Trade-off analysis of land use change, livelihoods and environmental services in the Upper Konto catchment (Indonesia): prospecting land use options with the FALLOW model

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Abstract: The study explored the use of the FALLOW model for assessing the impact of land use policies related to Designated Land Use to farmers' welfare and landscape carbon stocks in the Upper Konto catchment, East Java, Indonesia. A livestock (dairy cattle) module was added to FALLOW version 2.0 to enable simulating livelihood options in the area and four scenarios were explored: (0) baseline condition of protecting designated forest area, (1) full access to land, (2) conserving forest reserve only and (3) giving limited access to plant tree-based systems in part of state forest land. The study revealed that the current land use policy could lead to reduction in farmers' welfare ($US\$.capita^{-1}.year^{-1}$) and average aboveground carbon stocks ($Mg.ha^{-1}$). A change in land use policy by giving limited access to manage tree based systems in part of the State Forest Land could maintain the aboveground landscape carbon stocks level and reduced the decline of farmer's welfare. The result showed the efficacy of integrating economic, biophysical and farmers' learning dynamics in a simulation model such as FALLOW to explore various policy scenarios for natural resource management. FALLOW enables to prospect potential landscape trajectories and its consequences on landscape level indicators such as welfare and carbon stocks, for further discussion with local stakeholders. The results of model performance evaluation based on spatial accuracy and area inaccuracy revealed the need to refine the current new land allocation module.

Keywords: landscape modelling; land use policy; scenario analysis; trade-off analysis

Introduction

Throughout the world, conversion of natural forest, agricultural intensification and tree planting have environmental, economic and social impacts. Growing populations and market-based development accelerate changes in parts of the developing world. In areas where new land is no longer available and accessible, intensification may lead to conflicts. Trade-off analysis on the impact of land use change on livelihood and environmental services can help through evaluation of current land use and future management options. If scenario analysis is based on a credible landscape simulation model (Biggs et al., 2007; Carpenter et al., 2006; Swart et al., 2004), we can assess various land use options and its consequences for livelihoods carbon stocks and water flows, with various incentives and rules to enhance environmental service provisioning.

This paper evaluates, against data of actual patterns of change, the use of the FALLOW model (van Noordwijk, 2002; Suyamto, 2009) in assessing the trade-offs involved in land use change in the Upper Konto Catchment of East Java, Indonesia. The Upper Konto catchment (Niberring and Graaf, 1998; Rijsdick et al., 2007) is located in Malang Regency, East Java Province, Indonesia. It has an area of 237 km2 with around 50% of its land is controlled by the state (State Forest Land) for timber production (Production Forest) as well as for watershed protection purposes (Protection Forest, Figure 1). In the past, economic and population pressures had led to smallholder encroachment of this State Forest Land. Recently, a collaborative land management program has allowed farmers to cultivate this land by planting crops (i.e. maize, potato, cabbage, carrot) in between reforestation trees (*Pinus* sp, *Mahagony* sp.) planted by the State Forest, while maintaining or enhancing the existing tree growth. A program assessment showed that the project has not been fully successful, as numbers of healthy trees were far below the expected amount. The challenge now is identifying land use options that can be of mutual benefits to farmers as well as the management objectives of the State Forest Land of timber production and maintenance of environmental services. We used the FALLOW model to prospect the impact of land use policies on farmer's livelihood and carbon sequestration.

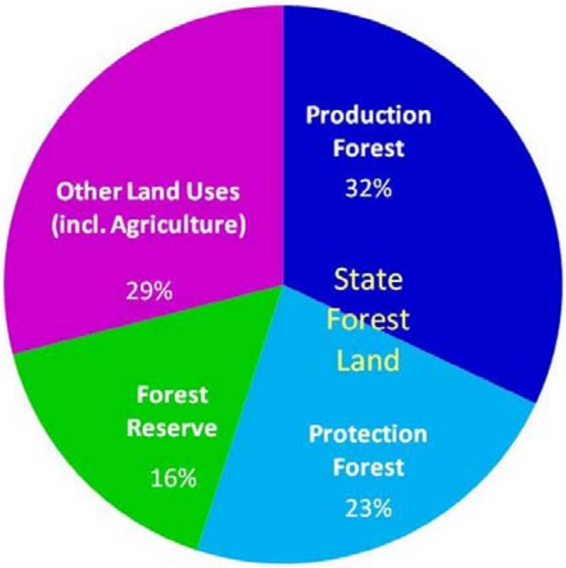

Figure 1. Designated land use of Upper Konto catchment (District Forestry Unit, 2000)

1. Data and Methods

1.1. FALLOW Model

Most simulation models that were applied for natural resource management or land use planning are land use change model that operates as a tool: (1) to analyze the drivers and consequences of land use change and (2) to explore the future of land use change (Verburg et al., 2004). Their function can be descriptive, to simulate the function of land use systems and their spatial patterns or prescriptive, to determine optimal land use configurations corresponding to specific objectives (Verburg et al., 2004). An example of descriptive models are CLUE (Verburg et al., 1999), CATCHSCAPE (Becu et al., 2003) and CORMAS (Bousquet et al., 2001). The FALLOW model is a descriptive model (http://www.worldagroforestry.org/af2/fallow). It was developed as an impact assessment tool integrating socio-economic and biophysical processes at landscape level (Table 1).

