International Journal of Applied Earth Observation and Geoinformation 13 (2011) 517–527

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

Tree survey and allometric models for tiger bush in northern Senegal and comparison with tree parameters derived from high resolution satellite data

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ARTICLE INFO

Article history:
Received 31 March 2010
Accepted 27 January 2011

Keywords:
Tree inventory
Field survey
Tree clumping
Image analysis
Allometric models
Remote sensing

ABSTRACT

A tree survey and an analysis of high resolution satellite data were performed to characterise the woody vegetation within a 10 × 10 km^2 area around a site located close to the town of Dahra in the semi-arid northern part of Senegal. The surveyed parameters were tree species, height, tree crown radius, and diameter at breast height (DBH), for which allometric models were determined. An object-based classification method was used to determine tree crown cover (TCC) from Quickbird data. The average TCC from the tree survey and the respective TCC from remote sensing were both about 3.0%. For areas beyond the surveyed areas TCC varied between 3.0% and 4.5%. Furthermore, an empirical correction factor for tree clumping was obtained, which considerably improved the estimated number of trees and the estimated average tree crown area and radius. An allometric model linking TCC to tree stem crosssectional area (CSA) was developed, which allows to estimate tree biomass from remote sensing. The allometric models for the three main tree species found performed well and had r^2-values of about 0.7–0.8.

1. Introduction

Estimating tree cover from high resolution remote sensing data is a well established technique and has been employed in numerous studies (e.g. Bai et al., 2005; Bunting and Lucas, 2006; Carreiras et al., 2006; Culvenor, 2002; Hansen et al., 2002; Hirata et al., 2009; Leckie et al., 2003; Pouliot et al., 2002; Song et al., 2010). However, historically most often aerial photography was used to estimate stand parameters like tree size, stand density and, ultimately, stand biomass for forestry management applications. With the launch of very high resolution (approximately 1 m spatial resolution panchromatic) commercial satellites like Ikonos and Quickbird, it is now possible to perform similar studies with spaceborne sensors. The short revisit time, scheduling of image acqusitions and the relative low cost, make data from spaceborne sensors an attractive data source.

In this study we estimate the tree crown cover, number of trees and other tree parameters for a Quickbird scene covering an area close to the town of Dahra in semi-arid northern Senegal, West Africa. At first glance tree inventory analyses in areas like the one studied here appear to be of limited use, as tree resources are limited and the potential for economic exploitation is small. However, potentially relevant applications are long term change studies and the estimation of carbon stocks contained in the woody vegetation. The feasibility for increasing carbon storage in natural vegetation for areas with slightly more rain (approximately 600 mm/year) has already been demonstrated by, among others, Toure et al. (2003). The combination of field studies of tree parameters like height, trunk diameter, and biomass content (both above and below ground) with remote sensing based estimation of tree cover allows large scale inventories of both, current and future carbon stocks. However, the immediate motivation for this study is to characterise a wider area around a test site, which consists of two towers with instruments used for validating remote sensing products. Tree crown cover is an essential parameter in many applications of remote sensing data, as it significantly influences surface reflectance and temperature as well as surface anisotropy in the visible and in the thermal domain. It is planned to utilise tree crown cover and other tree parameters in a separate study of angular dependency of land surface temperature, e.g. as obtained from the

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doi:10.1016/j.jag.2011.01.007

Spinning Enhanced Visible and InfraRed Imager (SEVIRI) onboard Meteosat Second Generation (MSG) satellites. In order to upscale radiometric point measurements performed at the station to the size of meteorological satellite pixels (1–5 km), the relevant land cover components, e.g. trees and bare ground, and their relative cover fractions have to be known.

A wide range of methods for tree delineation and thus tree crown cover estimation exist, ranging from traditional classification methods, over texture analysis to object-based image analysis, which works on pixel clusters instead of individual pixels. Despite an abundance of available methods, only few studies have addressed areas with sparse tree cover and with trees covering a wide range of sizes and ages; in fact, most studies have been on forests and plantations.

Bai et al. (2005) used black and white, 0.5 m resolution aerial photographs for estimating the tree encroachment on grasslands in British Columbia, Canada. They used a maximum likelihood classification to distinguish between grasslands and forests, the latter being split into tree crowns and tree shadows. This distinction was made to identify the transition zone between tree crowns and the grasslands. They compared the retrieved tree crown cover estimates with ground measurements and found a good overall agreement, with a slight tendency for underestimation of tree cover from image analysis at most densities, with dense tree cover being the exception. Also applying a classification based method, Hansen et al. (2002) used IKONOS 1 and 4 m resolution data to estimate tree crown cover for a number of test areas in Zambia. They used texture maps, NDVI, and the raw multispectral channels to classify the images into "crown" and "not crown". They compared this to field measurements and reached r^2-values of 0.867. The results were upscaled to ETM+ and MODIS scale using a relation between NDVI and crown cover for the validation of the MODIS Vegetation Continuous Fields (VCF) product.

