NATIONAL LAND COVER MONITORING USING LARGE, PERMANENT PHOTO PLOTS 1/

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Abstract--A study in the State of North Carolina, U.S.A., demonstrated that large, permanent photo plots (400 hectares) can be used to monitor large regions of land by using remote sensing techniques. Estimates of area in a variety of land cover categories were made by photointerpretation of medium-scale aerial photography from a single month using 111 photo plots. Many of these area estimates compared favorably with the most recent data from the traditional forest inventory, although sampling errors of the new system are at least eight times larger due to the small sample size. The new system detected what appears to be significant conversion of harvested forestland to planted pine plantations between 1983 and 1985. An inexpensive monitoring system based on remote sensing and large photo plots, which uses a variety of aerial photography and low-cost, analog satellite imagery, might be useful for detecting rapid changes in land cover and management practices. To detect slower changes in land cover and to monitor variables impossible to measure reliably using remote sensing (e.g., wood volume and quality, tree growth, and mortality), the more precise and expensive traditional techniques must still be used.

Abstracto--Un estudio en el estado de Carolina del Norte, EUA, demostró que grandes cuadros fotográficos permanentes (400 hectáreas) pueden ser utilizados para rastrear grandes regiones de tierra por medio de técnicas de percepción remota. Se hicieron estimaciones del área en varias categorias de cobertura terrestre. Estas estimaciones se hicieron por medio de fotointerpretación de fotografías a mediana escala para un mes usando 111 cuadros fotográficos. Muchas estimaciones de área se compararon favorablemente con los datos mas recientes de inventarios forestales tradicionales. Los errores de muestreo del nuevo sistema fueron al menos diez veces mas grandes que el sistema tradicional debido a el pequeño tamaño de muestra. El nuevo sistema detectó una importante conversión de tierra forestal cosechada a plantaciones de pino entre 1983 y 1985. Un sistema de rastreo barato, basado en percepción remota y grandes cuadros fotográficos, el cual utiliza imágenes de satélite analógicas de bajo costo y una variedad de fotografías aéreas, puede ser útil para detectar rápidos cambios en la cobertura terrestre y uso de la tierra. Para detectar cambios mas lentos en la cobertura terrestre y para rastrear variables imposibles de medir adecuadamente usando percepción remota (e.g., volumen y calidad de madera, crecimiento y mortalidad de árboles), las técnicas tradicionales mas precisas y costosas deben seguir siendo utilizadas.

Introduction

Periodic, extensive inventories of land cover and forest resources for the United States have been conducted by the USDA Forest Service, Forest Inventory and Analysis (FIA) Projects since 1928 (2). Emphasis in FIA has been on thorough ground sampling of small, permanent plots (0.4 hectares) on forestlands to estimate wood volume (sampling intensity is 1 plot per 25 km^2 in North Carolina). Independent estimates of area in forest and nonforest are made by photointerpretation of a large number of small, temporary plots on available aerial photography (one 16-point cluster plot per 1.5 km^2 in North Carolina). Adjustments for interpretation error and changes since the date of aerial photography are made by ground verification of photointerpreted classifications for a 10% subsample of temporary photo plots. Area estimates are required to convert estimates of wood volume per unit area from ground plots to volume estimates for large geographic areas (e.g., 40,000 km^2). The high costs of the FIA inventory have usually resulted in an 8- to 10-year interval between inventories for any one state (median area of a state is 150,000 km^2).

Estimates of land cover are needed for a single baseline date to conduct multi-state regional analyses for national planning by the Forest Service (3). However, the traditional FIA inventory estimates for individual states vary in age from 1 to 10 years (or more) depending on the inventory cycle time. In the past, ad hoc methods had to be used to "update" older inventories to the baseline date using professional judgment. More current estimates of area and wood volumes for forestlands have been requested also by regional, state, and industrial planners. In recent years, abbreviated "mid-cycle" updates for certain states have been produced by the Forest Service in cooperation with state governments and industry in response to this demand.

