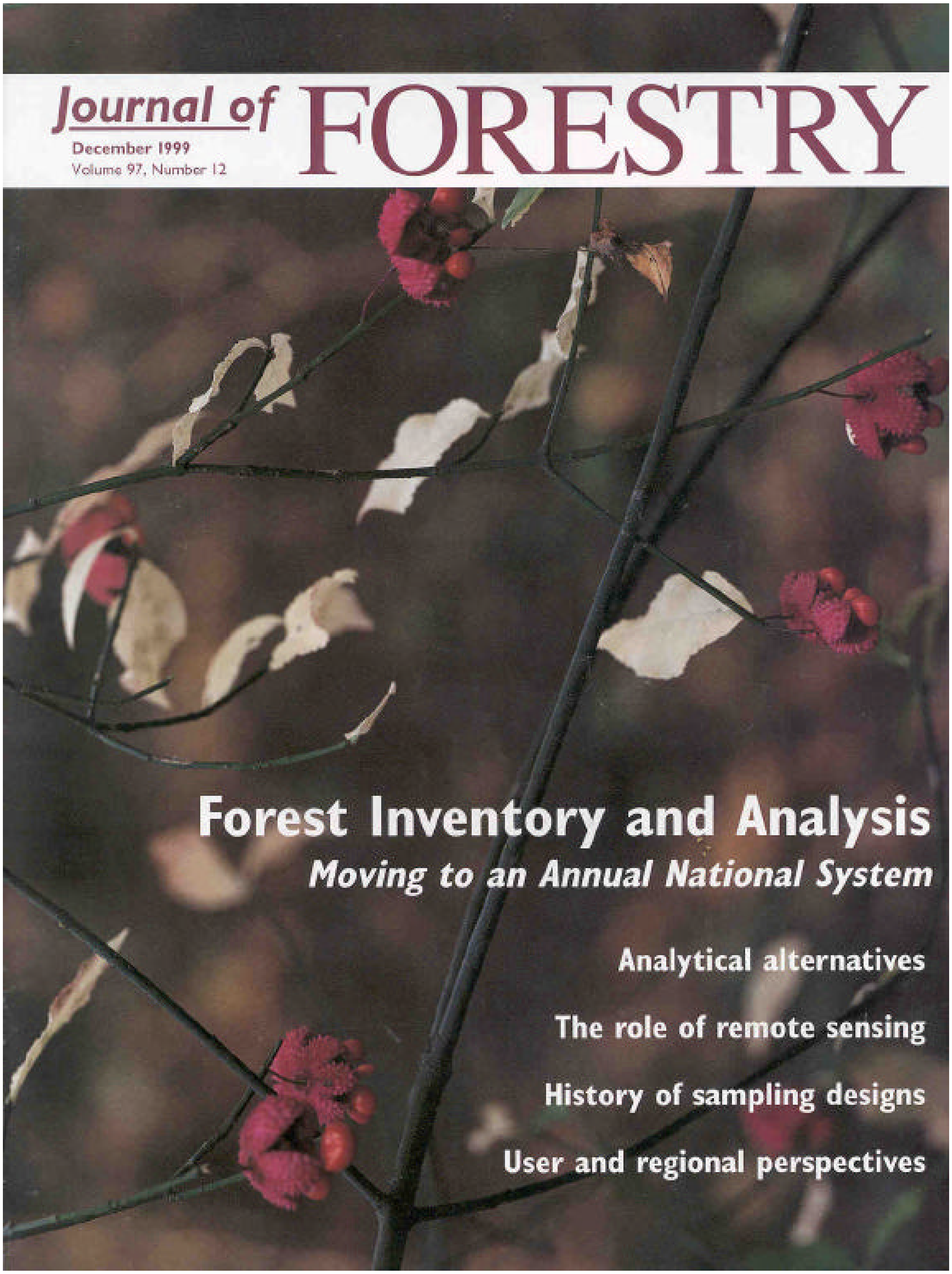
Forest Inventory and Analysis: A Special Issue of the Journal of Forestry

Forest Inventory and Analysis: Moving to an Annual National System Accurate and timely assessments of forest ecosystems are critical needs of modern forestry. The US forest inventory system, which provides the information for these tasks, is moving from a periodic to an annual basis, as mandated by the Farm Bill of 1998 and advocated by much of the forestry profession. The challenges of this mandate are considerable. The Forest Service's Forest Inventory and Analysis (FIA) program is the primary focus of these changes.

In December 1999, the Journal of Forestry published a special issue on the FIA program and the move to an annual inventory approach. The issue covers the history of forest survey sampling, current work taking place in specific regions, and user perspectives on the adoption of an annual inventory system. Articles discuss the need for reevaluation of analytical approaches; techniques for integrating auxiliary information into forest inventory; combining current with archival data; and the role of remote sensing technologies.

Link to the complete special issue of the Journal of Forestry (vol. 97, no. 12).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Forest Inventory and Analysis
Moving to an Annual National System
Analytical alternatives
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History of sampling designs
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Forest Survey Sampling Designs

A History

Extensive inventories of forested lands in the United States were begun in the early part of the 20th century, but widespread, frequent use was not common until after World War II. Various sampling designs have been tried; some have proved efficient for estimating certain parameters but not others. Some designs, though efficient in many respects, have been abandoned because of their complexity. Others, while possibly not demonstrating high efficiency, have been adopted because of their simplicity. This is a history of these applications.

By W.E. Frayer and George M. Furnival

One of the first signals of a need for a national forest inventory appears in Greeley's (1920) *Timber Depletion and the Answer*:

> The original forests of the United States are estimated to have covered 822 million acres and to have contained 5,200 billion board feet of timber.…There are left today about 137 million acres of virgin timber, 112 million acres of culled and second-growth timber large enough for sawing, 133 million acres partially stocked with smaller growth, and 81 million acres of devastated and practically waste land.…Three-fifths of the timber originally in the United States is gone.

The bulk of the report was a call for legislation to protect forestland from fire and to increase the area of public land. But one small section of the report read "legislation is needed… which will permit the Secretary of Agriculture to survey the forest resources of the United States, determine the present volume together with the present and possible production of each class of timber in every important forest region.…"

The remarks in Greeley's 1920 report were expanded in the *Capper Report* published the same year. The USDA Forest Service views this report as the first of a series that incorporated new data, and it was considered a milestone in appraising our timber supply. However, the report admits that "a comprehensive and fully adequate report…would require an exhaustive survey of the forest resources of the country…No such survey has ever been made." It was pointed out that "data… have been compiled from a great variety of sources secured for different purposes by different organizations with varying degrees of accuracy."

The second milestone report, the *Copeland Report,* was prepared by the Forest Service in 1930 and presented to Congress in 1933. It included new data that had become available to supplement the data of the *Capper Report,* but there was still no "grand sampling design" to acquire data.

Early Legislation and Applications

The McSweeney-McNary Forest Research Act of 1928 had authorized the Forest Service to conduct a national forest survey, calling for "a determination of the present and potential productivity of forest land." Because the main concern in those days was the timber situation, the survey was primarily a timber inventory. The survey began in 1930 (Andrews 1932; Wilcox 1938) in Oregon, McNary's home state, as described by Doig (1976). Planning had begun in 1929 when Thornton T. Munger, the first director of the Pacific Northwest Forest Experiment Station, received $30,000 in funding (Van Hooser et al. 1992). The first approach in the Pacific Northwest was to use available private data with some fieldwork for verification and supplementation. Doig described an experiment carried out in 1930–31 in


Courtesy of Weyerhaeuser Company Archives, Tacoma, Washington

Initial forest surveys were primarily timber inventories. Although extensive sampling began around 1930, not until the late 1940s were sampling designs developed for efficiency and suitability to local conditions.

Lewis County, Washington, in which a line-plot survey was run to compare it with compilations made for the area and to assess its potential for use in the South. Plots were one-quarter acre in size and spaced at 10-chain intervals on east-west strips run through forested areas. About 486 miles of survey line had been run by the end of June 1931. The fieldwork included 3,888 sample plots at a cost of $10,448. It was decided not to use the method in the Douglas-fir region because of the rugged terrain, but the method was adopted in the East.

Some results for Oregon and Washington were published in 1932 (Cowlin). A later report was published for the Douglas-fir region (Anonymous 1934). Wieslander (1935), head of Forest Survey at the California Forest and Range Experiment Station from 1935 to 1950, described the first steps of Forest Survey in California. He said that mapping was in progress and that there was a plan to take 35,000 field plots, but this was not done until after 1950.

In 1930 "Cap" Eldredge was placed in charge of Forest Survey in the South, headquartered at the Southern Forest Experiment Station in New Orleans. Two 1931 reports (Anonymous; Lentz) described the line-plot-sample method (based on the Lewis County experiment) that was proposed for 25 million acres of bottomland in the Mississippi Delta states. Two interim reports were made in 1932 (Anonymous; Lentz). Lentz reported that 5,815 plots had been taken on 4.4 million bottomland acres, and Eldredge (1935) noted that field inventory of 75 million acres in the South would be completed by April 1, 1935. A second report by Eldredge (1937) described methodology using three-man crews on parallel compass lines 10 miles apart taking quarter-acre plots at 10-chain intervals. He stated that analysis had begun and that some results had been published.

In 1938, Garver reported that the forest inventory phase was well along in the South, Pacific Northwest, and the Lake states. He said the job was half done; 289 million acres of forestland had been examined. There was no information on sampling design or intensity. Cunningham (1939a,b) reported that the inventory phase of Forest Survey in the Lake states had been completed in 1937, and he reported preliminary statistics on areas and volumes.

Forest Service Chief F.A. Wilcox stated in his 1938 annual report that

> We need in forests all the 630 million acres we now have and that are most valuable for forest growth. Yet unless it is abused and neglected, we probably do not and will not need more forest land. For 300 years our forests have been chopped, burned, and depleted. Yet with care and forethought there seems no excuse for a timber famine of national proportions.

He also stated that "the Forest Survey indicates that we have more forests than we thought…and more forest growth." It was also pointed out that Forest Survey had begun in 1930, and about one-half of the forests of the United States had been surveyed, with about 60 percent of the resulting data compiled.

With the outbreak of World War II, this status remained for several years. The 1940 *Yearbook of Agriculture* published several tables of information on the status of the nation's forests by R.E. Marsh, acting chief, and William H. Gibbons, senior forester, Division of Forest Economics, Forest Service. They had drawn on reports and unpublished manuscripts by many members of the Forest Service: "Where authoritative

Courtesy of USDA Forest Service

Remotely sensed data has long been used to enhance statistical and field information. Aerial photography was a common source by the 1950s, and photo plots and ground plots were combined to develop double sampling designs.

data on forest conditions such as those so far furnished by the Forest Survey have been available, they have been used. Where such data were not available, the best approximations possible, which are believed to be substantially near the truth, have been made." The Forest Service considers this data the third milestone report.

A New Era

Shortly after World War II ended, Forest Survey began in earnest. In two 1946 reports Chief Lyle F. Watts said that "during 1945 and 1946 the Forest Service has been making a reappraisal of the Nation's forest situation." Several tables were presented, and the general conclusion was that there was enough forestland but not enough timber. The survey was credited to R.E. Marsh and the data were compiled and presented by C. Edward Behre and S. Blair Hutchison. These reports are the fourth milestone.

The four milestone reports presented national results, but there is little information on how the results were obtained. Most survey efforts based on extensive sampling of the nation's forests began in 1930 or later. Starting in the late 1940s, Forest Survey began developing and applying sampling designs that were more efficient and better suited to local conditions. Cruise lines were largely abandoned in favor of permanent plots located randomly or on a grid. The actual sampling designs used began to appear more commonly in the literature in the 1950s. As pointed out in an excellent portrayal of the roots of forest inventory in America by Gregoire (1992), one of the first (if not the first) sampling texts of any kind was prepared specifically for forestry by Schumacher and Chapman (1942).

Becker (1950) described the Forest Survey procedures used in the central states. This effort was a function of the Central States Forest Experiment Station in Columbus, Ohio, where Becker was field supervisor for Forest Survey. He noted that a line-plot system was used in the central states where the effort began in 1946. The area estimates were based on aerial photo plots and a subsample of these plots were field-sampled to obtain volume estimates. He also indicated that a type of optimum allocation was used (at least a disproportional allocation). A higher intensity of field plots was used in sawtimber stands than in poletimber stands, and a higher intensity in poletimber than in seedling–sapling stands.

In the Pacific Northwest, estimating volumes in old-growth stands presented a different type of challenge than that faced in the East. Floyd Johnson, a statistician at the Pacific Northwest Forest and Range Experiment Station, began working on this challenge (Johnson 1950; Johnson and Hixon 1952). The approaches taken in Forest Survey were then, and are now, somewhat different at the different experiment stations. The large ownerships and high volumes in parts of the West often required a cooperative approach between agencies and private owners, with most wanting the survey results for management planning. The smaller ownerships and generally lower volumes by individual owners east of the Rockies enabled the stations there to design broad inventories, produce state reports, and for the most part leave management planning to the individual owners. Although different approaches were needed in different geographic regions, the autonomy of the individual stations in the East meant that differences in techniques appeared even when there would have been advantages gained by standardization.

Statisticians Join the Action

The approach of using aerial photo plots and ground plots in combination to estimate areas and volumes had been practiced for some time and was probably best described by Bickford (1952). He noted that the use of photo plots to form strata and to estimate their sizes, along with a subsample of those plots being measured as field plots, is a double sampling design. Specifically, it could be called stratified sampling with estimated stratum weights. He relied heavily on Neyman (1938), and shortly after on Cochran (1953), when the first edition of his popular textbook was published. By the 1970s, it appeared that some combination of satellite imagery, aerial photos, and ground plots would be useful in multiphase or multistage estimators. Frayer et al. (1979) and Jeyaratnam et al. (1984) were among many works that appeared in the literature at that time.

Simple as it seemed, the use of aerial photos to set up strata sometimes was confusing and was not always used to best advantage. The usefulness of photographs that were a few years old was often questioned, inefficiencies occurred when many strata were used, and photo interpreters spent a long time classifying the photo plots. Early work by Bickford showed the advantages of optimum allocation. However, over time, strata change, objectives may change, personnel most certainly change, and all of these factors argued for a simple, easily understood approach. Proportional allocation became more common over time.

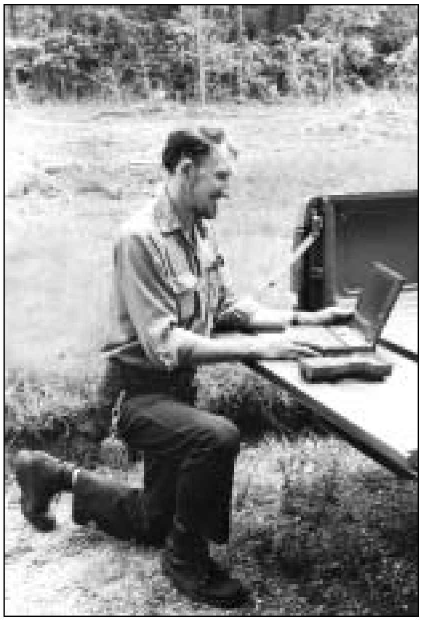
Sampling Designs Get Attention

The early 1960s brought changes in design and measurement techniques at several experiment stations. Point sampling had become very popular (Bitterlich 1948; Grosenbaugh 1952, 1958; Beers and Miller 1964). Remeasured plots were acknowledged as the most precise way to estimate growth and change (Hall 1959). Shiue (1960) and Shiue and John (1962) proposed systematic sampling with multiple random starts. To the purist, this approach had some appeal because it satisfied statistical theory and, at the same time, provided a consistent way to locate plots on maps, topo sheets, and photos. The approach was never adopted beyond the North Central Forest Experiment Station, however, and the station abandoned it to be more consistent with other stations. Sampling with partial replacement, the most complicated design ever used by Forest Survey, was implemented at the Northeastern Forest Experiment Station (Ware 1960; Ware and Cunia 1962; Bickford et al. 1963). In time this method was also dropped, primarily because of its complexity (Scott and Kohl 1992). Foresters in the West were adopting some of the procedures used in the East, such as combining aerial photo information and ground plots (MacLean 1963).

Fixed-radius plots were mostly abandoned in favor of point samples that provided for precise estimates of volume by sampling trees with probability proportional to basal area. At the same time, components of change were receiving prime attention (Hall 1959; Beers 1962). A sweeping change to point sampling was accompanied by the development of estimation procedures for growth components on remeasured points. Most stations were now using a cluster of 10 points roughly covering an acre. Although it was not discussed in detail other than in internal Forest Service documents, this cluster was based generally on tests conducted in the southeastern states. In the East, it was decided that it would be reasonable to sample approximately 20 trees on each cluster. Because it was generally accepted that 75 square feet of basal area was the minimum for a fully stocked stand, some stations started using 37.5-factor prisms (75 square feet divided by 20 trees times 10 points equals 37.5).

All of these activities in the early 1960s may have been the result of the fifth milestone report prepared by the USDA Forest Service (USDA-FS 1958). In preparing information for this 713-page report, data were compiled in a number of ways: for states that had been surveyed since January 1, 1947, information was based on the survey data; for 10 states in which surveys were in progress, the data collected were supplemented with some additional data; and for other states, special surveys were conducted to gather some information. This large effort, coupled with the fact that there were now competent statisticians at the experiment stations and forestry schools, probably helped provide the impetus for the myriad studies and publications of the early 1960s.

Another USDA Forest Service milestone report was released in 1965. *Timber Trends in the United States* was based on more complete data than any previous report. It included a description of a stand-projection procedure called the Timber Resource Analysis System (TRAS) used to standardize data to a common year for publication and to provide projections for the future. Some simulation studies using this procedure later showed that rates of change (harvest and growth components) are especially critical for such a projection procedure to have any precision (Frayer and Jones 1970).



Courtesy of Association of Consulting Foresters of America

Forest surveys have recently broadened to include the biological and ecological status of forest resources. PC-based resources (such as GPS and GIS technologies) help to provide and combine archival and current data.

