PROS AND CONS OF THE INTERPENETRATING PANEL DESIGN

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ABSTRACT.—The interpenetrating sample design has been selected for the USDA Forest Service's Annual Forest Inventory System. The advantages and disadvantages of this design are discussed by considering alternatives such as the formerly used periodic design, a concentrated grid design, and disturbance based sampling. Factors considered for each design include fulfilling 1998 Farm Bill requirements, relative cost, ease of implementation, and analysis options. Each design alternative has positive and negative attributes, but the interpenetrating design most clearly facilitates implementation of the new annual inventory system.

INTRODUCTION

A survey designer has an array of choices to confront when deciding how samples will be allocated in the field. Sample allocation also affects the options for analyzing the data. Survey design involves both of these choices, but the emphasis here will be on the sample allocation aspect.

Sample allocation decisions for USDA Forest Service Forest Inventory and Analysis (FIA) surveys must take into account the public-use nature of FIA data. First and foremost, the data should be amenable to standard analyses. Sample allocation should lead to robust data in the sense that the data are not optimized only for a limited purpose. For example, the data should not be collected in such a way that they are optimal for estimating forest growth but inadequate for estimating current volume by species. Unfortunately, it is inevitable that a design to optimize for variable A leads to suboptimality for variable B.

With the above factors in mind, FIA selected the interpenetrating design for the annual forest inventory system. This design allocates field plots to five panels that each provide systematic coverage for a state or any other region of interest. The systematic coverage implies that no variable is favored at the expense of another, and a number of analysis methods are valid.

SAMPLE DESIGN ALTERNATIVES

Each of four design alternatives will be discussed, followed by a section that suggests minor modifications to improve the interpenetrating (INT) design. The old FIA periodic (PER) design, which is being phased out, is discussed first. The INT and PER designs weight all plots equally, and both lend themselves to simple analysis options. The concentrated grid (CON) design can be viewed as a hybrid of INT and PER. A CON design would divide each state into five regions, and one region would be measured each year. The fourth design being considered is disturbance based sampling (DIS), which results in an annual system where disturbed plots are sampled with higher probability than undisturbed plots. As such, the DIS design is the only one that attempts to optimize for certain characteristics.

Periodic Design

FIA has employed the periodic design since the program began in the 1930s. Ideally, under the PER design, all plots in a state are measured in the same year. In practice, it may take 3 or 4 years to complete large, heavily forested states like Georgia or Maine. This design puts all of FIA's attention on the current few states where field work is underway. It provides a snapshot of the state that has maximum accuracy immediately following the field work and then deteriorates over the years until the next measurements are available. Estimates are derived under the PER design by averaging over all the data, which implicitly assumes that all plots were measured at the same time. The periodic system worked well for the first 50 years of FIA's existence, but began drawing criticism around 1990 primarily because the survey cycle was too long.

The first Blue Ribbon Panel report (American Forest Council 1992) (BRP I) did not call for dismantling the PER design, but requested reduction of the survey cycle from 10 years to 5 years. Some progress was made on this, but flat budgets and increasing demands on FIA ultimately caused the cycle to become longer than ever.

Some of the positive aspects of this design are:

- The design can be funded on a 5-year cycle.
- This design maintains the status quo so no other changes are required.
- Simple analysis options are available.

Some negative aspects of this design are:

- Attempts to improve timeliness under this design following BRP I failed.
- Budgets and activities within a state fluctuate wildly over time.
- Cross-state analysis is difficult because adjacent states are measured in different years.

Interpenetrating Design

The INT design was originally developed for the Southern Annual Forest Inventory System (SAFIS) pilot study, which began in 1995. The INT design is similar to the National Forest Health Monitoring design and calls for annual measurement of panels that consist of plots that systematically cover the region of interest. This design appealed to many southern state foresters who consequently supported SAFIS. The INT design made SAFIS somewhat compatible with the original Annual Forest Inventory System (AFIS) pilot study that began in the Lake States in 1992. The use of different designs for AFIS and SAFIS gave FIA the opportunity to study two alternative ways of "going annual." AFIS used the DIS design discussed below.

