



Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Northern Research Station | General Technical Report NRS-210 | March 2023

Statistics and Quality Assurance for the Northern Research Station Forest Inventory and Analysis Program, version 3

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Citation

Gormanson, Dale D.; Pugh, Scott A.; Barnett, Charles J.; Morin, Randall S.; Sowers, Paul A.; Westfall, James A. 2023. **Statistics and quality assurance for the Northern Research Station Forest Inventory and Analysis Program, version 3**. Gen. Tech. Rep. NRS-210. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 35 p. <https://doi.org/10.2737/NRS-GTR-210>.

Abstract

The USDA Forest Service Forest Inventory and Analysis (FIA) program collects sample plot data on all forest ownerships across the United States. FIA's primary objective is to determine the extent, condition, volume, growth, and use of trees on the Nation's forest land through a comprehensive inventory and analysis of the Nation's forest resources. The FIA program strives for transparency by making the methods and results of the inventory and analysis available to the public. The standard for distributing FIA data is the FIA Database (FIADB). FIADB data for individual states can be downloaded from FIA DataMart at <https://apps.fs.usda.gov/fia/datamart/datamart.html>. This report complements the Northern Research Station's FIA 5-year state reports and includes detailed information on forest inventory methods, important resource statistics, quality of estimates, and key references.

KEY WORDS: inventory, timberland, forest land, sampling error, sample design, volume, growth, mortality, removals

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Manuscript received for publication February 2022

Published by:
USDA Forest Service
One Gifford Pinchot Drive
Madison, WI 53726
March 2023

Visit our homepage at: <https://www.nrs.fs.usda.gov>

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INTRODUCTION

The Forest Inventory and Analysis ([FIA](#)) program of the [U.S. Forest Service](#) assesses America's forests through a comprehensive inventory and analysis of the Nation's forest resources and makes the methods and results of the inventory and analysis available to the public. FIA traces its origin back to the McSweeney-McNary Forest Research Act of 1928 (Public Law 70-466), which initiated the first forest inventories starting in 1930. The 1978 Forest and Rangeland Renewable Resources Research Act ([Public Law 95-307](#)) supplanted the McSweeney-McNary Act of 1928. The passage of the Agricultural Research, Extension, and Education Reform Act of 1998 ([Public Law 105-185](#)), also known as the 1998 Farm Bill, mandated changes in the way FIA conducted inventories. The revisions resulted in an enhanced FIA program, which included: (1) switching from regional periodic surveys to a national standardized annual inventory protocol where a proportion of permanently monumented plots in each state is measured every year on a continuous cycle; (2) using a nationally consistent core set of measurements; (3) producing state reports every 5 years; and (4) integrating the ground sampling components of the FIA program and the USDA Forest Service Forest Health Monitoring ([FHM](#)) program ([Bechtold and Patterson 2005](#)).

[“Forest Inventory and Analysis Program History”](#) (USDA Forest Service 2018) offers a brief, historic synopsis of legislation guiding FIA. “A History of the Forest Survey in the United States: 1830–2004” ([LaBau et al. 2007](#)) presents a history of the FIA (formerly known as Forest Survey) program in the United States as it evolved within the U.S. Department of Agriculture (USDA) Forest Service over a period of more than 100 years. More recent history focused on the FIA annualized national system is documented in [Bechtold and Patterson \(2005\)](#), [McRoberts \(2008\)](#), [McRoberts et al. \(2005\)](#), and [McRoberts and Miles \(2016\)](#). See the FIA library (<https://www.fia.fs.usda.gov/library>) for additional historical documentation.

Purpose and Scope of Document

This document provides an overview of the National FIA program. The detailed information presented includes forest inventory methods, important resource statistics, quality of estimates, and key references currently used by the Northern Research Station Forest Inventory and Analysis (NRS-FIA) regional unit. The procedures and guidelines described or referenced here complement NRS-FIA 5-year state reports. [Woodall et al. \(2006\)](#) conceptualized the template for what is now known as the “Statistics and Quality Assurance for the Northern Research Station Forest Inventory and Analysis Program” publication (originally the Part B) used to supplement NRS-FIA 5-year state reports. Subsequently, the NRS-FIA produced solely digital versions of these publications to convey this information more efficiently to inventory users. Such technical documentation may periodically be updated if there are changes or additions to methodologies, the database, and/or associated manuals. This third version¹ closely mirrors previous digital versions, former Part B, ensuing “Statistics, Methods, and Quality Assurance” reports, and technical specifications associated with the inventory across a myriad of sources. The appropriate version of the statistics and quality assurance document will be referenced in each 5-year state report. Definitions for FIA terms commonly found in the 5-year reports are available at <https://www.nrs.fs.usda.gov/fia/data-tools/state-reports/glossary/default.asp>.

Tables

Two different types of tables containing forest resource statistics are referenced in this report. Sampling tables are labeled with a letter (A through F) and summarize sampling design, major resource attributes, measurement quality, sampling bias, and nonresponse. Estimate tables contain assessments for attributes such as area, number of trees, volume, and weight. All tables are designated as “Table ST-##”, where ST is the abbreviation for the state of interest and ## refers to the table number or letter.

¹ Previous versions:

Gormanson, D.D.; Pugh, S.A.; Barnett, C.J. [et al.]. 2017. Statistics and quality assurance for the Northern Research Station Forest Inventory and Analysis Program, 2016. Gen. Tech. Rep. NRS-166. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 23 p. <https://doi.org/10.2737/NRS-GTR-166>; and

Gormanson, D.D.; Pugh, S.A.; Barnett, C.J. [et al.] 2018. Statistics and quality assurance for the Northern Research Station Forest Inventory and Analysis Program. Gen. Tech. Rep. NRS-178. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 25 p. <https://doi.org/10.2737/NRS-GTR-178>.

Background

Forest inventories are the foundation for forest management planning and are essential for framing policy and making sound management decisions that may include protection, utilization, and sustainability. The Forest Inventory and Analysis program is a strategic, design-based, multi-resource inventory providing current information and trends in forest resources. FIA is managed by the USDA Forest Service [Research and Development](#) branch and cooperates with [State and Private Forestry](#) and the [National Forest System](#). The primary objective of FIA is to determine the extent, condition, volume, growth, and use of trees on the Nation's forest land. FIA reports on status and trends in forest area and location; species, size, and health of trees; total tree growth, mortality, and removals by harvest; wood production and utilization rates by various products; and forest land ownership.

Prior to 1999, all forest inventories in the United States were conducted on a periodic basis. With the passage of the 1998 Farm Bill ([Public Law 105-185](#)), FIA is now required to collect data annually on a portion of plots within each state so that up-to-date information essential to framing realistic forest policies and programs is available. The 1998 Farm Bill also mandated that the program be enhanced. As a result, FIA significantly increased its capacity to analyze and publish data. FIA also expanded the scope of data collection to include soil, understory vegetation, tree crown conditions, down woody materials (DWM), and lichen community composition on a subsample of plots. In addition, the 1998 Farm Bill directed the Forest Service to partner with the states and nongovernmental interests to implement a nationally consistent, annual inventory program in all states and to produce state level reports every 5 years, thus ensuring the timely availability of data. The 2014 Farm Bill ([Public Law 113-79](#)) directed FIA to expand sampling to include urban trees on all land use types in select cities. After the 2014 farm bill expired in September 2018, the Agriculture Improvement Act of 2018, also known as the 2018 Farm Bill ([Public Law 115-334](#)) was signed into law December 20, 2018.

Four regional units are responsible for conducting the forest inventories and publishing summary reports. The Northern Research Station is responsible for Connecticut, Delaware, District of Columbia, Illinois, Indiana, Iowa, Kansas, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Nebraska, New Hampshire, New Jersey, New York, North Dakota, Ohio, Pennsylvania, Rhode Island, South Dakota, Vermont, West Virginia, and Wisconsin. The Southern Research Station is responsible for Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, Puerto Rico, South Carolina, Tennessee, Texas, U.S. Virgin Islands, and Virginia. The Rocky Mountain Research Station is responsible for Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming. The Pacific Northwest Research Station is responsible for American Samoa, California, Federated States of Micronesia, Guam, Hawaii, Marshall Islands, Northern Mariana Islands, Oregon, Palau, Washington, and Alaska. The reports are based on a statistical sample of field plots collected on all ownerships.

