USDA United States Department of Agriculture

Forest Service

North Central Research Station

General Technical Report NC-212

Integrated Tools for Natural Resources Inventories in the 21st Century

Proceedings of the IUFRO Conference August 16-20, 1998 Boise, Idaho, USA

Mark Hansen and Thomas Burk, Editors

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North Central Research Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication May 1, 2000
2000

Integrated Tools for Natural Resources Inventories in the 21st Century

Proceedings held at
Boise Centre on the Grove
Boise, Idaho

August 16-20, 1998

Edited by
Mark Hansen and Tom Burk

INTEGRATED TOOLS
FOR NATURAL RESOURCES
INVENTORIES IN THE 21st CENTURY

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PREFACE

Inventory has always been and continues to be central to forest management at all levels of practice. Designing, planning, and implementing inventories draws upon the expertise of many individuals within a forestry organization. For these reasons it is not surprising that our 1998 conference drew a contingent of over 325 forestry and related professionals from multiple organizational levels. There was also a distinct international flavor to the conference with over 30 foreign countries represented—again, evidence of the importance and pervasiveness of inventory in forestry practice.

By all accounts the gathering was a complete success: good attendance, a rich variety of papers, well-done presentations, fine hospitality and weather from the good folks of Boise, Idaho, and ample good food around which discussions could be continued and acquaintances made or reestablished. All this was made possible by the hard work of many people involved in organizing the conference and, of course, the enthusiastic participation of attendees.

Consideration of the papers presented at the conference points to several trends in inventory practice. The new "annual inventory" systems being developed were the subject of several papers, as well as a special session. Increased pressure on forest management has called for a corresponding increase in the need for timely data for which the annual inventory systems provide one approach. Concern over possible forest decline in many areas across the globe has spurred efforts in more effective forest health monitoring. These efforts continue to be improved in terms of statistical rigor and are now being seen as an integral component of a comprehensive inventory system. Growth modeling efforts and inventory have always been closely linked, but the use of models in the design of repeated inventories has grown considerably. Use of inventory data for model calibration and evaluation, as opposed to research plots, is receiving increased attention.

Remote sensing techniques continue to be evaluated for generating useful auxiliary data in forest inventories. Much has been learned with current efforts better matching imagery capability with data needs. Still greater gains will be needed as managers and decisionmakers call for more frequent inventories with broader applicability. Finally, a healthy call for simplicity in design was heard from many at the conference. Inventory data are being used to address an increasingly diverse set of questions by an increasingly diverse set of users. Optimality has little meaning under such circumstances, and statistical efficiency may not be conducive to broad application.

In addition to the conference paper and poster sessions, vendors shared the latest in technologies useful in inventories throughout the conference, and five half-day workshops presented the latest inventory tools. The conference ended with six field trips demonstrating a variety of current inventory techniques and implementations.

The papers that follow are generally "as provided" by the author. All authors were asked to obtain peer review of their manuscript, and we assume that was uniformly the case. Reviewers are identified in the acknowledgments of each paper. We have organized the papers into seven topical areas to give some sense of meeting themes.

Again, thanks to all those involved in organization and execution of this successful conference, especially to the members of the conference planning commitee—people who all put in lots of hard work and had great ideas—and to our sponsors who provided financial and other logistical assistance. We would also like to thank Lucy Burde and Mary Peterson for the hard work they did in editing and putting together these proceedings.

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Selection of Plot Remeasurement in an Annual Inventory

Mark H. Hansen, Hans T. Schreuder, and Dave Heinzen

Abstract.—A plot selection approach is proposed based on experience from the Annual Forest Inventory System (AFIS) in the Aspen-Birch Unit of northestern Minnesota. The emphasis is on a mixture of strategies. Although the Agricultural Act of 1998 requires that a fixed 20 percent of plots be measured each year in each state, sooner or later we will need to vary the scheme to accommodate pressing user needs and budget constraints while still preserving the integrity of the annualized cycle. Differing probabilities of selection will need to be accommodated; variance and confidence interval estimation can be done using bootstrap methods.

Under this different approach, the existing ground plot locations will all be remeasured periodically, but not following the regular 5-year cycle of 20 percent each year. A certain percentage of plots, say 10 percent of the currently installed grid, would be selected annually, so that all plots would be remeasured at least once over a 10-year period. In addition, Forest Health Monitoring (FHM) plots (about 2 percent of the existing locations) would be measured every 4 years, and another percentage, say an additional 10 percent, would concentrate on parts of the population of particular interest. For example, we might focus on plots more useful for annual forest area change estimation by selecting plots that are more likely to change to or from forest or select other plots that will be of greater value in improving plot predictions obtained from models. We use the term model in the broadest sense of small area estimation (includes multiple imputation, plot, and tree models to update individual plots or to predict for every ha in the population of interest). Alternatively, additional ground plots could be measured to assess annual acreage changes in selected areas.

Because of special needs, some plots might be measured several times in a 10-year cycle, really complicating the probabilities of selection for these plots. Typically, an approximately equal number of plots are measured each year, but under the strategy presented here we would have flexibility to accommodate funding or user-need changes.

