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Mapping beech (*Fagus sylvatica* L.) forest structure with airborne hyperspectral imagery

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ABSTRACT

Estimating forest structural attributes using multispectral remote sensing is challenging because of the saturation of multispectral indices at high canopy cover. The objective of this study was to assess the utility of hyperspectral data in estimating and mapping forest structural parameters including mean diameter-at-breast height (DBH), mean tree height and tree density of a closed canopy beech forest (*Fagus sylvatica* L.). Airborne HyMap images and data on forest structural attributes were collected from the Majella National Park, Italy in July 2004. The predictive performances of vegetation indices (VI) derived from all possible two-band combinations ($VI_{(i,j)} = (R_i - R_j)/(R_i + R_j)$, where R_i and R_j = reflectance in any two bands) were evaluated using calibration ($n = 33$) and test ($n = 20$) data sets. The potential of partial least squares (PLS) regression, a multivariate technique involving several bands was also assessed. New VIs based on the contrast between reflectance in the red-edge shoulder (756–820 nm) and the water absorption feature centred at 1200 nm (1172–1320 nm) were found to show higher correlations with the forest structural parameters than standard VIs derived from NIR and visible reflectance (i.e. the normalised difference vegetation index, NDVI). PLS regression showed a slight improvement in estimating the beech forest structural attributes (prediction errors of 27.6%, 32.6% and 46.4% for mean DBH, height and tree density, respectively) compared to VIs using linear regression models (prediction errors of 27.8%, 35.8% and 48.3% for mean DBH, height and tree density, respectively). Mean DBH was the best predicted variable among the stand parameters (calibration $R^2 = 0.62$ for an exponential model fit and standard error of prediction = 5.12 cm, i.e. 25% of the mean). The predicted map of mean DBH revealed high heterogeneity in the beech forest structure in the study area. The spatial variability of mean DBH occurs at less than 450 m. The DBH map could be useful to forest management in many ways, e.g. thinning of coppice to promote diameter growth, to assess the effects of management on forest structure or to detect changes in the forest structure caused by anthropogenic and natural factors.

1. Introduction

Information about the distribution of forest structural attributes such as tree diameter, basal area, height and density is essential for forest management. For example, thinning of high-density areas could promote diameter growth (Messina, 1992; Baldwin et al., 2000; Fuhr et al., 2001). Conventional forest inventory data have been collected by means of field surveys. Such surveys are time consuming, labour intensive and expensive when carried out over broad areas (Gower et al., 1999). Remote sensing, using current or anticipated air-spaceborne sensors is widely viewed as a time- and cost-efficient way to proceed with large-scale estimation of forest structural attributes.

A variety of remote sensors have been used in forest inventory studies including passive optical and active (radar and light detection and ranging (LIDAR)) sensors (Nilsson, 1996; Kasischke et al., 1997; Lefsky et al., 1999). The majority of sensors are broadband optical sensors such as Landsat^{TM}/ETM + and SPOT HVR with three to six broad spectral bands covering the visible, near infrared (NIR) and shortwave infrared (SWIR) regions (Woodcock et al., 1997; Franco-Lopez et al., 2001; Ingram et al., 2005). The most commonly used broadband remote sensing predictors of forest parameters are ratio indices (vegetation indices) computed from NIR and visible reflectance. The most known vegetation index is the normalised difference vegetation index (NDVI) developed by Rouse et al. (1974). NDVI is based on the contrast between the maximum absorption in the red due to chlorophyll pigments and the maximum reflectance in the NIR caused by scattering in the leaf mesophyll. For example, with increasing leaf area index (LAI) or canopy thickness, red reflectance decreases as leaf pigments

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absorb light, while NIR reflectance increases as more leaf layers are present to scatter the radiation (Gates et al., 1965). Thus, passive remote sensing of forest structural attributes such as tree diameter, height, density and biomass indirectly depends on the relationship between these parameters and parameters that have a direct control on the spectral reflectance such as LAI, canopy thickness and canopy biochemistry (Lefsky et al., 1999; Ingram et al., 2005). Broadband NDVI is a poor predictor of tree structural attributes for probably two reasons; firstly, broadband NDVI has been shown to saturate for a certain range of canopy cover or LAI ($LAI > 3$) (Sellers, 1985; Gao et al., 2000; De Jong et al., 2003) and secondly, broadband indices use average spectral information over broad bandwidths, resulting in loss of critical information (e.g. for canopy biochemistry) available in specific narrowbands (Gong et al., 2003; Thenkabail et al., 2004).