FOREST INVENTORY METHODS

Strategic Model

The Forest Inventory and Analysis program of the Northern Research Station (NRS-FIA) is part of the national enhanced FIA program that focuses on a set of six strategic objectives and are described as “ends” in [McRoberts \(2005, 2008\)](#), [McRoberts et al. \(2005\)](#), and [McRoberts and Miles \(2016\)](#):

- A standard set of variables with nationally consistent meanings and measurements
- Field inventories of all forested lands
- Nationally consistent estimation
- Adherence to national precision standards
- Consistent reporting and data distribution
- Credibility with users and stakeholders

To ensure that these six objectives are achieved, 10 strategic approaches have been prescribed and are presented as “ways” in [McRoberts \(2005, 2008\)](#), [McRoberts et al. \(2005\)](#), and [McRoberts and Miles \(2016\)](#):

- A national set of prescribed core variables with a national field manual that describes measurement procedures and protocols for each variable
- A national plot configuration
- A nationally consistent sampling design
- Estimation using standardized formulas for sample-based estimators
- A national database of FIA data with core standards and user-friendly public access
- A national information management system
- A nationally consistent set of tables with estimates of prescribed core variable
- Publication of statewide tables with estimates of prescribed core variables at 5-year intervals
- Documentation of the technical aspects of the FIA program including procedures, protocols, and techniques
- Peer review and publication of the technical documentation for general access

In summary, the strategic objectives and approaches create an inventory program with:

- A nationally consistent plot configuration
- A nationally consistent sampling design for all lands that includes the annual measurement of a proportion of plots in each state
- Nationally consistent estimation techniques and algorithms
- Integration of the ground-sampling components of the FIA inventory and detection monitoring by the USDA Forest Service Forest Health Monitoring program

Sample Design

To satisfy national FIA precision standards ([Hansen 2001](#)), a sampling intensity of about one plot per 6,000 acres is required. [Brand et al. \(2000\)](#) and [McRoberts \(1999\)](#) describe how the area of the United States was divided into nonoverlapping, 5,937-acre hexagons to meet sampling error requirements while saving as much historical measurement information as possible. After the FIA and [Forest Health Monitoring \(FHM\)](#) plot components were integrated, a sampling protocol was used to establish a base sample of at least one plot in each hexagon using the following rules:

1. If an existing FHM plot was located in a hexagon, it was selected.
2. If there was no FHM plot in the hexagon, the existing FIA plot from the previous periodic inventory nearest the hexagon center was selected.
3. If neither an FHM nor an FIA plot was in the hexagon, a new FIA plot was established at a random location in the hexagon.

The entire sample arrangement of permanent plots is considered an equal probability sample and is referred to as the Federal base sample. The collection of measurements on the base sample plots is funded by the Federal government.

In December 1999, the Journal of Forestry published a special issue on the FIA program and its transition to an annual inventory approach ([Journal of Forestry 1999](#)). It covers the history of forest survey sampling, the ongoing work in specific regions at the time, and user perspectives on the adoption of an annual inventory system, which began in earnest in 1999.

The Federal base sample consists of five interpenetrating, nonoverlapping panels or subsamples, each of which provides complete, systematic coverage of a state. Each panel is subdivided into 14 subpanels, producing a complete sample set of 70 subpanels, each associated with a hexagon. The time required to collect observations in all 70 subpanels defines the cycle length, which can vary based upon requirements and resources. The common cycle lengths for the 70-subpanel design are 5, 7, and 10 years. The panel assignments are used to distribute the samples across time in the same way the hexagons distribute the sample across space. See [Brand et al. \(2000\)](#) for an indepth description of (1) the FIA hexagon lattice sampling grid used to distribute plots across the landscape, i.e., the sampling framework, (2) the panel assignment to hexagons, (3) the assignment of plots to a specific hexagon, and (4) the integration of the FIA and FHM plot network.

Starting in 1999 and continuing through 2013, NRS-FIA collected data on 14 of the 70 subpanels (20.0 percent) every year, resulting in a 5-year cycle and remeasurement period for the annual inventory. In 2014, the annual sample changed to 10 subpanels (14.3 percent) per year, resulting in a 7-year cycle, with the first 7-year cycle being completed by 2021. All plots have been retained, and inventory estimates (both current and change) will continue to be based on the most recent measurements and remeasurements taken on these plots. As the 7-year cycle is phased in, the difference between the report year and average date of the recent data will increase from 2 to 3 years. The difference between the report year and the average midpoint year for change will increase from 4.5 to 6.5 years.

Sample plots are permanently established and are associated with one and only one hexagon. For estimation purposes, the panel of plots is considered an independent, equal probability sample of all lands in a state. The remeasurement of a panel of plots is also considered an equal probability sample of change occurring on all lands in a state. In many states inventoried by FIA, additional resources have been made available to intensify plot sampling either by adding plots to the base sample within a given cycle, or by shortening the currently funded cycle by collecting the full sample of plots in 5 years (ME, MN, and NJ).

Plot Configuration

The FIA sampling unit or plot consists of four circular 24-foot-radius subplots (1/24th acre) configured as a central subplot (point 1) and three peripheral subplots (points 2-4) (Fig. 1). The plot cluster design spreads the sampling unit out over about one acre of land; thus, more “independent” or “new” information is collected at each location versus simply taking measurements within one large plot. This reduces between-plot attribute measured variance and decreases the total number of plots necessary to achieve a given precision standard ([Scott 1993](#)). Centers of the peripheral subplots are located 120 feet from the central subplot at azimuths of 360°, 120°, and 240° from the center of the central subplot. All trees with a diameter at breast height (d.b.h.) of 5 inches or greater are measured on the subplots. Each subplot contains a circular 6.8-foot-radius microplot (1/300th acre) with center located 12 feet east of the subplot center on which all trees with a d.b.h. between 1 and 5 inches are measured. Forest conditions that occur on any of the four subplots are identified and recorded. The 58.9-foot-radius macroplots (1/4th acre) are used for sampling intensification or for sampling relatively rare events. Macroplots are not used by NRS-FIA but are used by the Rocky Mountain and Pacific Northwest Research Stations to sample large trees.

Field plot locations are monumented using the [global positioning system](#) (GPS). The sample site is “mapped” to identify and separate the various conditions that may occur throughout the location. In general, a “condition class” is a delineation of an area based upon land use, forest type, stand-size class, stand origin, reserve status, tree density, and owner group. For an area to be classified as forest it must be at least 1 acre in size and 120 feet wide. If two or more conditions occur within a plot, the boundary between them is mapped and the proportion of the plot in each condition is recorded. [Bechtold and Patterson \(2005\)](#) offer explanations of protocols used for mapping (or partitioning) plots by condition class and describe details of the estimation process in the plot configuration

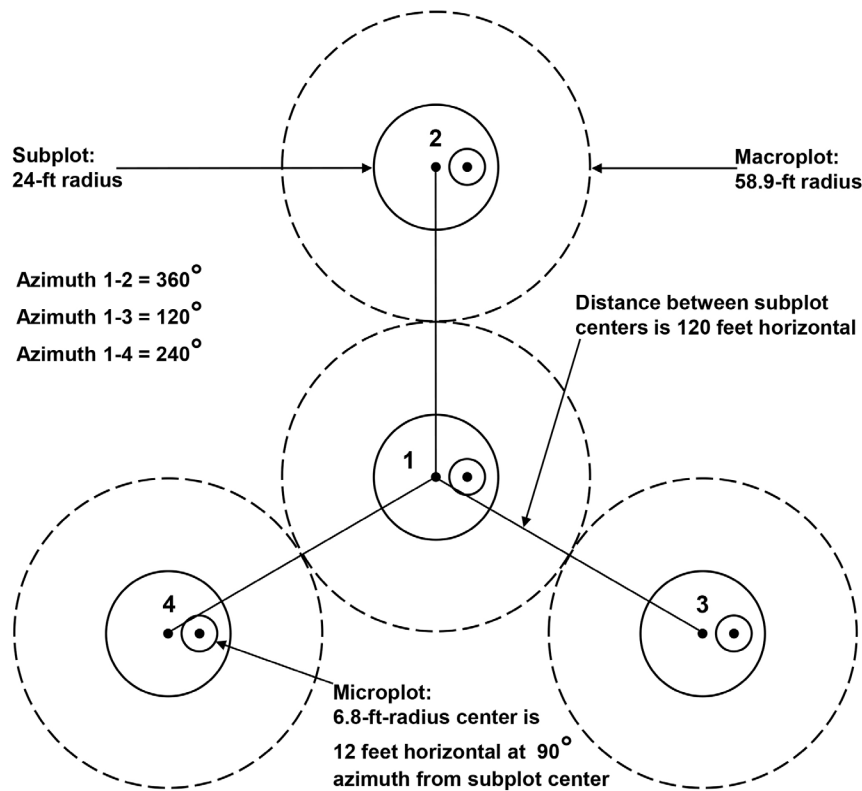


Figure 1.—National Forest Inventory and Analysis plot configuration (adapted from Bechtold and Patterson 2005).

when more than one condition is observed on a plot. “The National Core Field Guide, volume I: Field Data Collection Procedures for Phase 2 Plots, version 9.1” ([USDA Forest Service 2021a](#)), specifically section 2.0, covers field protocol mapping rules and provides field condition delineation illustrations.

MULTI-PHASE INVENTORY

FIA conducts inventories in multiple phases. Phase 1 (P1) uses remotely sensed data to obtain initial plot measurements and to stratify land area in the population of interest to increase the precision of estimates. In Phase 2 (P2), field crews visit the physical locations of permanent field plots to measure traditional inventory variables including tree species, diameter, and height. In Phase 3 (P3), field crews visited a subset of P2 plots to obtain measurements for an additional suite of variables associated with forest and ecosystem health. P3 has been replaced by Phase2+ (P2+), in which less data are collected per plot but more plots are sampled. Otherwise, P2+ follows the same paradigm as the retired P3, focusing on forest and ecosystem health. Normally, P2 and P2+ variables are acquired in the same visit. The three phases of the enhanced FIA program as implemented in this inventory are discussed in greater detail in the sections that follow.

