Forest Ecology and Management 274 (2012) 222–230

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

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

Estimation of rubber stand age in typhoon and chilling injury afflicted area with Landsat TM data: A case study in Hainan Island, China

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ARTICLE INFO

Article history:
Received 24 September 2011
Received in revised form 16 January 2012
Accepted 20 January 2012
Available online 31 March 2012

Keywords:
Stand age
Rubber plantation
Thematic Mapper (TM)
Natural disasters
Hainan Island

ABSTRACT

Stand age in rubber (*Hevea brasiliensis*) plantation is an important factor for production management and ecosystem modeling. The feasibility of detecting difference in rubber stand age using Landsat Thematic Mapper (TM) data in Hainan Island, an area frequently disturbed by typhoon (or hurricane, tropical cyclone) and chilling injury, was evaluated. The results indicated that most of the TM bands were negatively correlated with stand age, of which the near-infrared bands had the most stable and strongest coefficients. However, the correlation of infrared bands with stand age was dramatically weakened by disturbance of severe typhoon and chilling injury, which suggested that, to study the stand age of rubber plantation by remote sensing, it is more appropriate to use an image acquired in dry season and far from severe natural disaster. The TM bands, normalized- and ratio-based vegetation indices that computed from red and infrared bands (3–5 and 7), and tasseled cap components were employed to develop models for estimating stand age through multivariate regression analysis techniques. Four statistically significant models with R^2 ranging from 0.74 to 0.82 were obtained. When applied to the validation data, all the regression models showed an overestimation of young stands (about less than 25 years) and more severe underestimation of old stands due to the growth characteristics of rubber tree and disturbance of natural disasters. The incorporation of original bands with vegetation indices and tasseled cap components as independent variables could yield the highest estimated correlation index squared (I^2) value of 0.58, the RMSE value of 5.96 years, and less model bias than the other test models. This study demonstrated a close relationship between rubber stand age and Landsat TM data, and a promising prospect in application of TM data to investigating stand parameters in Hainan Island.

1. Introduction

Rubber tree is a most important arbor species, not only for the market of natural rubber, but also for the contribution to timber supply (Suratman et al., 2004; Jianing et al., 2010). As China's biggest rubber production base, Hainan Island is continuously increasing the cultivation of rubber trees and has now possessed a plantation area of 4.4×10^5 ha in 2010, occupying 13.8% of the total land area of the island and forming the largest artificial ecosystem there (Ju-sheng and Ru-song, 2003; Chen et al., 2007; Jianbo et al., 2010; Yeyong, 2010). Therefore, there is a need, whether from the perspective of production management or ecosystem modeling, to regularly collect and update rubber plantation parameters such as area, age, volume, and spatial distribution. On one hand, detailed inventory data will be beneficial for government officials to more accurately predict latex and timber production, and to make more suitable and more effective management strategies. On the other hand, many of the structural parameters, such as stand age, are important factors in determining the distribution of carbon pools and fluxes in forest ecosystems (Wulder et al., 2004; Zhang et al., 2004; Sivanpillai et al., 2006). A good understanding of these parameters will help researchers to carry out more in-depth studies on the rubber forest ecosystem such as its energy and mass exchanges and carbon cycle (Kimes et al., 1998, 1999; Wulder et al., 2004; Zhang et al., 2004; Sivanpillai et al., 2006; Wang et al., 2011).

Inventory information, however, is difficult to acquire for large spatial extents by field survey because obtaining such information is time-consuming, expensive, and labor-intensive. Fortunately, such efforts have been significantly improved by the emergence of remote sensing techniques. Medium spatial resolution imagery

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doi:10.1016/j.foreco.2012.01.033

such as Landsat TM (Sader et al., 1989; Fiorella and Ripple, 1993; Cohen et al., 1995; Jensen et al., 1999; Nelson et al., 2000; Wilsona and Sader, 2002; Lu et al., 2004; Lefsky et al., 2005; Song et al., 2007), Landsat ETM+ (Vieira et al., 2003; Wulder et al., 2004; Sivanpillai et al., 2006), SPOT HRV (Kimes et al., 1998, 1999; Zhang et al., 2004), or their combination (Brockhaus and Khorrama, 1992; Cohen and Spies, 1992; Zhang et al., 2004; Helmer et al., 2010) are the most extensively used imagery sources for studies of forest stand age, volume, basal area diameter, and biomass information. Among these studies, spectral bands, vegetation indices, and tasseled cap transformation are often used as independent variables in developing age prediction models through regression techniques (Wulder et al., 2004; Sivanpillai et al., 2006) or neural network approach (Jensen et al., 1999; Kimes et al., 1999), while classification techniques are employed in identifying age and other attributes (Fiorella and Ripple, 1993; Wilsona and Sader, 2002; Lefsky et al., 2005). This situation suggests that the satellite data, especially the Landsat TM and SPOT imagery, are potentially valuable for characterizing key stand characteristics.

