USING 30-METER SATELLITE DATA TO ESTIMATE BASAL AREAS OF INTENSIVELY MANAGED LOBLOLLY PINE STANDS

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PMRC TECHNICAL REPORT 2000-6

January 17, 2000

by

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ABSTRACT. As the forest products industry receives more competition from imports and products substitution, foresters and other natural resource managers are realizing the need for accurate, localized, timely estimates of forest land acreage. Spatial data, such as that from Landsat 5 Thematic Mapper (LTM), have been used in many parts of the world for forest inventory and analysis.

In an effort to study the usefulness of LTM data for timber inventory in the southeast United States, we designed a method to sample timber on a relatively tight grid (30 meters x 30 meters). Professional foresters collected timber cruising data from four by four blocks of 16 plots. Plot basal area was calculated from these field data. We used LTM data from both leaf-on and leaf-off time periods to predict the variation in basal area over the study area.

In the study described here we found that the spatial resolution of the LTM's sensors was not adequate to accurately distinguish variations in basal area data at the 30-m plot scale. However, at the 60-meter resolution the LTM regression estimator predicted the average basal area in mature, intensively managed loblolly pine plantations with an adjusted $r^2$ value of 0.92. The regression estimator based on data from a 3 x 3 chain (60 meter) cruise predicted the average basal area in the same stands with an adjusted $r^2$ value of 0.75.

KEY WORDS: forest inventory, Landsat, basal area.

1 BACKGROUND

The increasing economic competition in forest products and product substitutions as well as the progressive international exchange are motivating the call for new methods and technologies to improve the efficiency and accuracy of natural resource assessments. In 1998, the American Forest and Paper Association's Second Blue Ribbon Panel (BRP) on Forest Inventory and Analysis (FIA) Program formally acknowledged the importance of, and the need for, a consistent, timely, and accurate forest inventory system. The forest products industry is investigating opportunities to improve the quality of information available to the land managers through the use of satellite data.

Spatial data such as that from Landsat Thematic Mapper (LTM) have been used in many parts of the world to map natural resources. Several authors have reported statistically significant correlations between LTM data and forest field data (Brockhaus and Khorram 1992, de Jong 1994, Nemani and others 1993, and Trotter and others 1997). Only the work of Brockhaus and Khorram (1992) was conducted in the southeastern United States (Table 1).

We expect LTM data to be useful for forest inventories in the southeast. However, much work still needs to be done before such data can be used to their full potential. Specifically, studies must be done to document the signature differences between different forest types grown in the southeast.
Furthermore, differences in signatures related to basal area within a single stand type must also be investigated.

Another very important consideration when using LTM data is the method by which ground samples for training sites and verification sites are collected. In particular, different methods of spacing sample plots need to be evaluated before accurate recommendations can be made to industry.

<table>
<thead>
<tr>
<th>First Author</th>
<th>Study Location</th>
<th>Attribute</th>
<th>Estimated r²</th>
<th>Minimum Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brockaus</td>
<td>North Carolina</td>
<td>basal area</td>
<td>0.23</td>
<td>8,100 m²</td>
</tr>
<tr>
<td>de Jong</td>
<td>France</td>
<td>LAI</td>
<td>0.52</td>
<td>900 m²</td>
</tr>
<tr>
<td>Nemani</td>
<td>Montana</td>
<td>LAI</td>
<td>0.64</td>
<td>8,100 m²</td>
</tr>
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<td>Trotter</td>
<td>New Zealand</td>
<td>volume</td>
<td>0.31</td>
<td>900 m²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.85</td>
<td>400,000 m²</td>
</tr>
</tbody>
</table>

* leaf area index

## 2 Objectives

The primary objectives of the study documented in this article were:

1. To implement a field data collection protocol geared to the spatial resolution of BAF 10 cruise plots and the spatial resolution of LTM data.
2. To use both from summer and winter LTM data to predict variations in basal area for mature loblolly pine stands.