The same plots used for the PER design, laid out on the national FIA grid, are used for the INT design with minor exceptions. The annual panels for the INT design consist of roughly equal numbers of plots that are systematically distributed over the FIA grid for each panel. Therefore, data from an annual panel could be analyzed using methods used for the PER design. However, the precision of the estimates obtained from a single INT panel would be less than that obtained from the full PER sample. Alternative estimation procedures (Reams and Van Deusen 1999) that use data from previously measured panels can significantly improve INT design precision. Multiple imputation (Rubin 1987, Van Deusen 1997), which involves updating unmeasured plots with models or database matching, is one viable option. A moving average estimator can also incorporate measurements from all panels without complications due to updating.

The second Blue Ribbon Panel report (American Forest and Paper Association 1998) (BRP II) concluded that FIA should move to an annual INT design that would measure 20 percent of the plots in a state annually. Subsequently, the 1998 Farm Bill mandated that FIA adopt the INT design and produce a strategic plan (USDA Forest Service 1999) for implementation.

Some of the positive aspects of this design relative to the PER design are:

- It meets the 1998 Farm Bill requirements.
- Cross-state analyses are temporally consistent.
- Budgets don't fluctuate annually by state.
- The data can be analyzed by a number of approaches.
- The States are move involved.
- New computer programs will be developed for data management and analysis.

Some negative aspects of this design relative to the PER design are:

- Longer travel time between plots is required.
- The precision is lower in any given year.
- New software for data management and analysis is required
- Requirement of more state involvement could be problematic.

Disturbance Design

The disturbance sampling design (DIS) was developed for the AFIS pilot study in the Lake States. This design allocates sampling effort to plots with probability proportional to disturbance. The design called for measuring all disturbed plots each year and then taking a random or systematic sample of undisturbed plots. Disturbance would be detected via remote sensing. This design would be very good for determining the amount and impact of disturbance, but it leads to more complicated analysis options than either the INT or PER designs. Any analysis would have to differentiate between plots that were measured because they were disturbed versus the randomly chosen undisturbed plots. Proponents feel that the DIS design could be more economical to implement than a rigid INT design where 20 percent of the plots are measured each year.

The DIS design depends strongly on remote sensing to detect disturbance. This capability is available for Minnesota courtesy of the state Department of Natural Resources, but not necessarily for other states. The DIS design also depends on models to make predictions for unmeasured, undisturbed plots. However, it is statistically problematic to incorporate modeled plots that are selected with a different probability than the measured disturbed plots. One must account for the fact that models predict expected plot means rather than individual plot values. Therefore, treating modeled predictions like actual measurements leads to understating the true variance. Multiple imputation (Rubin 1987) is one way to incorporate variance into the process and to use models in a valid manor. This approach requires making several predictions for each plot and incorporating variability into the predictions. However, the systematically different handling of disturbed and undisturbed plots under the DIS design complicates the use of multiple imputation. In effect, the DIS design creates two strata: a disturbance stratum and a non-disturbance stratum. The complications arise, in part, because these strata change each year (Van Deusen 1993). Resulting change estimates will involve plots that were measured with probabilities and stratum that change over time. Incorporating modeled estimates under the INT design is much easier, specifically because of the equal probability (systematic) plot selection process.

Some of the positive aspects of this design relative to the INT design are:

- It can be very economical.
- Sampling is optimized for disturbed areas.
- It uses remote sensing to improve sampling efficiency.

Some negative aspects of this design relative to the INT design are:

- Statistical analysis is difficult.
- It is optimal for disturbance, but sub-optimal for growth.
- It depends on remote sensing to detect disturbance.
- It depends on models.

Concentrated Grid Design

The concentrated grid (CON) design has been proposed as a compromise between the INT and PER designs. A CON design calls for measuring an equal portion of the plots each year by dividing each state into five concentrated zones. In this way, annual measurements would be taking place in each state, but each within-state zone would be under a periodic survey. The CON design is very similar to the PER design, which divided states into survey units that were usually measured one at a time. Some would argue that it also meets the Farm Bill requirements, even though it circumvents the spirit of the Farm Bill. The CON design might also allow for reduced travel costs relative to the INT design. The CON design would make it difficult to produce state-level reports because plots in different parts of the state are measured in different years.

