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Biodiversity in rubber agroforests, carbon emissions, and rural livelihoods: An agent-based model of land-use dynamics in lowland Sumatra

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ABSTRACT

Rubber agroforests in the mostly deforested lowlands of Sumatra, Indonesia are threatened by conversion into monoculture rubber or oil palm plantations. We applied an agent-based model to explore the potential effectiveness of a payment for ecosystem services (PES) design through a biodiversity rich rubber eco-certification scheme. We integrated conditionality, where compliance with biodiversity performance indicators is prerequisite for awarding incentives. We compared a PES policy scenario to 'business-as-usual' and 'subsidized land use change' scenarios to explore potential trade-offs between ecosystem services delivery and rural income. Results indicated that a rubber agroforest eco-certification scheme could reduce carbon emissions and species loss better than alternative scenarios. However, the suggested premiums were too low to compete with income from other land uses. Nevertheless, integrating our understanding of household agent behavior through a spatially explicit and agent-specific assessment of the trade-offs can help refine the design of conservation initiatives such as PES.

1. Introduction

Land-use/cover change (LUCC) is a major driver of global environmental change and is accelerating due to continuous growth of the global population and export-oriented agriculture (DeFries et al., 2010; Lambin and Meyfroidt, 2011). Indonesia has been ranked as having the second highest rate of deforestation among tropical countries after Brazil (Margono et al., 2012) due to the rapid replacement of vast areas of primary lowland forests with monoculture plantations of oil palm, rubber and other crops (Broich et al., 2011; Dewi et al., 2013; van Noordwijk et al., 2012). As a result, Indonesia has been identified as one of the main global contributors of greenhouse gasses stemming from deforestation and forest degradation (IPCC, 2007), suffering associated with biodiversity loss, land degradation, and impairment of ecosystem services, along with resulting negative effects on local livelihoods. A recent land-use intensity analysis in Sumatra found that over time, land dynamics have shifted from an overall pattern of primary forest loss in the 20th century to the loss of agroforests during the 21st century (Villamor et al., 2014). Although lowland rubber agroforests (hereafter 'rubber agroforests') support relatively higher biodiversity, greater carbon stocks and local livelihoods, this land use is giving way to monoculture oil palm and rubber plantations (Rudel et al., 2009; van Noordwijk et al., 2012). Since very few primary forests remain in Sumatra, conserving rubber agroforests is one of the few options for supporting biodiversity on the island, and incentives to prevent further land cover conversion are an urgent conservation need (Ekadinata and Vincent, 2011; Feintrenie et al., 2010).

Payments for ecosystem services (PES) schemes are one of the policy options being considered to help sustain rubber agroforests in Sumatra. The PES schemes have been implemented in many countries, particularly in agricultural landscapes, to add ecosystem

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services (ES) to the portfolio of production choices in a sustainable way (Pagiola et al., 2004). Through PES, landuse decisions that contribute to greater ES provision can be rewarded with modest incentives, as there are land-use options in the mosaic of remaining natural or secondary forests with existing low-to-intermediate intensity agriculture that provide financial returns in addition to environmental benefits. However, there is no clear understanding of how PES schemes affect the synergies and trade-offs among ES or of the factors that contribute to participation in PES schemes. Four design principles have been identified to determine if a PES scheme is effective and fair: realistic objectives or goals, conditionality of benefits, voluntary participation, and pro-poor outcomes (van Noordwijk et al., 2007). Among these four principles, conditionality (i.e., benefits are conditional on achieving performance measures specified in contracts and understood by all relevant stakeholders) distinguishes PES from other conventional forms of incentives such as taxes and subsidies (van Noordwijk and Leimona, 2010). This PES principle establishes the need for performance indicators that can be measured to determine if the scheme is effective. To better understand the impact of PES schemes, including inherent complexities related to the future of rubber agroforests, we developed an agent-based model (ABM) that simulated land-use dynamics named the Lubuk Beringin-Land Use Dynamics Simulator (LB-LUDAS). We selected this modeling approach because it is primarily used for simulating socio-ecological processes to understand the dynamic interactions between the social and natural systems as well as for policy and institutional analysis of these systems (Kelly et al., 2013). Its main strength is that it incorporates the decision-making process of heterogeneous households (Matthews et al., 2007), while capturing feedback effects and nonlinearities from natural system processes. The main focus of ABM is the discovery of emergent behavior, where large-scale outcomes result from simple interactions of heterogeneous household agents. The agents are typically able to react to (locally) perceived changes in their environment through action on the environment or internal adaptation (Kelly et al., 2013). Because of this, many ABM models have been used to simulate LUCC scenarios taking land-use decisions into account (Bousquet and Le Page, 2004; Le et al., 2010, 2008; Villamor et al., 2011b). Recent similar applications include: simulating the effects of social norms on enrollment in a PES program in China (Chen et al., 2012), simulating land-use decision making of the farm households participating in PES schemes of the Sloping Land Conversion Program in China (Sun and Müller, 2013), and assessing changes in household-level inequity associated with the transition from shifting cultivation practices to rubber plantation adoption in Laos (Evans et al., 2011). Most of these applications have strongly emphasized the land-use decision making of households. Though very important, this aspect of PES is limited with respect to revealing the real impacts of these schemes on the provision of ES.

