USING CLASSIFIED LANDSAT THEMATIC MAPPER DATA FOR STRATIFICATION IN A STATEWIDE FOREST INVENTORY

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ABSTRACT.—The 1998 Indiana/Illinois forest inventory (USDA Forest Service, Forest Inventory and Analysis (FIA)) used Landsat Thematic Mapper (TM) data for stratification. Classified images made by the National Gap Analysis Program (GAP) stratified FIA plots into four classes (nonforest, nonforest/forest, forest/nonforest, and forest) based on a two pixel forest edge buffer zone. Estimates based on two-phase sampling for stratification were made at the county level. This procedure differed from methods used in previous inventories where stratification was based on the stereoscopic examination of aerial photo plots. Changes in plot design, sampling intensity, and population parameters between 1986 and 1999 make it impossible to attribute differences in sampling errors entirely to this change in methods. The stratified sample estimates based on TM data provided good estimates and greatly reduced costs by eliminating the need for thousands of aerial photos and manual interpretation of several hundred thousand photo plots.

INTRODUCTION

FIA statewide inventories provide estimates of forest resource parameters such as forest area and timber volume, growth, removals, and mortality estimates at the state, unit, and county level. FIA has used two-phase sampling for stratification (also called double-sampling) for a number of years. Cochran (1977) presents a good general description of double-sampling for stratification, and Loetsch and Haller (1964) present it in a forest inventory context.

This paper describes how the FIA program at the North Central Research Station (NCFIA) used Landsat TM imagery to replace aerial photos for phase one estimates in two statewide inventories. Using digital data to replace manual interpretation of aerial photos greatly reduced the work required to complete these inventories. First, we describe the methods used in the past and then the methods used in 1998. Finally, results from these two inventories are presented to show differences related to changes in phase one procedures.

BACKGROUND

Two-Phase Sampling for Stratification

NCFIA uses two-phase sampling for stratification. Phase one is a large sample used to estimate the size (area) of each stratum and phase two is a sub-sample of the phase one plots that estimates the mean within each stratum. Population level estimates (means and totals) are weighted sums of within stratum estimates. The variance of the estimate is reduced by selecting strata that have low within stratum variances and by increasing sampling. Increasing phase one intensity decreases the variance of the estimated stratum size estimates, and increasing the phase two intensity decreases the variance of the estimated within stratum estimates.

In two-phase sampling for stratification, it is very important that phase one determines strata for all plots (both phase one and phase two plots). It is also important that this assignment to a stratum does not change in phase two when the plot is measured and that the procedures used to determine this classification be identical for all phase one plots regardless if they are also phase two plots. Often in forest inventory applications, the strata have names similar or identical to ground classifications that are of interest in the final estimate. For example, the class of sawtimber may be one stratum. In the phase one sample, a plot is assigned to the sawtimber class based on aerial photo classification. This plot could be a phase two plot and thus sent to the field where it may or may not be ground classified as sawtimber.

Regardless of its ground classification, in the estimation procedure it must be included in the sawtimber stratum.

1986 Inventory Procedures

In 1986, NHAP photos (1:40,000) were assembled into township mosaics, and a systematic grid (one plot per 190.4 acres) was overlaid on each township mosaic. These phase one photo plots were classified by land use, forest type, and stand-size density. A total of about 250,000 photo plots formed the basis for the 1986 stratification. The photo classifications were collapsed into the 11 strata in table 1 for the final estimation.

Table 1.—*Aerial photo (size-density) classes used for stratification in 1986*

1	Sawtimber high	6	Seedling/sapling high
2	Sawtimber low	7	Seedling/sapling low
3	Poletimber high	8	Questionable
4	Poletimber med	9	Nonforest with trees
5	Poletimber low	10	Nonforest without trees
		11	Water

A systematic sample (every 17th) of photo plots was selected as a phase two sample and further examined to measure the parameters of interest. The plot design used in 1986 was a cluster of ten 37.5 basal area factor (BAF) sample points distributed over a 1-acre area. The plot was arranged with all 10 sample points in a single land use (forest or nonforest) as determined by plot center. Under this plot design, each plot represents a binary observation for all area estimates.

Problems With 1986 Inventory Procedures

Two procedural problems were identified that could produce bias in the estimates. One problem relates to methods used on phase two plots that were obviously nonforest on the photos. The other problem was an apparent inconsistency in the classification of phase two plots.

