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Research article

Estimating babassu palm density using automatic palm tree detection with very high spatial resolution satellite images

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ABSTRACT

High spatial resolution images as well as image processing and object detection algorithms are recent technologies that aid the study of biodiversity and commercial plantations of forest species. This paper seeks to contribute knowledge regarding the use of these technologies by studying randomly dispersed native palm tree. Here, we analyze the automatic detection of large circular crown (LCC) palm tree using a high spatial resolution panchromatic GeoEye image (0.50 m) taken on the area of a community of small agricultural farms in the Brazilian Amazon. We also propose auxiliary methods to estimate the density of the LCC palm tree *Attalea speciosa* (babassu) based on the detection results. We used the "Compt-palm" algorithm based on the detection of palm tree shadows in open areas via mathematical morphology techniques and the spatial information was validated using field methods (i.e. structural census and georeferencing). The algorithm recognized individuals in life stages 5 and 6, and the extraction percentage, branching factor and quality percentage factors were used to evaluate its performance. A principal components analysis showed that the structure of the studied species differs from other species. Approximately 96% of the babassu individuals in stage 6 were detected. These individuals had significantly smaller stipes than the undetected ones. In turn, 60% of the stage 5 babassu individuals were detected, showing significantly a different total height and a different number of leaves from the undetected ones. Our calculations regarding resource availability indicate that 6870 ha contained 25,015 adult babassu palm tree, with an annual potential productivity of 27.4 t of almond oil. The detection of LCC palm tree and the implementation of auxiliary field methods to estimate babassu density is an important first step to monitor this industry resource that is extremely important to the Brazilian economy and thousands of families over a large scale.

1. Introduction

The babassu (*Attalea speciosa* Mart. ex Spreng.) is a palm tree species native to dense and humid forests that is distributed across approximately 200,000 km^2 of forests and savannas in Brazil, with optimal development in secondary environments (Anderson and Anderson, 1985; May et al., 1985; Barot et al., 2005; Santos and Mitja, 2011; Coelho et al., 2012). Recent research emphasized the importance of this palm tree to industry, given its potential for biodiesel production (Da Rós et al., 2014) and bioenergy (Protásio et al., 2014); to ethnobotany, given its use diversity (Araujo and Lopes, 2012; Martins et al., 2014); to anthropology, given its economic and social importance for small farmers (Porro and Porro, 2014); and to medicine because babassu palm trees can become infested with triatomines, which transmit Chagas disease (Dias et al., 2014). Recently, babassu oleaginous almonds were considered as the third most important non-wood product of plant extractivism in Brazil (89,739 t/$56.7 million in 2013; IBGE, 2013). Nevertheless, a gap exists between the knowledge of this species

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and use of technologies that might aid in its management and sustainable exploitation.

In forest plantations, information on tree or palm tree density is obtained using remote-sensing techniques that aid in productivity monitoring, planning and management of African oil palm tree (Shafri et al., 2011; Srestasathiern and Rakwatin, 2014) and eucalypt (Whiteside et al., 2011; Zhou et al., 2013) plantations. The spatial information provided regarding the number of trees or palm trees enables (among other things) the identification of excessive mortality areas (Zhou et al., 2013) and the prediction of production dates (Malek et al., 2014), which are essential for resource management and conservation (Engler et al., 2013).

As an alternative to time-demanding tasks of individually counting trees or palm trees in the field, automatic-detection methods were developed using high spatial resolution images. The primary objective of this detection is to determine the location of the tree or palm tree crowns in an image (Srestasathiern and Rakwatin, 2014). Studies apply different techniques to delimit tree and palm tree crowns based on the value of each pixel in the image (Erikson and Olofsson, 2005). Some of the techniques used include the marked-point process (MPP) via Worldview 1 and Worldview 2 multispectral images (Zhou et al., 2013), the maximum local detection method using Kodak DCS 460 CIR and UltracamD digital camera images (Pouliot et al., 2002; Hirschmugl et al., 2007), and a technique based on the structure of the elements using an airborne AISA hyperspectral image (Shafri et al., 2011). These techniques are generally used for homogeneous forest plantations disposed along a line; not having other species within the plantation avoids confusion when analyzing the images.

The mapping of tree crowns in non-planted areas (i.e., those dispersed in cultivated areas or in homogeneous or heterogeneous natural forests) can be based on the detection of crowns via object-oriented classification using IKONOS and GeoEye images (Aouragh et al., 2013), the wavelet-transform technique (Zhang et al., 2006; Ghiyamat and Shafri, 2010), or via supervised classification techniques such as spectral angle mapper, a linear discriminant analysis, and the maximum likelihood method (Clark et al., 2005), both techniques use an airborne HYDICE hyperspectral image.

