REMOTE SENSING PRECISION REQUIREMENTS FOR FIA ESTIMATION[1]

Mark H. Hansen[2]

Abstract—In this study the National Land Cover Data (NLCD) available from the Multi-Resolution Land Characteristics Consortium (MRLC) is used for stratification in the estimation of forest area, timberland area, and growing-stock volume from the first year (1999) of annual FIA data collected in Indiana, Iowa, Minnesota, and Missouri. These estimates show that with improvements in the classification, ground plot location and geo-rectification methods, we should be able to meet the accuracy standard for timberland area estimates (3 percent per million acres of timberland) in most areas. To meet the accuracy standard for growing-stock volume estimates (5 percent per billion cubic feet of growing stock) under the base sampling intensity (one plot per 5,937 ac on a 5-year cycle) that FIA has implemented in the North Central Region, we must be able to create meaningful volume classes from TM imagery or find other means to improve our estimates. Improvements in classification methods are most important in areas where forest land makes up a small portion of the total land area. Simulations based on observed FIA data, an existing classification of Landsat TM data, and various assumptions are used to examine the expected accuracy of FIA estimates when a complete cycle of annual inventories (5 years) has been completed.

INTRODUCTION

FIA has made a commitment to an annual forest inventory with a base inventory of one ground plot every 5,937 ac with one n^{th} of the plots measured every year over a cycle of n years. In the North Central region, with the cooperative efforts of state agencies, plans are to measure plots on a cycle of n=5 years, with a 20 percent sample of the plots measured each year. Once the annual forest inventory is fully implemented, basic estimates of current conditions (e.g., timberland area and growing-stock volume) can be made from the moving average of estimates made from all plots measured over the full cycle. The first year's ground plot measurement data collected under this system in the North Central region are now available for the states of Indiana, Iowa, Minnesota, and Missouri. These plots were measured between October 1998 and September 1999.

These first year plot data, together with a thematic GIS layer based on the classification of Landsat TM data for stratification purposes, are used here to produce estimates and sampling errors for forest area, timberland area, and growing-stock volume. Stratification methods similar to those used in the last two periodic inventories conducted by NCFIA (Hansen and Wendt 2000) are used with data produced by MRLC (Vogelmann and others, 1998) for stratification into four classes. Here I examine the sampling errors that can be expected once the entire cycle of data is available (4 years from now) to see how close to meeting national accuracy standards we can expect our estimates will be.

Sampling errors can be reduced by various means including improving stratification, measuring additional sample plots, and using other estimation schemes. Measuring additional sample plots is extremely costly. Other estimation methods are possible and are a topic of current discussion that goes beyond the scope of this paper. Here I examine how much better the classification of Landsat TM data must be in order to reduce sampling errors to meet the national accuracy standards. Stratified random sampling estimation is used throughout the study.

DATA

NCFIA sampled 5,240 systematic plot locations in the four-state study area using the national FIA plot design, a cluster of four $1/24^{th}$ acre fixed area subplots. Of these plot locations, 1,467 (28 percent) contained some forest land. These plots were located across the landscape following the grid system described by Brand and others (2000). Data available for each plot included the geographic position of the plot center (measured by GPS and/or digitized from geo-referenced Landsat imagery), the proportion of forest and timberland area on the plot (an observation from 0 to 100 percent), and the growing-stock volume (cubic feet per acre) on the plot. The methods, procedures, and definitions used to observe the attributes of interest are available on-line at http://fia.fs.fed.us/manuals/.

FIA estimates are commonly reported at the state and unit (group of counties) level. Figure 1 shows these units for the study area. In this study I have classified units as sparse (less than 10 percent forest), mixed (10 to 45 percent forest), or heavy (greater than 45 percent forest) based on the most recent periodic FIA inventory (fig. 2). Table 1 presents the total number of plot locations and the number that contained forest land for each unit.

The thematic GIS layer based on the classification of Landsat TM data used in this project is the National Land Cover Data (NLCD) prepared by the Multi-Resolution Land Characteristics Consortium (MRLC). MRLC used dual date (leaves-on and leaves-off) imagery that was resampled into a 30- by 30-m pixel format, an Anderson level 2 classification scheme, various ancillary data sources, and a single

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[2] Research Forester, USDA Forest Service, North Central Research Station, 1992 Folwell Avenue, St. Paul, MN 55108.

