Impacts of Inaccurate Area Estimation on Harvest Scheduling Using Different Image Resolutions

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Abstract: Area estimation is widely used in forestry applications and can greatly affect how forest land is managed. This study examined whether image attributes and interpreters affected area estimation and management activities used in forestry practices. Seven interpreters, chosen for this study, delineated stands on two different images of the same area. Results from these interpretations were then entered into a harvest scheduling model to see how the differences affected the overall timber value predicted by the harvest schedule. Image attributes played a role; however, differences in interpretation were the primary cause of inconsistency in harvest values. The objective function values (OFV) for individual interpreters ranged from \$1.5 to \$2.3 million for Positive Systems® imagery and \$1.4 to \$1.9 million for scanned imagery. Average OFV between imagery and interpreters ranged from \$1.7 to \$1.8 million.

Key Words: image resolution, forest management, harvest scheduling, remote sensing, area estimation, GIS

ITRODUCTION

Many factors lead to proper forest management planning. For instance, stand delineation is an important factor in determining attributes of forest land. Stand delineation can influence the allocation of specific forestry practices and determine the acreage assigned to timber types on the site. Another major factor in forest management planning is area estimation. Area estimation is used to calculate volumes on a stand or forest level, and these volume estimates are used for appraising timber values. Area estimation does not affect rotation ages; however, it may affect appraisal prices for a property. With timber values, forest land can be assessed as economically mature or immature which can in turn affect harvest timings. Therefore, care should always be taken when predicting areas from stand interpretations. Payments, such as taxes and insurance, are made according to standing timber values and can be affected if areas are incorrectly delineated. Finally, delineation errors affect timber and land values and can cause problems for other aspects of forest management. For example, harvest schedules are determined by allocating resources to certain management strategies; therefore, these schedules may be sub optimal if area estimates are inaccurate. In addition, goal attainment may be adversely affected. This study focuses on the direct effect of all these factors on harvest scheduling results for a specific piece of property.

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The study location contains many stands of various types and composition. This area is currently managed by the U.S. Army Corps of Engineers for forestry and aesthetic uses, specified by the National Aeronautics and Space Administration (NASA). Space shuttle engine tests are the main use of this area.

Typically, aerial or satellite imagery is necessary for stand delineation. However, spatial resolution can affect area estimation. Repetitive stand lines on an image are identified using characteristics that are visible to the eye and may be incorrectly depicted because of detail lost to resolution differences. Differences between high and low resolution imagery need to be addressed to ensure that forest management decisions are appropriate.

With information on the effects area estimation has on land management, managers can adjust treatments to include errors made in area estimation. In addition, with activities being planned over extended periods of time, managers will be able to see the long-term effect caused by area estimation errors. Since monetary returns are commonly used for comparing management alternatives, information on the economic impacts of using certain types of imagery is a problem facing natural resource managers. Images of different resolutions may produce different interpretation results. However, if results do not differ, it makes sense to use imagery that has the lowest cost.

The objectives of this study are to: 1) estimate stand areas, using different imagery 2) develop a linear programming (LP) model that can be used for management planning, and 3) conduct a comparative analysis to assess imagery impacts on forest management planning. This analysis compared harvest schedules, using the same LP model, taken from both image types.

Area Estimation

Techniques that estimate land area from imagery generate errors that cause problems for land managers. Shadows thrown from objects above the earth's surface can cause problems in determining boundaries. Resolution and quality of an image are factors that contribute to inaccuracies in delineated stand boundaries. All of these factors greatly affect area estimation; however, little research has been done that relates these errors to forest management planning. Land managers and private landowners can ensure that optimal management decisions are made for their land by knowing how harvest schedules are affected by area estimation.

Conducting research on area estimation requires forest land to be broken up into stands for data collection and analysis. Volume estimates per unit depend on the actual area estimate along with the volume estimated for that site. Photo interpretation is a common way of determining areas from an image (Naesset 1999). Models are then used to determine delineation errors caused while drawing boundaries. Naesset (1999) used Monte Carlo simulation techniques to quantify positional errors. He determined that many factors can contribute to errors in area estimation. For instance, stands that are uniform are easier to distinguish than stands of varying tree species and density. Therefore, the difference in stand characteristics plays a role in determining stand boundaries. Naesset (1999) used the following classes: regeneration stage forest, thinning phase forest, non-productive, swamp, and lake. After these classes were determined, the area was broken up into stands and inventoried. Positional errors occurred where stands that were similar in species type and density adjoined. Also, tree shadows were a problem for boundary determination in stands where mature trees overshadowed younger stands. After stand boundaries were determined they were registered into pcARC/INFO. For all but the thinning phase forest, area estimates overestimated the area when compared to the true area.