A new system of permanent plots is being investigated for detecting changes in land cover over large geographic areas. To minimize cost, it relies largely on remote sensing. Although many remote sensing techniques are available,

1/ Paper presented at the Land and Resource Evaluation for National Planning in the Tropics International Conference and Workshop (Chetumal, Mexico, January 25-31, 1987).

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published reports of attempts to monitor changes in forest cover over very large regions have been few. (A review of that literature is available in Schreuder et al. (12)). With the new system, annual changes for each state would be monitored using simple photointerpretation techniques with aerial photography and analog satellite imagery. A primary motivation for investigating a new system is to provide more reliable regional land estimates for a single year, which are needed as initial conditions for forecasting models used in national planning.

The new system is intended to supplement, not replace, traditional FIA techniques. It would be directly linked to ongoing FIA state inventories and other data sources (e.g., planting and harvest drain estimates) using a Bayesian statistical estimator known as the Kalman filter (14). This filter can also incorporate information from a deterministic econometric model of land cover change (see, for example, Alig and Wyant (1)). This not only increases efficiency of the estimator, it also permits more frequent validation of the econometric model. Validation of such models is important because they are used by the Forest Service in national planning to predict the future condition of forestlands. Past validation efforts have been hindered because FIA data are only produced every 8 to 10 years for any one state, and these are the only reliable data available to both build and validate these econometric models. If successful, this combination of the proposed remote sensing system, traditional FIA data, and an econometric model would also improve the cost effectiveness and timeliness of the present FIA system, and could replace the mid-cycle updates produced in the past by FIA.

The annual rate of change in area for each land cover category detected by the new system could be used to update the most recent FIA estimates of area. Existing FIA data on wood volume per unit area could be used to update volume estimates. Errors accumulating in this procedure would be greatly reduced when each state was re-inventoried every 8 to 10 years using traditional FIA techniques.

Plot size for this new system is large (400 hectares) so that plots can be monitored using photointerpretation of satellite images, yet they are small enough so that complete stereo coverage can be obtained using conventional medium-scale photography. These plots are too large for practical measurement on the ground; rather, cover types within each plot would be monitored using only remotely sensed data.

Aerial photography has the spatial resolution needed for identifying different types of land cover and forest condition; however, this level of spatial detail might only be required every 5 to 10 years. Analog satellite photographs could be economically acquired every year, and would be adequate for photointerpreting drastic changes such as clearcutting; however, they lack the needed spatial resolution. Permanent photo plots permit both types of photography to be used together in a production system for frequent and detailed monitoring of change; the merits of one source of imagery compensate for the disadvantages of the other. Permanent photo plots are also proposed because they are generally more efficient for monitoring change (11).

The proposed system might be well suited to the tropics or in situations where technical capabilities are limited. The use of plots, rather than complete photo coverage of all lands, would reduce cost of aerial photography or other airborne data collection (e.g., radar). Medium-scale aerial photography requires less sophisticated aircraft than small-scale photography; the latter is often used for complete mapping of large regions. Photointerpretation of satellite and aerial photography requires less technical and financial resources than computer interpretation of digital satellite data. (However, large photo plots would be well suited as training or labeling sites in a digital classification, e.g., for vegetation maps every 10 years.) Photo plots would be much less expense to monitor compared to ground plots, especially in remote areas.

The use of satellite photographs, different dates of aerial photography for permanent plots, and the Kalman filter have not yet been evaluated for the North Carolina study area. Rather, this paper describes preliminary results for area estimates of land cover using only 1:12,000 scale color infrared transparencies from a single month (November, 1985) of 111 photo plots distributed over the entire State of North Carolina (1 plot per 1250 km^2). Comparisons are made to area estimates from the FIA inventory of North Carolina made in late 1982 and early 1983.