## 3 Methods

### 3.1 Field Samples

Accessible timber stands in Marion County (Figure 1) were stratified by management regime and stand age. Professional foresters collected common cruising data (dbh, tally, and heights) in 6 mature (14-20 year old) "old field" loblolly pine stands (4 unthinned; 2 thinned). Using a 10-factor prism-sweep at each plot center, two groups of sixteen plots were collected in each stand at a 30-m spacing (Figure 2). The plots were established at this tight spacing so the spatial resolution of the ground data would closely match the spatial resolution of the LTM data.

Plot centers were recorded with a GPS unit. Approximately 180 points were recorded per plot center. These data were differentially corrected using PathFinder Office software so they could be imported into a geographic information system. The basal area was calculated for each plot from a using the field data, (Plot_BA). An average basal area per four plots was also calculated (Avg_BA; Figure 2).

### 3.2 Satellite Samples

Landsat 5 Thematic Mapper (LTM) images from leaf-on (June) and leaf-off (December) time periods were clipped into two sections, which covered the region of the stand.
samples, and geo-rectified using the State's digital ortho quarter quadrangles (DOQQs) (Figure 1). Thirteen well-distributed ground control points (GCP) were used with the northern image, and 27 GCP were used with the southern image to rubber sheet the image in ERDAS Imagine. The resulting root mean squared errors (RMSE) were 0.385 cells (north) and 0.387 cells (south) (approximately 11.6 meters).

When the differentially corrected sample plot locations were overlaid onto the LTM images, the LTM data for several plots in one group were affected by the shadow from a cloud. These plots were removed from further analysis. Data for a couple of the targeted plots too close to roads or logging decks were also removed from further analysis. Of the original 160 cruise plots, 129 cruise plots were acceptable for analysis.

The digital plot centers were buffered at a radius of 10 and 29 meters respectively in a geographic information system (GIS) (Figure 2). The 10-m buffers approximated the size of the field plots (BAF 10; average tree diameter = 7.5 inches (19.1 cm); and limiting distance = 21 feet (6.3 meters)). The 29-m buffers approximated the sample area of four cruise plots averaged together. The GIS buffer coverages were used to spatially identify the LTM digital numbers recorded in six bands by the satellite. The selected digital numbers (excluding Band 6) were exported to a database. Using the compartment-stand-plot number as the common field, we joined the LTM data to the calculated basal area data.

4 Results

4.1 Correlations Between Individual Bands of LTM Data and Calculated Avg_BA. For basal areas ranging from 45 ft² to 195 ft², winter Band 7 and summer Band 2, selected using the 29-m buffer coverage, showed high correlations with the four-plot Avg_BA. The Pearson correlation coefficient between Avg_BA and winter Band 7 was -0.891; the Pearson correlation coefficient between Avg_BA and summer Band 2 was -0.851.

The variance of LTM values per Avg_BA for each band varied. The LTM values for winter Band 7 had the least variation per Avg_BA; winter Band 4 had the most variation per Avg_BA. The distribution of LTM values for winter Band 2 was greater than the distribution of LTM values for summer Band 2 (Figure 3).
4.2 Predicting Plot Basal Area Using LTM Data and the Adequacy of 30-meter Satellite Data for Forest Inventor. Plot BA, calculated from the cruise data, and the LTM values located in the 10-m buffers were analyzed together. Many different combinations of the 12 LTM bands were grouped for regression analyses. A regression equation using four LTM variables predicted Plot BA with an adjusted $r^2$ of 0.76 and a residual standard deviation of 23.5 (Table 2).