In 1986 phase two plot locations were defined by a pin prick on the photo; however, plots classified in stratum 10 (nonforest without trees) and 11 (water) were treated somewhat differently. All strata 1-9 phase two plots were field visited and permanently marked by a stake in the ground. In strata 10 and 11 there were very few field visits and the aerial photo classification was considered the correct observation. This eliminated visiting thousands of nonforest plots that were obviously nonforest from the photo. It assumes no error in the location and classification of these plots and no conversion to forest between the dates of photography and inventory. These assumptions were fairly safe due to a stable agricultural economy, but the lack of a field check of these two strata probably resulted in a small underestimation of forest land in 1986. Plots in these two strata were field visited only in a few counties where the photos were fairly old or where it was thought there could be significant changes from nonforest to forest.

If nonforest plots are not visited, the only permanent record of the location in two strata (10 & 11) is a pin prick. A stake in the ground is the permanent record of the location in strata 1-9. With remeasurement, errors in the transfer of a pin prick from an old photo to a new photo can result in an observation of nonforest to forest change but not a forest to nonforest change because old forest plots have stakes marking their location. Transferring locations from one photo to another is never perfect, especially with 1:40,000 scale photos from different years that are not ortho-corrected. With remeasurement these errors would bias the sample towards forest land.

A second problem observed with the 1986 procedures is an inconsistency in the photo classification of phase two plots. Double sampling for stratification assumes phase two is a random sub-sample of phase one. Ideally, the photo interpreters would first classify all the phase one plots (without knowing which are phase two plots) and then select the phase two plots. A selection system transparent to the interpreters was not implemented because of the difficulties involved. The systematic nature of the sample and the need to pin prick and collect additional information from the photo on phase two plots made it very inefficient to keep the identity of the phase two plots secret. The lack of independence became apparent in the questionable stratum. A plot should be classed questionable if the interpreter cannot accurately make a forest or nonforest determination. If classifications were done without prior knowledge, the expected ratio of phase two plots to phase one plots is 1:17 in every stratum. The observed ratio in Illinois was 1:8.11, about half the expected value in the questionable stratum. A chi-squared test for lack of independence was significant at the 10^{-10} level. It appears that the interpreters used this stratum more frequently on phase two photo plots than on non-phase two photo plots. In training and supervising the interpreters, we stressed the importance of consistency. The problem appears to be a tendency to do a "better" job at interpreting plots that will be sent to the field over those that will not. Interpreters know someone will be visiting the site they are classifying and must look at it just a little bit more closely.

Ensuring complete independence in the selection of ground plots in a remeasurement sample would greatly increase the phase one effort. It would require two people to work on every township mosaic. Much of the work would be a duplication of effort. One person would transfer the phase two plot locations (pin pricks) from the old photo to the new photo and then locate and label the other phase one plots (those that are not phase two plots) on the new photo. The second person would then classify each of these pin pricks. This would involve placing 17 times more pin pricks and labels on each photo. NCFIA uses photos that are borrowed from other agencies; however, if we were to pin prick and mark the photos every 191 acres rather than every 3,250 acres, we would most likely be forced to purchase photography, greatly increasing our costs.

Classified Digital Imagery for Stratification

Computer aided classification of digital imagery can efficiently map large areas independent of the phase two plot selection. Numerous platforms, sensors and spectral bands, pixel sizes, and classification algorithms are available and much research is ongoing. It is beyond the scope of this paper to review the work that has been done in this area as it relates to forest inventory applications. NCFIA has cooperated in and/or supported research efforts in remote sensing with various groups including MN DNR, Univ. of MN, IL Natural History Survey, IN Univ., WI DNR, Rand Corp., EPA, other FIA projects, and other USDA programs. NCFIA has also acquired the equipment and personnel necessary to process digital image data and has been using these capabilities on special projects in Nebraska and South Dakota. TM data have been used in most of these projects. Currently it appears to be the most promising available data source for use by FIA. The combinations of low cost, multi-spectral capabilities, long-term availability, and appropriate pixel size are among the reasons it has been the primary data source for most large-scale classification efforts investigated by FIA. The minimum size of a forest area defined by FIA is 1 acre, thus sensors with a pixel size larger than an acre can easily miss small areas of forest land, especially where forest is not the primary land cover.