Phase 1

Aerial photographs, digital orthoquads (DOQs: digitally scanned aerial photograph), and satellite imagery are used for initial plot measurement and stratification. Using remotely sensed, digital data, analysts determine a digitized geographic location for each field plot. A human interpreter assigns the plot a land cover/use, with primary focus on identifying forest land. All plot locations that could possibly contain forest land plus any additional plots that contained forest land at the previous measurement are selected for further measurement via field-crew visits in Phase 2.

Stratification and Precision

Forest inventory plans are designed to meet sampling error standards for area, volume, growth, and removals provided in the Forest Service directive (FSH 4809.11) known as the “Forest Survey Handbook” ([USDA Forest Service 2008](#)). These standards, along with other guidelines, are aimed at obtaining comprehensive and comparable information on timber resources for all parts of the country. FIA inventories are often designed to meet specified state level sampling errors at a 68 percent confidence limit (one standard error). See [Cochran \(1977\)](#) or [Schreuder et al. \(2004\)](#) for the derivation of standard error of a population. The “Forest Survey Handbook” ([USDA Forest Service 2008](#)) mandates that the sampling error for area cannot exceed 3 percent per 1 million acres of timberland. In addition, for the NRS-FIA region, sampling errors for volume, removals, and net annual growth have been targeted to not exceed 5 percent per 1 billion cubic feet (ft³) of growing stock on timberland. Natural variation is a property of a population e.g., the natural variability observed on most forest attributes within and between plots used by FIA to sample variables and make forest population variable inferences. FIA has limited monetary resources and the base sample size is permanent (fixed) and funded by the federal government. Consequently, FIA augments its precision requirements by using ancillary data to increase estimate variable precision without increasing sample size ([Hansen 2001](#), [McRoberts et al. 2005](#), [Smith 1991](#)). To increase estimate precision, regional units of the FIA program use satellite image-derived stratifications to produce stratified estimates of forest land area, volume, and other attributes after the forest mensuration data have been collected. However, it leaves the specific methodologies to the discretion of each regional FIA group. Land cover classifications derived from Landsat 5 TM and Landsat 7 ETM+ satellite imagery are common sources used by NRS-FIA for post-stratified estimation ([Bechtold and Patterson 2005](#)). [McRoberts et al. \(2005\)](#) describes several different approaches that have been used among the regional FIA work groups in the past.

Stratification is a method for increasing estimate precision without increasing sample sizes ([Smith 1991](#)). The procedure requires knowledge of stratum sizes and independent sampling in each stratum. In stratified sampling, the units of the population are subdivided into strata based on similarity of some characteristic (e.g., forest canopy cover). In the principle of stratification ([Stuart 1964](#)), members of different groups should be as different as possible (heterogeneous) and associates of the same group should be as similar as possible (homogeneous). The technique usually produces a weighted mean that has less variability than the arithmetic mean of a simple random sample of the whole population. [Bechtold and Patterson \(2005\)](#) provide a technical discussion of FIA’s stratified estimation

procedure. While stratification before selection provides the opportunity for larger gains in precision via unequal probability sampling designs, the FIA program uses permanent plots and has limited resources to alter sample intensities to optimize stratification or to capture changes in strata boundaries. For FIA, post-stratification still can provide gains in precision, albeit, usually more modest gains than the precision of estimates obtained with stratification before sampling. The main drawback with post-sampling stratification is that sample allocation cannot be controlled. Assuming sample sizes are random with respect to strata, then the realized sampling effort in a given stratum may contain too few samples to characterize a reliable mean and variance. However, in such cases, post-sampling stratification provides a means whereby stratification factors can be chosen in different ways, such as collapsing strata for different sets of variables in order to maximize estimate(s) precision gains ([Holt and Smith 1979](#), [Smith 1991](#)). Overall, gains in precision depend largely on the dispersion of stratum means, and differences in these means will usually result in gains and a reduction in sampling error will be realized ([Williams 1962](#)).

In general, current FIA stratification involves subdividing each state into geographic subdivisions, referred to as estimation units, based on factors such as geography, ownership, and sampling intensity. The area of each estimation unit is assumed to be known. All P1 and P2 sample points within an estimation unit are then assigned to a stratum based on remote-sensing imagery. A stratum is a nonoverlapping subset of the population under study with a known or estimated size. Plots are assigned to strata based on the best available coordinates. The stratified estimator used to compute population estimates for estimation units is described in [Bechtold and Patterson \(2005\)](#). Estimation units are considered independent, and therefore population totals and variances of population totals are additive. Precision of these estimates is governed by many factors including the sample intensity and quality of the stratification data used for estimation ([Hansen 2001](#)).

Stratification at NRS-FIA

NRS-FIA used the 2011 tree canopy cover ([TCC](#)) dataset and cartographic map product for post-stratification until December 2019. The 2016 tree canopy cover dataset was released and accessed September 2019 and is currently in use for post-stratification. The USDA Forest Service Geospatial Technology and Applications Center ([GTAC](#)) builds and maintains TCC datasets. The TCC datasets are Landsat-based and available at 30 ×30 m resolution for the conterminous United States, coastal Alaska in the southern portion of the state, Hawaii, Puerto Rico, and the U.S. Virgin Islands.

The 2016 TCC product maps data nominally between the years spanning 2011 to 2016. The 2016 TCC dataset was built for the National Land Cover Database ([NLCD](#)) and is one of several datasets maintained by the Multi-Resolution Land Characteristics Consortium ([MRLC](#)). This map product consists of a single percent tree canopy cover layer containing values ranging from 0 to 100 percent, with each individual value representing the area or proportion of that 900 m² cell covered by tree canopy. The product was also filtered and masked to eliminate obvious nontree areas and to create a more cartographically useful product. All data are projected to the USGS Albers Conical Equal Area projection using the NAD83 Datum and GRS 1980 Spheroid.

The overall NLCD database philosophy and methodology is presented in [Homer et al. \(2015\)](#) for the 2011 datasets and in [Jin et al. \(2019\)](#) for the 2016 products. [Coulston et al. \(2012\)](#) describe the methodology used to map canopy density. More information about the products, as well as file downloads, can be obtained at <https://www.mrlc.gov/> or at [USDA Forest Service FSGeodata Clearinghouse - USFS Tree Canopy Cover Datasets](#). Detailed information about the map canopy density product is found in the metadata file provided as part of the download package.

Strata for the entire NRS-FIA region were optimized based on observed natural clumping of pixel values. Using plot location information (center of the center subplot), a percent canopy density value is assigned to each plot. Plots are then aggregated into one of five strata based on the center of the center subplot. The percent canopy cover stratification scheme consists of five groupings: (1) 0 to 5 percent; (2) 6 to 50 percent; (3) 51 to 65 percent; (4) 66 to 80 percent; and (5) 81 to 100 percent. These groupings are presented for the NRS-FIA region in Figure 2.

