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Comparison of AVHRR Classification and Aerial Photography Interpretation for Estimation of Forest Area

Keith B. Lannom, David L. Evans, and Zhiliang Zhu

SUMMARY

The USDA Forest Service Southern Forest Experiment Station's Forest Inventory and Analysis (SO-FIA) unit uses a dot count method to estimate the percentage of forest area in counties or parishes from aerial photographs. Ground verification is used to adjust the photo interpretation estimates. This verification is expensive and time consuming. The research reported here was designed to determine whether Advanced Very High Resolution Radiometer (AVHRR) data could be used to estimate forest area at the county or parish level. For this study, AVHRR data for three parishes in central Louisiana were extracted from a 1991 AVHRR forest type map of the United States. Photo interpretation data were obtained from a digital mosaic of aerial photography of the parishes. Forest area estimates obtained by means of photo interpretation did not differ significantly from those obtained by analyzing AVHRR data. Thus, forest area estimation based on AVHRR data could replace forest area estimation based on the dot count method. Extension of testing to multiple, randomly selected counties or to individual aerial photographs is recommended.

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INTRODUCTION

The USDA Forest Service, Southern Forest Experiment Station's Forest Inventory and Analysis (SO-FIA) unit inventories forest resources in Alabama, Arkansas, Louisiana, Mississippi, Oklahoma, Tennessee, Texas, and Puerto Rico continuously on a rotation cycle of approximately 8 years. Data collected from sample plots on the ground are compiled into extensive databases and are currently the only source of detailed regional information on the Midsouth's forest resources (Rudis 1989).

The SO-FIA collects forest inventory data in permanent plots in a 3- by 3-mile grid and in intensification plots in a 6- by 6-mile grid. Data on tree species, tree volumes, occurrence of human activities, proximity to water, and evidence of forest management practices are gathered on all forested permanent plots. The only information gathered on nonforested permanent plots is the land use (agriculture, pasture, water, urban, etc.). All plots are visited by field crews during each inventory cycle. Intensification plots increase the field sampling intensity, thereby improving the aerial photo estimates of forest area at the county or parish level. Intensification plots are determined to be forested or nonforested and provide no other information. Percentage of forest cover (as a proportion of total land area) is determined by classifying points (dot counting) on aerial photographs on a forest or nonforest basis (Kelly 1990). Data from the permanent and intensification field plots are used to adjust the forest area estimates derived from aerial photo dot counts to the date of each survey and to correct any interpretation errors.

The SO-FIA is evaluating modeling techniques for predicting changes in forest resources for periods between survey cycles. An important element of update modeling is the estimation of forest cover. Management activity by forest industry changes the forest cover of the Midsouth constantly. Satellite imagery will provide more timely information concerning these resource issues.

Scientists at SO-FIA have developed techniques for mapping forest cover from satellite data. An important source of information is National Oceanic and Atmospheric Administration weather satellite data obtained from the Advanced Very High Resolution Radiometer (AVHRR). Local Area Coverage (LAC) data provide information on the spectral reflectance and thermal emittance of the Earth's surface in 1-square-kilometer picture elements (pixels). The AVHRR data can be collected daily and are useful for vegetation monitoring and mapping of large areas.

Early AVHRR research at SO-FIA focused mainly on uses of single-date imagery in the making of forest assessments (Teuber 1990, Zhu 1992). In subsequent research, single-date classifications were compared to reveal changes in distributions of forest cover (Zhu 1992). The availability of multidate composites of radiometry data for large areas (Eidenshink and others 1991) facilitated research in more detailed forest mapping and monitoring. Recently, studies such as those by Evans and others (1992), Iverson and others (1989), and Zhu and Evans (1992) have demonstrated that AVHRR analysis can provide detailed information about forest lands.