In recent years, remote sensing images have been widely used for rubber area mapping (Ekadinata et al., 2004; Suratman et al., 2005; Jinghong et al., 2010; Wasana, 2010), but few of them were used for characterizing rubber stand parameters. Suratman et al. (2004) found that near- and mid-infrared bands of TM data could provide the best correlation with rubber stand age and volume in Malaysia, and successfully developed regression models for volume (R^2 > 0.7, standard error of estimate, SE_E, <54 m^3/ha) and age (R^2 and SE_E ranged from 0.34 to 0.64, 6.4 to 8.2 years, respectively) (Suratman et al., 2002; Suratman, 2003). Recently, Jusoff and Yusoff (2009) estimated rubberwood volume in Malaysia using supervised classification method with UPM-APSB's AISA airborne hyperspectral data, and quantifying and mapping the individual crowns of rubber trees with an accuracy of 89.84%. However, the relationship between spectral reflectance and rubber stand characteristics may vary with different geographic settings (Sivanpillai et al., 2006), thus the utility of satellite data in Hainan Island should be preceded with testing, especially the island is characterized by frequent disturbance of natural disasters.

China has developed cold- and wind-resistant rubber clones, and many areas of southern China such as Hainan, Yunnan and Guangdong provinces are suitable for rubber cultivation. Benefiting from these clones, the northwest rubber cultivation area has extended to 22°N latitude and up to 1100 m in elevation without important loss of latex yield, well beyond the native environment of 10°N/S of the equator and 400 m above sea level (AMSL) (Guardiola-Claramonte et al., 2010; Li and Fox, 2012). Although the expansion is successful, the frequent disturbance of typhoon and chilling injury, which are unlikely to happen in other cultivation countries, has done a great damage to these non wind- and cold-resistant rubber plantations (He and Huang, 1987; Jiangwei et al., 2009; Liyan et al., 2009). Statistics indicate that more than 100 typhoons have hit Hainan Island since 1960s (Wei et al., 2006; Kairong et al., 2010). In the last decade, the island has experienced two most deadly natural disasters. One was the typhoon Damrey on September 26, 2005, the strongest one since 1974, with sustained wind at 55 m/s near the storm center, which destroyed most of the island's rubber plantations (Wei et al., 2006; Zheng and Tang, 2007). The other was the chilling injury in January, 2008, the coldest since the 1970s, with a low temperature around 10 °C and a duration of nearly 20 days (Jiangwei et al., 2009; Liyan et al., 2009). Unlike typhoon that occurs in short period but causes serious primary damages such as trunk and branch breakage and uprooting, chilling injury is usually accompanied with long-term second damages such as tree dieback, bark splitting and bleeding on the rubber plantation (He and Huang, 1987). These damages should be considered when use remote sensing data to study stand characteristics in this area because they will greatly alter the spectral reflectance values of images. Up to now, there have been few reports on applying remote sensing to study rubber plantation in Hainan Island, and the influence of natural disasters on stand attributes is still unclear. Therefore, this study were to (1) explore the relationship between TM data and rubber stand age by using sequential TM images, and analyze the effect of natural disasters; (2) investigate the feasibility of developing age prediction models using remote sensing techniques in Xinying state farm, Hainan Island, China.

2. Materials and methods

2.1. Study area

Xinying state farm (109°43′–109°51′E; 19°28′–19°38′N) is located in the northwestern Hainan Island, China (Fig. 1). The topography of the farm is typically characterized by a hilly plateau with an elevation of 188 m above the sea level at the center. The plateau is surrounded by flat lands with elevations of 20–160 m. Because of sunny and tropical weather with monsoons, the climate is favorable for agricultural development. The annual precipitation is 1600 mm. The rainy season (May–October) accounts for >89% of the total rainfall of the year, and typhoons of various scales always occur during this same period. The mean annual temperature, highest monthly average temperature (June–July), and the lowest monthly average temperature (January) is 22.9, 28.0, and 16.9 °C, respectively. The farm has reclaimed over 5000 ha of cultivated land and tropical rain forest since it was established in 1957. Of these lands, nearly 3000 ha were planted with natural rubber.

2.2. Stand inventory data

A shapefile format digital map at 1:10,000 scale was collected from the Bureau of Hainan State Farm. In the map, the attribute table of stand boundary layer contained information of stand name, tree clones, establishment year, management methods, and production. The age of each stand was calculated by referring to the attribute value of the establishment year. The stand boundary layer, was further rectified based on a corrected CBERS 02B (China–Brazil Earth Resources Satellite 02B) high-resolution image (acquired on August 16, 2008, 2.36 m at nadir) to make sure that all the polygons completely cover the stand boundary (Qi et al., 2008). Smaller stands with area less than one hectare (corresponding to 3×3 TM pixels) were excluded in the subsequent analysis, since reflectance value from the other features such as roads would influence the pixel values recorded for these stands. A simple fragmentation index, the perimeter/area (P/A) ratio, with a threshold value greater than 0.03 was used to eliminate thin and linear stands (Salas et al., 2003; Sivanpillai et al., 2006). Since the reflectance value of young and open-canopied stands are likely to be affected by ground cover crops, the stands younger than 6 years old were excluded from further analyses. After these filters, a total of 919 stands was obtained, but only 855 of them was selected due to the clouds and shadows in some of the TM images that will be introduced in below. A total of 171 stands, 20% of the reserved stands, were sampled by a simple random sampling (SRS) design for subsequent analysis.

2.3. Image processing

The synchronous shedding of rubber trees lasts 2–4 weeks in China. Therefore, the acquisition of images should not be in the leaf shedding and flushing alternation period (usually January to April), because the shedding and flushing will alter reflectance values