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Extraction of remote sensing-based forest management units in tropical forests

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ABSTRACT

As a spatial source of forest data, the forest stand is the basic unit for forest management and planning. Computerized segmentation of a diverse range of remote sensing material has been studied for delineating stands in various forest types, but is relatively rare under tropical conditions. In line with REDD+, which advocates sustainable forest management in tropical developing countries, we report here on the delineation of forest stands in Laos using data from Airborne Laser Scanning, Airborne CIR and ALOS AVNIR-2. Rather than using the spectral layers alone, the segmentation was applied to wall-to-wall maps of predicted values from empirical models that retrieve forest stem volume and basal area. The homogeneity of 96 sets of segmentation categorized according to the hierarchical mean sizes of the segments was evaluated quantitatively in terms of the AIC_{var} index and qualitatively by eye. The results show that the quality and performance of the empirical models are duly reflected in the quality and performance of the segmentation, and that the most competitive delineations are provided by models that involve ALS. Finally, the future prospects for using this empirical model-based segmentation approach to detect and quantify deforestation, or even forest degradation, and thereby to provide further support for the development of REDD methodology, are discussed.

1. Introduction

Tropical forests play an important role in both REDD and REDD+, since deforestation and forest degradation in the tropics have been considered as a clear cause of climate change, accounting for a large share of global greenhouse gas emissions (FCPF, 2012; The World Bank, 2012). Reducing Emissions from Deforestation and Forest Degradation (REDD) is an effort to constrain the impact of climate change by creating a financial value for the carbon stored in forests, as incentives for developing countries to reduce emissions from forested lands (UNFCCC, 2007; UN-REDD, 2012). Relative to REDD, REDD+ goes further and makes efforts to foster sustainable forest management, conservation and enhancement of carbon stocks (FCPF, 2012; UNFCCC, 2009). Although a remote sensing approach has been advocated for the technical development of REDD-related issues including sustainable forest management, there has been a scarcity of relevant studies in relation to tropical forests (GOFC-GOLD, 2009). To be in line with the three-Tier accuracies of carbon inventory proposed by International Panel on Climate Change (IPCC, 2006), airborne laser scanning data, airborne and satellite-based optical imagery are of great potential to be applied to tropical forests with corresponding cost-effectiveness (Hou et al., 2011).

Sustainable forest management and planning is normally based on stand-level inventories, and forest stands are formed on either an operational or a biological basis (Leppänen et al., 2008; Tokola et al., 2008). Remote sensing data have been tested to delineate forest stands for their objectivity and cost-effectiveness. Many studies have explored different approaches and performances of automatic forest stand delineation by means of satellite or airborne color infrared (CIR) techniques (e.g. Hagner, 1990; Hay et al., 2005; Leckie et al., 2003; Mäkelä & Pekkarinen, 2001; Radoux & Defourny, 2007; Sell, 2002; Tomppo, 1988). Airborne Laser Scanning (ALS) data, unlike satellite or aerial optical data, provide 3D information on forests, and the derived height metrics have been employed for stand delineation purposes (e.g. Diedershagen et al., 2004; Leppänen et al., 2008; Mustonen, 2007; Tokola et al., 2008). A canopy height model derived from ALS data has also been used in combination with airborne color infrared (CIR) data to delineate stands (Mustonen et al., 2008).

Segmentation is a way to achieve automatic stand delineation, which in image analysis refers to the clustering of adjacent pixels into units according to similarity criteria based on digital numbers and textures (Meinel & Neubert, 2004). In other words, it is a technique for subdividing imagery into meaningful homogenous regions (Baatz & Schäpe, 2000; Cheng et al., 2001; Haralick & Shapiro, 1992). As a spatial container of forest data, a stand should preferably be homogenous in its content (Koivuniemi & Korhonen, 2006), hence it should be delineated by reference to at least one of the accepted stand criteria, such as species composition, timber size, growing stock, stem density, canopy closure, site type, etc. (Leckie et al., 2003). Although there have been

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attempts to construct a unified segmentation principle (Allili & Ziou, 2007), the intrinsic essence of successful segmentation should be that it is capable of minimizing heterogeneity within segments and maximizing it between them. Segmentation algorithms can be categorized according to whether they represent an edge-based or an area-based approach (Muñoz et al., 2003). An edge-based approach formulates segments by establishing boundaries and detecting abrupt changes, whereas an area-based approach uses similarity rules to allocate pixels according to intensity, color, neighborhood texture or other properties. Several variants of such algorithms have been introduced by Narendra and Goldberg (1980), Pitkänen (2001) and Muñoz et al. (2003).

This paper aims to delineate tropical forest management units by means of an empirical model-based segmentation approach using both single and combined ALS, Airborne CIR and ALOS AVNIR-2 (Advanced Land Observation Satellite, Advanced Visible and Near Infrared Radiometer type 2) datasets to technically facilitate the sustainable forest management required under REDD+. The potential of this approach for application to the detection and quantification of deforestation, or even forest degradation, will also be explored and discussed so as to provide further support for developing the REDD methodology.

2. Materials

2.1. Experimental area

The Dongsithouane production forest, area c. 25,000 ha, in the province of Savannakhet (latitude 16° 33′ N, longitude 104° 45′ E) in Laos (Fig. 1) was used to test the segmentation approach. Based on the digital terrain model (DTM) from ALS, the elevation ranges from 95 m to 265 m with an average of 128 m. There are two distinct seasons, the wet (May to October) and the dry (November to April). The dry is comprised of the cool dry (November to February) and the hot dry (March to April). The average precipitation of the area was 1490 mm/year, with the smallest amount of 20 mm received in February (Weatherbase, 2012).

