TEMPORAL VALIDATION FOR A LANDSAT-BASED VOLUME ESTIMATION MODEL

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Abstract--Satellite imagery can potentially reduce the costs and time associated with ground-based forest inventories; however, for satellite imagery to provide reliable forest inventory data, it must produce consistent results from one time period to the next. The objective of this study was to temporally validate a Landsat-based volume estimation model in a four county study area for possible use in large-scale forest inventories. Data were derived from Landsat Thematic Mapper (TM) imagery of Choctaw, Clay, Oktibbeha, and Winston counties in central Mississippi and compared with field inventory data from the Mississippi Institute for Forest Inventory (MIFI) for 1999 and 2006 (Clay County 2007). Comparisons were made between Landsat-based and MIFI inventory-based (90 percent confidence level) cubic foot volume outside bark to a pulpwood top (CFVOBPW) estimates in each of 2 study years. Results showed that, with one exception for the hardwood forest type cover class, estimates from the Landsat-based volume model fell within a reasonable sampling error range (± 20 percent) when calibrated to the MIFI field inventory. Further research will be conducted on: (1) re-parameterization of the model to correct for bias using a small sample of field plots; (2) the model's spatial validity; and (3) its potential for providing acceptable data substitutes where field inventory data are missing, too costly, or unattainable.

INTRODUCTION

Forests cover roughly 19.8 million acres or approximately 65 percent of Mississippi (Glass 2007) and are integral to the economy, producing over $1.1 billion in harvested timber annually (Henderson and others 2008). Mississippi's forests are also the basis for other aesthetic and economic benefits associated with wildlife, recreation, and tourism (Dahal and others 2013). Because of the importance of forest resources to the economy of Mississippi, timely and precise forest inventories are needed to: (1) attract new forest products industries, (2) provide decision support information to existing forest products industries, and (3) monitor forest change to ensure sustainability. In addition to the precision necessary to minimize risk associated with economic investment decisions at any one point in time, forest inventories must also be consistently valid in order to be applicable across multiple time periods.

Traditional field-based forest inventories are costly, untimely, or unattainable due to budget restraints, logistics, topography, or other circumstances. The need for timely, cost effective data has promoted the use of remotely sensed data such as that derived from Landsat Thematic Mapper (TM) imagery because of its ability to quantify and qualify large areas. While field-based forest inventory systems are already in place at the state and county levels in Mississippi, the use of Landsat TM data alone has potential for providing acceptable volume estimates when USDA Forest Service Forest Inventory and Analysis (FIA) and Mississippi Institute of Forest Inventory (MIFI) data are unavailable or unattainable.

The purpose of this research was to temporally validate Landsat-derived cubic foot volume outside bark to a pulpwood top (CFVOBPW) estimates by comparing them to MIFI field-based CFVOBPW estimates at two separate time periods. Model performance of a 1999 MIFI pilot study of four counties (Choctaw, Clay, Oktibbeha, and Winston) in central Mississippi was compared to 2006 MIFI central region and 2007 north region inventory data to establish a standard on which to calibrate temporal validity for the Landsat-based estimations of the same time periods. Temporal validity can be established because both field plot estimates and Landsat-only based estimates are available for these specific years. The hypothesis of this work was that the Landsat-based estimates would fall within ± 20 percent of the MIFI field-based estimates.

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METHODS

MIFI Inventory Data

CFVOBPW was selected for comparing MIFI inventory and Landsat-based volume estimates because it was the MIFI inventory target/design variable and exhibited the least amount of variation among volume estimates. MIFI CFVOBPW estimates were obtained for four Mississippi counties (Choctaw, Clay, Oktibbeha, and Winston) inventoried in a 1999 pilot study (Parker and others 2005) and re-inventoried in the 2006 MIFI central region inventory (for Choctaw, Oktibbeha, and Winston counties) (Glass 2007) and the 2007 MIFI north region inventory (for Clay County) (Glass 2008). MIFI divides the state into five inventory regions sampled yearly on a rotating basis. Choctaw, Oktibbeha, and Winston counties were placed in the central inventory region while Clay County was placed in the north region causing it to be inventoried in a different year in the annual rotation.

MIFI CFVOBPW estimates for the four counties and two time periods were obtained from Mississippi Forest Inventory Dynamic Reporter Version 7 software (Matney and Schultz 2011) available through the Mississippi State University Forest and Wildlife Research Center (FWRC) and downloadable from www.timbercruise.com (Download Center-Desktop-Other Solutions-Mississippi Institute of Forest Inventory Dynamic Inventory Reporter). Dynamic Reporter forest type and species group report selections were made using criteria similar to those employed by MIFI in determining GIS forest cover type sampling strata, pine and hardwood. The pine stratum was specified as consisting of all species groups within all Society of American Foresters (SAF) forest types that were solely composed of pine. The hardwood stratum was specified as consisting of all species groups within all SAF forest types that were hardwood only. There were too few MIFI plots (n = 15) containing mixed pine and hardwood SAF forest types for a comparison of GIS and MIFI volume estimates (Wilkinson 2011). A minimum merchantable age of 10 was used for both pine and hardwood, and non-merchantable plots (non-forest, sub-merchantable, and regeneration) were also excluded.

