Preliminary Study On The Effects Inaccurate Area Estimation Has On Harvest Scheduling Using Different Image Resolutions[1]

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Abstract

Funding provided by
Mississippi State University, Department of Forestry and NASA

Acknowledgments
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Introduction

Many factors have important roles in forest management planning. For instance, stand delineation is an important factor in determining attributes of forest land. Area estimation is used to calculate volumes on a stand or forest level, and these volume estimates are used for appraising timber values. With timber values, forestland can be assessed as economically mature or immature which can affect harvest timings. Also, payments such as taxes and insurance are paid according to the value of standing timber and these values can be affected if areas are delineated incorrectly. 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 could be changed if area estimates are different. In addition, goal attainment may be adversely affected.

Typically, aerial or satellite imagery is necessary for stand delineation, however, these images have attributes that can affect area estimation. Image attributes such as spatial resolution can make an area appear more or less detailed depending on the resolution properties. Stand lines on an image are depicted using characteristics that are visible to the eye; however, if one image has a lower resolution than another, this limits the amount of detail that can be drawn from that image. Stand lines can then be incorrectly depicted because of detail lost to resolution differences. This difference between high and low resolution imagery needs to be addressed to ensure that management techniques are efficient. With information on the actual effects area estimation has on land management, land managers can adjust management applications 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 economic returns are commonly used for comparing management alternatives, information on the economic impacts of using certain imagery over another is a problem facing natural resource managers. Images of different resolutions will usually produce different results; however, if results do not differ it makes sense to use the image that has the lowest cost.

The objectives of this study are to: 1) estimate stand areas, using Positive Systems® imagery and scanned aerial photographs 2) develop a linear programming (LP) model that can be used for management planning 3) conduct a comparative analysis to assess imagery impacts on forest management planning. This analysis will compare harvest schedules, using the same LP model, taken from both image types. It is also necessary to determine if it is more economical to use area estimates from high or low resolution imagery to determine harvest schedules. Since little research exists on these issues, a greater understanding will facilitate better management decisions in the future.

Area estimation

Techniques that estimate 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 of certain areas. Resolution and quality of an image are factors that contribute to inaccuracies in delineated stand boundaries. All of these factors will greatly affect area estimation; however, little research has been done that relates these errors to forest management planning. By knowing how harvest schedules are affected by area estimation, land managers and private landowners are ensured that optimal decisions are made for their land.

Conducting research on area estimation requires land to be broken up into stands for data collection and analysis. The volume estimates for land 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 in his research: regeneration stage forest, thinning phase forest, non-productive, swamp, and lake. After these classes were determined, the area was broken up into stands and an inventory was carried out. Positional errors occurred where stands that were very common in species type and density adjoined. Also, tree shadows became a problem for boundary determination in stands that had mature trees that overshadowed younger stands. After stand boundaries were found they were registered into pcARC/INFO. For all but the thinning phase forest, area estimates overestimated the area when compared to true area.

The main approach for forest area estimation today is interpretation of aerial photographs; however, that is currently changing to the use of satellite imagery. Commonly an area must have at least 10 percent forested area and be at least 1 acre to be considered a forest in the federal inventory system (Wynne et al. 2000). Advantages of satellite images include: frequent updates are easily obtained, analysis of the imagery is easier due to software packages, larger views of an area are possible, and the need for frequent updates is increasing 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. The characteristics of an image that need to be addressed are the following: 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 the satellite and the number and width of the bands. Temporal resolution describes when and at what intervals an image is captured. Extent refers to the amount of area covered by one image (Green, 2000).

High-resolution imagery supplies very detailed representations of site-specific qualities. By having detailed imagery it is possible to monitor pest damage tree by tree, distinguish forest types, determine wildlife habitat and assess fire management operations. Six 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. By using coarse (low) resolution imagery, borderline pixels may be counted in an area when they are not truly included in the area. Thus, errors ranging from 40-50% have been reported while estimating burn scars using an advanced very high resolution radiometer (AVHRR) (Hlavka, 2000). The error normally increases as the size of a parcel decreases. A modeling approach might be taken to increase accuracy while still using lower resolution images based on relationships between observations at fine and coarse resolutions (Hlavka, 2000).