New Legislation, New Goals

The 1970s saw continued emphasis placed on Forest Survey. The original enabling legislation, the McSweeney-McNary Forest Research Act of 1928, was first amended by the Forest and Rangeland Renewable Resources Planning Act of 1974 and later by the National Forest Management Planning Act of 1976. Finally, the Forest and Rangeland Renewable Resources Research Act of 1978 replaced earlier legislation and authorized a continuing, comprehensive, nationwide survey and analysis of all renewable natural resources. The overall result was more responsibility and more funding for Forest Survey. Forest Survey by this time was known as Forest Resources Evaluation Research and later as Forest Inventory and Analysis. (For the purposes of this article, we use the term Forest Survey throughout.) Satellite data were now readily available (Langley 1971). Combinations of high-altitude photography, low-altitude photography, and field samples were used for effective three-phase sampling in Forest Survey (Kent et al. 1979; Johnston 1982). It was assumed that sampling of many resources—not just timber—was needed

(Frayer 1974, 1978a; McClure et al. 1979; Furnival 1979). Some (for example, Scott 1979) thought that interim data were needed, as survey cycles varied from less than 10 years in some states to almost 20 years in others. There was talk about producing annual estimates (Frayer 1978b). Another milestone report was published, *Outlook for Timber in the United States* (USDA-FS 1973). A stand projection system was again used to bring data to a common year (Larson and Goforth 1974). Peden et al. (1973) described how variance estimators could be used with these projections.

Forest Survey in many ways had matured. Numerous studies were conducted over the next two decades. Some were done within the survey units and many were done in conjunction with the Survey Techniques Project, which has been located at the Rocky Mountain Forest and Range Experiment Station since the late 1970s.

The maturity of Forest Survey was evidenced by publications for states, parts of states, and periodic milestone reports for the nation, as required by enabling legislation. Sampling designs were now mostly in place for the various stations, although there continued to be differences between stations.

New Developments

If you were to characterize the descriptions in each region, you could say that most states have been inventoried with a double sampling design, using photo plots for stratification and ground plots for volume measurements. You can readily see many differences. This is one factor that led to the formation of a blue ribbon panel on forest inventory and analysis. Its report (AFC 1992) offered many recommendations, including "increase consistency and compatibility among FIA (formerly Forest Survey) units." A second blue ribbon panel was assembled in 1997. Its report will recommend an annual inventory system and express strong support for standardizing plot configuration.

The Forest Service has already moved to standardize plots to a cluster of four fixed-radius plots. In 1995, a decision was made to abandon point samples in favor of a cluster of four 1/24-acre plots spread out over 1.5 acres. Field crews map any changes in land use or distinct changes within forest conditions on the cluster. This ends an era of nearly 40 years in which the most popular plot was a cluster of 10-point samples.

AFIS and SAFIS Studies

Two important studies are now under way. In northern Minnesota, the Annual Forest Inventory System (AFIS) is an attempt to use remote sensing (satellite data in this case) to stratify plots into classes with different probabilities of disturbance. Those with higher probabilities of disturbance would have a higher probability of being sampled in a given year, whereas other plots would be updated using models.

The Southern Annual Forest Inventory System (SAFIS) is similar, but probabilities of field plot selection will be equal (proportional allocation). Values for unmeasured plots may be imputed or estimated from models. Thus, the results at first may not be as precise as they might be with the AFIS approach, assuming the stratification by satellite imagery is successful, but the SAFIS group is avoiding the long-term complexities of using unequal probabilities with stratum boundaries changing over time. Rapid changes in land use as well as volumes in the South probably reduce the gains possible from optimum allocation.

Developments occur rapidly in this field. Both of these studies are the forerunners of an annual inventory system mandated by the 1998 Farm Bill that became law while this paper was in review.

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Sampling Procedures across the United States

The following procedures are in place for each USDA Forest Service research station and are based largely on an excellent in-house report (USDA-FS 1992). Although the current intense interest in monitoring resources has resulted in many changes since 1992, most are still evolving and are yet to be described in the literature. Each station's website is accessible from the Forest Service's main site at http://www.fs.fed.us/links/research.shtml.

Pacific Northwest Research Station (PNW)

The PNW Station covers the West Coast, including Alaska and California. Responsibility for California was originally assigned to the station in California (now the Pacific Southwest Research Station). Two approaches are used. In Alaska, sample populations are first identified by broad vegetation classification based on satellite digital data. Within these populations, the primary sample consists of a random selection of satellite pixels transferred to aerial photographs. Items classified on the primary photo samples include land class, ownership, forest type, and timber volume class. Secondary samples for ground examination are selected from the primary samples. All strata are sampled but the sampling intensity on nonforest strata is less than in forested strata. In other Pacific Coast states, the primary sample is defined by a systematic grid of permanent, mapped points. At each grid point, aerial photos are used to classify the land into strata similar to those used for Alaska. Secondary samples for ground examination are selected systematically from the primary sample locations. Secondary sample intensity can be varied to meet special objectives.

Rocky Mountain Research Station (RMRS)

The RMRS has responsibility for the Rocky Mountain West and the Southwest. The general approach is a stratified double-sampling design. The primary sample is defined by points on a systematic 1,000-meter grid. Each grid point is located on an aerial photograph for interpretation. Items identified for stratification include ownership, land class, and forest type group. The interpreted items are used to define sampling strata. The secondary ground sample is a subset of the primary sample at 5,000-meter intervals. A supplemental 5,000-meter field grid is available for sampling intensification as required by cooperators, and additional samples can be selected from the 1,000-meter primary grid.

North Central Research Station (NCRS)

The former North Central Forest Experiment Station has responsibility for the Midwestern and Lake states (the Central States Station was phased out in the 1960s). Using a systematic grid of 121 plots per township (36 square miles or 9,324 hectares) on aerial photographs, each photo plot is classified stereoscopically based on land use, forest type, size, and density. Ground plots are a systematic subsample of the photo plots.

Southern Research Station (SRS)

Until recently, the Southern Forest Experiment Station had responsibility for states in the mid-South. This station was recently combined with the Southeastern Station into the SRS, and the work handled by both will now be headquartered in Asheville, North Carolina.

Estimates of timberland area are based on forest-to-nonforest interpretation of plots on aerial photographs. These plots represent approximately 230 acres. The land-use interpretations are field checked at sample locations representing approximately 3,840 acres. After using these checks to adjust the photo interpretations, an estimate of the proportion of forest-to-nonforest area is made for each county. The proportion of forest area is combined with US Census land area data to derive county-level forest area statistics.

Descriptive forest resource statistics are derived from measurements at permanent sample plots located at the intersections of a three-square-mile grid; each plot represents, on average, 5,760 acres. The sample plots are remeasured at each survey to allow assessment of change (i.e., growth, removals, mortality estimates) and of current resource status.

Southeastern Forest Experiment Station

In the first phase of a two-phase design conducted by this station (now part of the SRS), a large number of cluster samples are interpreted from aerial photographs for forest, nonforest, and non-census water land use. In phase two, a smaller set of cluster samples are centered over each permanent ground sample and classified in the same manner as described above and then checked on the ground. The clusters checked on the ground are used to adjust the area estimates from the photo sample. A linear regression is fitted to develop a relationship between the photo and ground classification of the sub-sample. The entire photo estimate in phase one is thus adjusted for change in land use since the date of photography and for misclassifications.

The second-phase plots are permanent sample plots. All plots on timberland are used for volume-per-acre estimates, number of trees, and stand attributes, as well as estimates of growth, removals, and mortality.

Northeastern Research Station (NRS)

The former Northeastern Forest Experiment Station has responsibility for the states from Ohio to the west and Maryland to the south. A primary sample is obtained from a grid of photo points overlaid on aerial photographs of the inventory area. Interpretation of each photo point is for land use and timber volume class stratification. A secondary sample is taken for on-the-ground examination; samples include all ground plots measured at the last occasion and new ground plots that are added to make the ground sample proportional to the primary sample. Data from all plots, new and remeasured, are combined to calculate a single estimate of current volume.

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Adopting an Annual Inventory System

User Perspectives

The nation's Forest Inventory and Analysis (FIA) program is moving from a periodic to an annual forest inventory system. The annual system will better meet the increasing demand for current information and is backed by legislative mandate in the 1998 Farm Bill. For the annual system to succeed, FIA will need increased state-level participation, internal changes in emphasis, and greater use of technology. FIA personnel should be proud of the public support that led to this opportunity and respond quickly and decisively to a clear mandate for change.

By Paul C. Van Deusen, Stephen P. Prisley, and Alan A. Lucier

The Forest Inventory and Analysis (FIA) program is one of the most important services provided by the USDA Forest Service. For the past 70 years, FIA has provided the only comprehensive, scientifically credible data on the extent and condition of forest resources in the United States. These data paint a picture of the national forest resource and serve as the foundation of large-scale policy studies such as those required by the Resources Planning Act (RPA). FIA data are frequently used by government agencies, industry, and others in regional and subregional analyses that influence major economic and ecological management decisions.

Regardless of their views about forest utilization or preservation, most FIA users agree that these data are essential to monitoring a healthy and productive forest ecosystem. A current and accurate forest ecosystem inventory is prerequisite to substantive discussion of issues like sustainability, national forest policy, carbon sequestration, changes in growth and productivity, changes in land use and demographics, ecosystem health, and economic opportunities in the forest sector.

The FIA user community has become increasingly concerned by the inability of the USDA Forest Service to improve the timeliness of FIA information. Obstacles to producing more timely information have included increasing the number of variables being measured in the field and a flat budget. In recent years less than 1 percent of the Forest Service budget has been allocated to the inventory of the nation's forest resources, an amount smaller than some regional resource assessment and planning efforts.

These concerns led to the convening of a blue ribbon panel on FIA in 1991 (BRP I) and a second panel in 1997 (BRP II). The panels were organized by the American Forest & Paper Association and included user representatives across the forestry profession: universities, federal and state agencies, landowner associations, conservation organizations, forest products firms, and research centers. The panels assessed the needs and desires of a wide spectrum of users of FIA data and reports. The broad basis for consensus in these panel reports lends authority to their conclusions. The BRP II report identified five key findings or recommendations:

1. Elevate the priority of FIA in the Forest Service program.
2. Move to an annual inventory and analysis as quickly as possible.
3. Fulfill the congressional mandate of reporting on all lands.
4. Concentrate on the collection of "core" data until the annual inventory system is fully operational.
5. Develop a strategic plan that will accomplish all of the above with a specified target date.

The BRP reports and increasing public concern led Congress to underscore the importance of this program. Specific wording in the 1998 Farm Bill mandated the annual system and other BRP II recommendations, including the key recommendation that FIA and the National Forest Health Monitoring Program (FHM) merge their fieldwork to increase the efficiency and effectiveness of both programs.

Annual System

The BRP reports, the 1998 Farm Bill, increasing user demands, and positive Forest Service response have created an opportunity for FIA to be transformed into a system that can continue to fulfill its mandate and meet users needs. But the rebirth of FIA is still incomplete, and complacency on the part of users and the Forest Service could destroy the momentum for change and leave us with a crippled system. The 1998 Farm Bill did not include specific budget recommendations and the Forest Service and USDA have not yet indicated they are prepared to increase budget share for FIA in proportion to its importance.

Progress in implementing the annual system has been significant in some regions. The North Central and Southern regions have been conducting annual inventory pilot studies since 1992 and 1995, respectively, and are therefore farther along than other regions. The Southern region has implemented the annual system in several states and has a plan for implementation in the remaining southern states over the next few years. Likewise, the North Central region has begun implementation in Minnesota and is formulating additional plans. The Northeastern region began implementation in Maine this year, owing largely to the efforts by forestry leaders in that state.

The 1998 Farm Bill sets a goal of implementing the annual system in all regions on all forestlands within five years. It is surprising that many national forests and other federal forestlands are not currently inventoried by FIA. There can be no complete picture of the country's forest ecosystem unless all lands are included. All regions should be using compatible field procedures, analysis methods, and software as called for by BRP II and Forest Service planning documents (Anonymous 1999). Achieving this goal will take strong leadership at high levels in the Forest Service and USDA, along with the development of a cohesive team of project leaders who share this vision and cooperate to see it accomplished.

The current success in implementing an annual inventory in the South and North Central regions is the result of strong state-level participation, as well as leadership and risk-taking in the FIA units and national FIA program office. State crews are collecting much of the data with joint federal and state funding. The old model of predominant federal control and funding for FIA can be modified to include greater state-level participation; in fact, the annual system will facilitate this modification. FIA may someday evolve into an organization whose primary missions are ensuring data quality, controlling data management, and analyzing resource conditions and trends. Asking states to assume more responsibility for fieldwork may seem alien to a field-oriented program such as FIA, but rapidly growing needs for more timely and complete resource information demand that new approaches be considered.

> There can be no complete picture of the country's forest ecosystem unless all lands are included.

Implementing the Annual System

The challenges inherent in moving to an annual system are real and significant. For example, FIA reporting will be forever changed by the annual system and the Internet. With a periodic system, it was clear that analysis and reports should be issued immediately following completion of a state survey. With the annual system, every year is the same so there is no need for annual reports on each state. FIA will need to place more emphasis on making data and software available on the Internet so that users can create their own custom reports. FIA has already made substantial progress in this direction, but more is needed. FIA should still issue state reports every five years or so, but regular users will be able to continuously monitor the website and answer most of their questions without special assistance from FIA. Ideally, through the Internet users will have access to the same software that FIA uses to do internal analyses. Going online will expand the user base and free FIA personnel to focus on other things.

Substantial confusion exists between the change to annual plot-taking and a concurrent change in the design of the plots. The Forest Service has recently changed from a variable-radius plot scheme to a fixed-radius mapped plot, but this change is independent of the annual system (Scott and Bechtold 1995). Annual inventory can be conducted no matter which plot design is in place, but the simultaneous change to a nationally consistent plot layout has increased the cost of inventory, regardless of the timing of field sampling. For example, to compute components of inventory change, the Southern FIA unit (Thompson 1998) recently has been measuring all plots twice: once using the old system (for consistency in computations) and again under the new fixed-radius plot system (to establish a new basis for successive measurements). The draft strategic plan for FIA (Anonymous 1999) denotes the increasing costs for inventory under the annual system, but does not specifically identify the already increased costs of conversion to the new mapped-plot design.

Even when conversion to the mapped-plot design is complete, the cost of fieldwork will be a significant and growing concern. Therefore, FIA needs to find ways to generally hold these costs down. One option is to measure fewer variables on a plot. A plot currently takes about one day to complete, which should be considered an upper limit that cannot be exceeded. Cutting out enough variables to get back to doing two plots per day is a good goal but may be unreachable. One alternative (Anonymous 1999) is more judicious selection of core variables to be measured on every plot, and allowances for measuring some variables on subsets of all plots. Careful consideration of necessary precision levels might lead to different allocations of field effort. For example, there are fairly well understood and defensible guidelines on needed precision for estimates of wood volume, and these guidelines typically have driven the selection of sampling intensity. But once a sampling intensity is chosen to deliver the desired precision for volume estimates, it is not necessary that all other variables (soil types, textures and erosion classes, ground cover, tree damage codes and classes, recreation use) be recorded at exactly the same intensity.

Another alternative to save field sampling costs is to measure fewer plots each year. The current plan for the annual system is to measure 20 percent of the total FIA plots in each state. This is a good starting point, but after a while FIA could seek ways to reduce this percentage while maintaining acceptable precision. A 20-percent sample may be appropriate and necessary in the fast-changing forests of the Southeast, but far less is needed in areas where change is occurring at a slower pace.

Variability (precision) is determined by sample size and the estimation process used. The Forest Service should develop estimators for the annual system that will take advantage of the annual nature of the data. Estimating mean values of variables independently from one period to the next worked well under the old periodic design, but it would be wasteful using the annual system. Data from the previous few years contain much information about the current state of the forest, and should be incorporated into the estimation process. There is also an opportunity to incorporate models into the process. Plots that are not measured in the current year can be updated with models to improve current-year estimates (Fairweather and Turner 1983; Hansen 1990; Van Deusen 1997). In the ideal future of FIA, analysts will combine field measurements, remote sensing, and models to provide efficient and accurate annual updates of the status of the US forest ecosystem.

Longer-Term Views

The mandate for an annual inventory is the most significant opportunity for change and innovation in FIA since the program began. Given the rate of technological change, the future may arrive sooner than we expect, so anticipation is in order.

First, we believe that the ongoing change to an annual system is more than cosmetic. A simple view is that the annual system represents nothing more than changing the order in which plots are visited. We think an annual inventory is a giant step toward recognizing the increasing importance of the forest ecosystem to society. It requires nonfederal partners to play a greater role in conducting the inventory and makes possible ongoing participation by FIA users in Forest Service assessments of the state of the forest. The periodic system made it difficult for states and other users to remain engaged during the 10-year hiatus between inventories.

The periodic system of inventory has been troublesome when major disturbances such as hurricanes and ice storms have affected the forest resource. For example, Hurricane Hugo struck the South Carolina coast just one year after the sixth forest inventory of the state was published (Tansey and Hutchins 1988). Immediately the data on the current forest conditions were invalidated, and an interim special inventory was conducted. A subsequent report (Sheffield and Thompson 1992) provided valuable information on the damage to the state's forests. A year later, the seventh survey of the state was completed and reported by Conner (1993, 1998). However, many of the findings in these reports were dramatically affected by the hurricane, as they were drawn from changes observed between 1986 and 1992 field measurements. Yet these findings have been cited (Huckaby 1999), 10 years after the event, as indicating a need to change forest policy in the state. An annual inventory system would provide rapid and ongoing adjustments to the baseline to evaluate the dynamics of the forest resource.

> Given the rate of technological change, the future may arrive sooner than we expect.

For decades inventory specialists have wanted to use remote sensing technologies to gather more of their inventory information, but field measurements will still be required for the foreseeable future. The current plot design of four circular 1⁄24-acre plots 120 feet apart, works well for field crews in some situations, but we suspect that it is not ideal as ground truth for remotely sensed data with a resolution of less than 10 meters. If remotely sensed data is to take its rightful place in the FIA tool box, the field plots may have to be redesigned. If ground truth becomes a primary function of the plots, it will likely be necessary to characterize larger fixed areas (not necessarily by measuring every tree) to ensure spatial correspondence between remote sensing data and ground-truth data. In the early days of FIA, continuous strip cruising was used. Strip cruising now seems extravagant, and we suspect that today's system of placing one plot every 5,000 to 6,000 acres and making little use of satellite remote sensing will seem extravagant in the future.