2.2. Field data

The field data were based on a campaign conducted in February 2009 for the purpose of defining transects and collecting information on forest characteristics for modeling purposes. The sampling was designed by the mixture of random sampling and stratified sampling with the help of auxiliary data. The aim of this design was to reduce error and variation inside one forest class. The tally records showed the existence of 268 tree species in this area, with deciduous species dominant, principally represented by members of the Dipterocarpaceae family such as *Dipterocarpus tuberculatus*, *Pterospermum megalocarpum*, *Dipterocarpus alatus*, *Pentacme siamensis* and *Shorea obtuse*. The canopy closure was visually estimated and it ranged from 10% to 70%, although there could be errors since the survey was conducted in the cool dry season when dry diprerocarps had shed their leaves.

A total of 233 sample plots were surveyed in the Dongsithouane forests and the coordinates of the center of each plot were recorded by handheld GPS. These plots were located in linear clusters (or inventory lines), each cluster being a strip of size 100 by 20 m, divided into two plots at both ends each 20 by 20 m. The variable-size sample plot was defined by the following rules (Fig. 2): large trees with a diameter at breast height (DBH) of 20 cm or larger were measured on plots of 20 by 20 m (400 m^2), stems with a DBH of 10 cm or larger but less than

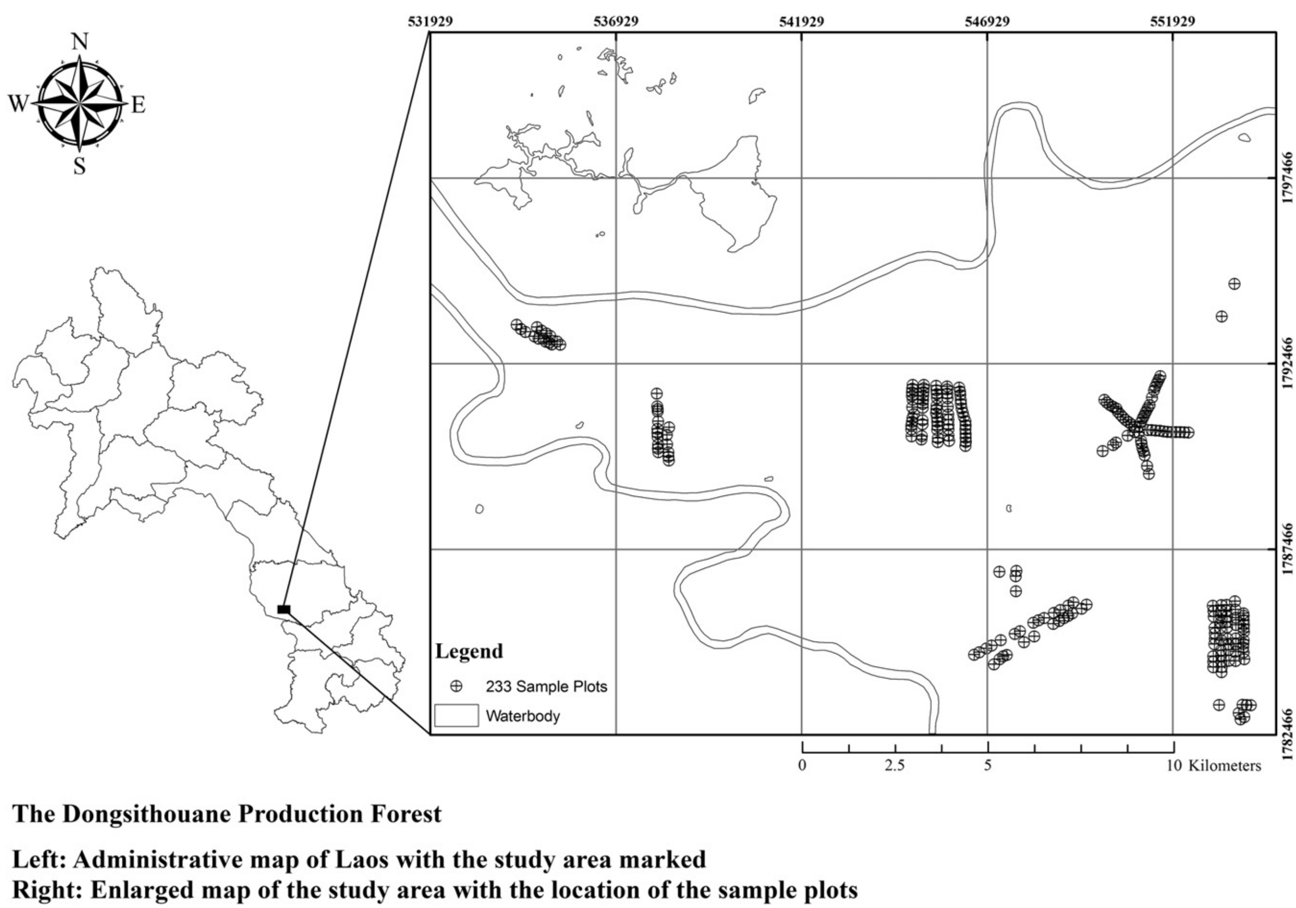

Fig. 1. The Dongsithouane forest area and location of the field plots, in Laos.