SAFIS DESIGN AND ESTIMATION TECHNIQUES

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ABSTRACT. To address the uncertainty of forest sustainability in the South, the Southern Forest Inventory and Analysis (FIA) program has initiated an annual surve!; system. Currently there are eight out of the thirteen southern states involved with annual forest surveys. The Southern Annual Forest Inventory System (SAFIS) sample design consists of five interpenetrating annual survey panels with no annual or multi-year overlap. In the transition period from periodic design to full implementation of the annual five-panel design, a number of analysis options are possible. Some options that have been considered include: (1) produce estimates based only on those plots measured each year; (2) average the new panel information with the previous periodic information using moving average models: (3) complete the first two or more annual panels (at least 40% percent of all FIA plots) before reporting current inventory information. These different options are being planned for because some states moved from to an annual survey immediately after completion of a periodic survey, while others moved from a periodic to annual survey with five or more years elapsed between surveys of any kind. The design and analysis concepts of SAFIS will be presented and discussed.

1 INTRODUCTION

The new Southern Annual Forest Inventory System (SAFIS) is being implemented to address state, regional, and national questions regarding past, current, and projected changes in the southern forests. The motivation to move from a periodic system to an annual system is related to several old and new resource information challenges. First, there are mounting questions regarding the sustainability of forestry in the South. Changes in the management of public lands have significantly reduced the level of timber harvest on national forest lands (USDA-FS 1998). Timber removals in the South are projected to increase sharply over the next several decades in response to harvest reductions on western public lands (USDA-FS 1995). Current analyses of southern timber projections indicate that for some regions in the South, timber removals exceed growth (Cubbage et al. 1995). After many decades of sustained inventory growth, southern inventories have leveled off. Increases in inventories are doubtful given the changing demographics and rapid urbanization of several historically important timber-producing regions.

To address the uncertainty of forest sustainability in the South, the American Forest & Paper Association (AF&PA), Southern State Foresters, and the Southern Governor's Association have recognized the need for a continuous forest inventory system. In response to this need, the AF&PA was instrumental in convening the second blue ribbon panel (BRP II) on FIA in October 1997. Key recommendations of BRP II include elevating the priority of the FIA program within the Forest Service, initiating annual inventories, reporting on all forestlands, and exploring partnerships for the delivery of the program (AF&PA 1998). Since BRP'II, the Southern State Foresters and the USDA Forest Service have collaboratively phased implementation of an annual forest inventory throughout the South.

The initiation of SAFIS is an acknowledgement that the need for current information on changes in southern forests has never been greater. The need for maintaining current inventory information nationwide is evidenced by the Agricultural Research, Extension and Educational Reform Act of the Farm Bill of 1998, which congressionally mandates FIA to implement an annual inventory nationwide.

In addition to questions of sustainability, the move toward national implementation of an annual forest survey has gained significant justification over the last several years. Annualized inventory systems fill the needs of integrated assessments that rely on the best and most current data for identifying trends, relating trends to likely or suspected causes and consequences, and providing possible outcomes of alternative actions.

Regional assessments of resource trends have proved difficult under the traditional periodic survey system. Using the periodic system it takes 10 to 12 years to inventory the entire South, because the survey is implemented on a state-by-state basis. This approach can lead to the undesirable circumstance of bordering states having data that varies in age by a decade or more. Public users of southern FIA data have noted that these data are accurate for two or three years but become increasingly unreliable over time. With rapid changes in the status and conditions of forestlands in the South, this system is inadequate. in addition, this system makes it difficult to observe trends, because plots can be remeasured at intervals of up to 12 years. In those cases it is entirely possible that important changes and trends are either missed or documented many years after they occur. which deprives decisionmakers the opportunity to implement changes in management or policies.

There are benefits and costs associated with an annualized inventory system. Some of the benefits include current and uniform information across all states owing to a continuous and seamless sampling program that provides annualized monitoring of important resource trends across the entire South. Because identical sampling and modeling efforts are performed each year, catastrophic events such as hurricanes and insect and disease epidemics can be observed and accounted for on an annual basis. The greatest benefit is that SAFIS provides data and methods for producing annual estimates.

On the cost side, compared to the past periodic system, SAFIS requires additional resources. In the periodic system, it takes an average of two years to collect the survey information for a state. Before SAFIS, the Southern FIA program worked in two out of 13 states at any point in time. Under the periodic survey paradigm about 8.3 percent of the plots in the South were measured in comparison to 20 percent as mandated by the Farm Bill. Additional resources are required to ensure the quality of the survey process, manage data, perform statistical analyses, and publish reports.

