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A preliminary comparison of Landsat Thematic Mapper and SPOT-1 HRV multispectral data for estimating coniferous forest volume

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Abstract. Digital Landsat Thematic Mapper (TM) and Satellite Probatoire d'Observation de la Terre (SPOT) High Resolution Visible (HRV) images of coniferous forest canopies were compared in their relationship to forest wood volume using correlation and regression analyses. Significant inverse relationships were found between softwood volume and the spectral bands from both sensors ($P < 0.01$). The highest correlations were between the log of softwood volume and the near-infared bands (HRV band 3, $r = -0.89$; TM band 4, $r = -0.83$).

1. Introduction

The potential to extract forest volume information from remotely sensed satellite sensor data could substantially aid inventories of forest resources. In this study, we examined the capabilities of both the Landsat Thematic Mapper (TM) and SPOT HRV multispectral satellite data to extract forest volume information. The TM has six reflective spectral bands with 30 m spatial resolution plus a thermal band, while SPOT has three reflective spectral bands with 20 m resolution (table 1).

There is normally an inverse relationship between vegetation amount and both visible reflectance (0·4 to 0·7 μm) and middle-infrared reflectance (1·3 to 2·6 μm) because of highly absorbing plant pigments and strong absorption from water in the leaves respectively (Curran 1980, Ripple 1986). Conversely, near-infrared reflectance typically has a direct relationship with vegetation amount because of scattering and little or no absorptance (Curran 1980). Researchers have found that this direct relationship in the near-infrared with increasing amounts of conifer biomass does not always exist. The near-infrared response can be flat (Franklin 1986, Peterson *et al.* 1987) or inverse (Danson 1987, Spanner *et al.* 1990) depending upon the amount and brightness of exposed understory or background.

A number of researchers have evaluated the potential for using SPOT HRV data (Danson 1987, De Wulf *et al.* 1990, Hame *et al.* 1988), TM simulator data (Franklin 1986), and TM data (Horler and Ahern 1986, Spanner *et al.* 1990) for estimating forest stand parameters, but only one study was found that compared SPOT and TM for monitoring forest stand parameters (Brockhaus *et al.* 1988). In the comparison study, several TM and SPOT bands were significantly correlated with basal area and stand age in coastal plain forests of North Carolina, although the authors concluded that these correlations were too low to be used in developing a predictive model (Brockhaust *et al.* 1988). Chavez and Bowell (1988) compared the spectral information content of TM and HRV data over geologic, urban, and agricultural sites in

Table 1. Comparison of Landsat TM and SPOT-1 HRV satellite sensor spectral characteristics for McDonald Forest study site (42,419 SPOT pixels and 21,120 TM pixels).

Landsat TM

Band	Spectral width (μm)	Digital numbers		
		Mean	S.D.	Range
1 (blue-green)	0·45–0·52	72·7	6·1	144
2 (green)	0·52–0·60	27·5	4·6	67
3 (red)	0·62–0·69	24·9	8·6	95
4 (near-IR)	0·76–0·90	94·7	20·4	145
5 (midle-IR)	1·55–1·75	59·5	23·2	139
6 (thermal-IR)	10·40–12·50	136·2	6·2	44
7 (middle-IR)	2·08–2·35	17·6	10·1	89

SPOT-1 HRV

Band	Spectral width (μm)	Digital numbers		
		Mean	S.D.	Range
1 (green)	0·50–0·59	28·2	4·2	105
2 (red)	0·61–0·68	17·8	5·4	91
3 (near-IR)	0·79–0·89	75·3	15·0	112

Arizona, U.S.A., and found the TM data contained more spectral information than the SPOT multispectral data, with TM bands showing field/soil information not available in the SPOT bands.

The objectives of our study were to compare information content of digital TM and HRV multispectral data over a forested test site and to examine the relationships between the sensor data and softwood volume. The study site was in McDonald State Forest located in the foothills of the Coast Range mountains just outside of Corvallis, Oregon (centred on 44° 37′ N lat., 122° 19′ long.). This forest is managed by the College of Forestry at Oregon State University. Douglas-fir (*Pseudotsuga menziesii*) is the dominant tree species. The study area consists of young forest plantations established after clearcutting and older forest stands (range 25–148 years old). Both deciduous shrub and herb understory are common throughout the forest. Precipitation averages 107 cm per year with most of it falling as rain from October through May.