Study Area

The State of North Carolina (136,000 km^2) was selected as a study area, although the methods examined in this pilot study are applicable to larger Regional and National inventories of land cover. North Carolina was chosen because it has a diversity of physiographic regions, representing many land cover conditions found in the eastern and southern United States. Elevations range from sea level to over 2,000 meters. Potential climax vegetation for most of the entire state is Appalachian oak forest or oak-hickory-pine forest (8). Pine forests represent earlier successional stages. Mountainous areas include forest species commonly found in more northern latitudes; the flat coastal plain includes sand ridges, bays, pocosins, and maritime forest. Relative to other temporate forests, vegetation in North Carolina is very diverse.

Forest industry has invested heavily in North Carolina, although the majority of forested land is presently owned by nonindustrial private landholders. This evokes a broad range of forest management practices. Government tax and cost-sharing programs have encouraged nonindustrial private landowners to plant pine trees, which control erosion, supply other public benefits, and provide a future source of valuable timber (5, 10). The rate of forest planting on nonindustrial private forestlands in the southern United States has increased fourfold between 1975 and 1985 (7). Much of the present forestland had been agricultural lands 50 to 100 years ago.

Urbanization is rapidly taking place in localized areas of North Carolina. Increased land values and shifts in ownership of forestland from farmers to other nonindustrial private landholders occur in much larger areas surrounding these growing urban centers. Changes in ownership and land values often cause changes in land use and forest management practices. This pattern is occurring in many other parts of the United States.

Methods

Stereoscopic aerial photo triplets, covering quad centers for every other row of USGS 7.5-minute topographic quadrangles, were acquired by the Forest Service in seven flying days between October 25 and November 9, 1985. This produced 405 photo plots distributed over the entire State of North Carolina at a cost of $26,000. Use of a Zeiss 3/ mapping camera with a 210-mm focal length lens yielded 1:12,000-scale coverage on 9x9-inch color infrared transparencies (Aerochrome 2443). This scale ensures complete stereo coverage of the 400-hectare photo plot. The Loran C navigation system was used to find the approximate plot center. Plot center was precisely defined by pin-pricking the center of the middle photo in the triplet set. This center was transferred visually onto the 1:24,000-scale, 7.5-minute topographic quadrangles. Elevation data from the map and flight altitude information from the data bank on the aerial photo containing the plot center were used to determine an average scale for the photo plot, and this scale was used to draw the circular photo plot. A subset of 111 plots was chosen for this study in a systematic fashion in order to reduce cost of this initial evaluation.

Polygons (e.g., tree stands) of relatively homogenous land cover (table 1) were delineated in stereo to a minimum size of 0.4 hectares on acetate sleeves for each photo plot. Most polygons range in size from 2 to 5 hectares, and most photo plots contain between 100 to 200 polygons. One photointerpreter needed 6 months to delineate all 111 photo plots. Computing the area of each polygon with a digital planimeter took an additional 4 months.

Each photo plot was used to estimate the proportion of total land area in each cover type. These were expanded to state and sub-state estimates and compared with estimates based on traditional FIA inventory techniques. All plots were assigned to one of four large, contiguous physiographic regions (strata): mountains, piedmont, and northern and southern coastal plains. Estimates of area and 95% confidence intervals for the entire state were made using stratified random sampling estimation (4). The

Table 1.--Level I and II classification categories for photointerpretation of forest cover condition.

LEVEL I		LEVEL II				
Code	Cover condition[a]	Stand origin	Stand size	Stand type	Stand closure[b,c]	Site potential[b]
1	Barrenland[d]	Plantation	Sawtimber	Pure pine	Closed canopy	Productive
2	Cropland	Natural	Poletimber	Mixed pine	Open canopy	Nonproductive
3	Grassland		Sapling-seedling	Oak-pine		Reserved
4	Shrubland[d]		Nonstocked[e]	Bottomland hardwood		
5	Urban area[d]			Upland hardwood		
6	Water area[d]					
7	Forestland					

[a]There is also a code 8 representing polygons obscured from aerial view by clouds.

