BACKGROUND FOR AFIS, THE ANNUAL FOREST INVENTORY SYSTEM

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ABSTRACT.—The Annual Forest Inventory System, AFIS, was jointly proposed and developed in the early 1990s by the Forest Inventory and Analysis programs of the North Central and Rocky Mountain Research Stations of the USDA Forest Service and the Forestry Division of the Minnesota Department of Natural Resources. The objective of AFIS was to establish the capability of producing standard statewide inventory estimates on an annual basis. The context in which AFIS was proposed was defined by two crucial constraints: the average annual cost could be no greater than that of periodic inventories and the precision of estimates could be no less than that obtained from periodic inventories. The system designed to achieve the objective while simultaneously satisfying the constraints included an annual sample of measured field plots, satellite-based remote sensing for area estimation and vegetation change detection, growth and mortality models for updating plots measured in previous years, and computerized databases of field plot information.

INTRODUCTION

The Renewable Forest and Rangeland Resources Planning Act of 1978 requires that the USDA Forest Service conduct inventories of forest land in the United States to determine its extent and condition and the volume of timber, timber growth, and timber removals. Under the auspices of the agency's national Forest Inventory and Analysis (FIA) program, five regional research stations conduct periodic, statewide forest inventories and publish summary reports for individual states. The data and reports resulting from these inventories have been the primary source of information on the status, trends, and use of public and privately owned forest lands in the Eastern United States. This information has been crucial to estimating current forest resource information and monitoring forest ecosystems.

The timeliness, precision, and spatial attributes of products resulting from the Forest Service's periodic approach to forest inventories have been issues of concern to users of inventory data. FIA clients have noted a variety of deficiencies associated with these periodic inventories: (1) the precision of estimates decreases over time due to factors such as changes in land use and tree growth, mortality, and removals; (2) the point-in-time nature of estimates is compromised by the necessity of conducting inventories in heavily forested states over multiple years; (3) the estimates are difficult to integrate across state boundaries because they may be conducted at dates differing by as many as 10 years; and (4) immediate estimates of the effects of catastrophic events such as ice storms, hurricanes, fire, and insect infestations are usually impossible.

In addition, the consequences of management alternatives are often difficult to determine. Changes in the management of public lands have resulted in substantial reductions in timber harvest on National Forest lands in some regions (USDA-FS 1998) with the anticipated response being a sharp increase in timber harvest in other regions (USDA-FS 1995). As a result, many segments of the populace are expressing concerns regarding the ecological and economic sustainability of U.S. forests: some segments are concerned with maintaining biological diversity; some are concerned with satisfying future economic and societal needs; while some are simply concerned that forest management practices conform to their personal value systems. These concerns demand integrated assessments based on current and accurate data to identify trends, relate trends to causes, and evaluate the consequences of alternative management strategies.

FIA clients have recognized these deficiencies and concerns and have proposed solutions such as increasing the sampling intensity, reducing the period between inventories, and conducting midcycle updates. While these solutions might resolve some of the deficiencies, they are expensive to implement and constitute a piecemeal approach to dealing with the problems inherent in periodic inventories.

BACKGROUND

In 1991, FIA scientists at the North Central Research Station (NCRS), USDA Forest Service, proposed research to develop procedures for conducting annual statewide forest inventories. At about the same time, the Resource Assessment Unit, Division of Forestry, Minnesota Department of Natural Resources (MN DNR) initiated investigations into the use of remote sensing technology to support continuously updated inventory on a production basis. Recognizing their mutual interest, the two units contacted the FIA unit at the Rocky Mountain Research Station (RMRS), which had national responsibilities for FIA techniques research. The three-way collaboration resulted in a vision for a comprehensive forest inventory system incorporating an annual sample of measured field plots, satellite-based remote sensing, a computerized database of plot measurement data, and a set of growth and mortality models to update information for plots measured in previous years. This system, the Annual Forest Inventory System (AFIS), had as its overarching objective the development of a set of procedures for forest inventory that would be capable of producing standard statewide forest inventory estimates on an annual basis. Development of AFIS was guided by the following set of constraints:

1. Cost: the cost of implementing and maintaining AFIS in a state would not exceed the average annual cost of conducting periodic inventories.
2. Precision: the precision of the annual AFIS inventory estimates would be as great or greater than those obtained from periodic inventories.
3. Plots: AFIS would maintain the existing network of FIA plots as much as possible.
4. Design: AFIS would modify but not radically redesign FIA procedures.

