Estimating Timber Volume in a multi-age Eucalyptus Plantation using temporal Landsat ETM+ imagery

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Abstract: Spatial estimation of timber volume is important in context of the businesses involved by helping to manage plantations more efficiently. Spatial estimates can also provide an accurate quantification of the above-ground carbon stock that can be traded under 'Clean Development Mechanism' projects of Kyoto Protocol. In this study, we demonstrate a methodology and show that timber volume in Eucalyptus Globulus plantation can be estimated using medium-resolution satellite imagery with visible and mid-infrared bands and temporal allometry data. Twelve Landsat ETM+ imageries were used to construct relationships with 4 years of allometry data from multi-age plantation sites in Chile. Necessary corrections and preprocessing were applied to both satellite imageries and allometry data prior to the analysis. Atmospheric correction, which is a critical part while dealing with temporal satellite imageries, were performed with an advanced image-based atmospheric correction procedure involving radiation transfer modeling, eliminating the need for additional atmospheric data. The results demonstrated that, mid-infrared band 5 (1.55-1.75 μm) followed by Band 2 (0.52-0.60 μm) of ETM+ were the strongest indicator for timber volume estimation. Several other vegetation indices were also checked for their usefulness in prediction of timber volume. The best vegetation index for estimating timber volume was found to be NDVIc as it eliminates the effects of canopy green-ness from canopy closure.
Keywords: Timber volume, DBH, height, Eucalyptus Globulus, Landsat ETM+.

1. Introduction

1) Background and significance

In order to estimate the timber volume in plantation projects, forest managers have been relying on inventory based approach which gives an averaged estimation of their plantation plots. Inventory based approach is often sufficient for homogenous and smaller plantations, but leads to errors when there is considerable variation in the plantation of even the same age due to climatic, soil and sivicultural conditions. Moreover, in large plantations, ground based survey methods are time-consuming, costly and laborious. In this context, in order to handle optimized response to changing market conditions, remote sensing is increasingly playing an important role by providing spatial data of equal quality for any part of the region or even the world. As [10] rightfully stated, information on plantation-resources of both economic and environmental value is being sought increasingly in detailed scale by the forest managers as they seek to increase economic return by matching harvest yield to the wood product type and grades, and remote sensing as a tool for mapping the harvest comes handy to none.

Here, in this paper we investigate the feasibility of estimating timber volume and related allometric parameters in spatial terms from low-cost medium resolution remote sensor of Landsat ETM+ in few varying age Eucalyptus Globulus plantations in Chile.

2) Timber volume estimation using RS in the past and this study

Optical passive remote sensing have been used in the past for estimating timber volume indirectly from remote sensing imageries or by integrating remote sensing derived variables to plant growth models which needs climatic, soil and sivicultural parameters for its estimation. Our study falls into the first category, which essentially involves formulating empirical relationship between features in remote sensing imageries and ground truth allometry data. Several works have been done, involving both plantations ([7], [10]) as well as natural forests ([4], [5], [9]). However, most of these studies are concentrated on conifer plantations or forests, and often involved single satellite imagery for a plantation or forests with varying age and in many cases with varying species. This study uses allometry data of individual trees spanning over 4 years and distributed over the plantations, and directly related them to the spectral features of near-concurrent ETM+ imageries. Twelve ETM+ imageries spanning over these 4 years (1999 ~ 2003) were used to temporally cover plots planted in the duration 1994 ~ 2001.

2. Study site

The study site is a commercial plantation in Chile owned by Mitsubishi Paper Corp. Ltd. Figure 1 shows the plantation plots marked red on a Landsat ETM+ band4 grey image subset. Plantations are mainly on flat plateaus surrounded by steep and narrow gullies running towards the ocean in the south-west. Weather in this region is mainly Meso-mediterranean type with average temperature of about 23^0 C in the summer and 6^0 C in the winter. Average rainfall is in the range of 20 – 250mm. The region has four seasons, Summer (Dec~Mar), Autumn, Winter (May~ Aug) and Spring.