The classification of TM data for an entire state is a very large project and should lead to a product that can be used in many applications. For NCFIA to obtain imagery and classify it for the sole purpose of stratification of the phase two plots would probably exceed the total cost of our current phase one procedures. As methods are improved and the cost of remote sensing coverage decreases this will probably change. NCFIA has typically borrowed photos, or in some states new photos were taken by a cooperating state agency with FIA and other uses in mind. Following this approach of using the best available photos for stratification we began looking for available classified imagery for stratification as we planned the 1998 inventories. Aerial photo plot sampling would be the fall back should the data not provide the level of accuracy needed.

METHODS AND DATA

1998 Stratification Using GAP Classified Landsat TM Data

NCFIA obtained two digital maps derived from TM data. These were made by the National GAP Analysis Program (GAP) (Scott *et al.* 1993). More information about GAP can be found at www.gap.uidaho.edu/gap/ and www.epa.gov/mrlc/.

The base data sets in Illinois were obtained over approximately 5 years (1991 to 1995) and classified into 20 land cover categories by the Illinois Natural History Survey. Four of these categories describe woodland and forest land; the rest are nonforested ranging from water, marsh, and grasses to agricultural and urban. The classification loosely followed an Anderson level 2 (Anderson *et al.* 1976) scheme, and the minimum mapping unit for classification was a single 28.5 x 28.5 m pixel. The data sets in Indiana were taken between 1988 and 1994 and classified into 18 land cover categories by Indiana University. Five of these categories describe woodland and forestland; the rest are similar to those for Illinois. The classification scheme followed the UNESCO system (UNESCO 1973) with a minimum mapping unit of 1 ha (2.47 acres). A sample portion of this image is shown in figure 1 with the 18 classes represented by different gray tones.

The classifications for both states were grouped into binary forest/nonforest images (fig. 2). Furthermore, since FIA defines forestland as being at least 1 acre in size, the Illinois forest classes were clumped and sieved to a one-acre minimum unit. The Indiana data were left at a one-ha minimum unit. This difference in minimum mapping units was of concern to us; however, the raw classified Indiana data were not available to us and in the final analysis we did not detect any problems as a result of the 1-ha mapping unit in Indiana. To improve the identification of plots that were likely to be misclassified or straddle a forest/nonforest edge, two new classes were created. Pixels near the boundary of a forest-nonforest edge were identified. Any forest pixel within two pixels of a nonforest pixel was placed in the forest/nonforest class, and any nonforest pixel within two pixels of a forest pixel was placed in the nonforest/forest class. This provided the four classes used for stratification in the estimation process. Figure 3 shows the same area with the final four classes delineated.

1998 Phase Two Field Procedures

Between 1986 and 1998, field procedures for NCFIA plots changed. The 1998 plot design consists of four 1/24 acre fixed area subplots distributed over an acre. Another major change is that plots can now sample more than one land use. A plot that straddles two land uses is considered a partial observation of each. Under this system, area estimation is not a binary procedure; instead observations can fall anywhere in the range 0-1. For example, a plot that lands 60 percent on forest land and 40 percent on nonforest land becomes an observation of .6 in the estimation of forest area.

Aerial photos were used in this inventory, but only to assist in plot location and observation. It was necessary only to obtain photos for the actual phase two plots rather than complete photo coverage. This greatly reduced the number of photos needed and enabled us to purchase these photos rather than borrow them. The first step in field plot work was to transfer every phase two plot location from the old photos to new photos. Plots were examined to determine if a field visit was necessary. Again, plots that were obviously nonforested were not sent out for field check, but any plot that appeared to possibly have trees on it was remeasured by a field crew. This nonforest interpretation from the photo should not be confused with the nonforest classification in the TM data. Because of the change in plot

Figure 1.—*A part of the classified Landsat TM image produced by Indiana State University for GAP. This classification contains the original 18 classes identified by GAP.*

Figure 2.—*The same part of the image with classes 8-15 combined into one class (forest - gray) and the other classes combined into a second class (nonforest - white).*

Figure 3.—*The same part of the image with the final 4 strata. Nonforest pixels within 2 pixels of forest (nonforest/forest - black) and forest pixels within 2 pixels of nonforest (forest/nonforest - light gray).*

design, pin pricked plot locations that were obviously nonforest without trees (not visited under the old design) but that fell within 200 feet of a forest area required a field visit.

