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Cross-border forest disturbance and the role of natural rubber in mainland Southeast Asia using annual Landsat time series

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ABSTRACT

The recent rise in global demand for natural rubber (*Hevea brasiliensis*) has led to expansive areas of natural forest being transformed into monoculture plantations. This paper explores the utility of annual Landsat time series for monitoring forest disturbance and the role of natural rubber in mainland Southeast Asia from 2000 to 2012. A region on the Cambodian–Vietnamese border was chosen for this study considering four primary questions: 1) how accurately can annual Landsat time series map the location and timing of forest disturbances in evergreen and seasonal tropical forests, 2) are there cross border differences in frontier and non-frontier forest disturbance rates between Cambodia and Vietnam, 3) what proportion of disturbances in frontier and non-frontier forests can be accounted for by the impact of rubber plantations, and 4) is there a relationship between global market prices for natural rubber and the annual rate of frontier forest clearing for rubber plantations on both sides of the border. We used LandTrendr (Landsat-based detection of trends in disturbance and recovery) for temporal segmentation of the Landsat time series and disturbance mapping. Our results show that this approach can provide accurate forest disturbance maps but that accuracy is affected by forest type. Highest accuracies were found in evergreen forest (90%), with lower accuracies in mixed (80%) and dry-deciduous forest types (83%). Our final map considering all forest types yielded an overall accuracy of 86%. Forest disturbance rates were generally higher on the Cambodian side of the border. Frontier forest disturbance rates averaged 3.8%/year in Cambodia compared to 2.5%/year in Vietnam. Conversion to rubber was the dominant form of frontier forest change in both countries (42% in Cambodia and 84% in Vietnam). Non-frontier forest disturbances averaged 4.0% and 2.5% in Cambodia and Vietnam, respectively, with most disturbances likewise linked with rubber plantations. Although rates of frontier forest disturbance differed in both countries, they each displayed similar correlations between disturbance rates related to rubber plantation expansion and price fluctuations of natural rubber. This suggests links between localized land cover/use change and international market forces, irrespective of differing political and socioeconomic backgrounds. Our study underlines the value of using dense Landsat time series when exploring the dynamics of human-induced land cover change.

1. Introduction

Tropical forests around the globe are undergoing a major transformation, largely attributed to anthropogenic disturbances (Wright & Muller-landau, 2006). Remote sensing analysis has identified Southeast Asia as one of the world's deforestation hotspots (Achard et al., 2002; Hansen et al., 2008a, 2013; Stibig et al., 2014), comparable to conversion rates found in Latin America. Historically, the causes of tropical deforestation have been broadly attributed to a number of factors including among others, population pressure, weak institutions and policy, and trade liberalization (Geist & Lambin, 2002; Laurance, 1999). Although each of these driving forces still heavily influences the fate of tropical forest, it is arguably the latter that currently poses the greatest threat in the Southeast Asian context (FAO, 2009; Rudel et al., 2009).

Regarding deforestation rates, distinction is often made between Insular and mainland Southeast Asia. A recent study by Stibig et al. (2014) showed annual deforestation rates (relative change percent) in Insular Southeast Asia to be much higher throughout the 1990s. From 2000 onwards, however, it was mainland Southeast Asia that experienced a greater relative change. Part of this reversal may be caused by the rising global demand for natural rubber (*Hevea brasiliensis*), fuelling increasing (but unstable) market prices from 2000–2012 (Fig. 1), and leading to unprecedented expansion of both smallholder and large

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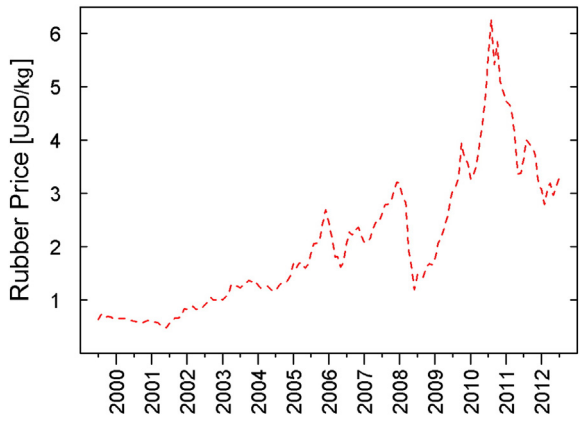

Fig. 1. Monthly price (USD/kg) for natural rubber on the Singapore/Malaysian stock exchange.
Source: World Bank (World Bank, 2014).

scale plantations across the region (Fox & Castella, 2013; ODC, 2014; Vrieze & Naren, 2012; Ziegler et al., 2009).

Two countries that play pivotal, albeit differing, roles in this forest transformation process in mainland Southeast Asia are Vietnam and Cambodia. In Vietnam, rapid forest loss from c. 1970 to c. 1990 (Bernard & Koninck, 1996) has been followed by a period of net reforestation during the 1990s (Meyfroidt & Lambin, 2008). In contrast, Cambodian forests had escaped earlier destruction, but are now expected to undergo major transformation (Southworth et al., 2012). Progressive market liberalization stemming from the turn of the millennium has sparked rapid expansion of rubber plantations among smallholders (Dararath et al., 2011; Hing & Thun, 2009), and more recently in the form of industrial Economic Land Concessions (ELCs). Meanwhile the natural rubber industry in Vietnam, which is already well established (FAO, 2010), is expanding rapidly again, especially since the early 2000s (Luan, 2013).