Few studies have used image-based palm tree detection directed toward regular African oil palm tree plantations. Currently, babassu plantations are not found in Brazil, which might explain why this species has not yet been evaluated using automatic detection via images from recent satellites such as GeoEye, Ikonos, Worldview or Quickbird (which offer a spatial resolution of less than 1 m). The development of images with a resolution of less than 1 m enabled the more precise detection of small objects such as tree crowns in agricultural areas and their different shapes (Aouragh et al., 2013) using canopy delineation algorithms (Culvenor, 2002).

Although the classic algorithms developed for crown delineation fundamentally assume that the center of a crown appears radiometrically brighter than its edge (Culvenor, 2002), the algorithm developed by Demagistri et al. (2014), adapted for open environments, extracts the image pixels that correspond to shadows using the mathematical morphology technique (Serra, 1982; Haralick et al., 1987). This algorithm permits the detection of palm trees in pastures and agricultural plantations with low-to-average palm tree density. This image analysis technique is important (Soille and Pesaresi, 2002; Giada et al., 2003) for the detection of individual trees (Jiang and Lin, 2013) and other objectives. This technique is known as “morphology” because it analyses the content and shape of the object and called “mathematical” because it is based on set theory, integral geometry, and algebraic structure (Giada et al., 2003). Therefore, this algorithm has been used to detect the babassu palm tree in open agricultural environments.

Studies on tree and palm tree-crown detection do not usually employ field methods to validate the spatial information (Clark et al., 2005; Zhang et al., 2006; Hirschmugl et al., 2007; Ghiyamat and Shafri, 2010; Shafri et al., 2011; Aouragh et al., 2013; Malek et al., 2014; Srestasathiern and Rakwatin, 2014). When used, these methods are typically restricted to measure crown diameter and individual density (Pouliot et al., 2002; Zhou et al., 2013), although other structural characteristics of the individuals might affect their detection using the algorithm. Therefore, understanding these characteristics is an important step to improve the reliability of spatial information.

A large diversity of palm trees exists in the Amazon region, including 195 species and 35 genera. The most important genera include *Attalea* and *Astrocaryum*, each with 28 species (Pintaud et al., 2008). In addition to *Attalea speciosa* (babassu), other large circular crown (LCC) species such as *Attalea maripa* (inajá), *Astrocaryum aculeatum* (tucumã), *Oenocarpus bacaba* (bacaba) and *Mauricia flexuosa* (buriti) are distributed in an isolated and random manner (D. Mitja, Personal communication). Because no methods are described in the literature that enable differentiation among LCC palm tree types using a high-resolution image, estimating the density of a species of interest (e.g., the babassu) using automatic detection is a real challenge.

In the present study, we analyzed the automatic detection of LCC palm trees using a high spatial resolution panchromatic image (GeoEye1 sensor, 0.50-m resolution, July/2013) taken on a community of small farms in the Brazilian Amazon after validating the remote-sensing data using photo-interpretation and field methods. Based on the automatic detection results, we implemented auxiliary field methods to estimate babassu density.

2. Material and methods

2.1. Characterization of the study area

This study was conducted in small farmlands in Benfica (S 05°16′20″, W 49°50′25″), (Itupiranga State of Pará (PA), southeast of the Brazilian Amazon) (Fig. 1). This site has 9501 ha, and its occupation started in 1986 successively by farmers and settlers. Its land regularization was consolidated by the National Institute of Colonization and Agrarian Reform (Instituto Nacional de Colonização e Reforma Agrária; INCRA) in 1996 (Arnauld de Sartre, 2004). The latest estimate indicated 183 agricultural establishments and approximately 1000 people in the community (Ritter et al., 2009).

The vegetation in this area is upland tropical forest, characterized by the presence of lianas and palm trees (Mitja and Miranda, 2010). The dense forest has a canopy between 25 and 30 m in height, although some trees (e.g., *Bertholletia excelsa* H.B.K) reach a height of over 50 m (Bertrand, 2009). Landsat 8-OLI images taken in 2013 (Fig. 1) showed that primary and old secondary forests (in dark green colors) covered 34% of the area in Benfica, whereas degraded pastures or pastures with little cover (in purple and pink colors) represented 31%; pastures in good states and young secondary forests (in light green colors) accounted for 31% of the area (Eric Delaître, Personal communication).

When forests are converted into pastures, some palm trees and timber species are maintained (Mitja et al., 2008; Santos and Mitja, 2011), thereby contributing to the composition of the local landscape that includes pastures containing woody species (15%) and pastures with babassu (12%; Sampaio, 2008). The high reproductive plasticity of babassu favors its development in agricultural areas (Barot et al., 2005) because the use of fire for agricultural management contributes to the germination and regeneration of babassu individuals (Mitja and Ferraz, 2001). Thus, the different