The main approach for forest area estimation in the past has been interpretation of aerial photographs; however, that is currently changing due to satellite imagery use. Commonly, an area must be at least 10% forested and at least 1 acre to be considered a forest in the federal inventory system (Wynne et al. 2000). Advantages of satellite images include easier analysis of imagery due to software packages, larger views of an area, and satisfying the increasing need for frequent updates due to the ever-changing landscapes (Wynne et al. 2000).

Selecting the type of imagery to be used in research, and how to interpret that image, depends on the project goals and budget restrictions. Characteristics of an image that need to be addressed include spatial resolution, spectral resolution, temporal resolution, and extent. Spatial resolution refers to the smallest object on an image that can be identified. Green (2000) defined spectral resolution as portions of the electromagnetic spectrum sensed by a satellite and the number and width of bands. Temporal resolution describes when and at what time intervals an image is captured. Extent refers to the amount of area covered by one image (Green 2000).

High-resolution imagery supplies detailed representations of site-specific qualities. By having detailed imagery, it is possible to monitor pest damage to individual trees, distinguish forest types, determine wildlife habitat, and assess fire management operations. Seven indicators used for manual interpretation of images are color, tone, texture, shape, size, pattern, and context of the feature of interest (Green 2000). Therefore, distinguishing between each of these indicators requires the use of high-resolution imagery. Pixel size plays a major role in the accuracy of area estimates by limiting the size object that can be viewed in detail. With smaller pixels, vegetative characteristics can be obtained from remotely sensed data and assist land managers in decision making.

METHODS

This study focused on the impacts of area estimation, using different imagery and interpreters, on forest management planning. Seven delineators were used to interpret stand boundaries from two different images of the same area. With this information, comparisons were made of the results to quantify the actual impact they had on a harvest schedule. The impacts found will help determine how much emphasis needs to be placed on delineation and imagery requirements. This research will also aid natural resource managers in decisions that determine the outcome of forest management practices.

In achieving the previously stated objectives, this study used information obtained from the NASA environmental office at the John C. Stennis Space Center. The Space Center is an area with a diverse coastal environment located on the Pearl River in Hancock County, Mississippi. This study used a 1,080 acre tract with different land and forest types. The tract is diverse in terms of tree species, stand density, land use, and topography. These characteristics were determined by aerial photographs, field observations, and consultations with the team leader of an inventory conducted on the site.

Color Infrared (CIR) photographs were obtained, along with Positive Systems® imagery, to use in the comparison. These images were obtained from the environmental office of NASA at the Space Center. The pixel resolution of the Positive Systems® imagery was 1 by 1 meter taken in the fall of 1998. The scanned aerial photographs had a resolution of 0.7 by 0.7 meters taken in the fall of 2000. The study site used for this research had not experienced any major harvesting activities between the dates of each image; therefore, image comparisons could be made without jeopardizing interpretation results (C. Case pers. commun., 2001). Students that had completed a course in forest photogrammetry in the Department of Forestry at Mississippi

State University were chosen for delineation duties. Interpretations of both images were then digitized using ERDAS Imagine software. CIR band combinations were used to help differentiate forest types on both images (i.e., hardwood and pine). Once all delineation's were completed, the acreages were determined using ArcView GIS.

A geographic information system (GIS) available for the area was assumed to be the true stand makeup for this study site. The original boundaries for this GIS were found using tax map information from Hancock County, MS. This GIS included several different timber types that had been determined previously from an inventory carried out at the Space Center. Since study delineations did not include information on stand types, other information had to be used for stand typing. The available GIS was used to assign stand types. Overlays of delineations and the GIS layer were done to assign correct stand types; however, when problems arose in determining which stand type to use, plot data for a specific area were used to assign the proper stand type. Plot data were generated from inventory information that had been entered into the GIS. Areas that did not have plot data available were compared visually to find similarities between spectral attributes of the questionable areas and then types were assigned accordingly.

Although field data from the Space Center were used in this study, landowner goals were hypothetical. WINYIELD 1.11 growth and yield software was used to determine an optimal management prescription that maximized land expectation value (LEV) (FRS 2002). Also, an optimal rotation age for mean annual increment (MAI) was determined to allow for more options in the decision making process. Discussions with the local area forester helped determine management strategies to be implemented in the area. Each prescription differed in some aspect from the others; however, all prescriptions were appropriate to the area. Costs associated with each prescription were obtained from Dubois et al. (2001). Costs included burning, herbicide use, and planting costs.