[b]Results for this category are not discussed in this paper because there are no published FIA estimates that can be used as reference data.

[c]For stands with an open overstory, a second interpretation is made for closure of the understory.

[d]Combined into a single category so that they can be compared to published FIA estimates (i.e., reference data).

[e]This category contains very little area, and results for it are not discussed.

3/ The use of trade and company names is for the benefit of the reader, such use does not constitute an official endoresement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

confidence intervals include only sampling error; other sources of error are assumed negligible. The Crámer-von Mises test (9) was used to test for the normal distribution (needed for valid confidence intervals) of percent forest among all 100 counties in North Carolina; the normality hypothesis was not rejected at the 0.05 level.

With the traditional FIA system (13), initial estimates of forest versus nonforest area were made in 1983 by photointerpreting 91,765 16-point sample clusters. Field crews on the ground checked 8,123 of these small, temporary photo plots, and these data were used to adjust for consistent bias in photointerpretation or changes from date of photo acquisition. Classifications to more detailed categories (table 1) were made using an independent set of 5,355 permanent ground sample plots. Data from all of these FIA plots were expanded to produce regional and statewide estimates of forest cover condition. These FIA data served as the reference to which area estimates from the 111 photo plots were compared. Details of the traditional FIA procedures can be found in Frayer and Beltz (6).

Results and Discussion

Figure 1 compares extensive estimates derived from the 1983 FIA survey and from the 1985 large photo plots. There are three likely sources of differences between the FIA and photo plot estimates: sampling error, photointerpretation error, and changes in land cover between 1983 and 1985. It is also possible that there is an unknown bias or error source in one or both sampling designs.

The photo plot estimates of forestland (fig. 1) are higher than the FIA estimates by 3,200 km^2. However, the 95% confidence interval for the photo plot estimate does contain the FIA estimate. Therefore, the difference between the two estimates of forestland can be explained by sampling error. The same situation exists for the "other" Level I categories in figure 1 (i.e., barrenland, shrubland, urban area, and water); the 800-km^2 difference can be explained by sampling error. However, the 95% confidence intervals for photo plot estimates of cropland and grassland do not contain the FIA estimates (fig. 1); sampling error cannot be readily used to explain all of these differences. When the 1985 photography was taken (late autumn), fallow agricultural fields and those types of cropland not obviously row crops can resemble grassland. Conversion of agricultural lands to grasslands between 1983 and 1985 is another possible explanation. When cropland and grassland categories are combined into a single cover type, then the 95% confidence interval for the photo plot estimate contains the corresponding FIA estimate (fig. 1); this difference can be explained by sampling error.

The photoplot and FIA estimates for area of naturally regenerated forestland are almost identical (fig. 1); however, the photo plot estimate of planted forestland is 6,800 km^2 larger than the FIA estimate. This latter difference is probably not entirely caused by sampling error because the FIA estimate is not within the 95% confidence interval of the photo plot estimate. We believe some, but not all, of the difference is caused by the planting of pine plantations between 1983 and 1985. In support of this belief, a preliminary study of photointerpretation accuracy suggests that this difference is probably not caused by interpretation error, and there are no other known sources of bias. Therefore, some of the difference might be caused by changes in the landscape, with sampling error causing the remainder of the difference.