In fact, FIA is planning to make more use of satellite imagery. Initially, it may be used as a substitute for the aerial photos that are currently used to estimate the proportions of forest and nonforest acreage by county using a double-sampling procedure. More ambitious applications of remote sensing are possible, but substantial progress may be hindered by the current plot design and lack of a far-reaching technology vision. Such a vision might lead to radical changes in the FIA system and yield significant improvements in information quality and cost-effectiveness. We envision a future FIA system that provides annual estimates of forest area by type that are highly accurate for survey units and perhaps individual counties. Field plots will continue to play critical roles that include ground truth for remote sensing and precise measurements of growth components, tree size, condition variables, and other tree and stand attributes.

Conclusions

The nation's forest inventory system is in transition as a result of changing information needs. The former periodic inventory had begun to fail in part because of inadequate budgets, but also because it was designed to meet the needs of an earlier era. Timely forest inventory information is critical to the long-term health and vitality of the resource and the forestry community. At the agency level, FIA needs to be elevated in importance relative to other programs. Internally, FIA needs to break with tradition and become more oriented toward data analysis and management while maintaining and improving field procedures. National consistency will require better cooperation and coordination among field units and a stronger national leadership.

FIA must seek additional state involvement in data collection to free its staff for other tasks. We are confident that FIA can successfully transition to an annual system as mandated in the 1998 Farm Bill. FIA personnel should be proud of their accomplishments and of the broad support they have received to enable their renewed mandate. They should make the most of this opportunity to create a new national inventory system.

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Rationale

The USDA Forest Service Forest Inventory and Analysis (FIA) program is changing to an annual inventory system that will operate at reduced intensity simultaneously in all states every year. This system will provide annual inventory updates in all parts of the country every year, and will make it easier for partners (mainly state forestry agencies) to collaborate in program planning and implementation. The change has significant implications for traditional and new users of the national inventory system.

By Andrew J.R. Gillespie

The USDA Forest Service Forest Inventory and Analysis (FIA) program provides periodic information on status and trends on a variety of parameters describing forests and forest use: area and location of forests; structure and composition of forests in terms of species, sizes, and volume; rates of tree growth, mortality, and removals; patterns of ownership of forestlands; and information on harvest efficiency and wood product flows throughout the United States (USDA-FS 1992). This information is of vital interest to numerous customers including managers, policymakers, environmental organizations, business interests, consultants, scientists, the media, and citizens who are interested in status, trends, stewardship, and sustainability of the nation's forested ecosystems. This program is referred to as a strategic inventory to distinguish it from more local, project-level inventories aimed at providing specific information for planning management actions.

FIA has historically conducted forest inventory on a state-by-state cycle. Under this model, we divide the country into zones and, within each zone, conduct statewide inventories one state at a time for all forestland outside of national forests. (National forest managers are responsible for forest inventory within national forests; many contract with FIA to provide consistent coverage across states.) Past inventory cycles have ranged from six to eight years in the South and 11 to 18 years in the rest of the country. In 1998, the total federal appropriation for FIA was $19.8 million, which was approximately 10.5 percent of the total research budget of $188 million, or 0.7 percent of the total Forest Service budget of $2.73 billion.

Alternatives for reducing the cycle with available funds, such as reducing the sample intensity or scope of data collected, are not acceptable to many program customers. Program investments in remote sensing tools have led to interesting new products, but current remote sensing technology is not capable of providing the required level of detail demanded by customers at the state and regional scales at which we operate. For example, FIA is required to report area estimates by detailed classifications of forest type, stand size, and stand volume that are not possible to classify with sufficient accuracy without substantial levels of ground-truthing. Nevertheless, we will continue to conduct research into ways to integrate new remote sensing tools into our inventory system to increase efficiencies and to develop useful new products.

In recent years, as budgets have remained relatively flat or declined (in real terms), FIA units have tended to divert ever-increasing shares of their budgets to collecting field data in an attempt to reduce or at least maintain the current inventory cycle. These steps have proved insufficient to maintain the inventory cycle at the desired eight to 10 years, and have compounded the problem by slowing the analysis and publication of inventory results. The result has been increasing customer concern that the FIA program is not meeting present customer needs, neither in terms of frequency of data nor in diversity of analytical products. These concerns have been expressed in two reviews of the FIA program by a cross section of program customers (American Forest & Paper Association 1992, 1998) who have encouraged us

for a National Annual Forest Inventory Program

to reassess the existing program to improve program performance.

One way to address some of the problems facing the program is to change to an annual inventory system. This approach has two major attractions. First, it guarantees that all states will have at least some new data available every year, which addresses concerns about data currency. Second, it makes it easier for partners to help share the costs of the program through a steady annual level of participation, which removes the program from total fiscal dependency on federal dollars.

FIA has been seriously considering an annual approach to forest inventory since 1992, when we began development of a prototype annual inventory system in Minnesota in cooperation with the Minnesota Department of Natural Resources. Satellite imagery analysis was used to differentiate between plots that could be modeled rather than visited, and plots where sufficient change had taken place to warrant a field visit. By visiting a smaller set of plots annually, and leveraging that information with remotely sensed data and models, it was hoped that a state-level report could be produced at more-frequent intervals—four years or less—for the same cost.

In 1996 we began testing and implementing a simpler approach in cooperation with a coalition of industry and state partners in the South. We divided the existing set of field plots into five overlapping panels, with the intent of measuring one full panel each year so that each plot would be measured once every five years. Because federal funding levels could only support a seven- or eight-year cycle, this approach would require additional sources of funds, either from the Forest Service or from partners. Several southern states have already stepped forward to invest significant amounts of their own money and staff time in support of the program (USDA-FS 1999b).

Other FIA units have until now been interested observers. However, the Agricultural Research, Extension, and Education Reform Act of 1998 (PL 105-185) directs all FIA units to change to an annual inventory system over the next five years. This law also significantly changes and expands the FIA mission in other ways, requiring more data collection on a wider array of parameters, mandating consistency in methods and data across all lands including national forests, and requiring analysis and reporting by states at five-year intervals. These requirements imply other necessary program changes that are described in the *Strategic Plan for Forest Inventory and Monitoring* (1999a). For purposes of this article, we assume that FIA will implement the full extent of sampling required by the legislation: 20 percent per year per state.

It is significant that this legislation was written and passed with little direct input from the Forest Service, which is largely a reflection of how frustrated so many program clients have been with the slow rate of change within the FIA program. This high level of interest is not to be taken lightly. Some aspects of the legislation, such as that mandating visitation of 20 percent of all plots in all states every year (essentially a five-year inventory cycle for every state), may not be the most efficient way to spend public resources. It is also important to note that the 1998 act is authorizing legislation and not appropriation legislation; there is no guarantee that funding will be provided to implement the mandated program. We are confident, however, that we can collaborate with our partners to craft a program that addresses customers' concerns in an efficient fashion, to the best ability of available resources.

Changing from the periodic approach to the annual approach has tremendous implications for many aspects of the FIA program, including logistics, cost efficiencies, partnerships, and the quality and utility of the resulting information products. The implications will be viewed differently depending on whether one is involved in implementing the program or is simply using the results. The following discussion touches on some of the major implications for program participants and customers alike.

Logistics and Cost-Efficiency

Changing to an annual inventory will have different implications for logistics and cost-efficiency in different parts of the country. Under the periodic approach, field personnel must relocate every year or two as they finish one state and begin another. This reduces retention of experienced crew people, who soon tire of the nomadic life and seek positions with more stability. Where we can operate year-round (mainly in the southern half of the country and in some flat northern states), an annual approach allows for stability in field staff by permanently stationing them within a certain working area. This will eliminate the cost of constantly relocating people, and will provide field staff with an opportunity for more normal lives, which should in turn lead to greater retention of experienced staff and lower training costs for replacements. Some of these savings will be needed to offset the increased travel costs, as crews will now cover every part of every state every year.

In the rest of the country, the combination of snow and steep terrain make fieldwork seasonal. In these areas, logistics for an annual inventory are more complicated and expensive because large numbers of people must be moved into these areas to complete the 20-percent plot coverage across the region within the operable window. For example, in the interior West, we estimate a need for 112 person-years of field crew effort per year to cover the entire region, or roughly double the staffing needed to implement an equivalent five-year cycle under a periodic inventory system (D. VanHooser 1998, pers. commun.). Where crews once would concentrate on measuring all plots in a smaller area, they will now need to cover a larger area, on average driving (or walking, in roadless areas) past two plots three miles apart for every plot they measure. Providing the coverage required will mean higher travel costs. Costs could be reduced by concentrating annual fieldwork in survey units; that is, dividing a state into five subunits and measuring all the plots within each subunit, one subunit per year. But we believe this approach is not consistent with the intent of the legislation, which aims to provide annual statewide updates of forest inventory data. At present we plan to provide uniform coverage by dividing all plots in a given state into five panels, where each panel provides full state coverage at approximately even density.

One immediate opportunity for increased efficiency is through the merger of the FIA program with the field plot portion of the Forest Health Monitoring (FHM) program (USDA-FS, 1998). Currently FHM is a related program that collects data on forest health parameters in all implemented states on an annual basis during a 10-week summer measurement window. There is some redundancy between the programs: for example, FHM collects a set of mensurational data that is largely duplicated on FIA plots, and it involves many of the same management and supervisory staff that also manage FIA. As FIA changes to an annual system, we intend to merge the sets of plots so that FHM plots will be a subset of the annual FIA panel of plots and will be visited by a single crew during the summer window to collect both FIA and FHM data. This merger would allow more-efficient use of the FHM funds (about $7 million in 1999) for focusing on extended ecological data. In addition, the merger will reduce the likelihood of multiple visits to the same plot that might annoy private landowners, and will increase analytical effectiveness by providing maximal linkage between the two databases. Because many states are partners in both FIA and FHM, combining these programs will enable states to reduce some overhead associated with participation.

The financial implications of the annual inventory system are not limited to fieldwork. We also expect to gain some efficiencies in data analysis. Data from adjacent states will now be available over common time periods, which will eliminate the need for investing time and energy in complicated and sometimes arbitrary updating processes as a precursor to analyses that span multiple states. The annual approach also offers a low-cost opportunity for additional reports to reflect significant environmental events that occur randomly over time, such as floods, ice storms, hurricanes, or fire. The annual approach provides a constant platform for responding to unpredictable events without having to commission or fund a special study.

Information Quality

Both the periodic and the annual inventory approaches are designed to provide unbiased estimates of parameters of interest. However, the parameters estimated are not necessarily the same for each approach. Under the periodic approach, the parameter estimates are assumed to describe the state of the forest at some specific point in time. The inventory is generally assigned to the year in which the bulk of the data were collected, although in reality inventory for some larger states may involve data collected over two to three years.

Under the annual inventory approach, we have more choices for parameters of interest. One approach would be to use some kind of moving average, combining the most recent observation for all n plots taken over the past five years. This would yield an estimate of the mean value over the past five years, which is not the same as the mean value in the present year. Another approach currently under consideration includes using a variety of modeling or imputation procedures to constantly update the past four years of data to the current year, to provide a full data set of n observations for the current year. Such modeling approaches will rely on historical data or other auxiliary information, which will themselves add components of variance. Research will be needed to quantify and incorporate the additional variance elements.

Information may be accurate and precise, yet still not be useful to users. Under the periodic approach, highly accurate and precise inventory information is available only periodically—at present, every eight to 15 years for each state. For users who need current information, this is not sufficient if too many years have passed since the inventory data were collected, or if a major disturbance event has occurred since the last inventory. The advantage of the annual approach for data users is that it yields some new information each year, with the information having an average age of 2.5 years (half the length of the measurement cycle) at any given time. Users who want continuous access to relatively recent data will prefer the annual approach, and users who can wait longer for more-precise data will prefer the periodic approach. The preference for an annual approach to inventory will likely be greatest for systems where the rate of change is greatest; for relatively stable systems, a periodic approach is probably more efficient.

Customer Confidence

Regardless of how accurate and precise the data, the information will not be useful if the ultimate consumers of the information do not believe it is reliable. Accurate information presented in a manner that undermines its own credibility is not useful. With the periodic approach to inventory, we have maximum precision at fixed intervals. We can say with confidence that the data reflect observations of a trend at fixed points in time, and that changes that occur between the points are reflected with some accuracy in the periodic observations.

Reporting updated estimates on an annual basis will inevitably invite comparison of the present estimates to the previous years, and will cause consternation and distrust if there is deemed to be a significant variation from year to year. While statistically understandable, such behavior could nonetheless cause users unfamiliar with technical issues to mistrust and doubt the results. This is more of a risk under the annual paradigm than it is under the periodic, where the lack of mid-cycle data prevents users from making the same comparison. Auxiliary information in the form of models or other assumptions may be incorporated to increase the precision of the annual estimates, but such procedures will themselves add additional components of variance that will need to be quantified and incorporated into variance estimates.

Partnerships

As the Forest Service increases its efforts at collaborative stewardship, FIA is increasingly relying on partnerships to accomplish the FIA mission. For purposes of this article, partnership is defined as a relationship where two or more parties share objectives and pool resources to reach those objectives. State forestry agencies in particular have historically partnered with FIA by contributing office space, staff time, vehicles, and other resources that allow FIA work to proceed at a faster pace. Many states have also contributed resources to FIA for purposes of collecting additional data beyond the base program, for example to intensify the plot network or to collect special interest variables on some or all plots.

However, it is often difficult for partners to participate more fully in the FIA program under the periodic inventory approach because the long intervals between repeated inventory activities make it difficult for states to support permanent inventory staff. Over time, normal employee turnover tends to reduce the number of staff familiar with the FIA program, methods, and opportunities. In addition, partners who want to seek resources to invest in FIA are forced to make infrequent requests to state legislators for large sums, rather than seeking a more modest investment on a continuous basis. The periodic nature of past inventory programs often leads to periodicity in relationships between FIA partners, resulting in a program that is forever locked in a less-productive "still-getting-to-know-you" kind of relationship.

The annual approach allows those relationships to mature. With operations in every state every year, FIA and partner staff will have the continuous contact required to build long-term working relationships. Partners wanting to contribute to enhancing the base program will be able to seek permanent budget allocations and staff to do so, and states that do not choose to contribute resources will still be guaranteed a base level of federal service. Because of annual fieldwork in each state, partners will have the opportunity in any given year to inject additional resources into the program for collecting

Key Forest Inventory Websites

Information about and generated by the national and regional forest inventory efforts described in this article and throughout this issue is available online.

USDA Forest Service Forest Inventory and Analysis (FIA)

http://www.srsfia.usfs.msstate.edu/wo/wofia.htm

This site links to all other online resources sponsored by this national program, including databases, documents for downloading, and the sites for the five regional offices. These two online databases are available:

• National FIA Database Retrieval System, from which one can create standard or custom output tables by summarizing information from the Eastwide/Westwide database

• Timber Product Output (TPO) Database Retrieval System, developed in support of the 1997 Resources Planning Act (RPA) Assessment.

An online library contains various documents, including the 1998 business report, the strategic plan, and the 1992 and 1998 blue ribbon panel reports. Program news and updates in a series of monthly newsletters also are available online.

Forest Health Monitoring (FHM)

http://willow.ncfes.umn.edu/fhm/fhm_hp.htm

Data from 1990 to 1998 are available in various forms: the data itself (through 1997), regional highlights for 1998, regional summaries, and fact sheets. Some of the information here is becoming out of date, having been written up before the strategic plan, and has not yet been updated. Much of this content will be added to the FIA website in the near future.

Annual Forest Inventory System (AFIS)

http://www.ncfes.umn.edu/4801/afis.html

AFIS is now undergoing development and pilot application in Minnesota. AFIS combines remote sensing, actual measurements of a relatively small number of tree stands, and computer models to provide an annual update of the state's forest conditions.

Southern Annual Forest Inventory System (SAFIS)

http://ncasi1.nerc.tufts.edu:443/projects/safis/

A small site for an important regional project that is the result of a partnership between southern states and FIA's Southern Research Station.

additional data about some issue relevant to their needs, without having to wait years until the next inventory for their state. For organizations looking to increase their involvement in FIA, the annual approach to inventory is clearly preferable to the periodic approach. In fact, full implementation of the 20-percent program envisioned by Congress likely will depend on significant partner contributions to augment a base federal program. Significant partner contributions are already forthcoming from many eastern states.

Conclusion

The change to an annual inventory program offers us the opportunity to simultaneously make other key changes that are needed to improve the FIA program, such as better integration with FHM, increased collaboration with partners, and increased consistency in approaches across all ownerships. It appears that the political momentum has already determined that FIA will move to an annual approach for the next generation of fieldwork, in advance of development and testing of the necessary technical program components such as compilation and analysis approaches. We have some work to do to catch up.

Simply changing the order in which we visit field plots is unlikely, by itself, to address customer dissatisfaction with the timing and scope of FIA program outputs. Nevertheless, the transition to an annual inventory system, if made simultaneously with other critical changes in the FIA program, in the long run will be in the best interest of the largest number of FIA customers whose greatest needs are for current information and a flexible program framework. If we can simultaneously address the existing problems of inconsistency in methods and incompleteness in coverage, and if we can form partnerships to make available the resources needed to increase the timing and scope of data collection and analysis, then we will be able to create a collaborative FIA program that will deliver better information for many years to come.

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Annual Forest Inventory

Cornerstone of Sustainability in the South

With many competing uses and large regional shifts in forestland use, the sustainability of southern forests is being questioned. The new Southern Annual Forest Inventory System (SAFIS) is being implemented to address regional, state, and national questions regarding past, current, and projected changes in the southern forest. The annual inventory system will provide the information needed to closely monitor and quantify the landscape dynamics of southern forests. These annual inventory data will form the basis of state, regional, and national forest sustainability assessments.

By Gregory A. Reams, Francis A. Roesch, and Noel D. Cost

The ecological and economic sustainability of southern forests is in question. Legitimate concern spans many public groups, from those concerned about maintaining biological diversity and the region's reservoirs of plant and animal genetic material, to forest landowners who manage forests to meet economic and societal needs, to average citizens interested in "doing the right thing," whatever that may be.

Changes in the management of public lands have significantly reduced the level of timber harvest on national forest lands (USDA-FS 1998). Timber removals in the South are projected to increase sharply over the next several decades in response to harvest reductions on western public lands (USDA-

Courtesy of USDA Forest Service

Hurricanes can instantaneously affect millions of acres of forestland. In 1989, Hurricane Hugo reduced the inventory of softwood growth stock by 21 percent in South Carolina (Sheffield and Thompson 1992). Annual forest inventories will provide nearly real-time estimates of change following catastrophic events.