Landsat Thematic Mapper (TM) Data

Techniques used for deriving volume data from Landsat TM imagery were modified from Wilkinson (2011). Both 1999 and 2006 image data sets were 30-m resolution projected in Mississippi Transverse Mercator (MSTM). Age, forest type, and radiance layers were subset to the four county study area and used as dependent variables in hardwood and pine stratum models. Age layers for 1999 and 2006 were constructed from a sequence of 14 times, representing every third year, from 1972 to 2006 using a Microsoft C++® program. Forest and non-forest cover type distinctions were made using approximately 300 clusters in unsupervised classification (Collins and others 2005). Hardwood and pine forest type pixel classifications were made interpretatively using an 80 percent or greater hardwood or pine rule. Anything < 80 percent was separated into the mixed category. The radiance layer was created using a reflectance to radiance model in ERDAS Imagine's® Model Maker function. Pixel values from bands 1 to 5 and 7of the original satellite images (1999 and 2006) were converted to radiance values by Chander and others (2007) procedures.

Volume Estimates

Once Landsat-derived variables were created, hardwood and pine CFVOBPW per acre models (equations 1 and 2) were constructed using techniques derived from Schultz and others (2006). Hardwood- and pine-modified power models were tested multiple times for efficiency, with age being used as a correction factor for the over/under prediction of the model. Both power models were run with SAS® Version 8 non-linear (NLIN) procedure using the Gauss-Newton method with CFVOBPW per acre as the dependent variable. The power models achieved higher index of fit (1 minus the quantity of the error sum of squares divided by the total sum of squares) than other models tested. Final models were incorporated into a Microsoft C++® program in order to calculate both total and average per acre volume for hardwood and pine. Volume data from both MIFI- and Landsat-based inventories were compared to help calibrate the standard from time period to time period. An acceptable sampling error range of ± 20 percent was evaluated for Landsat-based estimates of CFOBPW when compared to the MIFI field inventory standard.

$$\text{Pine } \widehat{\text{CFVOBPW}} = 22822.8 - 23600.6 AGE^{-0.3476}$$
$$-5089.6 R1^{-0.3449} R2^{0.2654} R3^{-0.0510} R4^{0.0756} R5^{0.2832} AGE^{0.1747} \quad (1)$$

$$\text{Hardwood } \widehat{\text{CFVOBPW}} = 316973 - 319999 AGE^{-0.00544} - 13053.8 R2^{1.6721} R3^{-4.1671} R4^{-2.4279} R5^{4.8113} AGE^{1.4272} \quad (2)$$

where *AGE* = age determined from a forest/non-forest change detection temporal sequence beginning in 1972; *R1* = Landsat radiance band 1; *R2* = Landsat radiance band 2; *R3* = Landsat radiance band 3; *R4* = Landsat radiance band 4; *R5* = Landsat radiance band 5; and a rectangle over the variable designates an estimated value.

RESULTS

MIFI 1999 CFVOBPW per acre volume estimates were 2,607 and 2,380 for hardwood and pine cover classes, respectively, while Landsat-derived per acre volume estimates were 3,808 and 1,978, respectively (table 1). The hardwood Landsat estimate exceeded the hypothesized ± 20 percent sampling error while the Landsat pine cover class fell within the ± 20 percent sampling error. MIFI 2006 CFVOBPW per acre volume estimates were 2,525 for hardwood and 2,064 for pine cover classes. Landsat per acre volume estimates were 2,477 and 2,091 for hardwood and pine cover classes, respectively. Both Landsat estimates were within 2 percentage points of the MIFI estimates, well within the hypothesized ± 20 percent sampling error.

Table 1—Cubic foot volume outside bark to a pulpwood top (CFVOBPW) per acre MIFI field inventory (±20 percent acceptable sampling range at the 90 percent confidence interval) and Landsat TM model derived estimations and percentage difference comparisons

Forest cover class/year	MIFI inventory	Landsat derived	Difference
	------CFVOBPW ac^{-1}--------		*--percent--*
Hardwood			
1999	2,607 ± 521	3,808	46.1
2006/2007	2,525 ± 505	2,477	1.9
Pine			
1999	2,380 ± 476	1,978	16.9
2006/2007	2,064 ± 413	2,091	1.3

DISCUSSION AND SUMMARY

With one exception, the 1999 hardwood cover class, power models based on Landsat data and age produced CFVOBPW per acre estimates that fell within our hypothesized sampling error range of ± 20 percent compared to MIFI inventory estimates. Further calibration and model refinement will be possible in 2014 when additional temporal data is available from the first re-measurement of the MIFI central inventory region and from Landsat 8 satellite imagery. Research is also in progress to spatially validate the models with MIFI data from other inventory regions and at different scales (e.g., county, multi-county, state, working circles, polygons). Extensibility of the procedure to other regions may require recalibration of the model through a small sample of ground truth points.

The models developed here are preliminary, and on-going research is being conducted to refine and improve them. As refinements and validations are made, the Landsat-based models have the potential for providing acceptable data substitutes where field inventory data are missing, too costly, or unattainable.

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