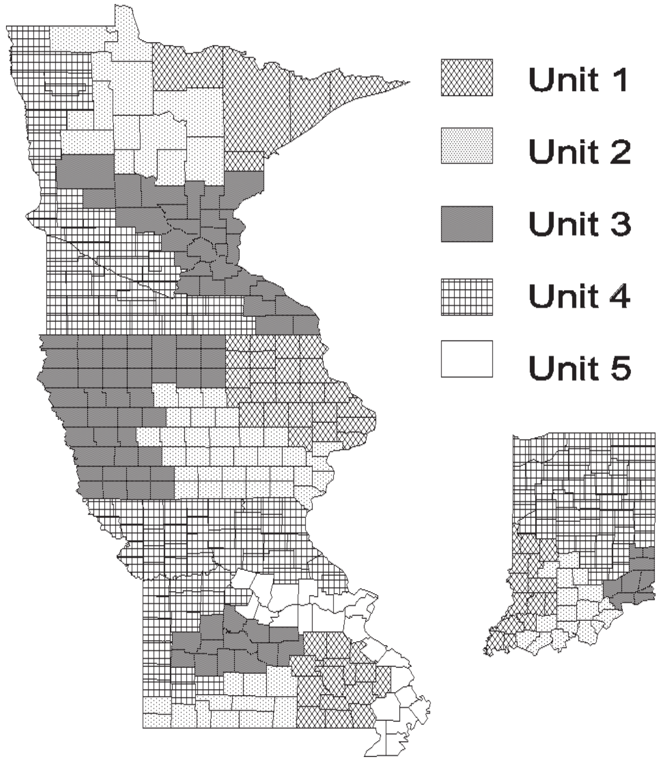

Figure 1—FIA inventory units in the study area.

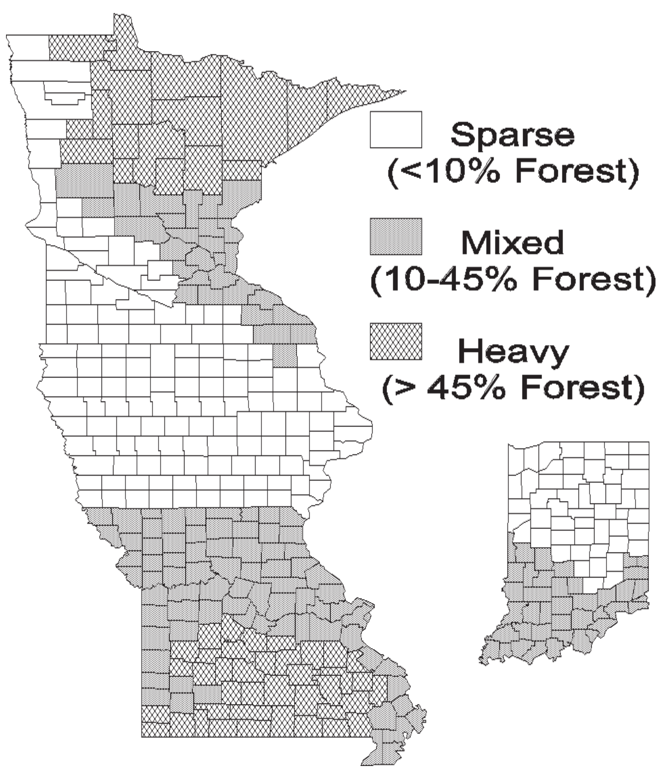

Figure 2—Sparse, mixed, and heavy forest FIA units.

pixel minimum mapping unit to classify geo-referenced imagery into the 21 classes shown in table 2. Imagery dates ranged from 1988 to 1994 over the study area. Detailed documentation of the methods used in classification and on-line access to the data are available at http://www.epa.gov/mrlc/.

ESTIMATION

Stratified Random Sampling

All estimates and sampling errors presented here are based on stratified random sampling estimators with stratification after the selection of the sample (poststratification) presented by Cochran (1977) with finite population correction ignored. The estimate of the population mean is the weighted average of the observed strata means from the sample

$$\bar{y}_{st} = \sum_{h=1}^{L} W_h \bar{y}_h \tag{1}$$

and the estimated sampling error is a weighted function of the within strata sampling errors

$$s_{\bar{y}_h} = \sqrt{\frac{1}{n}\sum_{h=1}^{L} W_h s_h^2 + \frac{1}{n^2}\sum_{h=1}^{L}(1-W_h)\, s_h^2} \tag{2}$$

where *L* is the number of strata, *n* is the total number of observations (plots), $\bar{y}_h$ and s_h^2 are the observed (estimated) mean and variance in statum h, and W_h is the stratum weight (proportion of the total population in stratum h).

Table 1—Number of total plot locations and plot locations that contained forest land by FIA unit

			Number of plot locations	
	State	Unit	Total	Forest
Sparse (< 10 percent forest)	IN	4	458	56
	IA	1	311	34
	IA	2	375	56
	IA	3	516	20
	MN	4	663	30
		Subtotal	2,323	196
Mixed (10 to 45 percent forest)	IN	1	124	35
	IN	2	134	61
	IN	3	53	22
	MN	3	413	93
	MO	4	664	155
	MO	5	265	89
		Subtotal	1,653	455
Heavy (> 45 percent forest)	MN	1	313	235
	MN	2	412	220
	MO	1	193	144
	MO	2	179	113
	MO	3	167	104
		Subtotal	1,264	816
		Grand total	5,240	1,467

