ISSUES RELATED TO PANEL CREEP

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ABSTRACT.—The annual inventory system was designed under the assumption that a fixed percentage of plots would be measured annually in each State. The initial plan was to assign plots to panels to provide systematic coverage of a State. One panel would be measured each year to allow for annual updates of each State using simple estimation procedures. The reality is that fluctuating budgets don't always permit a panel to be finished before the end of the field season. Therefore, sections of the State are left unmeasured, and State-level estimates can't be updated until the panel is completed. Creating extra panels is one way to reduce the impact of taking more than 1 year to measure a panel.

The annual inventory system, as mandated by the 1998 Farm Bill, was motivated by the public's desire to have a nationwide forest inventory system that could provide an annual update of each State's forests. The Farm Bill required an equal percentage of plots to be measured annually in each State. FIA provided for this requirement by dividing each State into panels consisting of subsets of plots that systematically cover the State. The panel system is an elegantly simple mechanism for obtaining annual estimates when one panel is measured each year. Annual estimates can be obtained by using individual panels or by combining the current panel with earlier ones.

FIA created 5 panels in the East and 10 panels in the West with the intention of measuring 20 percent and 10 percent of the plots in those respective regions. The reality is that uncertain budgets don't allow a rigid panel system to work as designed. FIA personnel have coined the term "panel creep" to describe panels that are only partially measured at the end of the field season. FIA has enough funding in the East to measure one-seventh of the plots per year, and panel creep will be avoided only in States that can "buy up" to 20 percent per year, such as Maine. As panel measurements creep into a second year, the Farm Bill vision of an annual inventory begins to fade.

REVIEW OF DESIGN ALTERNATIVES

When the annual inventory was being planned, a number of design alternatives were considered. A brief review of some of those alternatives is given to remind the reader why the panel system was chosen. This is followed by a discussion of modifications that make the interpenetrating panel design more flexible. The periodic design will be discussed because it was in place before the annual system. The concentrated grid design is discussed because it is an alternative way to take annual estimates. There is also some discussion of a disturbance design that was tested for implementing a different approach to the annual inventory in the Lake States.

Periodic Design

The periodic design was based on the premise that State-level estimates were important and that precision at a single point in time was the primary measure of quality. This led to the measurrment all the plots in a State over the course of 1 or more years and then remeasurement at approximately 10-year intervals. The remeasurement interval crept up to 15 years in some States (e.g., Maine) leaving an information gap that was unacceptable to many users. The call from users for timely data was documented in the first Blue Ribbon Panel (BRP I) report (American Forest Council 1992) and in BRP II (American Forest and Paper Association 1998). BRP I did not call for dismantling the periodic design, but requested reduction of the survey cycle from 10 years to 5 years. BRP II concluded that FIA should move to an annual system that would measure 20 percent of the plots in a State annually. This call for a drastic change in the system resulted from the periodic design's failure to produce more timely data.

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Concentrated Grid Design

The concentrated grid design was proposed as a compromise between the interpenetrating and periodic designs. An equal portion of the plots would be measured each year by dividing each State into concentrated zones. In this way, there would be annual measurements taking place in each State, but each within-State zone would be under a periodic survey. This design is very similar to the periodic 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 doesn't allow for annual statewide estimates. The concentrated grid design might also allow for reduced travel costs relative to the interpenetrating design. However, the concentrated grid design would make it difficult to produce State-level reports, because plots in different parts of the State are measured in different years.

Disturbance Design

The disturbance sampling design was developed for the Annual Forest Inventory System (AFIS) pilot study in the Lake States, which began in 1992. 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 interpenetrating or periodic designs. Any analysis would have to differentiate between plots that were measured because they were disturbed versus the randomly chosen undisturbed plots. Proponents felt that the disturbance design could be more economical to implement than a rigid interpenetrating design where 20 percent of the plots are measured each year. However, the disproportionate weighting of disturbed plots made the design appear to be too timber oriented, which was an argument against it.

Interpenetrating Design

The interpenetrating design was originally developed for the Southern Annual Forest Inventory System (SAFIS) pilot study, which began in 1995. This 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 interpenetrating design made SAFIS somewhat compatible with the original annual forest inventory (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."

The interpenetrating design is compatible with a number of estimators, because each panel provides systematic coverage of the State. Therefore, a single panel can be used to provide an estimate for a State by simply computing the mean and variance from individual per acre plot measurements. Likewise, several panels can be combined to provide estimates with increased precision. The interpenetrating design supports simple estimators but doesn't preclude more complex approaches that might increase precision.

ESTIMATORS

The focus here is on the 5-year moving average, because this has been chosen by FIA to be the default estimator for the annual inventory system. The discussion centers on some theoretical aspects of the moving average and how it is impacted by panel creep. A mixed estimation alternative to the moving average is also considered, because it has some advantages that justify its added complexity. The effect of panel creep on these estimators is also discussed.

