Modelling the Socio-Ecological System Dynamics of Rubber Agroforests to Design Reward Mechanisms for Agro-biodiversity Conservation

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Abstract: An agent-based modelling approach (LB-LUDAS model) was applied to simulate and visualize the temporal and spatial scale effects of the Payments for Ecosystem Services (PES) scheme on the trade-offs between goods and services in the rubber agroforest landscapes in Jambi Province, (Sumatra) Indonesia. The PES scheme under investigation is a form of eco-certification of biodiversity-friendly rubber agroforests, as an economic incentive to keep rubber agroforests from conversion into monoculture plantations. Within the model, we integrated the concept of PES conditionality, where biodiversity performance measures were set for household agents to qualify for incentives. On the other hand, species richness, carbon sequestration, and natural succession sub-models are imbedded in the landscape agents. During the simulation, we looked at three different price scenarios to determine how they will affect the land-use decision of the agents and the ecosystem services supply. The main results showed that PES for rubber agroforests could offer synergies among carbon emission reduction, biodiversity and livelihoods when compared to the existing land-use practices. At the same time, the scheme could reduce the trade-offs resulting from possible land-use/cover change. The results of the simulation were validated using a role-playing game testing responses to external agents.

Keywords: *Agent-based model, biodiversity performance indicator, conditionality, eco-certification, ecosystem service trade-offs, land-use/cover change, price effect*

1.   INTRODUCTION

Several studies have illustrated the effect of payment for ecosystem services (PES) on land use decision making, and the impact of social norms on the enrollment of PES, and assessed the effect on household income using agent-based models (ABM) (Chen et al., 2012; Evans et al., 2011; Sun and Müller, 2013). However, understanding how PES schemes and households adoption affects the goods and ecosystem services (ES) delivery are very few. In this paper, we explore the role of PES schemes to reduce the ES tradeoffs or enhance the synergies of various ES using ABM (i.e., Lubuk-Beringin – Land Use Dynamic Simulator or LB-LUDAS model). Since very few primary forests are left in Indonesia, maintaining agroforests is one of the last options for supporting the remaining biodiversity, and incentives to prevent further conversion to less biologically diverse land uses are seen as an urgent need. The type of PES scheme under investigation is an eco-certification or eco-labeling of rubber agroforests, in which a price-premium is added if a household will adopt and meet all the biodiversity performance criteria. The research question is whether eco-labelling or eco-certification of latex from rubber agroforest under a PES scheme could be a promising option for at least part of the households as well as by how much price increase is appropriate to make sure the continuous ES supply. Thus, we explored the effect of different price scenario under the PES scheme on the land-use decisions of the households.

2.   METHODS

2.1.   Study area and data

The study site includes three villages, namely Lubuk Beringin, Laman Panjang, and Buat, all located in Jambi Province, (Sumatra) Indonesia. Together, they have a total population of 2,207 inhabitants belonging to 553 households (Rantau Pandan Statistics 2003). The main source of staple food is rice paddies; the main source of income is rubber (*Hevea brasiliensis*) and occasionally durian and other local fruits obtained from the rubber agroforests. Rubber agroforest used to be the dominant land use in Jambi Province (van Noordwijk et al., 2012). However, due to the low latex productivity, farmers are now attracted to convert their farm lands into more profitable land use such as oil palm and monoculture rubber plantations.

We surveyed 95 randomly selected households in the study area from a total population of 550 households. The survey was conducted between February and March 2010 with the objective to elicit data on household characteristics, preferences, and behaviors. It explored: (1) household profiles and farm characteristics (from which existing land-use choices were generated); and (2) households' willingness to adopt PES. Based on the survey results we characterized the households using principal component and cluster analyses and identified two categories (Villamor, 2012). Type 1 households were described as "better-off households," and Type 2 households as "poor households." For each household type the existing household land-use choices were assessed using a multinomial logistic regression analysis. Willingness to adopt PES was assessed using a binary logistic regression analysis (Villamor, 2012; Villamor et al., 2011). The results of the land-use choice and willingness to adopt PES analyses became the basis of agent decision making for the business-as-usual (BAU) model scenario, along with PES scenarios.

2.2.   LB-LUDAS: model description

The study applies the LUDAS framework (Le et al., 2008). The description of the LUDAS model using the ODD protocol (Overview, Design concept, and Details) (Grimm et al., 2010) is described in Le et al. (2010). For application of PES, in the following the modified and new features in the LB-LUDAS model are described (Villamor, 2012; Villamor et al., under review).