Table 2—National land cover data classes

Class	Description
11	Open water
12	Perennial ice/snow
21	Low intensity residential
22	High intensity residential
23	Commercial/industrial/transportation
31	Bare rock/sand/clay
32	Quarries/strip mines/gravel pits
33	Transitional
41	Deciduous forest
42	Evergreen forest
43	Mixed forest
51	Shrubland
61	Orchards/vineyards/other
71	Grasslands/herbaceous
81	Pasture/hay
82	Row crops
83	Small grains
84	Fallow
85	Urban/recreational grasses
91	Woody wetlands
92	Emergent herbaceous wetlands

Here, the thematic GIS data (the pixels and their classification) define the population and sampling frame. These GIS data divides the population (total area of an inventory unit) into equal size pixels (sampling units) where each pixel has a distinct class (stratum) assigned to it. The ground plots provide an observation of the attribute of interest (y) for the specific pixel that contains the plot center. This observation is always a per unit area observation such as volume per acre. In the case of area estimation, for example, the area of timber land, this per unit area observation is a value from 0 to 1 that is the proportion of the ground plot that was observed to be timber land. Most estimates reported by FIA are totals rather than means and are the product of the estimated population mean $(\bar{y}_{st})$ and the known total area of the population (A) that is obtained from Bureau of Census data.

FIA Accuracy Standards

FIA has set national accuracy standard for its inventories. These standards are defined for a specified area or volume. The standard for the estimate of total timberland area is 3 percent per million acres and for growing-stock volume 5 percent per billion cubic feet. The equation

$$e = \frac{(\text{observed sampling error})\sqrt{\text{estimated total volume or area}}}{\sqrt{\text{specified volume or area}}} \quad (3)$$

converts the observed sampling error as a percent for an estimate to a specified volume or area standard basis (typically 1 million ac or 1 billion ft^3). For example, an inventory that yields an estimated area of timberland of 4 million acres with a 2.0 percent sampling error would not meet the standard because $(2.0\text{ percent})\sqrt{4{,}000{,}000\text{ acres}}/\sqrt{1{,}000{,}000\text{ acres}} =$ 4.0 percent per million acres, which is greater than the accuracy standard (3 percent per million acres) for timberland area estimates. In this paper equation 3 is used to convert sampling errors to a per million acres or per billion cubic feet basis. Also, to convert observed sampling errors from the first year of annual inventory data to a full cycle basis when estimates will be made based on the moving average of 5 years of observations, sampling errors are divided by the square root of 5. Dividing sampling errors by the square root of 5 is equivalent to increasing the sample size by a factor of 5 (based on the assumption of a representative sample of the population), which simulates estimation based on the average of five independent estimates.

Stratification

The NLCD data were used to create four strata (1-nonforest interior, 2-nonforest edge, 3-forest edge, 4-forest interior). This was accomplished in four steps:

1. NLCD classes 33 (transitional), 41 (deciduous forest), 42 (evergreen forest), 43 (mixed forest), 51 (shrubland), and 91(woody wetlands) were grouped into a single class (forest), and all other classes were grouped into a second class (nonforest).

2. A clump and sieve operation (ERDAS, 1997) was applied to this two-class image to create a two-class image with a minimum mapping unit of 1 ac (4 pixels).

3. Forest pixels within 2 pixels of any nonforest pixel were classified forest edge; all other forest pixels (those not within 2 pixels of nonforest) were classified forest interior.

4. Nonforest pixels within 2 pixels of any forest pixel were classified nonforest edge; all other nonforest pixels (those not within 2 pixels of forest) were classified nonforest interior.

In step 1, the NLCD shrubland class was included in the initial forest grouping because we found that some of the lands classified as shrubland by NLCD contained enough trees to meet the FIA definition of forest land. An example portion of the final reclassified image is shown in figure 3.

U.S. Bureau of Census data files were used in this study to provide the total area within each FIA unit and divide the imagery into FIA inventory units. TIGER county boundary files and ERDAS IMAGINE software were used to perform the data manipulation required to define the strata, match ground plot data to the appropriate pixels, and summarize the number of pixels by class and inventory unit. Oracle SQL programs were written to produce the estimates and sampling errors. In the estimation, the Bureau of Census information, together with the NLCD geo-referenced data, define the population (total area sampled).

