Annual Forest Inventories for the North Central Region of the United States

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The primary objective in developing procedures for annual forest inventories for the north central region of the United States is to establish the capability of producing standard forest inventory and analysis estimates on an annual basis. The inventory system developed to accomplish this objective features several primary functions, including (1) an annual sample of measured field plots, (2) satellite-based remote sensing for stratification into land use and land use change classifications, (3) a database of current and past plot and tree information, and (4) models for predicting the growth and survival of trees not measured in the current year. The discussion focuses on specific features and options for each function.

Key Words: Growth models; Imputation; Remote sensing.

1. INTRODUCTION

Forest inventory and analysis (FIA) is a continuing endeavor as mandated by the Renewable Forest and Rangeland Resources Planning Act of 1928. The objective of FIA has been to periodically inventory the forest land of the United States to determine its extent and condition and the volume of standing timber, timber growth, and timber depletions. U.S. Department of Agriculture (USDA) Forest Service regional research stations are responsible for conducting these inventories and publishing summary reports for individual states. The North Central Research Station (NCRS) is responsible for FIA for the north central region, which consists of the states of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, and Wisconsin. Inventories for these states have been conducted since the 1930s at recent intervals of 11–17 years and with inventories for heavily forested states such as Michigan, Minnesota, and Wisconsin taking up to 3 years each to complete.

The quality of periodic inventory estimates is degraded by the effects of conducting inventories over multiple years, and it further decreases over time due to factors such as

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changes in land use and tree growth, mortality, and removal. In addition, recent periodic inventory estimates for states in the north central region have been based on both observations from measured plots and model-based predictions of current conditions for plots not measured. The use of models to predict the status of plots not measured in the current inventory increases the overall precision of FIA estimates because more plots can be used, but it introduces imprecision at the plot level because of imprecision in the model predictions.

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

In 1990, NCRS proposed an annual forest inventory system based on annual samples of field plots, satellite-based remote sensing, individual tree diameter growth models, and database operations. NCRS collaborated with the Forestry Division of the Minnesota Department of Natural Resources (MN DNR) and the Rocky Mountain Research Station to formulate concepts and procedures for this system, and in 1992, the first annual sample of field plots was measured in Minnesota. In 1995, the Southern Research Station (SRS) initiated development of an annual forest inventory system for the southern region that was both similar and dissimilar in key aspects to the north central system. Although the north central system was implemented first, the industrial and political support for annual forest inventories generated by SRS may be credited with placing the topic on the Forest Service's national FIA research agenda.

Passage of the 1998 Farm Bill, formally known as the Agricultural Research Extension and Education Reform Act of 1998, mandated annual forest inventories throughout the nation with 20% of plots to be measured every year and resource reports to be published every 5 years. Positive, collateral effects of the Farm Bill include elimination of essential differences between the NCRS and SRS systems, the virtual merger of the two efforts, and agreement on a common objective for annual forest inventories, which is to develop the capability of producing standard FIA estimates on an annual basis.

Developers of annual forest inventory systems agree that such systems require several functions: (1) annual samples of measured field plots; (2) area classification based on remote sensing, primarily for stratification in the estimation process; and (3) a user-friendly, public database of plot and tree information. In addition, the timeliness of FIA estimates may be enhanced by inclusion of a fourth function, provision of methods for updating plot and tree information for plots not measured in the current year. Although all annual forest inventory systems share requirements for these functions, options selected for satisfying them may vary depending on regional forest conditions and resident expertise. The discussion that follows outlines some of the options that may be selected for the above functions and focuses in greater detail on the particular options selected for annual forest inventories for the north central region.