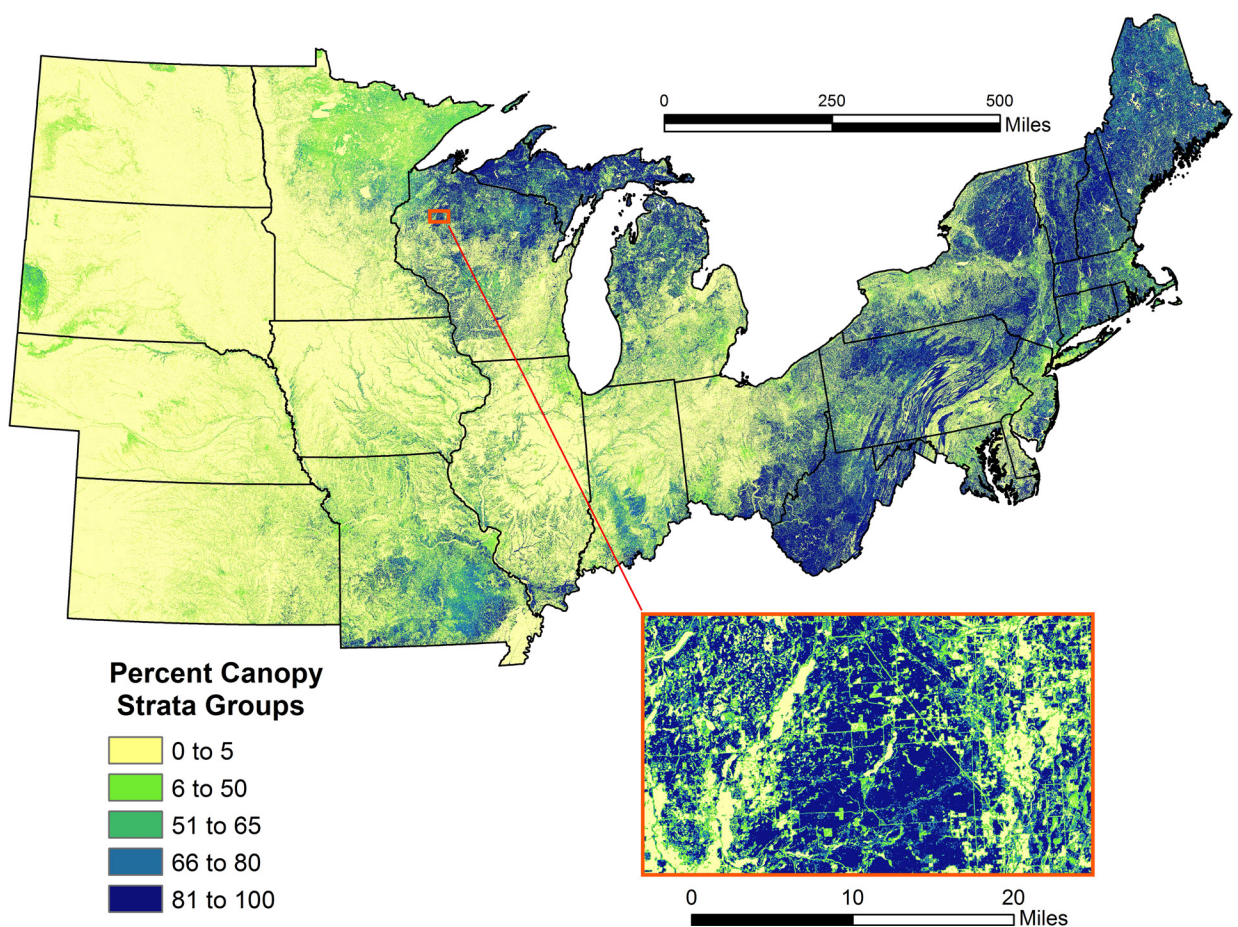


Figure 2.—Northern Research Station Forest Inventory Analysis percent canopy strata groupings used for stratification.

Pugh et al. 2018 describes the total area being evaluated at the FIA² unit or state level. An evaluation captures the time frame, type of estimates, and the associated computations (e.g., area, volume, growth, removals, and mortality) for a given inventory cycle. Refer to the FIA Database (FIADB) user guides

² FIA survey units are usually groups of counties within a State.

([Burrill et al. 2021](#) and [Pugh et al. 2018](#)) for more information on evaluations. In general, all evaluations employ the five strata groupings. Exceptions are the following indicators that use only two strata (0 to 5 percent and 6 to 100 percent): down woody materials, tree regeneration, invasives, crowns, and P2+ vegetation.

The strata are intersected with rasterized (30×30 m) versions of Topologically Integrated Geographic Encoding and Referencing (TIGER) shapefiles and ownership geospatial information (Table ST-A) to form estimation units that reduce bias due to nonresponse. When portions of plots are not sampled, the remaining sampled portions of plots within the same stratum are weighted more heavily to compensate. However, if these sampled areas are not representative of the nonsampled areas, the estimate can be sample biased. Dividing the population into estimation units defined by ownership isolates this bias (see Nonresponse Error).

TIGER shapefiles are one of the products available from the TIGER database that delineates geographic and political boundaries. Using the TIGER database, the U.S. Census Bureau calculates area for land and four water types by state and county. The basic spatial entities in the TIGER database are enumerated in the Geographic Areas Reference Manual ([U.S. Census Bureau 1994](#), see [Chapter 15](#)). TIGER classifies:

- Inland water—as all lakes, reservoirs, ponds, rivers, creeks, or similar bodies of water recorded in the TIGER data base as a two-dimensional feature (rather than as a single line). Rivers and bays that empty into large embayments, the Great Lakes and the oceans are treated as inland water from the point at which they are narrower than one nautical mile across. Note that features like intermittent water areas (e.g., streams) are considered part of the land area base and thus excluded from the inland census water definition.
- Coastal water—refers to any embayments across which one can draw a closure line from 1 to 24 nautical miles in length (inland from the point at which the closure line is one mile or less, the water is treated as inland water).
- Territorial sea—consists of water located between the 3-mile limit and the shoreline or the line that represents the extent of either inland or coastal water. It includes portions of the oceans but does not include the Great Lakes.
- Great Lakes—The five Great Lakes and inland water layer also includes embayments of the Great Lakes, using the same criteria that distinguish it from coastal and territorial waters.

The accuracy of any area measurement derived from the TIGER database is limited by the inaccuracy inherent in (1) the location and shape of the various boundary features, (2) rounding affecting the last digit in all operations that compute and/or sum the area measurement values of individual polygons, and (3) conversion of polygons to 30×30 m pixels and square meters to other measures (i.e., square meters to acres).

The pixel data defined above consists of categories, values, and counts. The pixel category is derived from the ownership and TIGER data and is used to form estimation units (e.g., a national forest, inland census water, or private lands). The pixel value is derived from the raw canopy cover data and is used to form strata according to the stratification groups defined earlier. The pixel counts are used to compute the total area of each estimation unit and the relative proportion of each stratum within an estimation unit or a stratum weight.

The plot intersection data consists of the pixel category and value for the pixel intersected by a given plot. This is used to assign every plot to an estimation unit and stratum.

Table ST-B shows the total area and number of plots within each stratum. The goal is a minimum of 10 plots intersecting each stratum. In cases where the minimum plot count cannot be met within a given stratum, that stratum is combined with the closest stratum by canopy percentage. If the minimum plot count of 10 is not met for an estimation unit, then it is combined with a nearby estimation unit preferably having similar pixel categories and a low pixel count. With only some exceptions to the 10 plots per stratum rule (e.g., Finger Lakes and Jefferson National Forests), a stand-alone estimation unit, such as a National Forest, generally will not be aggregated with another estimation unit unless the plot count for the estimation unit is less than 3. Also, the inland census water estimation unit uses an alternative minimum of 2 plots per stratum.

In summary, population estimates (Table ST-C) are based on known estimation unit areas, known stratum and estimation unit pixel counts, number of plots (e.g., P2 plots), and stratum weights. A stratum weight is the proportion of pixels assigned to the stratum in relation to the total number of pixels in the associated estimation unit. Stratum weights are used to calculate plot expansion factors (area represented by the plot). A plot expansion factor is calculated by stratum for each plot and is the product of the stratum weight and total known area of the associated estimation unit divided by the number of plots in the stratum. Population total estimates are obtained by summing the product of each plot expansion factor and mean plot attribute observation of interest across all plots. The supplementary document “Computation of FIA Plot Expansion Factors” ([USDA Forest Service 2005](#)) describes the derivation of expansion factors. For explicit FIA estimate examples, consult “The Forest Inventory and Analysis Database: Population Estimation User Guide” ([Pugh et al. 2018](#)). [Burrill et al. \(2021\)](#) provides the FIA database compilation framework.

Phase 2

In P2, field crews record a variety of data for plot locations determined in P1 to include accessible forest land. Before visiting plot locations, field crews consult county land records to determine the ownership of plots and then seek permission from private landowners to measure plots on their lands. At the plot, field crews determine the location of the geographic center of the center subplot using GPS receivers, maps, and notes from previous visits if available. For every condition on the plot (see Plot Configuration), they record the delineating attributes and other information such as land cover, stand age, site-productivity class, history of forest disturbance, and land use. For each tree, field crews record a variety of observations and measurements, including condition, species, live/dead status, lean, diameter, height, crown ratio (percent of tree height represented by crown),

crown class (dominant, codominant, suppressed), damage, and decay status. In order to facilitate tree location, field crews identify and map trees by polar coordinates (i.e., bearing and distance from plot center to each tree). All trees measured in the previous measurement during the initial plot visit are remeasured during subsequent revisits or otherwise accounted for, and any new trees that have grown onto the plot are measured. The field crew measurements are used in statistical models to calculate a variety of estimates ranging in scope from individual-tree volumes (see Data and Volume Models) to total forest biomass. The remeasurement of every tree enables the calculation of tree change components including growth, mortality, and removals. [USDA Forest Service \(2021a\)](#) covers P2 data collection procedures and [Burrill et al. \(2021\)](#) describe the P2 FIADB.

Phase 3 (1999–2010)

The third phase of the enhanced FIA program focuses on long-term, national research and monitoring on forest ecosystems health over time. P3 was administered cooperatively by the FIA program, other Forest Service programs, other Federal agencies, state natural resource agencies, universities, and the FHM program. The FHM program consisted of four interrelated and complementary activities: detection monitoring, evaluation monitoring, intensive site ecosystem monitoring, and research on monitoring techniques. Detection monitoring consisted of systematic aerial and ground surveys designed to collect baseline information on the current condition of forest ecosystems and to detect changes from those baselines over time. Evaluation monitoring studies examined the extent, severity, and probable causes of changes in forest health identified through the detection monitoring surveys. Intensive site ecosystem monitoring studies investigated regionally specific ecological processes at a network of sites located in representative forested ecosystems. Research on monitoring techniques focused on developing and refining indicator measurements to improve the efficiency and reliability of data collection and analysis at all levels of the program.