ESTIMATION WITH FOUR STRATA

The sampling errors of the area estimates are very dependent on the quality of the stratification. The estimate of forest area will have a low sampling error if the stratification is good, that is, if the forest interior stratum contains most of

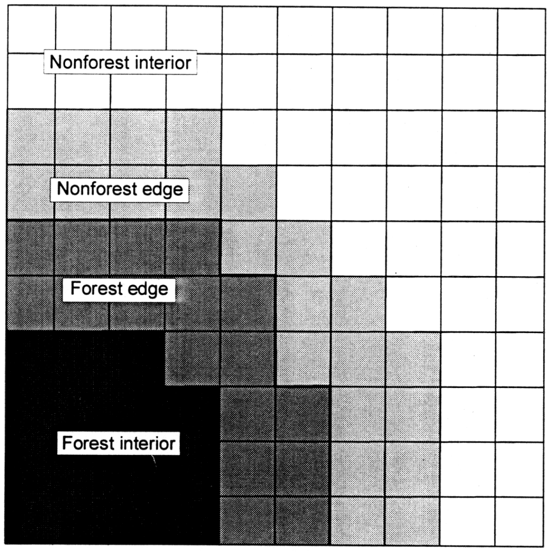

Figure 3—Example portion of the reclassified NLCD image.

the plots that are 100 percent forest, the nonforest interior stratum contains most of the that plots are 100 percent nonforest, and the two edge strata contain the plots that are on the forest/nonforest interface.

In meeting the national FIA accuracy standard for timberland area estimation, stratification becomes more important in areas where timberland is a small portion of the total land area. In populations that are more than 85 percent timberland, simple random sampling estimation will produce sampling errors less than 3 percent per million acres and statification is not required to meet the area accuracy standard at the current ground plot intensity. In populations that are 20 percent timberland or less, simple random sampling will produce sampling errors in excess of 7 percent per million acres. Figure 4 shows the expected sampling errors based on simple random sampling across the complete range of percent timberland when the total timberland area in the population is 1 million ac.

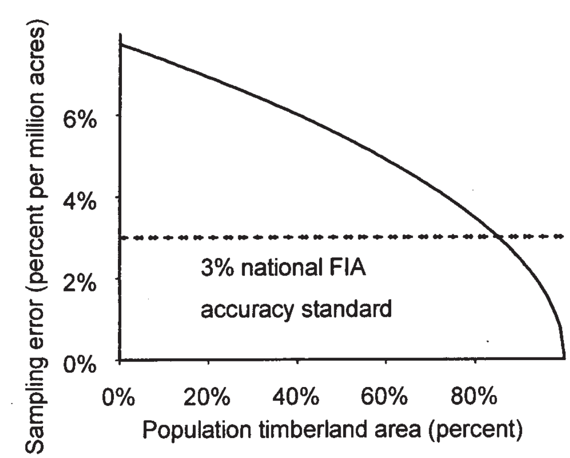

Figure 4—Expected sampling error (timberland area) from a simple random sample in a population of 1,000,000 acres of timberland and a sampling intensity of one plot per 5,937 ac.

The mean percent forest land within each of the four strata for all of the FIA units in the study area are shown in figure 5. This figure shows that the NLCD data with reclassification did a fairly good job of stratification. This figure is arranged with the heavily forested units at the top of the vertical scale and the sparsely forest units at the bottom. In all but one inventory unit (MO-2) the nonforest interior stratum contained less than 5 percent forest area, and in only one unit (MN-4) was the forest interior observed to contain less than 80 percent

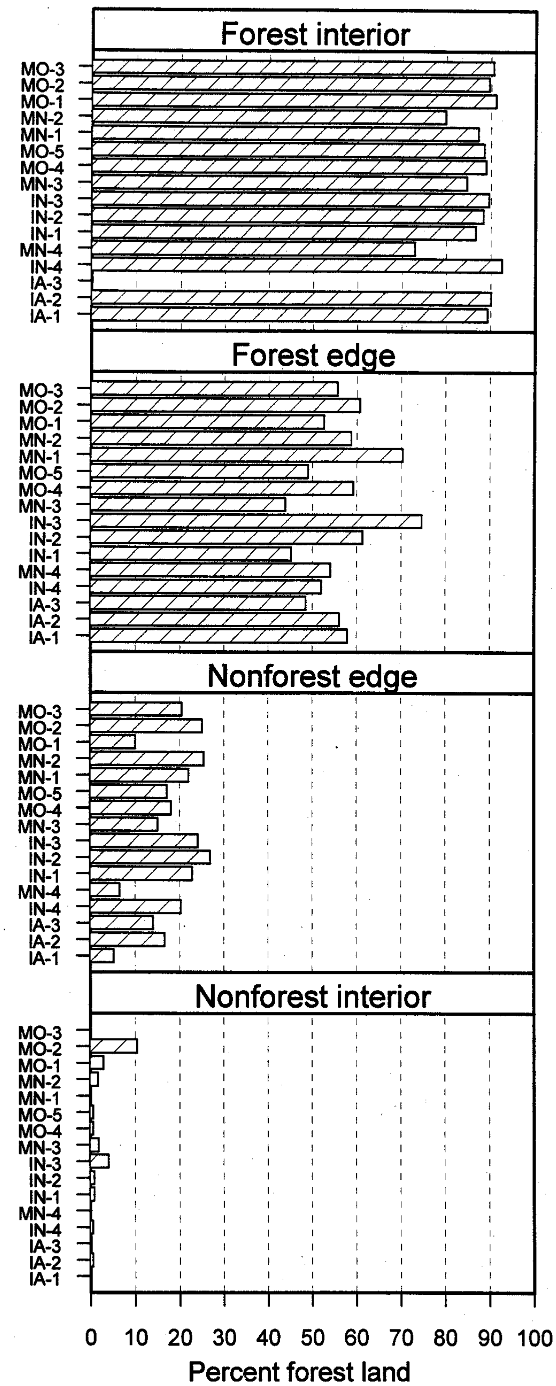

Figure 5—Mean observed percent forest land by FIA unit and the original four strata created from the NLCD data and the four steps described.

