Estimation of Stand Volume from High Resolution Multispectral Images

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Abstract – **The demand for alternative methods by which stand volume can be estimated has been driven by information needs to ensure current forest management practises and harvesting activities are sustainable. In this study, stand density in stems/ha and percent crown closure from high resolution multispectral video (MSV) images were used in regression models as predictors of stand volume (m^3/ha) for softwood, hardwood and mixed-wood species. Regression models with stand height were not consistently stronger predictors of stand volume than those models based only on stand density and crown closure. Stand height and stand density were highly correlated for softwood and hardwood species which suggested that either but not both, are needed as predictor variables. Stand height is one variable that cannot be obtained from the image directly, and must be obtained from field measurements or from digital forest inventory data. Regression results obtained in this study suggest hardwood volumes may be possible from image-derived stand density and crown closure alone, but the predictions of mixed-wood species volumes were improved with the use of stand height. The ability to predict softwood volumes using MSV data were inconclusive due to the small sample size, but interpretation of the study results suggest method refinements for deriving stand density and crown closure are necessary.**

I. INTRODUCTION

Tree volume estimation in Alberta often begins with intensive measurements of individual trees in field plots that include species composition, height and diameter at breast height (DBH). This information is applied to ecologically-based volume equations (Huang 1994) for each species, which are subsequently aggregated to obtain estimates of stand volume by forest cover type (m^3/ha) within provincial Natural Regions (Achuff 1994). Methods to quantify and monitor timber volumes are necessary to ensure forest management practises are sustainable by calculation of the annual allowable cut (AAC). The principle behind the AAC is that the volume of wood harvested must not exceed the volume of wood that can be grown, thus ensuring that timber supply is sustainable.

The Alberta Vegetation Inventory (AVI) is a vegetation inventory system that provides the information base to prepare forest management plans, classify wildlife habitat, and undertake integrated resource management planning (Nesby 1997). Data collected for the AVI is based upon photo interpretation of medium-scale aerial photographs that define similar stands of vegetation with respect to species composition, height, crown closure, age, and productivity (Nesby 1997). Although AVI information is critical for producing a forest and vegetation inventory, it is insufficient alone at providing accurate estimates of stand volume. Volume information is usually obtained by installing large numbers of ground-measured plots within stratified AVI cover types. Such plots, however, are costly to establish, measure and maintain (Alberta Forestry, Lands and Wildlife, 1991). Inventory classification systems such as the AVI are also changing by requiring existing attributes to be mapped to a larger number of more specific classes (Nesby 1997). Volume sampling needs will continue to increase which supports investigations into alternative tree volume estimation techniques. One approach may be the role of high-resolution airborne data to complement AVI data acquisition.

Over the past decade, several remote sensing data sources and techniques have been tested to determine their applicability for estimating stand volume including; airborne laser scanners (Naesset, E., 1997; Nelson, R. *et al.*, 1997), airborne lidar systems (Nilsson, M., 1996), airborne profiling radar (Hyyppa, J. and M. Hallikainen, 1996), CASI (Franklin and McDermid 1993), and satellite (Wulf et al. 1990; Gemmell 1995; Trotter et al. 1997). Many of these research endeavours have demonstrated that medium to strong estimates of stand volume may be obtained by using various linear or non-linear models.

The objective of this research was to determine if stand volume could be estimated for softwood, hardwood and mixed-wood species from high-resolution multispectral video (MSV) images using a regression modeling approach. This objective was addressed by modeling volume per hectare (m^3/ha) as a function of species composition, stems per ha and crown closure from field measurements in comparison to these same variables derived from MSV images. Most models used to estimate volume, however, includes stand height (Huang 1994) which cannot be obtained directly from high-resolution MSV images. The intent of this research was to combine stand attributes derived from a high-resolution image with stand height from the AVI to predict stand volume. In this study, field-measured stand height was used as a surrogate for stand height that would otherwise be obtained from the AVI. For each species, the models developed from field and image variables were compared with those that incorporated stand height to determine if statistical improvements would occur in volume prediction.