2. ANNUAL SAMPLE

2.1 FEDERAL BASE SAMPLE

Forest inventories are described as annual on the basis of the measurement of an annual sample of plots and the capability of annually producing population estimates; the basis is not a complete annual inventory of all plots. FIA precision standards require that standard errors of estimates not exceed 5% per billion cubic feet of growing stock or 3% per million acres of forest land area (USDA 1970). For the north central region, these standards have been found to require a sampling intensity of one plot for approximately every 6,000 acres. To satisfy this requirement, a grid of nonoverlapping hexagons, each approximately 5,900 acres in area, was constructed by dividing the hexagons established for the Forest Health Monitoring (FHM) program (Eagar et al. 1991; White, Kimerling, and Overton 1992). A field plot was selected for each hexagon of this grid in the following manner: (1) If an existing FHM plot fell within a hexagon, it was designated the grid plot for that hexagon; (2) if no FHM plot fell within a hexagon, the existing permanent FIA plot nearest the center of the hexagon was designated as the grid plot; and (3) if neither FHM nor permanent FIA plots fell within the hexagon, a new permanent FIA plot was established at the center of the hexagon. In Minnesota, of the over 9,100 hexagons that form the basis for the federal base sample, fewer than 20 did not have an existing permanent FHM or FIA plot within their boundaries, and all of these were located over large bodies of water that FIA did not previously sample. This grid of field plots has been designated the federal base sample, and its measurement is funded by the USDA Forest Service.

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. The only exception to equal probability of plot selection is for hexagons that include areas in two or more states; in this case, federal base sample plots were selected in the portions of hexagons in the state with the greatest area.

The federal base sample was systematically divided into five nonoverlapping, interpenetrating panels to accommodate the 1998 Farm Bill requirement for a 20% annual sample. Each year, the plots in a single panel are selected for measurement with panels selected on a 5-year, rotating basis. For estimation purposes, the measurement of each panel of plots is considered an independent sample of all lands in a state, and the cumulative measurement of all plots over the 5-year cycle is considered a single equal probability sample.

2.2 INTENSIFICATION SAMPLES

Some states contribute additional funding to intensify inventories as a means of increasing overall precision, addressing specific biological issues such as growth declines, or better estimating the effects of weather phenomena such as droughts, blow downs, and ice storms. Several options are available for selecting the intensification plots. First, the plots may be selected from the federal base sample, thereby increasing the proportion of plots measured annually and increasing the frequency of a complete sample. A second option is to select for each hexagon additional plots that have not already been selected for the federal base sample. This option reduces the area represented by each plot to less than 5,900 acres and increases the precision of all inventory estimates. A third option is to select plots that satisfy specific species, spatial, or other requirements.

The design for intensification plots may vary depending on the basis for the intensification. Most states that intensify an inventory are expected to select systematic coverage of the entire state or portions of the state. In these cases, plots not included in the federal base sample will be selected from hexagons corresponding to panels offset by a constant integer from the panel selected for measurement in the current year as part of the federal base sample. If permanent FIA field plots exist in these hexagons, one will be randomly selected as the intensification plot; if no such plots exist, new plots will be established in random directions and at random distances from the hexagon centers. Intensification samples selected in this manner are also considered equal probability samples.

The State of Minnesota provides additional funding to increase the inventory to at least double intensity. MN DNR has investigated selecting these plots on the basis of ground cover disturbance. Two premises underlie this approach: First, the growth and survival of trees on well-established, undisturbed plots can be updated with models with negligible bias for up to 20 years; but second, plots that have experienced severe vegetation loss cannot be adequately updated and must be remeasured to determine how they have regenerated. Thus, such intensification plots are selected according to three criteria: (1) All intensification plots are permanent FIA plots not selected for the federal base sample, (2) first priority intensification plots are those that have experienced substantial recent vegetation loss, and (3) remaining intensification plots are randomly selected from undisturbed plots but with remeasurement intervals not to exceed 20 years. Within each of the disturbed and undisturbed populations of intensification plots, the sample is designed to be an equal probability sample. Additional details concerning this approach are discussed in the sections that follow on remote sensing for disturbance detection and updating.

3. REMOTE SENSING

Remote sensing techniques are applied in forest inventories in the north central region for premeasurement forest/nonforest classification, for stratification for variance reduction and area estimation, and optionally for disturbance detection. Classified remotely sensed images are maps of the forest resource and are important products by themselves. Prior to the measurement of field plots, aerial photographs are examined to classify plots into three broad categories: forested, nonforested, and questionable. Field crews visit and measure plots in the forested and questionable categories, while the nonforested plots receive at most a cursory check by a field crew to assure correct classification.

