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Original Research Article

Completing yearly land cover maps for accurately describing annual changes of tropical landscapes

Kiswanto [a, b, *], Satoshi Tsuyuki [a], Mardiany [c], Sumaryono [b]

[a] *Graduate School of Agricultural and Life Sciences, The University of Tokyo, Japan*
[b] *Faculty of Forestry, Mulawarman University, Indonesia*
[c] *Research and Development Agency of East Kalimantan Province, Indonesia*

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ABSTRACT

Availability of up-to-date land cover information is increasingly important for describing annual changes in tropical landscapes that significantly affect ecosystem–economy interactions and environmental management. However, land cover change monitoring in humid tropical areas is complicated by difficult remote sensing conditions, which often leads to a crucial lack of accurate land cover information. In this study, we use visual interpretation of Landsat images in combination with existing land cover maps to create a set of annual maps for the East Kalimantan Province in Indonesia from 2000 to 2016. These datasets allow us to analyze the development of land cover change trends in the province since 2000 with high spatial and temporal detail. Our results reveal the acceleration of land cover changes, with overall cover changes from natural forest to plantation forest and other cultivated land cover classes, and undeveloped shrublands. The mapping approach used in this study effectively provides information on land cover changes in humid tropical areas, which can support environmental monitoring and government development programs.

1. Introduction

Land cover represents a significant issue in geographical analyses from physical geography investigations to environmental examinations and spatial planning (Rujoiu-Mare and Mihai, 2016). Land cover is a readily detectable parameter that, because it reflects the interaction between human socio-economic activities and regional ecological responses, can be used to represent ecosystem services and livelihood support (Costa et al., 2017; Gilani et al., 2015). Accurate, current, and long-term information on land cover is required for environmental studies, land management, suitable development, change monitoring, carbon stock estimations, and many other applications (Belward and Skøien, 2015; Chen et al., 2015; Congalton et al., 2014; Gómez et al., 2016; Huang et al., 2017; Jin et al., 2017; Xing et al., 2017). Land cover change detection is necessary for a better understanding of landscape dynamics during a given period of sustainable management (Rawat and Kumar, 2015). Changes in land cover reveal the effects of natural and human processes (Soffianian and Madanian, 2015) and affect local and regional climates, carbon, water, and biodiversity, which are major components of environmental change (Adhikari et al., 2017; Grimm et al., 2008; Turner et al., 2007; Yu et al., 2016).

* Corresponding author. Faculty of Forestry, Mulawarman University, Indonesia.
E-mail address: kiswantosardji@gmail.com (Kiswanto).

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High spatial resolution land cover information is essential for advancing environmental monitoring, which in turn supports decision-making and reporting processes (Kuenzer et al., 2014; Mack et al., 2017). Remote sensing is a powerful tool for obtaining spatial landscape data. It can be used to derive accurate and current spatial land cover information and monitor land cover changes over time (Brown et al., 2000; Hereher et al., 2012; Mashagbah et al., 2012; Purkis and Klemas, 2011; Reyes et al., 2017; Zanella et al., 2012). The accessibility of data from satellites, such as Landsat (Li et al., 2017; Roy et al., 2014), Satellite Pour l'Observation de la Terre (SPOT) (Disperati and Virdis, 2015; Mas and González, 2015), Synthetic Aperture Radar (SAR) (Reiche et al., 2015; Zhu et al., 2012), Moderate Resolution Imaging Spectroradiometer (MODIS) (Wan et al., 2015; Xin et al., 2013), and others, has improved global land cover classification through the use of remotely-sensed data (Goldblatt et al., 2018). Due to its extended (since 1972), continuous measurement record and free availability, Landsat data are frequently used to produce high-resolution maps (Hansen et al., 2013) and monitor global changes in variables such as settlement and population (Patel et al., 2015), urban growth (Mashagbah et al., 2012), deforestation and forest degradation (Margono et al., 2012; Romero-Sanchez and Ponce-Hernandez, 2017), tree diversity (Mohammadi and Shataee, 2010), carbon stocks and Greenhouse Gas (GHG) emissions (Liu et al., 2016; Pacheco-Angulo et al., 2017), and other land cover change effects.