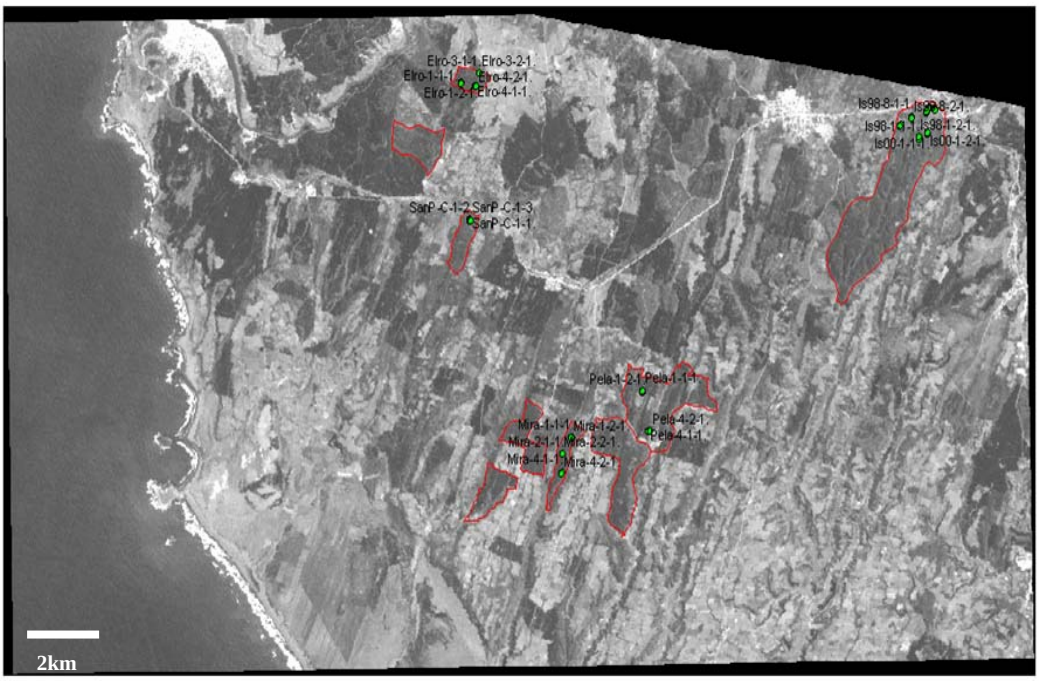

Fig. 1 Plantation plots (red) and ground truth data locations (green dots)

3. Data used

1) Allometry data

Four Years of allometry data were used in this analysis which were collected for the individual plantations. Data were collected for representative individual trees at the plots regularly, which included individual tree heights and DBH (Diameter at Breast Height of 1.3 m) at dates decided by the company managing it. Measurements were done starting from third year of plantation until the time of logging. GPS co-ordinates were available for only 19 locations across the plots for analysis (about half of total regular sampling locations) which were collected during a field trip to the site with a portable Digital Camera (Ricoh Caplio G3 Pro) with attached GPS receiver card (IOdata CFGPS2 card). Figure 1 shows the data locations (green dots) in the plantation plots which are used in this study.

2) Remote sensing data

Remote sensing data used in this study is from commercially available medium resolution Imageries from Landsat ETM+. Landsat ETM+ is an extension of the versatile Landsat TM sensor of NASA and has same visible and infrared bands that of TM. It has a ground resolution of 30 meters with a swath width of 185 km and visits the same position of the earth every 16 days making it suitable for monitoring plantations throughout a longer period of time with reasonable costs. To temporally cover the ground truth allometry data, a total of 12 ETM+ level 1G scenes were purchased from The University of Michigan's Center for Global Change and Earth Observations (www.landsat.org). Level 1G products are both radiometrically and geometrically corrected. Table 1 lists the band information for Landsat ETM+ sensor.

Table 1. Summary of Landsat ETM+ band information

	Band Width	Spatial Resolution
Band 1	**0.45 - 0.52µm (blue)**	**30 metres**
Band 2	**0.52 - 0.60µm (green)**	**30 metres**
Band 3	**0.63 - 0.69µm (red)**	**30 metres**
Band 4	**0.75 - 0.90µm (near infra-red)**	**30 metres**
Band 5	**1.55 - 1.75µm (mid infra-red)**	**30 metres**
Band 6	**10.4 - 12.50µm (thermal infra-red)**	**60 metres**
Band 7	**2.08 - 2.35µm (mid infra-red)**	**30 metres**
Band 8	**0.52 - 0.90µm (green - near infra-red)**	**15 metres**

4. Methodology

1) RS data preprocessing

Flowchart in figure 2 shows the pre-processing steps for remote sensing data. Absolute geometric precision is the first and one of the most important steps where ground truth data is related to satellite-received reflectances in a temporal scale. ETM+ level 1G products are geometrically corrected using data from onboard computers during imaging and re-sampled to the user-defined pixel size, map projection and rotation angle. However, this correction does not employ ground control or relief models to get absolute geodetic accuracy which may contribute to residual error of approx. 250 m in flat areas at sea level.