Linking the phase two plots to the classified Landsat TM data requires accurate location information for every phase two plot. A GPS unit was used to obtain this information on every plot that was field visited. Obtaining location information on nonforest plots without trees that were not field visited involved a digitizing procedure where the plot locations from the aerial photos were transferred to a georeferenced image file. The UTM coordinate obtained through digitizing or the GPS unit was used to link each plot to a specific pixel making it possible to assign each plot to a stratum. Errors in this UTM coordinate as well as errors associated with the georeferenced image file contribute to the overall estimates of sampling error. In the inventory we used the best methods we could to reduce this source of error. In this report we do not attempt to examine the contribution of this single source of error to the overall sampling error of the final estimates.

RESULTS

The described procedures produced estimates with sampling errors at or below the national accuracy standard for FIA inventories. Estimation was done on a county basis; however, in some predominantly nonforest parts of each state, several counties were grouped to create populations containing at least 30,000 acres of forest land. In counties within a National Forest, lands owned by the Forest Service were treated as a population separate from those that were not. This differed from the procedure used in 1986, where estimation was done by treating each forest inventory unit excluding Forest Service lands as populations (there are three forest inventory units in Illinois and four in Indiana) with National Forest lands making a final population in each state. In both inventories, sampling errors were computed for individual populations using two-phase sampling for stratification estimators described in Cochran (1977). In the 1998 estimates, the numbers of phase one plots (pixels) are so large that stratum areas can be considered known without error and the estimates are equal to stratified sampling estimates. State total sampling errors for estimates of forest area, growing-stock volume and growth and sawtimber volume and growth from both the 1986 and 1998 inventories are summarized in table 2, along with the number of phase one and phase two plots.

The differences in sampling errors cannot be entirely attributed to the change in stratification procedures. Changes in plot design, sampling intensity, and population parameters between 1986 and 1999 also have major effects. The new plot design samples trees 5 inches dbh and larger on a fixed area plot (equal probability) rather than a variable radius plot (probability proportional to basal area) so larger trees were sampled with a lower probability in 1998. This can have a major effect on

Table 2.—*Selected sampling errors and number of plots (phase one and two) for the 1986 and 1998 Illinois and Indiana inventories. Sampling errors were computed using double sampling for stratification equations (Cochran 1977).*

	Illinois		Indiana	
Sampling errors	**1986**	**1998**	**1986**	**1998**
Forest area	0.94%	1.49%	1.00%	1.52%
Growing-stock volume	1.99%	2.28%	1.57%	2.18%
Sawtimber volume	2.50%	2.57%	1.86%	2.47%
Growing-stock growth	3.36%	2.09%	3.42%	2.04%
Sawtimber growth	5.27%	2.47%	5.47%	2.39%
Plots	**1986**	**1998**	**1986**	**1998**
Number of phase one plots	194,815	179,674,504	126,629	104,057,965
Number of phase two plots (total)	10,847	11,521	11,440	6,326
Number of phase two (ground visits)	1,342	2,114	2,430	1,847
Percent ground visits	12.37%	18.35%	21.24%	29.20%

the variance of the observed volume per acre measurements in stands with large diameter trees. The change to a plot design with one or more conditions had an impact on the observed variance in area estimates. Also, in 1986, the State of Indiana provided additional resources to NCFIA to increase the intensity of phase two. This additional funding was not available in 1998 and the phase two sampling intensity was substantially reduced.

Figures 4-7 show the average observed mean and standard deviation of forest area and growing-stock volume estimates by stratum for both the 1986 and 1998 inventories. These figures show that the classified TM data provided reasonable stratification. The TM classification was not prefect in the identification of nonforest resulting in nonzero observations of forest land in stratum 4. This stratum (nonforest) is by far the largest stratum in both states, and the impact of a good, but less than perfect, stratification of nonforest lands in phase one has a large impact on the variance of any item that is zero on nonforest land. Under the 1986 system, where most nonforest phase two plots were not field checked and assumed to be a nonforest observation, the true mean and standard deviation within strata 10 and 11 shown in figures 4 and 6 are probably underestimates. The true mean and standard deviation are probably not quite as high as stratum 4 in figures 5 and 7. If, in 1986, as few as 1 in 1,000 nonforest without trees phase one plots were misclassified and were actually forest on the ground, the sampling errors on forest area estimates in 1986 would exceed those of the 1998 shown in table 2. Under stratified sampling, a small error in a very large stratum can have as much impact as a large error within a very small stratum.