The Minnesota Department of Natural Resources and the Forest Inventory and Analysis (FIA) Units of the North Central (NCFIA) and Rocky Mountain Research Stations cooperated on a project to test and implement an Annual Forest Inventory System (AFIS) in Minnesota. The purpose of this study was to develop a system to replace the 8- to 15-year periodic inventories conducted by the USDA Forest Service with a system through which plots are measured every year and estimates of the forest resources can be made annually. The AFIS system incorporates the previous set of plots and remeasures a portion at various times. Components of AFIS are: a tree-level forest growth simulator to update tree and plot measurement data on an annual basis, satellite imagery examined every 4 years to determine the extent and location of major changes in vegetation over time, and a system to select plots for measurement each year.

The Farm Bill of 1998 (U.S. Senate Bill 1150, Agricultural Research, Extension, and Education Reform Act of 1998) mandated that 20 percent of all plots be measured in each state each year. This percentage is likely to be reduced because of cost considerations. We have learned valuable lessons that will be helpful in planning intelligent plot selection for use in the future when a certain percentage of plots will be done in each state, but in many instances there will be a need to select additional plots and/or to modify the period between measurements. The purpose of this paper is to discuss the rationale used in the planned development of the plot selection method in AFIS prior to the Farm Bill of 1998 and to discuss how sample selection in annualized inventories can be modified to accommodate future needs based on our experience with AFIS.

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REVIEW OF LITERATURE

The sampling design used by NCFIA prior to the Farm Bill of 1998 was presented in Hansen (1990). This design is basically sampling with partial replacement (SPR) with the addition of a growth model and stratification for change. The three components required by the design were:

1. A set of remeasurable ground observation plots,
2. A growth model capable of updating these old plot data to the current date, and
3. A method for identifying change plots, i.e., those plots that the model is not capable of updating.

The sample design was simple in that the old plots were first stratified into two classes, changed and unchanged. The changed plots were treated separately in that traditional continuous forest inventory estimators were used (Schreuder *et al.* 1993). All unchanged plots were updated to the inventory date using the growth model. In addition, some unchanged plots were remeasured. These remeasured unchanged plots can be used to see how well the growth model works, i.e., how closely the updated, projected data match actual remeasurement data.

New plots were also added to improve the estimates and to ensure that the next survey had enough plots available for remeasurement or projection in the next inventory. As in SPR, new plots may only be necessary if the accuracies desired for estimates of volume and growth dictate that it is most efficient to add new plots, or if the time between the past and current surveys is so long that lost plots are a problem.

The STEMS growth model updated the unchanged plots (Hansen 1990). This distance-independent individual tree growth model was used because it is still the best system available for the type of data NCFIA collects. Any growth model that can produce estimates of the variables of interest from old plot data could be used. Improved models are now being developed (McRoberts 2000).

The system initially used change identified on current aerial photographs (scale:1/15,840) but then shifted to Landsat Thematic Mapper data. The sampling scheme produced a tree list for at least two points in time for all plots. These tree lists were then entered as individual observations of the plot in the NCFIA database. One important feature of the estimation process was that although all plots contribute to the estimates of area, volume, and growth, only the remeasured plots are used to estimate removals. However, this smaller sample is concentrated in the change strata, where the majority of the removals are found.

MANUAL AND DIGITAL CHANGE DETECTION

Landsat Thematic Mapper (TM) scenes were purchased on a regular 4-year interval to obtain imagery of Minnesota. All data were purchased from Earth Observation Satellite Company (EOSAT) of Lanham, MD.

The initial change stratification for AFIS was done manually only for the sample plot locations. Each plot was located on both the 1986 and 1990/91 TM imagery, and the vegetative cover of the two images at the plot location was observed. The plot was classified into one of five change-in-vegetative-cover classes (major increase, minor increase, no change, minor decrease, major decrease). We estimate the area within each change stratum based on these samples and treat these estimated strata sizes as known for estimation purposes.

Digital change detection is now being done on a pixel-by-pixel basis in Minnesota, which yields complete stratification of the population. Plots with considerable harvesting and mortality can be detected. This classification is based on the differencing (1990/91 value minus 1986 value) of three TM bands (3, 4, and 5) and a five-by-five pixel averaging of the combined differences. With digital change detection, strata sizes can be based on complete coverage using all pixels.

DESCRIPTION OF THE ASPEN-BIRCH UNIT

Kingsley (1992) noted that the Aspen-Birch Unit consists of five counties in extreme northeastern Minnesota, the most heavily forested area of the state. Today the unit is generally dominated by hardwoods, especially by aspen. The unit consists of 8.7 million acres of land, of which 7.4 million acres are forested; Cook and Lake Counties are more than 90 percent forested (see figure 1). Table 1, a condensed version of a table in Kingsley (1992), summarizes key information for the unit after the 1990 survey.