2. Methods

The satellite sensor images were from a 25 July, 1988 HRV scene and a 30 July 1988 TM scene. The SPOT data were obtained at a +10·7° incidence angle and processed at level 1B. Sub-areas representing approximately the same geographic areas were extracted from each image using the following procedure. Screen images of both the TM and HRV images were projected to permit selection of a set of pixels representing the same ground features. For each feature, a pair of x, y locations were determined, one from the HRV data and one from the TM data. A least-squares multiple regression was used to develop a transformation model (Isaacson *et al.* 1987). This approach permitted the direct transformation between TM image space and HRV image space without a resampling or rectification to a common scale or projection, thereby better preserving the original data values for more direct comparison of the study area images. The study area consisted of 169 rows and 251 columns of HRV data and 120 rows and 176 columns of TM data. No corrections were made for path radiance.

Forty-six forest stands were delineated on both the TM and HRV screen images. The delineations were made at locations of approximately one pixel width in from the edge of the stands to reduce edge effect. The mean pixel digital number (DN) was calculated for each band for each of the 46 stands for both the TM and HRV data. Softwood volumes ranged from 28·3 to 839·5 m³ ha⁻¹. Forest stand areas ranged from 2·1 to 74·1 ha. The number of interior pixels in the 46 stands ranged from 12 to 566 for the HRV data and 3 to 258 for the TM data.

A correlation analysis was conducted on all spectral bands from both image subsets (n = 46). Softwood volume data were obtained from permanent timber inventory plots established and maintained by College of Forestry staff, with volumes determined using local tarif tree volume computation guidelines. Softwood volume represents the volume of wood in the bole of the conifers and is expressed in cubic metres per hectare (m³ ha⁻¹). Correlation, simple, and multiple regression analyses were conducted on the spectral band/softwood volume data set.

3. Results and discussion

All of the spectral bands were highly correlated, both within and between the TM and HRV data sets (table 2). Because of the relatively homogeneous forested area in our test site, the correlation coefficients between any two bands tended to be higher

Table 2. Correlation coefficient matrix for the HRV, TM, softwood volume, and log softwood volume variables ($n = 46$). All correlations were significant at the 0.01 probability level.

	HRV1	HRV2	HRV3	TM1	TM2	TM3	TM4	TM5	TM6	TM7	Volume	Log volume
HRV1	1.00											
HRV2	0.90	1.00										
HRV3	0.87	0.62	1.00									
TM1	0.77	0.82	0.62	1.00								
TM2	0.93	0.79	0.87	0.80	1.00							
TM3	0.88	0.87	0.72	0.85	0.91	1.00						
TM4	0.81	0.57	0.97	0.69	0.88	0.73	1.00					
TM5	0.87	0.70	0.86	0.73	0.91	0.81	0.87	1.00				
TM6	0.60	0.65	0.44	0.76	0.61	0.65	0.49	0.50	1.00			
TM7	0.87	0.74	0.77	0.64	0.88	0.78	0.75	0.95	0.48	1.00		
Softwood volume	−0.77	−0.63	−0.82	−0.61	−0.72	−0.69	−0.76	−0.63	−0.40	−0.55	1.00	
Log softwood volume	−0.83	−0.65	−0.89	−0.58	−0.82	−0.72	−0.83	−0.76	−0.38	−0.71	0.92	1.00

than would normally be expected. This was also found to be the case with spectrally homogeneous areas analysed by Chavez and Berlin (1984). Similar inverse relationships were found between softwood volume and the spectral bands from both sets of data. The correlation coefficients ranged from -0.63 to -0.82 for HRV bands and from -0.40 to -0.76 for TM bands. The slightly higher correlations for the SPOT data may be due to differences in spatial resolution, the wavelength range or position of the bands, or the signal to noise ratios. The higher spatial resolution of the SPOT HRV may be more sensitive to vegetation density than the lower spatial resolution of the TM data set, although the correlation coefficient is larger for TM band 3 (-0.69) when compared to HRV band 2 (-0.63). An examination of the scatter diagrams revealed inverse curvilinear relationships between many of the spectral bands and softwood volume.

Log transformations of softwood volume increased the correlation coefficients for a number of the HRV and TM bands (table 2). This was probably due to the asymptotic nature of these relationships as tree volumes increased in older stands with higher canopy closure (Ripple 1985). Figure 1 shows similar relationships for both TM band 4 with log volume ($r = -0.83$) and HRV band 3 with log volume ($r = -0.89$). These results confirm those found by Danson (1987), where HRV band 3 was inversely related to mean height ($r = -0.83$) of conifers and DeWulf *et al.* (1990) who found HRV band 3 to have the strongest relationship with forest stand parameters. We speculate that these inverse relationships were caused by (1) increased canopy shadowing within larger older stands, and (2) decreased understory brightness with the closing of the conifer canopy (Spanner *et al.* 1990).

