



Current trends of rubber plantation expansion may threaten biodiversity and livelihoods[☆]



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ABSTRACT

The first decade of the new millennium saw a boom in rubber prices. This led to rapid and widespread land conversion to monoculture rubber plantations in continental SE Asia, where natural rubber production has increased >50% since 2000. Here, we analyze the subsequent spread of rubber between 2005 and 2010 in combination with environmental data and reports on rubber plantation performance. We show that rubber has been planted into increasingly sub-optimal environments. Currently, 72% of plantation area is in environmentally marginal zones where reduced yields are likely. An estimated 57% of the area is susceptible to insufficient water availability, erosion, frost, or wind damage, all of which may make long-term rubber production unsustainable. In 2013 typhoons destroyed plantations worth US\$ >250 million in Vietnam alone, and future climate change is likely to lead to a net exacerbation of environmental marginality for both current and predicted future rubber plantation area. New rubber plantations are also frequently placed on lands that are important for biodiversity conservation and ecological functions. For example, between 2005 and 2010 >2500 km² of natural tree cover and 610 km² of protected areas were converted to plantations. Overall, expansion into marginal areas creates potential for loss-loss scenarios: clearing of high-biodiversity value land for economically unsustainable plantations that are poorly adapted to local conditions and alter landscape functions (e.g. hydrology, erosion) – ultimately compromising livelihoods, particularly when rubber prices fall.

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1. Introduction

Hevea brasiliensis, the para-rubber tree, is the major source of natural rubber for the global annual production of >1 billion car, truck and aircraft tires (Li and Fox, 2012; WardsAuto, 2013). This rapidly expanding industry is driving land conversion to rubber

plantations in SE Asia where 97% of the world's natural rubber is produced (FAO, 2013). Natural rubber prices are volatile and dependent on many factors. The decade between 2001 and 2011 saw a tripling of rubber prices. A slowdown in demand (particularly in China) combined with rising stocks due to widespread rubber planting has since led to subsequent price declines of over 70% (Fig. B.1). However, the global consumption of natural rubber is expected to continue to grow, and rising prices in the immediate future are likely (Prachaya, 2015). Alternatives to natural rubber are still limited as synthetic rubber produced from petroleum does not match its resilience, elasticity, and abrasion resistance (Cornish, 2001).

Rubber was historically planted in the equatorial zone between 10° and –10° latitude (Priyadarshan et al., 2005). However, many traditional rubber growing areas in insular SE Asia are being

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converted to oil palm, which is even more lucrative but strictly humid-tropical (Fox and Castella, 2013). This and China's success in growing hardy rubber clones led to an expansion of rubber into non-traditional planting areas all over continental SE Asia (Li and Fox, 2012; Priyadarshan et al., 2005). Rubber production in continental SE Asia has increased by almost 1500% from just over 300,000 tonnes in 1961 to over 5 million tonnes in 2011 (FAO, 2013). The vast majority of these new rubber plantations are mono-cultures as opposed to the traditional mixed rubber agroforestry systems in Indonesia (Feintrenie and Levang, 2009; van Noordwijk et al., 2012). While the original expansion was driven by state agencies, the sector is now dominated by small-holders in China, Vietnam and Thailand, as well as large-scale economic concessions in Cambodia, Laos and Myanmar (Fox and Castella, 2013). The crop has brought wealth to many poor areas (Qiu, 2009), however, socio-economic concerns arise from a host of issues, including rubber price fluctuations, narrowing of income sources, potential loss of food security, dependency on global markets of small-holders who often have little knowledge of the latter, and "land grabbing" practices (Fox and Castella, 2013; Fu et al., 2010; Xu et al., 2014). Conversion to rubber plantations also has environmental implications such as reduction in water reserves (Guardiola-Claramonte et al., 2008; Ziegler et al., 2009), carbon stocks (de Blécourt et al., 2013; Li et al., 2008), soil productivity (Zhang et al., 2007), and biodiversity (Li et al., 2007; Warren-Thomas et al., 2015).

An understanding of which environments rubber has spread to and whether rubber cultivation on them is sustainable, is vital for wise land use planning and policy interventions. Currently, a quantitative region-wide assessment of the environmental space occupied by rubber plantations is lacking, as are assessments of the rates and consequences of establishing plantations in novel environments. Here we (a) quantify the environmental space in which rubber occurs naturally; (b) establish the extent and trends of plantation spread into marginal environments; (c) assess the types of land that are being converted; (d) use this information to predict future patterns of land conversion, and finally (e) evaluate the biodiversity and socio-economic risks of land conversion to rubber plantations.