In 1999, the ground-survey portion of the detection monitoring program was integrated into the FIA program as P3 and continued through 2010. Except for ozone injury, the P3 sample consisted of a 1:16 subset of the P2 plots with one P3 plot for approximately every 95,000 acres (Fig. 3). Ozone incidence and severity of injury for selected bioindicator species was surveyed on a separate sample grid ([Smith et al. 2008](#)). P3 measurements were obtained by field crews during the growing season and included an extended suite of ecological data for the NRS-FIA region:

- [Lichen diversity and abundance](#) (data collected in inventory years 2002-2005)
- [Soil quality](#) (2000-2005)
- [Vegetation diversity and structure](#) (2001-2003 and 2007-2010)
- [Down woody materials](#) (2001-2010)
- [Ozone incidence and severity of injury for selected bioindicator species](#) (1999-2010)
- [Tree crowns](#) (2000-2010)

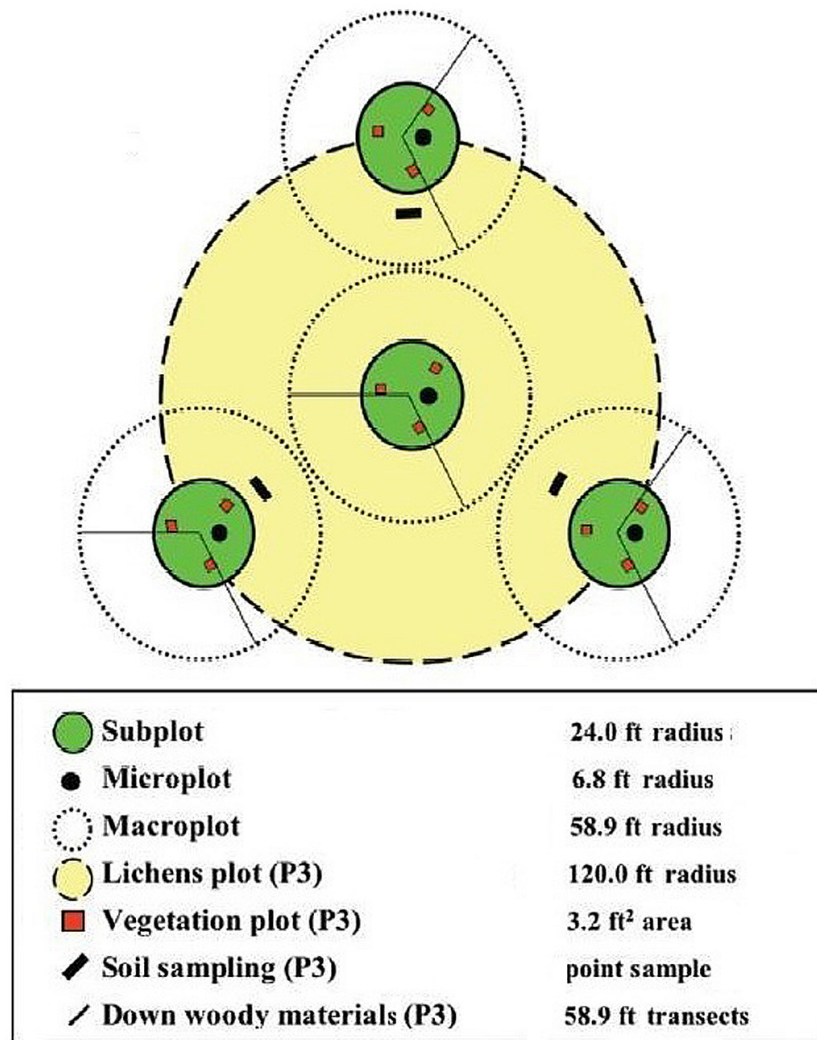


Figure 3.—Phase 2 plot configuration and Phase 3 plot configuration for lichens, vegetation diversity and structure, soil, and down woody materials inventory.

Phase 3 sampling varied by state, so P3 data collection may not have occurred in every state for every inventory year listed. All P2 measurements (except ozone injury) were collected on each P3 plot at the same time as the P3 measurements. [O'Neill et al. \(2005\)](#), [Schulz et al. \(2009\)](#), [Schomaker et al. \(2007\)](#), [Smith et al. \(2008\)](#), and [Woodall and Monleon \(2008\)](#) provide additional information on sampling and analysis of P3. The P3 database is described in [USDA Forest Service \(2014\)](#), P3 field guides are available at <https://www.fia.fs.usda.gov/library/field-guides-methods-proc/>, and P3 sampling and other research topics are covered at <https://www.nrs.fs.usda.gov/fia/topics/>.

P3 variables were selected to address specific criteria outlined by the Montréal Process Working Group for the conservation and sustainable management of temperate and boreal forests ([Montréal Process 2015](#))³ and are based on the concept of indicator variables.

³ Internationally agreed-upon criteria and indicators for the conservation and sustainable management of temperate and boreal forests: <https://montreal-process.org/>.

Observations of an indicator variable represent an index of ecosystem functions that can be monitored over time to assess trends. Indicator variables are used in conjunction with each other and with other data, such as P2 data, data from FHM evaluation monitoring studies, and ancillary data, to address ecological issues such as vegetation diversity, fuel loading, regional air-quality gradients, and carbon storage. The P2 and P3 data of the enhanced FIA program are a primary source of reporting data for the Montréal Process.

Phase 2+ (2012 to present)

For most forest health indicators, P2+ is a more refined and statistically powerful version of P3. The P3 sample included approximately 6.3 percent of the P2 plots. Since 2012, the P2+ protocols have included approximately 12.5 percent of the P2 plots (including the historical P3 plots) and the sampling intensity may increase to approximately 25 percent depending upon future funding. The soils indicator is the one exception that will remain with the 6.3 percent sample intensity using the historical P3 plots and sampling protocol. The field guide for collecting attributes on P2+ plots ([USDA Forest Service 2021b](#)) includes details on sampling sapling length, tree regeneration, vegetation profiles, invasive plants, down woody materials, soils, and tree crowns. Apart from an invasive plants inventory, which started in 2009, P2+ was initiated in 2012 with completion of the first cycle of measurements in 2018. The second cycle was initiated in 2019 and is ongoing.

Tree Regeneration

The tree seedling sample is designed to inventory and monitor the forest's regenerative capacity ([McWilliams et al. 2015](#)). Seedling counts are used along with the sapling tally to estimate tree regeneration. Information on seedlings, specifically lengths (heights), is required for estimating regeneration success. These data are used with estimates of competing vegetation derived from the vegetation profile and data on the abundance and character of invasive plants. These three components form the basis for analysis of regeneration adequacy, and hence, the ability of native forests to regenerate, and provide an indication of the expected future forest composition.

Vegetation Profile

Vegetation data are collected to describe the vegetation structure for vascular plants. The data collected provide a horizontal and vertical estimation of vegetation located within the sample area. Information on the abundance and structure of understory plant communities can be used in many ways, including to assess wildlife habitat, biomass, forage availability, grazing potential, vegetation competition with tree growth, fuel loadings from understory vegetation, and potential site productivity.

Invasive Plants

The invasive plants protocol documents the abundance of selected species and monitors change in abundance of these species over time. When combined with other plot data and other datasets, the invasive species data can be used to predict the future spread of selected species. Invasive plant species are having tremendous economic and ecological impacts on our nation's forests, and the impacts are increasing over time. Providing statistically valid estimates of the distribution and abundance of some of the most damaging species will give managers and policy makers a better understanding of the problem. Each FIA unit, in collaboration with vegetation experts, as developed a list of the most important invasive species to monitor on forested lands in their region. The invasive plants protocol was implemented on approximately 20 percent of plots from 2009 through 2011 but has been part of the P2+ sample (12.5 percent) since 2012.

Down Woody Materials

Down woody materials (DWM) are the dead material on the ground in various stages of decay. Down wood components and fuels estimated by the FIA program are coarse wood, slash, fine wood, and litter and duff depth ([Woodall and Monleon 2008](#)). DWM are important components of forest ecosystems across the country and are used to help describe:

- Quality and status of wildlife habitats
- Structural diversity within a forest
- Fuel loading and fire behavior
- Carbon sequestration (amount of carbon tied up in dead wood)
- Storage and cycling of nutrients and water (important for site productivity)

Soils

The soils indicator ([Amacher and Perry 2010](#)) is used to assess forest ecosystem health in terms of the physical and chemical properties of the soils. The soil resource is a primary component of all terrestrial ecosystems, and any environmental stressor that alters the natural function of the soil has the potential to influence the vitality, species composition, and hydrology of forest ecosystems. Specifically, soils data are collected to assess:

- Potential for erosion of nutrient-rich topsoils and forest floors
- Factors relating to the storage and cycling of nutrients and water
- Availability of nutrients and water to plants (dependent upon soil structure and texture)
- Carbon sequestration (the amount of carbon tied up in soil organic matter)
- Deposition of toxic metals from pollution
- Acidification of the soil from deposition of pollutants

Crowns

The condition of tree crowns is an important indicator of tree and forest health. The crowns indicator is used to assess the health and vigor of trees based on two metrics, crown dieback and uncompact live crown ratio. Crown dieback refers to the recent mortality of branches with fine twigs, which begins at the terminal portion of branch and proceeds toward the trunk. Uncompact live crown ratio is a percentage determined by dividing the live crown length by the total tree length.

Trees with vigorous, healthy crowns tend to have higher growth rates. By contrast, trees with damaged or degraded crowns have a reduced capacity for photosynthesis and slower growth rates. Many stressors have been correlated with crown degradation including insects, disease, weather events, senescence, competition, and atmospheric deposition. Additionally, trees with unhealthy crowns are more susceptible to mortality.