forest land. Because there was very little forest interior in western Iowa (IA-3), in that unit I combined the forest interior and forest edge strata into the forest edge strata in all analyses in this paper.

Table 3 shows the estimate of total forest area, timberland area, and growing-stock volume (based on the 1999 plot data and the stratification described previously) for the three groups of FIA units shown in figure 2 (sparse, mixed, and heavy forest) and sampling errors based on various assumptions, each a progressive improvement in the stratification. The first sampling error column in this table (sampling error for a single year estimate) is the actual estimated sampling error based on the data from only 1 year. This sampling error represents a sampling intensity of one plot per 29,685 ac and is the observed sampling error of the estimates in the first column of numbers (single year estimate). All other sampling errors in this table have been converted to a per million acres or per billion cubic feet basis for the moving average estimate given 5 years of data based on equation 3 divided by the square root of 5. The different columns simulate progressive improvements in classification that could possibly improve the estimation but still use the same four strata.

The column labeled "nothing added" is simply the expected sampling error with 5 years of data based on stratification using only the existing NLCD data and the procedures to define four strata as previously described. This column was computed by applying equation 3 to the numbers in the two columns to its left (to convert to per million or per billion) and dividing by the square root of five (to simulate the addition of 4 more years of data at the same intensity). It should be noted that the expected sampling errors in all cases failed to meet the FIA accuracy standards and that they are highest in the sparsely forested unit and lowest in the heavily forested unit. Without improvements to the classification, we should not expect to meet accuracy standards, especially in areas that are sparsely forested.

In an attempt to reduce sampling error by improving the stratification, I have simulated the effect that having perfect knowledge of all reserved lands would have on the estimates. Under this scenario, reserved lands would be treated as a subpopulation. This was simulated by moving reserved plots into a different population and moving a proportional area from the NLCD data. Reserved lands are areas such as parks and wilderness areas where timber harvest is prohibited.

By definition, plots on reserved lands have observed values of zero for timberland area and growing-stock volume. However, they are often forested and thus increase the variability in the forest strata in the estimation of timberland area and growing-stock volume. In application, the treatment of reserved lands as a subpopulation would be possible through the acquisition of good maps and/or GIS layers that show reserved lands from various land management agencies. This has been done in the past when aerial photos were manually interpreted but has not yet been

Table 3—Estimates and sampling errors based on stratified random sampling estimation and the existing four strata with various improvements to the classification

				Sampling error (percent per million acres or billion cubic feet) after 5 years with various improvements in classification				
Units	Item	Single year estimate (million acres or billion cubic feet)	Sampling error for a single year estimate (% of estimate)	Nothing added	Add GIS layer for reserved land	Add GIS layer for reserved land and census water	Add GIS layer for reserved land, census water, and most farm lands	Add GIS layers and improve location data
Sparse	Forest area	4.27	4.74	4.38	4.31	4.31	3.67	3.04
	Tmbld area	3.79	5.5	4.79	4.68	4.68	4.13	3.71
	GS volume	4.01	8.34	7.46	7.33	7.33	7.02	6.73
Mixed	Forest area	10.99	2.86	4.23	4.2	4.2	3.66	2.96
	Tmbld area	10.51	3.02	4.38	4.31	4.31	3.81	3.12
	GS volume	12.61	4.56	7.24	7.18	7.18	6.84	6.44
Heavy	Forest area	22.76	1.49	3.19	3.19	3.11	2.97	2.56
	Tmbld area	21.05	1.8	3.69	3.38	3.29	3.18	2.83
	GS volume	19.41	3.26	6.42	6.26	6.22	6.16	6.03

implemented into the NLCD classification. I simulated adding such a GIS layer for reserved lands by moving all the plots on reserved lands and their associated area to a new stratum. In all but one case, this action reduced sampling errors (one estimate of forest area showed no change in sampling error), although the sampling errors are still above the national accuracy standard. The biggest reductions in sampling errors came in the heavily forested units where large areas of reserved forest lands are found (e.g., Boundary Waters Canoe Area and Voyageurs National Park). Here, sampling errors for timberland area and growing-stock volumes decreased substantially (3.69 to 3.38 and 6.42 to 6.26 percent, respectively). However, sampling errors for forest area did not change (3.19 percent).