II. METHODS

A. *Study Area*

The study site for this research was located on a south-west facing slope near Barrier Lake, in Kananaskis Country, Alberta at an elevation of approximately 1400 m. This site is within the Montane Forest Region M.5 (Rowe 1972) that is dominated by trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsamifera* L.), lodgepole pine (*Pinus contorta* Lamb.), and white spruce (*Picea glauca* [Moench] Voss). A further detailed description of the plant community types found within this study area is provided in Archibald *et al.* (1996).

B. *Field Data Collection*

Field data was collected during July, 1997 at fifteen field plots that included five for each species of softwood, hardwood and mixed wood. Plot size was 100 m^2, and plots were located along four transects that were surveyed along an east/west gradient. Field plots were located near each MSV image centre because previous work (Gerylo *et al.*, 1997) suggested radial displacement effects on the accuracy of species identification and classification would be minimized at near nadir positions.

Within each field plot, diameter at breast height (DBH) and total height was measured for each tree. Percent species composition was determined by calculating the frequency of each tree species, and crown closure was estimated with the aid of a spherical densiometer at five locations within each plot.

C. *Stand Volume Calculation*

Stand volume was calculated for each tree within plots using an Alberta Environmental Protection program written for the Statistical Analysis System (*SAS*) (Huang 1994). Tree variables including species, height, and DBH are applied to the volume equations to obtain estimates of stem volume. Individual tree volumes were totaled for each plot and divided by the plot area to determine plot volumes (m^3/m^2). Plot volumes were then converted to a per hectare estimate of stand volume (m^3/ha).

D. *Multispectral Video Images*

High-resolution Multispectral Video images were acquired on July 11, 1996 using three co-registered SONY CCD video cameras (Roberts, 1995) flown from approximately 150 m above ground that yielded a pixel size of 0.32 m by 0.25 m. Images were captured at three bandwidths which ranged from 490 to 565 *nm*, 585 to 660 *nm*, and 720 to 850 *nm*, respectively. Band-to-band registration was performed to eliminate a camera mis-alignment that occurred during the flight. Dark-object subtraction was performed on the images to reduce the effect of atmospheric aerosols.

E. *Feature Extraction from MSV Images*

Crown closure estimates were obtained by using a feature extraction technique that involved application of a high-pass Laplacian filter to isolate individual tree crowns (Gerylo *et al.* 1998). Filtered pixel values, which represented tree crown pixels, were written to a new image channel that was used for calculation of the percentage of tree crown pixels found within each plot to estimate crown closure.

Stand density was determined by a 3-step process that started with a 3 pixel by 3 pixel maxima filter to identify the locations of local maxima on the NIR channel of the multispectral video image. The brightest pixel within a tree crown was assumed to approximate the location of the tree apex. Due to the high-resolution of the image, however, gaps in the canopy resulted in large regions from which understory species were also identified as tree stems. To reduce the influence of the understory, a logical AND operation was performed with a Laplacian-filtered crown image as the second step. The third step was to estimate stand density by counting the total number of tree stems identified within each plot, and transforming this value to a per hectare basis.

Species composition was calculated by applying a species identifier to each identified tree stem, and calculating the proportion of each species found within every plot. Each stem location was given a species identifier by multiplying the stems image with a species classification image. Species classifications were performed by submitting training signatures of the sunlit side of tree crowns to the maximum likelihood classifier (Gougeon 1995). Classified tree species were then grouped into three categories that included softwood (>80% Pine and Spruce), hardwood (>80% Aspen), and Mixed - wood (<80% hardwood/softwood composition).

Stand height for each plot was measured in the field and used in both the field and image-based regression models to estimate volume. Depending on the informational utility of stand height in volume estimation, future applications could obtain this information from a digital forest inventory such as the AVI.

E. Statistical Analysis

Simple descriptive statistics were computed for the volume, stand height, stand density and crown closure variables for each species. Pearson's correlation coefficients were also computed between volume per ha and field and image variables to determine their relative association to volume. Due to the relatively small sample size of 5 plots for each species, transformations were not explored and each variable was assumed to be linearly associated with stand volume. Twelve regression models were fitted, six with stand height and six without stand height. Within each set of six regression models, equations from field and image variables that included stand density and crown closure were compared for softwood, hardwood and mixed-wood species.

