International Journal of Applied Earth Observation and Geoinformation 50 (2016) 80–88

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

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

Assessing the potential of multi-seasonal WorldView-2 imagery for mapping West African agroforestry tree species

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ARTICLE INFO

Article history:
Received 23 July 2015
Received in revised form 4 February 2016
Accepted 16 March 2016
Available online 24 March 2016

Keywords:
Tree species mapping
WorldView-2
Agroforestry
Parkland
Sudano-Sahel

ABSTRACT

High resolution satellite systems enable efficient and detailed mapping of tree cover, with high potential to support both natural resource monitoring and ecological research. This study investigates the capability of multi-seasonal WorldView-2 imagery to map five dominant tree species at the individual tree crown level in a parkland landscape in central Burkina Faso. The Random Forest algorithm is used for object based tree species classification and for assessing the relative importance of WorldView-2 predictors. The classification accuracies from using wet season, dry season and multi-seasonal datasets are compared to gain insights about the optimal timing for image acquisition. The multi-seasonal dataset produced the most accurate classifications, with an overall accuracy (OA) of 83.4%. For classifications based on single date imagery, the dry season (OA = 78.4%) proved to be more suitable than the wet season (OA = 68.1%). The predictors that contributed most to the classification success were based on the red edge band and visible wavelengths, in particular green and yellow. It was therefore concluded that WorldView-2, with its unique band configuration, represents a suitable data source for tree species mapping in West African parklands. These results are particularly promising when considering the recently launched WorldView-3, which provides data both at higher spatial and spectral resolution, including shortwave infrared bands.

1. Introduction

High resolution satellite remote sensing represents an efficient option for conducting comprehensive and detailed mapping of tree attributes over larger areas (Ustin and Gamon, 2010). The accurate mapping of tree species using satellite data can be highly useful for a range of research and management application areas. For example, spatial datasets that integrate information on tree structure (e.g., crown size) and species can open up new possibilities for studying the ecology and functioning of trees over large areas (Cho et al., 2012). Some key topics in this field of research include the influence of trees on soil properties, ground water recharge and land productivity (Bargués Tobella et al., 2014; Bayala et al., 2014). Multi-temporal datasets of this sort also enable monitoring of tree cover structure and floristic composition, and provide a means to study the response of trees to changes in climate and land use over broad spatial scales.

Successful remote sensing based tree species mapping has mainly been achieved using data from airborne hyperspectral systems (Cho et al., 2010; Clark et al., 2005; Dalponte et al., 2012; Féret and Asner, 2011, 2013). Such systems acquire spectral measurements in hundreds of narrow wavelength bands with a high potential to resolve the subtle spectral features that differentiate tree species (Ustin and Gamon, 2010). However, the relatively small footprint and high costs restricts the application of airborne systems. Furthermore, multiple flight lines need to be mosaicked into a single scene in order to cover large areas, which is complicated due to bidirectional reflection distribution function effects (Colgan et al., 2012). It would therefore be preferable to achieve this task using data from space borne sensors, which have the advantage of enabling consistent and repeated data acquisition at relatively low costs.

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http://dx.doi.org/10.1016/j.jag.2016.03.004
0303-2434/

Satellite based tree species mapping has previously been limited by the spectral and spatial resolutions of the available sensor systems (Cho et al., 2012; Immitzer et al., 2012). However, the latest generation of very high resolution (VHR) satellite systems has approached the level of hyperspectral systems by acquiring spectral data in strategically located and relatively narrow wavelength bands with high relevance for tree species mapping (Cho et al., 2012). WorldView-2 is one such sensor that has shown promise in different types of ecosystems, including temperate forest (Immitzer et al., 2012; Waser et al., 2014), urban forest (Verlic et al., 2014), mangrove forest (Heenkenda et al., 2014), plantation forest (Peerbhay et al., 2014), and savanna (Cho et al., 2012). Research exploring the potential of VHR satellite systems in African ecosystems has been limited in number despite the practical and economic benefits of this data source. In Kruger Park, South Africa, Cho et al. (2012) classified five savanna tree species using WorldView-2 imagery with an overall accuracy of 77%. Peerbhay et al. (2014) reported an overall accuracy of 85.4% when classifying six commercial tree species with WorldView-2 in KwaZulu-Natal, South Africa. Even higher accuracies were achieved by Adelabu and Dube (2015) who reported an overall accuracy of 88.8% using Quickbird imagery to classify five tree species in Botswana. The previous research on this topic has exclusively concentrated on the southern regions of Africa. In the present study, we shift the geographical focus to West Africa and evaluate the potential of WorldView-2 to map tree species in the traditional agroforestry system, the so called parklands.