In this research we simultaneously addressed the integration of household decision making regarding PES participation and competing policies, and the potential ES trade-offs or synergies emanating from those decisions. Also, we explicitly integrated conditionality as an innovative aspect of assessing PES schemes using an ABM to assess the effectiveness of the proposed PES design. By coupling the socio-economic and ecological systems of the rubber agroforest landscape, our objectives were: (1) to test the internal consistency of the model as a basis for exploring policy options that extend beyond historical trends; (2) to explore the policy efficiency of environmental programs that provide economic incentives for achieving environmental goals, specifically in the form of eco-certification and price supports for biodiversity-friendly rubber production; and (3) to quantify trade-offs between local livelihoods and ES delivery (i.e., agro-biodiversity conservation, carbon emission reduction, and crop yields) across plausible levels of external investment. Household land-use choices, behavior, and preferences were determined using a combination of methods and translated into decision rules for the LB-LUDAS model.

2. Study area and data

2.1. Study area

The study area includes three villages, Lubuk Beringin, Laman Panjang, and Buat, in the Jambi Province of Indonesia on the island of Sumatra, and the surrounding area of around 15,000 ha (Fig. 1). The area stretches along the foothills of Kerinci Seblat National Park, which is home to endangered species such as the Sumatran tiger. There are four major land-use/cover types in the study area: forest, rubber agroforest, monoculture rubber, and rice field (Table 1). Rubber agroforest was formerly the dominant land use in Jambi Province (van Noordwijk et al., 2012).

Due to the relatively low latex productivity of rubber agroforests, most of the surrounding area has been converted to more profitable land uses such as monoculture rubber and oil palm plantations. Moreover, initial investments for plantation establishment were made through loans from private sector and state-owned companies provided to farmers through credit cooperatives as a form of agricultural support (i.e., low-cost capital with a maximum value of about US$ 5800). Oil palm concessions were planned and licensed by the provincial government for virtually all secondary forests, often including large tracts of rubber agroforest owned and managed by smallholders (Minister degree No. 720/KPTS-II/1989). This effort has been accompanied by a government settlement program to address labor shortages in the provinces. Jambi is one of provinces targeted by the program, in which a large settler workforce, mostly from Java, is allocated to the labor-intensive rubber and oil palm plantations. The settlers are provided with land share certificates for 2 ha parcels for the establishment of monoculture rubber or oil palm plantations (Vermeulen and Goad, 2006).

A number of studies have described the rich biodiversity and ecosystem functions supported by rubber agroforests (Beukema et al., 2007; Griffith, 2000; Joshi et al., 2003; Rahayu, 2009; Rasnovi, 2006; Schroth et al., 2004; Tata et al., 2007; Tomich et al., 2004, 1998, 2001). To protect the rubber agroforests from conversion to other land uses, conservation agreements were developed under the Rewarding Upland Poor for Environmental Services (RUPES) program of the World Agroforestry Centre (ICRAF). The main purpose of these agreements was to develop and test appropriate schemes for agro-biodiversity conservation for agroforests through an action-research approach. Conservation agreements are the initial step toward institutionalizing payment schemes for agro-biodiversity through eco-certification (Villamor et al., 2011a). Eco-certification efforts target the raw materials from crops produced in biologically diverse transitional systems and verify that producers have used management practices that conserve ecosystem services (Bennett, 2009). In 2009 the Waseda-Bridgestone Initiative of Japan granted financial support to a local NGO, Komunitas Konservasi Indonesia, together with ICRAF for a feasibility study of the eco-certification of rubber in the villages of Lubuk Beringin and Laman Panjang. According to the results of this feasibility study, local agroforest farmers were negotiating for an increase of US$ 1 over the baseline price (a 40% increase) for dry rubber latex (Akiefnawati, personal communication).

2.2. Data

We surveyed 95 households in the study area between February and March 2010 that were randomly selected from a total