

Annual Forest Inventory and Monitoring System

The North Central Perspective

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The USDA Forest Service is developing procedures for annual forest inventories to establish the capability of producing annual estimates of forested area, timber volume, related variables, and changes in these variables. The inventory system (JAFIMS) features an annual sample of measured field plots; remote sensing; a database of plot and tree information; logistical procedures for supporting field crews; and an optional function, mechanisms for updating the status of plots measured in previous years. The discussion focuses on system implementation in the North Central region.

By Ronald E. McRoberts

The Renewable Forest and Rangeland Resources Planning Act of 1978 requires that the USDA Forest Service conduct periodic inventories of forestland in the United States to determine its extent and condition and the volume of standing timber, timber growth, and timber depletions. Five separate Forest Inventory and Analysis (FIA) programs, located in USDA Forest Service research stations, conduct these inventories and publish summary reports for individual states.

The quality of periodic inventory estimates decreases over time because of factors such as changes in land use and tree growth, mortality, and removals. Quality is further degraded by the effects of conducting inventories in heavily forested states over multiple years. FIA clients recognize these deficiencies and have proposed solutions, such as increasing the sampling intensity, reducing the period between inventories, and conducting mid-cycle updates. Although these solutions might resolve some of the deficiencies, they are expensive to implement and are a piecemeal approach to dealing with the problems inherent in periodic inventories.

In the early 1990s, scientists in the FIA program at the North Central Research Station (NCRS) formulated concepts that led to implementation of the first large-scale annual forest inventory system under the auspices of the USDA Forest Service. Planning

and implementing this system was a joint effort of NCRS, the Rocky Mountain Research Station, and the Minnesota Department of Natural Resources (MN DNR). Shortly after the system was implemented, the Southern Research Station (SRS) implemented an annual inventory system that was both similar and dissimilar in key aspects to the NCRS system. Although the NCRS effort was initiated before the SRS effort, the political and industrial support generated by SRS was primarily responsible for placing annual forest inventories on the national FIA agenda.

With passage of the 1998 Farm Bill, formally known as the Agricultural Research, Extension, and Education Reform Act of 1998 (PL 105-185), Congress required that the Forest Service conduct annual forest inventories in all states. The Farm Bill established further requirements: (1) each year, 20 percent of plots are to be measured in each state; (2) the annual data are to be made available each year; and (3) statewide resource reports are to be published every five years. In addition, the Farm Bill required integration of FIA and the Forest Health Monitoring (FHM) program (Eagar et al. 1991; White et al. 1992) at the level of plot measurement. FHM is a national program that uses data from ground plots, aerial surveys, and other sources to produce annual estimates of the status, changes, and trends in indicators of forest health.

One result of the Farm Bill has been the virtual merger of the NCRS and SRS efforts. Scientists from the two stations have agreed on a common statement of objectives, a common set of system functions, and a common name, the Joint Annual Forest Inventory and Monitoring System (JAFIMS). The common name has been selected to distinguish the inventory system developed by the two stations from other approaches to annual forest inventories. "Joint" connotes that the system is being developed and implemented by more than one station, and "monitoring" connotes integration with FHM.

The primary objective of JAFIMS is to maintain the capability of producing annual statewide estimates of forested area, timber volume, related variables, and changes in these variables. The system designed to accomplish this objective features several distinct functions: (1) an annual sample of measured field plots; (2) remote sensing for area estimation and stratification; (3) a user-friendly, publicly accessible database of plot and tree information; and (4) logistical field procedures for implementing the inventory. In addition, JAFIMS features an optional function: (5) mechanisms for updating plot and tree information for plots that have not been measured in the current year. Although these functions generally characterize Forest Service annual forest inventory systems, the options selected for implementing them may vary by region.

Annual Sample

The characterization of USDA Forest Service forest inventories as "annual" is based on the measurement of a proportion of plots each year and the capability of producing annual FIA estimates, not on a complete annual inventory of all permanent plots. FIA precision standards require a sampling intensity of one plot for approximately every 6,000 acres in the North Central region (USDA-FS 1970). To satisfy this requirement, the geographical hexagons established for the FHM program were divided into 27 smaller FIA hexagons, each of which contains approximately 5,900 acres. A grid of field plots was established by selecting or es-

tablishing a plot in each smaller hexagon: (1) if an FHM plot fell within a hexagon, it was selected as the grid plot; (2) if no FHM plot fell within a hexagon, the plot from the existing network of permanent FIA plots

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(Vasilevsky and Essex 1977; Schmidt 1998) that was nearest the hexagon center was selected as the grid plot; and (3) if neither FHM nor existing FIA plots fell within the hexagon, a new permanent FIA plot was established at the hexagon center and selected as the grid plot. This grid of plots is called the federal base sample and is considered an equal probability sample; its measurement in the North Central region is funded by the federal government.