Adding information about census water is simulated in the next column using the same techique. The decrease in sampling errors that this produces is again only seen in the heavily forested units such as northern Minnesota where water is a fairly large portion of the total area. In application this could be done through GIS layers that are available from the Bureau of Census.

In the next column I simulated what would happen if we had access to a good GIS layer that could identify 80 percent of the agricultural lands in each unit. Since several government agricultural programs either have this type of GIS information available or are in the process of creating GIS information, it may be possible to identify major agricultural areas known to be nonforest and segment them in the estimation. In effect, the addition of these GIS layers is simply a method to treat areas we know are different as a subpopulation. The addition of these various GIS layers did reduce sampling errors, but it did not produce any sampling errors below the national accuracy standards. Other GIS layers for things such as urban areas, transportation, and other nonforest areas by definition may be available and could possibly improve the stratification somewhat.

Closer examination of the data showed that many of the ground plots that were totally misclassified (forest interior plots that contained no forest land or nonforest interior plots that contained 100 percent forest land) were within 2 pixels of an edge stratum. Sixteen of the total 24 (67 percent) nonforest interior plots that contained 100 percent forest land were within 2 pixels of nonforest edge and 29 of the total 54 (54 percent) forest interior plots that contained no forest land were within 2 pixels of forest edge. This suggests that poor geo-registration of the image and/or plot poor location information may be responsible for much of the error. To simulate the effect that improvements in location information (either ground plots or pixels) could reasonably have on the final estimates, I randomly moved 40 percent of these misclassified interior plots to the adjacent edge strata, along with a proportional amount of the total area, and produced the last column of table 3. In the heavily forested units, sampling errors for timberland area (2.83 percent) were less than the national standard, and in the mixed and sparse units they were reduced considerably (3.12 and 3.71 percent, respectively) and were not far above the standard. Sampling errors for growing-stock volume were reduced, but are still considerably above the 5 percent per billion cubic foot standard (6.03 to 6.73 percent). Figure 6 contrasts the mean percent forest land in these revised strata with the mean from the original strata by inventory unit. The net effect of the changes to the original data was an increase in average percent forest land in almost every case in the forest interior, forest edge, and nonforest edge strata. The net effect in the nonforest interior stratum was mixed. However, this stratum was greatly reduced in size relative to the other strata with the addition of the GIS layer for agricultural lands.

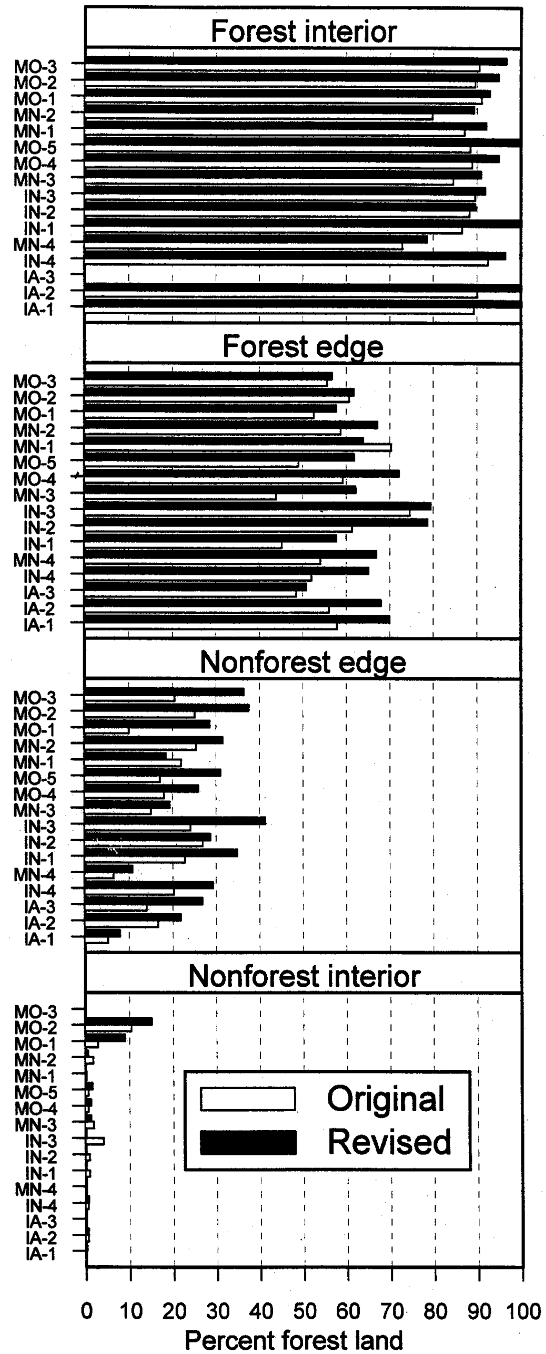

Figure 6—Mean percent forest land in original stratification contrasted with the mean percent forest land after simulation to improve the stratification by the addition of GIS layers and improved location information.

