Procedures to Handle Inventory Cluster Plots that Straddle Two or More Conditions

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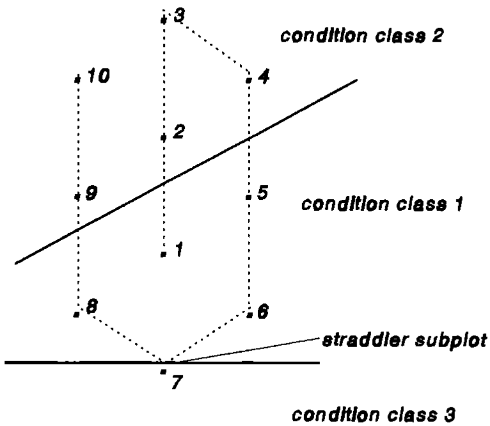
ABSTRACT. We review the relative merits and field procedures for four basic plot designs to handle forest inventory plots that straddle two or more conditions, given that subplots will not be moved. A cluster design is recommended that combines fixed-area subplots and variable-radius plot (VRP) sampling. Each subplot in a cluster consists of a large fixed-area subplot for estimating area and tallying large trees, a microplot (small fixed-area subplot) for tallying small trees, and a variable-radius plot for tallying intermediate size trees. Subplots are assigned a condition class based on a classification algorithm. For subplots that straddle conditions, boundaries are mapped for area estimation, and the condition class of each tree is recorded. For some straddler subplots, there may be insufficient trees for specific conditions to allow unambiguous classification by computer algorithm. We discuss several possible solutions for this problem. FOR. SCI. MONOGR. 31: 12–25.

ADDITIONAL KEY WORDS. Forest Inventory and Analysis, forest survey, national forest inventories, cluster sample, edge effect.

THE OBJECTIVE OF FOREST INVENTORY AND ANALYSIS (FIA) is to periodically inventory the Nation's forestland to determine its extent, condition, volume of timber, growth, and removals. FIA is a continuing endeavor of the USDA Forest Service as mandated by the Renewable Resources Research Act of 1978. Up-to-date resource information is essential to frame forest policies and programs. All FIA units use two-phase (double) sampling. Aerial photo plots are used in the first phase; and a type of cluster plot design, either plots or points or a combination of both, forms the second or ground phase. In January of 1991, Forest Inventory and Analysis (FIA) project leaders and inventory design specialists met with a panel of university and forest industry biometricians to discuss two key issues: (1) is it appropriate to move subplots within a cluster to keep them within a single condition class, and (2) how should we handle plots that straddle two or more conditions[1] (Figure 1). These issues are important because moving subplots causes estimation bias by changing the probabilities of selection for trees near condition edges, trees that commonly differ from those in the center of the condition. In a simulation study, Williams et al. (1995) found that estimation biases as high as 100% could result for populations where boundary trees differed substantially from interior trees. Bias would be especially likely for populations with much boundary such as areas with a great mix of agricultural and forestland uses or areas with significant amounts of bottomland hardwoods (ri-

[1] A committee of FIA scientists has been appointed to develop appropriate definitions and procedures for identifying condition class. Things such as state, sampling unit, and county borders, major land use change (forest/nonforest, forest/water), as well as traditional forest classifications such as forest type, stand size, and past treatment may be considered condition classification variables.



parian zones). The simplest solution to the bias problem, not moving subplots and averaging conditions including nonforest conditions across all subplots, was rejected because of resulting errors in plot classification. For example, a straddler plot with five subplots in oak and five subplots in pine can be classified as mixed oak/pine when two distinct conditions are actually present. The panel concluded that the bias resulting from moving subplots could be serious and hence unacceptable, and that the alternative practice of averaging across condition boundaries was also unacceptable.

Subsequently, the FIA project leaders decided to discontinue the practice of moving subplots. An *ad hoc* committee was appointed to address the field measurement and estimation problems and opportunities created by this decision.

ALTERNATIVES

After reviewing numerous alternatives, the committee decided to look seriously at four basic designs termed FUZZ, FOLD, FUZZ/FOLD, and FULLY MAPPED. These four designs are described in detail below. Data from folding and fuzzing field trials in California, mapping field trials in Forest Health Monitoring (FHM) studies, and FIA data indicate that 10 to 20% of all 1 ac cluster plots will straddle two or more conditions, and that approximately 10% of these will contain boundaries that occur directly on one or more of the subplots (2% of all subplots). Straddler plots can be handled by partitioning the subplots into like conditions; major problems arise only where a boundary crosses a subplot (as opposed to a boundary that occurs between subplots).