3.1 STRATIFICATION

Remote sensing techniques are applied in forest inventories to stratify plots for variance reduction purposes and to estimate the surface area and surface area change in the resulting strata. Where available, the Gap Analysis Program (GAP) (NCASI 1996; Scott and Jennings 1997) is used to accomplish these tasks. GAP analyses are generally conducted by state agencies or universities and are based on two-date, same-year satellite imagery from the Landsat Thematic Mapper (Bauer et al. 1994; Rack 1994; Hopkins, Maclean, and Lillesand 1988; Moore and Bauer 1990). This imagery consists of separate reflectance values for each of seven spectral bands for 30-m $\times$ 30-m pixels. The GAP analyses stratify pixels across entire states into strata related to land use, vegetative cover, and tree density.

Where GAP is unavailable, NCRS, with cooperation from MN DNR, uses similar methods to classify Landsat Thematic Mapper (TM) imagery into broad land use classes. The spectral band values are standardized to adjust for year-to-year differences for factors such as season, sun angle, atmospheric conditions, and sensor response. In addition, the images are referenced to the Universal Transverse Mercator (UTM) projection, and plot locations are refined and edited to ensure that plots can be accurately located on the ground. After standardization and referencing, digital methods are used with the spectral band values to classify pixels into strata representing the following ground cover classes: cloud or cloud shadow, water, nonforest land, upland coniferous forest, lowland coniferous forest, upland hardwood forest, and lowland hardwood forest.

3.2 DISTURBANCE DETECTION

An alternative for intensifying the annual sample investigated by MN DNR relies on a combination of disturbance-based sampling and model-based updating. The underlying assumption is that the model predictions of growth and survival represent, on average, actual growth and survival. However, it is known to be difficult to accurately predict growth and survival for plots that have experienced recent severe disturbance. Thus, if intensification plots are selected on the basis of disturbance, it is necessary to identify these disturbed plots so that they may be remeasured to determine their current condition and so their predisturbance conditions are not erroneously included in FIA estimates subsequent to the disturbance. To this end, digital procedures are used with Landsat TM imagery to predict ground cover disturbance for forested FIA plots.

Digital disturbance detection consists of comparing the digital values for the spectral bands using computer-based algorithms. For each pixel, the difference between the digital value for the two most recent sets of imagery is calculated for each spectral band. Differences for selected bands are then combined to calculate index values using algorithms designed to maximize the correlation between the index and actual vegetation change. Based on their index values, pixels are classified into strata representing five vegetation change classes: major vegetation loss, minor vegetation loss, little vegetation change, minor vegetation gain, and major vegetation gain. The first two classes correspond to locations with predicted high probabilities of disturbance due to factors such as harvesting, stand treatment, or catastrophic mortality. Pixel-based maps representing vegetation change classes are overlaid on the array of permanent FIA plots and an index of plot disturbance is assigned to each plot.

The index of plot disturbance is a continuous variable, and the point on the continuum of values at which disturbance is declared is somewhat arbitrary. For application, the mean and standard deviation of these index values for all plots are calculated, and a map is constructed based on categories of integer numbers of standard deviations from the mean. The accuracy of disturbance detection using 4-year imagery for plots whose predicted vegetation loss is greater than 1 SD above the mean has been partially assessed using plot sheet comments recorded by field crews. Plots predicted to have lost vegetation were found to have experienced vegetation loss in 67% of cases, while plots predicted to be unchanged were found to have experienced no change in 95% of cases. Virtually no cost is associated with selecting a plot for measurement that was erroneously predicted to have lost vegetation; the plot is simply treated like other unchanged, measured intensification plots. Thus, although the 67% 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 unchanged is much greater. Such plots likely will not be selected for inclusion in the intensification sample, and their predisturbance volume will be erroneously carried forward. However, the prediction success rate for this category of plots is very high at 95%.

4. DATABASE

The heart of annual forest inventories is the database of plot- and tree-level information. Information for all permanent FIA plots and for all trees on them is entered into this repository. Many FIA users are at least as, if not more, interested in the database of plot and tree information than in the published assessments and reports. Thus, extracts of this database are designed and maintained as a public, accessible, user-friendly medium for transferring information.