The research reported here was conducted to determine whether AVHRR classifications could be used to estimate forest area at the county or parish level. Iverson and others (1989) found a high correlation between AVHRR-derived and Forest Service county-level estimates of percentage of forest cover. If forest area estimates based on AVHRR classification are not significantly different from those based on photo interpretation, then AVHRR classifications might be a replacement for the present method of estimating forest area. Replacing dot count estimates with AVHRR forest area estimates would provide two benefits. First, changes in forest area between field cycles could be monitored without extensive field verification of photo interpretations. Second, field visits to intensification plots used to calibrate dot count estimates of forest area would no longer be necessary.

Keith B. Lannom is a research forester at the Forest Sciences Laboratory, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, Starkville, MS 39759; David L. Evans is a supervisory research forester at the Forest Sciences Laboratory, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, Starkville, MS 39759; and Zhiliang Zhu is a senior scientist with Hughes STX Corporation, EROS Data Center, Sioux Falls, SD 57198.

METHODS

Study Area

The study area is Grant, La Salle, and Natchitoches Parishes in central Louisiana (fig. 1) and is approximately 661,500 hectares in size (table 1). The Red River runs southeast across Natchitoches Parish and also forms the border between Natchitoches and Grant Parishes. There are large agricultural areas on both sides of the Red River. Most of the area's forest cover is loblolly–shortleaf pine, but various hardwood species occur in the bottomlands. A recent SO-FIA survey (Rosson and others 1991) found that 44.1 percent of the 503,000 hectares of forest land in the three parishes is in pine. The rest of the forest cover consists of oak–pine, oak–hickory, oak–gum–cypress, and elm–ash–cottonwood types.

Commercial timber harvesting is prevalent throughout the area. The typical harvesting operation involves removing all the merchantable trees for utilization. Part of the Kisatchie National Forest is within Grant and Natchitoches Parishes. Small clearings occupied by oil and gas wells are common in northwestern and southeastern La Salle Parish. The city of Natchitoches is the only large urban locality in the three-parish site. The rest of the study area is mainly rural with scattered small towns.

Definition of Forest Area

For consistency, the aerial photography used to provide photo interpretation data was interpreted in accordance with the same guidelines SO-FIA personnel follow when performing dot counts on aerial photos. The SO-FIA definition of forest land is:

> Land at least 10-percent stocked by forest trees of any size, or formerly having such tree cover, and not currently developed for nonforest use. The minimum area for classification of forest land, or subclass of forest land, is 0.4 hectares (1 acre). Roadside, streamside, and shelterbelt strips of timber must have a width of at least 36.6 meters (120 feet) to qualify as forest land. Unimproved roads and trails, streams, and clearings in forest areas shall be classified as forest if they are less than 36.6 meters in width (USDA–FS 1991).

According to this definition, any regeneration area regardless of tree age and tree size is considered to be forest land. Nonforest land is:

> Land that has never supported forests and lands formerly forested where use for timber management is precluded by development for other uses. Includes areas used for crops, improved pasture, residential areas, city parks, improved roads of any width and adjoining clearings, power line clearings of any width and adjoining clearings (USDA–FS 1991).

Table 1.— *Area by parish and land class (Rosson and others 1991)*

Parish	All land[†]	Forest land*			
		Total	Timberland[‡]	Reserved timberland[§]	Nonforest
	Thousand hectares				
Grant	169.0	134.9	134.9	0.0	34.1
La Salle	165.2	140.7	140.7	0.0	24.5
Natchitoches	327.3	227.4	223.8	3.6	99.9

*Land at least 10-percent stocked by forest trees of any size, or formerly having such tree cover, and not currently developed for nonforest use.

[†]From U.S. Department of Commerce, Bureau of the Census.

[‡]Forest land that is producing or capable of producing at least 1.4 m^3 of industrial wood per hectare per year.

[§]Forest land sufficiently productive to qualify as commercial forest land, but withdrawn from timber utilization through statute or administrative designation.

All areas of water, including rivers, other streams, and ponds, were classified as nonforest.

