5 Combining Panels for Forest Inventory and Analysis Estimation

Paul L. Patterson and Gregory A. Reams[1]

5.1 Single Panels vs. Multiple Panels

The term **panel**[2] denotes a set of samples where the same elements are measured on two or more occasions. Historically, Forest Inventory and Anaysis (FIA) has used a single panel to conduct **periodic surveys**. Annual panels, however, allow greater flexibility because they can be combined in a variety of ways. Note that FIA assumes complete spatial coverage for each panel across the **population** of interest. When estimating inventory **attributes** for a single panel, the estimation approach proceeds as outlined in chapter 4. When estimating inventory attributes for combined panels, however, such procedures may require modification, depending on how the panels are combined. Related modifications are discussed in conjunction with the two specific methods presented in sections 5.2.1 and 5.2.2.

Dividing a single large periodic survey into a series of smaller surveys by measuring panels, one at a time, has several noteworthy advantages:

1. Individual panels can yield information about variations that occur within a measurement **cycle**; they can estimate year to year as well as long-term cycles and trends. This greatly improves our ability to understand the causes and timing of changes in the resource, as opposed to assuming linear trends.
2. Successive measurement of panels can provide quicker feedback to facilitate decisions that depend on knowledge of fluctuations in the survey attributes. If necessary, field protocols can be modified at the next scheduled panel, rather than waiting for a full inventory cycle to be completed.
3. Panels are highly responsive to widespread catastrophic events. The impact of a catastrophic event that occurs in a single year (e.g., fire or hurricane) can be gauged immediately. In the past, alternative methods such as interim periodic surveys were used to deal with catastrophic events (Sheffield and Thompson 1992).
4. Panels provide a natural, temporal link to other annual ancillary data.

---

[1] Paul L. Patterson, Mathematical Statistician, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO 80526-1891; and Gregory A. Reams, FIA National Program Manager, USDA Forest Service, 1601 North Kent Street, Arlington, VA 22209.

[2] First use of a glossary term in each chapter is in bold face.

Although annual inventories are considered superior to periodic inventories for FIA applications, conversion comes at a price. Some advantages of periodic surveys include:

1. Travel cost is minimized. Annual inventories require field crews to travel across the entire population each time a panel is measured.
2. Change estimates apply to just two points in time (although field measurements often take 2 to 3 years to complete). With multiple panels, change estimates are staggered over two inventory cycles, rather than just one.
3. The length of time required to measure individual panels can be inconsistent and difficult to manage. Budget constraints, regional issues, and logistical problems all influence the time needed to complete individual panels and sets of panels. As a result, the time required to complete a panel (or **subpanel**) typically does not equal exactly 1 year. From State to State, the time needed to finish one complete set of inventory panels can range from 3 to 10 years due to panel acceleration or panel creep as discussed in chapter 2.
4. The sample size is nearly always sufficient. A single panel has sampling errors that are $\sqrt{P}$ times larger than when using all P panels. However, as FIA moves to the annual system this will cause a short-term problem for analysts who must report results from only one or two panels of data. The problem also may make some of the more sophisticated methods for combining panels inappropriate for small samples. For example, recent data from 220 counties in Indiana, Missouri, and Illinois, where two panels have been completed, showed an average of only two forested **plots** per county per panel.

Additional discussion of the advantages and disadvantages of multiple or single panels is provided by Köhl and Scott (2000).

FIA uses panels to measure both current inventory and change. Change can be estimated in a multitude of ways. One method uses the net difference between two sequential, but different, panels. Assuming this approach involves independent samples, the variance of the difference is the sum of the variances, roughly $2s^2/n$. Measuring different panels over time yields estimates of net change, but only remeasured panels can provide information about specific **components of change** behind the net change. The latter are particularly useful for researching the dynamics of causation and associated relationships. There, change is directly observed, so the variance is reduced by the correlation, R, between measurements, roughly $(1 - R^2)s^2/n$. Alternatively, this can be expressed as the reduction in the variance of the difference due to the covariance between occasions:

$v(y_t - y_{t-1}) = v(y_t) + v(y_{t-1}) - 2\,\mathrm{cov}(y_t, y_{t-1})$. The remeasured panels approach is generally preferred for its robustness, efficiency, and ability to isolate individual components of change.

5.2 Combining Panels

There is currently no **prescribed core** procedure for combining panels. Due to different spatial, temporal, and forest characteristics within and among regions, it is not clear if any single technique will work for all. Whatever estimation strategy is used to estimate current conditions, variance reduction usually can be attained by combing current data with earlier data from previous panels. Several estimation strategies have been devised to take advantage of previous data (Czaplewski 1995, Reams and Van Deusen 1999); those now being investigated by FIA include:

1. The **moving average** (MA)
2. The temporally indifferent (TI) method
3. Modeling [updating plots, mixed estimators (Van Deusen 2002), Kalman filters (Brockwell and Davis 1996), and various time series models (Johnson and others 2003)]

The first two are relatively straightforward, highly compatible with the estimators presented in chapter 4, and discussed in further detail in sections 5.2.1 and 5.2.2. The third technique, modeling, has so many possible variations that potential approaches are beyond the scope of this chapter.

