The Enhanced Forest Inventory and Analysis Program of the USDA Forest Service: Historical Perspective and Announcement of Statistical Documentation

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ABSTRACT

The Forest Inventory and Analysis (FIA) program of the USDA Forest Service has initiated a transition from regional, periodic inventories to an enhanced national FIA program featuring annual measurement of a proportion of plots in each state, greater national consistency, and integration with the ground sampling component of the Forest Health Monitoring (FHM) program. The transition has required conceptual and technical changes in the statistical methodology that supports the program. This article provides a brief historical perspective on the FIA program, announces publication of the statistical documentation supporting the program, previews individual chapters in the documentation, and provides a brief discussion of areas where investigations are continuing.

Keywords: Ends-ways-means, sampling estimation, remote sensing

Forest inventories conducted under the auspices of the Forest Inventory and Analysis (FIA) program of the USDA Forest Service historically have been commodity oriented, with emphasis on estimating the area and volume of the nation's timber supply. These statewide inventories typically have been conducted on productive timberland but not on other forestlands, not on reserved lands, and, depending on the region, not on National Forest lands. The design and implementation of FIA inventories have been the responsibility of the five regional FIA programs that administer them with plot configurations, sample designs, measurement protocols, analytical techniques, and reporting standards frequently tailored to regional requirements. These inventories were characterized as periodic surveys because field crews were concentrated in one or two states until the measurement of all plots was completed. States were selected for inventories on a rotating basis with time intervals between inventories for the same state ranging from 6 to 18 years. The plot measurement component of periodic inventories required from 1 to 4 or more years, with the analysis component requiring an additional 2–5 years.

The timeliness, quality, and usefulness of estimates obtained from periodic surveys came under scrutiny in the 1980s and 1990s. Estimates were degraded by the effects of conducting inventories over multiple years, and the bias and uncertainty of estimates increased over time because of factors such as change in land use, tree growth, tree mortality, and removals between inventories. The periodic nature of these inventories made consistent interstate estimation difficult, even within regions, and interregional estimation was even more difficult because of varying plot configurations, sample designs, and measurement protocols. When compounded by the lack of measurements on all forested lands and the inconsistency in measurements of National Forest System lands in some regions, these factors caused national compilations to depend on a variety of ad hoc techniques. Finally, the environmental and forest ecosystem health interests of groups challenging the commodity focus of FIA inventories were difficult to address using only traditional FIA measurements. FIA clients recognized the deficiencies inherent in these regional, periodic inventories and registered their dissatisfaction.

In response to user concerns regarding the health of forest ecosystems, the Forest Health Monitoring (FHM) program was initiated in 1990 as a cooperative effort

among state and federal agencies. The FHM program focuses on assessing and monitoring the health and sustainability of the nation's forests and consists of four primary activities: detection monitoring, evaluation monitoring, intensive site monitoring, and research on monitoring techniques. Together, these four activities permit predictions of where and how future ecosystems might change under various environmental and management conditions.

In response to user concerns regarding the timeliness of traditional FIA estimates, in 1990, the North Central Research Station initiated a pilot study with the objective of annually producing statewide inventory estimates that were no more costly and no less precise than those obtained from periodic inventories in the year of their completion. In the mid-1990s, the Southern Research Station initiated a second pilot study with the objective of a 5-year cycle of complete remeasurement of all plots augmented with state financial support. In addition, two Blue Ribbon panels provided recommendations to the Forest Service regarding the scope and conduct of forest inventories. The 1992 report of the first Blue Ribbon Panel (American Forest Council 1992) recommended a nationally consistent approach to the collection, analysis, and reporting of forest inventory data, and the reports of the second panel (American Forest and Paper Association 1998, 2001) affirmed the recommendation of the first. The cumulative effect of the pilot studies and the Blue Ribbon Panel reports was passage of the *Agricultural Research, Extension, and Education Reform Act of 1998* (Farm Bill, US Laws, Statistics, etc., Public Law 105-185).

The 1998 Farm Bill directed the Secretary of Agriculture to produce a strategic plan for forest inventory featuring an annual system, state reports every 5 years, a set of core variables with national definitions and measurement standards, and integration of the ground sampling components of the FIA and FHM programs. This legislation, together with the coalescing of the two pilot studies and national cooperation in standardizing inventories, resulted in an annual forest inventory program, designated Enhanced FIA.

