling methods.

We counted all stems of appropriate DBH in a given area for the FRP-AC, FRP-HA, QUAD, and BT. We used a 10-factor prism when applying the VRP method (*2,11,12*). We tallied trees that subtended an angle equal to or greater than that of the prism.

When using the PCQ method we divided sampling points into four quarters (*3,4*). In each quarter we tallied the nearest tree $\geq$11.43 cm. We did not sample small stems when using the PCQ method. We then measured from the sample point to the nearest tree in each quarter (quadrant) and recorded this measurement. We placed BTs on randomly located lines running the length of the stand by using a transect width of 1 m (Table 1). We tallied all trees within the 1 m transect width and tallied every other border-line tree.

Data Analysis: To facilitate comparison, density estimates were summarized on a hectare basis. Stems were classified into two size classes for analysis: 2.54 to 11.42 cm and ≥11.43 cm. A difference value was obtained by subtracting actual stems/ha from estimated stems/ha. Chi-square analysis was used to determine the accuracy of sampling methods ($P < 0.05$; 13). We also analyzed the data as a randomized complete block design (ANOVA) with stands as the block and sampling technique as the treatments to determine if mean density estimates were different between techniques. Technique means were separated with the protected least significant difference (LSD) test (*14*).

RESULTS

As expected, we found wide variation among sample plot estimates within a given technique by stand density. Therefore, we were not able to detect a significant difference in density estimates between sampling techniques by using the LSD test ($P > 0.05$). We found that technique performance was apparently dependent on the size class and distribution of woody stems in a given stand. We did detect differences in accuracy using chi-square analysis.

Stems 2.54 to 11.42 cm: The FRP-AC and FRP-HA methods were accurate in the high density stand ($\chi^2 = 0.11$ and 0.01, respectively, $P < 0.05$; Fig. 1). Both FRP methods underestimated stem density on less dense stands (Fig. 1). The QUAD method was not accurate and underestimated density in both high and moderate density stands, but did produce reasonable estimates in low density stands. The VRP method produced varied estimates across all three levels of stem density and was judged to be unsuitable for small stems (Fig. 1). The BT technique produced more accurate results at low densities than at moderate and high densities (Fig. 1).

Stems ≥ 11.43 cm: The FRP-AC and QUAD produced accurate ($\chi^2 = 3.20$ and 1.60, respectively, $P < 0.05$) estimates of stem density in high density stands (Fig. 2). The BT was somewhat accurate for high density stands ($\chi^2 = 4.10$, $P < 0.10$). The QUAD and BT methods produced accurate ($\chi^2 = 1.50$ and 2.30, respectively, $P < 0.05$) estimates at

TABLE 1. Total time (minutes) required to sample approximately 10% of a hectare using various sampling techniques on Pushmataha Forest Habitat Research Area, Summer 1994.

Stem Size-Class, Technique [a]	Stand Density		
	High	Moderate	Low
Stems 2.54-11.42 cm			
FRP-AC[b]	50	30	20
FRP-HA	55	34	25
QUAD	63	44	41
BT	144	99	86
Stems ≥ 11.43 cm			
PCQ	235	104	47
All stems			
FRP-AC	160	145	137
VRP	72	47	34
BT	327	225	195

[a] FRP-AC = fixed-radius plot, 3.64 m radius (0.01 acre); FRP-HA = fixed radius plot, 5.64 m (0.01 ha); QUAD = 10 m X 10 m quadrat, (0.01 ha); VRP = variable-radius plot; BT = belt transect; PCQ = point-center-quarter.

[b] These times for this technique were relative estimates because all stem size classes were counted when applying this technique.