The federal base sample was systematically divided into five interpenetrating, nonoverlapping panels. Each year the plots in a single panel are selected for measurement with panels selected on a five-year rotating basis. Before the field measurement of plots, remotely sensed images are examined to classify plots into three broad categories: forested, nonforested, and questionable. Whereas nonforested plots receive at most a cursory check to ensure correct classification, field crews visit plots in the forested and questionable categories. They measure individual tree attributes such as diameter, crown ratio, and mortality, and record plot level attributes such as land use, forest type, and ownership.

The federal base sample is considered an equal probability sample of the total surface area of a state, with the basis for inference residing in the sample design. Equal probabilities for plot selection result from the random orien-

tation of the system of the FHM hexagons and the lack of relationship between the locations of the hexagons and the locations of permanent FIA field plots.

Intensification Sample

Some states contribute additional funding to intensify inventories as a way to increase precision, address biological issues such as growth declines, or investigate the effects of weather phenomena such as droughts, blow downs, and ice storms. Several options are available for selecting intensification plots. First, if a state wants simply to increase the precision of the overall inventory, a systematic distribution of supplementary plots across the entire state is appropriate. In this case, supplementary plots are established in all hexagons, and the intensification sample consists of the supplementary plots from a panel whose number is offset by a constant number from the panel currently measured for the federal base sample.

A second option is to select plots that satisfy species, spatial, or other conditions. Minnesota has experimented with this option in a unique manner: intensification plots have been considered for selection on the basis of vegetation disturbance. The underlying assumption is that the growth and mortality of trees on well-established, undisturbed plots can be predicted adequately for intervals of up to 20 years using models such as the Stand and Tree Evaluation and Modeling System (STEMS) (Belcher et al. 1982). The intensification sample would consist of supplementary plots selected according to three ordered criteria: (1) plots that experienced substantial recent vegetation loss; (2) plots that have not been measured in the past 20 years; and (3) plots randomly selected from among undisturbed plots.

Remote Sensing

Remote sensing techniques are applied in forest inventories for area estimation, for forest-nonforest stratification, for post-measurement stratification for variance reduction purposes, and optionally for disturbance detection. Where available, the Gap Analy-

sis Program (GAP) (NCASI 1996; Scott and Jennings 1997) is used for area estimation and stratification. GAP analyses are generally conducted by state agencies or universities, are based on two-date, same-year satellite imagery from the Landsat Thematic Mapper (Bauer et al. 1994), and classify pixels across entire states into strata related to land use, vegetative cover, and tree density.

The estimate of surface area in each stratum is calculated as the product of the total number of pixels classified into the stratum and the 900-square-meter area per pixel. The area represented by each plot in a stratum, called the area expansion factor, is calculated as the ratio of the pixel-based area estimate and the number of plots in the stratum. Thus, while area expansion factors across an entire state will average approximately 5,900 acres by design, there will be some variation among strata.

Remote sensing techniques for classifying plots with respect to vegetation change have been developed by MN DNR to facilitate the optional sample intensification scheme and to identify plots that have been harvested between measurement years (MN DNR 1999). For each 30m × 30m Landsat Thematic Mapper pixel, the difference between the digital values is calculated for each spectral band for two sets of imagery obtained in different years. The differences for selected bands are combined to calculate index values for each pixel using an algorithm that maximizes the correlation between the index and ground vegetation change. The mean and standard deviation of these index values are calculated, and a pixel-based map is constructed based on five categories of deviations of individual pixel values from the mean. The pixel-based map is overlaid on the array of plots, and each plot receives a disturbance value.

The accuracy of disturbance detection for plots whose disturbance value predicts substantial vegetation loss has been partially assessed using plot sheet comments recorded by field crews. Plots predicted to be disturbed were found to have experienced vegetation loss in 67 percent of cases, whereas

plots predicted to be unchanged were found to have experienced no vegetation loss in 95 percent of cases. For purposes of disturbance-based sampling, virtually no cost is associated with erroneously selecting a plot for measurement that was predicted to be disturbed but was found by the field crew to have experienced no vegetation loss; the plot is simply treated like other undisturbed, measured plots. Therefore, although the 67-percent prediction success rate is rather low, there is little penalty for an incorrect prediction. However, the penalty associated with erroneously predicting a plot to be undisturbed is potentially much greater. Such plots likely will not be selected for inclusion in the intensification sample, and their predisturbance plot volume will be erroneously carried forward. Fortunately, the prediction success rate for this category of plots is very high at 95 percent.

Database Operations

The database consists of plot and tree information for all permanent FIA plots and is crucial to inventory estimation, analysis, and reporting. Because many FIA users are more interested in the database than in the pub-

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lished assessments and reports, extracts of the database are designed to be a public, accessible, and user-friendly medium for transferring information.

FIA programs use database operations to accomplish a variety of tasks such as selecting plots to be measured, retrieving and verifying data from previous inventories, preparing field data recorders, producing field crew plot

sheets, entering and editing remotely sensed and field data, tracking the progress of inventories, calculating estimates, creating files for public access, and storing information for future inventories (Hansen 1998). Although individual FIA programs may accomplish these tasks in somewhat different ways, standardization of the FIA plot design and field procedures, agreement on a common set of estimates and a common table format for reporting purposes, and selection of a common database management system are leading to greater overall uniformity.