Although timely and accurate data on land cover within the humid tropical landscape is required for monitoring annual changes, particularly in Indonesia (Hansen et al., 2009), it remains difficult to procure multiple Landsat images without clouds within a given year (Zhu and Woodcock, 2014). The presence of clouds, shadows and illumination in Landsat images can cause serious problems for remote sensing applications, including mosaic generation (Roy et al., 2010), atmospheric correction (Nazeer et al., 2014), land cover classification (Hereher et al., 2012), and change detection (Mas and González, 2015). Other complicating factors include the diversity in tropical land cover (Zanella et al., 2012) caused by deforestation (Ramachandran and Reddy, 2017), which affects the selection of training areas appropriate for digital image classification. Ecological applications sometimes require the detection of land cover classes that cannot be distinguished using digital image classification methods (Puig et al., 2002).

In order to avoid misinterpretations that may motivate flawed conservation actions, it is important to use consistent land cover classification methods when performing landscape ecology studies (Zanella et al., 2012). Land cover classification using visual interpretation is often the most effective in the humid tropical landscapes. In Indonesia, land cover classification has been regulated under a national standard (BSN, 2010) that uses visual interpretation (BSN, 2014). Visual interpretation generally involves one or more fundamental activities: viewing images, making measurements on images, performing image interpretation tasks, and transferring interpreted information to base maps (Lillesand et al., 2014). Visual interpretation can be used to efficiently classify complex and heterogeneous landscapes with image pattern characteristics (Zanella et al., 2012) and deliver better spatial detail (Puig et al., 2002) and enhanced quality from medium-resolution satellite data (Ghorbani and Pakravan, 2013). Visual interpretation can also be used to calculate landscape metrics for patches generated by automatic grouping procedures (Antrop and Van Eetvelde, 2000).

In this study, we had two specific objectives: (1) to complete yearly land cover classification maps for the East Kalimantan Province in Indonesia from 2000 to 2016, and (2) to test the applicability of this type of datasets in land cover change analysis in tropical landscapes. To address the first objective, we combined existing land cover maps, Landsat imagery, and visual interpretation to create a series of yearly land cover maps. These maps were subsequently used to analyze the annual spatio-temporal variation trends in the province.

2. Materials and methods

2.1. Study area

The study was conducted in the East Kalimantan Province of Indonesia (Fig. 1), which is located between 2°33′ N and 2°25′ S and between 113°44′ E and 119°00′ E. Note that East Kalimantan Province was split into two provinces (North and East Kalimantan) in 2012. However, for consistency in our results, we refer to the new East Kalimantan province and district definitions throughout the study period. The province has a total area of 12,733,250 ha, which can be divided into a land area of 12,620,448 ha, an inland water area of 112,802 ha, and a coastal area (0–6 km) of 2,565,600 ha. As the third largest province in Indonesia, East Kalimantan comprises approximately 6.7% of total area of Indonesia that consists of 7 districts (Kutai Kartanegara, Berau, Kutai Timur, Kutai Barat, Paser, Penajam Paser Utara, and Mahakam Ulu) and 3 cities (Samarinda, Balikpapan, and Bontang); the provincial capital is located in Samarinda. East Kalimantan is bounded by Sarawak of the Malaysia state to the northwest, the Celebes Sea to the northeast and the Makassar Strait to the southeast, the North Kalimantan Province to the north, South Kalimantan Province to the south, Central Kalimantan Province to the southwest, and West Kalimantan Province to the west (BPS, 2017).

East Kalimantan is also a leader in both carbon storage and biodiversity in Southeast Asia due to its tremendously high species richness (Budiharta et al., 2014; de Bruyn et al., 2014; Slik et al., 2010). East Kalimantan contains almost 15 million ha of forests (FCPF, 2017) and includes lowland, montane, swamp, and mangrove forests (Wilson et al., 2010). A combination of timber plantations, oil palm plantations, coal mining, agriculture, and forest fires have threatened biodiversity and caused carbon emissions (Brown et al., 2011; Carlson et al., 2013; Gaveau et al., 2016; Pearson et al., 2014; Sodhi et al., 2004).