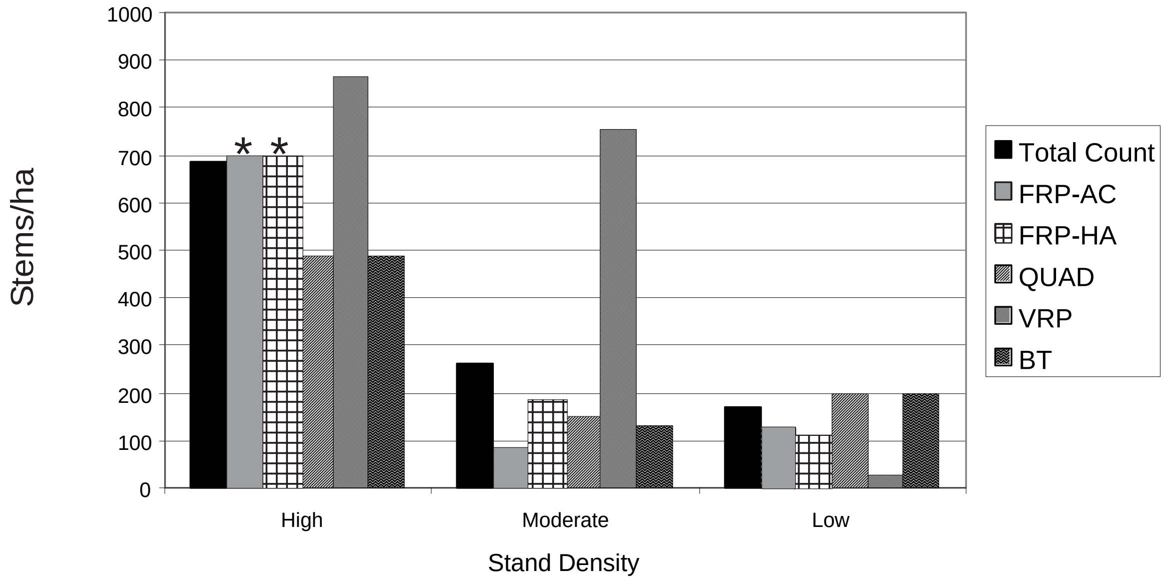

Figure 1. Comparison of five forest sampling techniques for stems 2.54 - 11.42 cm in diameter, in high-density, moderate-density, and low-density stands on Pushmataha Forest Habitat Research Area, summer, 1994. FRP-AC = fixed-radius plot, 3.64 m radius (0.01 acre); FRP-HA = fixed radius plot, 5.64 m (0.01 ha); QUAD = 10 m X 10 m quadrat (0.01 ha); VRP = variable-radius plot; BT = belt transect; PCQ = point-centered quarter. Those bars with an * were significantly accurate (*P* < 0.05) using the chi square test.