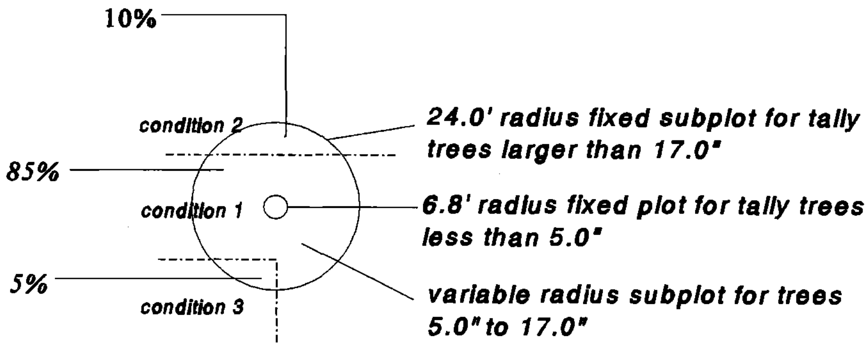
Each of the proposed designs can incorporate a combination of fixed- and variable-radius tallies similar to those currently used by all six FIA units, as well as provision for a regeneration or microplot at each subplot location. All the plot designs consist of a cluster of subplots that are always installed in a fixed pattern, regardless of land-use or condition class. The committee also considered the implications of each design if demand for statistics on nontimber forest resources increases and considered these implications in the final selection. Evaluating possible future directions for FIA, we also considered replacing the variable-plot component with a fixed plot. This design probably offers the greatest flexibility in adapting to alternative future data needs but sacrifices efficiency in volume estimation.

After considering the alternatives of flexibility and efficiency, the committee decided to recommend a method that combines fixed-area and VRP sampling. We describe this recommended design in detail and present the appropriate implementation procedures in this paper. Estimation equations are presented by Scott and Bechtold (1995); change estimation procedures are presented by Williams and Schreuder (1995).

RECOMMENDED SOLUTION

We recommend a modified mapping option (Figure 2) that permits the retention of much of the current FIA plot designs but adds condition-class mapping over each subplot:

1. Plot clusters are laid out in a predetermined and consistent manner, regardless of land class or forest condition.
2. A large fixed-radius plot is added to the FIA subplot design to serve as an outer boundary for condition mapping of the area of each subplot as well as a limit for tallying very large trees; that is, very large trees are tallied on a fixed-area plot. To retain the current distance between subplots and to ensure that subplots do not overlap, we recommend a large plot radius of 24 feet in the East. This is the limiting distance for a 17.0-inch tree, using a BAF 37.5 prism. In the Pacific Northwest, it would be reasonable to retain the currently used 17-m radius although the cluster layout used by the eastern units might be considered for the eastside inventories. For the Intermountain West, the appropriate radius would depend on inventory needs; but using one of the two proposed radii would help maintain consistency among FIA units.
3. Condition class(es) will be identified for each subplot. Condition class is defined as a land use class or a distinctive forest condition class (e.g., pine versus oak or sawtimber versus seedling and saplings). A microplot is needed at each subplot to ensure sufficient tree tally in the smaller (less than 5.0 inches dbh) size classes.



4. Condition class boundaries that intersect the perimeter of the large fixed-radius subplot are mapped. The proportion of each condition class occurring on the plot is used to estimate area by condition.
5. For each plot that straddles the boundary between two or more conditions, the proportion of subplot area that falls in each condition is determined and used to allocate the plot expansion factor. Proportion of area in each condition is computed by summing condition areas from the subplots completely or partially within the condition.
6. Very small conditions may be delineated on a subplot and may have insufficient tree tally data for accurate classification. In addition, all conditions may not share the regeneration microplot. Although this is not a real problem for population estimation because another subplot with a regeneration plot in the condition should balance the missing data condition, it may create the need for special handling when conducting plot-level analyses. But some possible solutions to this problem include:
   a. Measure additional subplots in the condition for the purpose of classification only.
   b. Enlarge the subplot to take in additional trees for use in classification only.
   c. Carry a condition class of unclassifiable in the data set.
   d. Allow the use of field crew call. This option will be necessary for nonforest conditions, where ownership is a condition class variable, and for nonstocked forest conditions.

This option offered the best compromise for (1) historical continuity, (2) ease and accuracy of classification, and (3) sampling efficiency. This design will enable FIA to eliminate concerns about edge-bias without compromising its ability to meet the present and future perceived data needs of its users. In this option the standard FIA plot design remains almost intact. Although some large trees are dropped from the sample, the number is small. An analysis of the most recent Minnesota inventory showed that less than 5% of the tally trees were over 17.0 in. in dbh. This deficiency is somewhat ameliorated by the fact that the rare extremely large tree that may be too far away and obscured by underbrush will not be in the sample and will also not be double-tallied. Current procedures maintained by the recommended design are:

1. The historical practice of tallying trees less than 5 in. in dbh (or 12.5 cm in Alaska or 17.5 cm in the Pacific Coast States) on small fixed-radius microplots (2 m radius in Alaska, 3.3 m in the Pacific Coast States, and 6.8 ft in all other areas),
2. The selection of larger trees with a prism (BAF 37.5 in the East and BAF 20, 30, or 40 or metric equivalent in the West). In the Pacific Coast States, the use of a large fixed-radius plot (17 m) around each subplot for tallying trees larger than 90 cm (17 m is the limiting distance of a 90 cm tree with a metric BAF 7) is retained.