Table 1.—*Selected forest statistical information for the Aspen-Birch Unit*

Description	Total	Standard error (% of the total)
Growing-stock volume (1990) (million ft^3)	5,608.3	1.08
Growing-stock growth (1977-89)(million ft^3/yr)	132.1	1.88
Timberland area (1990) (thousand acres)	5,878.7	0.57

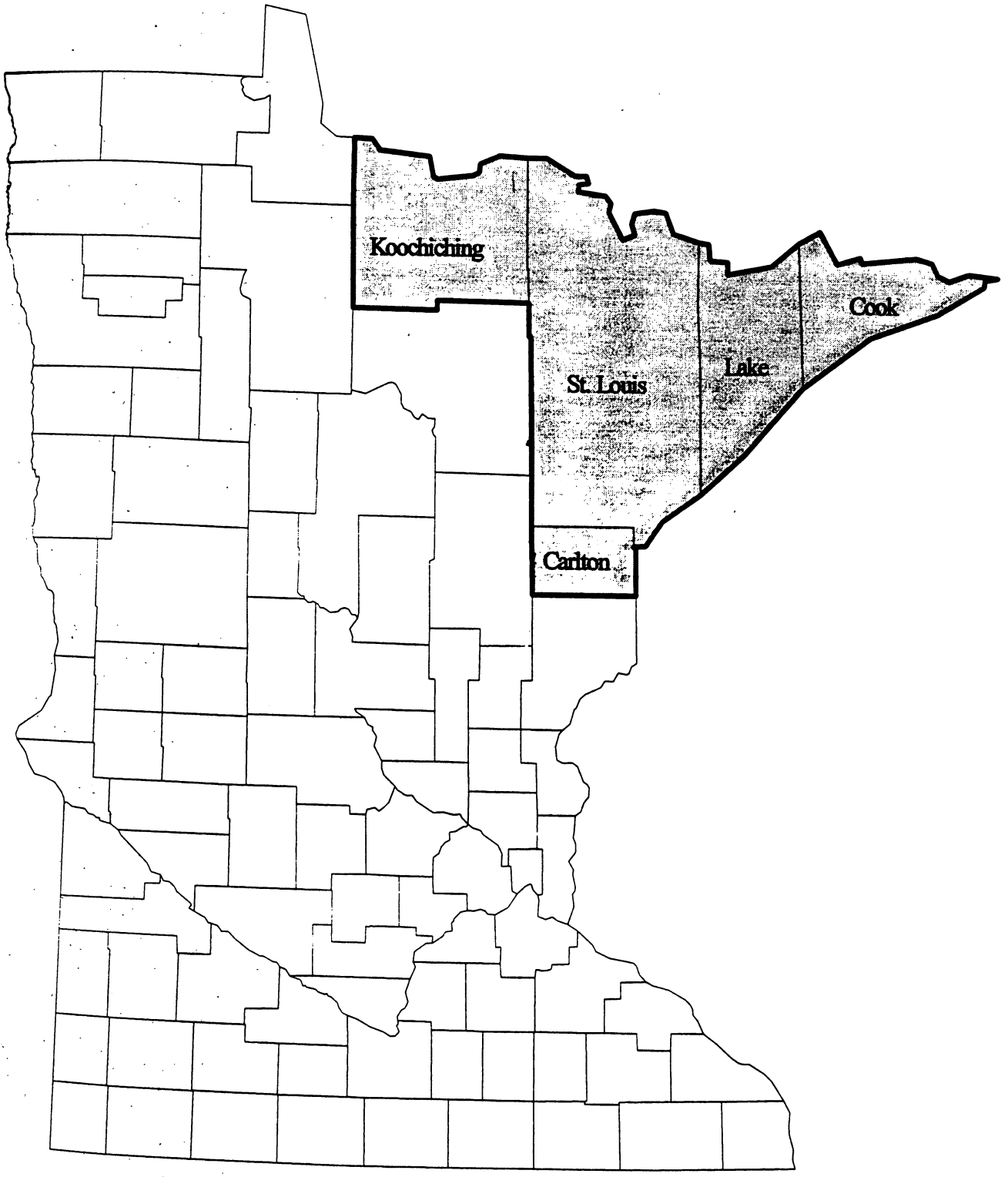

Figure 1.—*The Aspen-Birch Unit, Minnesota.*

The unit has a strongly fiber-oriented forest economy. The area has a mixture of timberland owners (23 percent state, 22 percent federal, 21 percent county, 15 percent private individuals, 8 percent forest industry, and 11 percent other private) and a wide range of upland and lowland forest types. The area of sawtimber-size stands increased 476,200 acres from 1977 to 1990, although poletimber and seedling-sapling stands still dominate.

The 1977 inventory was the fourth FIA inventory in Minnesota and consisted of an entirely new sample. The methods and results of this inventory were described by Spencer and Ostrom (1979). The three previous inventories used different methods and did not establish any permanent sample plots that were remeasured in this inventory. In the Aspen-Birch Unit, this inventory consisted of (1) a phase 1 sample of over 36,000 photo plots that were used for stratification of the total area into aerial photo classes and (2) a systematic phase 2 sample of 5,099 plots. These plot locations were the base sample used for the 1990 (fifth) inventory that used the methodology described above.