Lacking an adequate cartographic map for our study area, all ETM+ imagery subsets for the study area are registered to an IKONOS Pan imagery for the same area using affine transformation and with a RMSE of less than a pixel (30 m). We omitted orthographic correction from our analysis as all the locations of ground truth allometry data resided on flat parts of the plantations. For application of the developed relationships to parts of the plantations on the slopes however would require orthographic correction with a suitable DEM of the region for accurate spatial estimates of our parameters of interest.

Geometrically corrected satellite-derived digital numbers are converted to at-ground reflectances using the modified dense dark vegetation (MDDV) algorithm after [8] which utilizes image-based information for atmospheric correction using a radiative transfer model such as 6S (Second Simulation of the Satellite Signal in the Solar Spectrum). To reduce the inherent noise in the image and to reduce the effects of errors due to image registration and the limited spectral and

spatial resolution of the imagery, a low pass filter of 3x3 is applied.

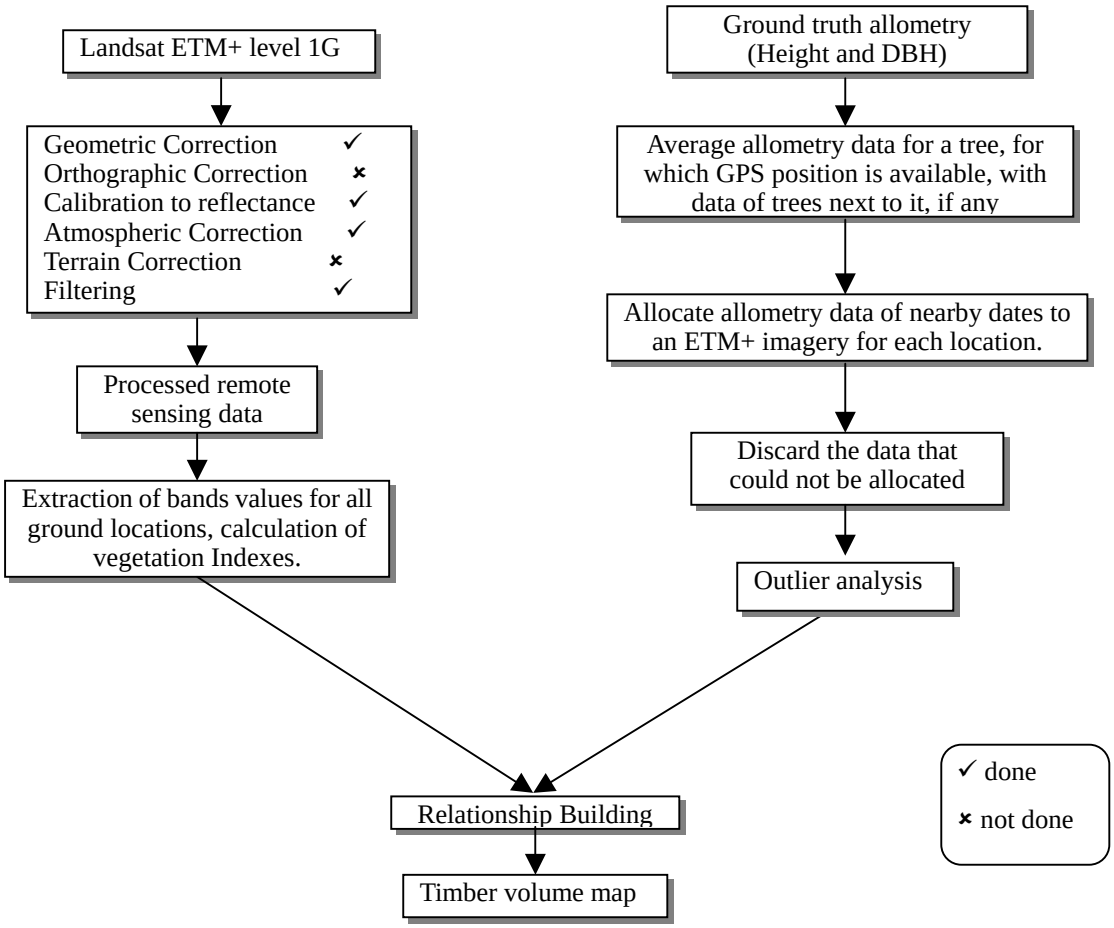

Fig. 2 Research flow for timber volume estimation methodology adopted in this study