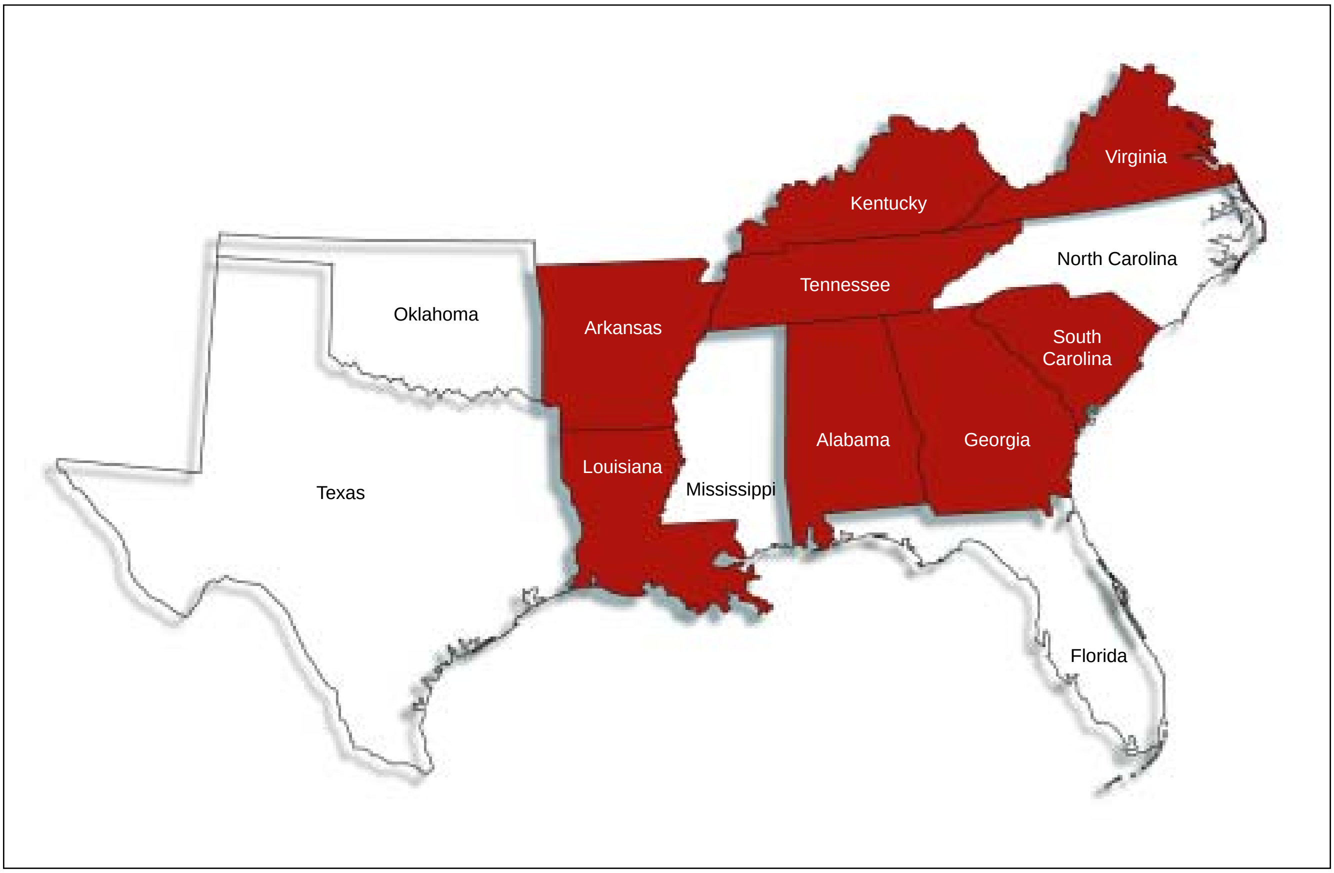

Figure 1. **By the end of 1999, eight southern states will be conducting joint state and federally sponsored annual forest inventories. All 13 southern states will likely implement the annual survey design by the year 2000.**

FS 1995). Current analyses of southern timber projections indicate that for some regions in the South, timber removals exceed growth (Cubbage et al. 1995). The question of whether the South can maintain or increase current levels of production cannot be answered at this time (Nilsson et al. 1999). After many decades of sustained inventory growth, southern inventories have leveled off. Increases in inventories are doubtful given the changing demographics and rapid urbanization of several historically important timber-producing regions.

The sustainability of timber and wood fiber supply is only one of many components of the forest sustainability issue. Fundamental sustainability depends on ecosystem processes that work at varying spatial and temporal scales and humankind's use and alteration of the dynamics and functioning of forest systems (Smith 1970). An incomplete yet significant list of ecosystem stresses exerted by humans include land conversion, introduction of insects and disease, air pollution, and forest fragmentation. Humankind is suspected of contributing to climate change, which results in ecosystem stress.

Forest sustainability issues are not restricted to federal lands. Because nonfederal forests account for two-thirds of the nation's forested area, they will play the predominate role in determining the sustainability of not only the nation's forests but of our planet as well. The role of nonfederal forested lands is especially critical in the South, site of 41 percent of the nation's timberland; 92 percent of these lands are nonfederal. The South provides 67 percent of the nation's pulpwood, 50 percent of its plywood, 40 percent of its hardwood lumber, and 33 percent of its softwood lumber. Few of these production statistics are projected to decrease. The entire country is relying less on the timber resources on public lands, resulting in an increased dependence on privately held timber, particularly in the South. According to the most recent Resources Planning Act (RPA) projections of future demands for timber products, the consumption of pulp, paper, and paperboard will continue to rise and may increase by as much as 50 percent by the year 2040 (Haynes et al. 1995).

Estimating and maintaining current forest resources information is fundamental to providing real-time monitoring of forest ecosystems. The national Forest Inventory and Analysis (FIA) program of the USDA Forest Service is the primary source of information on the status, trends, and use of the nation's forests on public and privately owned lands. The FIA program is administered regionally by five research stations, with the Southern Research Station responsible for maintaining current inventories in 13 states, Puerto Rico, and the Virgin Islands *(fig. 1).*

To address the uncertainty of forest sustainability in the South, the American Forest & Paper Association (AF&PA), Southern State Foresters, and the Southern Governors' Association have recognized the need for a continuous forest inventory system. The AF&PA was instrumental in convening the second blue ribbon panel (BRP II) on FIA in October 1997. Key recommendations of BRP II include elevating the priority of the FIA program within the Forest Service, initiating annual inventories, reporting on all forestlands, and exploring partnerships for delivery of the program (AF&PA 1998). Since BRP II, the Southern State Foresters and the USDA Forest Service have collaboratively phased implementation of an annual forest inventory throughout the South. The Southern Annual Forest Inventory System (SAFIS) is the result of this partnership between southern states and the Southern Research Station's FIA program.

The initiation of SAFIS is an acknowledgement that the need for current information on changes in southern forests has never been greater. The need for maintaining current inventory information is evidenced by the Agricultural Research, Extension, and Education Reform Act (PL 105-185) (the Farm Bill) of 1998, which congressionally mandates FIA to implement an annual inventory system nationwide.

Past and Future Directions

A chronology of congressional mandates for forest resource assessments is useful for understanding the nearly 70-year metamorphosis of the USDA Forest Service's FIA program. The McSweeney-McNary Forest Research Act of 1928 directed the Forest Service to conduct periodic assessments of the nation's forest resources. The mission of this act was to estimate forest area, timber volume, growth, and cut. The forest inventories were charged with providing the information needed to formulate policies and principles for sustained forest use.

The McSweeney-McNary Forest Research Act led to the creation of the USDA Forest Service's Southern Forest Survey program in the 1930s. (Forest Survey later became the FIA program.) These initial forest surveys were key sources of information for the development of a fledgling pulp and paper industry in the South. Since then the program has continued to provide an unbiased public database that be can used by all citizens to estimate trends in forest area, distribution, species composition, and other vital forest statistics.

In the 1970s three pieces of legislation—the Forest and Rangeland Renewable Resources Planning Act of 1974, the National Forest Management Act of 1976, and the Forest and Rangeland Renewable Resources Research Act of 1978—expanded the objectives of the forest survey to include measurements related to wildlife, ecology, aesthetics, and recreation and other types of human impacts. The Farm Bill of 1998 mandated the Forest Service to implement annual surveys whereby 20 percent of FIA's one-sixth-acre ground plots are measured each year. These laws are in place to ensure the availability of accurate data and information for determining the sustainability of forest resources.

Since FIA's inception, the most basic goal of the program has been to provide a strategic survey that estimates total forest area and gives inventory estimates of broadly defined forest types. Examples include strata means and totals of forest types based on tree species composition, average stand age, tree size, and ownership. Changes in society's information needs have greatly influenced FIA and the use of its data over the years and will continue to do so. For example, key global climate change issues over sources and sinks of greenhouse gases in forests now are being investigated through the use of FIA data (Heath and Birdsey 1997).

The move toward national implementation of an annual forest survey has gained significant justification over the last several years. Annualized forest inventory systems fill the need for integrated assessments that rely on the best and most current data for identifying trends, relating trends to likely or suspected causes and consequences, and providing possible outcomes of alternative actions.

Regional assessments of resource trends have proved difficult under the traditional periodic survey system. Using the periodic system it takes 10 to 12 years to inventory the entire South, because the survey is implemented on a state-by-state basis. This approach can lead to the undesirable circumstance of bordering states having data that varies in age by a decade or more. Public users of southern FIA data have noted that these data are accurate for two or three years but become increasingly unreliable over time. With the rapid changes in the status and conditions of forestlands in the South, this system is inadequate. In addition, this system makes it difficult to observe trends, because plots can be remeasured at intervals of up to 15 years. In those cases it is entirely possible that important changes and trends are either missed or documented many years after they occur, which deprives decisionmakers of the opportunity to implement changes in management or policies.

There are benefits and costs associated with an annualized inventory system. Some of the benefits include current and uniform information across all states owing to a continuous and seamless sampling program that provides annualized monitoring of important resource trends across the entire South. Because identical sampling and modeling efforts are performed each year, catastrophic events such as hurricanes and insect and disease epidemics can be observed and accounted for on an annual basis. The greatest benefit is that SAFIS provides data and methods for producing annual estimates, which provide critical information for effective policy and forest management decisions in the South.

On the cost side, compared to the periodic system SAFIS requires additional resources. In the periodic system, it takes an average of two years to collect the survey information for a state. Before SAFIS, the southern FIA program worked in two out of 13 states at any point in time. Under the periodic survey paradigm, about 8.3 percent of the plots in the South were measured in comparison to 20 percent as mandated by the Farm Bill. Additional resources are required to ensure the quality of the survey process, manage data, perform statistical analyses, and publish reports. SAFIS would not exist without the partnership between the Southern State

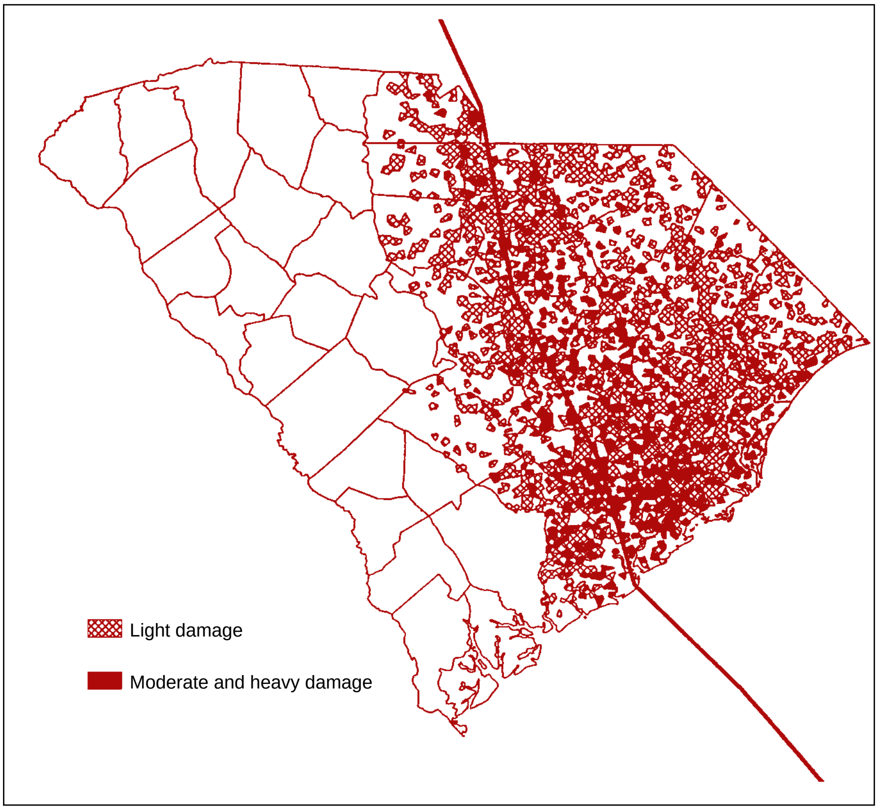

Figure 2. **The distribution of forestland in South Carolina damaged by Hurricane Hugo, by degree of damage.**

Foresters and the Southern Research Station's FIA program, which combines funds with intellectual and physical human resources. The annual survey is currently under way in eight states *(fig. 1).* Fiscal year federal dollars in 1999 for the operation of southern FIA include $8.2 million to the Southern Research Station, $1.2 million in federal cost-share to participating states, and combined state contributions (for Alabama, Arkansas, Georgia, Kentucky, Louisiana, South Carolina, Tennessee, and Virginia) of $2.5 million.

Design of SAFIS

In designing inventory systems it is important to recognize that definitions of sustainability change over time and vary according to location and interests. Changes in forest type and condition have accelerated, and the rapid pace of change likely will continue. The combined effect of real change and definitional changes calls for a resilient and simple sampling frame. This goal is in direct contrast to many operational timber inventories in which the sampling strategy is specifically tied to the efficient estimation of one or two closely related parameters of interest.

Fortunately for the continuity aspect of FIA, the types of measurements that are necessary to estimate forest resources are as valid today as they were 30 years ago, and it is unlikely they will change tomorrow. Facilitating recognized objectives and, as new resource questions emerge, introducing new ones into a long-term forest resource sampling design is of great importance, both technically and politically. Both aspects must be addressed because society's information needs are essential to defining the objectives of a federal inventory and monitoring program.

Another dominant consideration in planning a long-term monitoring program is the inevitability that a highly efficient sample design—one that optimizes on one or very few resources of interest—will go out of date. Examples in forest inventory include the use of stratification and variable probability of selection based on volume or value per unit area. Design features that involve complex sample structure create potentially serious difficulties, whereas an equal probability design permits greater adaptability and flexibility. To minimize sample design obsolescence, structure should be employed sparingly and with awareness of its undesirable effects; variable probability sampling designs and other complex sampling schemes are less amenable to the multiple and changing objectives that long-term monitoring programs must address, and therefore should be avoided (Overton and Stehman 1996).

Simplicity is desirable for many reasons. Not only will sample elements change over time (for example, a pine plot becomes a parking lot) but so will the overall objectives. Adding to the call for simplicity is the growing recognition that data collected from federally funded monitoring programs should be accessible to the public at large (Cowling 1992). With a relatively simple sample design, it is more likely that valid results and conclusions can be reached by various public users of the FIA database.

The simplicity and resiliency needs of the southern FIA program have resulted in the use of an equal probability systematic sample design (Roesch and Reams 1999). This interpenetrating design uses five annual panels, whereby plots measured in year 1 will be remeasured in year 6. In this mode of operation the survey cycle will always be one year, and the plot cycle will be five years. If funding difficulties occur it is likely that a smaller proportion of the plots will be measured each year.

Under the annual survey system, core data will be compiled each year into a standard set of tables for each state and released in hard copy and electronic formats. Data will be released within six months of the end of an annual measurement period.

Every five years a complete analytical report will be produced for each state. For the 13 states served by the Southern Research Station, two or three state reports will be prepared per year by the FIA program in collaboration with state, federal, academic, and other knowledgeable individuals.

Each state report will document the following: (1) the current status of the forest based on the last five years of data; (2) trends in forest status and condition over the preceding 20 years, with emphasis on comparing the most recent data with data from the previous period; (3) timber product output information for the state; (4) analysis and discussion of the probable forces causing the observed conditions; and (5) projection of the likely trends in key resource attributes over the next 20 years, under a range of plausible scenarios.

In the transition period from periodic design to full implementation of the annual five-panel design, the following options for analysis and reporting are being considered: (1) produce estimates based only on those plots measured each year; (2) average the new panel information with the previous periodic information using moving average models; (3) complete the first two or more annual panels (at least 40 percent of all FIA plots) before reporting current inventory information. These options are being discussed because circumstances may dictate the reporting of information before the five-year analytical report is prepared.

Assuming a state does not receive new inventory information until all five panels are measured, some southern states will be relying on information that is 15 years old. At the very least the southern FIA program expects that a number of FIA customers will either use estimators developed by FIA for items 1 through 3 above or develop their own. Southern FIA believes it should provide statistical methods for developing interim estimates for public users.

Once the new rotating panel design has been fully implemented, the increased flexibility in inventory estimation techniques will be realized. Several approaches have been presented by the scientific community and are under investigation by FIA scientists and the external users of FIA information (Van Deusen 1996; Reams and Van Deusen 1999; McRoberts et al., in press; Reams and McCollum, in press). Some of the methods can be implemented immediately, and several others will need further research and pilot testing before implementation is considered (McRoberts 1999; Roesch and Reams 1999).

New design features give rise to different and improved methods of analyses. However, new estimation methods usually undergo both a research and a user group development and phasing period. Annualized estimates that are most similar to the periodic system estimates will provide the foundation of first-generation annual inventory estimates (Roesch and Reams 1999). First-generation estimates will use rolling or moving average techniques based on averaging the last five years (panels) of data (Reams and Van Deusen 1999; Roesch and Reams 1999). Because inventory estimates are based on the five-year moving average, the perceived danger of mistaking fluctuations in estimates of inventory because of random sampling with real change is minimized. Based on a minimum number of assumptions, moving average methods have been shown to be identical to estimation techniques used by FIA under the periodic system (Reams and Van Deusen 1999). Second-generation methods that involve tree- and plot-level modeling and other modeling updating techniques will be incorporated based on performance and utility to the program (McRoberts 1999; Reams and Van Deusen 1999; Roesch and Reams 1999).