OTHER SURVEYS

National Woodland Owner Survey

The National Woodland Owner Survey (NWOS) is conducted by FIA as the social complement to FIA's biophysical inventory. The goal of the NWOS is to increase our understanding of the diverse and dynamic group of owners that is the least understood—families, individuals, and other unincorporated groups, collectively referred to as “family forest owners” ([Butler et al. 2021](#)). Specifically, the NWOS addresses the following questions:

- Who owns the forests of the United States?
- Why do they own forest land?
- What have they done with the forest land in the past?
- What do they intend to do with it in the future?

Questionnaires are mailed to selected private forest ownerships across the region following established survey protocols ([Butler et al. 2021](#)). Ownerships are selected with probability proportional to size. The greater the area of forest land owned, the greater the probability of being included in the survey. An ownership is a legal entity that has proscribed legal rights over a specific resource. In the case of family ownerships, it is composed of one or more owners (i.e., individuals). Results from the NWOS on private forest ownerships are available in [Butler et al. \(2021\)](#). Details about NWOS sampling design, estimates, and analysis procedures are available in [Butler and Caputo \(2021\)](#). These materials and other information pertaining to the NWOS can be accessed at www.fia.fs.usda.gov/nwos.

Timber Product Output Survey

The Timber Product Output Survey (TPO) is a cooperative effort by state agencies and FIA. All primary wood-using mills within a state are canvassed using mail questionnaires supplied by FIA. These questionnaires are designed to determine the size and composition of the primary wood-using industry, its use of roundwood, and its generation and disposition of wood residues. Nonresponding mills are contacted through additional mailings, telephone calls, and personal contacts until nearly a 100-percent response rate is achieved. Completed questionnaires are forwarded to FIA for compilation and analysis.

As part of data processing and analysis, all industrial roundwood volumes reported on the questionnaires are converted to standard units of measure using regional conversion factors. Timber removals by source of material and harvest residues generated during logging are estimated from standard product volumes using factors developed from logging utilization studies previously conducted by FIA (unpublished). More information on the TPO survey is available at <https://www.nrs.fs.usda.gov/fia/topics/tpo/>.

Urban FIA

Urban FIA methods and protocols are used to produce estimates of the quantity, health, composition, and benefits of urban trees and forests. The Urban FIA program complements existing regional and local efforts to provide a cohesive picture of urban forest conditions in the United States. The Urban FIA program fuses the infrastructure of the traditional, rural-focused FIA program with the urban inventory expertise provided by i-Tree, a state-of-the-art, peer-reviewed software suite from the USDA Forest Service that provides urban forestry analysis and benefits assessment tools. More information on Urban FIA, i-Tree, access to frequently asked questions, field guides, and general information regarding the program can be found at <https://www.fia.fs.usda.gov/program-features/urban/>. [Edgar et al. \(2020\)](#) provide a comprehensive review of the Strategic National Urban Forest Inventory for the United States.

MODELS FOR VOLUME, BIOMASS, AND CARBON

The FIA program strives for transparency by making the national core dataset and accompanied documentation available to the public. The FIADB is available to the public through the FIA DataMart (<https://apps.fs.usda.gov/fia/datamart/datamart.html>). Estimates can be generated for forest area, number of trees, volume, biomass, carbon, growth, removals, and mortality (see Table ST-C and Estimate Tables).

[Miles and Hill \(2010\)](#) document the methodology used in estimating live-tree gross, net, and sound volume for each state in the NRS-FIA region. Sound volume is of particular interest because it is an input to the Component Ratio Method ([Heath et al. 2009](#)) used in live-tree biomass and carbon estimates ([Radtke et al. 2017](#)). [Woodall et al. \(2011\)](#) provide methods and models for estimating aboveground volume, biomass, and carbon for trees in the United States. [Woodall et al. \(2015\)](#) present the U.S. forest carbon accounting framework.

NRS-FIA uses volume models specific to different regions of the northern United States. The Lake States model is used in Michigan, Minnesota, and Wisconsin ([Hahn 1984](#)). The Plains States model is used in Kansas, Nebraska, North Dakota, and South Dakota ([Hahn and Hansen 1991](#)). The Central States model is used in Illinois, Indiana, Iowa, and Missouri ([Hahn and Hansen 1991](#)). The Northeast States model is used in Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, and West Virginia ([Scott 1981](#)). [Hansen \(2002\)](#) details the regional methods used to create the volume models.

Integration with Previous Inventories

To improve consistency, efficiency, repeatability, and reliability of the inventory, updates have been implemented over time. FIA endeavors to be precise in definitions and implementation. The program tries to minimize changes to these definitions and to collection procedures, but that is not always possible or desirable in a world of changing values, objectives, and technology. Change is inevitable. FIA strives for clarity and transparency to facilitate quality analyses of the inventory data. The changes presented below apply to the NRS-FIA region. Consult FIA state reports for information on changes made at the state level.

For consistency sake, a national plot configuration was implemented by all five regional FIA units in 1999. Prior to this plot configuration, periodic inventories used both fixed and variable-radius subplots. The design uses a cluster of fixed-radius subplots exclusively (see Plot Configuration). Both designs have strong points, but they often produce different classifications for individual plot characteristics. [Scott \(1993\)](#) presents the optimal cluster design developed for the FHM Program of the United States that was adopted by the FIA program. As stated in Plot Configuration section, the design reduces between-plot attribute measured variance and decreases the total number of plots necessary to achieve a given precision standard. The design is a cost-effective method for sampling a core set of common measurements using standardized methods for national sample surveys.

The annual inventory includes observations from all forest land types, whereas, observations on reserved and “other” forest land were limited in periodic inventories. Methods for determining stocking, forest type, and stand-size estimates have been improved twice since the annual inventory started. All annual data have been updated with the improvements to facilitate easier temporal analyses. In addition, forest types in the annual inventories have been updated compared to periodic inventories where fewer and less precise forest types were assigned. FIA uses a field-crew recorded stand-size class and forest type when a condition is less than 25 percent of the plot area; otherwise, stand-size class and forest type are assigned with an algorithm using trees tallied on the plot. Field-crew recorded classes are available for all conditions, regardless of size, and consider trees on and adjacent to the plot, while the algorithm only uses trees tallied on the plot. Most analyses use the algorithm assigned stand-size class and forest type whenever available.

[Arner et al. \(2003\)](#) describes the stocking algorithms used to assign stand stocking class, stand-size class, and forest type. A relative stocking measure is applied where stand density is expressed in relation to a standard that accounts for the effects of stand development and species composition. The growth potential of a stand is reached when it is fully stocked. A standard for some fully stocked medium-diameter stands (plurality of poletimber-size trees) is a basal area of 80 square ft/acre or more. Using this example, a fully stocked small-diameter stand, with a basal area less than 80 square ft/acre, would have enough trees to attain a basal area of 80 square ft/acre when the trees reach poletimber size. By species or forest type, tree diameter, tree crown position, and site factors (e.g., rock outcrops and soil moisture) dictate the stocking value of each tree. The individual tree stocking values are summed to determine stand stocking class, stand-size class, and forest type.

In an effort to increase consistency among states and across inventory years, a refined set of procedures determining reserve status was implemented with version 6.0 of the FIA field manual ([USDA Forest Service 2012](#)), which took effect with the 2013 inventory year (beginning in October 2012). Furthermore, all previously collected annual inventory data (1999 to present) have been updated using the proposed standardized interpretation. Timberland estimates generated for annual data prior to the 2013 inventory year differ from previously published estimates. The improved implementation of the reserve status definition increases the spatial and temporal precision of timberland estimates allowing for higher quality trend analyses and potentially better forest management decisions.

COMMON SOURCES OF ERROR

In statistical terminology, error refers to random variation associated with certain procedures and processes. In the strictest statistical interpretation, bias refers to an estimator that has an expected value that differs from the “true value” of the population parameter being estimated ([Cochran 1977](#)). However, other sources of bias may be present in the form of systematic deviations resulting from sampling, model predictions, or measurement methods that are not implemented as designed. Sampling, measurement, prediction, and nonresponse are the common sources of error in sample-based estimates. In theory, each of the sources contributes to the total variability; however, random sampling error is often the only source of variability used to indicate the precision of the estimate. This statistic represents the expected variation in the estimate that would occur if the entire sampling and estimation process were to be repeated many times.

FIA reports random sampling error for each estimate but treats measurements and model predictions as observations without error, and their contribution to the error of an estimate is not explicitly accounted for. FIA attempts to minimize nonresponse error and sampling bias via the estimation methods, including the construction of estimation units and strata (described in more detail below).

Sampling Error

The sampling process (selecting a random subset of a population and calculating estimates from this subset) causes estimates to contain error they would not have if every member of the population (e.g., every tree in the state) had been observed and included in the sample (a census or complete enumeration of a population). Sample plots are located randomly within a hexagonal grid that covers the United States and abroad. The result is a systematic unaligned sample for which simple random sampling estimators are used.

Procedures for statistical estimation are described in [Bechtold and Patterson \(2005\)](#).