The second category of forestland is timber size class. Sapling-seedling stands are defined as stands dominated by trees with a diameter at breast height (d.b.h.) under 12.5 cm. Sawtimber stands are dominated by hardwood trees with d.b.h. exceeding 27.5 cm or softwood trees in excess of 22.5 cm d.b.h. Poletimber stands fall between these two extremes. Stand height and crown diameter are used to photointerpret timber size class. The differences between the 1983 FIA and 1985 photo plot estimates of forested area in sawtimber and poletimber size classes are likely caused by sampling error (see 95% confidence intervals in fig. 1). However, the photo plot estimates of sapling-seedling area is 4,700 km^2 larger than the FIA estimates. This difference is probably not caused entirely by sampling error. Preliminary assessments of photointerpretation accuracy suggest that this difference in sapling-seedling estimates is not caused by consistent misinterpretation, and no other types of bias are suspected. Therefore, some of this difference might be caused by regeneration of forestlands between 1983 and 1985.

Forest type is the last category of forestlands that can be evaluated using published FIA estimates. There is close agreement between the FIA and photo plot estimates of area in the bottomland hardwood type (fig. 1). However, the 1985 photo plot estimates of area in the upland hardwood type is significantly less than the 1983 FIA estimate by 9,500 km^2. Conversely, the photo plot estimates were significantly larger than the FIA estimates for pine (11,000 km^2) and oak-pine (4,500 km^2). Again, preliminary analyses of photointerpretation accuracy suggest that these differences are caused more by sampling error and changes in forest cover between 1983 to 1985 than by photointerpretation error.

The final comparison is for forestland area by each of the four physiographic regions in North Carolina (fig. 1). There were 31 photo plots in the southern coastal plain, 24 in the northern coastal plain, 35 in the piedmont, and 21 in the mountains. Confidence intervals for the corresponding FIA estimates are also given in figure 1. These latter estimates were made using over 91,000 plots (13). Compared to these FIA estimates, the confidence intervals for the photo plot estimates of area in forestland are 8 times larger in the piedmont, 10 times larger in the mountains and southern coastal plain, and 12 times larger in the northern coastal plain.