The advent of narrowband or hyperspectral (imaging spectroscopy) and LIDAR sensors has raised new expectations about the possibilities of improving the estimation of forest structural parameters. One hand, imaging spectroscopy can provide information on the cover, abundance and concentration of biochemicals and on the other hand, LIDAR can provide information on the cover, height, shape and architecture of vegetation (Lefsky et al., 2005; Asner et al., 2007). The use of imaging spectroscopy for forest stand structural estimation is based on the assumption that increased identification of particular spectral features associated with narrowbands could improve estimation of forest attributes compared to broadband sensors (Lefsky et al., 2001; Lee et al., 2004). However, it is difficult to infer from existing literature whether hyperspectral sensors provide an improvement over multispectral sensors for remote sensing of forest structural attributes. For example, Lefsky et al. (2001) observed a slight increase in the ability of airborne visible–infrared imaging spectrometer (AVIRIS) to predict forest stand attributes relative to single date Landsat^{TM} data, but a better performance of multitemporal Landsat^{TM} data. Gong et al. (2003) showed that indices involving NIR and SWIR Hyperion bands were better than NIR-red indices for LAI estimation. Lee et al. (2004) found no improvement of AVIRIS NDVI over ETM + NDVI for LAI estimation. The potential of hyperspectral data for estimating forest stand attributes for different ecosystems and seasons is not fully understood.

The objective of this study was therefore, to assess the utility of hyperspectral data in estimating and mapping forest structural parameters including mean diameter-at-breast height (DBH), mean tree height and tree density of a closed canopy beech forest (*Fagus sylvatica* L.).

2. Materials and methods

2.1. Study site

The study site was located in Majella National Park, Italy (latitude 41°52′ to 42°14′N, longitude 13°50′ to 13°14′E) covering an area of 74,095 ha (Fig. 1). The park extends into the southern part of Abruzzo, at a distance of 40 km from the Adriatic Sea. This region is situated in the massifs of the Apennines. The park is characterised by several mountain peaks, the highest being Mount Amaro (2794 m). The region is characterised by Mediterranean climate: hot and dry summers and cool and wet winters. The specific study site (latitude 41°49′ to 42°14′N, longitude 13°57′ to 14°3′E) is situated between Mounts Majella and Morrone to the east and west, respectively. It covers an area of 40 km by 5.5 km.

Over the last 60 years, depopulation, changes in the socio-economic conditions and the creation of the National Park in 1995 have led to a pronounced drop in the local demand for small size timber, firewood and charcoal (Ciancio et al., 2006). As a consequence, abandoned settlement and agricultural areas within the specific study area are returning to Oak woodlands at the lower altitude (400–600 m) and beech (*Fagus sylvatica*) forest at the higher altitude (1100–1800 m). Between these two formations is a landscape composed of shrubby bushes, patches of grass/herb vegetation and bare rock outcrops. The study was, however, limited to beech forest habitats at altitudes between 1100 and 1800 m. Many beech coppices in the site are returning to high forest. However, a combination of thinning and the occurrence of avalanches in Majella have given rise to a compound coppice, which is a mixture of coppice and high forest.

2.2. Image acquisition and processing

Airborne HyMap (Kruse et al., online) data of the study site were obtained on 15 July 2004. The flight was carried out by DLR,

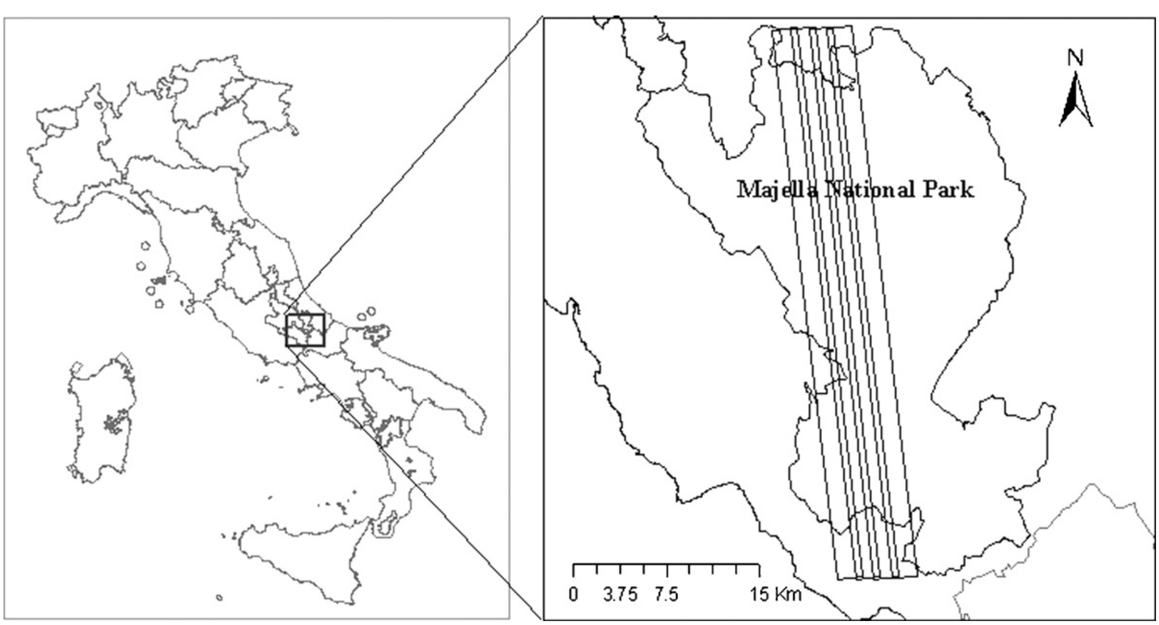

Fig. 1. Location of the Majella National Park, Italy and overlapping HyMap flight lines.