Statistical notation follows [Cochran \(1977\)](#). [Pugh et al. \(2018\)](#) presents examples using Structured Query Language (SQL) to obtain population estimates and associated sampling errors.

Every estimate has an associated sampling error that is typically expressed as a percentage of the estimated value (the estimated value plus or minus the sampling error). This sampling error is the primary measure of the reliability of an estimate. State reports utilize a sampling error based on one standard error. See Table ST-99.

Estimators used by FIA are unbiased under the assumptions that the sample plots contain a random sample of the total population and the observed value for any attribute is the true value for that variable of interest. Deviations from these basic assumptions are not reflected in sampling error computations.

Measurement Error

Errors associated with the methods and instruments used to observe and record the sample attributes are called measurement errors. On FIA plots, attributes such as the diameter and height of a tree are measured with various instruments, and other attributes such as species and crown class are observed without the aid of an instrument. On a typical FIA plot, 15 to 50 trees are observed and 15 to 20 attributes are recorded on each tree. In addition, many attributes that describe the plot and conditions on the plot are observed. Measurement protocol deviations, such as tree diameters consistently being measured at an incorrect place on the tree, can also be reflected in other associated estimates (e.g., tree volume models use tree diameter). Even without measurement deviations, random error in the measurements can reduce the precision of estimates if the plot-to-plot variation is increased. See Data Collection Quality Assurance and Quality Control for methods NRS-FIA uses to minimize and track measurement error (Table ST-D and ST-E)

Prediction Error

Errors associated with using mathematical models (such as volume models) to estimate attributes of interest based on observed samples or other modeled attributes are called prediction errors. In state reports, the primary attributes of interest include area, number of trees, volume, biomass, growth, removals, and mortality. Estimates of area and number of trees are based on direct observation and do not rely on prediction models. Models are used to predict volume and biomass estimates of individual-tree volumes. [Hahn \(1984\)](#), [Hahn and Hansen \(1991\)](#), and [Scott \(1981\)](#) address estimates of prediction errors associated with the volume models for NRS-FIA. Change estimates such as growth, mortality, and removals are based on these model-based predictions of volume from both the current plot measurements and the measurements taken in the previous inventory.

When comparing FIA estimates to other data sources, users need to be aware of the prediction models used in both estimates. If both estimates are based on the same prediction models with matching fitted parameter values, the prediction bias of one estimate should cancel out that of the other estimate. If the estimates are based on different prediction models, the prediction error of both models must be considered.

Nonresponse Error

Nonresponse error occurs when crews are unable to make measurements within a plot (or a portion of a plot). Nonresponse falls into three classes:

- Denied access—Entire plots or portions of plots where the field crew is unable to obtain permission from the landowner to measure trees on the plot.
- Hazardous/inaccessible—Entire plots or portions of plots where conditions prevent a crew from safely accessing the plot or measuring trees on the plot.
- Other—Plots where the field crew is unable to obtain a valid measurement for reasons other than those stated.

Nonresponse has two effects on the sample estimate. First, it reduces sample size, which leads to an increase in sampling error. Second, when nonresponse occurs in the survey, the mean and variance are computed based on an incomplete sample size, and the estimate can be sample biased. The “nonresponse” part of the population often has a different mean from the “response” (i.e., sampled or observed part) portion of the population ([Cochran 1977](#)). The degree of this bias may be unknown but can become large if the nonsampled population differs greatly from the population that can be observed. Even an overall nonresponse rate of 1 percent can cause considerable bias if not properly accounted for. This is particularly true in states and estimation units that are not heavily forested. The main source of nonresponse is denied access to plots, which occurs primarily on lands in private ownership. Nonresponse occurs less frequently for plots on nonforest land and water because crews rarely need to physically occupy the plot, and permission is not needed because the observation can be obtained from aerial imagery or other sources of remotely sensed information. Nonresponse bias can be mitigated by isolating ownerships and land types prone to nonresponse into their own strata and estimation units.

NRS-FIA mitigates bias by using estimation units defined by ownership categories (e.g., national forest, other public, census water, and private) and strata defined by canopy cover bins; see Table ST-F as described earlier. NRS-FIA removes plots that are totally nonresponse (replacement plots are not obtained) from the sample, and stratum estimates (means, totals, and sampling errors) are obtained from only those plots with at least partial observations. The net effect in the estimates of means and totals is that the average of the observed measurements within plots by stratum or strata becomes the estimate for all nonresponses within that stratum or strata and respective estimation unit. The nonresponse rate in one stratum does not affect the estimate in other strata.

In Table ST-1 of the state reports, denied access, hazardous, and other nonresponse are acknowledged as classes in the NRS-FIA region for which estimates on attributes such as forest area and timber volume are unable to be provided. However, the total estimated area in each of the nonresponse classes is reported. In the remaining estimate tables, the sample with observations are treated as the complete random sample of the state, so there are no nonresponse classes.

Nonresponse plots in the inventory are not permanently removed from the FIA sample. In future inventories, field crews will again attempt to access and obtain measurements within these plots. At that time, permission to access these plots may be obtained, hazardous conditions may have changed, and other circumstances that caused plots to be dropped from a specific inventory cycle may be different.

DATA COLLECTION QUALITY ASSURANCE AND QUALITY CONTROL

To ensure that all NRS-FIA observations are made to the highest standards possible, a regular program of quality assurance and quality control is an integral part of all NRS-FIA data- collection efforts. This program begins with the documentation of protocols used in the inventory, followed by extensive crew training. All crew members must pass a certification session for every new field guide version released (typically an annual event) and must be assessed (work of crew member is graded) annually at a minimum of four check plots. New NRS- FIA crews have 8 weeks of one-on-one training followed by training plots (no official grading) and check plots at random times. Communication among crews is continuous, addressing issues and questions as needed. Errors found in initial measurements are corrected on training plots but not normally corrected on check plots.

Blind checks are another quality assessment tool where a random sample of at least 4 percent of all plots are measured independently by a quality assurance (QA) crew. QA crews have as much or more experience and training in FIA field measurements as that of standard FIA crews. The standard crew and QA crew measurements are recorded and stored in a database, but they are not compared in the field and no initial measurements are changed.

Blind check measurements are used to observe how often individual field crews are meeting a set of measurement quality objectives (MQOs) that are set for every data item collected and to assess the overall compliance among all crews. Each MQO consists of two parts: a tolerance or acceptable level of measurement error and an objective in terms of the percent of measurements within tolerance. Table ST-D shows the compliance rates for various measurements. Data in the column labeled “All NRS States” are derived from all measurements made by NRS-FIA crews within the entire 24-state region. Training and supervision of crews is a regional effort, and crews often work in more than one state. Regional data quality observations reflect the overall measurement quality of all data collected by NRS-FIA.

In the NRS-FIA region, many variables, such as d.b.h., have a low tolerance (± 0.1 inch) and a high percentage of data within the tolerance (e.g., at least 90 percent). Measurements for determining tree size class are precise. In contrast, a few variables such as stand age have a larger tolerance (± 10 years) and less data within the tolerance (e.g., less than 80 percent). The estimate of stand age is based on the composition of all age classes within a stand. Often, stands are heterogeneous by age but a single value must be assigned to them. Sometimes this confounds analysis of stand age over time. In addition to percent compliance to MQOs, the average differences between measurements obtained by standard field versus QA field crews is identified. These differences and confidence intervals (based on parametric bootstrap estimates) are presented for continuous variables (e.g., diameter and height) in Table ST-E. Analogous comparisons using discrete or coded variables (e.g., crown class and tree status) are not appropriate.

Blind check measurements do not provide observations of bias in field measurements (average difference between field measurements and true values) because they are paired observations of two field measurements. The QA crew in these blind checks typically has more training and experience with FIA field measurements than the standard crew, but both crews use the same methods and instruments to obtain measurements. These methods have been identified as the best available and selected for nationwide use by FIA; they are commonly used by similar natural-resource inventories. A basic assumption is that when applied correctly these methods provide unbiased observations of the attribute they are designed to measure. Under this assumption, average differences in Table ST-E are due to the difference in experience and training between the standard field and QA crews.

Nonresponse bias was previously identified as a potentially serious source of error (see Nonresponse Error). Field crews follow a thorough protocol to limit nonresponse ([USDA Forest Service 2021a](#)). If the crew is not successful in contacting a landowner by phone or in person then a letter is sent to the landowner requesting access to the plot. After 20 days of no response, a second letter is sent to the landowner. After 30 days of no response following the second letter, the plot is classified as denied access. All attempts to contact the landowner and any correspondence are documented and saved.

In addition to regular training, monitoring, and assessment, quality control is facilitated by using portable data recorders (PDR) and logic checks as crews enter observations from a plot. As a crew member enters an observation, the PDR limits entries to valid codes for discrete variables or checks for potentially out-of-range values for continuous variables. For example, a height of 80 feet for a 5-inch d.b.h. tree would produce an alert on the PDR. For remeasurement plots, current entries are compared against information from

the previous visit and potential issues are communicated through the PDR. For example, the PDR would produce an alert if a tree was a green ash (*Fraxinus pennsylvanica*) in the previous visit but the current entry indicates that the tree is a white ash (*Fraxinus americana*). Hundreds of logic checks are run on the PDR while on the plot. Analogous logic checks are administered every time data are migrated from one location to another until the data are finally posted in the FIADB.