The 1998 strata 2 and 3 were designed to contain the plots near forest edges and performed well. Over 60 percent of the ground plots with both a forest and nonforest condition were in one of these strata.

The change from considering each unit a population to considering counties or county groups as populations had significant effects on our county-level estimates. In 1986, all estimates were developed at the unit level and prorated back to the county on the basis of phase one data. This procedure used all phase two ground plots from the entire unit to estimate within stratum means for every county and masked real differences between counties and underestimated the true sampling errors of the county level estimates. The direct development of county-level data for 1998 estimates provides estimates of true differences between

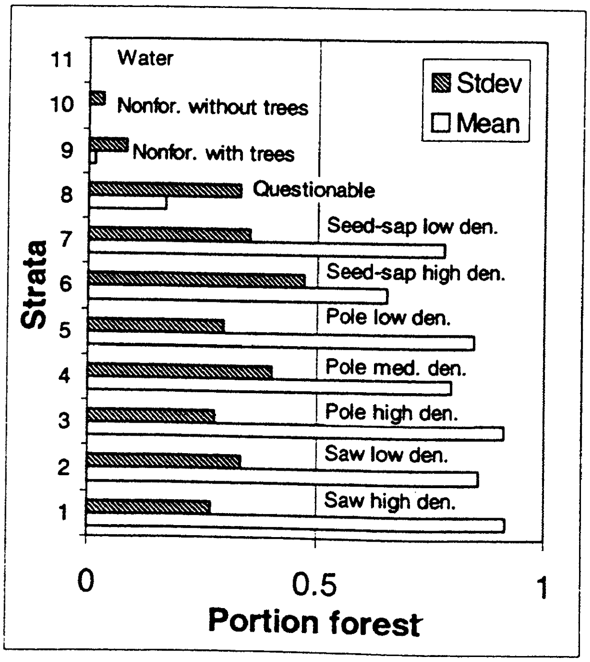

Figure 4.—*1986 forest area data by the 11 aerial photo strata used in 1986.*

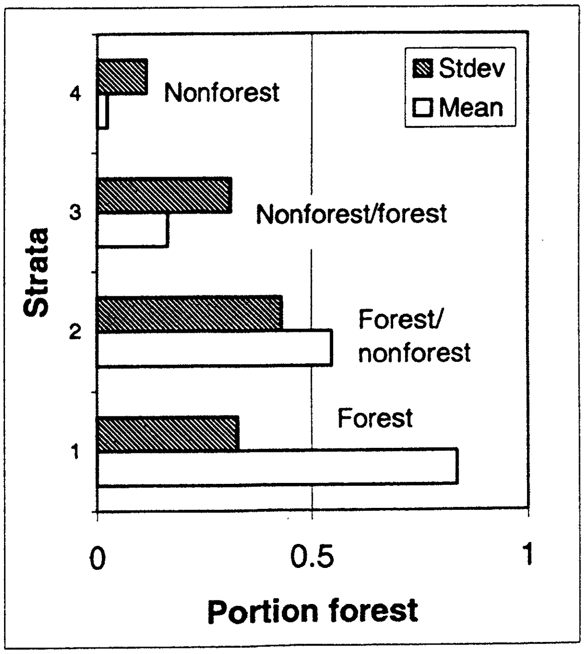

Figure 5.—*1998 forest area data by the 4 Landsat TM strata used in 1998.*

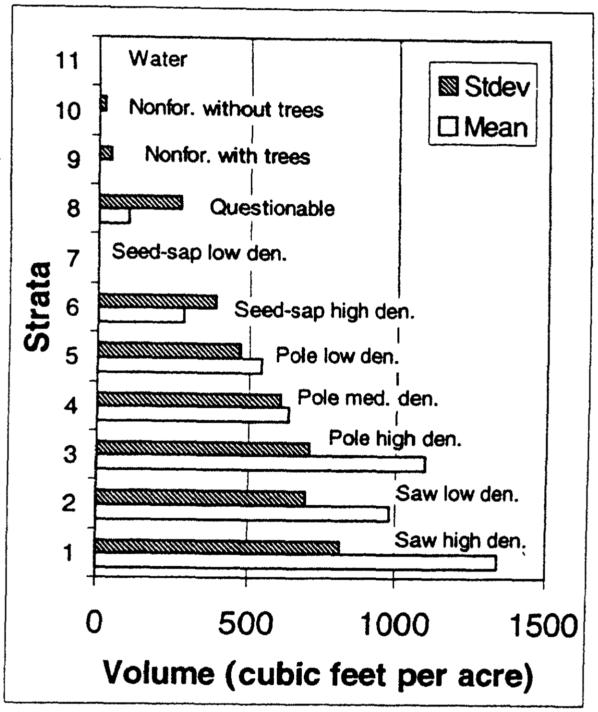

Figure 6.—*1986 growing-stock volume data by the 11 aerial photo strata used in 1986.*

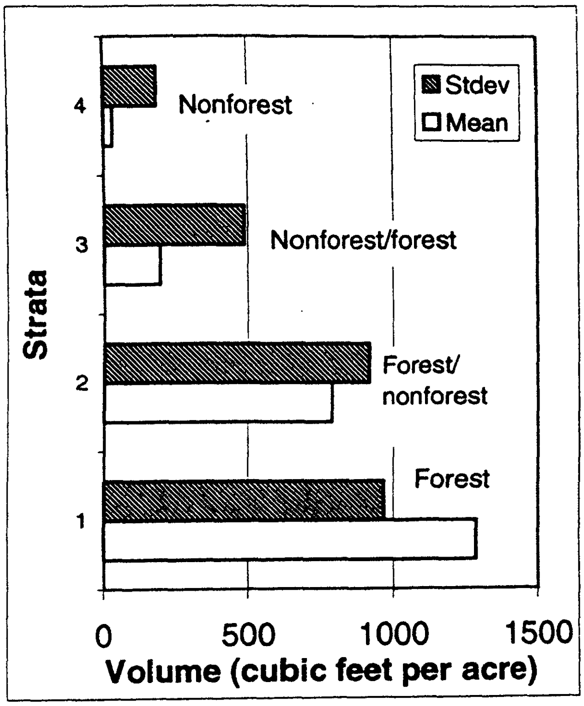

Figure 7.—*1998 growing-stock volume data by the 4 Landsat TM strata used in 1998.*

counties and the sampling errors reported are not based on assumptions that may not be valid. This level of estimation was possible because of the relatively high resolution (number of phase one sample plots per county) of the TM data compared to the photo plot sampling used in 1986.

CONCLUSIONS AND RECOMMENDATIONS

Consistency in classification across large areas is most important in an application such as this. FIA provides estimates at many levels (county, unit, state, regional, and national). A system that does a good job of classifying forest land in one part of the state but not another or classifies one forest type but not another may significantly bias estimates for some users. The approach we used here, to identify only a few strata (four) and produce estimates for relatively small areas (counties or groups of counties), was selected to reduce any inconsistencies in classification that could exist in the data due to scene differences across the state.