5.2.1 The Moving Average Method

Let P denote the number of panels to be combined for analysis. Let Y_p denote the true quantity for panel p, where $p = 1,\ldots,P$; and let $\hat{Y}_p$ denote the estimate of Y_p obtained using the appropriate technique from chapter 4. Note that each panel is treated as an independent estimate, which permits:

1. The weighting of individual panels
2. **Phase 1 stratification** instruments to differ among panels (i.e., different maps may be used to stratify different panels)

Using the above notation, the MA estimator is given by:

$$\hat{Y}_{MA,P} = \sum_{p=1}^{P} w_p \hat{Y}_p \tag{5.1}$$

where

$\{w_p\}_{p=1,\ldots,P}$ is a set of constant positive weights that sum to 1 across all combined panels (Roesch and Reams 1999)

The variance formula for $\hat{Y}_{MA,P}$ is:

$$V\left[\hat{Y}_{MA,P}\right] = \sum_{p=1}^{P} w_p^2 \, V\left[\hat{Y}_p\right], \tag{5.2}$$

where

$V\left[\hat{Y}_p\right]$ for each panel is calculated as specified in chapter 4

The MA estimator is appealing because it is simple and the use of previous panels can lead to a substantial reduction in the variance over the variance of an estimate based on an individual panel (Gillespie 1999).

Roesch and Reams (1999) suggest that equal weighting of all panels ($w_p = \frac{1}{P}$, for $p = 1, \ldots, P$), or heavier weighting of more recent panels would be appropriate in equation 5.1. Johnson and others (2003) have shown, with simulation based on FIA data, that in most situations the moving average with equal weights has the smallest mean squared error.

Because the MA is a weighted sum of estimates across all panels of interest, it can be viewed as an estimate of the attribute of interest at some time between the first and last years of the time period from which the panels were drawn. The specific point in time depends on the weights used, as well as the direction and magnitude of change that have influenced that attribute from panel to panel. Also, moving averages and related techniques result in estimators that dampen trends by obscuring annual fluctuations, and in that sense do not measure the current status of a finite population, but rather a temporal average of that population. Such estimators will make changes appear smaller than they are, and the use of older panels potentially creates a lag bias when estimating current conditions. However, in the absence of some widespread catastrophic event, the smoothing and lag effects of moving averages usually will be inconsequential and more than offset by the reduction in variance acquired from using the maximum number of available panels (Johnson and others 2003). Still, there is some concern that potential lag bias may mask time trends (Roesch and Reams 1999). FIA is now researching whether lag bias significantly influences trends associated with the attributes of interest occurring on **forest lands**. Obviously, in the presence of a widespread catastrophic event, lag bias cannot be ignored. The best way to adjust methods for such situations is also an area of ongoing research.

Finally, the MA approach does not require separate Phase 1 stratification for each panel. Thus, the weighting feature of the MA estimator may still be used when applying the same Phase 1 stratification to any or all panels.

5.2.2 The Temporally Indifferent Method

The temporally indifferent (TI) method differs from the MA method in that all panels of interest are pooled into the equivalent of one large periodic inventory, and the same Phase 1 stratification is applied across all panels. Although this approach lacks some of the flexibility offered by alternative methods of combining panels, it does have advantages over periodic inventories because individual panels can be used to produce spatially unbiased estimates before the results of a complete periodic inventory are available. Note that in the simple random sampling case, the TI method is equivalent to the MA with weights proportional to the number of plots in each panel.

The TI method is simpler than the MA approach in that estimation proceeds directly as specified in chapter 4, without the added complication of weighting (i.e., equations 5.1 and 5.2 are not used). In addition to simplicity, use of the TI method may be advantageous when sample sizes per panel are small. For example, when the MA approach is used in conjunction with stratification, the variance estimates for individual panels may be inflated by small sample sizes within each stratum. This could offset the variance reduction obtained through the MA estimator's weighted sum. When this is the case, the larger sample sizes per stratum attained with the TI method could reduce the variance considerably more than the MA alternative.

Finally, potential smoothing of temporal trends and lag bias associated with catastrophic disturbances present the same problems described for the MA estimator, with the added disadvantage that no weights are used to adjust for these effects. If weighting is necessary to overcome lag bias or to adjust for catastrophic events, the MA method is preferred.

5.3 Literature Cited

Brockwell, P.J.; Davis, R.A. 1996. Introduction to time series and forecasting. New York: Springer Verlag. 420 p.

Czaplewski, R.L. 1995. Continuous adaptive monitoring of status and trends in ecosystem conditions. Proceedings of the 1995 Society of American Foresters conference. Bethesda, MD: Society of American Foresters. 482 p.

Gillespie, A.J.R. 1999. Rationale for a national annual inventory program. Journal of Forestry. 97: 16-20.

Johnson, D.S.; Williams, M.S.; Czaplewski, R.L. 2003. Comparison of estimators for rolling samples using forest inventory and analysis data. Forest Science. 49(1): 50-63.

Reams, G.A.; Van Deusen, P.C. 1999. The southern annual forest inventory system. Journal of Agricultural Biological and Environmental Statistics. 4: 346-360.

Köhl, M.; Scott, C.T. 2000. A comparison of periodic versus permanent surveys. In: Burk, T.E.; Hansen, M.H., eds. Integrated tools for natural resources inventories in the 21st century: Proceedings of the IUFRO Conference. GTR–NC–212. St. Paul, MN: U.S. Department of Agriculture Forest Service, North Central Research Station: 94-103 p.

Roesch, F.A.; Reams, G.A. 1999. Analytical alternatives for an annual inventory system. Journal of Forestry. 97: 33-37.

Sheffield, R.M.; Thompson, M.T. 1992. Hurricane Hugo: effects on South Carolina's forest resource. Res. Pap. SE–284. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 51 p.

Van Deusen, P.C. 2002. Comparison of some annual forest inventory estimators. Canadian Journal of Forest Research. 32: 1992-1995.