2 DESIGN OF SAFIS

A dominant consideration in planning a long-term inventory and monitoring program is the inevitability that a highly efficient sample design, one that optimizes on one or very few resources of interest, will go out of date. The use of stratification and variable probability of selection based on volume or value per unit area are good examples. Design features that involve complex sample structure create potentially serious difficulties, whereas an equal probability design permits greater adaptability and flexibility. To minimize sample design obsolescence, structure should be employed sparingly and with awareness of its undesirable effects; variable probability sampling designs and other complex sampling schemes are less amenable to the multiple and changing objectives that long-term monitoring programs must address, and therefore should be avoided (Overton and Stehman 1996).

Simplicity is desirable for many reasons. There is growing recognition that data collected from federally funded monitoring programs should be accessible to the public at large (Cowling 1992). With a relatively simple sample design, it is more likely that valid results and conclusions can be reached by various public users of the FIA database.

The simplicity and resiliency needs of the Southern FIA program have resulted in the use of an equal probability systematic sample design (Roesch and Reams 1999). This interpenetrating design uses five annual panels, whereby plots measured in year (panel) 1 will be remeasured in year 6. In this mode of operation the survey cycle will always be one year, and the plot cycle will be five years. If funding difficulties occur it is likely that a smaller proportion of the plots will be measured each year.

In the transition period from periodic design to full implementation of the annual five-panel design, the following options for analysis and reporting are being considered: (1) produce estimates based only on those plots measured each year; (2) average the new panel of plots with the previous periodic information using a moving average model; (3) complete the first two or more panels (at least 40 percent of all FIA plots) before reporting current inventory information. These options are being considered because circumstances may dictate the reporting of information before completion of all five panels (Reams and Roesch 1999).

Option 1 above, where only the most current panel information is used for statistical estimates is a reasonable alternative for state level statistics and for a minimal number of post-stratification schemes. Estimates by FIA under option 1 will rely on simple random sampling (srs) theory to provide population estimates for an individual panel.

Under option 1, consider Y_j to be the value of the y variable for thejth population element: in FIA's design, this is a ground plot of approximately 1/6 acre. The mean is,

$$\bar{y} = \frac{\bar{y}}{n} = \frac{1}{n} \sum_{j}^{n} y_j$$

and the variance is

$$\operatorname{var}(\bar{y}) = (1 - f)\frac{s^2}{n},$$

where

$$s^2 = \frac{1}{n-1} \sum_{j}^{n} \left(y_j - \bar{y}\right)^2$$

and $f = n / N$.

Option 2 and 3 under SAFIS will rely on the moving or weighted average. After full implementation of SAFIS users will most likely want to use data from all five annual panels. Some users of FIA data have suggested that it makes sense to emphasize the freshest data in the estimation of population statistics. Clearly 4- and 5-year-old panels contain information that is more valuable than no data at all, but these data are clearly dated and less reflective of current values than the most recent panels. This suggests that using a simple moving average model for the sample mean could serve those who want to weight equally and those who prefer to weight panels as they deem appropriate. The moving average sample mean is,

$$\bar{y}_w = \sum_{p=1}^{5} W_p \bar{y}_p.$$

where $\Sigma W_p = 1$ and $\bar{y}_w$ equal to the sum of thep panel sample means $\bar{y}_p$. The sample mean is obtained seperately and independently for each panel, and it is then multiplied by the weight of the panel. The products are summed over the p panels to obtain the weighted sample mean. The variance of this weighted mean is obtained by combining the separate variances of the panel means. The variance of each panel mean is multiplied by the square of the panel weight and the products are summed over the p panels, i.e.,

$$\mathrm{var}(\bar{y}_w) = \sum W_p^2 \,\mathrm{var}(\bar{y}_p) .$$

Weights are frequently chosen to represent the proportions of the population elements in each panel with $W_h = N_h/N$. These are the weights advocated by Southern FIA, however this does not preclude the use of other weighting schemes, either by FIA or public users of the data. For users that may want to emphasize the most recent panels (plots) several obvious weights are 0.4, 0.3, 0.2, 0.05, 0.05: 0.4, 0.1. 0.2, 0.1, 0.1; 0.3, 0.3, 0.2, 0.1, 0.1, and there are many other combinations that sum to 1. The long-standing periodic forest inventory system within Southern FIA most often collects current cycle data over a 2- or 3-year period per state. Equal weighting is applied to all plots in estimating population statistics and, if this precedent were followed, would suggest a weighting scheme of 0.2, 0.2. 0.2, 0.2. 0.2, i.e., equal weighting.