2. Material and methods

2.1. Model of historically suitable environments

We developed a global bioclimatic model of the environmental space where rubber would naturally occur ('historically suitable' space) based on the natural distribution of *H. brasiliensis*, and used this to identify where rubber is planted into novel environments. For this we obtained 97 geo-referenced and herbarium vouchered records (GBIF, 2013) of wild origin, which capture the range of environmental conditions the species occupies within its native range (Amazon Basin and Matto Grosso in Brazil, Guianas). To characterize the environmental space we acquired data on 31 topographic, climatic and substrate related environmental variables, which have been reported to directly or indirectly influence the suitability of habitat for rubber (Table B.1; 2.1.1). We then used a species distribution modelling approach, whereby the native rubber records were combined with environmental layers to produce a spatially explicit model of habitat suitability for rubber. We explored a range of modelling methods using the R library 'dismo' (Hijmans et al., 2013) of which MaxEnt (Phillips and Dudik, 2008) produced results that were closest to areas known to be historically suitable for rubber (Li and Fox, 2012; Priyadarshan et al., 2005), and response curves that were in closest agreement with existing

literature on agricultural trials (Mokhtatar et al., 2011; Nair et al., 2010; Priyadarshan, 2003a, 2003b, 2011; Priyadarshan et al., 2005; Rao et al., 1998). The final model achieved a mean Area Under Curve (AUC) of the receiver operating characteristic of 0.97 (± 0.014 SD) under 10-fold cross-validation. Measures of confidence were derived by performing calculations on three thresholds for converting the continuous habitat suitability predictions into binary maps. For further details on the environmental variables, and model settings, selection, validation and performance see Appendix A.

2.2. Contemporary distribution of rubber plantations

The current distribution of rubber plantations in continental SE Asia was based on a map generated by Li and Fox (2012) using MODIS Terra 16-day composite time-series NDVI products spanning March 2009 to May 2010 at a resolution of 250 m. The available data cover the following areas: S China, all of Laos and Cambodia, most of Vietnam, N and central Thailand and S and E Myanmar (Fig. 1b). No data are available for the following areas: S Thailand, SW Vietnam and W Myanmar. When we use the term "continental SE Asia" we mean the entire region as delineated by country boundaries. Our definition of continental SE Asia does not include peninsular Malaysia. When we use the term "study area", we are referring to the rectangular area for which we have rubber distribution data. The available data differentiate between young (<4 years old) and mature (≥ 4 years old) plantations. To test for scale-dependency of the results we further gathered high-resolution rubber plantation maps for Xishuangbanna, China for four time intervals: four Landsat TM/ETM images from 1988, 1992, 2002 and 2006 (spatial resolution c. 30 m), and 48 RapidEye images of level 3A captured in 2010 (spatial resolution c. 5 m) (Xu et al., 2014). To analyze whether there were significant shifts in the environmental niche rubber plantations occupied between 2005 and 2010 (respectively, in Xishuangbanna between 1988 and 2010) we followed a statistical framework developed by Broennimann et al. (2012), using default settings for the resolution of the environmental space ($N = 10,000$ grid cells), and the smoothing parameters of the kernel density function. In addition we undertook an analysis of environmental similarity between the natural *H. brasiliensis* range and the environments occupied by rubber plantations in mainland SE Asia by calculating a multivariate environmental similarity surface (Elith et al., 2010).

2.3. Characterization of novel environments

We trawled the academic literature, reports from governmental and non-governmental organizations, and local news sources for qualitative information and quantitative data on levels of rubber tree mortality and average annual yields in relation to environment. We then delineated and mapped generalized environmental thresholds to characterize the novel environmentally marginal space that rubber is being planted into, at three hierarchical levels:

Level 1. Novel marginal environments: this encompasses all environmental space that rubber is being planted into that is different from the historically suitable growing space.

Level 2. Sub-optimal marginal environments: a subset of level 1, where there are reports of environmental stresses reducing yields and/or the harvesting period, increased time to maturity and/or susceptibility to diseases.

Level 3. Risky environments: a subset of level 2 where environmental stresses are so severe that there is a risk of unsustainability – either due to reported high plantation mortality and/or evidence for negative feedbacks between

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