An LP model was run to determine which prescription was most desirable. LINDO was used to maximize the main objective and assist in determining the effect stand delineation had on harvest scheduling (LINDO 2001). The harvest schedule was for a planning horizon of 35 years with frequent activities occurring over the forest area as a whole. A basic example of the model is:

Objective Function
MAX NPV = $\sum \alpha_{ij} X_{ij}$
Decision Variables
X_{ij}= number of acres of stand i treated with prescription j
α_{ij}= NPV of stand i treated with prescription j
Constraints
$\Sigma X_{ij} \leq$ available acreage
Σ total revenue over 5-year period $\geq$ \$70,000

The hypothetical goal developed for the landowner was to maximize NPV. Net present values were found for each prescription using WINYIELD 1.11. Per-acre volumes were provided from 2000 inventory information to determine total volumes of certain stands. This information helped determine current stand conditions and the growth potential for certain areas.

Results obtained from this model were viewed as an optimal schedule of activities for the forest, given the specified objective function and constraints. The objective function value was the main criteria for evaluating the effect of area estimation on harvest schedules. Therefore, this value was examined to determine the amount of fluctuation possible when different interpreters or imagery was utilized.

RESULTS

There were differences in stand delineation between delineators, as well as between imagery types. Delineations were done by computer, where the scale of the photo was frequently changed making some stand characteristics easier to find than normal. Figure 1 demonstrates differences in stand delineation made by the same interpreter using different image types.

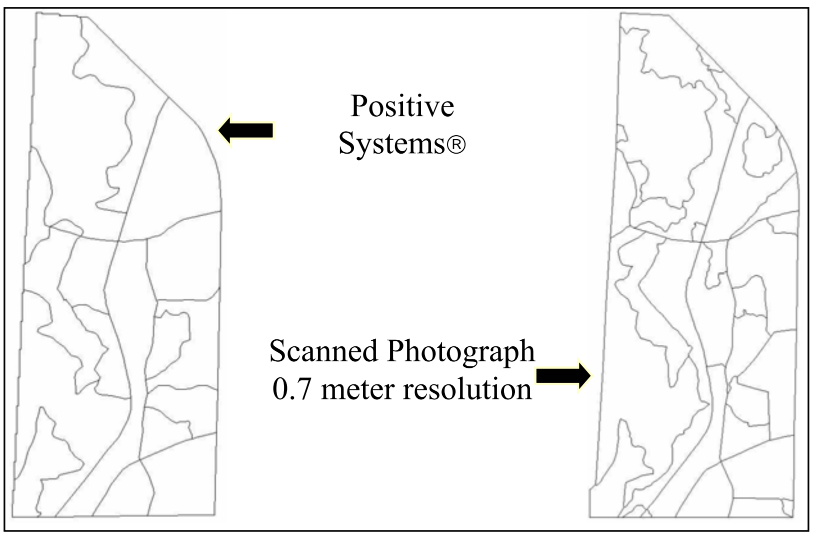

Figure 1. Example of delineations from different image types.

Throughout the delineation process, many polygons differed between interpreters and imagery. The variation of polygons in the delineation process suggested the amount of inconsistency that can be found in stand interpretation. These polygon differences were summarized in Table 1.

Table 1. Number of identified timber stands across interpreters and imagery, on the study area at the John C. Stennis Space Center.

Interpreter	Positive Systems®	Aerial Photo
1	30	21
2	16	27
3	24	26
4	33	25
5	26	22
6	31	33
7	24	20
Average	26	25
Minimum	16	20
Maximum	33	33

Prescriptions were written for each stand type which included all potential activities taking place during the 35-year planning horizon. Optimal prescriptions using LEVs and MAI were also found using Winyield 1.11 software. These prescriptions led to schedules for thinning operations as well as final harvests. Once optimal prescriptions were found, six different prescriptions were written for each stand type that included alternative management regimes.

A harvest scheduling model was run using each interpreter's stand type and acreage results by image. Each model determined the best prescription for maximizing NPV and produced acres allocated by prescription and associated costs, revenues, and wood flows. An overall OFV is determined for each interpreter's results. This value is the optimal NPV for managing the study area with the given constraints; however, results showed that the OFV changed as delineations or images changed (Table 2).

Table 2.Objective function values by interpreter and imagery on the study area at the John C. Stennis Space Center.

Interpreter	Imagery	
	Positive Systems®	Aerial Photo
	($)	($)
1	2,277,420	1,729,663
2	1,636,718	1,880,735
3	1,594,490	1,687,620
4	2,074,342	1,530,457
5	1,502,128	1,517,227
6	1,870,560	1,884,127
7	1,602,161	1,376,052
Average	1,793,974	1,657,983
Minimum	1,502,128	1,376,052
Maximum	2,277,420	1,884,127

The harvest schedule was first determined using the acreage estimates from GIS. The OFV was $1,906,451. This value was assumed to be the true value. For Positive System® imagery, OFV ranged from -21.2% to 19.5% of true value. For the scanned imagery, OFV ranged from -27.8% to -1.2% of true value. When all interpretations for each image were averaged, the Positive Systems® image had an average OFV difference of -5.9% and the scanned image had an average OFV change of -13.03%.