The Enhanced FIA program uses the ends-ways-means strategic planning model to emphasize and promote national consistency. Ends are the criteria that must be satisfied for the program to be characterized as nationally consistent; ways are the procedures that lead to achieving the ends; and means are the resources that are committed to the effort. The Enhanced FIA program is described in terms of six ends:

End 1: A standard set of variables with nationally consistent meanings and measurements
End 2: Field inventories of all forested lands
End 3: Consistent estimation
End 4: Satisfaction of precision standards
End 5: Consistent reporting and data distribution
End 6: Credibility with users and stakeholders

These ends describe the major foci of the Enhanced FIA program and provide direction for methodological research. To assure that the six ends are achieved, 10 ways have been prescribed:

Way 1: A national set of prescribed core variables with a national field manual that prescribes measurement procedures and protocols for each variable
Way 2: A national plot configuration
Way 3: A national sample design
Way 4: Estimation using standardized formulas for sample-based estimators
Way 5: A national database of FIA data with core standards and user-friendly public access (Mapmaker)
Way 6: A national information management system
Way 7: A nationally consistent set of tables of estimates of prescribed core variables
Way 8: Publication of statewide tables of estimates of prescribed core variables at 5-year intervals
Way 9: Documentation of the technical aspects of the FIA program including procedures, protocols, and techniques
Way 10: Peer review of and public access to the technical documentation

The result of the ends and ways is an inventory program with identifiably new features: (1) a nationally consistent plot configuration; (2) a nationally consistent sample design for all lands; (3) annual measurement of a complete systematic sample in each state; (4) reporting of data or data summaries within a prescribed interval after completion of designated proportions of plot measurements; (5) provision for multiple estimators for combining data for multiple panels and for techniques for updating information; (6) state inventory reports every 5 years; and (7) integration of the ground sampling components of the FIA and FHM detection monitoring activity.

Documentation, review, and publication of the conceptual and technical features of the Enhanced FIA program as prescribed by Ways 9 and 10 contribute to accomplishment of End 3, consistent estimation, and End 6, credibility with users and stakeholders. In particular, the purposes for publishing the statistical documentation are fourfold:

1. To ensure a common understanding and practice among the regional FIA programs
2. To facilitate development of the national program including the national information management system
3. To provide a defensible statistical basis for the sampling and estimation components of the program
4. To promote credibility with users and stakeholders

Although the primary intended audience for the documentation is the national FIA program itself, the program's users and stakeholders also may find it useful for understanding FIA methods. To the extent possible at the present time, the documentation addresses the full range of conceptual issues, technical details, and statistical techniques for sample-based estimation. The four sections that follow provide previews of the technical chapters of the documentation.

Sampling Frame

The Enhanced FIA program conducts inventories in three phases. The primary objective of Phase 1 is to stratify land area in the population of interest for purposes of reducing the variances of estimates. Phase 1 entails the use of ancillary data, including remotely sensed imagery in the form of aerial photography or satellite imagery or both, to stratify the land area in the population of interest and to assign plots to strata. Phase 2 entails visits by field crews to the physical locations of permanent groundplots to measure the traditional suite of FIA variables. The Phase 2 sample is based on a national array of approximately 6,000-ac (2,400-ha) hexagons containing one permanent groundplot each and is designated the federal base sample (Figure 1). For the entire country, the hexagons have been systematically formed into five groups called panels such that no adjacent hexagons are in the same panel and the plots associated with each panel provide a

complete, systematic sample of each state. Panels are selected for measurement on a rotating basis, and measurement of all accessible plots in one panel is completed before measurement of plots in a subsequent panel is initiated. The primary objective of Phase 3 is to measure additional variables related to the health of forest ecosystems. The Phase 3 sample comprises a one-sixteenth subset of the Phase 2 plots, resulting in a sampling intensity of one plot per approximately 96,000 ac (39,000 ha). Chapter 2 of the documentation describes the three phases in detail and the genesis of the national sampling frame and its theoretical basis. These three phases provide the basic framework for the structure of the Enhanced FIA program.

Plot Configuration

All Phase 2 plots installed since the year 2000 conform to the national standard plot configuration (Figure 2). Each plot consists of four 24-ft (7.31-m) radius circular subplots configured as a central subplot and three peripheral subplots located at distances of 120 ft (36.58 m) and azimuths of 0, 120, and 240° from the center of the central subplot. Each subplot includes a 6.8-ft (2.08-m) fixed-radius microplot on which seedlings and saplings are sampled and a regionally optional, 58.9-ft (18.0-m), annular macroplot on which large trees are sampled. Chapter 3 of the documentation describes the history and rationale for this configuration and explains the protocols used to address special situations such as inaccessible plots and plots that straddle distinctly different land cover, land use, and management conditions. Sampling on Phase 3 plots includes all Phase 2 sampling in addition to sampling associated with five forest health indicators: tree crowns, soils, lichens, down woody materials, and understory vegetation diversity. Two other indicators, ownership and ozone, are observed off the FIA plot network.