THE AFIS APPROACH

To a large degree, the first two constraints dictated much of the form that AFIS would take. The 1990 periodic inventory of Minnesota (Miles *et al.* 1995) reported approximately 16.7 million acres of forest land and featured estimates based on data for 13,618 plots. Of these plots, 10,212 plots had been measured between 1986 and 1991, and 3,406 plots had been updated to 1990 using the STEMS growth and mortality models (Belcher *et al.* 1982). Funding for this inventory came from the Forest Service and the State of Minnesota with the latter contributing funds to measure twice as many additional plots as were funded for measurement by the Forest Service. The 3,404 plots whose measurement was funded by the Forest Service were described as a single intensity inventory, while the total of 10,212 plots (1/3 of 10,212 plots) was described as a triple intensity inventory. Thus, the cost constraint for a single intensity inventory was quantified as 262 plots per year, the quotient of 3,404 plots and the 13 years since the previous inventory.

The precision of the triple intensity inventory resulted from data for 13,618 plots distributed over approximately 16.7 million acres. Using the previous 1:2 Federal to State funding ratio, 4,539 of these plots were allocated to the Forest Service's single intensity inventory. Thus, the precision constraint for a single intensity inventory was quantified as no more than 3,675 acres per plot, the quotient of 16.7 million acres and 4,539 plots. Note the apparent incompatibility between the precision constraint of 3,675 acres per plot and the approximately 63,600 acres per plots resulting from the cost constraint of 262 plots per year.

The AFIS solution for simultaneously satisfying the annual cost and precision constraints was to use models to update to the current year information for a large proportion of plots measured in previous years. In particular, of the 4,539 plots for which data would be required annually, 262 plots would be measured while current information for the remaining 4,277 plots would be obtained by using models to update previous measurements. Based on more than a decade of experience, FIA scientists at NCRS were confident that the models would produce adequate results, on average over large areas, for plots that had not had substantial vegetation loss due to mortality, harvest, or other factors. However, the adequacy of results for disturbed plots would be questionable. Thus, the AFIS approach to annual inventories required identification of disturbed plots so that data for them could be obtained from field measurements rather than from model updating. The proportion of forest area in Minnesota losing substantial vegetation each year was estimated at 2 percent or less. Therefore, of the 262 plots to be measured annually, approximately 91 plots (2 percent of 4,539 plots) would be selected because they had experienced substantial disturbance, while the remaining 171 would be selected from among undisturbed plots.

At the rate of 262 plots per year, slightly more than 17 years would be required to complete a single measurement of all the 4,539 plots necessary to satisfy the single intensity precision constraint. However, some plots measured early in a 17-year cycle would be expected to experience vegetation disturbance due to harvest or other removals later in the cycle and therefore would require a second measurement before the end of the cycle. Thus, the time to complete at least one measurement of all plots was extended to 20 years.

MN DNR proposed using remote sensing techniques with satellite data obtained from the Landsat-5 Thematic Mapper as a means of predicting the disturbance status of plots. The basis of the predictions would be differences observed between two sets of TM data for the same area, separated by one or more years, but for the same time of year. Initially, a new set of imagery and a set from 4 years in the past were obtained, indices of vegetation change were calculated for each pixel, and a disturbance status was predicted for each plot. All plots predicted to have experienced substantial vegetation loss would be selected for measurement within the succeeding 4 years, the planned interval between acquisitions of new imagery and predictions of vegetation change.