Linear programming

Linear programming (LP) plays a major role in decision making and multiple objective management. LP is used to allocate resources of forestland while maximizing a given objective; therefore, it is very useful for forest management planning. Most studies on LP have not addressed the effect of inaccurate area estimation on harvest scheduling. In spite of this, LP proves to be useful in obtaining a better understanding of multiple objective management.

Research has been done on many aspects of LP and how it can be used for multiple objective planning. Curtis (1962) defined LP as a technique for specifying how to use limited resources or capacities of a business to obtain a particular objective. Forest property has many alternative solutions that affect how it is managed. These alternatives are sometimes hard to choose between unless aided by computer programs (Robak, 1984). Using LP requires certain characteristics be present to have an achievable objective. Landowner objectives must be clearly stated before anything can be solved, and restrictions or constraints also have to be accounted for before a solution can be considered optimal (Curtis, 1962). Curtis (1962) created a model for the management of 22,000 acres of forest land. Two objectives were specified with this model which were subject to many limiting factors (acres, budget, etc.); however, what is optimal for one piece of land will not necessarily be optimal for another. The assumption that present management is satisfactory plays a major role in deriving a management objective (Curtis, 1962).

LP is useful for many aspects of timber management. For example, LP can be used to assist choices on rotation age, thinning intensity, and silvicultural applications (Field, 1977). Since most publicly owned forests are managed for multiple-use, LP is very applicable. Most decisions made through LP allocate how much of a certain area should be devoted to a specific prescription (Dean, 1996). Halterman et al., (1973) showed that LP was used to achieve two outputs: timber and wildlife management. If these goals were managed without the aid of computers, the best combination might not be met. In a study of genetic improvement programs, LP was used to direct decisions made to maximize certain traits in tree breeding research (Land and Mattheiss, 1984).

LP is a desired tool for conducting research on alternative solutions for forest regulation and sustained-yield management. Hoepner et al., (1966) used LP to determine a schedule for timber harvest that maximized a property's present net worth. The solution for the problem provided a schedule of harvest over a 50-year period, if all assumptions remained valid for 50 years. Therefore, the solution of a model can only be as accurate as the data used in construction (Loucks, 1964). With all the information provided from a linear program, a forester is still needed to determine the effects of certain constraints on the final solution (Loucks, 1964).

A fair amount of research has been done on LP and area estimation in the past; however, the literature is limited on research relating these topics to harvest scheduling. Most work that has been done on LP was for production or strategic planning. Area estimation research has been limited to mainly the accuracy of the area estimate itself. Tree species used in studies found were mainly from the northern United States. Therefore, this research will prove beneficial to the body of knowledge in relationships between area estimation and forest management planning.

Methods

This study focuses on comparing alternative imagery used for stand delineation in forest management planning. Several delineators were used to interpret stand boundaries from two different images of the same area. A harvest-scheduling model will then be used to conduct a comparative analysis of the results taken from the actual interpretations. Objective function values will be compared to see how much the interpretation differences played a part in affecting the optimal value. Thus, by comparing values computed using different image interpretations the impact image attributes have on the harvest schedule can be determined.

In achieving the previously stated objectives, this study uses information obtained from John C. Stennis Space Center, an area with a diverse coastal environment. The Space Center is located on the Pearl River, in Hancock County, Mississippi. This study uses a 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 leader of the inventory conducted on the site.

Color Infrared (CIR) photographs were obtained for the block chosen, along with Positive Systems® imagery, to use in the comparison. These images were obtained from Stennis Space Center. The resolution for the Positive Systems® imagery used is 1 by 1 meter taken in the fall of 1998. The scanned aerial photographs have a resolution of .7 by .7 meters taken in the fall of 2000. Students that have completed a course in Forest Photogrammetry were chosen from Mississippi State University for delineation duties. Both images were then digitized using ERDAS Imagine software by these delineators. CIR band combinations were used to help differentiate forest types on both images (i.e. hardwood and pine). Once all delineations were completed the acreages were determined using ArcView GIS.