There are circumstances in which the five-year moving average will overestimate or underestimate current inventory. These situations are most obvious when there is either an abrupt shift in inventory or a strong trend in the variable of interest. For example, if a hurricane similar to Hugo hit South Carolina during the measurement of panel 3, inventory estimates based on a five-year moving average would overestimate inventory in the eastern half of South Carolina *(fig. 2)*. In this case, basing estimates on the two panels measured after the hurricane (panels 4 and 5) would be a reasonable alternative. Other possible solutions would be to use more-sophisticated time series models that can more readily account for trend or discontinuities in inventory.

Improved Assessments

Large-scale assessments of forest sustainability related to one or more major public policy themes or initiatives are becoming increasingly necessary. Well planned and executed annual survey systems can provide the basic initial baseline and monitoring information to address the many scientific and societal issue–driven assessments of sustainability.

Currently, the importance of forests and forest management to the global carbon cycle is a controversial subject being negotiated for the Kyoto Protocol to the United Nations Framework Convention on Climate Change. FIA survey data are used to estimate US forest carbon stocks so that sources and sinks of carbon can be identified. This represents a relatively new and unique use of FIA data and is certainly not a traditional one. Such use of these data would not have been predicted by inventory specialists even a decade ago. FIA data are the very foundation of US carbon stock estimates, and in all likelihood they will continue to provide the basic monitoring data for carbon stock changes both regionally and nationwide. FIA is the only national public database that can estimate and provide continuous monitoring of forest carbon stocks in the United States (Heath and Birdsey 1997; Joyce et al. 1997).

FIA data will continue to provide the basic information at the forest area, plot, and tree level for all types of regional, national, and international forest assessments. National resource assessments such as RPA (Powell et al. 1993) and the recently completed Southern Appalachian Assessment (SAMAB 1996) rely heavily, in many cases exclusively, on FIA data to describe and estimate current conditions and trends of forests within a region. Annual information will allow for continued monitoring of forest resource trends and suspected causes addressed by the Southern Appalachian Assessment.

In the dual realm of strategic inventories and landscape-scale assessments, annual survey systems provide the information essential for monitoring resource conditions and trends. Annual inventory systems that are cost-effective, are publicly entrusted, and provide unbiased information of forest resource trends, are requisite for sound strategic planning, management, and conservation of the nation's forests.

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Joint Annual Forest Inventory and Monitoring System

The North Central Perspective

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

By Ronald E. McRoberts

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

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

In the early 1990s, scientists in the FIA program at the North Central Research Station (NCRS) formulated concepts that led to implementation of the first large-scale annual forest inventory system under the auspices of the USDA Forest Service. Planning and implementing this system was a joint effort of NCRS, the Rocky Mountain Research Station, and the Minnesota Department of Natural Resources (MN DNR). Shortly after the system was implemented, the Southern Research Station (SRS) implemented an annual inventory system that was both similar and dissimilar in key aspects to the NCRS system. Although the NCRS effort was initiated before the SRS effort, the political and industrial support generated by SRS was primarily responsible for placing annual forest inventories on the national FIA agenda.

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

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

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

Annual Sample

The characterization of USDA Forest Service forest inventories as "annual" is based on the measurement of a proportion of plots each year and the capability of producing annual FIA estimates, not on a complete annual inventory of all permanent plots. FIA precision standards require a sampling intensity of one plot for approximately every 6,000 acres in the North Central region (USDA-FS 1970). To satisfy this requirement, the geographical hexagons established for the FHM program were divided into 27 smaller FIA hexagons, each of which contains approximately 5,900 acres. A grid of field plots was established by selecting or establishing a plot in each smaller hexagon: (1) if an FHM plot fell within a hexagon, it was selected as the grid plot; (2) if no FHM plot fell within a hexagon, the plot from the existing network of permanent FIA plots (Vasilevsky and Essex 1977; Schmidt 1998) that was nearest the hexagon center was selected as the grid plot; and (3) if neither FHM nor existing FIA plots fell within the hexagon, a new permanent FIA plot was established at the hexagon center and selected as the grid plot. This grid of plots is called the federal base sample and is considered an equal probability sample; its measurement in the North Central region is funded by the federal government.

Plots are classified into three categories: forested, nonforested, and questionable.

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

The federal base sample is considered an equal probability sample of the total surface area of a state, with the basis for inference residing in the sample design. Equal probabilities for plot selection result from the random orientation of the system of the FHM hexagons and the lack of relationship between the locations of the hexagons and the locations of permanent FIA field plots.

Intensification Sample

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

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

Remote Sensing

Remote sensing techniques are applied in forest inventories for area estimation, for forest–nonforest stratification, for post-measurement stratification for variance reduction purposes, and optionally for disturbance detection. Where available, the Gap Analysis Program (GAP) (NCASI 1996; Scott and Jennings 1997) is used for area estimation and stratification. GAP analyses are generally conducted by state agencies or universities, are based on two-date, same-year satellite imagery from the Landsat Thematic Mapper (Bauer et al. 1994), and classify pixels across entire states into strata related to land use, vegetative cover, and tree density.

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

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

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

Database Operations

The database consists of plot and tree information for all permanent FIA plots and is crucial to inventory estimation, analysis, and reporting. Because many FIA users are more interested in the database than in the published assessments and reports, extracts of the database are designed to be a public, accessible, and user-friendly medium for transferring information.

Establishing the Eastwide and Westwide formats provides easy public access to FIA database information.

FIA programs use database operations to accomplish a variety of tasks such as selecting plots to be measured, retrieving and verifying data from previous inventories, preparing field data recorders, producing field crew plot sheets, entering and editing remotely sensed and field data, tracking the progress of inventories, calculating estimates, creating files for public access, and storing information for future inventories (Hansen 1998). Although individual FIA programs may accomplish these tasks in somewhat different ways, standardization of the FIA plot design and field procedures, agreement on a common set of estimates and a common table format for reporting purposes, and selection of a common database management system are leading to greater overall uniformity.

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

Estimation

The properties of the statistical estimators used to calculate annual FIA estimates depend on the sampling designs used to collect the data. Regardless of the estimation technique employed, data resulting from the measurement of some plots from the federal base sample will be available each year. Therefore, the simplest way to calculate annual FIA estimates is to use only the data from the panel of plots measured in the current year. Such estimates reflect current conditions and are based entirely on measured plots, but their precision will be unacceptable for some variables because of the small annual sample size. An alternative is to use the data for all plots obtained from the five most recent panels of measurements and employ a moving average estimator. The advantage of this alternative is that precision is increased because data for all plots are used for estimation; the disadvantage is that the estimates do not reflect current conditions but rather an average of conditions over the past five years. Another alternative is to update to the current year data for plots measured in previous years and then base the estimates on data for all plots. If the updating procedures are unbiased and sufficiently precise, this alternative increases the precision of the estimates without the adverse effects of using out-of-date information. Thus, a variety of estimation procedures are available under JAFIMS, with the moving average agreed on as the default.

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

Updating

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

The FIA program at NCRS has used the STEMS (Belcher et al. 1982) growth models to update plots and trees not measured in the current year. These regional models were developed from data collected primarily from long-term research plots and have generally been accepted for application in the North Central region. Nevertheless, research to improve the efficacy of the growth models has been undertaken with several objectives: (1) to calibrate the models using FIA data rather than data from research plots; (2) to use current statistical techniques that were unavailable when the STEMS models were developed; and (3) to incorporate a climatic component into the models. The hypotheses underlying the third objective are that incorporating a long-term climatic component will provide greater spatial precision, and incorporating an annual climatic component will provide greater temporal precision. Unpublished analyses indicate that the bias in the models is both negligible and less than that for the STEMS models and that the effects of imprecision in the model predictions are very small relative to the variation among measured plots within a stratum.

Logistically, annual inventories may permit long-term cost savings, but the initial implementation may be costly.

Field Logistics

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

- Supervising field crews becomes more difficult, because they are distributed across an entire region rather than concentrated in a few states. Additional field crew supervisors must be hired or additional levels of supervision must be established. Existing supervisors must travel extensively (or use technology to provide oversight remotely) or field crews must be granted greater independence.
- Because field crews will be in multiple states simultaneously, uniformity must be developed and maintained with respect to field manuals, data recorder programs, and editing programs.
- Many smaller, permanent locations for stationing field crews must be arranged, the preferred solution being collocation with other Forest Service units or land management agencies. In addition, each location must be provided with computer, communication, and support services that otherwise could be transported with the field crews as they move.
- Some states will not require a large enough annual sample to justify permanent stationing of a full-time crew. But the requirement to measure plots systematically distributed throughout these states each year may substantially increase travel costs. Alternatives include contracting for part-time crews in those states, having crews from adjacent states satisfy the requirement, and maintaining a small number of crews in permanent travel status to cover several such states.
- Quality assurance and quality control issues will require greater attention because of less-intense supervision, variability among field procedures, and diversity among field crews and their funding sources.

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

Conclusion

In 1998 the initial panel of plots based on the grid of hexagons was selected for Minnesota, Missouri, Indiana, and Iowa; logistical procedures were implemented; and field measurements were initiated. Although some issues remain to be resolved and analyses of efficiencies and precision remain to be completed, JAFIMS appears to be a viable solution for satisfying the demands of FIA users for more precise, timely, and accessible FIA information.

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Analytical Alternatives for an Annual Inventory System

Methods for analyzing data from the Southern Annual Forest Inventory System (SAFIS) are discussed. Differences between the annual inventory approach and the more traditional periodic approach require that we revisit the previous assumption that there are no important spatial and temporal trends in the data. Over the next few years, the USDA Forest Service Southern Research Station will be evaluating models of varying complexity to determine the most efficient estimation approach for each variable, at all spatiotemporal scales of interest.

By Francis A. Roesch and Gregory A. Reams

The USDA Forest Service Southern Research Station (SRS) Forest Inventory and Analysis Unit (FIA) has initiated an annualized forest inventory sampling design, the Southern Annual Forest Inventory System (SAFIS). SAFIS was introduced to improve estimation of both the current resource inventory and changes in the resource. Under the previous periodic inventory system, individual states were inventoried over a two- to three-year period, about every 10 years. Many factors, including rapid land use changes and the intense forest dynamics in the southern United States, contributed to diminished confidence in inventory estimates that were more than a few years old. It was decided that an annualized inventory system, in which data is collected statewide every year, would provide more timely and useful estimates. We will discuss some of the analytical proposals for data from this system.

Before the SAFIS effort, the North Central Research Station (NCRS) had been conducting an annualized inventory in Minnesota in cooperation with the Minnesota Department of Natural Resources. More recently, the Agricultural Research, Extension, and Education Reform Act of 1998 (PL 105-185) directed the entire Forest Service to move toward an annualized inventory. Although this article addresses SAFIS directly, recent developments have led to SRS and NCRS scientists joining forces to investigate the challenges and opportunities arising from this transition to annual inventories.

The plot arrangement for the SAFIS sample design resulted from an intensification of the National Forest Health Monitoring (FHM) grid, which has been described as a component of a global environmental monitoring sample design (Overton et al. 1990; White et al. 1992). The sample plots are located in a systematic triangular grid with five interpenetrating panels. One panel per year is measured for five consecutive years. Every five years the panel measurement sequence reinitiates. If panel 1 was measured in 1998, it will also be measured in 2003, 2008, and so on. Panel 2 would then be measured in 1999, 2004, 2009, and so on. The panels will be as well dispersed as possible if we apply them according to the pattern in *figure 1.* Note that in a triangular grid the cells are hexagonal in shape. The result of this pattern is that each element has no immediate neighbors from the same panel.

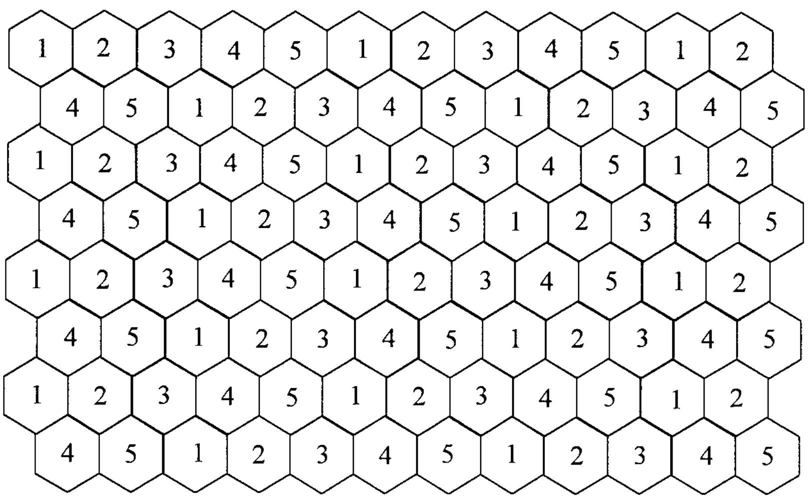

***Figure 1.* An interpenetrating pattern for a five-panel design. No element has another member from the same panel as an immediate neighbor.**

Implementation of SAFIS requires a transition from one of two variations of a periodic system to the rotating panel design described above. The first of the two variants of the periodic sample design, that found in the western states within the SRS area of responsibility, consists of a collection of three-square-mile grids placed randomly within each survey unit. The survey units are of such a size that there are typically

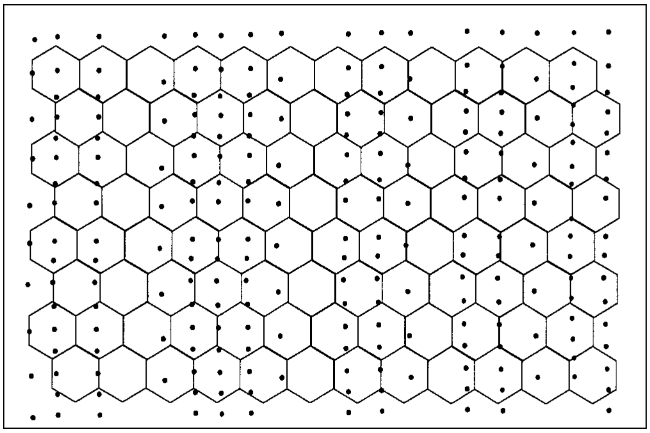

***Figure 2.* Example of a coarse mapping of existing plot locations.**

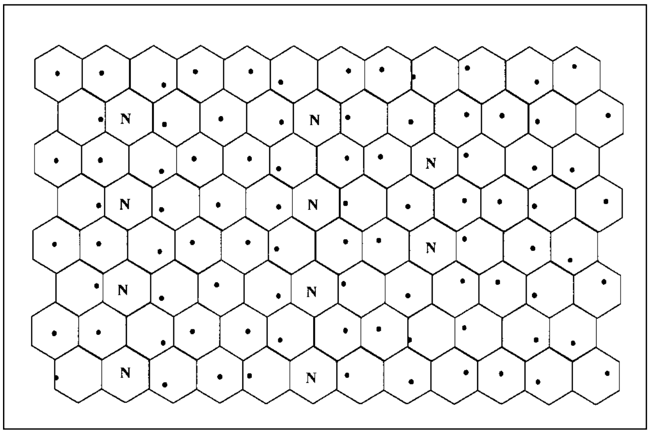

***Figure 3.* Example of a coarse mapping of existing plot locations after deletions of unneeded plots. Cells containing an "N" would require new plots under option (3a).**

several within a state. The second variant of the periodic sample design, occurring in the eastern SRS states, underwent a number of changes over past decades. Unfortunately, not all of these changes have been well documented. The resulting pattern of plot locations on the landscape is a somewhat irregular grid, of a higher spatial density than desired.

SAFIS has presented a few challenges with respect to inventory goals that can sometimes be at odds. For instance, an obvious goal would be to ensure that the transition is as smooth as possible, and another goal would be to implement the new design as quickly as possible while minimizing cost. The goal of a smooth transition can conflict with the goal of quickly implementing the new design. To ensure a smooth transition, we must maintain temporal consistency and continuity for trend estimation. We could argue that this would be easier to accomplish if we retained as many of the old plot locations as possible. Although it is true that there is a cost associated with establishing new field plot locations, the quickest and easiest implementation of the new design would occur if an entirely new grid of sample points is established across the SRS area of responsibility.

There are numerous methods we might use to choose existing sample point locations for retention in the new design. The different methods involve varying degrees of compromise between simplicity and the desire to sacrifice as little of the historical trend information as possible. The options we consider here are to:

1. eliminate all the old plot locations and start over with a triangular grid
2. delete plot locations until a roughly regular grid results, at the same intensity as the desired grid
3. use a coarse mapping to assign existing plots to the nearest grid point *(fig. 2)*. Subsequent to the coarse mapping, we could:
    a. delete any extra plots in each grid cell and establish new plots at the center of every empty cell *(fig. 3)*, or
    b. assign residual plots within one grid cell of an empty cell to the empty cell and establish new plots at the center of any still-empty cell *(fig. 4)*.

Option 1 is the most expensive and option 2 is the least expensive. The variations of option 3 are considered a compromise because they do not result in a regular grid of points at a fine scale, but they do at a coarse scale. Also, they provide a formal mechanism for assigning the existing locations to a regular grid of cells, and could be analyzed, with caveats, as though the sample consisted of a regular grid.

The advantage of option 1 is that we would be starting fresh with nothing messy or complex to compensate for in the future. Also, the entire SRS would operate under a single sample design with no conflicts in concept or analytical procedure. The disadvantages are that it would result in a gap in observations of trend and would necessitate replication of all pre-field work with respect to point location identification and classification.

Option 2 has the advantage of being quick and easy to implement. In addition, trend information will benefit from the continuity of plot locations. The drawbacks include the fact that some clumping of plot locations will occur and, if spatial relationships are modeled, there could be potentially large differences in the analytical procedures between eastern and western states for some variables.

Option 3a also has the advantages that trend information will benefit from the continuity of sample locations and some of the work that goes into point location identification and classification will be reusable. Less clumping of plot locations will occur than with option 2 and there will be at most small differences in analytical procedures within the station. As with option 2, the actual location of plots would not be regularly spaced at the finest scales of measurement. We note that option 3b retains more of the original plot locations than option 3a. Therefore, trend information will benefit to a greater extent under option 3b. Most of the work that has gone into point location identification and classification will be reused. Again, as with option 3a, small differences of analytical procedures may be necessary.