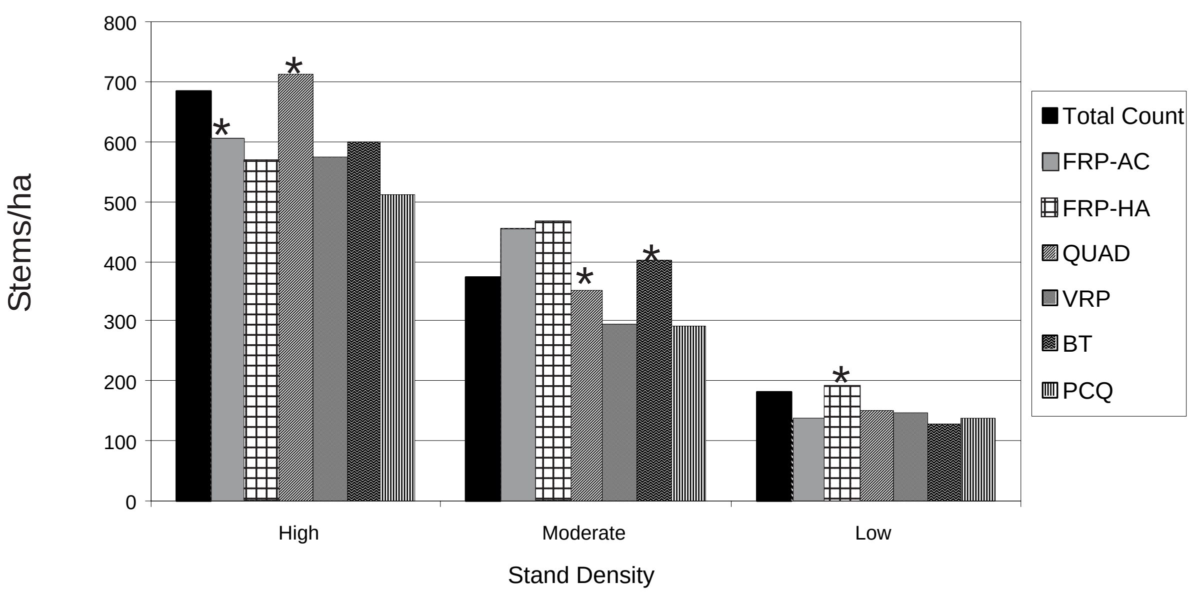

Figure 2. Comparison of six forest sampling techniques for stems ≥ 11.43 cm in diameter, in high density, moderate density, and low density stands on Pushmataha Forest Habitat Research Area, summer, 1994. FRP-AC = fixed-radius plot, 3.64 m radius (0.01 acre); FRP-HA = fixed radius plot, 5.64 m (0.01 ha); QUAD = 10 m X 10 m quadrat (0.01 ha); VRP = variable-radius plot; BT = belt transect; PCQ = point-centered quarter. Those bars with an * were significantly accurate (*P* < 0.05) using the chi square test.

moderate stem densities, and the FRP-HA produced accurate ($\chi^2 = 0.80$, $P < 0.05$) results in the low density stand (Fig. 2). The QUAD technique produced estimates within 26 stems of the actual, across all stands (Fig. 2). The PCQ and VRP methods underestimated stem densities in all three stands, but the difference was proportional and constant across all stand densities (Fig. 2).

Sampling Time: The FRP-AC was the fastest method applied, closely followed by the FRP-HA and QUAD methods for small diameter stems (Table 1). The BT was much slower because of setup time needed to apply this method. The PCQ method was not directly comparable to other methods because we used it for estimating larger diameter trees. It performed more time efficiently in stands with low density, but was much slower in stands with high densities (Table 1). The VRP method was the most rapid of all techniques to sample all stem size-classes. The BT method was the slowest technique, taking more than twice the time of other methods (Table 1).

DISCUSSION

Sampling Accuracy: Vegetation is often clumped or patchy in distribution (*5*). The high standard deviation we found associated with mean estimates derived from these sampling methods reflects the clumped and patchy distribution of trees within these stands. Four of the seven accurate estimates were from sampling techniques applied in the high density stand. Density estimates from the various sampling techniques in the high density stand were generally more accurate because our observations were that stems tended to be more evenly distributed. Stems in the moderate and low density stands tended to be clumped and patchy in distribution in violation of the statistical assumption that stems were randomly distributed. In situations with nonrandom distributions, sampling intensity must be increased until the variance is lowered rather than going with a set 10% minimum level sample.

VRPs and FRPs are unbiased for all distributions but distance measures are not (*6,15,16*). Any biases found in estimates may be related to field technique or may be attributable to stand conditions such as poor visibility in dense stands and bias arising when determining if a tree should be tallied when using the VRP method. This is particularly problematic when making determinations with a prism for small diameter stems close to the sampling point in dense stands (*6*). This was apparent in widely varying estimates of stems <11.43 cm derived by the VRP method in different density stands. However, we found that the VRP consistently underestimated density for larger stems.

FRPs (circular) were indeed accurate and unbiased at high stem densities, but variation increased between samples when applied to the lower density stands. Under these conditions sampling intensity must be increased and pre-sampling with attention to variance estimates should increase confidence in the estimates.

Sampling and Time Efficiency: The techniques that performed best for sampling stems <11.43 cm across different density stands included the FRP methods of different size. The FRP-AC was relatively time-efficient and produced excellent results regardless of stem size in the high density stand. However, it produced estimates of poor accuracy in our sparse stand. An advantage of this method is its ability to be applied to all stems regardless of size. The only problem with the method is that it requires more samples to obtain the same sampling intensity as other methods. The FRP-HA has the same advantages and produced similar results to those of the FRP-AC method, but has the additional advantage of sampling a larger area, therefore, requiring fewer samples than the FRP-AC to obtain the same sampling intensity.

All methods used to sample stems ≥11.43 cm produced relatively accurate estimates in the high density stand and may be attributed to the relatively high stem density and even distribution of stems in this stand. The QUAD method consistently produced the most efficient results for sampling larger stems (≥11.43 cm), except for the low density stand. The QUAD method can also be used to sample all stems in an area regardless of size, but produced less accurate estimates than those of the FRP-AC or FRP-HA methods when samp-ling small stems. However, the QUAD provided more accurate estimates of larger stems than did both FRP methods. The QUAD tended to be less time-efficient than the FRP methods and required the use of a transit and tape measure for accurate plot layout or a large sampling quadrat, which can be cumbersome to transport and set up in dense stands. The QUAD method requires considerable care so that stems are not counted twice.