Sample-Based Estimators

The Enhanced FIA program features sample-based estimation. In Chapter 4 of the documentation, estimators used for area and forest attribute totals are described under assumptions for simple random estimation, stratified estimation, and double sampling for stratification. Variance estimators are provided so that sampling errors may be calculated for all estimates. Estimators are derived to accommodate plots that contain multiple land uses or straddle population boundaries or both. Ratio-of-means estimators are described so that estimates may be computed on per-unit-area, per-tree, and per-stand bases. Methods also are described for estimating the components of change between measurements such as growth, mortality, and removals.

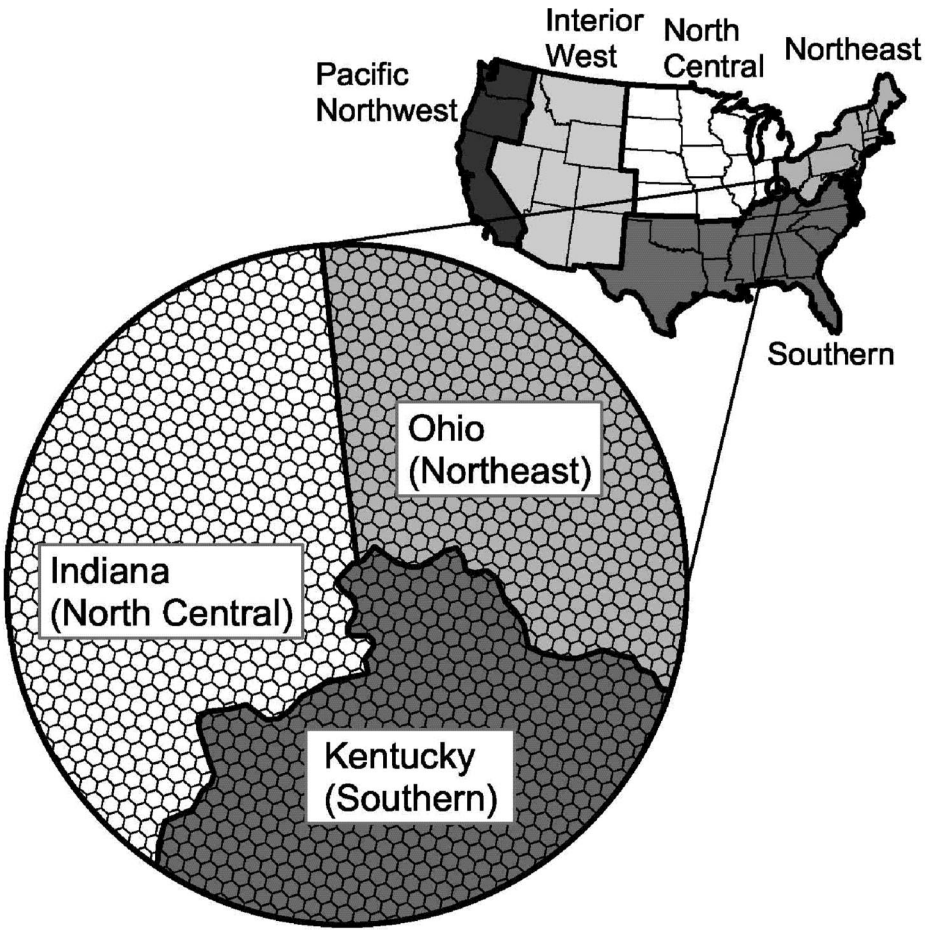

Figure 1. Sampling hexagons illustrating the same system across states and regions.

Combining Data for Multiple Panels

The Enhanced FIA program does not prescribe a method for estimating forest attributes from data obtained from multiple panels. Spatial, temporal, and forest characteristics within and between regions suggest it may not be possible to prescribe a single technique that will produce estimates with satisfactory properties for all regions. Although full discussion of the many possible modeling approaches is beyond the scope of the statistical documentation at the present time, Chapter 5 of the documentation begins with a discussion of the advantages and disadvantages of both the periodic surveys as previously conducted and the current multiple-panel FIA surveys. The chapter also provides detailed discussion and documentation of the moving average method and the temporally indifferent method as viable approaches for producing 5-year estimates of forest attributes from multiple panels as required by the Farm Bill.