Analysis

As we discuss the different analytical approaches for the SAFIS design, we assume that option 3a above will be used to assign existing plots to their enclosing cells and that new plots will be established at the centers of all empty cells. We

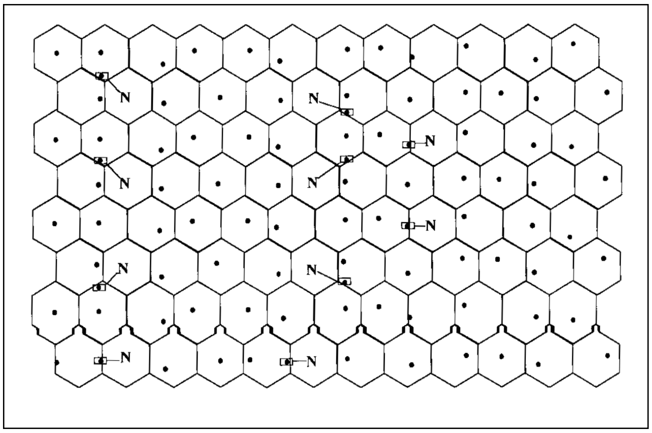

Figure 4. **Option (3b) would utilize extra plots in adjacent cells for assignment to empty cells.**

recognize that there will be some demand for analyses during years 1 through 4 of the annual design in a given area. For these transition years, FIA will provide composite estimates formed by the appropriate weighting of estimates from the complete periodic inventory combined with estimates from the incomplete annual inventory. In this article, we examine procedures to be used once a full series of observations is available; that is, when all five panels have been measured at least once.

The major difference among the analytical procedures being proposed is in the extent to which spatial patterns and time trends are ignored. That is, in extensive inventories, such as SAFIS, one may or may not wish to make the usual assumption that spatial location or actual year of measurement within a single panel series is unimportant in the analysis. We will briefly discuss some of the analytical procedures being proposed while keeping this perspective at the forefront. To do this we must provide notation that will allow the use of a full spatial-temporal model; however, we will occasionally be able to collapse the model along one or more dimensions.

One of the measured variables for each plot will be the proportion of plot area in each condition class. A condition class is defined as the combination of variables that identify different strata. Forest condition classes are at least an acre in size and identified by land use, forest type, stand origin, stand size, stand density, and ownership class (Anonymous 1998). Assume that we seek estimates for each condition class observed in a survey unit. Also assume that the horizontal and vertical positions of cell centers are numbered from west to east and south to north, respectively. Let:

h_i = horizontal position i ($i = 1,\ldots,I$)
v_j = horizontal position j ($j = 1,\ldots,J$)
t_t = time t ($t = 1,\ldots,5$)
c_k = condition class k ($k = 1,\ldots,K$)
X_{ijtk} = the per-acre value observed at h_i, v_j, and t_t, for c_k
A_{ijtk} = the area in acres sampled in c_k at h_i, v_j, and t_t

$$C_{ijtk} = \begin{cases} 1 & \text{If } c_k \text{ occurs at } h_i, v_j, \text{and } t_t, \\ 0 & \text{Otherwise} \end{cases}$$

A_P = plot area

The focus here is on estimation of a per acre value (V) for condition class k under different assumptions of spatial and temporal trend.

If we assume that there is no time or spatial trend at the observed scales, then our data model would have the simplest form possible, and the overall mean for the five-panel series would provide the best estimator of a per-acre value (V) for condition class k:

$$V_k = \frac{1}{A_{S_k}} \sum_{t=1}^{T} \sum_{i=1}^{I} \sum_{j=1}^{J} \frac{A_{ijtk}}{A_P} X_{ijtk}$$

Otherwise, if we were willing to ignore any spatial trend, we could calculate the mean within each panel for an estimate each year:

$$V_{tk} = \frac{1}{A_{S_{tk}}} \sum_{i=1}^{H} \sum_{j=1}^{J} \frac{A_{ijtk}}{A_P} X_{ijtk}$$

where $A_{S_{tk}}$ = sum of the plot areas sampled in condition class k at time t.

This approach would, however, provide an inadequate sample for many variables. Rather, we should explore different models for the time trend to efficiently use the entire five-panel sample. The simplest model, that of no time trend, would weight the panels equally:

$$V_k = \sum_{t=1}^{5} .2\, V_{tk} \qquad (1)$$

This is the method used by FIA for periodic inventories in states that required more than one year to inventory. An advantage to using this approach initially is that the current software used by FIA would be applicable.

Because the time duration of measuring all five panels is somewhat longer than the duration of one to three years per state that it took for the periodic inventories, equal weighting of plots across panels may have the tendency to mask temporal trends. One suggested solution for this problem has been to form an estimator in which panels that were-measured more recently are weighted more heavily than those measured earlier. This estimator would take the following form:

$$V_k = \sum_{t=1}^{5} w_t V_{tk} \qquad (2)$$

And w_1 through w_5 would be weighted so that the sum is equal to 1, such as .1, .1, .2, .3, and .3, respectively. If one used the preceding weighting scheme, it would be analogous to stating that one has three times as much confidence in panels 4 and 5 being fair representations of today's condition as panels 1 and 2.

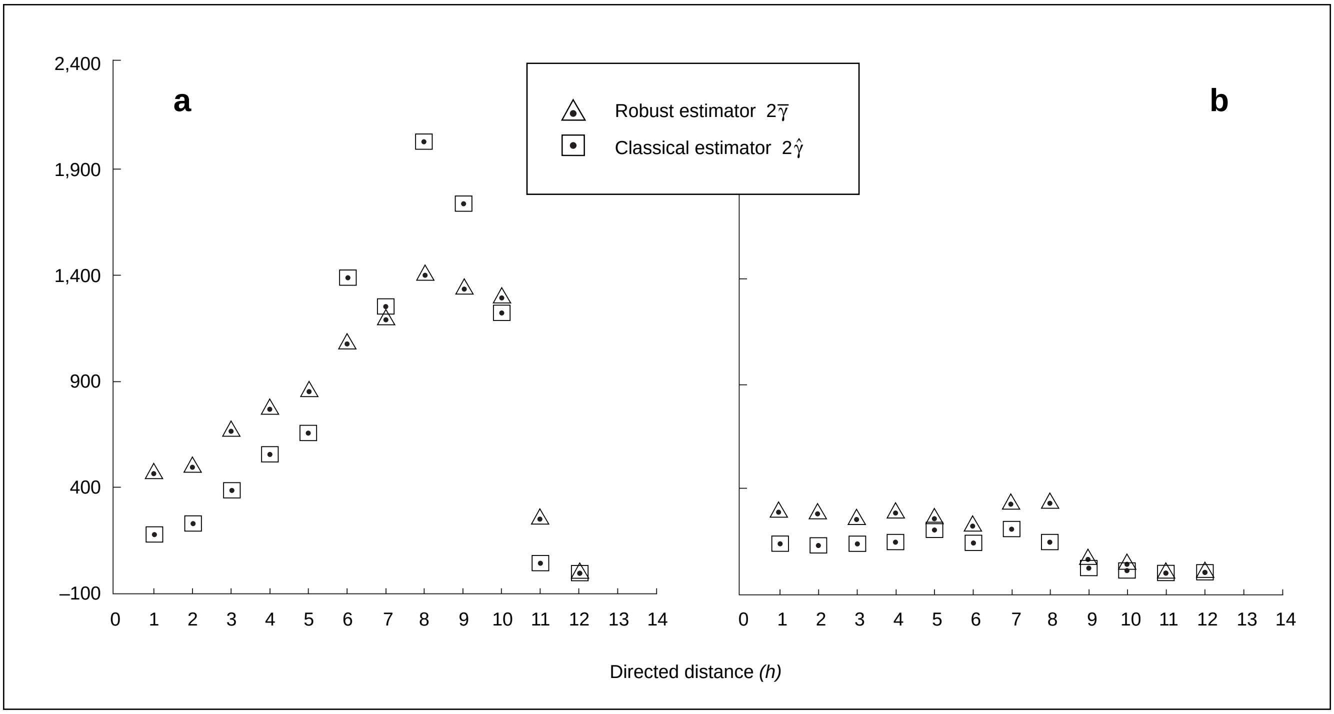

Figure 5. **(a) Estimated NE/SW variogram for percent basal area spruce/fir. (b) Estimated NE/SW variogram of residuals from the median polish.**

A less arbitrary approach would be to attempt to model the time trend within a panel series. Van Deusen (in review) presents a mixed estimator that can incorporate increasing levels of constraints on the derivatives of the time trend, allowing one to model various levels of complexity in the time trend. The mixed estimator literally mixes two models: the first describes the relationship of observations within each panel (or time period) and the second describes the time trend. The mixed estimation approach is both powerful and practical for most variables of interest to FIA. A slightly more complex formulation than that given by Van Deusen would be appropriate to satisfy FIA's charge to recognize changes in condition class within field plots. This might be considered necessary because, although each plot samples the same amount of surface area, the area of a condition class sampled by a plot can vary from zero to the size of a plot. Therefore, individual plot averages for a particular condition class have different bases of support and should probably be weighted accordingly.

Finally, as pointed out in Roesch (1994) for the case of forest health monitoring, some variables will display spatial trends within condition classes in extensive inventories. Spatial analyses are of interest any time the measurement of a variable is likely to be different solely because of the spatial location of the observation. In these cases, a larger class of models, which include spatial correlation, should be used. Along these lines we could fully analyze the effect of all of the spatial dimensions or we could implicitly undermine the importance of one (or more) of the dimensions by collapsing it down into the remaining dimensions (as is usually done for elevation). Having the ability to discover and remove spatial correlation makes it easier to investigate other potentially important relationships in the data, and will at times provide a simple explanation for high variability in a measurement of interest.

To perform a spatial analysis at a particular scale, the first step is usually a coarse mapping, which is accomplished by segmenting an area with a specific size grid and pooling the plots within each segment (see Cressie 1991). Next, the median polish technique is often used to decompose the value in each cell at each time (X_{ijtk}) into its assumed components of an effect common to all cells, spatial effects in two directions, and a residual:

$$X_{ijtk} = C_{tk} + H_{itk} + V_{jtk} + R_{ijtk}$$

where:

C_{tk} = the "common" effect at time t $(t=1,\ldots,5)$
H_{itk} = the *ith* horizontal effect $(i=1,\ldots,I)$
V_{jtk} = the *jth* vertical effect $(j=1,\ldots,K)$
R_{ijtk} = the residual in cell i,j at time t

For T time periods, the result is a $1 \times T$ vector C of common effects, two matrices ($\boldsymbol{H}$ and $\boldsymbol{V}$) of directional effects, and a matrix $\boldsymbol{R}$ of residuals.

Although there are ways other than the median polish to accomplish this decomposition, we do not want the effects to be overly influenced by any outliers present. See Cressie (1991) for a defense of the two-way median polish when outliers are a potential concern. The matrix $\boldsymbol{R}$ can be evaluated for special cases in the same manner as the more familiar residual analysis for regression. Subsequent to the median polish we can obtain residuals that are not time-detrended by adding the "common" effect for each time period back into the residuals:

$$W_{ijtk} = R_{ijtk} + C_{tk}$$

We could then treat the matrix **W** as an independent set of time-series observations, and analyze the time trend.

One way to ensure that suspected spatial trends have been removed is to estimate the variogram at a series of directed distances. The variogram is the variance of the difference in values, separated by a specific distance and direction, observed at defined points in space. If s represents an observation point, h represents a directed distance, and $X(s)$ represents the value of the variable at point s, then the variogram is defined as $2\gamma(h) = \mathrm{var}(X(s+h) - X(s))$. By plotting estimates of the variogram for different values of h, we can determine the magnitude of spatial correlation for a variable at different scales.

The classical estimator of the variogram is:

$$2\hat{\gamma}(h) = \frac{1}{N(h)} \sum_{i=1}^{N(h)} (x_i - x_{(i+h)})^2$$

where:

$N(h)$ = the number of distinct pairs of points separated by directed distance h

$x_{(i+h)}$ = the estimate (or observation) of the variable at the point separated from point i by directed distance h

Any trend in variogram estimates will show the spatial correlation in the variable. For example, *figure 5,* taken from Roesch (1994), shows the variogram plots before and after a median polish was used to remove spatial correlation from the data. The relatively flat variogram of *figure 5(b)* shows that the median polish had effectively removed the spatial correlation from the data represented by the variogram in *figure 5(a).*

Conclusion

This discussion of the proposed methods for analyzing data from the SAFIS design has shown how these proposals differ mostly in the level of simplification accepted. Traditionally, FIA has given estimates for survey units, which are fairly extensive areas of land within a state. Plots in a survey unit were measured in one or at most two years. Therefore, it was not only reasonable but necessary to ignore time trend in variables during the execution of the survey. In addition, the survey units were thought to be small enough that spatial trend within the unit was not important for the variables of interest. The new sample design has two profound effects: the importance of the survey unit as a logistical tool is eliminated, and the measurement of plots is spread out over five years. These effects require that we revisit the previous assumptions of there not being important spatial or temporal trends within an area for each variable of interest. Probably we will find that these assumptions are often appropriate and, in these cases, the use of the estimator in equation (1) will be valid. Over the next few years, FIA will be evaluating models of varying complexity to determine the most efficient estimation approach for each variable, at each spatial scale of interest.

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Improving Forest Inventories

Precise estimates of standing inventory often are needed in a very short time; for example, in appraisal situations for acquisitions and divestitures. Opportunities to integrate auxiliary information into forest stand inventory are considerable, and the potential benefits are very attractive. This article presents three popular techniques for incorporating auxiliary information into forest inventory: list sampling, stratification, and Poisson sampling.

By Andrew P. Robinson, David C. Hamlin, and Stephen E. Fairweather

"Why are we doing all this cruising?" "Do we have to measure *everything*?" "With all the data we've been collecting for the past 20 years, isn't there some way to cut back on the amount of work we have to do?"

These management questions are quite familiar, and warranted, because in forestry we have a wealth of data, models, and rules-of-thumb that can be used to make our current inventory efforts more efficient than ever before. Statistically speaking, inventory foresters are often in a position to use auxiliary information to design and implement forest inventories.

Auxiliary information is information that is used to develop, support, or execute an inventory design. It is typically related to, but distinct from, the "item of interest," which is the subject of the inventory. The quality of an estimate of the item of interest can be vastly improved for the same overall cost by using auxiliary information. Despite the widespread acceptance of auxiliary information in sampling theory (see Cochran 1977; Särndal et al. 1992), techniques that feature the use of auxiliary information often meet resistance in some circles of forest inventory.

This article presents three techniques for incorporating auxiliary information into forest inventory. Our emphasis is on the practical application of estimating timber volume at the stand and forest levels. As much as possible, calculations have been excluded, but are available from the authors on request.

Background

The objective of sampling is to obtain estimates of population parameters, such as the total, for one or more variables of interest, such as volume, without measuring every member of the population. We will focus on estimating the total standing volume for a forest.

The population is divided into physical or logical units, called sampling units. Here, the sampling units are either plots or trees. The number of sampling units in the population is the population size. A subset of the units in the population is chosen in some way for measurement: the number of units selected in the sample is the sample size. Each unit selected in the sample is measured to obtain the variable of interest.

We use the sample to represent the population, and we scale the sample estimate to the population total using an expansion factor. This expansion is called estimation, and its result is the estimate. The correspondence between the estimate and the population parameter is uncertain because the estimate comes from a sample, not from the whole population. This uncertainty is called sampling error, and is quantified by the standard error of the estimate.

The standard error is used to calculate an α% confidence interval for the estimate. Imagine that the entire procedure (including the sample selection) was repeated on the same population a large number of times. Then on average α% of the confidence intervals calculated would contain the true underlying total, if certain assumptions were true. Formulae for calculating all these quantities can be found in any basic statistics or forest mensuration reference. A fundamental criterion for success in sampling is as small a confidence interval as possible for a given price, or alternatively, as inexpensive as possible an interval of fixed length.

We are concerned with a particular type of auxiliary information: one or more variables that are (1) closely related to the value of interest, (2) available for every unit in the population, and (3) quick or inexpensive to measure. For example, if the variable of interest is tree volume, then potential auxiliary variables might include diameter, height, and species, whereas for stand volume candidates would be aspect, cover type, and elevation. The judicious and profitable use of auxiliary information in sampling is as much an art as it is science. Experience and experimentation are both required to discover what is likely to work in any given situation.

1 List Sampling

In industrial forest management we must frequently provide accurate and precise estimates of standing inventory in a very short time. These conditions are typical in appraisal situations for acquisitions and divestitures, for which time frames of two weeks for fieldwork are not uncommon. Fortunately, we often have access to an existing but outdated stand-based inventory, so we can use auxiliary information from the existing inventory to acquire a quick and accurate estimate of the current inventory.

In list sampling the sampling unit becomes the stand itself. That is, the population consists of a list of stands, and the sample size refers to how many stands will be visited to measure the variable of interest. In *table 1* we have a population of 34 pine stands from the southern United States, all 20 to 25 years old, comprising a little more than 1,200 acres. The total weight of pulpwood is our variable of interest. How could we estimate it efficiently?

We are going to use several sampling techniques in this case. First, we will consider the area of each stand to be the auxiliary variable, because for this age class the volume of timber should certainly be related to the stand area. Second, because we would like to concentrate our fieldwork in the most important stands—the stands with the most volume—we will select the stands to visit with probability proportional to size (PPS). This technique is analogous to selecting trees on a prism plot with probability proportional to each tree's basal area, so work is concentrated on the larger, more-valuable trees. Third, we will use list sampling to get the PPS sample of stands. Finally, we will use a "mean of ratios" estimator: we determine the ratio of tons to acres, and use that value in concert with the total acreage to estimate the total tonnage. Biometricians will rec-

Table 1. Unit-level data for list sampling example: probability proportional to size with replacement, sample size 8.

