

1 The Enhanced Forest Inventory and Analysis Program

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1.1 Purpose and Scope of the Documentation

The Agricultural Research, Extension, and Education Reform Act of 1998 (Public Law 105–185), also known as the 1998 Farm Bill, prescribed conceptual changes in approaches to forest inventories conducted by the Forest Inventory and Analysis (FIA) Program of the U.S. Department of Agriculture (USDA) Forest Service. Realization of these conceptual changes required development and implementation of technical changes, some of which are substantial. The underlying purposes for documenting the conceptual and technical features of the resulting Enhanced FIA Program are fourfold:

1. To ensure a common understanding and practice among the regional FIA programs
2. To facilitate further development of the national core program, including FIA's National Information Management System (NIMS)
3. To provide a defensible statistical basis for the sampling and estimation components of the program
4. To promote credibility with users and stakeholders

The primary intended audience for this version of the documentation is the national FIA Program itself. Nevertheless, our users and stakeholders will also find it useful for understanding FIA methods and, as the Enhanced FIA Program matures and as internal issues are resolved, documentation specifically intended for external use will be published. To the extent possible at the present time, this documentation addresses the full range of conceptual issues, technical details, and statistical techniques for sample-based estimation.

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1.2 Overview of the Enhanced Forest Inventory and Analysis Program

1.2.1 Historical Perspective

Forest inventories conducted under the auspices of the national FIA Program 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**² but not on **other forest lands**, not on **reserved forest lands**, and depending on the region, not on National Forest System lands. The design and implementation of FIA inventories have been the responsibility of the five regional FIA Programs that administer them; and **plot** configurations, sampling designs, measurement protocols, analytical techniques, and reporting standards frequently have been tailored to regional requirements. Those 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 (Gillespie 1999). The plot measurement component of periodic inventories for any given State required from 1 to 4 years, depending on the magnitude of the resource, the number of plots to be measured, and the number of field crews. The analysis component required an additional 2 to 5 years, during which time FIA staff analyzed the data and then compiled, published, and distributed reports.

The timeliness, quality, and usefulness of estimates obtained from periodic inventories came under scrutiny in the 1980s and 1990s. Estimates obtained from these inventories were degraded by the effects of conducting them over multiple years, while the bias and uncertainty of estimates increased over time due to 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, while interregion estimation was even more difficult due to varying plot configurations, sampling designs, and measurement protocols. These factors, when compounded by the lack of measurements on all forested lands, 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.

² The first use of a glossary term in each chapter is in bold face.

FIA clients recognized the deficiencies inherent in these regional, periodic inventories. They registered their dissatisfaction and proposed solutions. Concerns related to **cycle length** led to proposals to increase the sampling intensity, reduce cycle lengths, and conduct midcycle updates. Clients also advocated consistency across regions and measurement of all vegetation on all forested lands. Various solutions were proposed to resolve these issues, but most were expensive to implement and represented only a piecemeal approach to dealing with problems inherent in the periodic inventories.

1.2.2 Forest Health Monitoring

In response to user concerns regarding the health of forest ecosystems, the Forest Health Monitoring (FHM) Program was established in 1990. It was an independent, cooperative effort among multiple State and Federal Agencies focused on assessing and monitoring the health and sustainability of the Nation's forests using nationally standardized inventory procedures. The FHM Program consists of four primary activities. In the first—detection monitoring—field crews measure selected biotic and abiotic features of forests called “indicators” during a baseline period. The same features are remeasured at regular intervals to identify changes associated with natural forest succession and ecosystem disturbances. In the second activity—evaluation monitoring—teams of ecologists, entomologists, hydrologists, pathologists, silviculturists, and others conduct intensive field sampling and provide combined interpretations when the causes of detected changes are unknown. In the third activity—intensive site monitoring—long-term research is conducted on watershed-sized sites that have diverse forest types and biomes typical of those found in the United States. In the fourth activity—research on monitoring techniques—researchers focus on developing and refining indicator measurements to improve the efficiency and reliability of data collection and analysis. Together, these four FHM activities permit predictions of where and how future ecosystems might change under various environmental and management conditions.

1.2.3 Annual Inventories

The impetus for the transition from regional, periodic inventories to nationally consistent, annual inventories came from two pilot studies in the 1990s and the reports of two Blue Ribbon Panels. In 1990, the North Central Research Station began a pilot study with the objective of producing annual, statewide inventory estimates that were no more costly and no less precise than those obtained from periodic inventories in the year of their completion. The 1992 report of the first Blue Ribbon Panel (BRP-I) recommended a nationally consistent approach to the collection, analysis, and reporting of forest inventory data (American Forest Council 1992). The first step toward

this goal was a directive issued in 1995 by the USDA Forest Service, Deputy Chief for Research instructing FIA to adopt the FHM plot configuration as a national replacement for the various regional plot configurations.³ In the mid-1990s, the Southern Research Station began a second pilot study that featured annual inventories augmented with State support and based on a 5-year measurement **cycle**. The cumulative effect of the North Central and Southern Research Stations' pilot studies, the report of BRP-I, and the report of the 1998 Blue Ribbon Panel (American Forest and Paper Association 1998), which affirmed the recommendations of BRP-I, was passage of the 1998 Farm Bill [Agricultural Research, Extension, and Education Reform Act of 1998 (Public Law 105–185)].