Specifics

The minimum dbh for inclusion in the large fixed-radius plot should be large enough to ensure that most of the tally is picked up on the microplot or the VRP plot, but not so large as to exclude virtually all large trees. The appropriate radius is a function of the BAF used and the dbh of the largest trees in the inventory. In the Pacific Coast States, a 17 m radius plot coupled with a metric 7 (English 30.49) BAF accounts for only 5 to 10% of the basal area sampled. That is, trees less than 90 cm account for 90 to 95% of the basal area in the Pacific Northwest. In much of the East, trees larger than 17 in. are rare, fewer than 5% of the tally trees in Minnesota. For such areas, we suggest a 24 ft radius plot coupled with a 37.5 BAF variable-radius plot. In the West, the 17 m plot will work with a BAF 30 but is too large for use with a BAF 40. Data from eastern Oregon suggest that a 13 m radius (the limiting distance of a 73 cm tree) would be satisfactory. More work is needed to determine an appropriate large fixed-radius plot size for each geographic region and to evaluate the implications of using different plot sizes for different regions.

To implement this recommended design, a fixed cluster must be installed over the existing cluster that may include moved subplots based on the location of the original plot center (point 1). Based on data for the Arkansas Delta, about 20% of all plot clusters have subplots that have been moved since the 1960s with, on average, two to three subplots moved per cluster. This means that one out of every five plots will require the measurement of more than the currently established number of subplots: (1) new subplots for inventory and change overlaying old, unmoved, subplots; (2) new subplots for inventory replacing old moved subplots, and (3) old moved subplots remeasured for change only if desired. Data from other regions indicate similar percentages. Once adopted, the recommended design would maintain the current subplot cluster design and should maximize subplot overlay thereby minimizing additional tree tally on initial installation.

Because the land use at plot center will no longer determine the land use for the entire cluster plot, it will be necessary to visit any cluster plot that may include forestland within its boundaries. Although the total number of cluster plots actually visited on the ground will increase, the total number of forested subplots cruised should remain the same, that is, the number of forest subplots on nonforest cluster plots is expected to equal the number of nonforest subplots on forested cluster plots. Because the crews in some FIA units already check nonforest plots for proper land class, the only additional cost for those units would be establishment cost.

An additional problem may occur when a cluster plot straddles a population boundary (state, inventory unit, or an unsampled ownership) because in the double sampling design used by most FIA units, a cluster plot with its center outside the population would carry zero weight from the initial phase. We propose handling this situation by measuring only clusters with centers inside the population boundaries, including nonforest areas such as agricultural, urban, and water areas. Only those subplots inside the boundary would be sampled, but the cluster would retain its full weight from the first phase. An alternative would be to use the fuzz solution and ignore the boundary.

Many of the computational problems associated with boundaries, tracking conditions, area calculations, and tree expanders have already been worked out as part of the Forest Health Monitoring program. However, allowing multiple conditions within cluster plots does create some additional work. It may be necessary to increase subplot size or number or to rely on field personnel to subjectively determine the condition class of small conditions that have insufficient tally for the classification algorithms to work. Much of this effort can be facilitated by proper training and the use of the classification algorithms in data recorders. Plot-level data (site, slope, aspect, etc.) must be collected for each condition present on a cluster plot, although subsampling may suffice.

Simple Examples

Three simple examples illustrate the application of the recommended method. Detailed estimation equations are presented in Scott and Bechtold (1995). Suppose the plot design is a single 1/5-ac plot (no cluster). Given this design for the plot shown in Figure 2, the area assigned to each condition in a two-phase sampling design would be as follows: 10% to condition 2, 85% to condition 1, and 5%

to condition 3. In a simple case using a 10-subplot cluster design, 5 subplots may be completely in condition 1, and 5 subplots may be in condition 2. In this case, the area assigned to the plot would be split evenly between the two conditions. A more complicated situation involving three conditions is shown in Figure 3. Here subplots 1, 2, 3, 9, and 10 are completely within condition 1; subplot 4 is split 61% in condition 1, 39% in condition 2; subplot 5 is split 64% in condition 1, 36% in condition 2; subplot 6 is split 39% in condition 1, 40% in condition 2 and 21% in condition 3; subplot 7 is entirely within condition 3; and, finally, subplot 8 is split 72% in condition 1 and 28% in condition 3. This means that 73.6% [(5 * 100 + 61 + 64 + 39 + 72)/10] of the area is assigned to condition 1, 11.5% [(39 + 36 + 46)/10] is assigned to condition 2, and 14.9% [(21 + 100 + 28)/10] is assigned to condition 3.