Overview

Agents, state variables and scales: There are two types of agents. First, human agents are representations of individual farming households with state variables on social, natural, physical, financial and human resources, and policy access. Second, landscape agents (i.e., congruent land pixels or patches) with state variables corresponding to GIS-raster layers of biophysical spatial variables, spatial neighbourhood characteristics, spatial economic variables (e.g., proximate distance to road and town centre or market), spatial institutional variables (e.g. owner and protection zoning), and households' landscape vision (Le et al. 2008). One grid cell or pixel represents 30 m x 30 m, and the model landscape covers 156 km^2. The adaptive traits of each individual agent are explicitly processed mainly by land-use decisions and the change in

behaviour strategies (i.e., preference coefficient of land-use choice function and willingness to adopt PES policies, and structure of labour allocation).

Process overview and scheduling: One time step represents one year. The main time loop of the simulation program, called annual production cycle, includes sequential steps, which are agent-based and integrated with patch-based processes. The ten basic simulation steps are: (1) set-up initial state of the system, (2) update agent and patch attributes, (3) adopt behaviour parameters, (4) farmland choice, (5) forest choice, (6) other income sources, (7) update changes in agent and patch attributes, (8) create new agents, (9) translate annual land-use changes, and (10) calculate ecosystem services (e.g. crop productivity, species richness, and carbon sequestration).

Details

Input: Data and parameters were parameterized and calibrated for each sub-model (Table 1).

Table 1 External input data and sub-models in LB-LUDAS model

Sub-model	Parameter	Data source
Carbon stocks per land-cover type	Time average C-density: 1-150 Mg ha^{-1}yr	Tomich et al. 1998
Forest/ rubber agroforest growth (Le, 2005)	Basal area: 21-41 m^2 ha^{-1}	Rahayu 2009; Rasnovi 2006
Land-use choice	Characteristics of farm plot owner (e.g. age, education status, income, etc.); natural land attributes (e.g. wetness index, slope, etc.); neighborhood characteristics of land use (e.g. enrichment factor of land-use types)	Field survey / GIS-based calculations
PES adoption	Characteristics of farm plot owner (e.g. age, education status, income, etc.); access to conservation policies	Field survey
Rubber agroforest latex yield	800- 1200 kg ha^{-1}yr^{-1}	Field survey
Rubber monoculture yield	1200-1800 kg ha^{-1}yr^{-1} (2009-2010)	ICRAF data
Species richness	26-80 tree species per ha	Rahayu 2009
Upland rice yield	600-800 kg ha^{-1}yr^{-1}	Field survey

Sub-models

PES-adoption sub-model (nested within Land-use choice sub-model) calculates stochastically the probability of the household agents whether to adopt or not to adopt the PES scheme based on their preference coefficients. These preference coefficients were derived from binary logistic regression (Villamor et al., 2011). The sub-model is linked to the Calculate-species-richness sub-model, creating the interaction between socio-economic state variables and the bio-physical processes in the systems. This sub-model is integrated in the agent's decision-making routines with a simple rule base: (1) if the household decides to adopt the PES scheme, then do rubber agroforest, (2) otherwise look for other land-use types for current landholdings. If the latter case is realized, the household agent will execute Land-use choice sub-model. The main variables of the sub-models are shown in Table 2.

Calculate-species-richness sub-model deterministically calculates the estimated species richness of the land cover (e.g. rubber agroforests). The estimated species richness of rubber-agroforest serves as a biodiversity performance measurement for the eco-certification scheme (see section 2.3). The species richness is estimated using the power function of species-area relationship (Villamor et al., under review).

Natural-transition sub-model performs the natural succession among vegetation types based on accumulated vegetation growth and ecological edge effects. Its rules are based on the evaluation of four patch variables, namely (i) previous cover type, (ii) life span of existing cover type, (iii) existing stand basal area, and (iv) distance to nearest forest.

Carbon emission sub-model: The land-cover-derived C-stocks method is applied by assigning the time-averaged C-stocks and is estimated in the LB-LUDAS model.

Financial-return sub-model estimates the annual financial returns to household agents from major land uses. The yields generated from the crop production sub-model (rubber and rice) are captured by this sub-model,

where all crop production costs (e.g., labour and agro-chemical input costs) are deducted from annual revenues. At the end of each time step the results are used to estimate the net present value (NPV) of the different land uses, which serves as an indicator of the livelihood options of household agents in each scenario. To investigate the financial returns of land-use types (i.e., rubber plantation, rubber agroforest, and rice), we calculated their NPV over 20 years. The interest rate is 20%. Rice value is US$ 1 kg^{-1} and dry rubber is US$ 2.5 kg^{-1}. Variable costs of each crop were derived from Wulan et al. (2008) and labour costs are US$ 2 day^{-1}. We assumed that an additional income of up to US$ 70 ha^{-1}yr^{-1} is generated beginning at year eight from fruit trees intercropped within rubber agroforests as observed from the field survey.