INITIAL PLOT SELECTION CRITERIA

AFIS was first implemented in 1992, 2 years after the 1990 (fifth) periodic inventory of the area was completed. At that time we began selecting plots for remeasurement. The first year of AFIS continues with this same system of numbering inventory cycles and is referred to as the sixth cycle. Each additional year of AFIS is another cycle. There were several objectives in the development of the initial implementation of the plot selection methodology of AFIS, including:

1) Identify and remeasure the strata containing disturbed plots more intensively than strata containing undisturbed plots. Disturbed plots are basically plots where forest conditions have changed drastically due to outside events such as harvesting, stand treatment, and catastrophic mortality that go beyond changes that growth models such as STEMS can predict.

2) Remeasure a percentage of undisturbed plots to test and adjust the STEMS model for current conditions that may differ from those that existed when STEMS was originally calibrated. Methods to adjust the STEMS model for local conditions have been used extensively by NCFIA (Smith 1983), and these methods correct the regional model to conditions that are unique to the region and time period where additional remeasurement data exist.

3) Remeasure or drop each plot before it is so old that remeasurement is difficult. This is to ensure that plots are not lost and dropped out of the system. Plots become increasingly more difficult to locate as time since last visit increases. The cost of remeasurement and the probability of lost data both increase over time.

4) Remeasure some undisturbed plots more frequently. Year-to-year changes in weather can influence growth and mortality, and models should be recalibrated to account for changes in growth due to these effects. These measurements could also be used to help estimate the error in predictions of growth both from the growth model (prediction errors) and from remeasurement data (measurement errors).

5) Stabilize the number of plots that are measured each year to avoid year-to-year changes in budgets needed for plot measurements. Under the current periodic inventories, the number of plots measured in a state changes drastically from year to year.

6) Maintain the existing core set of permanent plots as much as possible.

7) Ensure a probabilistic sample every year. This ensures that sample-based estimates of population parameters can always be made.

Based on these criteria, the following plot selection algorithm was developed for the first 4 years (1992, 1993, 1994, and 1995) of AFIS in the Apen-Birch Unit of Minnesota.

1) In 1992, plots were selected using a systematic sample with a random start of the existing plot locations (originally established as a systematic sample) in the Aspen-Birch Unit since the disturbance information was not available at the time 1992 field work began. No priority was given to plots based on the time since last measurement. The plots measured in the 1990 inventory have the same probability of selection as plots measured in the 1976 inventory, found to be undisturbed in 1990, and not selected for remeasurement in 1990.

2) In 1993 to 1995, one-third of the plots identified as disturbed by the manual disturbance classification were selected for remeasurement. For each disturbed plot, a measurement year (1993, 1994, or 1995) was assigned using a random number generator.

3) In 1993 to 1995, a sample of 1/20th of undisturbed plots were selected for remeasurement with the probability of selection proportional to the number of years since the plot had last been measured. This method gave higher selection probabilities to plots that had not been measured recently and allowed for some plots to be measured on a more frequent basis.

Table 2 shows the numbers of plots that were selected in each inventory starting with the 1977 periodic inventory. This table accounts for all plots. Most of the nonforest without trees plots are not visited by a field crew. These plot locations are identified on aerial photographs during each inventory to verify that they are still nonforest plots and are primarily water, marsh, and agricultural lands that are easily identified as nonforest on aerial photos.

As indicated, for example, in Schreuder and Wardle (1999), the database will be or will become the main product of these annualized inventories. Because of this and increased sophistication in users, we expect the following objectives:

1) For annual estimates of totals and rate of change, use areas of sufficient size to have an adequate sample.

2) Assess annual changes in acreage for major cover types. Assess annual changes in volume by species by the four regions in Minnesota, such as aspen/birch, northern pine, central hardwood, and prairie, (hardwood sawtimber, black spruce stands, conifer stands, aspen/birch acreage).

3) Meet FHM (forest health monitoring) needs.

4) Identify areas with high unexpected disturbance for which a "quick" followup example is desired, either by ground plots or very low altitude photo plots.

5) Test and verify models.

6) Asses land-use change.

CONTINUATION OF PLOT SELECTION IN ASPEN-BIRCH UNIT

Data from the first 4 years of AFIS have yielded observations of the disturbance rates that have occurred in this unit. Over the nominal 4-year time period (1986 to 1990/1991) of manual TM disturbance detection, an overall disturbance rate of approximately 3.0 percent per year (592 disturbed forest plots from a total of 4,880 forest plots over 4 years) was observed. This disturbance can be broken down into two groups:

a) Plots that had been classified as disturbed between the 1977 and 1990 inventories.

b) Plots that had been classified as undisturbed between the 1977 ans 1990 inventories.