Stand number	Acres	Cumulative acres	Probability	Random number	Cruise estimate (tons)
1	45.1	45.1	0.038		
2	13.8	58.9	0.011		
3	23	81.9	0.019	66.0	2,256
4	15	96.9	0.012		
5	9.9	106.8	0.008		
6	35.6	142.4	0.030	124.0	2,873
7	64.9	207.3	0.054		
8	24.6	231.9	0.020		
9	76.5	308.4	0.064		
10	33.7	342.1	0.028		
11	1.2	343.3	0.001		
12	18.4	361.7	0.015		
13	27.8	389.5	0.023		
14	153.8	543.3	0.128	405.0, 425.7	16,478
15	63.3	606.6	0.053		
16	9.6	616.2	0.008		
17	74	690.2	0.062		
18	8.5	698.7	0.007		
19	1.5	700.2	0.001		
20	61.3	761.5	0.051	739.1	5,838
21	11.6	773.1	0.010		
22	79.4	852.5	0.066	840.4	8,880
23	21.5	874.0	0.018		
24	4	878.0	0.003		
25	0.9	878.9	0.001		
26	14.6	893.5	0.012		
27	41.6	935.1	0.035		
28	9.2	944.3	0.008		
29	27.8	972.1	0.023	949.1	1,691
30	9.5	981.6	0.008		
31	9.8	991.4	0.008		
32	68.8	1,060.2	0.057		
33	24.8	1,085.0	0.021		
34	116.7	1,201.7	0.097	1,159.4	8,155
Total	1,201.7		1.000		

ognize this as the Horvitz-Thompson estimator.

The first step in selecting our PPS sample of stands to visit is to accumulate the stand areas *(table 1).* We do this because the probability of selecting a stand to visit will be proportional to the stand's area; that is, larger stands will have a higher chance of being visited than smaller stands.

Suppose budget and time constraints dictate that only eight stands can be visited. We pick eight random numbers in the range 0 to 1201.7 and for each random number we find the stand associated with a cumulative area that is larger than or equal to the random number *(table 1).* For example, one of the random numbers was 739.1. The first stand in the list with a cumulative acreage greater than or equal to 739.1 was Stand 20, so it was selected for a ground visit. The probability of selecting any stand each time is shown in *table 1.* This probability of selection on any one draw is equal to the area of the stand divided by the total area in the population.

Notice that Stand 14 was selected twice: because we are sampling with replacement, any of the stands have a chance of appearing more than once in the sample. Stand 14 also happens to be the largest stand in the population, making up about 12.8 percent of the total area, so it's not surprising that it was randomly picked twice.

The next step in the process is to visit the selected stands on the ground, and determine for each one an estimate of pulpwood tons. These estimates are shown in the column labeled "Cruise estimate" in *table 1.*

We now have an auxiliary variable, x, for every stand in the population, and an observed value of interest, y, for a subsample of stands. When the stands to visit have been selected with PPS, the appropriate unbiased estimator for the population total Y is

$$Y_{est} = X\,\bar{r} \qquad (1)$$

Where Y_{est} is the estimate of the total of y (total tons of pulpwood), X is the observed total of x for the population (total acres), and $\bar{r}$ is the average ratio of y to x from the sample. To compute $\bar{r}$ we simply find the eight ratios of y to x, and take their average. In our example $\bar{r}$ turns out to be 91.36, which can be interpreted to be 91.36 pulpwood tons per acre. Multiplying by X, or 1,201.7 acres, we arrive at an estimate of 109,783 tons. Later work, which included complete enumeration, led to a total of 108,210 tons, which is very close to the sample-based estimate.

Calculation of the 95 percent confidence interval for Y_{est} results in an interval of ±18,931 tons, or ±17.2 percent. How can this be improved? As with any sampling method, we can probably reduce the standard error by increasing the sample size, so it would be helpful to visit more stands on the ground. Also, the size of the variance of Y_{est} depends on the variance of the ratios; the more constant the ratios, the tighter the confidence interval. This suggests that careful stratification of our stands into homogeneous groups based not only on age but also on site index, species, stocking, etc., might be beneficial.

As an example, this technique was used successfully for the appraisal of a Southern Hemisphere plantation forest. One notable difference was that instead of using stand area as the auxiliary variable, an estimate of stand volume was used. The estimate was made using a yield model that predicted volume based on age, site index, and original stems per hectare. These estimated stand volumes were then arranged in a list, just as in *table 1,* and the probability of selecting any particular stand to visit on the ground was proportional to its estimated volume. (Technically this would be known as sampling with probability proportional to estimated size, or PPES.) This tended to concentrate the fieldwork in the stands of highest value, either because they were large or because they carried a lot of volume per hectare. The end result was an estimate of total volume with a 95 percent confidence interval of ±5 percent on a property of 16,880 acres. This was accomplished by sampling 172 stands out of a total of 1,723 stands divided into six carefully defined strata.

2 Stratification

Stratified sampling is perhaps the best-known application of auxiliary information in forest inventory, and appears in mensuration texts at least as early as 1949 (Chapman and Meyer 1949). Foresters have used stratified sampling successfully since at least the early 1900s (Schreuder et al. 1993), and have developed good institutional knowledge of what kind of auxiliary information works in stratification.

Stratified sampling uses auxiliary information to divide the population of interest into two or more subpopulations, called strata, where each stratum should be more homogeneous than the population as a whole. By dividing the population into several more homogeneous strata, we expect that the sampling within each stratum will be more efficient, and therefore that the estimate of the population total will be improved. Making the stratification rules is something of an art, and is where the auxiliary information is applied in stratified sampling.

The most common source of auxil-

Table 2. Stratum-level information for the stratified sampling example.

Stratum	1	2	3
Acres	16	18	14
Number of plots	8	9	7
Board feet per acre	1,938.5	30,658.2	62,812.3
Standard deviation	1,514.2	7,914.0	18,840.0
$S_{\bar{y}}$	535.3	2,638.0	7,120.9
Standard error	27.6%	8.6%	11.3%
Proportion	0.3333	0.3750	0.2917
Total volume	31,016	551,848	879,372
S_y	8,565	47,484	99,692
95 percent confidence interval (total)	19,752	107,416	235,734

iary information for stratified sampling in timber inventory is aerial photographs. Each stand is identified on the photograph and assigned to a stratum based on density, species composition, average tree size, or age class from the photograph. This is the familiar process of phototyping. All stands within each phototype are treated as a single stratum. Because density, species composition, and age are all correlated with volume, the resulting strata are usually more homogeneous with respect to volume than the whole population. Digital analysis of remotely sensed data can also be applied to stratification. This method has the advantage of consistent application of classification rules, and has worked well where detailed stand descriptions are not required before sampling.

Defining strata from photos or digital imagery is not always easy, especially in areas where many species grow together in mixed-age stands. Keeping a few principles in mind will help:

- Keep it simple. Define strata that can be identified consistently on photos. The objective is to reduce variability, not to account for all possible combinations of species, size, age, and stocking.
- Make strata mutually exclusive and comprehensive. Each stand should fall in one and only one stratum, and there should be a stratum for each stand.
- Create a stratum for the stands that do not easily fit your stratification rules. Frayer (1978) showed that this technique can reduce variability in the remaining strata, and save time in typing. For example, very simple rules might specify strata for pure hardwoods, pure conifer, and mixed stands. In this case, the mixed stands are the stands that do not fit easily into the definite strata.
- Keep the photo classification and ground classification independent. Photo interpreters should not know which stands will or will not contain ground plots. Field crews should not know the phototype classification of the stands in which ground plots are located.

Although any sample scheme may be applied within each stratum, we will confine ourselves to stratified sampling with simple random sampling within strata, that is, stratified random sampling. An estimate is calculated for each stratum and these estimates are combined based on the proportion of the population in each stratum. The computational details can be found in most forest mensuration texts.

Now, suppose we have 48 acres to cruise in a small woodlot. An hour with an aerial photo lets us break the area into three strata of 16,18, and 14 acres respectively, and a day in the woods gets us the cruise data. *Table 2* summarizes the cruise for each stratum.

Combining the stratum estimates gives us a total volume estimate of 1,460 mbf for the woodlot, and a 95 percent confidence interval of ±230 mbf. By way of comparison, calculating a total volume from all of the plots together gives us the same total (because the plots per acre are the same in each stratum) but results in a 95 percent confidence interval of ±541 mbf. To match the stratified sample's confidence interval without stratifying would require about 70 plots rather than 24. The time spent stratifying from the photo was clearly well spent.

3 Poisson Sampling

Poisson sampling is also known as probability proportional to prediction (3P) sampling. Poisson sampling is an efficient, variable-probability sampling strategy for focusing resources on one variable of interest. Poisson sampling is unique in that it uses auxiliary information collected during the inventory itself, so it does not need to be known beforehand. In forest inventory, Poisson sampling is most often applied to estimate the total volume of a stand, and the sampling units are the trees. Poisson sampling is a good way to get an estimate for a highly valued, relatively infrequent component of a stand that might otherwise have to be 100 percent cruised (for example, redwoods or black cherry).

The essence of Poisson sampling is calibration:

1. A prediction is made of the variable of interest for every unit in the population.
2. A sample is taken and the variable of interest is measured for each unit in the sample.
3. The estimate of the total is the total of all the predictions calibrated by the sample data.

If the predictions match the measured values well, a variable population can be sampled very efficiently. The prediction is typically a visual guess, which is quick and cheap, and can be surprisingly precise (Avery and Burkhart 1994). The sample is selected with probability proportional to the prediction; that is, trees with larger predictions are assigned a higher probability of being included in the sample. Several different approaches can be taken to estimate the total; the simplest is the mean of ratios.

Each unit in the population is visited, and sample selection proceeds by comparing the prediction for the unit in question to a random number: the unit is selected if the prediction is the higher of the two. This means that the

Table 3. Unit-level information for the Poisson sampling example. Volumes are in board feet. Desired sample size is 3.

Tree	Guessed volume	Random number	True volume	Ratio
1	200	310	210	
2	360	701	350	
3	250	752	270	
4	180	208	190	
5	250	631	250	
6	300	791	280	
7	320	111	300	0.9375
8	300	24	310	1.0333
9	250	478	270	
Total	2,410		2,430	Mean ratio 0.98542

sample size is no longer fixed and known during the design; it is now a random variable.

To implement the variable-probability sampling scheme, a collection of at least one random number per sampling unit in the population is needed. To obtain the random numbers, a prior guess of the population total is required. The quality of this guess is not of great importance; however, if it is underestimated, then a larger sample size will be selected than is desired, and vice versa. This guess is divided by the desired sample size to obtain the upper limit of the random numbers. The lower limit is 0, and the random numbers must be integers uniformly distributed between these limits.

The advantage of Poisson sampling is that, although it requires two levels of auxiliary information—the prior guess of the total and the prediction for each sampling unit—it generates the latter on the fly. Having the set of random numbers before going out into the field is likely to be cheaper than measuring the auxiliary variable for each unit and then, in a separate sampling visit, measuring the variable of interest.

Consider the sample data in *table 3.* We have a population of nine trees, and we would like a sample size of three. We guess that the total volume for the population will be 2500 bf. Therefore, to obtain a sample size of three we generate random numbers from 0 to 833.3. These numbers are compared with the tree volume estimates as they are made. In *table 3,* only two trees are included in the sample: trees 7 and 8. The ratio of true-to-guessed volume is calculated for each one, and the average of these two ratios is multiplied by the total of the guessed volumes: $2{,}410 \times 0.98542 = 2{,}374.85 = 2{,}400$ bf to two significant figures. Calculation of the standard error (not shown here) leads to 115.5 bf. (The confidence interval is omitted because with a sample size of two it is quite large.)

One reason given for reluctance to embrace Poisson sampling is that the sample size is variable (see Biggs et al. 1985). This factor has two ramifications: the expected costs of a survey are difficult to calculate, and the expected width of the confidence interval of the variable of interest is difficult to achieve.

A commonly applied extension of Poisson sampling is the identification of sure-to-be-measured trees. Before the random numbers are generated, a maximum volume prediction is guessed. Any number larger than that volume is replaced with a set of asterisks to simplify the fieldwork. Then in the field, any tree with a predicted volume higher than this limit is called a sure-to-be-measured tree, and is considered separately. This adaptation is identical to stratification of the population into two strata according to the prediction, and measuring every tree in the sure-to-be-measured stratum. Although it has the advantage of ensuring that the largest trees will all be measured, this technique rather flies in the face of sampling theory and complicates the implementation somewhat.

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Multistage Remote Sensing

Toward an Annual National Inventory

Remote sensing can improve efficiency of statistical information. Landsat data can identify and map a few broad categories of forest cover and land use. However, more-detailed information requires a sample of higher-resolution imagery, which costs less than field data but considerably more than Landsat data. A national remote sensing program would be a major undertaking, requiring unprecedented partnerships between federal programs and stakeholders.

By Raymond L. Czaplewski

The Forest Inventory and Analysis (FIA) program of the USDA Forest Service produces a baseline and long-term set of scientifically sound resource statistics for the 748 million acres of forest and woodland ecosystems in the United States. These data are used to assess the extent, health, productivity, and sustainability of public and private forestlands. FIA information is critically important at many scales to effectively deal with conservation challenges; influence patterns of capital investment; and meet the needs of the forestry profession, resource managers, forest landowners, and the public.

FIA methods vary somewhat by region, but the following description is a valid generalization. The first phase uses a sample of 9.4 million plots, with one plot per 240 acres. Each plot is inexpensively classified into a few categories of land cover using high-altitude aerial photography. The second phase uses a subsample of 364,000 one-acre field plots, 120,500 of which are forested, with one plot per 6,200 acres. A two-person field crew can measure one forested field plot in one day. The Forest Health Monitoring (FHM) program measures more-expensive indicators on a subsample of 13,500 plots, 4,500 of which are forested, with one plot per 167,000 acres. Remote sensing at the first phase improves FIA estimates of forest area and population totals, but detailed information on forest composition and condition *(table 1)* primarily relies on expensive field data. Forest Service funding in 1999 was $37.2 million.

Although FIA is among the best programs of its kind in the world, more than half of all FIA information is out-of-date. Current FIA procedures and funding allow a 10- to 15-year remeasurement cycle, but data more than five years old are not reliable (American Forest Council 1992). The Agricultural Research, Extension, and Education Reform Act of 1998 (PL. 105-185, Section 253) directs the Forest Service to produce more-timely FIA data and to better utilize remotely sensed data.

Rates of Change

Rapid changes in forest conditions, real or perceived, fuel the demand for annual FIA data. Rapid changes are driven by urbanization, implementation of public policies, and fluctuating economics in the forest products and agricultural sectors over large geographic regions (from 10 million to 50 million acres). Examples include clearing of forestland for agricultural or urban uses, conversion of agricultural lands into forestland, harvesting of wood, and regeneration of harvested forests. Other rapid changes are episodic, caused by hurricanes, wind, ice storms, floods, droughts, and insect epidemics. These processes cause changes in forest cover that can be detected with a variety of remote sensing technologies, the success of which depend on sensor resolution.

I assume that other indicators of forest conditions change more slowly among detailed categories of forest *(table 1)*. An example is the average volume and number of trees per acre by tree species and two-inch diameter class. I make the same assumption for trends in down woody debris, nontree vegetation, and similar characteristics. Many other aspects of forest health are affected by gradual changes in forest demographics and anthropogenic stressors, such as air pollution, climate change, exotic species, and diseases. These slow and ubiquitous processes are measured with field plots in the FIA and FHM programs.

If these assumptions are approximately true, then remote sensing could be more efficient than field plots for frequent monitoring of rapid changes. However, less-frequent remeasurement of field plots remains essential to monitor gradual changes in forest composition and calibrate for errors in remotely sensed measurements.

Remote Sensing Technologies

Remote sensing can improve efficiency if remotely sensed data are available when needed and if they are well correlated with important field measurements *(table 1).* For example, augmentation of field data with aerial photography can be six to 15 times more efficient in estimating total area of forest, and twice as efficient in estimating total wood volume (Aldrich 1979). A wide range of remote sensing technologies are used in forestry. Satellite data are correlated with some attributes in *table 1*, but information content increases with sensor resolution. Regardless, remotely sensed data contain various degrees of measurement errors that require statistical calibration with current FIA field data. My discussion of satellite data is based on reviews by Wynne and Carter (1997) and Holmgren and Thuresson (1998); my assessment of aerial photography is based on Aldrich (1979).

Table 1. Forest Inventory and Analysis field data used in primary statistical tables.

Forest conditions	Number of classes
Plot-level conditions[1]	
Land use[2,3]	5
Forest type	
broad[2,4]	29
detailed[4]	136
Stage of stand development[2]	4
Stand density[2,5]	5
Stand origin[2] (natural, artificial)	2
Land ownership	10
Stand age	9
Stand productivity	7
Number of trees[2,6], wood volume[2,6]	continuous
Growth[6], mortality[2,6], removals[2,6]	continuous
Tree-level conditions[1]	
Tree species[4]	331
Tree size (diameter at breast height)	2-inch classes
Tree damage	10
Tree quality, value	5
Wood volume	continuous
Growth in wood volume	continuous

[1]FIA measures many other indicators that describe landscapes, habitats, non-tree vegetation, etc.
[2]Photo interpretations and photogrammetric measurements with high-resolution imagery are well correlated with these field measurements (Aldrich 1979). The correlation is much lower with Landsat data and NAPP aerial photography.
[3]Includes timberland, other forestland, protected forest, nonforest land, and water.
[4]Any single geographic region has only 20 to 40 percent of these national categories.
[5]Includes overstocked, fully stocked, understocked, and nonstocked.
[6]Totals are produced for thousands of permutations of different tree and forest categories.

Low-resolution satellite data include AVHRR, MODIS, OrbView-2, ERS-2, and SPOT 4. These data are inexpensive and cover vast areas, having a 600- to 1,800-mile swath width. Spatial resolution is poor, with each pixel ranging between 160 and 320 acres in size. These data have proved successful for continental scale maps of forested landscapes, global change models, and detecting hot spots of severe deforestation within densely forested landscapes. These remotely sensed data do not have sufficient resolution to reliably measure and monitor most indicators of forest conditions in *table 1.*

Medium-resolution satellite data include Landsat-5&7, Radarsat, SPOT-2&4, IRS-C&D and P2&5, Spin-2, EOS AM-1, and CBERS-1&2. These sensors have a reasonably small pixel size of 30 to 100 feet wide, and they are relatively inexpensive for large areas, having a 30- to 100-mile swath width. For example, the conterminous United States is covered by 540 Landsat scenes. However, there is a limit to what can be measured by a satellite orbiting 500 miles from Earth. These data can separate forest from nonforest, and reasonably identify a few broad types of forest and several levels of forest density. Landsat data can distinguish more-detailed categories of forest cover with customized approaches (Wynne and Carter 1997). These data can identify recent clearcuts, but they are less successful with partial cuts. Landsat data can identify advanced regeneration of forests after land clearing. These data can identify urban centers, but they are less successful with sparse urbanization. They can measure size, shape, and connectivity of forest patches. High-quality, cloud-free data are available for most temperate regions each year or two, which is sufficient for annual inventory and monitoring.