Release of the Documentation

An external editor was engaged to coordinate double-blind technical reviews of the documentation by subject matter and statistical specialists from the university, government, and forest industry sectors. After several rounds of reviews and revisions, and with the written approval of the editor, the documentation has been released as a peer-reviewed General Technical Report of the Forest Service (GTR SRS-80; Bechtold and Patterson 2005) and may be ordered or downloaded free of charge (Southern Research Station Publications). Documenting the Enhanced FIA program is regarded as a continuing, dynamic process. Additional documentation is required for some components of the Enhanced FIA program; e.g.,

Phase 3 estimation, model-based updating procedures, quality assurance and control, and long-term directions.

Continuing Investigations

Although the documentation addresses an extensive range of situations, there remain some unresolved issues and issues that require additional investigation. The following discussion identifies a few of these issues and indicates approaches that may be taken to investigate them.

The Enhanced FIA program attributes observations and derived estimates (e.g., volume) representing the entire plot to the point corresponding to the center of the center subplot. This practice assumes that the primary sampling unit is a dimensionless point, although the FIA plot clearly has two, if not three, dimensions. The properties of the estimators used in conjunction with this practice require additional investigation. For example: (1) Are the estimators unbiased? (2) What are the effects of assigning a plot to a stratum on the basis of the stratum corresponding to the single point when the two-dimension plot area extends into multiple strata? (3) What are the effects of declaring an entire plot inaccessible on the basis of the single point being inaccessible? The approach to resolving these issues will be via simulations and mathematical and statistical derivations.

Although the Enhanced FIA program does not prescribe a single method for combining data from multiple panels, most regions have expressed a preference for the 5-year moving average. Although moving average estimators have the advantage of simplicity, they may not yield unbiased estimates for specific time points within the panel series. For example, because the moving average assumes a linear trend, it is prone to bias when one or more panels are affected by catastrophic events such as hurricanes, ice storms, or insect infestations. Approaches to circumventing this bias will include investigations of separate individual panel estimates, weighting individual panel estimates, using time series and imputation models (Reams and Van Deusen 1999), and using the mixed estimator approach proposed by Van Deusen (2002).

For a variety of reasons, some regions such as interior Alaska, west Texas, and the piñon-juniper area of the Southwest are not well suited for sampling at the same temporal or spatial intensity as the rest of the country. Nevertheless, estimates for these regions still are required. Several alternatives merit investigation. First, the temporal and spatial intensity of sampling may be reduced under assumptions that the forest component of these regions changes very slowly and that less precision is required for their estimates. Second, reduced intensity sampling used in conjunction with model-based or model-assisted techniques may prove beneficial. Finally, quite precise small-area estimates of the primary forest attributes, area and volume, have been obtained from model-based maps constructed from satellite imagery and inventory plot data. It remains to be determined if sufficiently accurate and cost-efficient estimates can be obtained using the model-assisted and model-based approaches for large areas.