In summary, current information for 4,539 plots would be required annually to satisfy the precision constraint. Of these 4,539 plots, information for approximately 4,255 plots would be based on measurements in previous years that had been updated to the current year using models, while field measurements would be obtained for the remaining approximately 262 plots. The 262 plots measured in a year would include a random 25 percent sample of those predicted to have experienced substantial vegetation loss based on the most recent remote sensing analyses. The number of these disturbed plots selected each year was expected to be approximately 91 plots. The remaining plots to be measured in a year, expected to be approximately 171 plots, would be randomly selected from among the undisturbed plots with probability of annual selection inversely related to the time since last measurement; i.e., plots that had been recently measured would have a low probability of selection, while plots whose remeasurement interval was approaching 20 years would be selected for remeasurement with a probability approaching one.

FUNDING AND SUPPORT

Funding to support the AFIS research effort was contributed primarily by the USDA Forest Service and the State of Minnesota and secondarily by states and forest industry groups in the Lakes States. NCRS and RMRS contributed the salaries and operating expenses for the equivalent of four full-time scientists whose efforts included construction of a computer database, data editing, development of the sampling design, initial work on construction of diameter growth models and analysis of uncertainty, and preliminary data analyses. MN DNR contributed the salaries and operating expenses for scientists conducting remote sensing research on techniques for using satellite data to distinguish between forest and nonforest lands and to detect forest areas that had lost substantial vegetation. In addition, MN DNR funded the measurement of approximately 750 plots per year from 1992 to 1999. This latter funding was crucial to initiating AFIS while simultaneously proceeding with periodic inventories in the other states for which NCRS has inventory responsibilities. Without this commitment by MN DNR, AFIS would not have been financially feasible. Additional funding to support the modeling research was obtained from the States of Wisconsin and Michigan and forest companies and corporations including ABT, Blandin Paper, Champion International, Colonial Craft, Louisiana Pacific, Mead, Potlatch, Tenneco, and Weyerhaeuser. The latter additional funding was held and disbursed by the Great Lakes Forest Alliance.

EPILOGUE

In the mid-1990s, the Southern Research Station (SRS) implemented an annual inventory system that was both similar and dissimilar in key aspects to the NCRS system. Although the NCRS effort was initiated before the SRS effort, the political and industrial support generated by SRS was primarily responsible for placing annual forest inventories on the national FIA agenda. With passage of the 1998 Farm Bill, formally known as the Agricultural Research, Extension, and Education Reform Act of 1998, Congress required the USDA Forest Service to conduct annual forest inventories in all states. Two features of national annual forest inventories emerged as a result of the Farm Bill: the federally funded base sample would feature one FIA field plot per approximately 6,000 acres and 20 percent of these plots would be measured each year. Based on 16.7 million acres of forest land in Minnesota, the Federal base sample would require approximately 2,800 plots of which approximately 560 would be measured each year. These two requirements of the Farm Bill, one plot per 6,000 acres and measurement of 560 plots per year, greatly relaxed the original AFIS constraints of one plot per 3,675 acres and measurement of 262 plots per year. Relaxation of these constraints had an important impact on annual inventory requirements in the North Central region. Because trees in this region generally grow relatively little in the 5 years between measurements, not updating information for plots measured in previous years is expected to have little detrimental impact on annual estimates. Thus, the roles of models for updating purposes and remote sensing for disturbance detection are non-essential for annual inventories under the Farm Bill, whereas they were absolutely essential under the AFIS constraints. As a result, the AFIS concept of disturbance-based sampling has been abandoned in favor of a systematic distribution of plots across all ownerships and forest cover types, and inventory estimates based on 5-year moving averages have been accepted as defaults, but with provision for optional enhancements using updating techniques based on growth models, imputation, or other methods.

LITERATURE CITED

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