Data Sources

Three data sources were used for this research: photo interpretation data, sample point interpretations (dot counts), and AVHRR classifications. The photo interpretation data were used to demonstrate the spatial accuracy of the AVHRR data. Currently, SO-FIA uses the dot count data for forest area estimation. The photo interpretation and dot count estimates were derived from the same photos and same classification guidelines. However, the photo interpretation estimates are based on total enumeration, whereas the dot count estimates are based on a sampling scheme.

Photo Interpretation Data.—The aerial photo interpretation served two purposes for this study. First, it provided a benchmark estimate of percentage of forest land within each parish. Second, it served as reference data for the comparison to the AVHRR classification.

The photo interpretation data used in the study were produced by interactive digital interpretation of a mosaic of video-scanned aerial photos. A video camera system captured National Aerial Photography Program (NAPP) 1:40,000-scale prints taken in early 1990, digitally, as raster files. All images covering a parish were rectified to 1:24,000 quad sheets and joined together to form a single digital image of each parish (fig. 2). Digital Line Graph (DLG) 1:2,000,000 data from the U.S. Geological Survey were utilized to exclude image data outside of the parish borders.

Forest land, forest regeneration areas, urban areas with tree cover (e.g., parks or residential areas),

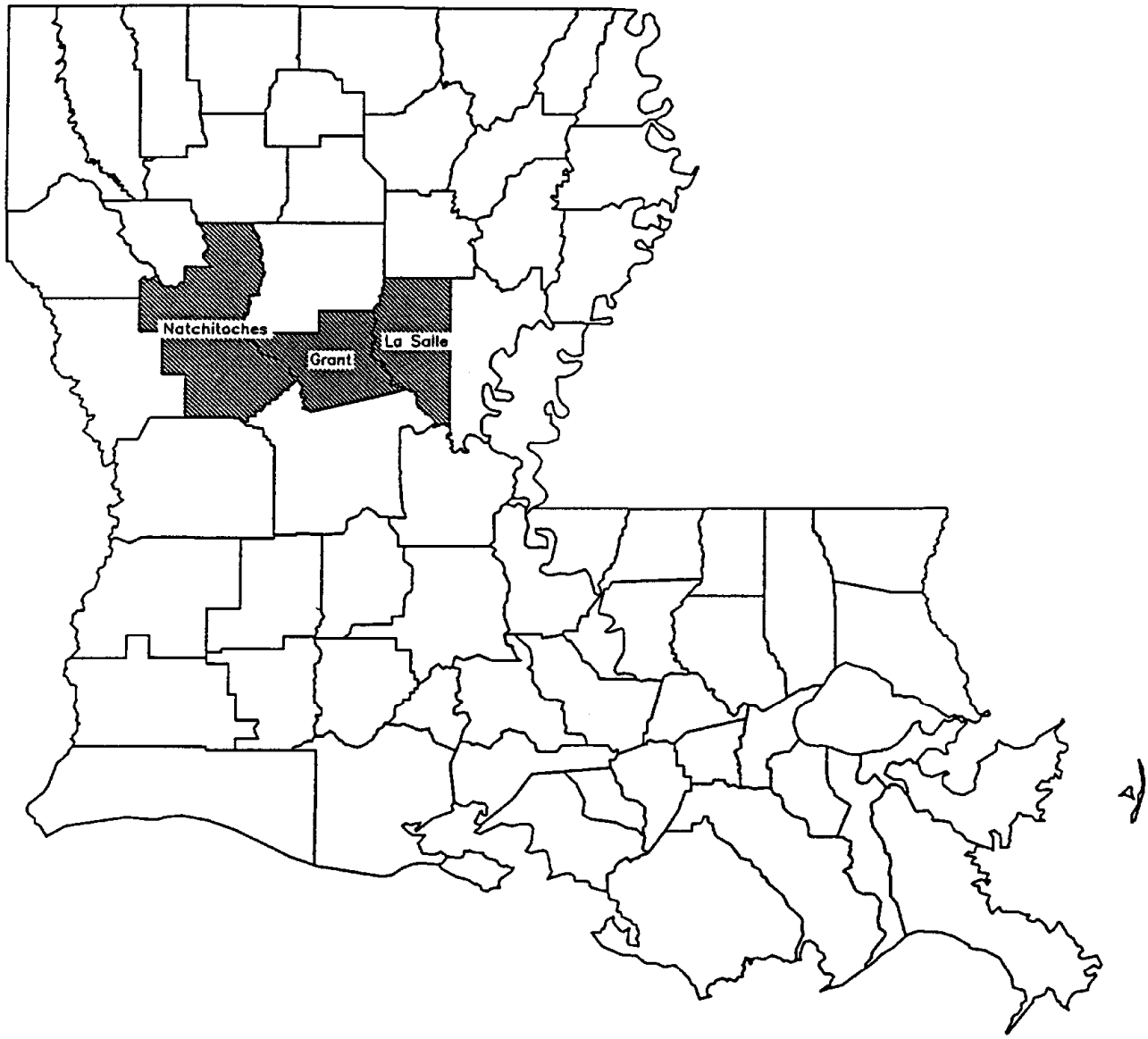

Figure 1.— *Location of study area in central Louisiana.*

nonforest land, and water were delineated by digitizing boundaries directly onto the mosaics displayed on a computer monitor. The interpretation polygons were used to create a grid format file. The interpretation classes were combined into either forest or nonforest categories. Forest regeneration areas were categorized as forest, and urban areas with tree cover were categorized as nonforest areas.

Sample Point Interpretations (Dot Counts).— The locations of all SO-FIA permanent forest inventory and intensification plots were marked on the aerial photos. A photo interpreter decided whether each plot was forested or not, and this decision was validated by field personnel as they visited each plot. The numbers of correct and incorrect interpretations were used to adjust the percentage of forest area calculations.

A mylar overlay with a five-by-five matrix of dots was used to sample the area around each permanent plot marked on the photos (fig. 3). Locations under each dot were interpreted as forest or nonforest. The proportion of dots falling on forest land was used to estimate percentage of forest area at the parish level. Information obtained in validation visits to field plots was used to derive correction factors employed to update the area estimates to the date of the current survey and to correct photo interpretation errors.

AVHRR Data.—The AVHRR data were extracted from land classifications used to create the 1993 Resource Planning Act (RPA) Forest Type Group map. These classifications were based on nine biweekly composites obtained between March 1 and November 21, 1991. For each 2-week period, five channels of AVHRR