Border regions between countries provide an ideal case for studying the relative importance of political and economic impacts on land cover change (Kuemmerle et al., 2006). Although the Cambodian–Vietnamese border region shares similar natural forest composition (Wikramanayake et al., 2000), differing land governance regimes inevitably lead to alternate land cover/use change pathways. Aside from historical differences, recent regional inter-governmental cooperation led to the formation of the *Cambodian–Laos–Vietnam Triangle* in 2004, aiming to develop the border region, including investment in natural rubber plantations (Gironde, 2012; Ishida et al., 2013). Studying this border region from a remote sensing perspective will contribute to understanding how these political backgrounds have shaped historical forest cover, but also whether global market forces influence land use decisions, irrespective of political and socio-economic contexts.

When analyzing forest cover change dynamics it can be useful to consider the forest frontier, defined by Chomitz et al. (2007) as beyond the boundary where forest and agricultural (or agroforest) interact. Non-frontier forest (e.g. plantations, fallow regrowth) often do not provide the same benefits of mature frontier forest vegetation in terms of ecosystem services such as climate and water regulation, carbon storage, and biodiversity richness (e.g. Numata et al., 2011). Distinguishing between frontier and non-frontier forests in change analysis helps evaluate the quality (in broad terms) of forest undergoing change (Tropek et al., 2014).

From a monitoring perspective, the Landsat mission in particular maintains attributes that are highly suitable for mapping forest cover and associated change over time at varying spatial scales (Hansen & Loveland, 2012; Tucker et al., 2004). A number of regional scale analyses have focused on specific themes, for example, mapping selective logging (Asner et al., 2005), burned area (Matricardi et al., 2010), or shifting cultivation dynamics (Inoue et al., 2010). In Southeast Asia Landsat data has been used to map regional rubber plantation extent (Dong et al., 2013; Li & Fox, 2011) and change dynamics (Li et al., 2006; Liu et al., 2013). National scale Landsat studies have focused on general land cover change (Fry et al., 2011), or specifically on forest cover loss (Broich et al., 2011; Hansen et al., 2008b, 2009) often coupled with forest degradation (Asner et al., 2009; Margono et al., 2012). At pan-tropical to global scales Landsat analysis have largely focused on forest cover loss, taking a sampling approach (Achard et al., 2014; Hansen et al., 2008a), and more recently wall-to-wall coverage (Hansen et al., 2013). Studies with the aim of broader scale mapping of rubber plantations in Southeast Asia have generally favored the use of MODIS sensors (Dong et al., 2012; Li & Fox, 2012; Senf et al., 2013), likely due to reduced preprocessing time, coupled with the advantage of phenological time series. Advancements in automated Landsat preprocessing however (Ju et al., 2012; Zhu & Woodcock, 2012), have given rise to a new era in Landsat change detection methods, moving away from traditional bi-temporal change detection (Coppin et al., 2004), and towards more dense time-series approaches (Broich et al., 2011; Huang et al., 2010; Kennedy et al., 2010; Zhu et al., 2012). The utility of such optical time series remains to be fully explored in a tropical environment where persistent cloud and aerosol contamination presents an ongoing challenge (Grogan & Fensholt, 2013; Leinenkugel et al., 2013).

Southeast Asia hosts a wide variety of tropical forest types ranging from moist evergreen to dry-deciduous. Despite a number of studies focusing on dry forest systems (Clark et al., 2010; Helmer et al., 2010), in comparison to tropical evergreen forest, they remain largely understudied. Part of the reason for this stems from the fact that they are more difficult to monitor using satellite imagery, with dry season senescence often causing confusion in vegetation change analysis (Asner, 2001; Sánchez-Azofeifa et al., 2009), frequently leading to higher mapping error (Couturier, 2010; Barreda-Bautista et al., 2011, Chap. 11; Stibig et al., 2014). Time series trajectory approaches are considered more robust against inherent noise in the data (e.g. inter annual variation) (Hostert et al., in press) and therefore may be more suited to change detection within dry forest types. To our knowledge, no study has tested the applicability of trajectory-based forest change approaches in deciduous tropical dry forest systems.

The main objective of this study was to explore the utility of annual Landsat data for mapping land cover change associated with forest disturbance along the border region of Cambodia and Vietnam from 2000–2012, with distinct attention to the role of natural rubber plantations both in frontier and non-frontier forest systems. Using a selected study area we specifically ask the following research questions:

- How accurately can annual Landsat time series map the location and timing of forest disturbance in tropical evergreen and seasonal forest landscapes?
- Are there cross border differences in frontier and non-frontier forest disturbance rates between Cambodia and Vietnam?
- What proportion of disturbances in frontier and non-frontier forests can be accounted for by the impact of natural rubber plantations?
- Is there a relationship between global market prices for natural rubber and the annual rate of frontier forest disturbance caused by rubber plantation expansion on both sides of the border?

2. Study area

The study area encompasses most of a single Landsat footprint (path 125, row 052) on the Cambodian–Vietnamese border (Fig. 2) and includes evergreen, mixed-deciduous, and dry-deciduous forest types (Walston et al., 2001), as well as extensive areas of plantations, predominantly natural rubber. The total study area covers 22,420 km^2, with 54% located in Vietnam and 46% in Cambodia. We estimated that 57% of the

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