Although real data are used in this study, the goals of the landowner are hypothetical. To make the model realistic, silvicultural prescriptions determined for the project area are the most appropriate. WINYIELD 1.11 growth and yield software was used to determine an optimal management prescription that maximized land expectation value (LEV). Once this was determined, three separate prescriptions were then simulated with different initial cuts before converting to the max LEV prescription. Discussions with the Area Forester helped in the determination of management strategies to be implemented on the area. Each prescription will differ in some sense; however, each one will be applicable to the area. Costs associated with each prescription were obtained from Dubois et al. (2001). Example costs include: burning, herbicide use, planting, and logging costs. Stumpage price information was obtained from

TimberMart South for 2001. The costs and revenues were computed for a 35 year planning horizon. Net present values (NPV) were then determined for each prescription for use in the LP model.

Delineations do not include information on stand types; therefore, other information has to be used to assign stand types. A geographic information system (GIS), available for the area delineated, will be used to assign these stand types. Overlays of the delineations and the GIS layer will be done to assign the correct stand types; however, if problems arise in determining which stand type to use, plot data for a specific area can be used to assign the proper stand type. Areas that do not have plot data available will be compared visually to find similarities between spectral attributes of the questionable areas and then types will be assigned accordingly.

In determining which prescription is most desirable, an LP model will maximize the main objective and assist in determining the effect stand delineation has on harvest scheduling. This harvest schedule will be for a planning horizon of 35 years with activities occurring on a yearly basis throughout the forest area as a whole. An example of this program is as follows:

- Decision Variables
    - X_{ij}= number of acres of stand i treated with prescription j
    - α_{ij}= net present value (NPV) of stand i treated with prescription j
- Objective Function
    - MAX NPV = $\alpha_{11}X_{11}+ \alpha_{12}X_{12}+\ldots\ldots\alpha_{ij}X_{ij}$
- Constraints
    - available acreage
    - minimum/maximum volume cut
    - available budget
    - etc.

The hypothetical goal developed for the landowner is to maximize NPV. Net present values are found for each prescription using WINYIELD 1.11. Per-acre volumes were provided from inventory information collected in 2000 to determine the total volumes of certain stands. This information helped in determining current stand conditions and also showed what growth potential certain areas possessed. Other objectives given by the landowner will be looked at as constraints to the main objective. After the model is written, it can be solved using LINDO. The results can be viewed as an optimal schedule of activities for the forests given the specified objective function and constraints.

Preliminary results

Differences in delineation are being found between delineators, as well as between imagery. An interpreter of one image might say that an area has five stands and the next interpreter of the same image will say it is only one; whereas, an interpreter of the same image will say an area has one stand and on the other image say it is two or three stands (Figure 1). The reasons for differences on these interpretations can be attributed to the image attributes in some cases, but the main cause would be interpreter error. It is expected that additional differences will be shown once the model results are analyzed; however, the effect these different interpretations have on a harvest schedule is not yet determined.