Moved Cluster Centers

In some regions it has been the practice to move the cluster center away from a condition boundary. The Arkansas data suggest that about 5% of the moved plots

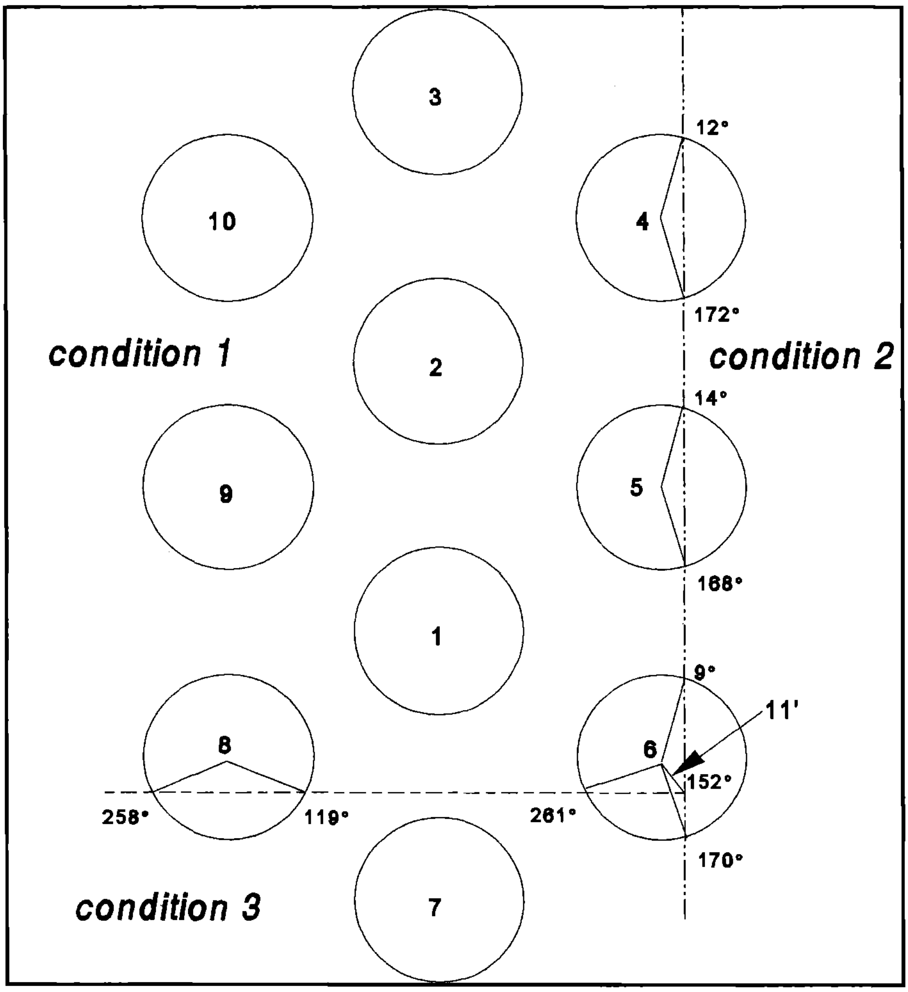


FIGURE 3. Three condition example.

involved the moving of the cluster plot center. Where the cluster center has been moved, its original location must be tracked through the tally sheets to avoid a bias toward forested subplots. When establishing the new clusters in those regions where the original cluster plot center cannot be established, it will be necessary to randomly locate cluster plots in the vicinity of the original location. Establishing the recommended design will require the establishment of new plot clusters over an entire cycle.

ALTERNATIVES NOT SELECTED

The Fuzz Design

The FUZZ design is unique in that boundaries are ignored and trees are tallied without regard to any contrasting conditions. FUZZ is incurred whenever tree tally is combined across two or more conditions and refers to the possible lack of consistency between area classifications (forest type, stand size, stand origin, etc.) and tree data. For example, a subplot located on the boundary between a pine plantation and a hardwood stand might be typed as a mixed pine-hardwood forest (Figure 4). Fuzzing results in a bias and lack of precision in area and volume classification by condition class, but is unbiased for volume estimation at the population level.

Entire plots are fuzzed when area data are collected only at one subplot (usually the cluster plot center). The high degree of fuzz incurred by mixing conditions across whole plot or plot cluster has been rejected as intolerable. A more acceptable level is produced when fuzzing is confined to individual subplots within a cluster. This requires the re-collection of area data each time a different condition class is encountered at a subplot center. In effect, this methodology recognizes boundaries *between* subplots, but ignores boundaries occurring *within* individual subplots. If a given plot contains more than one subplot center condition, the subplots occurring in each condition are tracked separately. The FUZZ design can be used with all types of tree tally-fixed-area, combination variable radius (VRP), and fixed-area plots, and VRP plots.

