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Forest tree species discrimination in western Himalaya using EO-1 Hyperion

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ABSTRACT

The information acquired in the narrow bands of hyperspectral remote sensing data has potential to capture plant species spectral variability, thereby improving forest tree species mapping. This study assessed the utility of spaceborne EO-1 Hyperion data in discrimination and classification of broadleaved evergreen and conifer forest tree species in western Himalaya. The pre-processing of 242 bands of Hyperion data resulted into 160 noise-free and vertical stripe corrected reflectance bands. Of these, 29 bands were selected through step-wise exclusion of bands (Wilk's Lambda). Spectral Angle Mapper (SAM) and Support Vector Machine (SVM) algorithms were applied to the selected bands to assess their effectiveness in classification. SVM was also applied to broadband data (Landsat TM) to compare the variation in classification accuracy. All commonly occurring six gregarious tree species, viz., white oak, brown oak, chir pine, blue pine, cedar and fir in western Himalaya could be effectively discriminated. SVM produced a better species classification (overall accuracy 82.27%, kappa statistic 0.79) than SAM (overall accuracy 74.68%, kappa statistic 0.70). It was noticed that classification accuracy achieved with Hyperion bands was significantly higher than Landsat TM bands (overall accuracy 69.62%, kappa statistic 0.65). Study demonstrated the potential utility of narrow spectral bands of Hyperion data in discriminating tree species in a hilly terrain.

1. Introduction

1.1. Species discrimination using remote sensing

Species-level information of the forests is essential for understanding their composition and distribution which in turn helps in monitoring large areas for sustainable management (Sobhan, 2007). Conventionally, species discrimination for floristic mapping involved exhaustive field work and is time-consuming as well as expensive (Kent and Coker, 1992). Remote sensing is advantageously used in such a situation to discriminate different species based on their unique spectral properties that is attributed to the species biochemical and biophysical parameters (Clark et al., 2005). The variation in concentration of biochemical constituents in plants also leads to variation in their spectral reflectance. However, subtle variations in reflectance of plants due to species taxonomic variability are difficult to resolve using multispectral remote sensing data. Hyperspectral data sets due to their relatively narrow bandwidth (5–10 nm) and large number of spectral bands (about 100–250) as compared to larger bandwidth (70–400 nm) multispectral data sets (5–10 bands) (Schmidt and Skidmore, 2003), has ability to resolve subtle absorption and reflectance features of plant species facilitating their discrimination and mapping.

1.2. Dimensionality reduction of hyperspectral data

The higher spectral resolution increases the dimensionality of hyperspectral data. Hence, it is absolutely necessary to reduce the number of bands and use only the optimal bands for further data processing. Several dimensionality reduction techniques such as principal component analysis (PCA), minimum noise fraction transform (MNF), stepwise discriminant analysis (SDA), decision boundary feature extraction (DBFE), sequential forward floating (SFF), steepest Ascent (SA), genetic algorithms (GA) (Asner and Heidebrecht, 2002; Landgrebe, 2003; Melgani and Bruzzone, 2004; Myint, 2001; Neville et al., 2003; Okin et al., 2001; Platt and Goetz, 2004; Rashed et al., 2003) have been described. PCA reduces the dimensionality of data by segregating noise from set of uncorrelated bands. MNF is a modified PCA which does data reduction more effectively than PCA by producing principal components with decreasing noise level. DBFE approach retains most of the original information while transforming the original feature space into a space of lower dimensionality (Melgani and Bruzzone, 2004).

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SFF minimize redundant contiguous bands applying local correlation criterion and subsequently uses a discriminative function for transformation of data into lower dimensionality feature space (Gomez-Chova et al., 2003). SA algorithm is used for feature optimization from multivariate datasets. GA is iterative pattern recognition technique for feature selection as well as classification. The optimal wavebands for target discrimination can be identified using multivariate separability measures such as Wilk's lambda (Thenkabail, 2002). SDA is easy to use and is widely used optimal band selection method (Jain et al., 2007; Lucas et al., 2008; Ray et al., 2010; Van Aardt and Wynne, 2001; Vyas et al., 2011). Vyas et al. (2011) identified 22 best Hyperion bands to discriminate eight tropical vegetation classes of tropical dry deciduous forests in Gujarat, India. Thenkabail et al. (2004) applied stepwise discriminant analysis and recommended 22 best narrowbands (from 168 hyperspectral bands), in the 350–2500 nm range to discriminate natural vegetation species of shrubs, grasses, weeds, and agricultural crops based on the hyperspectral data from African savannah.