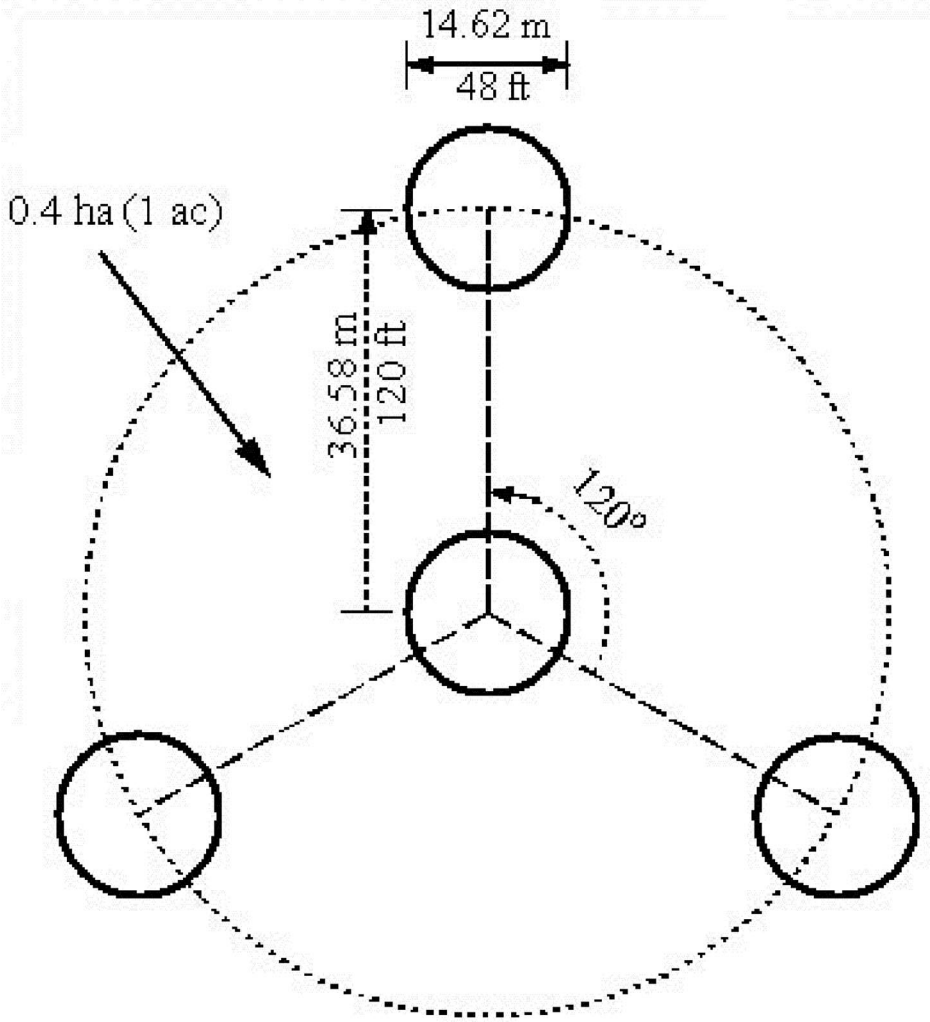

Figure 2. National, standard FIA plot configuration.

Enhanced FIA estimates for some attributes rely on models of relationships between the attribute and ancillary variables. For example, volumes of individual trees are predicted using regression models based on observations of tree diameter, height, and species. Two aspects of this modeling component require investigation. First, the volume models have been mathematically formulated and calibrated independently for the five regional FIA programs with the result that applicability of the models is governed by administrative boundaries. Thus, the same tree, were it moved among the southeast portion of Indiana in the north central region, the southwest portion of Ohio in the northeastern region, and the most northern portion of Kentucky in the southern region might be predicted to have quite different volumes (Hansen 2003). Efforts have been initiated to move to a common mathematical form for volume models and to calibrate them for recognized ecological provinces rather than states or administrative regions. Second, in the estimation process, the effects of uncertainty in model predictions on the uncertainty of tree, plot, and county estimates require investigation.

For reasons such as hazardous conditions and denied access, portions of FIA plots occasionally are not sampled. To compensate, an adjustment factor is introduced to properly scale observations and measurements. However, because the proportion of a plot that is not sampled is not constant, the adjustment factor is a variable. Several issues related to the variation in the adjustment factor require investigation: (1) the effects of the variation on the properties of larger-scale estimates, (2) approaches to estimating totals based on separate component totals, and (3) alternative approaches to calculating the adjustment factor (e.g., Van Deusen [2004]).

Although the FIA plot configuration is not optimal for estimation of any particular forest attribute, it is regarded as appropriate for estimating a wide range of attributes. However, plots are difficult to classify with respect to some conditions; e.g., forest cover type when multiple forest cover types are observed on the plot. This problem is exacerbated when only a small portion of a single subplot is observed in a condition. Three approaches merit investigation: (1) more robust classification approaches such as fuzzy logic; (2) incorporation of single condition classification algorithms into field data recorder software to assist field crews in classifying small portions of plots; and (3) additional sampling to classify small portions of plots.

Summary

The Enhanced FIA program of the Forest Service is rapidly implementing an annual inventory system that features a nationally consistent plot configuration, a nationally consistent sample design, integration with the ground sampling component of the FHM program, a complete statewide systematic annual sample of each state, and new reporting requirements. Implementation of this system has required new and consistent statistical methods for computing estimates. The FIA program has committed substantial time and effort to documenting these methods and has contracted with an external editor who coordinated several rounds of double-blind reviews by government, academic, and industry experts. Although continuing statistical investigations will be conducted, this initial version of the documentation is now available to the public.

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