In order to identify individual trees or tree clusters, Leckie et al. (2003) segmented individual tree crowns using a spectral valley-tracing algorithm effectively treating the digital numbers (DN) as a height map. Subsequently they classified the individual crown/cluster objects according to species based on 0.6 m resolution multispectral airborne CASI-sensor data. The valley-tracing method relies on the contrast between the tree crowns and the gaps between canopies appearing bright and dark respectively, in order to identify the gaps between the crowns. In cases where the trees are clumped together, the trees cannot be separated using such an approach as the dark gaps are absent. Hirata et al. (2009) used a similar approach developed for the delineation of watersheds. Using an inverted panchromatic band from Quickbird scenes, crowns and crown tops appear as depressions like in a digital elevation model, allowing for the delineation of crowns as if they were watersheds. Another approach which is frequently applied, is the identification of crown centres by finding local maxima in spectral bands sensitive to vegetation (Culvenor, 2002). The crowns are then expanded from the centre points by expanding the area, either by specifying a threshold value or by a maximum allowed step pixel value. A third commonly applied technique is matching templates of trees with identified tree objects (Larsen and Rudemo, 1998). This requires a priori knowledge about tree structure and size, and also assumes that trees are not clumped.

An alternative, geo-statistically based method for tree crown estimation was proposed by Song and Woodcock (2003), who used semi-variograms of images at different spatial resolutions to identify tree crown size. They tested the method on synthetic data as well as on Ikonos data and found that the quality of the results depend largely on the ratio between image resolution and tree crown size, with the best results achieved for ratios close to unity.

The use of allometric models for forest inventories has a long history, but they are most commonly applied to mono-cultural commercial stands to estimate yields. Despite the broad application of these models, a wide range of different functions are used to model the relation between the parameters, which included trunk diameter at breast height (DBH), tree height, crown radius and crown area. Zhang (1997) discussed the use of six different functions for allometric models of DBH-tree height relationships. They found that the functions perform almost equally well in terms of r^2-values, but the main differences occurred in terms of the "saturation"-point for tree height. The saturation point is defined as the maximum tree height, which in terms of the mathematical function is the asymptote of the function. They concluded that the selection of the model should be based more on the predictive capabilities and robustness of the model rather than on its performance in terms of high r^2-values or root mean square error.

2. Study area

The study area is a test site located north-east of the town of Dahra in northern Senegal in West-Africa and includes towers equipped with instruments for validating satellite products (Stisen et al., 2008; Fensholt and Sandholt, 2005). The field site is hosted by the Centre de Recherches Zootechniques de Dahra, Institut Sénégalais de Recherches Agricoles (ISRA).

Annual mean precipitation is approximately 370 mm (1960–2007), but with considerable inter-annual variation. The site is classified by Le Houerou (1989) as being in the Sudano-Sahelian ecoclimatic zone, although this zone is defined as having mean annual rainfall between 400 mm and 600 mm. The classification is based on older rainfall data; in the mean time (since the seventies) the region has suffered from decreased rainfall as has most of West-Africa. The growing season is relatively short, lasts up to 100 days and occurs between July and October.

The areas around the towers are used as grazing land for the zoological research station, but also as farmland. Additionally, gum arabic plantations are present in the immediate surroundings. Trees are relatively sparse and the surface cover is dominated by annual grasses (e.g. *Schoenefeldia gracilis*, *Digitalia gayana*, *Dactyloctenium aegypticum*, *Aristida mutabilis* and *Cenchrus bifloures*) (Fensholt et al., 2006; Elberling et al., 2003). The soil is sandy and reddish in colour and was classified as an Arenosol by Batjes (2001).

On October 28th 2008, the area around the towers was burned by a bushfire. Bush fires occur regularly and mainly affect the herbaceous cover, while trees are generally less affected. This bushfire however, also damaged the trees, leaving some of them scorched and without any green leafs. Furthermore, almost all of the herbaceous cover was burned, leaving the surface clear of vegetation and dark in colour, which was still the case during a field visit in June 2009. The area affected by the bushfire is clearly visible in the Quickbird image (Fig. 1) and covers a large part of the study area, but not the plantations in the south and the south-east.

3. Method and data

The tree cover at the Dahra field site is sparse and the dominating land cover is scattered agricultural fields and savannas used as grazing lands by pastoralists. Trees are scattered in the landscape, either as isolated trees or as small clumps, where in some cases their distribution is induced by old dune systems. The task of identifying trees in this part of Senegal is, thus, not a case of tree stand parameter estimation for uniform, mono-culture stands as traditionally done in forest management studies. Tree age and size vary widely, and, depending on the species, some trees are actively shaped by both people and animals. These factors also influence the development of allometric models, which relate different tree parameters to each other, since the trees are not allowed to develop undis-