ESTIMATION WITH ADDITIONAL VOLUME STRATA

It is apparent that strata are needed to improve volume estimates, or that some other method must be found to reduce sampling errors to attain the national accuracy standard for volume estimates. To reduce sampling errors from 6 to 5 percent by increasing sampling intensity would require 44 percent more plots. That would be very expensive. Here I simulate adding volume strata to see how the sampling errors for growing-stock volume change.

Initially, I subdivided both the forest interior and forest edge strata into two strata each. I did this by generating a value based on a function of observed basal area, stand age, and a random number, ordered the plots based on this value, and placed the top half in one stratum (high volume) and the other half in another stratum (low volume). The goal was to divide each of the two original forest strata into two equal size strata that approximate a fairly good classification. This procedure created four strata (forest interior-low, forest interior-high, forest edge-low, and forest edge-high) from the forest inerior and forest edge strata. Table 4 summarizes observed volume per acre in these classes. The high and low volume strata have significantly different means. Figure 7 shows the distribution of volume per acre for these strata. These simulated strata are different without being too good. There is significant overlap as would be expected in any real classification, and both classes have large numbers of plots with zero volume per acre. The effect that adding these two volume strata has on the estimation is shown in table 5. Sampling errors for the area estimates change only a little compared to large reductions in the sampling errors on volume. This stratification did not meet the national accuracy standard for growing-stock volume in any of the units.

Table 4—Summary of observed volume per acre with the addition of two volume strata

Units	Stratum	Mean	Standard deviation
		Cubic feet per acre	
Sparse	Forest interior - low	636	613
	Forest interior - high	1,670	674
	Forest edge - low	365	693
	Forest edge - high	853	734
Mixed	Forest interior - low	690	578
	Forest interior - high	1,662	810
	Forest edge - low	444	591
	Forest edge - high	1,101	858
Heavy	Forest interior - low	444	404
	Forest interior - high	1,138	703
	Forest edge - low	362	442
	Forest edge - high	1,002	743

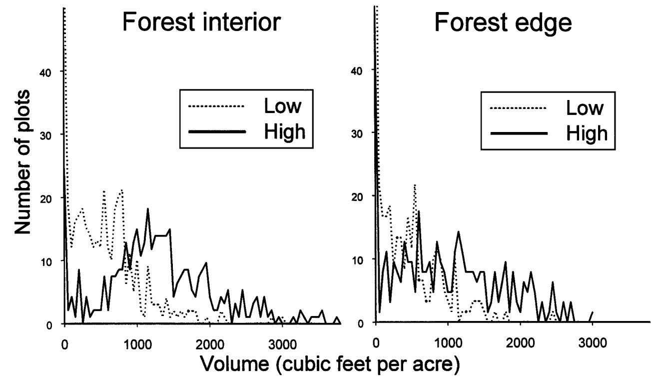

Figure 7—Distribution of plot volume per acre within the simulated high and low volume strata.

A second stratification into three volume classes (high, medium, and low) was created using a similar procedure. These strata are summarized in table 6 with the distributions shown in figure 8. Table 5 show the 5 percent per billion cubic feet standard was met in the heavily forest units (4.91 percent) but not quite met in the mixed and sparse units (5.31 and 5.66, respectively). The addition of the three volume strata also improved the timberland area estimates enough to meet the accuracy standard in the mixed forest units by stratifying many of the misclassified forest plots into the low volume strata. In the sparse forest units, even better stratification would be needed to meet both the area and volume standards. Since area and volume estimation are linked, it is difficult to meet volume standards without also meeting the area standards.

These simulations suggest that fairly good volume classification is needed to meet national accuracy standards for growing-stock volume estimation. Figure 9 shows the

Table 5—Sampling errors with the addition of simulated volume classes

Units	Item	Sampling error after five years with various improvements in classification: Without volume classes	With 2 volume classes	With 3 volume classes
		%/million ac or billion ft^3		
Sparse	Forest area	3.04	3.07	2.97
	Tmbld area	3.71	3.78	3.69
	GS volume	6.73	6.32	5.66
Mixed	Forest area	2.96	2.99	3.01
	Tmbld area	3.12	3.15	3.15
	GS volume	6.44	5.64	5.31
Heavy	Forest area	2.56	2.57	2.58
	Tmbld area	2.83	2.83	2.83
	GS volume	6.03	5.29	4.91

Table 6—Summary of observed volume per acre with the addition of three volume strata

Units	Stratum	Mean	Standard deviation
		Cubic feet per acre	
Sparse	Forest interior - low	425	506
	Forest interior - medium	1,017	559
	Forest interior - high	1,840	556
	Forest edge - low	273	744
	Forest edge - medium	577	336
	Forest edge - high	1,106	821
Mixed	Forest interior - low	584	616
	Forest interior - medium	798	467
	Forest interior - high	1,790	740
	Forest edge - low	311	559
	Forest edge - medium	668	453
	Forest edge - high	1,410	878
Heavy	Forest interior - low	339	366
	Forest interior - medium	646	372
	Forest interior - high	1,291	690
	Forest edge - low	425	506
	Forest edge - medium	1,017	559
	Forest edge - high	1,840	556