Advantages of the FUZZ Design

1. Field procedures are simplest in that no mapping is required. All area classifications are linked to the subplot centers.
2. Boundaries are implicitly recognized between subplots.
3. Horizontal distances to tally trees are not necessary.
4. All conditions are based on subplot centers, which technically means there are no plot

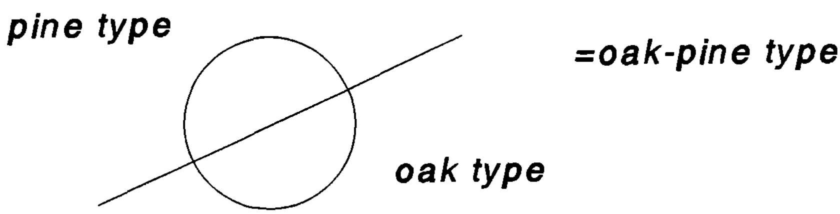


FIGURE 4. Straddler subplot—fuzz solution.

fragments that present classification difficulties or lack small-tree tally (missing microplots). In reality, these pieces still exist, but they are ignored.
5. Subplot area expanders (to population level) never have to be proportioned between two or more conditions.

Disadvantages of the FUZZ Design

1. The ability to stratify the sample by conditions is seriously compromised because data from multiple conditions cannot be extracted.
2. Mixing data from multiple conditions can result in serious classification errors, especially when the tree tally is used to derive area classifications.
3. Plot-level stand parameters can be distorted by mixed data from multiple conditions. For example, artificially low numbers of trees per acre are assigned to subplots with mixtures of forest and nonforest condition classes.
4. Trees on nonforest subplots that straddle forest conditions must be tallied to account for undersampling on forested subplots that straddle nonforest conditions. This will necessarily lead to reporting problems such as timber volume assigned to nonforest acres, and small fragments with insufficient tally to classify by algorithm (Figure 5).

THE FOLD DESIGN

The FOLD design corresponds to the tree concentric method described by Gregoire and Scott (1990). This design is also compatible with a fixed-radius plot design, a combination of fixed and VRP plots, and a VRP plot design. However, unlike some of the other designs, the FOLD design does not require the outside limits of the subplot to be defined by a large fixed-radius plot.

The FOLD plot design differs from other designs considered in that tree tally on each subplot is limited to trees falling in the same condition class as the subplot center. All other trees are ignored even though they are "in" on a fixed or VRP plot. Thus, trees are never tallied in a stand condition class that differs from the one associated with the subplot center.

The elimination of tally on nonforest subplots and in condition classes that differ from the center condition changes the probability of selection for tally trees near a boundary. The trees per acre expansion factor of each of these trees must be increased to account for the changed probability of selection. To understand how this is done, imagine a circle drawn around each tally tree (Figure 6). On a fixed plot, the radius of that circle will be the plot radius; on a VRP plot, the radius will be the limiting distance of the tree. If the circle around a tally tree is intersected

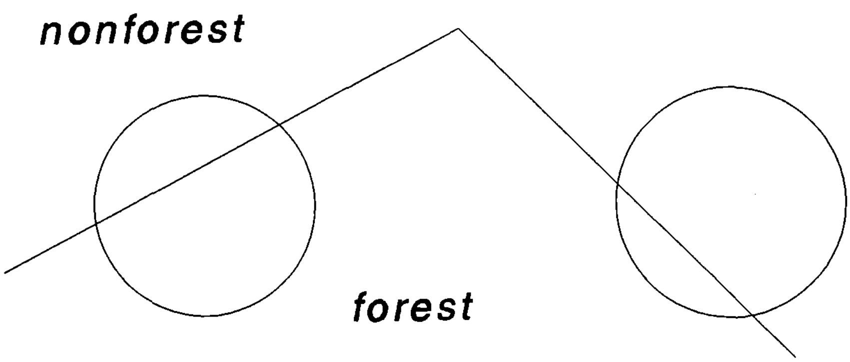


FIGURE 5. Straddler subplot—forest/nonforest.