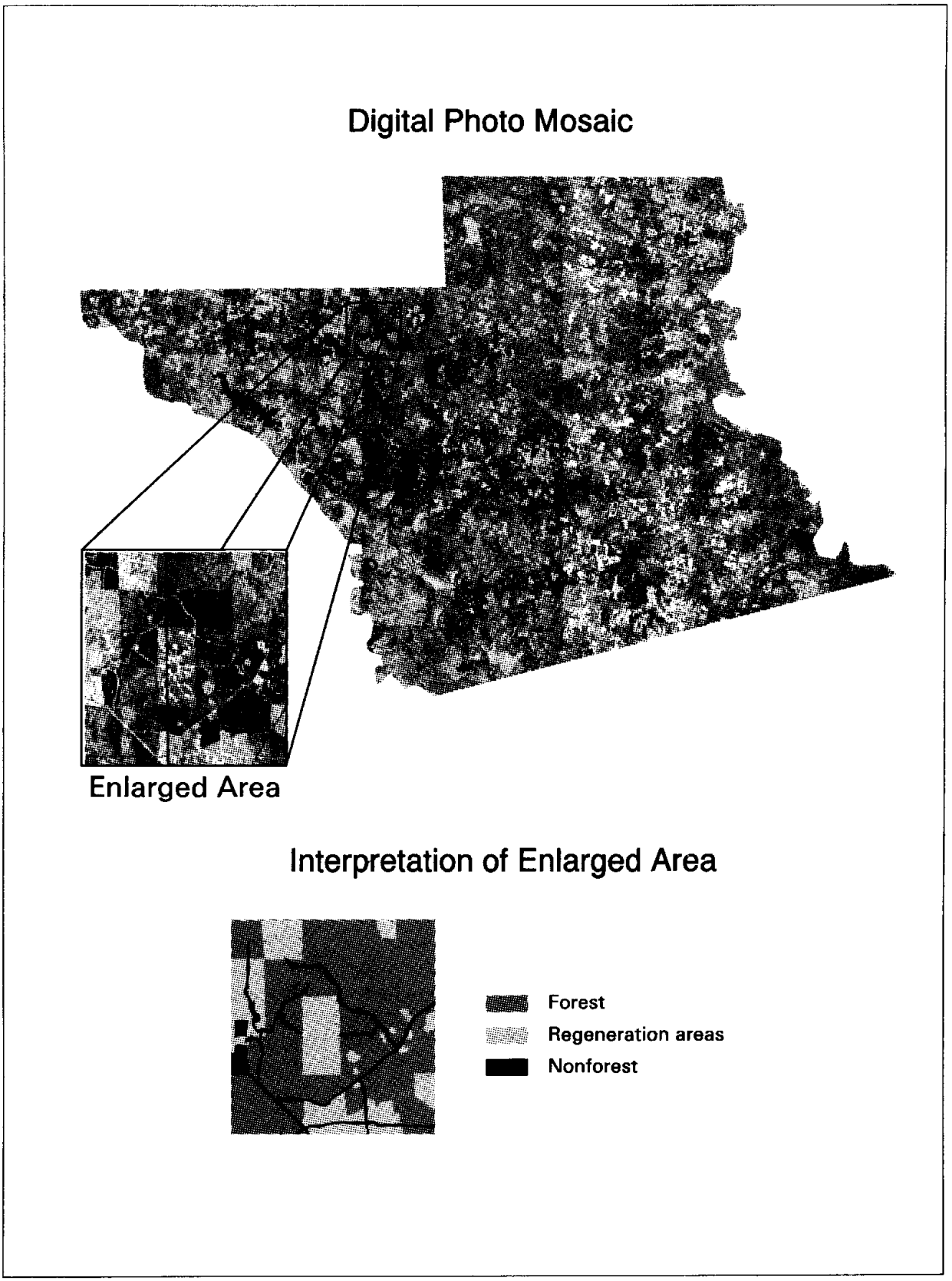

Figure 2.— *Digital photo mosaic, enlarged area, and example interpretation for Grant Parish.*