5. ESTIMATION

The characteristics of annual FIA estimates depend on the features of the designs used to collect the data on which they are based. Annual forest inventories in the north central, northeastern, and southern regions feature measurement of one panel of plots each year. Therefore, the simplest approach to calculating annual FIA estimates is to use only the data from the panel of plots measured in the current year. While these estimates reflect current conditions and are based entirely on measured plots, their precision will be unacceptable due to the small annual sample size. An alternative is to base the annual estimates on information in the database for all plots. The advantage of this alternative is that precision is increased because all plots are used for estimation; the disadvantage is that the estimates do not reflect current conditions but rather a moving or rolling average of conditions over the past several years. Another alternative is to first update to the current year information for all plots measured in previous years and then base the estimates on all plots. If the updates are unbiased and sufficiently precise, this alternative increases the precision of the estimates without the adverse effects of using out-of-date information. However, unbiased updating methods are required, and methods to estimate the precision of these updates may be complex.

Whichever estimation alternative is selected, area expansion factors, indicating the area each plot represents, are calculated for each stratum by dividing the remotely sensed stratum area by the total number of field plots in the stratum. For the federal base sample, area expansion factors will vary slightly by stratum but will be approximately 5,900 acres per plot over the 5-year cycle. If only a single panel is used in estimation, the area expansion factors will be approximately 29,500 acres per plot and the estimates will be much less precise than if all five panels are used. Strata estimates are obtained as the sum over sample plots within strata of the products of plot-level estimates and strata area expansion factors. Estimates for contiguous areas such as FIA units or states are obtained by aggregating results over strata for plots that fall within the defined area. Estimates for populations of intensification plots selected in accordance with designs different than the design for the federal base sample must be calculated separately and combined with the federal base sample estimates using appropriate statistical procedures.

6. UPDATING

Two updating methods are under investigation: predicting individual tree growth and survival using models and imputing missing values from a pool of similar data.

6.1 MODELS

For a dozen years, the FIA program at NCRS has used the STEMS (Stand and Tree Evaluation and Modeling System; Belcher, Holdaway, and Brand 1982) growth and survival models to update plots and trees not measured in the current inventory. 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 both the growth and survival models has been undertaken with several objectives: (1) to calibrate the models using FIA data rather than data from nonrepresentative research plots, (2) to incorporate a climatic component, (3) to utilize current statistical techniques that were unavailable when the STEMS models were developed, (4) to develop methods for accurately estimating the uncertainty of the model predictions, and (5) to quantify the adverse effects on the precision of model predictions when using predictors such as site index, stand basal area, and average stand diameter, whose values are estimates rather than observations, or predictors such as crown ratio that are known to be difficult to accurately measure (McRoberts 1994). Issues related to the first objective are described and discussed by Holdaway (1999). Issues germane to the fifth objective relate to the uncertainty in tree and stand conditions at a point in time because of measurement errors and sampling variability. This uncertainty has two adverse effects: First, uncertainty in the values of predictors used to calibrate the models adversely affects the precision of model parameter estimates; and second, uncertainty in tree and stand conditions at the time of last measurement adversely affects the precision of the predicted current tree conditions.

The diameter growth models are in the form of the product of a regional average component and a modifier component and are calibrated separately for each species. The regional average component is based on the gamma function and uses current diameter at breast height (DBH) as a predictor variable. The modifier component has the form of an exponential function and uses as predictors the departures from regional averages for individual tree variables, such as crown ratio and crown class, and stand variables, such as basal area and physiographic class. For each species, only those predictor variables that significantly improve quality of fit are selected for the model. Thus, while the general form of the model is the same for each species, the specific predictor variables and the parameter estimates vary by species. The results of unpublished studies indicate that the bias in these models is both negligible and less than that for the STEMS models.

Simulation studies (McRoberts, Lessard, and Holdaway 1999) indicate that coefficients of variation for 5-year diameter predictions range from less than 0.02 to approximately 0.10, depending on the tree conditions, while coefficients of variation for 20-year predictions range from less than 0.08 to approximately 0.15, again depending on tree conditions. Variance estimates used to calculate these coefficients of variation include the effects of uncertainty due to residual variability around the predicted growth curves, covariances of parameter estimates, uncertainty in the values of the predictor variables, and uncertainty in the conditions of the tree and stand for which growth is predicted. Although these coefficients of variation for individual trees may be considered large, the models are not intended primarily for stand-alone, individual tree growth predictions but rather for growth predictions that will be aggregated over larger areas. For large area estimates, two conclusions from the simulation studies are relevant: First, coefficients of variation due only to model prediction uncertainty for region-wide estimates are generally less than 0.01; and second, the component of uncertainty in large area FIA estimates due to the growth model predictions is very small relative to the variation among plots.