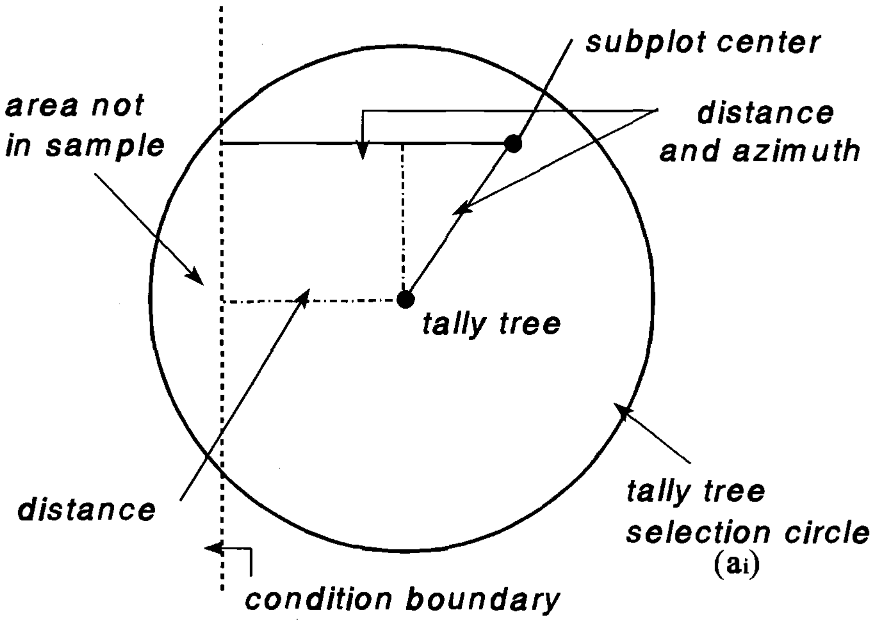


FIGURE 6. Straddler subplot—fold solution.

by a condition-class boundary, then the trees per acre expansion factor for that tree must be adjusted. The proper adjustment factor is the inverse of the proportion of the tree circle that falls in the same condition class as the tally tree, as shown in the following equation.

$$\Pi_i = \Pi_i^* \frac{a_i^*}{a_i} \tag{1}$$

where

Π_i = actual probability of selecting tree i,

Π_i^* = unadjusted probability of selecting tree i,

a_i = selection circle area for tree i,

a_i^* = new selection semicircle area

= a_i − area not in sample (see Figure 6)

Note:

w_i = correct weight for tree $i = 1/\Pi_i$,

w_i^* = unadjusted weight for tree $i = 1/\Pi_i^*$

The only measurements needed to compute the probabilities Π_i are the perpendicular distance and azimuth from subplot center to the boundary (or boundaries) and the distance and azimuth from subplot center to the tally tree (Figure 6). It should be noted that the method suggested here is correcting the tree circle area even though tree-border distance is not directly measured.

Advantages of the FOLD Design

1. No tree tally or mapping is required on subplots with nonforest centers.
2. If the microplot center coincides with the subplot center, microplot tally is available for all subplots, simplifying area-classification. For some other designs considered, small plot fragments that lack small tree tally (no microplot present) may preclude the use of plot tally to determine area classes.
3. Classification is straightforward in that it is based solely on trees from a single condition class. This is the only design where photo class corresponds exactly with ground class.
4. Reporting is straightforward in that tree volume is never associated with a nonforest-land class or assigned to the wrong condition.
5. Each subplot samples a single condition. There are no subplot fragments to present classification difficulties.
6. Subplot area expanders (to population level) never have to be proportioned between two or more conditions.

Disadvantages of the FOLD Design

1. More plots and subplots are affected by boundaries than in other designs. The probability of selection for a tree is affected by a condition boundary less than twice the subplot radius away from the tree. For the other designs, only the boundaries that intersect the subplot boundary influence data collection.
2. Field errors in boundary identification and placement are more serious in the FOLD design than in alternative designs because (a) boundaries that are distant from plot center may be missed; (b) imprecise boundary location affects tree expansion. (On other designs, the boundary placement affects tree classification but not tree expansion.)
3. Easily obtainable tree data may not be collected for trees in a condition that differs from that at the subplot center.
4. Horizontal distances to tally trees and boundaries are required on FOLD subplots.
5. Change analysis may be confusing on FOLD subplots—particularly when condition-class boundaries change between inventories.
6. Field crews must map any condition boundary that is within the limiting distance of the largest tally tree. More condition boundaries will be mapped for this design than for any of the other alternatives.

THE FOLD/FUZZ COMBINATION

As the title implies, the FOLD/FUZZ combination incorporates elements of both the FOLD and FUZZ designs. As in the FUZZ option, contrasting forest conditions in this design are fuzzed (mixed) on individual subplots. Unlike the FUZZ design, however, forested condition classes in this design are never mixed with nonforest condition classes. Instead, subplots with forested center conditions are folded along boundaries with nonforestland uses. The general idea behind the FOLD/FUZZ combination is to keep field procedures as simple as possible without having to visit or assign volume to subplots that have a nonforest center condition. The FOLD/FUZZ design is compatible with the fixed, combination VRP/fixed, and VRP plot types.