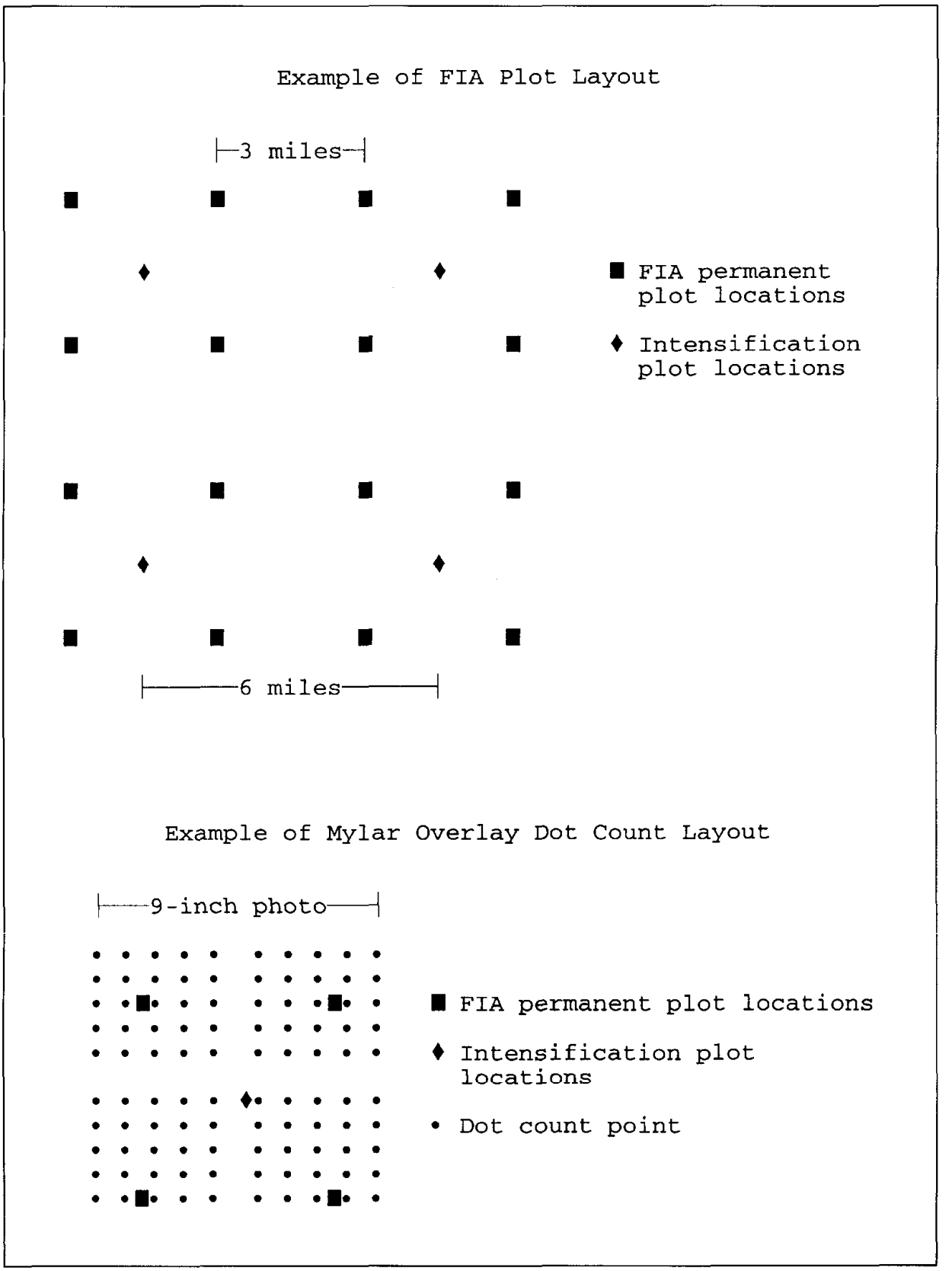

Figure 3.— *Schematic figure of FIA permanent and intensification plot locations and the mylar overlay used to sample the forest area around the permanent plots.*

data were entered: the visible, near-infrared, mid-infrared, and thermal channels, and a Normalized Difference Vegetation Index (NDVI) channel. The lower 48 States were stratified into 15 physiographic regions based upon ecoregions, land surface forms, soils, potential vegetation, and land physiography (Zhu 1994). Percentage of forest cover of each physiographic region was modeled using a process adapted from Iverson and others (1989). Regression procedures were used to predict percentage of forest cover within the AVHRR pixels. Results of this modeling were used to identify forest land for further spectral classification. Spectral classifications of forest type groups in each region were performed on areas with more than 25 percent forest cover. The spectral channels used for classification were those that had the most significant loadings in the regression models. Percentage of forest cover data were used as an ancillary data layer in the RPA forest type group classification.

The forest type groups were classified by means of an unsupervised statistical clustering procedure performed on the AVHRR biweekly composite data sets (Zhu and Evans 1992). Twenty-three forest type groups were identified by the classification. Before the RPA map was published, it was reviewed by other Forest Service FIA units and various other organizations. The AVHRR classification procedure identified four forest type groups in the Louisiana study area: longleaf–slash pine, loblolly–shortleaf pine, oak–hickory, and oak–gum–cypress.