Once the new rotating panel design has been fully implemented, the increased flexibility in inventory estimation techniques will be realized. Several approaches have been presented by the scientific community and are under investigation by FIA scientists and the external users of FIA information (Van Deusen 1996a; Reams and McCollum in press; McRoberts et al. 1999, Reams and Van Deusen 1999). Some of the methods can be implemented immediately, and several others will need further research and pilot testing before implementation is considered.

New design features give rise to different and improved methods of analyses. However, new-estimation methods usually undergo both a research and a user group development and phasing period. Annualized estimates that are most similar to the periodic system estimates will provide the foundation of first-generation annual inventory estimates (Roesch and Reams 1999). First-generation estimates will be moving average models. Because inventory estimates will be based on the five-year moving average. the preceived danger of mistaking fluctuations in estimates of inventory because of random sampling with real change is minimized. Based on a minimum number of assumptions, moving average methods have been shown to be identical to estimates used by FIA under the periodic system (Reams and Van Deusen 1999). Second-generation estimates will use tree- and plot-level modeling and other model-based updating techniques such as time series models, mixed estimation and possibly Bayesian models.

Some of the specific model formulations for future second-generation estimates for SAFIS follow. All prior options for inventory estimation assume that no serial correlation exists between obsenations. This is not a true reflection of our sample because all panels will be remeasured very 5 years. There is also a desire to combine modeled (updated) plots with measured plots. There are a number of time series models and assumptions that can be used to improve the efficiency of our estimates. In particular the mixed estimator (Theil 197 1) has be suggested (Van Deusen 1996b) for this application.

For mixed estimation, Van Deusen (1996b) suggested the following model is justified for a systematic sampling analysis assuming the population is in random order (Cochran 1977):

$$\bar{y}_t = \mu_t + \bar{e}_t, t = 1,\ldots, T,$$

Where $\bar{y}_t$ is the observed sample mean, μ_t is the true population mean, and $\bar{e}_t$ is the error term with mean zero and variance σ_t^2 / n_t. This model assumes no serial correlation between $\bar{e}_t$ and $\bar{e}_{t-j}$ for all j. With SAFIS, the same subset of plot will be measured after 5 years; therefore. it is difficult to justify the assumption of no serial correlation. The above analysis could be modified to incorporate serial correlation to improve the efficiency of the estimates. The estimators would be similar to those for sampling with partial replacement (Ware and Cunia 1962, Scott and Kohl 1994, Van Deusen 1989).

To incorporate growth projections from models and the time series nature of the data, consider the model

$$x_t - x_{t-1} = \mu_t - \mu_{t-1} + v_t,$$

where, v_t is an error term with mean zero and variance λ_t^2 / m_t where m_t denotes the sample size for the x'_s. The x'_s are restricted to values that are modeled or in some way estimated on the unmeasured plots for the current year. The above equation provides an independent estimate of change in the population mean over time based on modeled x'_s. There are advantages to the approach of modeling change in that any additive bias disappears.

4 SUMMARY

For those familiar with the longstanding lo-year periodic FIA survey, the interpenetrating panel design of SAFIS is analogous to taking the large periodic survey and dividing it into five repeated smaller samples. The chief advantage of the annually repeated survey over the traditional periodic sample is that the separate annual samples provide information about variations that occur between the periods. This results in the ability to estimate annual and secular trends. Also, the sum of repeated surveys over the entire period can lead to better statistical inference than a single. concenuated, one-time survey.

Probability selection of time segments from an entire interval permits statistical inference from the sample to an average condition over the interval. In comparison, the traditional FIA periodic survey for an entire interval demands judgement and assumptions about the nature of variation over the entire interval. The one-shot survey is exposed to more risks of secular and catastrophic variations. known or unknown. The strength of the SAFIS repeated survey is that it relies on averaging out the variations over the repeated survey (Kish 1965).

The SAFIS design provides for increased flexibility of measurement and estimation. Each estimation option presented provides a different process for modeling each of the annual panels over the repeated survey cycle. For example, estimates of inventory based on pooling all data to a common year or averaging estimates over all five panels leads to identical estimates, given the same number of member plots are used for the analysis. The use of interpenetrating annual panels will encourage the use of models to estimate or update unmeasured plots (out-year panels). The mixed estimator illustrates the time series nature of SAFIS and provides a model for combining predicted and measured values.

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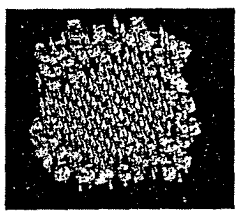

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