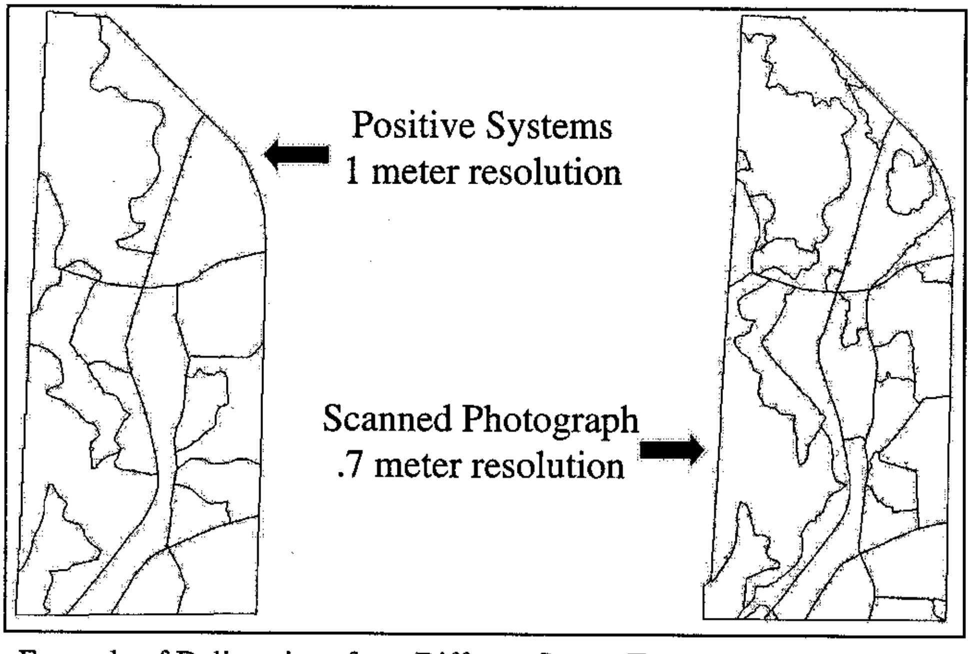

Figure 1. Example of Delineations from Different Image Types.

Future work

Further work is necessary to draw definitive conclusions on this topic. Areas that have been delineated still need to be typed and assigned the correct NPV's. The LP model will need to be completed to assess the impact of these estimates on the harvest schedule results. Finally, a sensitivity analysis will be conducted to determine what changes can be made in forest management to better benefit forest landowners.

Literature cited

Curtis, F.H. 1962. Linear Programming the Management of a Forest Property. Journal of Forestry. 60(9):611-616.

Dean, D.J. 1996. Timber Harvest Scheduling using linked GIS and Operations Research Techniques: Current Status and Future Developments. In: Proceedings of the Southern Forestry Geographic Information Systems Conference (G.J. Arthard and W.C. Hubbard, eds.). pp. 1-12.

Dubois, M.R., C.B. Erwin, and T.J. Straka. 2001. Costs and Cost Trends for Forestry Practices in the South. Forest Landowner. 60(2):3-8.

Field, D.B. 1977. Linear Programming: Out of the Classroom and into the Woods. Journal of Forestry. 75(6):330-334.

Forest Resources Systems, Inc. 2002. WINYIELD user's manual, version 1.11 edition. Forest Resources Systems, Inc., Clemson, SC. 78 p.

Green, K. 2000. Selecting and Interpreting High-Resolution Images. Journal of Forestry. 98(6):37-39.

Halterman, B.G., T.J. Lyon, R.L. Miller, and E.F. Thompson. 1973. Integrating timber and wildlife management planning. The Forestry Chronicle. 49(6):247-250.

Hlavka, C.A. 2000. Statistical Models of Landscape Pattern and the Effects of Coarse Spatial Resolution on Estimation of Area with Satellite Imagery. In: Mowrer, H.T. and R.G. Congalton, eds. Quantifying Spatial Uncertainty in Natural Resources: Theory and Applications for GIS and Remote Sensing. Chelsea, MI: Sleeping Bear Press. p. 161-169.

Hoepner, P.H., W.E. Kidd, Jr., and E.F. Thompson. 1966. Forest Regulation by Linear Programming-A Case Study. Journal of Forestry. 64(9):611-613.

Land, S.B. and T.H. Mattheiss. 1984. A Tree Breeding Strategy Based on Multiple Objective Linear Programming. Interfaces. 14(5):96-104.

LINDO Systems, Inc. 2001. LINDO user's manual: the optimization standard, version Hyper 6.1 edition. LINDO Systems, Inc., Chicago, IL. 298 p.

Loucks, D.P. 1964. The Development of an Optimal Program for Sustained-Yield Management. Journal of Forestry. 62(7):485-490.

Naesset, E. 1999. Effects of Delineation Errors in Forest Stand Boundaries on Estimated Area and Timber Volumes. Scandinavian Journal of Forest Research. 14(6):558-566.

Robak, E.W. 1984. Toward a Microcomputer-Based DSS for Planning Forest Operations. Interfaces. 14(5):105-111.

Wynne, R.H., R.G. Oderwald, G.A. Reams, and J.A. Scrivani. 2000. Optical Remote Sensing for Forest Area Estimation. Journal of Forestry. 98(5):31-36.