Advantages of the FOLD/FUZZ Combination

1. On subplots with nonforest centers, no tree tally or mapping is required.
2. On subplots with forested centers, field crews are not required to define boundaries between forest conditions.
3. Boundaries between forest conditions are implicitly recognized between subplots.
4. No timber volume is assigned to nonforest condition classes.

5. All conditions are based on subplot centers, which technically means there are no plot fragments that present classification difficulties or lack small-tree tally (missing microplots). In reality, these pieces still exist, but they are simply ignored by mixing them with the subplot center condition.
6. Subplot area classification expanders never have to be proportioned between two or more conditions.

Disadvantages of the FOLD/FUZZ Combination

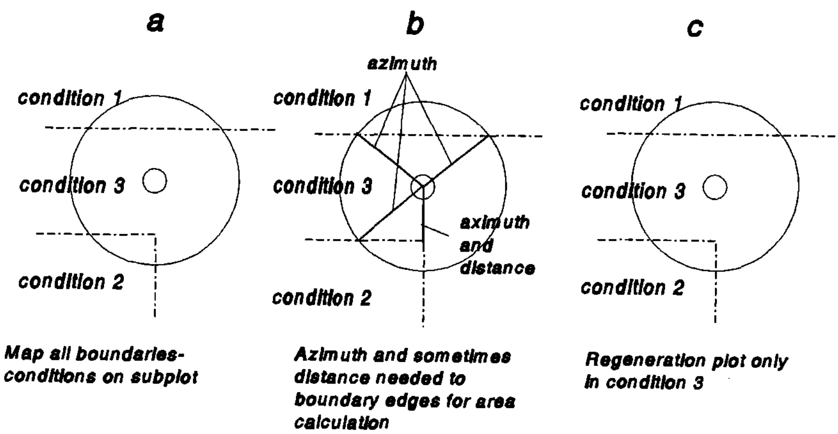
1. The ability to stratify the sample by conditions is seriously biased because data from multiple forest conditions cannot be extracted.
2. Mixing data from multiple conditions can result in serious classification bias, especially when the tree tally is used to derive area classifications.
3. Field crews must map boundaries between forest and nonforest conditions on subplots with forested centers.
4. Horizontal distances to tally trees and boundaries are required on forested subplots with nonforest conditions.
5. Field errors in forest/nonforest boundary placement have serious implications for the same reasons described in the FOLD design. That is, distant boundaries may be missed and imprecise boundary location affects tree expansion.
6. Boundary changes can complicate change analysis on FOLD subplots.

THE FULLY MAPPED DESIGN

In this approach, called the FULLY MAPPED design (Figure 7), the areas of all conditions on a straddler subplot are mapped and their respective tally trees identified. The plot area expander is proportioned in accordance with the proportion of the mapped area that falls in each condition sampled, as determined by mapping. Trees per acre expanders are a function of subplot size (fixed-area sampling) and are not affected by the proximity of a condition-class boundary.

Advantages of the FULLY MAPPED Design

1. Tree per acre expanders remain constant over time as long as plot size remains constant and do not need to be adjusted, tree-by-tree, for distance to a condition boundary.
2. Because tree per acre expanders do not depend on boundary location, boundary delineation is less critical than in the FOLD or FOLD/FUZZ design.



3. Boundaries are not restricted to straight lines and do not have a maximum number. However, a limit of two straight lines to describe a boundary that intersects a subplot is a practical one imposed by field operations and computer estimation procedures.
4. Data collection is more cost-effective than for the folded designs because the entire subplot is used to collect data.
5. There is no averaging of data across conditions.
6. Because the probabilities of selection do not change, change estimation is simple.
7. Both area estimation and volume estimation by condition classes are unbiased and efficient.
8. Data are obtained on boundary lengths between conditions.
9. The FULLY MAPPED design offers greatest flexibility for obtaining nontimber data. This design would allow varying data collection designs from the complete enumeration of fixed-area plots to multiple mill-acre quadrats.

Disadvantages of the FULLY MAPPED Design

1. More boundary information is needed when boundaries intersect the subplot. The measurements needed are the azimuth from plot center to the points where the boundary (or boundaries) intersect the subplot edge and the distance and azimuth from subplot center to any corners in the boundaries.
2. On subplots that straddle boundaries, the proportion of each subplot located in each condition must be calculated. The accuracy with which the area expander is proportioned between conditions is dependent on the accuracy of boundary placement.
3. Very small conditions may be delineated on a subplot and may have insufficient tree tally data for accurate classification. In addition, all conditions may not share the regeneration microplot. Although this is not a real problem for population estimation because another subplot with a regeneration plot in the condition should balance the missing data condition, it can create the need for special handling when conducting plot-level analyses.
4. There is a slight chance, even at the population level, of having condition area without associated regeneration tally.