Although the VRP method was one of the fastest methods, its use should be limited to primarily larger stems with a DBH ≥11.43 cm. The VRP method produced poor and wide ranging accuracies on smaller stems (<11.43 cm), overestimating dense stands and underestimating low-density stands. The VRP also tended to underestimate overall stem density of stems ≥11.43 cm, but estimates were a consistent percent difference across all stand densities and may be reduced if additional samples were taken.

The BT produced poor estimates on small stems, but relatively accurate estimates on larger stems. Although it can be used to sample all stems regardless of size, this method was not very time-efficient, primarily because transects must be set up and measured before sampling can begin. This method would be best suited to long transects, with the aid of a compass and a device to measure distance traveled. The BT method may be best applied in transition zones or gradients where the vegetation changes in composition and density (*6*).

The PCQ method was quite time-efficient, but was applied only to larger stems. The PCQ method tended to under-estimate actual stem density in all stands, but like the VRP, the PCQ method also maintained a consistent percent difference in observed versus estimated stem densities across all stands regardless of overall stem density. That distance techniques may give biased estimates, depending on tree spatial distributions, is an inherent disadvantage.

Shape: FRPs with a circular shape tended to produce the most accurate results on smaller stems (2.54 to 11.42 cm), especially when applied in dense, evenly distributed stands. This can be attributed to the small perimeter to area ratio in a circle; therefore, an observer is less likely to have to make a decision to tally a stem or not because it intersects the plot (*17*). Also, the rotating radius of the plot allows an observer to ensure all stems are tallied and are only tallied once. When using a large quadrat (10 m x 10 m) it is easy to miss stems or to tally them twice (*6,18*). The FRP methods or circular-plot sampling methods are quick and simple to apply in areas with low to moderate density of stems or areas with low vegetation, but become awkward in dense, shrubby communities (*6,18*). Smaller FRP or square-plot methods can be used in stands with dense vegetation (*18*).

Size: It is essential for quadrat size to be adapted to the characteristics of the vegetation being sampled (*18*). The greater the species diversity and the more heterogeneous life forms found in a community, the larger the quadrat size needed to adequately characterize the community (*18*). Regardless of shape, perimeter to area ratios decrease with an increase in quadrat size (*17*). Based on the diversity found in many forested communities and on perimeter to area ratios, larger circular plots would be most appropriate (*17*).

CONCLUSIONS

It is important for managers to know the general characteristics of the stand they are attempting to sample because no single method is efficient for sampling all stem sizes and densities. Sample procedures provide only an estimate, and this estimate may be smaller or greater than actual stem density depending on the sample method applied and stand density. Methods should be chosen that reflect unbiased estimates of density given various stand conditions and distributions.

Circular and fixed area methods, such as the FRP-AC and FRP-HA, were the most time-efficient and produced the most accurate estimates of all stems in a stand regardless of size. The QUAD produced slightly more accurate estimates of larger stems, but produced less accurate estimates of small stems and was also less time-efficient. The VRP was extremely time-efficient and produced precise estimates of larger stems, but tended to underestimate the actual number of stems. The PCQ method also produced time-efficient and precise estimates of larger stems, but underestimated actual stem density. Furthermore, the PCQ may produce biased estimates depending on stem distribution in a stand. Both the VRP and PCQ produced precise estimates, regardless of stem density; therefore, these methods are usable when the manager takes into account that the estimate obtained may be low. By calculating the appropriate sample size from a preliminary field size, estimates may be closer to the true mean and may reflect unbiased estimates of stem density when applying the VRP method.

We recommend using a combination of an FRP method and VRP method when sampling stems of all sizes in variable-density forested communities. FRP methods provide relatively accurate and time-efficient results on small stems (DBH 2.54-11.42 cm), while the VRP method is time-efficient and relatively accurate at sampling larger stems (DBH $\geq$11.43 cm). The number of samples should be based on the standard deviation or coefficient of variation of a preliminary field sample. The combination of these methods will provide accurate and time-efficient results for sampling woody species regardless of size.

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