The annual disturbance rates in the a and b groups was 1.1 percent and 3.2 percent, respectively. Based on these observed disturbance rates, we developed a function that we use in our projection to simulate the probability that a plot will be classified as disturbed based on the number of years since the plot was last measured. This function is flat for the first 4 years and then increases linearly after that. A number of plots were considered disturbed in two consecutive 4-year TM cycles. As we visited these plots in the field, it became apparent why. The first classification was often due to a decrease in the canopy (caused by harvesting, fire, or some other event), and the second disturbance was often an increase in canopy related to the regeneration of the plots. It was inefficient to remeasure these plots for the second disturbance. Usually the condition of plot regeneration could not be characterized yet. The first measurement provided the needed information on removals and mortality and often gave as good an estimate of regeneration as a second remeasurement 1 to 4 years later. We decided that if a plot was classified as disturbed in two consecutive 4-year TM cycles, the first measurement data would be examined, and if the plot had been harvested in the first measurement, we would not remeasure the plot in the second 4-year TM cycle. Instead, we used the growth model to project these plots for another 4 years but still included them in the disturbed strata. These plots are typically clearcut, and a 4-year projection simply moves them from a 1- to 3-year-old seedling/sapling stand to a 5- to 7-year-old seedling-sapling stand, neither of which would contain merchantable volume. Unless we find that the observed disturbance on these plots is of considerable interest for other reasons, they may not be measured again possibly until they become well-established poletimber stands, most likely at about age 15-20.

Table 3 shows the expected number of plots to be measured in the Aspen-Birch Unit for each cycle (year) of

Table 2.—*Number of plots selected in FIA inventory cycles 4 to 9 by type of plot and ground classification, Minnesota, Aspen-Birch Unit*

Inventory cycle and ground classification	Total number of plots	New or replacement plots	Undisturbed plots remeasured	Type of plot Disturbed plots remeasured	Undisturbed plots projected	Disturbed plots projected
Cycle 4 - 1977						
Timberland	3,275	3,275	0	0	0	0
Other forest	620	620	0	0	0	0
Nonforest with trees	40	40	0	0	0	0
Nonforest without trees	1,164	1,164	0	0	0	0
TOTAL	5,099	5,099	0	0	0	0
Cycle 5 - 1990						
Timberland	4,880	1,452	900	1,689	839	0
Other forest	1,012	620	51	37	285	19
Nonforest with trees	49	13	18	16	2	0
Nonforest without trees	1,566	463	373	140	575	15
Lost/denied access	140	0	3	136	1	0
TOTAL	7,647	2,548	1,345	2,018	1,702	34
Cycle 6 - 1992						
Timberland	4,870	2	304	66	3,694	804
Other forest	1,013	0	87	2	891	33
Nonforest with trees	54	0	6	0	40	8
Nonforest without trees	1,568	0	122	10	1,340	96
Lost/denied access	4	0	3	1	0	0
TOTAL	7,509	2	522	79	5,965	941
Cycle 7 - 1993						
Timberland	4,860	1	109	254	3,887	609
Other forest	1,015	0	3	0	977	35
Nonforest with trees	56	0	1	2	45	8
Nonforest without trees	1,573	0	1	4	1,462	106
Lost/denied access	2	0	0	2	0	0
TOTAL	7,506	1	114	262	6,371	758
Cycle 8 - 1994						
Timberland	4,853	0	83	248	3,913	609
Other forest	1,016	0	25	15	955	21
Nonforest with trees	57	0	0	3	46	8
Nonforest without trees	1,577	0	31	31	1,433	82
Lost/denied access	1	0	0	1	0	0
TOTAL	7,504	0	139	298	6,347	720
Cycle 9 - 1995						
Timberland	4,854	0	76	289	3,920	569
Other forest	1,016	0	21	11	959	25
Nonforest with trees	57	0	1	5	45	6
Nonforest without trees	1,576	0	34	36	1,430	76
Lost/denied access	0	0	0	0	0	0
TOTAL	7,503	0	132	341	6,354	676

AFIS by the number of years since last remeasurement. The numbers here are a total of the timberland, other forest and nonforest with trees land-use classes, the plots that require field crew visits. Plots without trees are not included in this and following tables because they do not require field crew measurements, typically the major cost of the inventory. These numbers are based on a slight modification of our original plot selection criteria, assuming a disturbance rate that is constant for each cycle. The modified plot selection criteria are as follows:

1) Disturbance detection will be done every 2 years. This disturbance information will be available at the start of cycle 10, 14, 18, ... measurement periods.

2) Any plot identified as disturbed will be remeasured in one of the next 4 years after disturbance has been observed.

3) The total number of plots to be measured each year will be held to a constant, desired total number of field plots (n_t).

4) Once the disturbed plots have been identified (n_d), n_u (= n_t-n_d) plots will be selected from the undisturbed plots by giving highest priority to those with the longest time since last remeasurement. That is, no undisturbed plots that were measured in the 1990 inventory will be remeasured until all the undisturbed plots from 1977 have been remeasured. Similarly, as we move ahead into future years of AFIS and all the 1977 plots have been remeasured, no undisturbed plot that was last measured in the nth cycle will be remeasured if undisturbed plots from the (n-1) th cycle have not been remeasured.