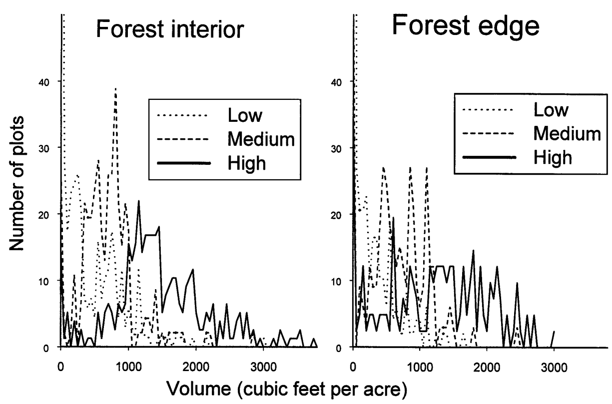

Figure 8—Distribution of plot volume per acre within the simulated high, medium, and low volume strata.

distribution of FIA plots measured in the mid-1980's FIA inventories in Illinois and Indiana. In those inventories, 3,269 FIA plots were classified into nine size-density classes using stereo pairs of 1:40,000 aerial photos. Based on this classification, I created the three best strata I could find by collapsing the three classes with the highest average volume per acre into one strata (high) and similarly collapsing the other classes to create medium and low volume strata. This figure also shows the distribution of the forest interior plots in the simulated three volume classes. To assist in visual comparison, I have adjusted the scale to a common total number of plots in all strata. Table 7 summarizes volume per acre for these two data sets. The two distributions have similar shapes. However, it appears that the simulated strata do a better job of distinguishing between the high and

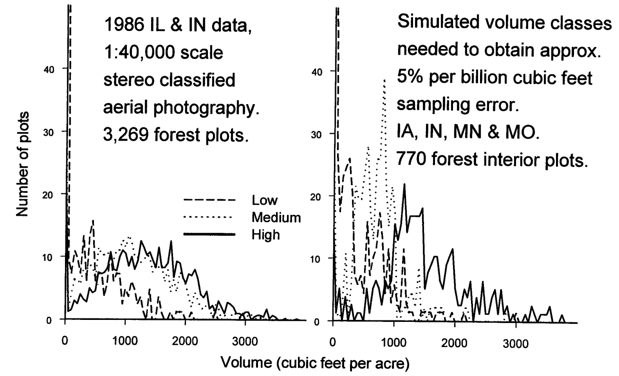

Figure 9— Distribution of the volume per acre data summarized in table 7. The data on the left are from manual stereo interpretation of aerial photos (1980's Illinois and Indiana inventory data). The data on the right are the simulated Landsat TM classification (1999 forest interior strata from Iowa, Indiana, Minnesota, and Missouri) that produced volume estimates of approximately the national standard (5 percent per billion cubic feet). Total number of plots in all strata have been adjusted to an equal basis to aid in visual comparison.

medium volume plots and that the low volume stratum produced from the aerial photos was somewhat better than the simulated low volume stratum.

There are a number of differences between the two data sets contrasted in table 7 and figure 9. The data sets are from different regions (Illinois and Indiana vs Indiana, Iowa, Missouri, and Minnesota), used different ground plot designs, and were measured at different times. They are only shown here to illustrate that the quality of volume classification needed from Landsat TM to meet or nearly meet existing national FIA accuracy standards is about the same as we were obtaining from manual interpretation of aerial photos.

Table 7—Comparison of observed volume per acre within three volume classes, manual stereo interpretation of aerial photos (1980's Illinois and Indiana inventory data) vs simulated Landsat TM classification (1999 forest interior strata from Iowa, Indiana, Minnesota and Missouri)

	Method			
	Manual stereo interpretation of aerial photos		Simulated Landsat TM classification	
Class	Mean	S.D.	Mean	S.D.
Low	224	426	402	456
Medium	1,003	725	706	420
High	1,272	797	1,466	738

DISCUSSION

The analysis and simulations I have done here suggest that through the use of Landsat TM imagery, forest/nonforest classification, ancillary data sources (GIS layers), and improved registration and GPS locations, we will meet or nearly meet the FIA accuracy standards for area estimation at the one plot per 5,937 ac sampling intensity we have implemented. To meet sampling accuracy standards for growing-stock volume estimation, additional stratification is needed. Major investments in improving stratification must be made to obtain the degree of classification needed to meet the volume accuracy standards. To meet these accuracy standards given this sampling intensity, we must be able to identify volume classes from remote sensing with about the same degree of accuracy as we did using manual interpretation of aerial photos in past applications.

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