Several points of agreement regarding database operations have emerged among FIA programs in recent years. First, establishment of the Eastwide (Hansen et al. 1992) and Westwide (Woudenberg and Farrenkopf 1995) database file formats has provided common, well-documented, easy public access to FIA database information. Second, acceptance of a set of common estimates and of a common table format for reporting purposes establishes uniformity among FIA programs and provides linkage between resource publications and the databases.

Estimation

The properties of the statistical estimators used to calculate annual FIA estimates depend on the sampling designs used to collect the data. Regardless of the estimation technique employed, data resulting from the measurement of some plots from the federal base sample will be available each year. Therefore, the simplest way to calculate annual FIA estimates is to use only the data from the panel of plots measured in the current year. Such estimates reflect current conditions and are based entirely on measured plots, but their precision will be unacceptable for some variables because of the small annual sample size. An alternative is to use the data for all plots obtained from the five most recent panels of measurements and employ a moving average estimator. The advantage of this alternative is that precision is increased because data for all plots are used for estimation; the disadvantage is that the estimates do not reflect current conditions but rather an average of condi-

tions over the past five years. Another alternative is to update to the current year data for plots measured in previous years and then base the estimates on data for all plots. If the updating procedures are unbiased and sufficiently precise, this alternative increases the precision of the estimates without the adverse effects of using out-of-date information. Thus, a variety of estimation procedures are available under JAFIMS, with the moving average agreed on as the default.

Regardless of the alternative selected, FIA estimates for the federal base sample for areas such as counties, FIA units, or states are obtained as the sum over strata of within-stratum estimates. Within-stratum estimates are calculated as the sum over all plots falling within both the stratum and the selected area of the product of plot-level estimates and the stratum area expansion factor. For intensification samples obtained using different designs, such as disturbance-based sampling, separate estimates must be calculated and combined with the federal base sample estimates.

Updating

Two options for updating plot information are under investigation: imputing missing values from a pool of data obtained under similar conditions, and predicting individual tree growth using models. The first method is referred to as imputation (Rubin 1987) and is being investigated by SRS. Imputation is a two-step process: (1) plots not measured in the current year are matched with a pool of similar plots measured in the current year; and (2) estimates of current year properties for each nonmeasured plot are obtained by substituting the properties for a plot selected randomly from the pool of similar plots. This method is particularly appropriate when a large proportion of plots are measured each year or when a large number of plots are measured in the current year that are similar to previously measured plots.

The FIA program at NCRS has used the STEMS (Belcher et al. 1982) growth models to update plots and trees not measured in the current year.

These regional models were developed from data collected primarily from long-term research plots and have generally been accepted for application in the North Central region. Nevertheless, research to improve the efficacy of the growth models has been undertaken with several objectives: (1) to calibrate the models using FIA data rather than data from research plots; (2) to use current statistical techniques that were unavailable when the STEMS models were developed; and (3) to incorporate a climatic component into the models. The hypotheses underlying the third objective are that incorporat-

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ing a long-term climatic component will provide greater spatial precision, and incorporating an annual climatic component will provide greater temporal precision. Unpublished analyses indicate that the bias in the models is both negligible and less than that for the STEMS models and that the effects of imprecision in the model predictions are very small relative to the variation among measured plots within a stratum.

Field Logistics

The requirement to measure plots every year in all states creates both opportunities for and obstacles to efficiency. The primary opportunities relate to the advantage of stationing field crews in permanent locations. The obstacles, however, require complex coordination:

- Supervising field crews becomes more difficult, because they are distributed across an entire region rather than concentrated in a few states. Ad-

ditional field crew supervisors must be hired or additional levels of supervision must be established. Existing supervisors must travel extensively (or use technology to provide oversight remotely) or field crews must be granted greater independence.

- Because field crews will be in multiple states simultaneously, uniformity must be developed and maintained with respect to field manuals, data recorder programs, and editing programs.

- Many smaller, permanent locations for stationing field crews must be arranged, the preferred solution being collocation with other Forest Service units or land management agencies. In addition, each location must be provided with computer, communication, and support services that otherwise could be transported with the field crews as they move.

- Some states will not require a large enough annual sample to justify permanent stationing of a full-time crew. But the requirement to measure plots systematically distributed throughout these states each year may substantially increase travel costs. Alternatives include contracting for part-time crews in those states, having crews from adjacent states satisfy the requirement, and maintaining a small number of crews in permanent travel status to cover several such states.

- Quality assurance and quality control issues will require greater attention because of less-intense supervision, variability among field procedures, and diversity among field crews and their funding sources.

From a logistical perspective, annual inventories may permit long-term cost savings, but the initial coordination will be difficult and the initial implementation may be costly.

Conclusion

In 1998 the initial panel of plots based on the grid of hexagons was selected for Minnesota, Missouri, Indiana, and Iowa; logistical procedures were implemented; and field measurements were initiated. Although some issues remain to be resolved and analyses of efficiencies and precision remain to be completed, JAFIMS appears to

be a viable solution for satisfying the demands of FIA users for more precise, timely, and accessible FIA information.

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