Agroforestry is the main livelihood strategy for people in the Sudano-Sahelian zone of West Africa and comprises critical sources for fuel wood, timber, medicine, fodder and food and help regulate soil properties, including nutrients, carbon and water content (Bargués Tobella et al., 2014; Bayala et al., 2015; Sinare and Gordon, 2015). Similar agricultural landscapes characterized by a significant tree cover component are common in other semi-arid areas, including southern Africa, India and Australia (Boffa, 1999). In the Sudano-Sahelian zone, climate change has triggered a dieback of the highly valued agroforestry tree species which are often adapted to wetter conditions (Gonzalez et al., 2012; Maranz, 2009). Altered land use practices, such as shortened fallow periods, also have adverse effects on the regenerative capacity of valued tree species in this area. (Ræbild et al., 2012). These two factors are causing concern for the long-term sustainability of the parkland systems in the Sudano-Sahelian zone. Efficient methods for detailed mapping of parkland trees are therefore needed to aid ecosystem research and natural resource monitoring in this region.

A critical issue for remote sensing based tree species mapping is to determine when image data should be acquired during the year in order to optimize the classification accuracy (Cho et al., 2012). Knowledge about when the spectral signature of the tree species is most distinct, and thus the potential for accurate tree species identification is the greatest, is valuable for local users and can help plan the image acquisition. Previous research about VHR satellite based tree species mapping has only used single date imagery. Knowledge about the effects of image acquisition timing for tree species mapping is therefore limited, especially in African ecosystems. In addition, the use of multi-seasonal spectral data may improve accuracies of tree species mapping (Reese et al., 2002). Since VHR satellite imagery is rather costly, local users need to know if acquisition of multi-seasonal data is a financially sensible alternative. For these reasons, the aim of this study was to explore the potential of single date as well as multi-seasonal WorldView-2 for mapping agroforestry tree species, commonly found throughout the parklands of the Sudano-Sahelian zone, at the individual tree crown level. WorldView-2 imagery acquired over an area in central Burkina Faso from the wet season (early July) and the early dry season (late October) was first used separately and the results were compared to provide insights to the optimal timing of data acquisition. The wet and dry season imagery was then combined to assess the effects of using a multi-seasonal approach for tree species mapping.

Table 1
Acquisition characteristics of the WorldView-2 imagery used in this study.

Sensor properties	Wet season	Dry season
Acquisition date	18–07-2012	21–10-2012
Acquisition time	11:07:43	13:55:15
Mean off-nadir angle	18.8°	12.9°
Mean sun azimuth	58°	153.4°
Mean sun elevation	72.1°	64.5°
Mean satellite azimuth	351.1°	192.4°
Mean satellite elevation	68.8°	75.3°

2. Materials and methods

2.1. Study area

The study site is located 30 km south of Ouagadougou in the commune of Saponé (12°04′48″N, 1°34′00″W) and covers an area of 100 km^2. This area is an agroforestry parkland landscape primarily used for small scale crop cultivation and pasture. The terrain is gently undulating and the soils are characterized by sandy clay textures and low nutrient content (Jonsson et al., 1999). The climate is semi-arid and bi-modal, with the wet season extending between May and October and mean annual rainfall of 800 mm. Approximately 70% of the rains fall between July and September. Current mean tree canopy cover is 15% (Karlson et al., 2015) and the tree layer is dominated by typical parkland tree species, including *Vitellaria paradoxa* and *Parkia biglobosa*. The field layer consists of annual grasses, crops and coppice regrowth. The structure of the tree cover and the field layer is highly influenced by land use.

2.2. WorldView-2 datasets

Two WorldView-2 images acquired in 2012 were used in the study, including an image from the middle of the wet season in July and an early dry season image from October (Fig. 1, Table 1). WorldView-2 collects data in one panchromatic band at 0.5 m × 0.5 m pixel size and eight multispectral bands at 2 m × 2 m pixel size. The WorldView-2 bands were first converted from digital numbers to top-of-atmosphere reflectance based on instructions provided by Updike and Comp (2010). Pan-sharpened 0.5 m multispectral images were then created for July and October using the Hyperspherical Color Space (HCS) algorithm (Padwick et al., 2010), which was specifically developed for use with WorldView-2 data. The pan-sharpened dry season image was rectified to the Universal Transverse Mercator (UTM) coordinate system (zone 30N) using 35 ground control points collected in the field and third order polynomials, with a registration error of less than one pixel. The wet season image was then registered to the dry season image, also with an error of less than one pixel.

2.3. Ground reference dataset

Georeferenced data from a field inventory (Karlson et al., 2014) were used to identify and select individual tree crowns in the WorldView-2 imagery for inclusion in the reference dataset. The field inventory was conducted in October and November 2012, and therefor coincided with the dry season satellite data acquisition. The six most common tree species in the study area were sampled, including *Eucalyptus camadulensis*, *Lannea microcarpa*, *Lannea Acida*, *Mangifera indica*, *Parkia biglobosa* and *Vitellaria paradoxa* (Table 2), which accounted for 80% of all trees in the inventory.