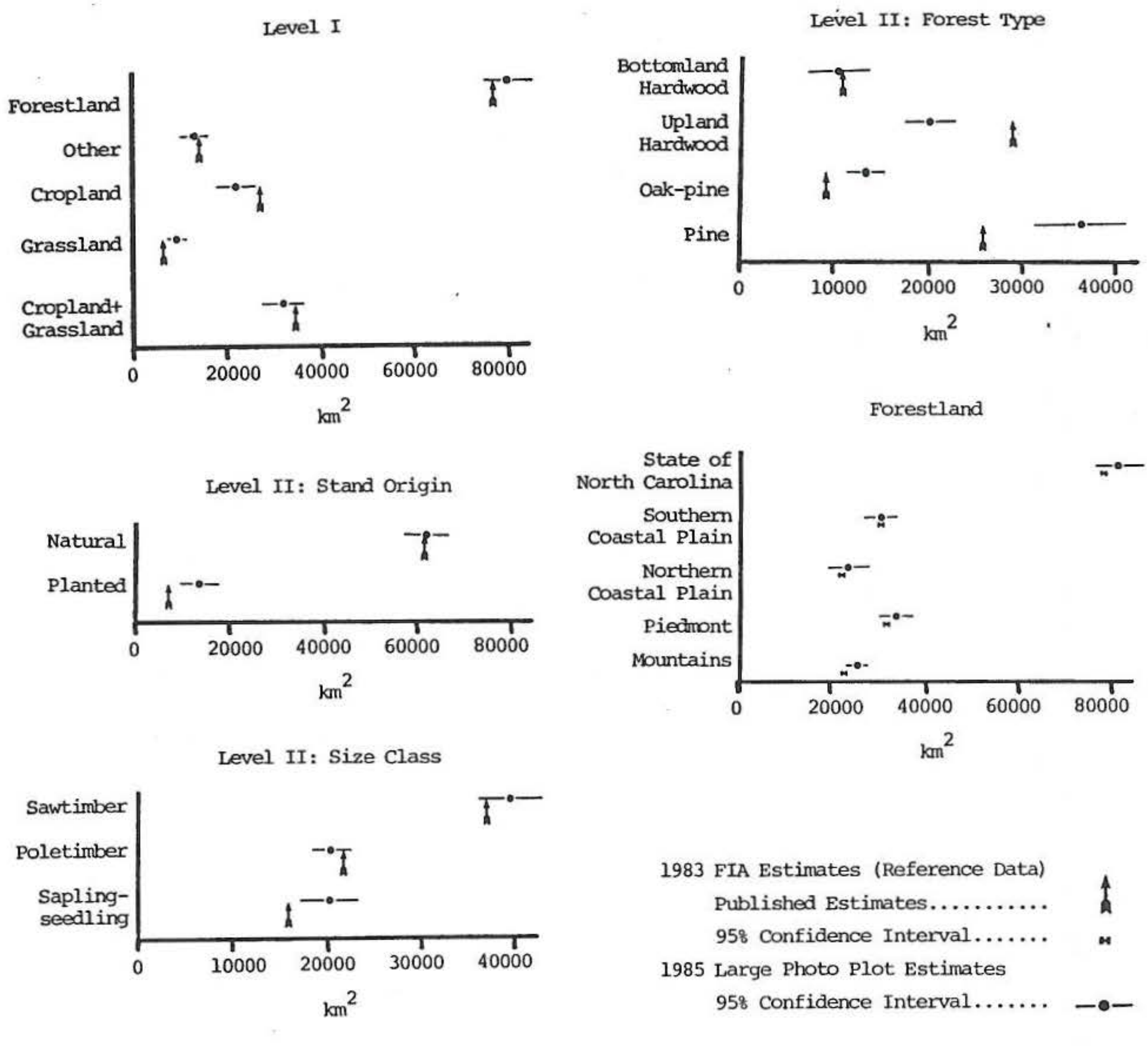

Figure 1. Comparison of land cover area estimates between 1983 FIA data (used as reference) and 1985 photo plot estimates

However, the FIA estimates for Level II classes (table 1) require data from an additional 5,355 ground plots.

The photointerpreter, who mapped the vegetation on all 111 400-hectare photo plots, noticed a large number of young planted pine stands. Many appeared to be sawtimber before planting (based on surrounding vegetation and residual standing trees). This observation is consistent with all of those differences (between the FIA and photo plot estimates) that were probably not caused by sampling error alone. Compared to FIA estimates from 1983, the 1985 photo plot estimate of planted forestland is high by 6,800 km^2; the sapling-seedling estimate is high by 4,700 km^2; pine and oak-pine estimates are high by 15,500 km^2; while the estimate for upland hardwoods is low by 9,500 km^2. Preliminary assessments of photointerpretation error, using 0.4-hectare ground plots, suggest that most of these differences are not caused by misinterpretations with consistent biases. These differences might be caused by an unknown source of bias in one or both sampling designs; however, extreme care was taken to avoid such problems in both systems, and this is an unlikely explanation. Some, but probably not all, of these differences were caused by sampling errors. The confidence intervals are calculated considering only sampling error; measurement error is assumed negligible. If this assumption is grossly incorrect, then the confidence intervals are too small, and differences between the two inventories which appear significant might not be truly significant.

An unknown portion of these differences could be caused by changes in forest cover between 1983 and 1985. According to the best available independent data 4/, 1000 km^2 of pine plantations were established in North Carolina between the two inventories. (This is based on historical trends between 1974 and 1983.) Therefore, the new photo plot system has probably detected an actual change in land cover, but much of the apparent change is likely sampling error.

The confidence intervals for photo plot estimates are generally ten times greater than those for traditional FIA estimates; however, the photo plot estimates for forest cover area are much less expensive and can be repeated more frequently. The traditional FIA techniques are more precise and produce much more information than area estimates (e.g., estimates of existing wood volume, tree diameter distributions and tree counts, and annual growth and mortality rates). Each sampling approach could complement the other in order to produce more timely and adequately detailed information for National Planning in the United States.

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