As can be seen in table 3, a few (26) plots will go 22 years between remeasurement in the year 1999; however, in 2008 there are 225 plots that will go 18 years between remeasurement, and then the system stabilizes and no plot goes more than 17 years without remeasurement. The probabilities of selecting each plot will be kept track of carefully and in some cases will have to be 1 in a certain year. After the year 2012, the distribution of plots by years since last measurement stabilizes. These projections assume that the disturbance rate does not change and that over time we continue to sample the same number of plots each year. The effect that changes to these assumptions can have on the number of plots selected can be seen in tables 4 and 5.

Table 4 presents a second estimate of the plots to be measured over a number of cycles of AFIS using the same for remeasurement is clearly apparent when you compare tables 3 and 4. In this scenario, it takes longer (2016) for things to stabilize. Once a stable state is reached, plots can go 21 years without remeasurement, but fewer plots reach this maximum.

The reasons for these differences are clear. In both cases we are measuring the same number of plots each year. With a higher disturbance rate, more resources must go into measuring the disturbed plots (at less than the maximum interval) thus requiring this maximum interval to increase. If there was no disturbance, the system would stabilize at a maximum remeasurement period of N_t/n_t years where N_t is the total number of plots available for remeasurement.

Table 5 shows how this plot selection method responds to changes in the disturbance rate. We start with the disturbance rate used in table 3, but change detection done in 2000 and 2004 assumes the much higher rates of disturbance that we used in table 4. After 2004, we again go back to the original disturbance rate. This fluctuating disturbance rate is similar to what would happen when a major short-term disturbance such as a wind storm, a temporary increase in harvesting, or a period of drought causes high mortality. Note how the change in disturbance modifies the age of the plots selected for remeasurement for a while; however, after the original disturbance rate returns, the system eventually reaches the same stable state it has in table 3.

In this scenario, once the system has reached stability, only disturbed plots would have a remeasurement period less than the maximum period set. This selection method meets all of our original criteria for plot selection except for criterion 4: remeasure some undisturbed plots more frequently. This original criterion was designed to provide a data set to help estimate and calibrate the growth model for changes in weather or other factors. The original plot selection method of remeasuring undisturbed plots with probability proportional to the number of years since last measurement did provide undisturbed plots with various remeasurement periods. But these plots did not really meet the objective for which the criterion was designed. For estimation and modeling of short-term changes in growth and mortality, what is needed is a set of sample plots that continue to be remeasured on a regular short-term basis. Under our original plan, an undisturbed plot may be measured in 2 consecutive years and then not remeasured again for 20 years. After we initially developed the AFIS plot selection criteria, the Forest Health Monitoring program (FHM) was implemented in Minnesota. FHM plots, a systematic sample of 325 forest plots across Minnesota (83 in the Aspen-Birch Unit), are now being measured on a rotating basis every 4 years and can be used for calibration of growth and mortality models to account for

Table 3.—*Total number of forest and nonforest with trees plots measured in the field by years from last measurement (constant disturbance rate for all cycles)*

Cycle	Year	Total number of plots	Number of years since last measurement																					
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
10	1996	390	4	4	4	4		71													303			
11	1997	390		4	4	4	4		71													303		
12	1998	390			4	4	4	4		105													269	
13	1999	390				4	4	4	4		349													269
14	2000	390	4	4	4	4	8	7	7	9		343												
15	2001	390		4	4	4	4	8	7	7	9		343											
16	2002	390			4	4	4	4	8	7	7	9		343										
17	2003	390				4	4	4	4	8	7	7	9		343									
18	2004	390	4	4	4	4	7	8	8	8	8	7	8	9		311								
19	2005	390		4	4	4	4	7	8	8	8	8	7	8	9		311							
20	2006	390			4	4	4	4	7	8	8	8	8	7	8	9		311						
21	2007	390				4	4	4	4	7	8	8	8	8	7	8	9		311					
22	2008	390	4	4	4	4	7	8	8	8	8	8	8	8	8	7	8	63		225				
23	2009	390		4	4	4	4	7	8	8	8	8	8	8	8	8	7	21	268		7			
24	2010	390			4	4	4	4	7	8	8	8	8	8	8	8	8	35	251	9		7		
25	2011	390				4	4	4	4	7	8	8	8	8	8	8	8	47	241	8	9			7
26	2012	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
27	2013	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
28	2014	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
29	2015	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
30	2016	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
31	2017	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
32	2018	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
33	2019	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
34	2020	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
35	2021	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
36	2022	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
37	2023	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
38	2024	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
39	2025	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
40	2026	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
41	2027	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
42	2028	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
43	2029	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
44	2030	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
45	2031	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
46	2032	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
47	2033	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
48	2034	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
49	2035	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
50	2036	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
51	2037	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
52	2038	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
53	2039	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
54	2040	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
55	2041	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
56	2042	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
57	2043	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
58	2044	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
59	2045	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
60	2046	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
61	2047	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
62	2048	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
63	2049	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
64	2050	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
65	2051	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
66	2052	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
67	2053	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
68	2054	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
69	2055	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		