1.3. Classification techniques for species mapping

Various classification methods, both parametric and nonparametric, are used for mapping species using hyperspectral data. Spectral Angle Mapper (Vyas et al., 2011; Clark et al., 2005), Linear discriminant analysis (Du and Ren, 2003; Clark et al., 2005); Decision tree classifier (Lawrence et al., 2004; Pal and Mather, 2003), Artificial neural networks (Erbek et al., 2004; Foody, 2004), Support Vector Machine (Dalponte et al., 2009; Plaza et al., 2009) and Random forest (Chan and Palinckx, 2008) are some of the advanced methods of hyperspectral data classification. SAM and SVM are the commonly used classifiers for hyperspectral data classification. SAM determines the spectral similarity, compares unknown image spectra with known endmember spectra by calculating the angle between the corresponding vectors in feature space (Kruse et al., 1993). SAM does not consider the absolute reflectance, but considers only the shape of different spectra (Waske et al., 2009), and contain the effect of topography and solar illumination on target classification. However, SAM is a non-iterative process, it therefore does not optimize classification accuracy from misclassified pixels (Soman et al., 2009). The iterative process based classification method such as SVM is therefore widely used for hyperspectral data classification. SVM is a supervised, non-parametric, machine learning technique. SVM does not depend on statistical data distribution (Mountrakis et al., 2011). SVM approach performs well with small training samples, even with data with hyper dimensional feature space are classified, because it only considers training data close to the class boundary (Melgani and Bruzzone, 2004; Pal and Mather, 2006). Both SAM and SVM classification approaches have features applicable to target discrimination in hilly region are therefore selected for comparison and development of efficient technique.

1.4. Tree species mapping in western Himalaya

In the temperate Himalaya, studies carried out using multispectral data have discriminated gregarious species, viz., chir pine (*Pinus roxburghii*), cedar (*Cedrus deodara*) and broadleaved species viz., grey oak (*Quercus leucotrichophora*), brown oak (*Quercus semicarpifolia*), etc., in their zone of dominance, primarily taking advantage of their association with altitude and aspect along with spectral information with reasonable accuracy. However, in the ecotonal zone (1750–2200 m amsl), it has not been possible to discriminate intermingled patches of gregariously occurring species, viz., white oak, brown oak, rhododendrons, fir, spruce (*Picea smithiana*), blue pine (*Pinus wallichiana*) solely based on spectral information without taking altitudinal reference. Since vegetation-topographical associations are generally inconsistent at local scale, classification incorporating topographic information results in arbitrary discrimination of intermixed species.

In this context, the present study was conducted to evaluate the potential of EO-1 Hyperion data for discrimination and classification of forest tree species in western Himalaya. The subobjectives of the study were: (i) to find out Hyperion wavebands useful for discrimination of gregarious forest tree species using step-wise discriminant analysis, (ii) to compare the performance of SAM and SVM algorithms in classifying forest tree species, (3) to assess the improvement in classifying forest tree species using narrow wavebands of Hyperion over broad bands of Landsat TM.

2. Study area

The study area, located between 30°25′50″ to 30°30′36″ N and 77°58′39″ to 78°04′51″ E, (Fig. 1), stretches from Purola to Sankri in the higher reaches of western Himalaya in Uttarakhand State of India, covers an area of 250 km^2. It includes Upper Yamuna and Tons Forest Divisions and also part of Govind Wildlife Sanctuary. The terrain is mountainous with altitude varying from 1600 m near Purola to 3940 m msl near Sankri. Two major rivers, i.e. the Yamuna and the Tons are noticeable in the area. The climate of the study area varies from sub-tropical at lower elevations to temperate and alpine at higher elevations. The rainfall varies from 1000 to 1500 mm annually.

The study area was selected considering the presence of a range of tree species, characteristics of western Himalaya. Due to the variation in rainfall, altitude and aspect, the study area supports three type groups of forest viz., the sub-tropical pine forests, Himalayan moist temperate and the Moist alpine scrub (Champion and Seth, 1968). The major tree species include chir pine (*P. roxburghii*), grey oak (*Q. leucotrichophora*), brown oak (*Q. semicarpifolia*), cedar (*C. deodara*), fir (*Abies pindrow*), spruce (*P. smithiana*), rhododendron (*Rhododendron arboretum*), etc. The patches of temperate and alpine grasslands and rocky slopes also occur in the study area.

3. Data

The Earth Observation-1 (EO-1) Hyperion and Landsat TM data of 2nd April 2010 and 3rd March 2010 respectively were downloaded from the USGS website (URL: glovisusgs.com). Cloud-free subsets of 33 km by 7.5 km from both the data were selected for the study. The EO-1 satellite is in an orbit that covers the same ground track as Landsat TM, approximately one minute later. This enables to obtain images of the same ground areas at nearly same time, so that direct comparison of results can be made for Hyperion and Landsat TM. Hyperion sensor images the area at 30-m ground sample distance over a 7.5 km swath and provides 242 spectral bands from 357 to 2576 nm at 10 nm sampling interval. Hyperion image was procured in L1R (radiometrically corrected) and L1T (terrain corrected and georeferenced image) data format. Hyperion scene of early summer (April month) was selected because of its higher signal to noise ratio owing to higher interspecies phenological variability and better solar illumination in the study area during that period.

The ancillary data *viz.*, Survey of India topographic sheets (53J/1, 53I/4, 53J/3, 53J/2) on 1:50,000 scale and latest forest working plans of Tons and Upper Yamuna Forest Divisions were also used for background information.