Available online at www.sciencedirect.com
SCIENCE DIRECT
Forest Ecology and Management 223 (2006) 45–53
Forest Ecology and Management
www.elsevier.com/locate/foreco

Estimation of tree canopy cover in evergreen oak woodlands using remote sensing

João M.B. Carreiras *, José M.C. Pereira, João S. Pereira

Department of Forestry, Instituto Superior de Agronomia, Tapada da Ajuda, 1349-017 Lisboa, Portugal

Received 1 April 2005; received in revised form 21 October 2005; accepted 24 October 2005

Abstract

The *montado/dehesa* landscapes of the Iberian Peninsula are savannah-type open woodlands dominated by evergreen oak species (*Quercus suber* L. and *Q. ilex* ssp. *rotundifolia*). Scattered trees stand over an undergrowth of shrubs or herbaceous plants. To partition leaf area index between trees and the herbaceous/shrubby understorey requires good estimates of tree canopy cover and is of key importance to understand the ecology and the changes in land cover. The two vegetation components differ in phenology as well as in radiation and rainfall interception, water and CO_2 fluxes. The main goal of this study was to estimate tree canopy cover in a *montado/dehesa* region of southern Portugal (Alentejo) using remote sensed data. For this purpose we developed empirical models combining measurements obtained through the analysis of aerial photos and reflectance from Landsat Thematic Mapper (TM) individual channels, vegetation indices, and the components of the Kauth–Thomas (K–T) transformation. A set of 142 plots was designed, both in the aerial photos and in the satellite data. Several simple and multiple linear regression models were adjusted and validated. A subset of 75% of the data ($n = 106$) was used for model fitting, and the remainder ($n = 36$) was used for model assessment. The best linear equation includes Landsat TM channels 3, 4, 5 and 7 ($r^2 = 0.74$), but the Normalised Difference Vegetation Index (NDVI), the components of the K–T transformation, and the Atmospherically Resistant Vegetation Index (ARVI) also performed well ($r^2 = 0.72$, 0.70, and 0.69, respectively). The statistics of prediction residuals and tests of model validation indicates that these were also the models with better predictive capability. These results show that detection of low/medium tree canopy cover in this type of land cover (i.e. evergreen oak woodlands) can be accomplished with the help of high and medium spatial resolution satellite imagery.

Keywords: Landsat Thematic Mapper (TM); Aerial photo; Linear regression; Evergreen oak woodlands; Tree canopy cover

1. Introduction

Savannah-type Mediterranean evergreen oak woodlands are widely distributed in the Iberian Peninsula, as well as in other areas with the Mediterranean type of climate, e.g., in parts of California, Chile, South Africa and Australia. These are complex ecosystems with open, heterogeneous canopies with shrub or annual herbaceous understories (Joffre et al., 1999; Baldocchi et al., 2004). In the Iberian Peninsula, large areas of these woodlands depend upon human action, forming a multiple use agroforestry system, called *montado* in Portugal and *dehesa* in Spain. For example, in Portugal, they cover an area of approximately 1.2 Mha (DGF, 2001). The most common oak species are holm oak (*Quercus rotundifolia* Lam. syn. *Quercus ilex* L. ssp. *rotundifolia*) and cork oak (*Quercus suber* L.). They are exploited for cork, wood and extensive agriculture or grazing, in proportions that vary with local conditions and history. The landscapes are typically heterogeneous and include three distinct variants, which differ in terms of land use intensity and land cover structure (Blanco et al., 1997):

- Relatively denser oak woodlands are more common in steep areas and poor soils, unsuitable for agricultural use. Land use intensity is low, and a diverse shrub community species dominates the understorey. In Portugal dense cork oak stands were planted for cork production in better soils.
- Pastures represent an intermediate level of land use intensity. Tree cover is sparser, and the understorey is dominated by a great variety of annual/biennial herbaceous plant communities. The productivity of these communities is dominated by climatic factors, and typically they display large interannual variability in plant cover.
- Dryland farming of cereal crops in areas with deeper soils, such as the bottom of valleys. During fallow years, these areas

* Corresponding author. Tel.: +351 213653387; fax: +351 213645000.
E-mail address: jmbcarreiras@isa.utl.pt (João M.B. Carreiras).

0378-1127/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2005.10.056

may be used as pastures. There is a tendency for abandonment of this type of agriculture and the *montado*/*dehesa* reverts to one of the former land cover types (Lourenço et al., 1998).

Tree density in *montado* ecosystems frequently ranges from 30 to 60 trees ha^{-1} (Blanco et al., 1997), but higher and lower densities are common. In Portugal, about half of the area of *Q. suber montados* has tree canopy cover in the 10–30% class, one quarter of the area in the 30–50% class, and the remaining quarter in the >50% tree canopy cover class, whereas holm oak woodlands are even sparser, with about 85% of the area in the 10–30% canopy cover class (DGF, 2001). These low tree densities result from specific land use objectives and management practices, which transformed the relatively denser primordial woodlands and forests into landscapes structurally similar to savannas.