Table 4.—*Total number of forest and nonforest with trees plots measured in the field by years from last measurement (higher disturbance than in table 3)*

Cycle	Year	Total number of plots	Number of years since last measurement																									
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
10	1996	390	4	4	4	4		178													196							
11	1997	390		4	4	4	4		178													196						
12	1998	390			4	4	4	4		178													196					
13	1999	390				4	4	4	4		178													196				
14	2000	390	4	4	4	4	19	18	18	23		207													89			
15	2001	390		4	4	4	4	19	18	18	23		287													9		
16	2002	390			4	4	4	4	19	18	18	23		287													9	
17	2003	390				4	4	4	4	19	18	18	23		287													9
18	2004	390	4	4	4	4	19	19	20	20	17	16	16	20		227												
19	2005	390		4	4	4	4	19	19	20	20	17	16	16	20		227											
20	2006	390			4	4	4	4	19	19	20	20	17	16	16	20		227										
21	2007	390				4	4	4	4	19	19	20	20	17	16	16	20		227									
22	2008	390	4	4	4	4	19	19	20	20	17	17	17	18	15	14	14	17		168								
23	2009	390		4	4	4	4	19	19	20	20	17	17	17	18	15	14	14	17		168							
24	2010	390			4	4	4	4	19	19	20	20	17	17	17	18	15	14	14	17		168						
25	2011	390				4	4	4	4	19	19	20	20	17	17	17	18	15	14	14	17		168					
26	2012	390	4	4	4	4	19	19	20	20	17	17	17	18	14	15	15	15	12	11	11	59		75				
27	2013	390		4	4	4	4	19	19	20	20	17	17	17	18	14	15	15	15	12	11	40	98		7			
28	2014	390			4	4	4	4	19	19	20	20	17	17	17	18	14	15	15	15	12	43	93	13		7		
29	2015	390				4	4	4	4	19	19	20	20	17	17	17	18	14	15	15	15	43	94	11	13		7	
30	2016	390	4	4	4	4	19	19	20	20	17	17	17	18	14	15	15	15	12	12	12	55	79					
31	2017	390		4	4	4	4	19	19	20	20	17	17	17	18	14	15	15	15	12	12	53	85	7				
32	2018	390			4	4	4	4	7	19	19	20	20	17	17	17	18	15	15	15	12	48	90	12	7			
33	2019	390				4	4	4	4	19	19	20	20	17	17	17	18	14	15	15	15	38	99	12	12	7		
34	2020	390	4	4	4	4	19	19	20	20	17	17	17	18	14	15	15	15	12	12	12	55	79					
35	2021	390		4	4	4	4	19	19	20	20	17	17	17	18	14	15	15	15	12	12	53	85	7				
36	2022	390			4	4	4	4	19	19	20	20	17	17	17	18	14	15	15	15	12	48	90	12	7			
37	2023	390				4	4	4	4	19	19	20	20	17	17	17	18	14	15	15	15	38	99	12	12	7		
38	2024	390	4	4	4	4	19	19	20	20	17	17	17	18	14	15	15	15	12	12	12	55	79					

Table 5.—*Total number of forest and nonforest with trees plots measured in the field by years from last measurement (high disturbance rate in 2000 and 20*

Cycle	Year	Total number of plots	Number of years since last measurement																					
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
10	1996	390	4	4	4	4		71													303			
11	1997	390		4	4	4	4		71													303		
12	1998	390			4	4	4	4		105													269	
13	1999	390				4	4	4	4		349													269
14	2000	390	4	4	4	4	19	18	18	23		296												
15	2001	390		4	4	4	4	19	18	18	23		296											
16	2002	390			4	4	4	4	19	18	18	23		296										
17	2003	390				4	4	4	4	19	18	18	23		296									
18	2004	390	4	4	4	4	19	19	20	20	17	16	16	20		227								
19	2005	390		4	4	4	4	19	19	20	20	17	16	16	20		227							
20	2006	390			4	4	4	4	19	19	20	20	17	16	16	20		227						
21	2007	390				4	4	4	4	19	19	20	20	17	16	16	20		227					
22	2008	390	4	4	4	4	7	8	8	8	7	7	7	7	6	5	5	7		292				
23	2009	390		4	4	4	4	7	8	8	8	7	7	7	7	6	5	5	7		292			
24	2010	390			4	4	4	4	7	8	8	8	7	7	7	7	6	5	5	133		166		
25	2011	390				4	4	4	4	7	8	8	8	7	7	7	7	6	5	177	105			22
26	2012	390	4	4	4	4	7	8	8	8	8	8	8	8	7	7	7	7	94	176	14			
27	2013	390		4	4	4	4	7	8	8	8	8	8	8	8	7	7	7	174	111	5			
28	2014	390			4	4	4	4	7	8	8	8	8	8	8	8	7	7	209	76	6	5		
29	2015	390				4	4	4	4	7	8	8	8	8	8	8	8	7	241	44	7	6		5
30	2016	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	225	7				
31	2017	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
32	2018	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
33	2019	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
34	2020	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
35	2021	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
36	2022	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
37	2023	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
38	2024	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
39	2025	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
40	2026	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
41	2027	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
42	2028	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
43	2029	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
44	2030	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
45	2031	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
46	2032	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
47	2033	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
48	2034	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
49	2035	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
50	2036	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
51	2037	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
52	2038	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
53	2039	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
54	2040	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
55	2041	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
56	2042	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
57	2043	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
58	2044	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
59	2045	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
60	2046	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
61	2047	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
62	2048	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
63	2049	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
64	2050	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
65	2051	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		
66	2052	390	4	4	4	4	7	8	8	8	8	8	8	8	8	8	8	55	232					
67	2053	390		4	4	4	4	7	8	8	8	8	8	8	8	8	8	51	237	7				
68	2054	390			4	4	4	4	7	8	8	8	8	8	8	8	8	45	243	8	7			
69	2055	390				4	4	4	4	7	8	8	8	8	8	8	8	37	251	8	8	7		