The 1998 Farm Bill directed the Secretary of Agriculture to produce a strategic plan for forest inventory with several features—an annual forest inventory program; State reports every 5 years; a set of **prescribed core variables**, standards, and definitions; 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, with identifiably new features:

1. A nationally consistent plot with four fixed-radius **subplots**
2. A systematic national sampling design for all lands
3. A complete, systematic, annual sample of each State
4. Reporting of data or data summaries within 6 months of completion of designated proportions of plot measurements
5. Provision for several estimators to combine data from multiple **panels**, some of which incorporate updating techniques
6. State inventory reports every 5 years
7. Integration of the FIA field component and the ground sampling component of the FHM detection monitoring activity

Implementation of the last feature was facilitated by the 1995 USDA Forest Service directive instructing FIA to adopt the FHM plot configuration, and takes advantage of efficiencies gained by consolidating the field components of these two forest inventories.

³ SESCO, Jerry A. 1995. Letter dated March 30 to Station Directors and WO Research Staff Directors. On file with: FIA National Program Leader, USDA Forest Service, Forest Inventory and Analysis, Rosslyn Plaza, 1620 North Kent Street, Arlington, VA 22209.

1.2.4 National Consistency

Concern among FIA clients regarding the lack of program consistency was comparable to their concerns about the lack of timely FIA estimates and the need to monitor forest ecosystem health and sustainability. As a means of emphasizing national consistency in the Enhanced FIA Program, its technical aspects are described using the Ends-Ways-Means strategic planning model. Ends are the criteria that must be satisfied for the program to be characterized as nationally consistent; Ways are the procedures and protocols that lead to achieving the Ends; and Means are the resources that are committed to the effort. The following discussion focuses on selecting a set of Ends that lead to national consistency, and identifying technical Ways to achieve them. Some Ends require prescribed Ways to achieve them, while others require flexibility in the selection of Ways. The guiding principle is that Ways are to be facilitating, not inhibiting, and that they are to be prescribed only where necessary to achieve the Ends. Thus, the Ends leading to national consistency are achieved, while creativity and innovation to further enhance the FIA Program are encouraged.

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:
 - (a) the ability to obtain estimates for areas larger than the single county level for which FIA usually reports estimates
 - (b) the ability to obtain data and estimates for user-defined applications and areas of interest
- End 4: national precision guidelines
- 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 ensure that the 6 Ends are achieved, 10 Ways have been prescribed. To achieve End 1, Ways 1 and 2 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

Core variables are identified in the national field manual and are measured on each plot in every State by field crews from each of the five regional FIA programs. Additional **enhanced prescribed core variables** and **nonprescribed optional variables** may be included, but no prescribed core variable may be deleted. Agreement on measurement protocols and procedures has required compromise among representatives of the five regional FIA programs, but that has led to a broad national consensus.

To achieve End 2, Way 3 has been prescribed:

Way 3: a national sampling design

The national sampling design emerged as a result of its development and implementation in one regional FIA program and its subsequent acceptance and implementation in two others. Both the national sampling design and the national plot configuration represent broad consensus, and both are described in greater detail in chapters 2 and 3.

Achieving the two components of End 3 is facilitated by the three Ways already described. However, to fully achieve End 3a, a fourth Way also has been prescribed:

Way 4: estimation using standardized formulae for sample-based estimators

End 3b was deemed necessary to accommodate the large number of non-FIA researchers, both within and outside the USDA Forest Service, who seek to use FIA data for their own applications and areas of interest. To achieve End 3b, two additional Ways have been prescribed:

Way 5: a national FIA database with core standards and user-friendly public access

Way 6: a national information management system

Ways 5 and 6 are necessary to make user friendly FIA data available to the general public while also yielding estimates that are consistent with those presented by the FIA Program. In addition, Ways 5 and 6 greatly facilitate Way 4, in particular, and estimation within the FIA Program, in general.

Compliance with the national FIA Program's precision guidelines (U.S. Department of Agriculture Forest Service 1970) associated with End 4 requires flexibility in prescribing Ways. The current guidelines primarily relate to estimates of forest area and inventory volume, and are formulated quantitatively as:

$$\frac{[Var(\hat{Y})]^{0.5}}{\hat{Y}} \left[\frac{\hat{Y}}{S} \right]^{0.5} \leq PREC$$

where

\hat{Y} = the estimate of the **attribute** of interest

$Var(\hat{Y})$ = the estimate of the variance of \hat{Y}

S = a scaling factor—one million acres for area estimates and one billion cubic feet for volume estimates

$PREC$ = the target precision per S units, which is 0.03 for area estimates or 0.05 for volume estimates in the Eastern United States and 0.10 in the Western United States

Guidelines for the precision of estimates of other attributes may be considered on a case-by-case basis as the need arises.