The 1:2,000,000 DLG files of the parish boundaries were used to extract the AVHRR classifications that matched the photo interpretation data. The classifications were recoded to forest and nonforest classes.

Classification Comparisons

Two types of comparisons were used to evaluate the utility of AVHRR data to estimate forest area at the parish level. The first was a test of site-specific (pixel-to-pixel) agreement between the AVHRR classifications and the photo interpretation data. To allow this direct comparison, the photo interpretation data were resampled using a nearest neighbor technique to match the pixel size of the AVHRR data. The site-specific agreement comparisons were used to judge the integrity of the AVHRR classifications. The results were used to calculate an overall agreement of AVHRR classifications to the photo interpretations. Because it cannot be assumed that the photo interpretations were 100-percent correct, the term "percentage of agreement," rather than the term "percentage of accuracy," is used here.

Congalton (1991) recommended reporting classification accuracy (agreement in this case) in the form of an error matrix. Overall, producer's and user's percentage of agreements were calculated for the comparisons. Producer's agreement is a measure of omission error and is the number of correct samples divided by the total number of reference (ground) samples for a category (Story and Congalton 1986). User's agreement, or commission error, is the number of correct samples in a category divided by the total number of samples in that category as identified from the map (Story and Congalton 1986).

Another measure of the site-specific agreement, the KHAT statistic, was computed by means of a Kappa analysis. Congalton (1991) and Rosenfield and Fitzpatrick-Lins (1986) review the Kappa analysis procedure. The KHAT statistic takes into account the major diagonal and off-diagonal elements of the error matrix. Including the off-diagonal elements incorporates the overall, producer's, and user's agreement measures into a single estimate of agreement.

The second method of evaluation employed normal tests for differences between proportions. These were used to determine whether there were significant differences among estimates of forest area by the dot count method, the photo interpretation method, and the AVHRR classification method (Fleiss 1981). The following equation was used to compare the percentage of forest area estimates:

$$z = \frac{|(p_1 - p_2| - \frac{1}{2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}{\sqrt{(\bar{p})(\bar{q})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

where p_1 (p_2) was the proportion estimated from method 1 (2) and n_1 (n_2) was the total sample size used in estimation by method 1 (2). The Z statistic was a test for equality of two proportions. Values of the other variables in the equation were solved for by:

$$\bar{p} = \frac{(p_1)(n_1) + (p_2)(n_2)}{n_1 + n_2}$$

and

$$\bar{q} = 1 - \bar{p}.$$

RESULTS

Site-Specific Test

The measures of agreement were calculated from data reported in the error matrices (table 2). The overall agreement percentages for the parishes indicate that the AVHRR classification method was fairly successful in separating forest land from nonforest land (table 3). The data for this table were derived by pixel-by-pixel cross-comparisons between the input

Table 2.— *Error matrices for the comparison of the photo interpretation data with the Advanced Very High Resolution Radiometer (AVHRR) data*

Parish AVHRR class	Photo interpretation class	
	Forest	Nonforest
Grant		
Forest	1, 264	152
Nonforest	140	161
La Salle		
Forest	1, 301	146
Nonforest	124	141
Natchitoches		
Forest	1, 963	251
Nonforest	195	898

data sets. Both the producer's and user's agreement measures for the nonforest category for Grant and La Salle are lower than the same measures for Natchitoches Parish (table 3), but it was expected that inclusion of the off-diagonal elements of the error matrix in the calculation of the KHAT statistic would produce this result. The overall agreement percentage and the KHAT statistic were highest for Natchitoches Parish (table 3).

The physical size and spatial distribution of nonforest areas in each parish influenced the measures of agreement. Most nonforest areas in Grant and La Salle Parishes were small and discontinuous, whereas Natchitoches Parish had many large, unbroken agricultural fields. The low resolution of the AVHRR data hindered identification of nonforest areas in Grant and La Salle Parishes, and thus reduced the measures of agreement for these two parishes.