CONDUCTING TESTS FOR STATISTICALLY SIGNIFICANT DIFFERENCES

Analysts often try to determine whether the difference between estimates is statistically significant. A common but incorrect method identifies a significant difference when the ranges of two estimates fail to overlap based on a specified level of uncertainty (e.g., one standard error). For example, the estimate of timberland acreage for the southern Lower Peninsula of Michigan ranged from 2.4 to 2.5 and from 3.5 to 3.6 million acres (one standard error) for the 1980 and 2014 inventories, respectively. Since these ranges do not overlap, one might conclude that there is significantly more timberland in the southern Lower Peninsula of Michigan in 2014 versus 1980. Although the estimate increased substantially, the comparison does not account for covariance. Samples measured in 1980 and again in the 2014 inventory are not independent observations and thus have covariance.

[Westfall et al. \(2013\)](#) found that bias can occur when testing for differences and not accounting for covariance. Standard analytical tools accounting for covariance in FIA estimates are not available yet. The Difference Tester (under development) will account for covariance when comparing total (totals version) and per-acre (ratio version) estimates of a chosen attribute over time. A calculated z-score and p-value will indicate the likelihood that a difference is different from 0 (no difference). Difference Tester will test for statistically significant change in forest land area and various tree attributes. It will be possible to identify changes in tree carbon, tree biomass, volume of live trees, volume of standing dead trees, tree sawlog volume, number of live trees, and number of standing dead trees. Comparisons of total and per-acre estimates will be possible. A user will need knowledge of the FIA inventory, FIA database, SQL, and statistics to effectively use Difference Tester.

Currently in FIA, sample sets of change are only identified between consecutive plot visits. Hence, estimates of change with associated sampling errors are only available between consecutive plot visits. Following this restriction, the Difference Tester will only identify differences between consecutive plot visits. For example, one will be able to test for change associated with the 2017 inventory which covers change from plots measured in 2006-2011 and then again in 2011-2017. Change detection between nonconsecutive plot visits (e.g., 1980 inventory to 2017 inventory) will not be possible with the Difference Tester. Currently, there is SQL that generates statistics accounting for covariance. The SQL for total and ratio estimates is in the REF_DIFFERENCE_TEST_TOTALS and REF_DIFFERENCE_TEST_PER_ACRE table of the FIADB, respectively. This SQL will be the primary code base of the Difference Tester.

ADDITIONAL INFORMATION

Books and Publications

There are several noteworthy introductory books available on sampling from a natural resources standpoint. For example, [Schreuder et al. \(2004\)](#) serves as a broad introduction to the statistical techniques of sampling natural resources; starting at a very basic level and progressing to more advanced methods. The book includes introductory material, much of which is taken from the classic introductory book by [Freese \(1962\)](#). They also include supplementary tools and materials and identify key references for readers wishing to pursue the subject further.

[Bechtold and Patterson \(2005\)](#) explain the three phases of FIA's sampling design, describe the sampling frame and plot configuration, present the estimators that form the basis of FIA's National Information Management System, and show how annual data are combined for analysis. They also reference several internet-based supplementary documents that provide greater detail about some of the more obscure aspects of the sampling and estimation system, as well as example calculations for most of the common estimators produced by FIA.

Websites

National Forest Inventory and Analysis Program

- Forest Inventory and Analysis National Program (<https://www.fia.fs.usda.gov/>)
- FIA Library (<https://www.fia.fs.usda.gov/library/index.php>)
- Database documentation (<https://www.fia.fs.usda.gov/library/database-documentation/index.php>)
- Field guides, methods, and procedures (<https://www.fia.fs.usda.gov/library/field-guides-methods-proc/index.php>)
- Sampling and estimation documentation (<https://www.fia.fs.usda.gov/library/sampling/index.php>)
- Data and Tools (<https://www.fia.fs.usda.gov/tools-data/>)
- Design and Analysis Toolkit for Inventory and Modeling (DATIM) (<https://www.fs.usda.gov/emc/rig/DATIM/index.shtml>)
- EVALIDator Web version (<https://apps.fs.usda.gov/fiadb-api/evalidator>)

Northern Research Station Forest Inventory and Analysis Program

- Northern Research Station Forest Inventory and Analysis (<https://www.nrs.fs.usda.gov/fia/default.asp>)
- Links to NRS-FIA field guides (<https://www.nrs.fs.usda.gov/fia/data-collection/>)
- State-level annual reports (<https://www.nrs.fs.usda.gov/fia/data-tools/state-reports/default.asp>)
- Forest Service publications (<https://www.nrs.fs.usda.gov/pubs/>)

Accessing 5-year State Reports and Tables

Beginning with the 2014 inventory year, tables are available online as supplemental files that accompany the NRS-FIA 5-year state reports. Tables are in a Microsoft® Excel format and can be accessed from the “Publications Toolbox” located from the introductory index page for a state’s 5-year report.

To find a report for any particular state:

- Go to <https://www.nrs.fs.usda.gov/pubs/>
- In the upper search window, type in the name of the state in which you are interested (e.g., Missouri Forests).
- In the long list of titles that include your state’s name, search for the report titled “STATE Forests 20xx”, where “STATE” is the state you are searching for. (e.g., Missouri Forests 2018). Click on the title to open the introductory page.

The screenshot shows the USDA Northern Research Station website. The top navigation bar includes links for Forest Service Home, About the Forest Service, News, Jobs, Maps, Help, and Contact Us. The main content area is titled 'Search for Publications' and includes a search bar with the text 'Missouri Forests' and a 'Search' button. Below the search bar, there is a section for 'Search for Publications' with radio buttons for 'Northern Research Station' (selected) and 'All Records in Treesearch'. The search results are displayed in a table with columns for Title, Author, and Year. The table lists several publications, including 'Missouri forests 2018: summary report' and 'Forests of Missouri, 2019'. Red circles highlight the search criteria and the 'Missouri forests 2018: summary report' entry.

Title	Author	Year
Responses of natural and artificial pin oak (<i>Quercus palustris</i>) reproduction to a sequence of silvicultural release treatments in bottomland hardwood forests in southern Missouri	Hayford, Isaac ; Knapp, Benjamin O.; Kabrick, John M.	2023
Family forest (10+ acres) ownership characteristics: Missouri, 2018	USDA Forest Service.,	2021
Forests of Missouri, 2020	USDA Forest Service.,	2021
Missouri forests 2018: summary report	Goff, Thomas C.; Albright, Thomas A.; Butler, Brett J.; Crocker, Susan J.; Kurtz, Cassandra M.; Lister, Tonya W.; McWilliams, William H.; Morin, Randall S.; Nelson, Mark D.; Piva, Ronald J.; Riemann, Rachel ; Vickers, Lance ; Walters, Brian F.; Westfall, James A.; Woodall, Christopher W.	2021
Forests of Missouri, 2019	USDA Forest Service.,	2020
The impact of climate change on forest systems in the northern United States: Projections and	Moser, W. Keith; Butler-Leopold, Patricia ; Hausman, Constance ; Iverson, Louis; Ontl, Todd ; Brand, Leslie ; Matthews.	2020

Computer screen shot of publication search page for Missouri Forests FIA report.

- Find the “Publication Toolbox” on the upper right-hand side of the page. The tables will be in a zipped file.

See the previous section “Tables” (page 2 of this report) for an explanation of the table-naming conventions. For state reports dated 2018 and after, the NRS-FIA 5-year report is in the form of a digital collection of StoryMaps (Esri, Redlands, California). A summary report (pdf format) is published to accompany the digital collection. Links to the digital collection, along with the tables, are available in the toolbox.

The screenshot shows the Northern Research Station website. The header includes the USDA logo and the Northern Research Station name. The main navigation bar has links for Forest Service Home, About the Agency, and Contact the National Office. The left sidebar contains a search bar and a list of navigation links: Research Programs, Publications & Products (with sub-links for Rooted in Research, Research Data Archive, Podcasts, and Video & Webinars), Tools & Applications, Locations, Scientists & Staff, About NRS, Partnerships, and NRS News. The main content area is titled 'Missouri forests 2018: summary report' and lists the authors: Goff, Thomas C.; Albright, Thomas A.; Butler, Brett J.; Crocker, Susan J.; Kurtz, Cassandra M.; Lister, Tonya W.; McWilliams, William H.; Morin, Randall S.; Nelson, Mark D.; Piva, Ronald J.; Riemann, Rachel; Vickers, Lance; Walters, Brian F.; Westfall, James A.; Woodall, Christopher W. The page also includes a 'Publication Toolbox' on the right, which is circled in red. The toolbox contains the following links: Download PDF (2.0 MB), Missouri Forests 2018: Interactive Report, Zip file containing tree species list, estimate tables, and quality assurance tables in Excel format (1.9 MB), and Statistics and quality assurance for the Northern Research Station Forest Inventory and Analysis Program.

Computer screen shot of index page for Missouri Forests 5 year report, including the Publication Toolbox where the digital collection and supplemental information, including estimation tables, can be downloaded.

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