Some of the positive aspects of this design relative to the INT design are:

- It may meet the Farm Bill requirements.
- Travel costs could be lower.
- Precision for sub-regions is higher for a given year.
- It is similar to the PER design and therefore involves less change.

Some negative aspects of this design relative to the INT design are:

- It may not meet the spirit of the Farm Bill.
- It makes cross-region analyses difficult.
- It is more periodic than annual in nature.

MODIFICATIONS TO THE INTERPENETRATING PANEL DESIGN

The INT panel design has been chosen for the new annual forest inventory system being implemented by FIA. Alternative designs are of academic interest, but FIA has already made substantial commitment to the INT design. While the INT design has many desirable attributes, it has some aspects that can be legitimately criticized. The purpose of this section is to suggest minor modifications to the standard INT design to rectify limitations that it can impose on analysis and logistics options.

Strict adherence to the INT design would eventually lead to having only 5-year growth intervals in the database. However, estimates will be made annually, which implies that the INT design is not design unbiased. In other words, estimates from a rigid INT design for intervals other than 5 years would depend on models/assumptions. Fluctuating budgets and special surveys may create additional problems with a rigid INT design. For example, it would be difficult to measure 20 percent of the plots annually in a year when the budget is reduced. It would be equally problematic to measure more than 20 percent of the plots in a budget increase year without deviating from the basic design. However, a simple alteration to the basic INT design can alleviate these problems.

Consider the possibility of creating small clusters of adjacent plots. Each cluster would contain one plot for each panel being maintained under the INT design. For example, the basic design that meets Farm Bill requirements has five panels, so each cluster would have five plots (fig. 1). Panel assignments could be rotated within clusters at periodic intervals as a simple way to obtain design unbiasedness. Thus, the plots change panel membership on a periodic basis. This ensures that a mix of growth intervals is always being measured.

The second problem with the basic INT design can be alleviated by creating "extra" panels, preferably in increments of five (fig. 2). If there were 10 panels, for example, it would still be possible to measure 20 percent of the plots each year by measuring two panels. Measuring 3 of 15 or 4 of 20 panels would also work. Extra panels become advantageous when the need arises to deviate from annually measuring 20 percent of the plots. If the budget decreases under a 15-panel system, one can drop back to measuring either one or two panels rather than the usual three per year. Alternatively, the number of panels can be increased in a good budget year.

The extra panel approach adds flexibility to the basic INT design, so that fluctuating budgets or special surveys can be seamlessly accommodated. Rotation of within cluster plot-to-panel

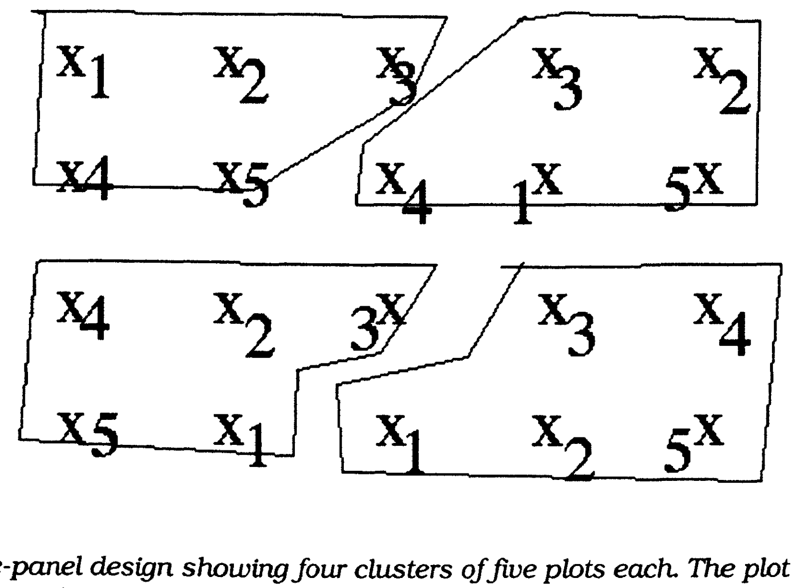

Figure 1.—*A five-panel design showing four clusters of five plots each. The plot location is represented by an x. The panel assignment is given by the number next to the plot.*