Moving Average

The moving average is easy to apply and will work under the interpenetrating panel design (Roesch and Reams 1999). Consider first how the moving average works under an ideal scenario where one of five panels is measured each year. FIA plans to produce estimates using 5 years or panels worth of data. For years t-4 through t, this can be written as

$$MA_{t-4,t} = \sum_{j=t-4}^{t} w_j \bar{y}_j$$

where $\bar{y}_j$

is the average of all plot values measured in year j, and w_j is a weight such that $\sum w_j = 1$. The weight, w_j, ensures that each panel is weighted according to the proportion of the total plots it contains. With an exact 20 percent sample, $w_j=0.2$.

The panel mean is unbiased for the true underlying value, β_t, and we can write

$$\bar{y}_t = \beta_t + e_t$$

where e_t is a random error term. It follows that the expected value of the moving average is

$$E(MA_{t-4,t}) = \sum_{j=t-4}^{t} w_j \beta_j$$

Therefore, $MA_{t-4,t}$ estimates the weighted average over the last 5 years and is not an unbiased estimate of the value at any particular time. This is similar to what was done under the old periodic survey. It often took 3 or more years to complete the full periodic survey in a State, and State estimates were obtained by averaging all plots together as if they had been measured in the same year.

The variance of the moving average is easy to derive as

$$V(MA_{t-4,t}) = \sum_{j=t-4}^{t} w_j^2 \, V(\bar{y}_j)$$

where $V(\bar{y}_j) = \sigma_j^2 / n_j$, σ_j^2, is estimated from the between-plot variance within the panel and n_j is the number of plots in the panel measured in year j.

Change is at least as important as current status to most users of FIA data. FIA has promised to provide change estimates between 5-year time intervals, but many users will want to look at annual change estimates. The following equation shows the difference between the 5-year moving averages at year 6 and year 5 assuming that each panel contained 20 percent of the plots.

$$\begin{aligned} MA_{2,6} - MA_{1,5} &= \frac{1}{5}\left[(\bar{y}_2+\bar{y}_3+\bar{y}_4+\bar{y}_5+\bar{y}_6) - (\bar{y}_1+\bar{y}_2+\bar{y}_3+\bar{y}_4+\bar{y}_5)\right] \\ &= \frac{1}{5}\left(\bar{y}_6 - \bar{y}_1\right) \end{aligned}$$

The final estimate is shown to consist of the difference between measurements in year 6 and year 1, all divided by 5. Since we are still looking at the ideal scenario where the same panel is remeasured after 5 years, the year 6 measurements and the year 1 measurements come from the same panel. In other words, annual change from the moving average estimator is estimated from the 5 year change in the current panel, and the other four panels are ignored. This is a valid approach but does not use the data efficiently.

The moving average can still work with panel creep. However, a panel should not be incorporated onto the moving average until it is completely measured. This is important because the plots were assigned to panels to provide systematic coverage of a State. Therefore, a partially measured panel is likely to systematically exclude a section of the State and would lead to a biased estimate. Panel creep also means that the moving average after 5 years might consist of only 60 or 80 percent of the plots in a State. Also, the moving average loses some simplicity with panel creep, since the measurement year of the plots within a panel can now vary.

Mixed Estimator

Mixed estimation (Theil 1971) is analogous to Bayes methods in that it includes some prior information that influences the final results. It is more complicated than the moving average, but it provides model-unbiased estimates of current status, change estimates over any time interval, and variance estimates. Numerous variations that can be considered (Van Deusen 1996, 1999a), but only a single promising variant is presented here.

A mixed estimator is defined by an observation equation and a transition equation, where the transition equation is analogous to the Bayesian prior distribution. Therefore, mixed estimation is a cross between Bayesian and frequentist approaches. The observation equation used here is

$$\bar{y}_t = \beta_t + e_t$$

where e_t is an independent random error with mean 0 and variance σ_t^2/n_t . A sensible transition equation is

$$\beta_t - 2\beta_{t-1} + \beta_{t-2} = v_t$$

where v_t is an independent random error with $p\,\sigma_t^2/n_t$ variance and p is a parameter that is estimated from the data. The uncertainty associated with the transition equation increases with p, which diminishes the influence of the transition equation. As p goes to infinity, the mixed estimator would approach the mean for each panel assuming no panel creep. The transition equation provides some linkage between current values and those preceding it. This smoothing effect makes sense, since most forest statistics will tend to change little from one year to the next.

The estimation process is best described using matrix notation. The equations stay the same regardless of how much data are used, and the estimates will usually improve with more data. Therefore, there is no reason to use only the most recent 5 years of data. The matrix estimation equations for years 1 through T are

$$\hat{\beta} = \left[\Sigma^{-1} + \frac{1}{p}R'\Omega^{-1}R\right]^{-1}\Sigma^{-1}\bar{Y}$$, and

$$V(\hat{\beta}) = \left[\Sigma^{-1} + \frac{1}{p}R'\Omega^{-1}R\right]^{-1} ,$$

where,

$$\hat{\beta} = [\beta_1, \beta_2, \ldots, \beta_T] \;,\quad \Sigma^{-1} = DIAG(\sigma_1^2/n_1, \sigma_2^2/n_2, \ldots, \sigma_T^2/n_T)$$

, R is used to implement the selected transition equation, Ω contains transition variances on the diagonal, and $\bar{Y} = [\bar{y}_1, \bar{y}_2, \ldots, \bar{y}_T]$. More details can be found in Van Deusen (1999).