High-resolution satellite data include Ikonos-2, OrbView-3&4, EROS-B1&2, and Quickbird-1&2, although none are operational yet. The two- to six-mile swath width, and small pixel size of three to 10 feet wide, are best suited for imaging small sites. These satellite data have capabilities, limitations, and costs similar to high-altitude, nine-inch-square, 1:40,000 small-scale aerial photographs from the US Geological Survey (USGS) National Aerial Photography Program (NAPP). Each NAPP photograph covers an area five miles wide. These satellite and photographic data can reliably distinguish a few broad types of forest in each region, several stages of stand development, clearcuts and many partially cut areas, regeneration after land clearing, and concentrations of tree mortality. Photo interpreters can identify forest stands, land use, distance to adjacent roads and water, forest fragmentation, and many types of urbanization. Depending on scale, it would take 200,000 to 1 million images to cover the United States. The USDA National Agricultural Statistics Service and USGS National Wetlands Inventory use NAPP photographs for national mapping on a 20-year time frame, but this is not practical for annual monitoring. The NAPP schedule for image acquisition is poorly suited to annual monitoring, but satellite data are expected to be available when needed.

Large-scale aerial photography ranges in scale from 1:2,500 to 1:12,000. Commercial aerial survey companies routinely acquire this type of custom imagery for small sites. Each photograph covers an area one-tenth to two miles wide depending on scale and format. Photo interpreters could reliably identify many of the forest cover conditions in *table 1.* Measurements might include five to 10 broad types of forest; five stages of stand development; three stand-density classes; clearcut and partial cut areas; regeneration success; stand origin (natural, artificial); three to five severity levels for tree mortality; most indicators of urbanization and fine scale forest fragmentation; and stand size, shape, and edge metrics. This type of photography would require many millions of images to completely cover the nation, but sampling makes this imagery feasible on the national scale.

Using Remotely Sensed Data

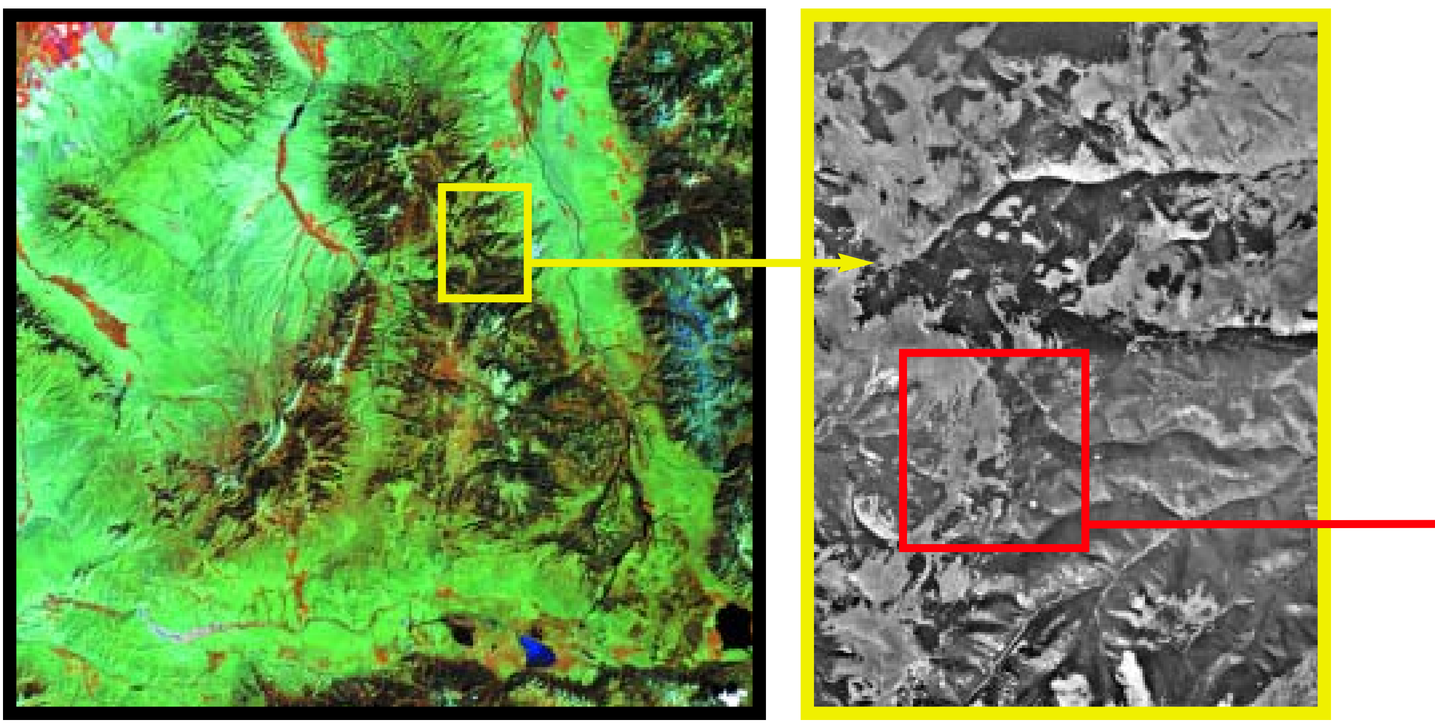
Numerous land management agencies use remote sensing for portions of the country, but only a few programs consistently cover the whole country. Several of these programs use Landsat data to map the conterminous United States. Other programs use a sample of higher-resolution aerial photography to produce statistical estimates.

The USGS Multi-Resolution Land Characteristics (MRLC) program uses Landsat data to map three forest categories, three urban categories, three woodland categories, three agricultural categories, and 21 other categories of land use and cover (Volgelmann et al. 1998). The USGS Gap Analysis Program (GAP) maps critical habitats to help conserve biological diversity. GAP uses 18 categories of forest, although not all occur in every region. Both programs use sophisticated remote sensing techniques that require considerable analytical input. MRLC began in 1995 with an annual budget of $10 million, and GAP began in 1994 with an annual budget of $3.6 million. Neither program has yet covered the entire country. These programs plan to update their maps to compensate for changes in land cover, perhaps on a 10-year cycle.

Three programs use a sample of aerial photography to cover the United States. The FIA program uses small-scale NAPP photography for 9.4 million photo-interpreted plots. The USDA Natural Resources Conservation Service's National Resources Inventory (NRI) uses NAPP and small-format aerial photography for 300,000 primary sampling units. Most sampling units are 160 acres, with a sampling intensity of 1 to 4 percent of the total land area. Accuracy of NRI data is limited by quality and scheduling of aerial photography. NRI has been conducted once every five years, but is changing to an annual system, much like FIA. The annual budget for NRI is $8.5 million. Finally, USGS National Wetlands Inventory uses a sparse sample of small-scale NAPP photography for its estimates of status and trends, but this is a minor part of its overall mapping program.

The Minnesota Experience

The Annual Forest Inventory System (AFIS) began in 1991 as a joint effort between the Minnesota Department of Natural Resources and the USDA Forest Service. Lessons learned in AFIS are relevant to the mandate in Public Law 105-185. AFIS successfully used numerous Landsat scenes to classify land cover into a few broad categories and detect abrupt changes over

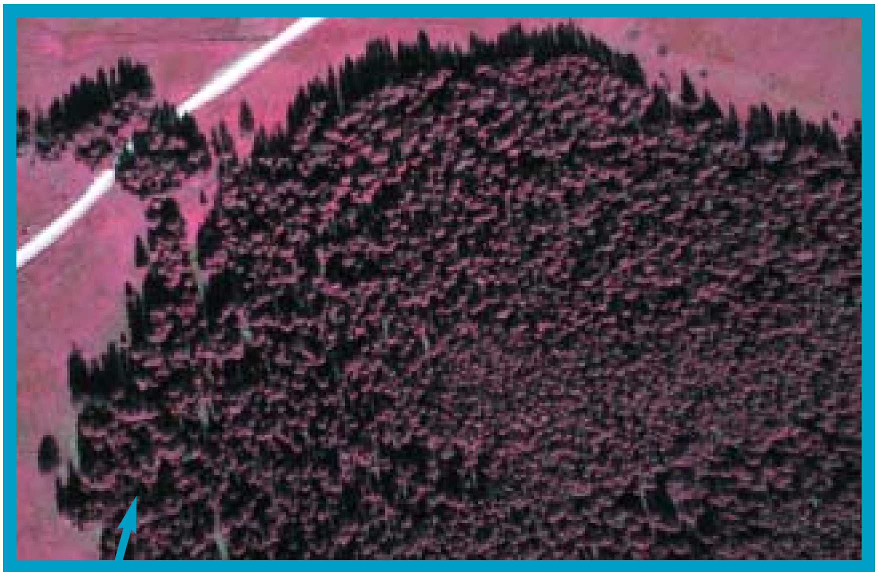


time. AFIS processed Landsat data that was re-imaged over four-year intervals, but vigorous regeneration of clearcuts reduced the accuracy of change detection. Had Landsat data been purchased along orbital paths rather than physiographic regions, change detection could have been conducted every two years at little extra cost. A single technician could process a Landsat scene in five to 10 days because changes in land cover were detected with simple digital methods. AFIS classifications of land cover with Landsat replaced NAPP photography for the first phase in the FIA statistical design, and image acquisition dates for Landsat were more compatible than NAPP for an annual system. In addition, Landsat provided maps of land cover and change that are not feasible for large regions with aerial photography or field sampling.

If Landsat data suggested that an FIA plot might have been affected by timber harvest or change in land use, then the plot was remeasured by a field crew. Remeasuring consumed about half the budget for field data. Misregistration and other errors with Landsat data caused incorrect classification of some FIA plots as having changed. Much of the expensive field data merely verified whether or not these plots were cleared of trees. In the beginning, AFIS did not use aerial photography because Landsat is less expensive for large regions. During later stages of AFIS, a sample of aerial photography was reconsidered because high-resolution imagery could reduce the cost of field data to verify change detection from Landsat data.

Multistage Sampling

AFIS demonstrated that Landsat data can improve FIA products. However, Landsat data alone do not greatly reduce the required amount of field data. Landsat provides only broad information about forest conditions, and the detailed information in *table 1* requires field measurement. However, high-resolution imagery provides much more detailed data that are bet-



Real or perceived rapid changes in forest cover and conditions fuel the demand for annual FIA data. The causes of such changes can be detected with a variety of remote sensing technologies and data types. Levels of sensor resolution are key to successful detection; some of those levels are illustrated in this sequence of photographs of the Beaverhead-Deerlodge National Forest in Dillon, Montana.
Left to right: **A Landsat Thematic Mapper (TM) satellite image; a higher-resolution digital ortho quad image; a high-altitude aerial photograph; a digital infrared camera image (above). The latter was taken five years after the TM image, closer to the time when the change in forest cover was investigated. To assess conditions at the forest, plot, and tree levels costs less than field data but more than Landsat data.**

All images courtesy of USDA Forest Service Remote Sensing Applications Center, Salt Lake City, Utah ter correlated with attributes in *table 1.* A multistage statistical design can combine wall-to-wall Landsat data at the first stage, a sample of high-resolution imagery at the second stage, and traditional FIA and FHM field plots at the third stage. The National Academy of Sciences recommended a similar approach 25 years ago (Aldrich, 1979). I describe two enterprises that would implement a multistage design.

The first enterprise would acquire all Landsat scenes that cover the conterminous United States. Multi-date Landsat data would rapidly identify abrupt changes in spectral reflectance that are often associated with clearcuts, landclearing, and reforestation. Change detection allows relatively inexpensive updates to existing MRLC and GAP maps. FIA would use updated maps to replace its photo interpretation of 9.4 million first-phase plots. Direct annual cost is estimated at $1.5 million to $2 million.

The second enterprise would acquire a national sample of large-scale aerial photography or high-resolution satellite imagery. The resulting data would detect changes in land use, partial cuts, forest management, and severe episodic events. Sample imagery would include 364,000 primary sampling units, each covering an existing FIA field plot. Each sampling unit could range from 40 to 640 acres in size, and the collection of sampling units would encompass 1 to 10 percent of the total land area. The large sampling units would better capture rare features than one-acre FIA field plots, which encompass only 0.016 percent of the landscape. Each year, 20 percent of the large sampling units would be remeasured with new high-resolution imagery. Photo interpreters would delineate and classify land uses, land cover, and forest stands within each sampling unit. Photogrammetry would produce more-detailed measurements of forest characteristics at secondary sampling points within each 40- to 640-acre sampling unit, and one of these points would be a one-acre FIA field plot. These measurements would be well correlated with many field observations in *table 1.* Photo interpreters would measure changes over the five-year interval between acquisition of new imagery for each permanent sampling unit. High-resolution imagery could improve statistical efficiency, allowing a reduction in the required number of FIA sampling units. Calibrated measurements from the high-resolution images might even replace field data for inaccessible areas. The large sampling units better match the scale of Landsat images than one-acre FIA plots, thus improving the linkage between Landsat data and more accurate measurements of sampling units. This enterprise could cost $15 million to $25 million each year.

The latter enterprise is similar to the National Resources Inventory (NRI). The cost of new imagery and interpretation might be shared between FIA and NRI, which would make the enterprise more feasible and efficient. This partnership poses considerable technical challenges, such as: incremental alignment of separate FIA and NRI sampling frames; complex statistical techniques for calibration and composites of multiple time-series of multivariate sample data; a sophisticated information management system; capacity-building in the aerial survey industry to deliver large quantities of photography; and adjustments for cloud cover and missing data (Czaplewski 1999). Bureaucratic challenges would be equally formidable (USDA Forest Service Inventory and Monitoring Institute 1998). Robust solutions to these challenges are untested, cost-effectiveness must be evaluated, and risks must be reduced through simulations and realistic pilot tests.

Conclusion

Congress has emphasized the need for more-current statistical information about the nation's forests. Traditional FIA field procedures would satisfy this need at an estimated annual cost of $82 million. Multistage remote sensing might save $20 million each year and produce valuable new products. Implementation requires an unprecedented infrastructure that can acquire and process hundreds of Landsat scenes and tens of thousands of high-resolution images each year. Expectations must be kept realistic, numerous details await analysis, and formidable problems remain unsolved. Multistage sampling with remote sensing was envisioned by the National Academy of Sciences in 1974, but the vision has never been implemented. However, if these challenges can be overcome, a partnership among existing federal programs could produce the world's premier system to estimate national trends in land cover and land use, detect changes in health of wildlands and agricultural landscapes, evaluate effectiveness of public policies, and guide sustainable use of the nation's natural resources.

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The New and Improved FIA Program


Bob Goodlatte and James Garner

Determining the ecological and biological significance of our forest resources in an accurate and timely manner is one of the most important pursuits in modern forestry. That is the mission of the USDA Forest Service's Forest Inventory and Analysis (FIA) Program. FIA is the most complete forest census in America, providing the only continuous national inventory that quantifies the status of forest ecosystems across all private and most public forestland.

Because of its fundamental importance in measuring sustainability, FIA is universally popular among professional foresters, environmentalists, industry, private landowners, and virtually any other group that has an interest in forest management. Yet, despite such broad-based support, FIA is only now coming of age as a 21st-century management tool.

In 1998 Congress enacted legislation to greatly improve the FIA program. Congress has been clear in its mandate, requiring the agency to complete annual inventory updates, reduce inventory cycles to five years, use the latest technologies, and make current data available to the public in a user-friendly format. Congress has also substantially increased funding for FIA.

It is now up to the Forest Service to make FIA succeed. Success will only occur, however, if the Forest Service makes a number of key changes to its current policies and practices. We recommend the following.

First, Forest Service Chief Michael Dombeck must make FIA a clear research priority. So far neither the agency's budget requests nor the chief's statements to Congress have established this priority. The chief's commitment thus far has been, at best, to maintain the status quo. With ecological sustainability in the balance, this position is unacceptable.

Second, the Forest Service must communicate effectively with the states. National working groups are important for consistency, quality control, and other issues of general concern. But more important is a state-specific liaison system that ensures the Forest Service will adapt the new congressional mandate to the unique structure, policy, budget processes, operating procedures, and information and reporting needs of each state.

Third, the Forest Service must provide an analysis and reporting system that matches the data collection services provided by the states. Most state foresters, especially in the Northeast and South, have invested considerably to improve data collection as part of their commitment to make FIA work. Many have committed to deadlines for delivering accurate data, relying on promises from the Forest Service. Failure by the agency to analyze and report data in a timely manner would embarrass not only the Forest Service, but also those state foresters who have raised the expectations of their customers.

One way for the Forest Service to keep analysis at pace with data collection is to draw on the resources of the university sector. Using university expertise, technology, and personnel to handle data entry, editing, compilation, and other essential tasks could significantly reduce the backlog of plot data editing, which has reached 1,000 plots per month in the South.

Fourth, the Forest Service must begin today to invest in the technologies of tomorrow. The move to further declassify high-resolution satellite images could signal an opportunity for FIA by greatly improving information on real-time land use change, forest disturbance, and other ground change. Such technology could be applied over a wide landscape with few personnel and relatively modest investments.

The use of such technology presents another opportunity to involve the universities. The forestry colleges at Virginia Tech and Mississippi State University already are working closely with NASA to study forest resources using remote sensing and other leading-edge technologies and applications. The Forest Service's work with NASA, USGS, NOAA, and other federal partners should focus on harnessing such ongoing efforts.

Finally, the Forest Service must insist that the National Forest System cooperate fully in the effort to coordinate the FIA program nationwide. Some western regions have refused to implement the new FIA program in favor of parochial data collection systems developed with little regard for the need for national consistency. One way to rectify this problem is for Congress to divert funding within the Forest Service from the National Forest System to Forest Service Research with instructions that the diverted funds be used to implement the law. This somewhat draconian approach can be avoided, however, if regional foresters demonstrate greater willingness to cooperate.

The improved FIA program is the cornerstone of ecologically and biologically sustainable forest practices in the 21st century. Congress has provided the framework. Willing partners are in place to help with the transition. The future is waiting. Now is the time for the Forest Service, beginning with Chief Dombeck, to make it happen.

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