2) Data grouping

As the dates of ground-truth data collection were different from the dates of satellite overpass, it was necessary that, the available allometry data be properly allocated to an ETM+ scene for each ground-truth allometry data location. We assumed that an ETM+ imagery taken on day D of the year will be able to represent allometry data taken within day (D-30) to (D+30) of the same year. Any allometry data not satisfying the above condition were eliminated from the analysis.

3) Outlier Removal

Removal of outliers is important as inclusion of bad data severely affects the relationships. As a first step, Mahanoblilis distance with a Jacknife approach was employed to remove the outliers. Data from two locations were consistently found to be erroneous and hence eliminated.

4) Calculation of Timber volume

Ground truth timber volume data was calculated for locations and dates where both tree height and DBH values were available. Timber volume was calculated using the equation below :

$$V = a + b * (DBH^2) * H \qquad (1)$$

where, a & b are constants, V is theTimber volume, DBH is diameter at breast height and H is tree height.

After logging, timber volume was calculated for the sampled trees using the expression below (Smarian type):

$$V = (BD^2 + UD^2) * L * 3.14/80000 \quad (2)$$

where, BD is the diameter at log base, UD is diameter of log head and L is log length.

Table 2. Indices used in this study

Vegetation index[a]	Formula[b]
NDVI	$\frac{NIR - Red}{NIR + Red}$
NDVIc	$\frac{NIR - Red}{NIR + Red} \times \left[1 - \frac{(MIR - MIR_{min})}{(MIR_{max} + MIR_{min})}\right]$
SR	$\frac{NIR}{Red}$
SRc	$\frac{NIR}{Red} \times \left[1 - \frac{(MIR - MIR_{min})}{(MIR_{max} - MIR_{min})}\right]$
SAVI	$\frac{1.5(NIR - Red)}{NIR + Red + 0.5}$
SARVI	$\frac{25(NIR - Red)}{1 + NIR + (6 \times Red) - (7.5 \times Blue)}$
SLAVI	$\frac{NIR}{Red + MIR2}$
Infrared Index	$\frac{NIR - MIR1}{NIR + MIR1}$

[a]NDVI, Normalized Difference Vegetation Index; NDVIc, NDVI with middle-infrared (MIR) correction; SR, Simple Ratio; SRc, SR with MIR correction; SAVI, Soil Adjusted Vegetation Index; SARVI, Soil and Atmosphere Resistant Vegetation Index; SLAVI, Specific Leaf Area Vegetation Index.
[b]NIR, near infrared; tm, Landsat Thematic Mapper (followed by band number).

5) Relationship Building and map generation

Atmospherically corrected reflectances for all the ground truth locations were extracted from the 12 ETM+ imageries and for visible bands (1,2 and 3), near infra-red band (4) and mid-infrared bands (5, 7). Vegetation Indexes used in this study are listed in table 2. For NDVIc, MIR_{min} (fully closed canopy)and MIR_{max} (open canopy) values were extracted from each imagery manually.

Best linear relationships are selected for generating the maps. Timber volume map can be generated by using directly the best relationship for timber volume, or from the height map and DBH map generated from best DBH and height relationships. Here we used DBH and height maps to generate volume map.

5. Results and discussion

1) Relationships with bands and VIs

Figure 3 shows the regression results between ETM+ reflectances and different indices, and allometry variables. Figure 4 shows the best relationships between ETM+ spectral features and allometric variables of height and DBH.