TABLE 1
DESCRIPTIVE STATISTICS FOR FIELD AND IMAGE VARIABLES

Variable	Mean	Standard deviation	Standard error
Softwood: Field			
Volume (m3/ha)	271.8	34.2	15.3
Height (m)	16.6	2.3	1.0
Stand density (stems/ha)	920	690.6	308.9
Crown closure (%)	51.8	10.2	4.6
Softwood: Image			
Stand density (stems/ha)	940	296.6	132.7
Crown closure (%)	41.4	2.1	0.93
Hardwood: Field			
Volume (m3/ha)	285.0	60.2	26.9
Height (m)	16.6	3.3	1.5
Stand density (stems/ha)	1980	962.8	430.6
Crown closure (%)	54	5.9	2.6
Hardwood: Image			
Stand density (stems/ha)	1540	450.6	201.5
Crown closure (%)	48	1.0	0.4
Mixed wood: Field			
Volume (m3/ha)	305.5	41.4	18.5
Height (m)	17.1	1.3	0.6
Stand density (stems/ha)	940	336.1	150.3
Crown closure (%)	60.8	3.8	1.7
Mixed wood: Image			
Stand density (stems/ha)	880	249	111.4
Crown closure (%)	45.8	3.6	1.6

III. RESULTS

Descriptive statistics for stand volume and height derived from field measurements, and stand density and crown closure obtained from both the field and MSV images are summarized in Table 1. For the 15 plots, crown closure estimated from MSV images were 80% accurate when compared to field measurements. Crown closure estimates derived from the image were also smaller and therefore conservative when compared to field measurements obtained with a densiometer. Stand density expressed as number of stems per ha was similar for softwood, but underestimated for hardwood and mixed wood (Table 1). On average, stand density derived on MSV images was 62% accurate.

Among the three species, the correlation coefficients between height and volume were lowest for hardwoods and highest for softwoods (Table 2). These values are directly attributed to the relative ease with which conifer heights can be measured in comparison to hardwood species. Correlation coefficients between stand density and stand volume were also generally higher than the correlation between stand height or crown closure and stand volume (Table 2). Field-measured stand density and crown closure were also, on average, more highly correlated with stand volume than these same variables estimated from MSV

TABLE 2
PEARSON'S CORRELATION COEFFICIENTS

Stand volume	Stand height	Stand density	Crown closure	Stand height vs. Stand density
Softwood: Field				
Stand volume	-0.68	0.80	-0.33	-0.92
Softwood: Image				
Stand volume	-0.68	0.65	0.42	-0.18
Hardwood: Field				
Stand volume	-0.19	0.37	0.49	-0.95
Hardwood: Image				
Stand volume	-0.19	0.12	-0.04	0.93
Mixed wood: Field				
Stand volume	-0.46	0.65	-0.76	-0.18
Mixed wood: Image				
Stand volume	-0.46	0.50	0.30	-0.15

is necessary. Both softwood and hardwood stand height and stand density correlation coefficients exceeded 0.92, which may suggest both variables are not needed in a regression model to predict stand volume.

Regression models with stand height were not consistently stronger predictors of stand volume compared to those based only on stand density and crown closure (Table 3). Using field variables, softwood and hardwood equations without stand height had higher adjusted R^2 and lower root mean square errors (RMSE) than those with stand height (Table 3). Models to predict mixed-wood species stand volume, however, were better predictors with stand height.

Hardwood volumes were predicted with the highest adjusted R^2 value of –0.96 using stand density and crown closure from MSV images. When stand height was added as a predictor variable, mixed-wood volumes were predicted with the second highest adjusted R^2 value of -0.82. The difficulty in estimating softwood stand volume suggests improvements to the digital image estimates of stand density and crown closure are necessary. The correlation coefficient between stand density and stand volume was 0.80 for the field data but only 0.65 for the image data (Table 2). A relationship should also exist between stand density and crown closure. The correlation coefficient for the field data between these two variables was –0.78, but only –0.29 for the MSV image data. Improvements to the estimation of stand density and crown closure on the MSV image may improve the ability to predict stand volume. A larger sample size, however, would also permit separate equations to be developed for lodgepole pine and white spruce. For the data used in this study, the regression equations explained 96% and 82% of the variation in stand volume for hardwood and mixed-wood species, respectively, whereas only 22% of the explained softwood stand volume was achieved (Table 3).