With the HRV data, stepwise multiple regression ($P \leqslant 0.05$) resulted in only one independent variable (band 3) for predicting log softwood volume ($r = -0.89$). With the TM data set, bands 4 and 2 were significant using the stepwise procedure with log softwood volume as the dependent variable ($R^2 = 0.73$). The simple regression of log volume on TM band 4 alone explained just slightly less variance ($r^2 = 0.69$) than the stepwise procedure above. This indicates that the additional spectral bands available on the TM sensor may not contribute significantly to increasing the accuracy of
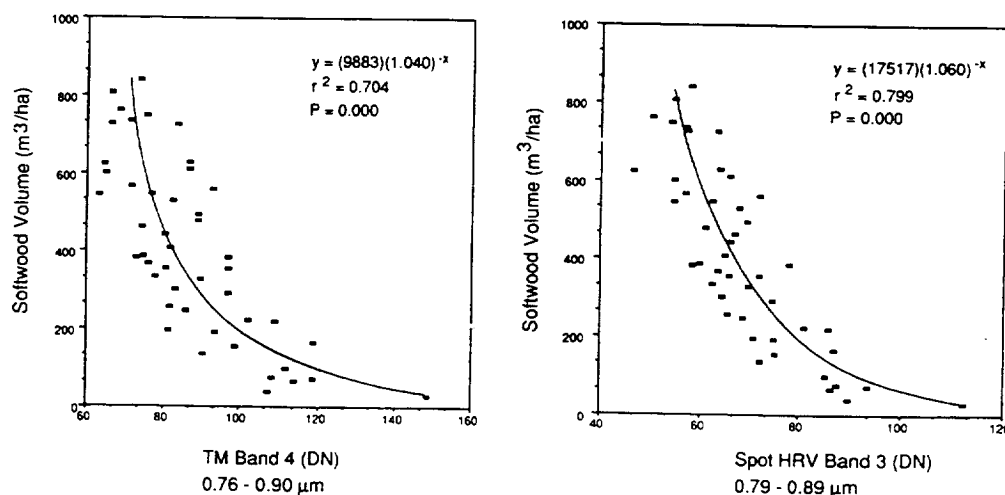

Figure 1. Scatter diagrams and results of regressing softwood volume on both TM band 4 and HRV band 3 for the McDonald Forest study site. Each point on the scatter diagrams represents 1 of 46 observations.

estimates of softwood volumes in relatively homogeneous Douglas-fir stands. Simple regression is preferred because when spectral bands are used as independent variables in multiple regression, intercorrelations among spectral bands can affect the regression coefficients and the sum of squares. It should be noted that the regressions in figure 1 involving softwood volumes were intended only for the comparison of HRV with TM data. In actual applications, line fitting corrections may be necessary (Curran and Hay 1986).

We believe the success of using the single-infrared bands to determine softwood volume was due to the following:

(a) Since the understory had a highly reflective shrub and herb layer, the young open conifer stands with low softwood volume had higher radiance than the older voluminous stands having more shadows, thus causing the strong inverse relationships.

(b) The dynamic range of the infrared bands were higher than the other spectral bands.

(c) The study area was relatively homogeneous and dominatd by Douglas-fir trees. In study areas that are heterogeneous with more than one vegetation cover type, multiband data sets will probably be critical for estimating softwood volume.

Under the conditions of this study, the following conclusions can be drawn:

(i) Both HRV and TM data sets exhibited high band to band correlations.

(ii) Both HRV and TM data showed similar significant inverse relationships with softwood volume.

(iii) We speculate that the inverse relationships were caused by canopy shadowing and/or the extent of the bright deciduous understory exposed to the sensor.

(iv) With the exception of the red bands (HRV band 2 and TM band 3), the HRV data had slightly higher correlations with softwood volume than the TM data. This was probably due to the higher spatial resolution of the HRV although differences in the location and width of the bands or the signal to noise ratios could also be factors.

(v) The near-infrared band was the most accurate for predicting softwood volume from both the HRV and the TM.

(vi) We speculate that inverse curvilinear relationships between spectral bands and softwood volume were caused by asymptotic charactristics of the forest canopy/spectral relationship.

Acknowledgments

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