2.3. Scenario

The scenarios are primarily based on household land-use decisions under different policy contexts.

1) Business-as-usual (BAU) scenario — agents operate on the premise that there is no policy intervention available. We simulated existing land-uses on the agent's landholdings over a 20-year period with changes to biophysical conditions based on temporal dynamics and population increase.

2) PES scenario - agents operate on the premise that a *conditional* eco-certification scheme is offered. First, the agent assesses the existing land-use choice. Then, the agent assesses whether to adopt PES or not using the PES-adoption sub-model. If an agent adopts PES their biodiversity performance measures (Table 2) are generated by two sub-models (i.e., *Calculate-species-richness* and Forest-Growth-Response, Le et al. (2008)) and evaluated for PES compliance

A price premium is awarded to agents that meet all of these criteria and no payments are available for partial compliance. To understand the possible amount of price premium, we tested a 10%, 20% and 40% increase of price value from the baseline price of (US$ 2.5[1])

Table 2 Proposed eco-certification criteria for rubber agroforest based on Tata et al. (2007) integrated into LB-LUDAS model

Biodiversity performance target
i. At least four different trees species (>10 cm DBH) within an 8 m radius of a random observation point within the plot (based on an average of five observations);
ii. If there are less than six species the relative stand basal area of the rubber trees is determined, with a threshold of 2/3 coverage; and
iii. At least one tree with a DBH of >40 cm within a 25 m radius (based on an average of five observations).

2.4. Run set up summary

A total of five simulation runs were independently performed for BAU scenario while three simulation runs were performed for each price scenario under PES. For each scenario, we took the average values. Each run has 20 time steps or years and the model is programmed in Netlogo version 4.1.

2.5. Validation

A social validation approach was conducted to validate the results of the LB-LUDAS simulation through role-playing games (Villamor and van Noordwijk, 2011). Land-use game boards were used to represent each of the target villages and same survey respondents played the games where they could directly change their land-use/cover type according to their negotiations with actors promoting either conversion or conservation of rubber agroforests.

3. RESULTS AND DISCUSSION

3.1. Land-use/cover change

The land-use change trends of three main land uses simulated under BAU and PES scenario (Figure 1). A decreasing trend of rice field is observed both under the BAU and PES scenarios. For agroforests, a larger rubber agroforest area was simulated under the PES scenario than BAU, suggesting that rubber agroforest is preferable by household agents under the PES scenario. No change of rubber monoculture was observed under PES scenario while a decreasing trend of rubber monoculture was observed under the BAU scenario.

Within the PES scenario, we compared the simulated land use map according to different price increase on baseline price with the 2005 land-use map to see the potential change. Table 3 summarizes the land-use

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[1] Average price per kilogram of dry rubber was US$ 2.5 during the data collection (2010).

changes at 10%, 20% and 40% increase of baseline price. Results show as the price premium increases, the area of rice field increases while the area of rubber monoculture decreases. For rubber agroforests, no apparent trend was observed that links to the price scenario.
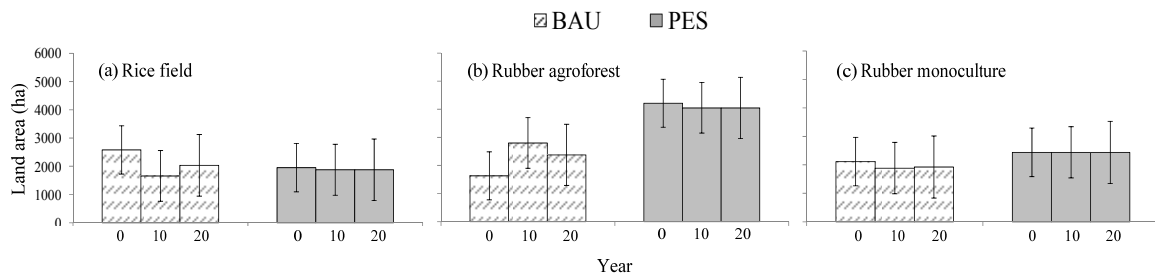
Figure 1. Simulated land-use trends under the BAU and PES scenarios.

Table 3 Land-use change compared to 2005 land-use map.