One major advantage with this approach to stratification is that it enabled us to conduct a stratification completely blind of the ground plot locations, removing a source of bias that could not be quantified. This can only be done if the image data are referenced and accurate plot location data are available for phase two plots. Errors in referencing and/or plot locations will be an additional source of error and contribute to misclassification. Further, if a classified image is going to be used for stratification, then the ground plot data cannot be used as an aid in the classification, such as training sets in supervised classification.

Although the TM data classified by GAP was a good source of phase one data, we need to keep looking at other sources. Since FIA is an ongoing project, new data for stratification are needed on a periodic basis, especially in areas where the forest landscape is changing. GAP does not currently have the long-term commitment that FIA needs. The classified data being produced by EPA's Landscape Characterization in the Environmental Monitoring and Assessment Program (EMAP) are one possible source of classified data that should be considered. We need to continue to search for cooperators who are interested in land cover classification at or above the state level on a continuous basis. FIA needs to continue to develop its own capabilities to classify remote sensing data. Because it is such a large effort to gather the data and do this kind of classification cooperators will always be needed in these efforts.

As inventories are repeated, the identification of changes in classification will provide additional strata and improve our estimates of change. If strata for forest to nonforest and nonforest to forest change over time can be created, then estimates of land use change over time will benefit. Other strata that help in the estimation of growth, removals, and mortality may also be possible.

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