IV. DISCUSSION

The study results verify the supposition that stand volume can be estimated with stand parameters derived from high-resolution MSV image data. The extent to which the study results can be applied, however, is dependent on constraints imposed by sample size and the judicious selection of appropriate variables by species to estimate stand volume. Regression model performance varied with field and image

TABLE 3
STAND VOLUME EQUATIONS FROM MULTIPLE LINEAR REGRESSION

Regression models	Adjusted R^2	Root Mean Square Error
Regression models with stand height:		
Field:		
Softwood: Stand volume = 42.28 + 2.15 (Stand height) + 0.07 (Stand density) + 2.42 (Crown closure)	0.49	24.5
Hardwood: Stand volume = -1186.9 + 45.62 (Stand height) + 0.16 (Stand density) + 7.54 (Crown closure)	0.24	52.2
Mixed wood: Stand volume = 1463.2 – 22.7 (Stand height) – 0.03 (Stand density) – 12.11 (Crown closure)	0.98	5.67
Image:		
Softwood: Stand volume = 380.77 – 32.9 (Stand height) – 0.19 (Stand density) + 14.81 (Crown closure)	0.22	30.19
Hardwood: Stand volume = -25.04 – 44.32 (Stand height) + 0.31 (Stand density) + 11.64 (Crown closure)	-0.02	60.77
Mixed wood: Stand volume = 363.7 – 21.8 (Stand height) + 0.02 (Stand density) + 6.59 (Crown closure)	-0.82	55.95
Regression models without stand height:		
Field:		
Softwood: Stand volume = 76.98 + 0.07 (Stand density) + 2.53 (Crown closure)	0.74	17.43
Hardwood: Stand volume = 31.79 + 0.01 (Stand density) + 4.19 (Crown closure)	-0.44	72.16
Mixed wood: Stand volume = 681.31 + 0.03 (Stand density) – 6.60 (Crown closure)	0.19	37.15
Image:		
Softwood: Stand volume = 35.55 + 0.07 (Stand density) + 4.19 (Crown closure)	-0.03	34.77
Hardwood: Stand volume = 452.34 + 0.02 (Stand density) – 4.08 (Crown closure)	-0.96	84.26
Mixed wood: Stand volume = 209.89 + 0.08 (Stand density) + 0.56 (Crown closure)	-0.49	50.57

data and whether stand height were incorporated into the model.

The root MSE values for prediction of stand volume ranged from 30 to 84 m^3/ha (Table 3). Improvements are needed to reduce these root MSE values before the regression models could be considered acceptable for operational use. Differences in model performance, however, were observed for different species. Investigations of alternate model forms are needed, but this would only be possible with larger sample sizes.

Stand density, crown closure and/or stand height served as predictor variables of stand volume. Most models that are used to estimate volume incorporate a measure of total height (Avery and Burkhart 1994; Huang 1994). At present, stand height is the only variable that cannot be obtained from the image directly, and must be measured in the field or obtained from AVI data. High correlations that may exist among these predictor variables, however, can result in multicollinearity effects.

Stand height and stand density was highly correlated for softwoods and hardwoods (Table 2). Multicollinearity occurs when predictor variables are correlated with each other, and will influence the regression model by causing large variances and covariances for the least squares estimators of the regression coefficients (Montgomery and Peck 1982). Variations in stand density were much greater in mixed-wood stands that may explain in part, the lower correlation between stand height and stand density. The regression model to predict stand volume for mixed-wood species was therefore improved with the addition of stand height.

V. CONCLUSIONS AND RECOMMENDATIONS

Stand volume can be estimated with stand parameters derived from high-resolution MSV image data for hardwood and mixed-wood species. Stand height is needed as an additional predictor for mixed-wood species that may be obtained from field sampling or data integration with digital AVI data. The feasibility by which high-resolution images can be used to estimate stand volume, would be greatly enhanced if statistically adequate estimation could be achieved using image variables alone. Research directed at defining the extent by which image-derived stand attributes can be used to estimate stand volume may prove productive. At present, the volume prediction results for softwood species is inconclusive. It is apparent that the model form used to estimate volume will vary by species. A larger sample size over a greater range of vegetative conditions should be acquired and alternate model forms should be investigated.

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