From correlations with atmospherically corrected Landsat ETM+ bands, it was found that, near infra-red band 5 was the best predictor for height, DBH and timber volume followed by band 2 in the study site. Similar results were found by previous studies, mainly in conifer species. Mid-infrared region being the most sensitive to changes in forest wood volume, reflectance in this region were found to be directly related to the extent of canopy closure ([1], [6]). Our results closely resembles to the case study by [7] in a conifer plantation in Galloway, England. Similar to [7], we found that, canopy reflectance in MID-IR band 5 decreases very sharply during the early stages of growth and then levels off once the forest stand starts to

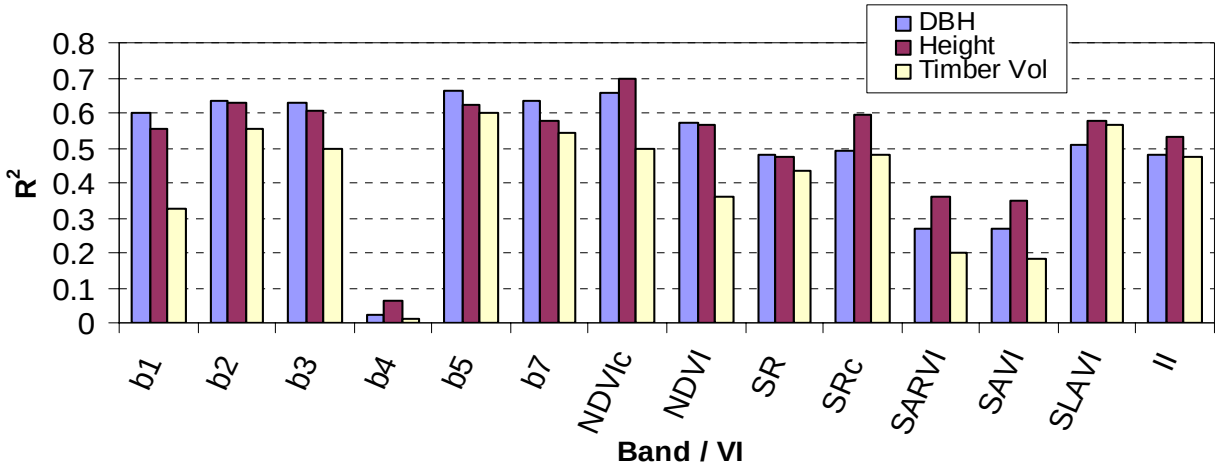

Fig. 3 Coefficients of determination (R^2) between allometry variables and different indices, and ETM+ band reflectances

reach a height of 15m. This is the point where the under-story canopy is starved of its light for survival and ceases to exist. These results are consistent with several previous studies which suggested that, the effect of the highly reflective under-story vegetation is the primary factor in making mid-IR the better predictor than NIR band. Due to larger leaf angle scattering albedo in mid-IR, crown development has a much stronger counteracting effect on reflectance decreases than from reduction in under-story vegetation [7]. Canopy shadowing is another important variable in determining mid-infrared response and thought to be at least as important as canopy water changes ([2], [6]). In our case, competition gave rise to thinning of the stands and larger spacing between them, which contributed to more shadowing on adjacent stands. Despite the growth to relatively closer canopies, gaps remained exposing a shadowed background contributing to lesser reflection in mid-IR band 5. This also explains why the correlation with NDVI and other indexes were low, whereas correlation with SLAVI or NDVIc is higher.