selection criteria and assumptions, but this time with a somewhat higher assumed disturbance rate. The disturbance rate still remains constant over time. The effect that a change in the disturbance rate has on the plots selected weather and other short-term effects. Plans are to incorporate these plots into AFIS to improve the model and increase the accuracy of the estimates. This merging of AFIS and FHM is facilitated by a decision made in 1995 to use the same field plot design for FIA and FHM.

This was what was planned prior to the Farm Bill of 1998.

> This bill mandates that each year a certain percentage of plots will be measured in each state. Given this we see the following as an opportunity of building on the current mandate:

This alternative approach contains elements of both the AFIS plot selection that was just presented and the plot selection mandated by the 1998 Farm Bill and previously advocated by SAFIS where 1/nth of the plots are measured each year regardless of disturbance.

Based on our experience with sample selection in the Aspen/Birch Unit, we propose the following sample selection strategy assuming a total sample of n plots each year:

1. Select the FHM plots for remeasurement every 4 years say n_1 each year. This yields a sample of about 5 percent of the plots, 25 percent of which would be measured in each of the 4 years, which yield reliable growth and mortality measurements (measurements of less than 4 years may have too much measurement error in them to be useful).

2. Implement a grid subsample of x percent of plots each year, n_2 plots, so that all plots would be measured over 100/x years. Typically x might be 5 percent so that all plots would be measured in 20 years.

3. Select a certain number of plots (n_3) in the disturbed and a smaller percentage of plots, say n_4 actual plots, in the undisturbed strata.

4. Allow for a certain number of additional plots that can be remeasured in response to specific needs in any given year, say n_5 plots.

The above is an idealized version of plot selection, resulting in $n_1+n_2+n_3+n_4+n_5$ plots. If this number exceeds n, we would have to cut down on n_3 and/or n_4 to ensure that actual number of plots equals n.

ESTIMATION ISSUES

Although we like the concept of giving all sample units equal probability of selection each year, as we are instructed to do under the 1998 Farm Bill, we believe this may be unrealistic particularly as states, industry, and other users see opportunities of getting more frequent inventory information for the state and parts of the state. If unequal sampling probabilities are used, estimation becomes more complex and users of the data must be more aware of the complexities of sampling design in their analysis of the data.

Estimating parameters such as totals is not difficult as long as the probabilities of selection for the sample plots are kept track of properly. Difficulties are anticipated in the joint probabilities of selection for units that are needed in classical variance estimation. If it is difficult to obtain such joint probabilities of selection, we plan to use bootstrap techniques for variance and confidence interval estimation (Schreuder *et al.* 1993). Even if such joint probabilities can be readily computed, we will probably use bootstrapping since such nonparametric techniques generally yield more reliable confidence intervals for estimates.

It may be possible to maintain a base equal probability sample and use the proposed sampling strategy for intensification purposes only. There are advantages and disadvantages to such an approach. The base sample could serve users who wish to avoid the complexity of the intensified sample. This sample would provide consistent, unbiased estimates of population parameters based on simple, widely used methodology. Users of the base plus intensified samples would need to understand the complexities of the intensified sample and incorporate them into their estimation procedures. By doing so, they could obtain better estimates of many parameters. The possibility of conflicting estimates from the two approaches is a real problem and is one that would require a great deal of education for those using FIA data. The higher cost due to more frequent remeasurement of the simple, equal probability approach will have to be compared to the complexities and possible apparent inconsistencies of the unequal probability approach.

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Includes 96 papers presented at the conference Integrated Tools for Natural Resources Inventories in the 21st Century, August 16-20, 1998, in Boise, Idaho, USA. This conference drew several hundred forest inventory and related professionals from multiple organizational levels and over 30 foreign countries. Topics covered include those related to natural resource inventory design, analysis and management applications; measurement consistency issues; data management, GIS and remote sensing applications; forest growth model interfaces; and special purpose inventories and applications.

KEY WORDS: Integrated inventories, inventory databases, remote sensing, urban forestry, volume, biomass, height, modeling, spatial information, growth, survival, mortality, annual inventories.