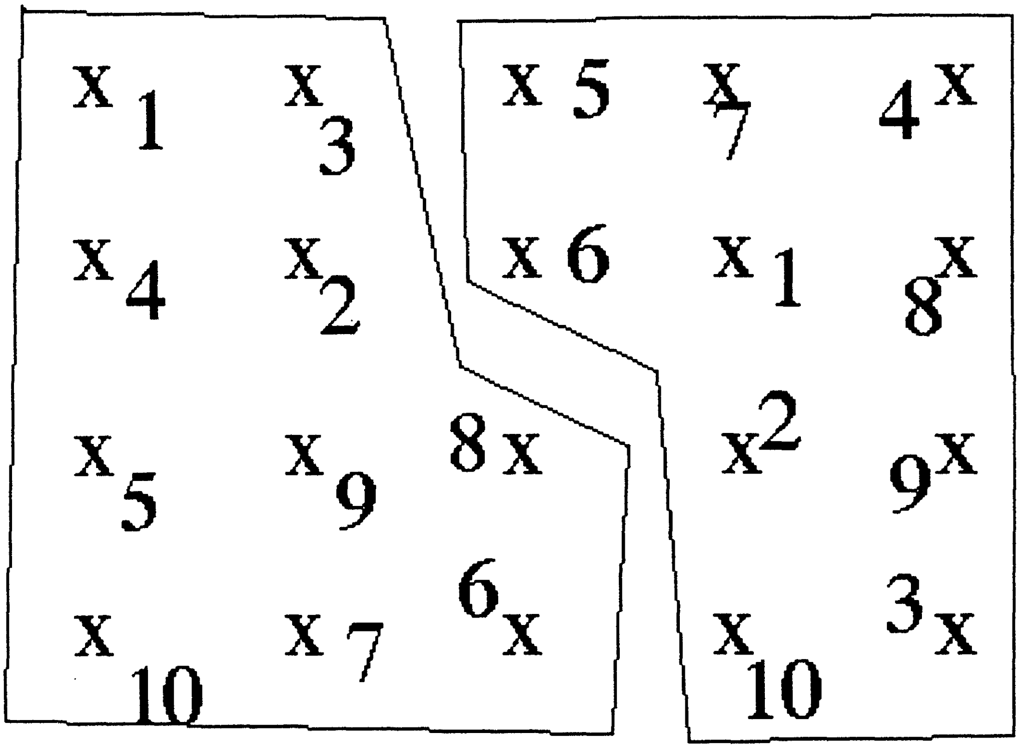

Figure 2.—*A 10-panel design showing four clusters of 10 plots each.*

assignments allows for a range of measurement intervals to be present in the database. This adds the desirable feature of design unbiasedness to the resulting estimates and can work within the context of extra panels. These ideas are discussed in somewhat more detail in Van Deusen (2000).

SUMMARY

Four sampling designs that could be used by FIA have been briefly discussed, with emphasis on the INT design that has already been selected for the new annual forest inventory system. All designs could operate with plots laid out on the national FIA grid using traditional field procedures. Recent changes made to FIA plot configuration and measurements were not required for the annual inventory system. For example, the decision to change from variable radius plots to fixed area plots with mapping (Scott and Bechtold 1995) was made prior to the 1998 Farm Bill. Current plans also call for fitting FIA field plot locations to a triangular grid (Roesch and Reams 1999). This will result in equal plot intensity nationally and will facilitate formation of five panels for the INT design.

Analysis options for either the PER, INT, or CON designs have much overlap because all use systematic, equal-probability sampling. The DIS design selects disturbed and undisturbed plots with different probabilities, and depends on remote sensing and models to be effective. The remote sensing and modeling capabilities required for the DIS design are not available at this time in each state, which precludes the use of this design at the national level. However, the advantages that can accrue from modeling and remote sensing can also be realized under the INT design. The INT design does not require models or remote sensing to be effective, but they can be used if available. The INT design can use models within the context of a procedure like multiple imputation to improve the precision of estimates and obtain valid confidence intervals. Therefore, the choice of the INT design by FIA is a prudent one.

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