The Mediterranean evergreen oak woodlands differ from tropical savannahs in the timing of rainfall, which in the former occur during the relatively cool autumn–winter months. This leads to severe water deficits during the hot Mediterranean summer. As a consequence large intra-annual variations in plant cover occur (Baldocchi et al., 2004). The understanding of ecosystem structure and function (e.g., radiation and rainfall interception, water and CO_2 fluxes) requires the partitioning of total leaf area index between the tree component and the herbaceous/shrubby understorey. The two vegetation layers differ in phenology and functioning. For example, whereas the sparse tree cover remains green and may have access to perennial water sources for year-long metabolic activity (David et al., 2004), the herbaceous layer dries out in the dry summer. In addition to the spatial and temporal heterogeneity, the *montado*/*dehesa* landscapes are today subject to rapid changes resulting from land abandonment, changing fire regimes and tree decline (Brasier, 1992, 1996; Terradas, 1999; Stoate et al., 2001; Romero-Calcerrada and Perry, 2004).

Given the economical, ecological, and historical significance of these ecosystems, it is important to monitor the changes that affect them, in a timely and cost-effective manner. Satellite remote sensing provides a potentially useful tool for such monitoring, but the problem is complex because of the intrinsic diversity, structural complexity, and seasonal variability of the *montado*/*dehesa* landscapes. The designation of a relatively broad range of land cover types, under a common land use name, leads to a problem of mismatch between informational classes (i.e. those meaningful to a user), and spectral classes (those which share similar spectral properties) (Swain and Davies, 1978). In the case of the *montado*/*dehesa* systems, informational land use classes tend to be very heterogeneous from the spectral standpoint, reflecting their internal ecological variability. This is a severe problem for qualitative land use mapping, where the goal is to discriminate between distinct land cover types. Quantitative characterisation of a biophysical attribute such as tree canopy cover is also quite challenging in these landscapes, because of the very broad range in tree density, and of the wide variety of understorey cover types. The signal (tree canopy) has to be detected and quantified against a very noisy background of bare soils, agricultural crops, pastures and shrubs.

The main goal of this study was to estimate tree canopy cover in a *montado*/*dehesa* region of southern Portugal (Alentejo) using remote sensed data. Several studies have produced good and promising results. Joffre and Lacaze (1993) used panchromatic SPOT High Resolution Visible (HRV) (10 m spatial resolution) and Landsat Thematic Mapper (TM) (30 m spatial resolution) satellite imagery to estimate tree density in a savannah-type ecosystem (holm and cork oaks), in southern Spain; tree density was estimated with reasonable accuracy through the application of spatial filters to the panchromatic SPOT HRV band ($r = 0.94$), from the original panchromatic SPOT HRV ($r = -0.85$), and using a combination of Landsat TM channels 2 (TM2), 3 (TM3) and 4 (TM4) ($r = -0.61$). Salvador and Pons (1998) used Landsat TM imagery combined with fieldwork to estimate dendrometric variables (including tree canopy cover) used in forest inventories in the Mediterranean region, relying on regression models; these were found to be consistent with the expected vegetation spectral response; most of the multiple linear regression models fit well the data, allowing quantitative predictions for several field variables from remote sensing data; the best linear regression ($r^2 = 0.64$) for predicting tree canopy cover in *Q. ilex* stands included Landsat TM channel 7 (TM7). Pereira et al. (1995) used Landsat TM imagery and fieldwork measurements to determine biomass, percent canopy cover and canopy volume in Mediterranean shrublands; the best results were obtained with the Normalized Difference Vegetation Index (NDVI) to estimate percent canopy cover ($r^2 = 0.65$). Oliveira (1998) used field radiometry and Landsat TM imagery to estimate several shrub parameters in the Alto-Dão e Lafões region (Portugal); field radiometry results showed that the Landsat TM3 channel was the one better correlated with canopy cover ($r = -0.91$) and the NDVI proved to be the vegetation index (VI) with better performance ($r = 0.75$); regarding the Landsat TM imagery, it was found that TM3, channel 5 (TM5), and TM7 yielded the better correlation with canopy cover ($r = -0.87$) and the Atmospherically Resistant Vegetation Index (ARVI) was the best VI ($r = 0.86$). Calvão and Palmeirim (2004) collected field data over Mediterranean shrublands and developed correlations between several biophysical parameters and spectral variables (single channel reflectance and NDVI) from Landsat TM data; the higher correlation for canopy cover was obtained with TM3 ($r = -0.91$) and NDVI ($r = 0.91$).

2. Study area and methods

The study area is located near the city of Évora (University of Évora/Mitra Campus, 38°32′N and 8°00′W), comprising an area equivalent to a Landsat TM mini-scene (approximately 50 km × 50 km). The data used in this study came from two distinct sources: 1-m spatial resolution ortho-rectified digital infrared aerial photography from a flight in the summer of 1995 (acquired between 28 August and 13 September) (Table 1) and 30-m Landsat TM imagery from the same year (acquired on 15 August). Proximity between the dates of the two data sources is