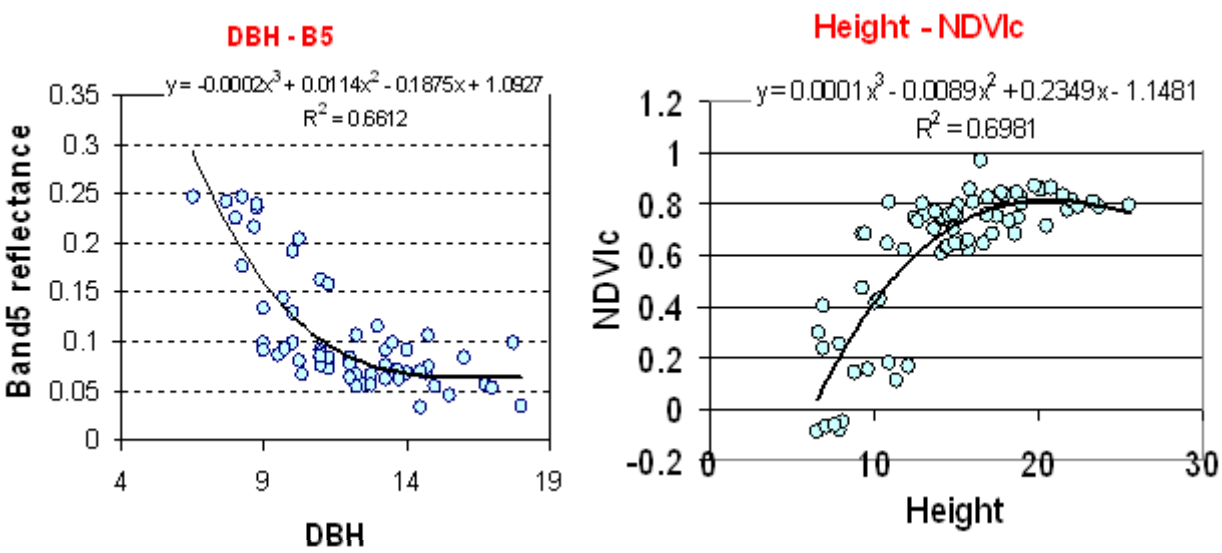

Fig. 4 Best relationships for DBH and Height

2) DBH, Height and Volume map

Generated DBH, height and timber volume maps from ETM+ imagery on 2003-05-18 are shown in figure 5.

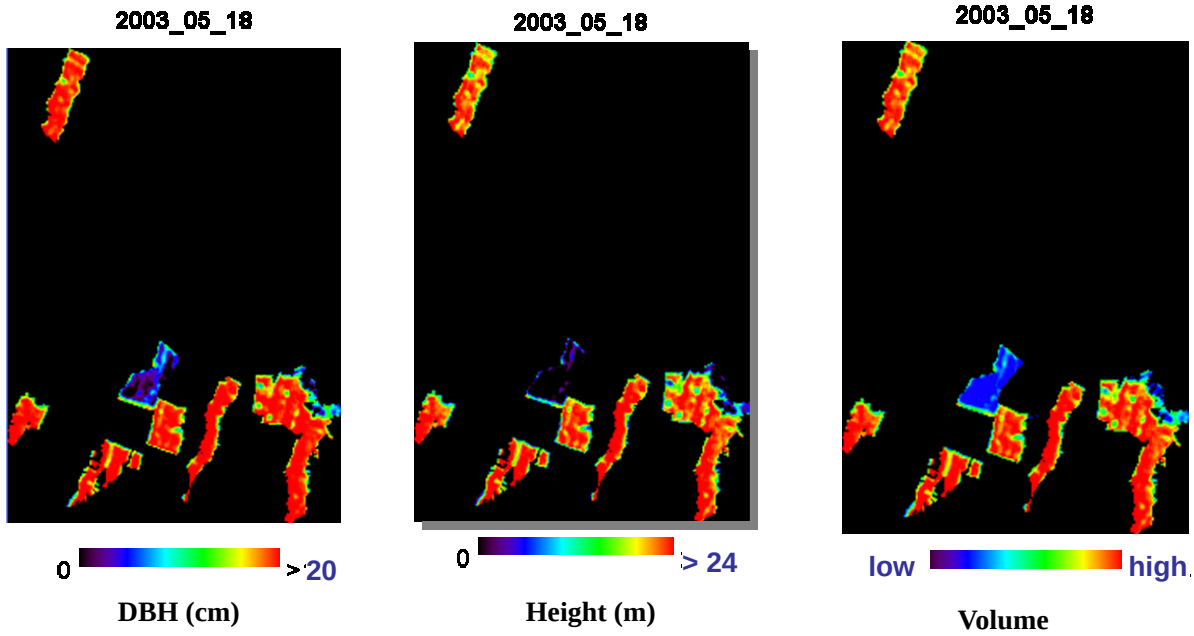

Fig. 5 Generated DBH, height and volume maps for 18th May, 2003

6. Conclusions and recommendations

Tree level data for allometric variables of height, DBH and timber volume have been found to correlate high with Landsat ETM+ features in the Eucalyptus Globulus plantation at the study site. The developed models could be considered time and space-independent across the study region as they included data spanning across the wide landscape and plantations of different age. Effect of under-story vegetation on the ETM+ features were evident but could not be analyzed quantitatively due to the lack of proper data. Due to this effect, mid-IR band 5 came out to be the strongest predictor for DBH, height and timber volume followed by green band 2. This strong correlation of mid-IR band with the allometric variables have led to stronger correlation of indexes which included mid-IR bands, such as NDVIc or SLAVI, in comparison to others. Best DBH and height models were used to generate volume map.