These are relatively simple equations that provide all required estimates. For example, to estimate the change from time t-k to t simply use $\hat{\beta}_t - \hat{\beta}_{t-k}$. A complete covariance-matrix is available, which makes it possible to estimate the variance of change. Thus, mixed estimators provide very general capabilities for estimating status and trend.

Mixed estimators will work with panel creep, but are subject to the same constraint as the moving average on using only fully measured panels. The estimation equations remain essentially the same with panel creep, but the direct correspondence between measurement year and panel is lost. The means in $\bar{Y}$ would be estimated only from that portion of a panel that was measured in the appropriate year.

DESIGN MODIFICATIONS

The only way to avoid panel creep would be to have adequate resources, which can't be assured. Budgets might be inadequate or field crew personnel might leave unexpectedly. However, there are design modifications that could lessen the impact. The most obvious is to create extra panels or subpanels (Van Deusen 1999b). Another approach would be to sequence the measurement of plots within a panel in such a way that near systematic coverage would be maintained even in the presence of panel creep. This would allow the panel measurements to be included even though some plots aren't measured yet.

Creating Subpanels

Creating subpanels or extra panels has two advantages: 1) panel creep is less likely to occur with smaller panels and 2) the impact is less when panel creep does occur. Suppose there were 20 panels in all States, with each panel providing near systematic coverage of a State. It would be possible to measure four panels per year to get 20 percent or two panels to get 10 percent of the plots per year. A reduced budget could be accommodated in the East by measuring three instead of four panels, while a budget increase might allow five panels. Panel creep is less likely to occur because each panel now contains only 5 percent of the plots, and it should be easier to ensure that a panel is completed before the end of a field season. An incompletely measured panel should still not be used for estimation purposes, but this means that less than 5 percent of the plots are withheld as opposed to almost 20 percent under a five-panel system.

The plan for the East is to measure some States over 7 years and others over 5 years, which suggests that 35 panels be created to accommodate both options. This certainly can be done, but each panel would contain less than 3 percent of the plots. There is a point at which panels contain so few plots as to be logistically unacceptable. If we agree that some amount of panel creep is inevitable, then the issue is best framed around a tolerable percentage of plots that could be potentially withheld due to panel creep. For example, a five-panel system might lead to nearly 20 percent of the plots being measured, but unavailable for estimation purposes until after the next field season when the panel is completed. A 20-panel system should have no more than 5 percent of plots withheld, and a 35-panel system should result in no more than 3 percent withheld.

A 20-panel system would seem to be a reasonable goal. It accommodates 5- or 10-year cycles evenly, but doesn't quite work for a 7-year cycle. However, there is no guarantee that any number of panels would eliminate panel creep. If we manage to measure 21 panels over 7 years, then an extra 5 percent of the plots are measured: with 19 panels in 7 years, we have a 5-percent shortfall. A 20-panel system might be a reasonable compromise between having large travel times among plots in the same panel and minimizing the chance that a panel is partially finished at the end of the year.

Some logistical issues are associated with smaller panels. Plots are far apart in small panels, so several panels should be measured concurrently to minimize travel time. This could lead to having several small, yet incomplete panels at the end of a field season. This could be avoided by stopping work on one of the panels when it becomes clear that resources are insufficient to finish all panels.

CONCLUSIONS

FIA plots have been assigned to panels in such a way that each panel contains about the same number of plots and provides systematic coverage of a State. FIA created 5 panels in the East and 10 in the West. The annual forest inventory system was originally designed on the assumption that one panel would be measured each year in each State. Panel creep occurs when the field season ends before a panel is completed.

The down side to panel creep is that the entire panel should be excluded from State-level estimates until it is completely measured. This is because a section of the State is likely to be systematically underrepresented if partial panels are used in the estimation process, which could lead to biased estimates. With a five-panel system, this means that 20 percent of the plots are unavailable until the panel is completed. Panel creep therefore has a detrimental impact on the annual nature of the inventory. Even though measurements are taken annually, it may not be possible to provide annual updates when panel creep occurs.

This problem could be ameliorated by creating extra panels so that each panel contains fewer plots but still provides systematic coverage. This lessens the chance that panel creep will occur and reduces the number of measured plots that are unusable when it does occur. Panel creep has been inadvertently built into the system in the East by creating five panels per State when the FIA budget would only support measuring some States over a 7-year period. Therefore, it seems that the number of panels should be increased to at least match the expected measurement cycles throughout the country. Creating enough extra panels to accommodate budget fluctuations seems to have a number of pros and few cons.

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