The mapping option is best suited to the use of fixed-area plots. In fact, the use of mapping with variable-radius subplots is potentially complicated because the size of the area that needs to be mapped depends on the size of the largest tally tree, and it will change over time. With fixed-area plots, the mapped area is limited to a predetermined fixed size. Each tally tree is then associated with one mapped condition within the fixed area. In addition, with fixed-area plots the tree tally is larger and classification problems due to insufficient tally should be less frequent. Fixed-area plots are also perceived to be better for change detection, modeling uses, and nontraditional FIA data uses. They are also conceptually easier to explain to users.

However, one of the biggest disadvantages of the fixed-area plot design is the number of trees that must be tallied if cluster size and/or plot area are not changed. Most of the cost associated with subplot establishment can be attributed to the number of trees tallied per subplot. A straight switch to fixed-area plots would undoubtedly increase the cost of plot establishment and slow the inventory cycle. With the increased tree tally on fixed-area plots, the number of subplots per cluster or subplot size could be reduced to compensate for the extra costs and result in a more extensive tree tally for the same cost. Past studies of desirable fixed-plot designs have resulted in the Forest Health Monitoring design (Bechtold et al. 1992). This design is a radical change from the current 5- or 10-subplot cluster; and its adoption could result in the loss of some historical tree remeasurement data or require the remeasurement of old plots while new plots are installed, a significant added cost. In addition, it is still not known how large a sample is needed for plot/condition classification.

FIELD EXPERIENCE

To determine the feasibility of the proposed design, the staff of the Forest Inventory and Analysis unit at the North Central Forest Experiment Station wrote a field manual and data recorder program that implement the design. Field crews have installed the design at approximately 100 locations in the course of the regular inventory. The crews have reported no problems and have indicated that they prefer it to the previous design. The only added expense encountered has been when remeasuring previously moved subplots. Some reviewers of this design have indicated there may be problems maintaining repeatability of condition-class boundaries. This problem has been addressed at the North Central FIA by requiring that a condition-class boundary be visible on aerial photography and that transition zones be included with the condition at subplot center.

A version of the recommended design was also implemented in 1991 in northern California where 750 to 800 plots were installed using this design. Field personnel have reported that this design is easier to lay out and that it removes the personal bias encountered in moving subplots. The field supervisor reported that using the new design uncovered several cases where points had been incorrectly moved and/or the cluster center had been incorrectly classified due to incorrect movement. By incorrectly moved we mean that as far as can be determined the field procedures in effect had not been correctly applied. On the negative side, personnel report that recording data by condition class is more complex and requires more training.

SUMMARY

We examined four of many possible plot designs for FIA inventories. None of the designs is perfect, but we are able to recommend a design that is a variation of a fully mapped design that can accommodate FIA's need for historical continuity and practical field procedures. One of our recommendations, the addition of conditions within plots, will add another dimension to existing databases. However, we should emphasize that additional condition data will also help refine our estimates of condition area (forest type, stand size, etc.) and improve our estimates of land clearing and reversion rates, the two largest sources of unexplained variation in our growth, removals, and mortality procedures. The precision of area-change estimation is improved because only the changed portion of a cluster plot is assigned to a condition that actually changes rather than having the entire cluster plot assigned to either a changed or unchanged condition.

Overall, by eliminating the bias due to subplot moving and the misclassification due to averaging conditions, the recommended procedure will improve reliability of final statistics, meet our users' needs, and maintain much historical integrity which will enhance FIA credibility.

Finally, if cost and consistency were not factors, we would recommend a totally fixed-plot design combined with mapping of condition classes.

LITERATURE CITED

BECHTOLD, W.A., V.J. LABAU, W. MCLAIN, and P. ROGERS. 1992. Site classification, growth, and regeneration. *In* Forest health monitoring field methods guide (national guide), Conkling, B.L., and G.E. Byers (eds.). U.S. Environmental Protection Agency, Office of Research and Development, internal rep. Research Triangle Park, NC. 434 p.

GREGOIRE, T.G., and C.T. SCOTT. 1990. Sampling at the stand boundary: A comparison of the statistical performance among eight methods. P. 78–85 *in* Research in Forest Inventory, Monitoring, Growth and Yield. IUFRO World Congress, Virginia Polytechnic Inst. and State Univ., Blacksburg, VA, Publ. FWS-3-90.

SCOTT, C.T., and W.A. BECHTOLD. 1994. Techniques and computations for mapping plot clusters that straddle stand boundaries. For. Sci. Monogr. 31:46–61.

WILLIAMS, M., and H.T. SCHREUDER. 1995. Change estimation for the fully mapped design used by FIA and FHM and simulation results for estimation and change estimation. For. Sci. Monogr. 31:26–45.

WILLIAMS, M., H.T. SCHREUDER, and R. REICH. 1994. The extent of bias caused by substituting points in forest survey—a simulation study. USDA For. Serv. Res. Pap. RM-00. in prep.

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