In future, it is suggested that, better estimation of timber volume can be achieved through an object-oriented approach by considering the factors involving the data to be used, the methodology to be employed and sivicultural as well as sampling practices to be employed in the field. Firstly, sensors with smaller view angles have been suggested to produce better correlation between forest stand variables and red radiance features by previous studies. Moreover, higher resolution sensors with narrower bands will most likey improve the estimation as found previous studies. Secondly, a suitable ground allometry data collection scheme with a view to aid remote sensing and modeling research can greatly improve the results and make it easy to develop a systematic operational monitoring scheme. Smaller ground survey plots, which is also the case in this study, is one of the common problem with the analysis of the satellite imagery, often making the ground truth data not representative of the area that contributes to the reflectance of the pixel. Bigger ground survey plots, of at least the size equal to the ground resolution of the sensor is suggested. Moreover, data on under-story vegetation can greatly improve the capacity for analysis and interpretation of the remote sensing data and hence improve the estimates. Thirdly, pruning and thinning of the forest under investigation can affect considerably on the final result of the analysis. While employing temporal data, un-even sivicultural practices both temporally and spatially can make it difficult to get a good relationship between the feature spaces and the allometric variables. Therefore, accurate sivicultural information can help interpret the causes for weak relationships and eventually may help to improve it. Last but not the least, integrating the present remote sensing data to a model which can simulate the growth of the forest using climatic, soil and sivicultural practices can greatly increase our capacity for future predictions and to understand about climatic, soil and sivicultural factors acting on the growth of plantation forest. In the present study, developed model are often the snapshots of the present and the past, and only can be extended for the future if same climatic, soil or sivicultural conditions exist. But, as the growth models can incorporate the climate and soil effects dynamically, they are the best alternative for a sustainable, scientific and flexible plantation management practice. Detailed discussion on this scheme is itself a separate broad study area requiring model tuning, validation of the results and generation of phonological parameters from remote sensing imageries.

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References

[1] Butera, M. K., 1986. A correlation and regression analysis of percent canopy closure versus TMS spectral response for selected forest sites in the San Juan National Forest, Colorado. *IEEE Transactions on Geoscience and Remote Sensing*, 24, 123–129.

[2] Cohen, W. B., and Spies, T. A., 1992. Estimating structural attributes of Douglas-fir/western hemlock forest stands from Landsat and SPOT imagery, *Remote Sens. Environ.* 41:1-17.

[3] Curran, P. J., and Hay, A. M., 1986. The importance of measurement error for certain procedures in remote sensing at optical wavelengths. *Photogrammetric Engineering and Remote Sensing*, 52, 229–241.

[4] Fazakas, Z., Nilsson, M., Olsson, H., 1999. Regional forest biomass and wood volume estimation using satellite data and ancillary data, Agricultural and Forest Meteorology 98-99 : 417-425.

[5] Gemmel, F. M., 1995. Effects of forest cover, terrain, and scale on timber volume estimation with thematic mapper data in a Rocky Mountain site. *Remote Sensing of Environment*, 51, 291–305.

[6] Horler, D. N. H., and Ahem, F. J., 1986. Forestry information content of Thematic Mapper data, *Int. J. Remote Sens.* 7(3): 405-428.

[7] Puhr, C.B., and Donoghue, D.N.M., 2000. Remote sensing of upland conifer plantations using Landsat TM data: a case study from Galloway, south-west Scotland. Int. J. Remote Sens., 21(4): 633-646.

[8] Song, C., and Woodcock, C.E., 2003. Monitoring forest succession with multi-temporal Landsat Images: Factors of Uncertainty, IEEE Trans. Geoscience and Remote Sens., 41(11): 2557~2566.

[9] Tomppo, E., Nilsson, M., Rosengren, M., Aalto, P., and Kennedy, P., 2002. Simultaneous use of Landsat-TM and IRS-1C WiFS data in estimating large area tree stem volume and aboveground biomass. Remote Sensing of Environment, 82 :156–171.

[10] Trotter, C. M., Dymond, J. R., & Goulding, C. J., 1997. Estimation of timber volume in a coniferous plantation forest using Landsat-TM. International Journal of Remote Sensing, 18, 2209– 2223.