A 95% confidence interval was computed for each image to see if the true OFV was included. The standard deviation for the Positive Systems® imagery was $290,023.36. The confidence interval was $1,525,748 to $2,062,200. The standard deviation for the scanned image was $192,499. The confidence interval was $1,479,952 to 1,836,014.

Using $1,906,451 as the true value, a hypothesis test was conducted to see if the image values differed significantly from the true value. The alpha level was 0.05 with 6 degrees of freedom. For both images, the rejection region for the t-statistic was +/- 2.4469. Positive Systems® imagery had a t-statistic of -1.0261, which failed to reject the null hypothesis of H0: μ=$1,906,451. Therefore, the Positive Systems® results were not significantly different from the true results at a 95% level of confidence. The scanned imagery had a t-statistic of -3.4150, which rejected the null hypothesis. Therefore, the scanned image results were significantly different from the true results at a 95% level of confidence.

DISCUSSION AND CONCLUSIONS

This study compared the use of different imagery for stand delineation and its associated impacts on area estimation and harvest scheduling. Also examined was the stand interpreter error on the delineation process. These objectives were accomplished by utilizing a linear programming model for optimization of net present value. Imagery and interpreters played an important role in the outcome of a harvest schedule.

The primary concern in forest management planning is the landowner's objectives. In this study, the landowner was NASA at the Stennis Space Center. NASA has timber management as its primary goal. Net present value was chosen for this objective because many landowners want to maximize the net worth of their investments. Other maximization values could have been chosen to see how they affected the harvest schedule; however, this study focused on maximization of net present value.

Delineation results show that there are important differences in stand interpretations between imagery and interpreters. Interpreter skill level may have an important impact on stand delineation. As previously mentioned, one interpreter indicated that one area on an image contained three different stand types and another interpreter identified only one stand type. No contributing factor influencing number of stands delineated could be consistently identified. Results could also be dramatically different between imagery. Logically, the number of timber stands found should be higher on the image with higher resolution because of the amount of detail portrayed. However, this theory was not demonstrated in the results. In higher resolution imagery, the number of timber stands identified was frequently less than on the lower resolution imagery, due to interpreter error.

The harvest scheduling model developed for this study included all prescriptions and their associated values. This model was constrained by acreage and budget constraints. Acreage constraints were the main focus since they were directly affected by delineation results. The model was written with all other values remaining constant except for the acreage estimates by stand type. This accomplished one of the main study objectives by strictly showing how acreage estimates affected harvest schedules. The results indicated that acreage estimates definitely were a major factor in determining the value of a harvest schedule. However, the contributing factor to the acreage estimation error did not consistently identify imagery or interpreters as the determining factor. OFV ranged from $1.5 to $2.3 million for Positive Systems® imagery and $1.4 to $1.9 million for the scanned image. The average OFV's for each image seemed to imply that the imagery was not a major source of variation in the OFV. However, when confidence intervals and hypothesis tests were conducted, they showed that Positive Systems® imagery results did not differ significantly, at a 95% level of confidence, from the true OFV, whereas the results of the scanned imagery were significantly different from the true OFV, at a 95% level of confidence. These tests imply that the image attributes did play a major role in the accuracy of the OFV.

FUTURE RESEARCH

With the many advancements in high quality imagery, future research could determine the effects of drastically different image resolutions on harvest schedules. Since this research only looked at 0.7 and 1 meter image resolutions, another project could be organized to determine the lower threshold image resolution that would still improve the accuracy of interpretations.

There are several software advancements (i.e., eCognition) that are utilizing an automated style of stand delineation and inventory analysis. These technical improvements in forestry will greatly change the way forests are managed when compared to current practices. For instance, companies have constructed programs that will identify all trees in a specific area. With this kind of information, individual tree values can be used with common correlations (i.e., live crown ratio) to determine many factors used in management planning. Of these factors, stand delineation can be done automatically with the proper tools. Therefore, it could be possible to determine what effect these innovations will have on acreage estimation in the future. Research conducted on this new technology could be similar to the research conducted in this study; however, alternative methods for stand determination would be used.

There are many aspects that cause differences in forest management strategy; however, there will always be some sort of error present in any modeling or estimation process. Forest management is moving to more efficient management technologies. With this change, there will always be factors that need to be addressed to determine if current practices are enhancing the future of the forestry profession.

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