6.2 Imputation

The second updating method is referred to as imputation (Poso 1978; Holm, Hagglund, and Martensson 1979; Rubin 1987; Moeur and Stage 1995) and is being investigated by SRS. Imputation uses the information obtained from plots measured in the current year to update information for plots measured in previous years. The essence of this method is to match each plot or tree measured in a previous year with a pool of similar plots or trees measured in the current year. The similarity criteria must be objective and selected prior to implementing the imputation procedure. As an example, volume growth for a plot randomly selected from a pool of similar plots measured in the current year would be used to predict the volume growth of a plot measured in the previous year. In this manner, information for plots measured in a previous year is updated to current conditions. This procedure is applied

Table 1. Numbers of Quaking Aspen Trees

Site index (ft)	Crown ratio (%) 9–11 inch diameter class 0–19	20–39	40–59	60–79	11–13 inch diameter class 0–19	20–39	40–59	60–79
20–29	2	1	0	0	0	0	0	0
30–39	1	17	4	0	0	0	0	0
40–49	10	62	29	1	10	46	15	0
50–59	67	221	41	1	33	187	40	1
60–69	84	469	71	1	51	372	64	4
70–79	90	493	69	6	43	335	55	3
80–89	37	215	21	2	26	172	21	1

each year to plots not measured in the current year. When the plot is again selected for measurement, the observed measurements replace the updated values in the database. This method is appropriate when a relatively high proportion of plots is measured each year and when large numbers of plots are measured in the current year that are similar to plots measured in the previous year.

In the north central region, most stands regenerate naturally, are uneven-aged, and are characterized as mixed species. A cursory investigation of imputation as a means of updating tree diameters for the north central region used the STEMS predictor variables (diameter, site index, crown ratio, basal area, and the ratio of tree diameter to average stand diameter) as factors for establishing a pool of similar trees. A table of the number of quaking aspen trees, the most abundant species in Minnesota, for two annual samples cross-tabulated by diameter, site index, and crown ratio (Table 1) reveals many cells with small numbers of trees. If the cross-tabulation were expanded to include five categories for each of the remaining predictor variables, basal area and relative diameter, many cells would have fewer than 10 observations. For the north central region, this is considered inadequate. Thus, while investigations of imputation continue, models are used for updating purposes in the north central region.

7. WORKS IN PROGRESS

Research is continuing in three major areas: regeneration models, survival models, and incorporation of a climatic component in the diameter growth models. Although harvested areas for which all trees have been removed can be detected with sufficient accuracy, regeneration in these areas is usually uncertain for up to 5 years. However, because it is inappropriate to classify harvested plots as unstocked for 5 years, a procedure for estimating initial regeneration is being developed. Research is in the planning stage for construction of new individual tree survival models using methodology developed in the health and medical communities for clinical trials applications. Finally, research has been initiated to incorporate climatic components into the diameter growth models. The underlying hypotheses are that inclusion of a long-term climatic component will provide greater spatial precision and that inclusion of an annual climatic component will provide greater temporal precision.

8. CONCLUSION

Annual forest inventories for the north central region using the functions previously discussed were initiated in Minnesota in 1992 when the first annual sample of field plots was measured by MN DNR. Since that year, approximately 750 plots have been measured annually in Minnesota's four inventory units. In 1997, standard FIA estimates were calculated and tables were constructed for Minnesota's aspen–birch inventory unit for the years 1992–1995 with a prototype annual inventory system. Although the results have not been published, two conclusions emerge: (1) The system works, standard FIA estimates can be produced, and standard FIA tables can be constructed using these annualized methods; but (2) issues related to precision and uncertainty must be thoroughly investigated and communicated due to the small annual sample sizes.

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