Table 2. LTM variables used in 10-m plot regression analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta$ Band 2</td>
<td>(Band 2$<em>{winter}$) - (Band 2$</em>{summer}$)</td>
</tr>
<tr>
<td>$\Delta$ Band 7</td>
<td>(Band 7$<em>{winter}$) - (Band 7$</em>{summer}$)</td>
</tr>
<tr>
<td>NDVI$<em>p$$</em>{winter}$</td>
<td>$\left(\frac{\text{Band}4_i - \text{Band}3_i}{\text{Band}4_i + \text{Band}3_i} \times \left(1 - \frac{\text{Band}5_i - \text{Band}5_{image_min}}{\text{Band}5_{image_max} - \text{Band}5_{image_min}}\right)^wint\right)$</td>
</tr>
<tr>
<td>$\Delta$ NDVI$_p$</td>
<td>(NDVI$<em>p$$</em>{winter}$) - (NDVI$<em>p$$</em>{summer}$)</td>
</tr>
</tbody>
</table>

The low basal area measured at Plot 6, surrounded by plots with higher basal areas, was not recorded in the LTM data (Figure 4). This was probably due to both the RMS errors incurred during rectification as well as the satellite sensor "carry over" between measurements. We concluded that the LTM data did not contain adequate resolution to discern significant within-stand variation in basal area at the 30-meter resolution.

Predicting Average Basal Area (Avg BA) Using LTM Data

Avg BA, calculated from the cruise data, and the LTM values located in the 29-m buffers were analyzed together. Many different combinations of the 12 LTM variables were grouped for regression analyses. Winter Bands 2, 4 and 6 along with summer Band 2 were the LTM variables that best predicted the variation in basal area within the sampled stands (Equation 1). The adjusted $r^2$ value for this equation was 0.92 (Figure 5). The standard deviation of the residuals was 11.7. All of the LTM variables used in this regression were significant at or below the 0.01 level.

Equation 1

predicted _avg _BA = 198.05 + (10.39 × w int er2) + (3.92 × w int er4) + (−7.98 × w int er7) + (−9.87 × summer2)

Equation 1

Predicting Average Basal Area Using Randomly-Selected Cruise Data

The tight cruise spacing used in this study afforded the opportunity to compare, at a spatial resolution of 60 meters, the precision of an LTM basal area estimator (Equation 1) with the precision of field data collected using a 3 x 3 chain (60 meter) spacing. Using a systematic random sampling design, four field samples were possible (Table 3). Each sample had a 0.25 probability of being selected. Samples 1 and 2 were each selected once; sample 4 was selected twice.

The basal areas for the randomly selected plots were compared to the four-plot average for each 3,600-m$^2$ area. The plot basal area predicted the four-plot average basal area with an adjusted $r^2$ of 0.75. The standard deviation of the residuals was 21.8 (Figure 6).

Table 3. Cruise plot sample sets

<table>
<thead>
<tr>
<th>Sample</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Plots 1, 3, 9, 11</td>
</tr>
<tr>
<td>2</td>
<td>Plots 2, 4, 10, 12</td>
</tr>
<tr>
<td>3</td>
<td>Plots 8, 6, 16, 14</td>
</tr>
<tr>
<td>4</td>
<td>Plots 7, 5, 15, 13</td>
</tr>
</tbody>
</table>
5 CONCLUSIONS

The forest products industry is looking to intensive management to increase the rate at which wood fiber is produced in the southeast. Intensive management frequently includes greater application rates of herbicides and fertilizers, which translates into greater input costs per acre. Given the increase in risk resulting from the increased investment, it is important that managers use accurate inventory data to predict returns.

The field sampling design used in this study worked well with the spatial resolution of the LTM data. In this study, the LTM data was not adequate to estimate basal area for plots spaced at 30 meters. However, a LTM regression estimator was found that predicted the average basal area of mature, intensively managed loblolly pine at a spatial resolution of 60-meters with an adjusted $r^2$ of 0.92.

Field cruising will always be an important part of the forest inventory system. High quality field measurements recorded by professional foresters in the field are required for baseline inventory information, and LTM classification and verification. LTM data provide an additional source of information to improve inventory precision at the 60-meter scale.

REFERENCES