Land use	% land area in	% land area after year 20		
	2005 land use map	10% increase of baseline price	20% increase of baseline price	40% increase of baseline price
Rice field	1.,5	11.2	12.3	15.6
Rubber agroforest	14.4	14.0	15.3	12.4
Rubber monoculture	23.0	14.9	13.1	12.8

3.2. Ecosystem services (ES) delivery indicators

From those land-use changes, the potential impact on the ES delivery was estimated. Between BAU and PES scenarios, the key indicators for ES delivery are presented in Table 4. The results suggest that under the PES scenario performs better for maintaining species richness, and reducing carbon emissions. In terms of price scenarios, biodiversity and carbon emissions did not differ substantially.

With regard to yields, the rubber yield from agroforest increases as the price premium increases, along with its uncertainty (i.e., standard deviation). However, the rice yield is highest under the BAU scenario while a gradual decreasing trend of yield as the price increases in price premium under the PES scenario. The yield of rubber monoculture would be highest with 20% PES price premium though would not differ substantially in comparison to other scenarios.
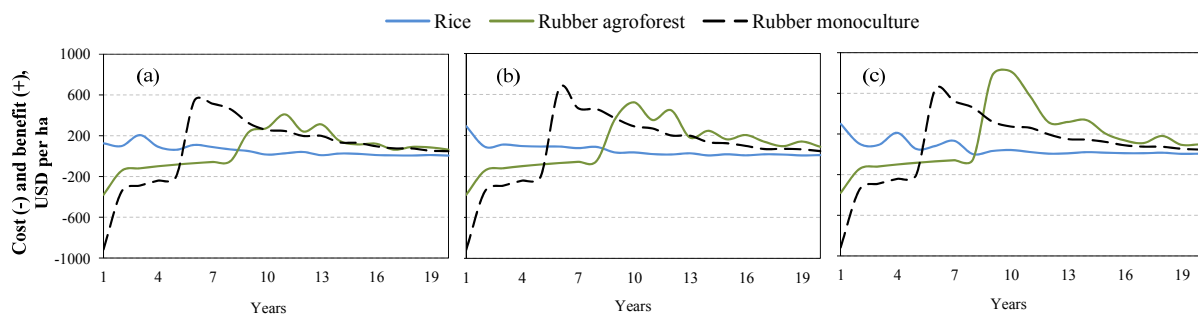
In terms of PES adoption, the highest number of PES adopters is at the 40% price premium. This suggests that an increase of price premium would increase the number of PES adopters.

Table 4 Simulated results in three scenarios based on key indicators

Indicator	Scenario			
	BAU	PES (10% price premium)	PES (20% price premium)	PES (40% price premium)
Biodiversity				
a. Species richness	64%	92%	93%	91%
b. Species loss	36%	8%	7%	9%
Carbon emissions (Mg ha^{-1} yr^{-1})	0.4	0.2	0.2	0.2
Agronomic yield				
a. Rice (kg ha^{-1} yr^{-1})	552 ± 104	493 ± 158	491 ± 156	486 ± 170
b. Rubber agroforest (kg ha^{-1} yr^{-1})	1,026 ± 222	1,032 ± 381	1,230 ± 419	1,227 ± 441
c. Rubber monoculture (kg ha^{-1} yr^{-1})	1,036 ± 82	1,033 ± 90	1,051 ± 127	1,027 ± 94
PES-Adopters	0	32%	36%	40%

3.3. Potential income from key land uses

Different PES values would lead to different NPV of land uses (Figure 2). Results show that over 20 year period, rubber monoculture has the highest net returns (US$ 1,360) even at 10% price increase for PES for rubber agroforest (Figure 2a). Consequent increase in PES values for rubber agroforest would lead that this land use would have the highest net returns (e.g., at 20% price increase the NPV is US$ 1,940, and at 40% price increase the NPV is US$ 2,960). At the same time, returns from rubber agroforest and monoculture would substantially vary over the years due to their yield fluctuations. In contrasts, the returns from rice would be lowest, yet variability in its NPV would be also lowest.

Figure 2. Effect of (a) 10%, (b) 20% and (c) 40% increase on PES price premium on the NPV of the major crops in the study area

4. CONCLUSIONS

Our study showed that PES through eco-certification for rubber agroforest landscape performs better in synergizing the key ES such as biodiversity, carbon stock enhancement and crop production compared to BAU scenario. In terms of ES delivery, the different price scenarios for price premium under the eco-certification scheme do not substantially alter the goods and ES delivery. However, between 20% and 40% price increase of baseline price, rubber agroforest could compete with rubber monoculture in terms of financial returns. Along with the increase of price premium is the increase of PES adoption.

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