Budgetary constraints and natural variability among plots prohibit sample sizes sufficient to satisfy precision guidelines, unless the estimation process is enhanced using ancillary data. With FIA's traditional sample-based estimation, enhancement has been achieved via **stratified estimation** using remotely sensed data as the basis for **stratification**. However, regional differences in species diversity, topography, forest management practices, and other factors may require qualitatively different approaches to stratification to achieve End 4. Thus, no Ways regarding stratification are prescribed other than that the stratifications should be statistically defensible and feasible for incorporation into NIMS. However, assuming that the historical levels of sampling variability and the benefits of stratified estimation would continue, the national sampling intensity in terms of number of plots per unit area was selected so that, on average across much of the Nation, compliance with the precision guidelines would be achieved.

End 5 reflects FIA's response to users and stakeholders who desire consistency and temporal compatibility in cross-State and cross-region estimates of prescribed core variables.

Two Ways are prescribed to ensure that End 5 is achieved:

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

Finally, achieving End 6, credibility with users, will require that the FIA Program not only develop and implement a nationally consistent program, but that technical details of the program be transparent and subject to stakeholder and public scrutiny. Thus, two additional Ways have been prescribed:

- Way 9: the technical aspects of the FIA Program, including procedures, protocols, and techniques, are documented
- Way 10: the technical documentation is peer-reviewed and published for general access

1.3 Overview of the Documentation

The documentation is divided into chapters, of which the following sections are brief overviews.

1.3.1 Sampling Frame

Chapter 2 describes in detail the Enhanced FIA Program's three phases in the context of sample-based estimation. **Phase 1** is designed to produce stratifications of land area in the **population** of interest to reduce variance in the estimates. It entails the use of ancillary data, including remotely sensed imagery in the form of aerial photography and/or satellite imagery, to stratify the land area in a population of interest and to assign plots to **strata**. In **Phase 2**, field crews visit permanent ground plots and measure the traditional suite of FIA variables. The Phase 2 sample is based on a national array of approximately 6,000-acre hexagons containing one permanent ground plot each. It is designated the Federal base sample. In **Phase 3**, field crews measure additional variables related to the health of forest ecosystems. The Phase 3 sample comprises a 1/16th subset of the Phase 2 plots, resulting in a sampling intensity of one plot per approximately 96,000 acres. Because Phase 3 plots (previously denoted FHM plots) are also Phase 2 plots, they include all measurements made on Phase 2 plots, plus measurement of the FHM biotic and abiotic features associated with forest and ecosystem health. The chapter 2 documentation describes the three phases in greater detail, as well as the genesis of the national sampling frame and its theoretical basis.

1.3.2 Plot Design

Chapter 3 describes the history, rationale, and configuration of Phase 2 and Phase 3 ground plots, as well as explanations of protocols used for mapping (or partitioning) plots by **condition class**. The basic FIA area and tree **attributes** are described, including those measured in the field and those computed from field measurements. Special situations that influence data collection and processing also are addressed.

1.3.3 Sample-Based Estimators

Chapter 4 focuses on the sample-based approach to estimation and describes the estimators used for area and forest attribute totals 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 each cell in every output table. Estimators are derived to accommodate sample plots that contain multiple land uses and/or straddle **population boundaries**. **Ratio-of-means** estimators are described so that estimates may be computed on per-unit-area, per-tree, and per-stand bases. Methods are also described for estimating the **components of change** between measurements such as growth, mortality, and removals.

1.3.4 Combining Data for Multiple Panels

Chapter 5 provides a brief overview of considerations when selecting techniques to obtain multiple panel estimates of forest attributes for the required 5-year reports. Several strategies are noted including **moving average** estimation, a temporally indifferent method that ignores the multiyear nature of the multiple panel data, and model-based updating. Special attention is given to the moving average and the weighted moving average methods. As of the date of this publication, no national default estimator had been selected.

1.3.5 Notation and Glossary

Chapter 6 provides a reference for the consistent mathematical and statistical notation used throughout this documentation, and chapter 7 provides a comprehensive glossary of terms and expressions.

1.3.6 Web-Based Supplementary Documentation

The supplementary documents referenced in this manuscript are posted on the Web site http://srsfia2.fs.fed.us/publicweb/statistics_band/stat_documents.htm.

The purpose of these documents is to provide details about the algorithms, equations, and other specifics of the national FIA Program that are too technical for the chapter discussions. These documents are posted on the Internet because they are dynamic. They are currently in various stages of completion, and periodically will be updated and revised to accommodate changes in protocol and demand for technical detail. More information may be added to this Web site in the future as unresolved and new issues are presented and addressed.

1.4 Literature Cited

- American Forest Council. 1992. Report of the Blue Ribbon Panel on Forest Inventory and Analysis. Arlington, VA: American Forest Council. 14 p.
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