Table 3.— *Percentage of overall, producer's, and user's agreement and KHAT statistic (estimate of agreement from Kappa analysis) for comparisons of the Advanced Very High Resolution Radiometer (AVHRR) classification to the photo interpretation*

Parish	Agreement			KHAT statistic
	Overall	Producer's	User's	
	Percent			
Grant	83.0			42.1
Forest		90.0	89.3	
Nonforest		51.4	53.5	
La Salle	84.2			41.7
Forest		91.3	89.9	
Nonforest		49.1	53.2	
Natchitoches	86.5			69.9
Forest		91.0	88.7	
Nonforest		78.2	82.8	

Forest regeneration areas of any age or tree size were included in the forest category in the photo interpretation data. Young regeneration areas are spectrally similar to some agricultural fields because both have little vegetative cover and large proportions of bare soil. It is likely that some areas in early stages of forest regeneration were misidentified as nonforested areas during the classification of AVHRR data. This would have reduced agreement between the AVHRR classifications and the photo interpretations. Because the AVHRR classification method did not separate forest areas by age class, the extent of this problem could not be determined.

Forest Percentage Estimates.—Listed in table 4 are the estimates of forest percentage for each parish by data source.

Table 4.— *Estimates of percentage of forest at the parish level and confidence intervals by data source*

Parish	Photo interpretation	Dot count	AVHRR classification
	Percent		
Grant	81.8 ± 0	78.4 ± 1.5*	82.5 ± 0
La Salle	83.2 ± 0	82.0 ± 2.1	84.5 ± 0
Natchitoches	65.3 ± 0	67.6 ± 1.0	66.9 ± 0

*Confidence intervals for the dot count estimates are from Rosson and others (1991).

Normal Tests Between Two Proportions.—The normal test between two proportions indicated that there were no significant differences (at the 95-percent confidence level) between forest area estimates obtained by photo interpretation and forest area estimates obtained by the AVHRR classification method for all three parishes. Significant differences were detected between the photo interpretation and dot count estimates for Grant and Natchitoches Parishes. Because the photo interpretation data are total enumerations, forest area estimates based on them are probably as accurate as or more accurate than estimates based on the dot counts. However, the current dot count method utilizes field validation visits to update the forest area estimate to the date of the field work. These estimate adjustments could have caused the photo interpretation and dot count estimates to be significantly different in areas where the forest cover was altered by harvesting operations. The AVHRR and dot count estimates did not differ significantly for La Salle and Natchitoches Parishes.

SUMMARY AND CONCLUSIONS

The present method of estimating forest area by the dot count method is expensive and time consuming.

Field personnel must visit each permanent and intensification plot to determine the true condition of the land cover. No other resource data are collected on intensification plots, so the cost of establishing and using those plots is high in relation to the extent of data acquired. Reliable estimates of forest area from AVHRR classifications would eliminate the need for expensive visits to intensification plots. These AVHRR forest area estimates could be used routinely in forest inventory work at regional to national scales. These area estimates could also be produced for use in statistical prediction of changes in forest resources between field survey years.

This research has demonstrated that AVHRR classifications can be the basis for parish- or county-level percentage of forest estimates that do not differ significantly from those obtained by detailed photo interpretation. However, additional investigation is needed to identify and correct problems associated with classification of young forest regeneration areas on the basis of AVHRR data. Extension of this work to comparisons for multiple random counties or single aerial photographic interpretations could provide further justification for the application of AVHRR data for routine forest area estimation.

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Forest area was estimated using AVHRR data and dot count procedures.

Keywords: Dot counts, forest area estimates, photo-interpreted data.

United States
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Southern Forest
Experiment Station
701 Loyola Ave., Rm.T-10210
New Orleans, LA 70113-1920

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