Traditional economic theory suggests that people make decisions based on the expected change in level of 'well-being'. Therefore, many landscape dynamics models use land use systems profitability as the main driving factors for land use change. In recent years, it has been acknowledged that inclusion of non-economic factors as drivers of landscape dynamics is quite important (Edward-Jones, 2006). In addition to land use system profitability, the FALLOW model includes farmers' learning dynamics as a factor that influencing farmers' land use choices at plot level, hence affecting soil fertility, food security and above-ground carbon stocks. Farmers adjust their expectation of benefit/profit gained from land use systems depending on learning style (α) and external information (β) such as from extension worker or development agents (Figure 1).

For the purpose of simulating the landscape dynamics of Upper Konto catchment, an additional module of livestock (dairy cattle) was added to the current FALLOW Version 2.0. The livestock module links the 'Land use & cover change' module with 'Household economic' module (Figure 2).

Table 1. Processes modelled in FALLOW

Process	**Level**	**Agent**
Decision making • what livelihood options? • how many plots to open and where?	community for non land-based systems, plot for land based systems	average farmers, can be differentiated by ability to adopt and learn extension agent (implicit)
Biophysical processes • yield, • soil fertility dynamics, • land use succession, • aboveground biomass	plot	-
Institutional (access to land, new infrastructures)	watershed (study area level)	-

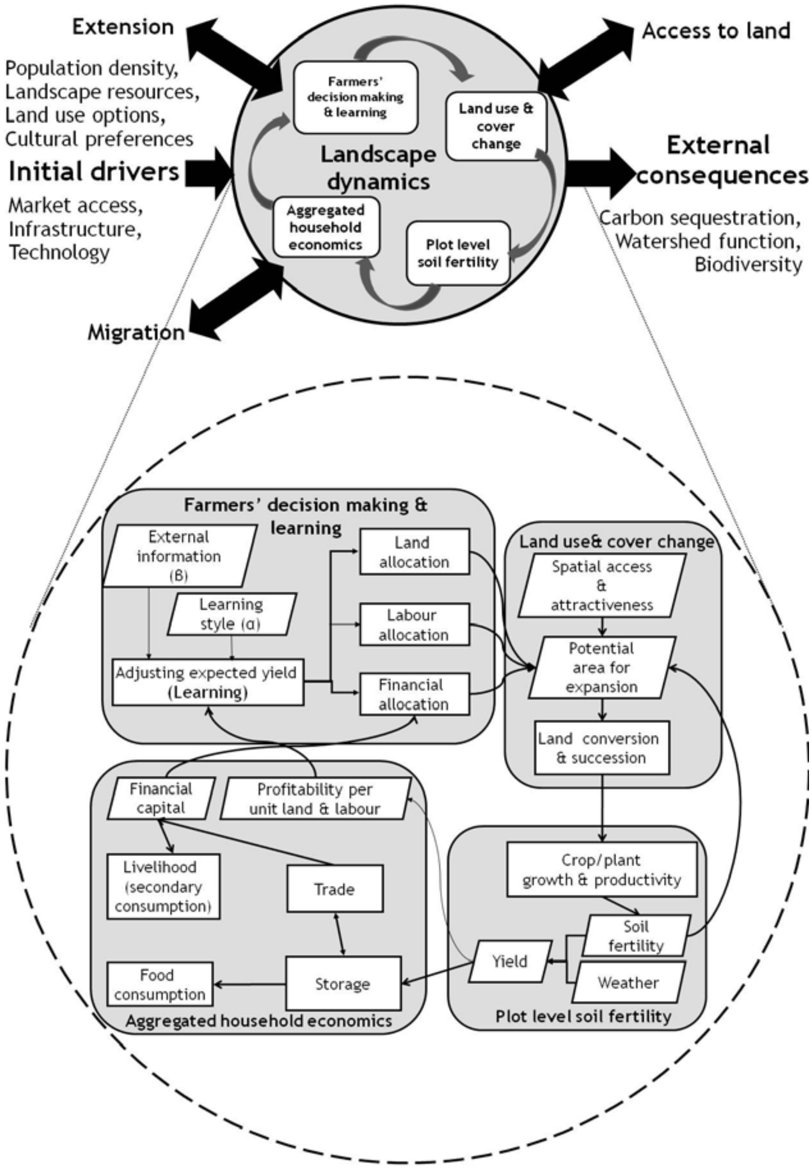

Figure 2. Schematic diagram of FALLOW model, with zoom-in's on four model sectors including farmers decision making process and their learning dynamics.

1.2. Data for input parameters

A semi-structured interview was carried out in 2008 to obtain productivity and profitability information of the main land use and livelihood options in the Upper Konto catchment area. The main livelihood options in the area were staple food (rize and maize) systems, horticulture, coffee, cacao and dairy cattle. Cacao and horticulture systems were the highest in terms of return to labor and return to land (unpublished data). Additional socio-economic information was also acquired based on a household survey undertaken in 2008 to assess the impact of Community-Based Forest Management Programme (*PHBM = Pengelolaan Hutan Berbasis Masyarakat*) on farmers' income (Khususiyah, 2009; Khususiyah and Suyanto, *in prep*.).

Information on carbon densities at plot level for the main land cover/use systems of Upper Konto catchment: Forest, Forest Plantation, annual crop systems and agroforestry systems (cacao and coffee) were based on intensive carbon measurements carried out between 2006 and 2007 (Hairiah et al., *in* prep.).

1.3. Scenarios for trade-of analysis and model performance evaluation

After model parameterization, we used the FALLOW model to evaluate plausible land use policy options (Table 2) and prospect its consequences on farmers' welfare (secondary consumption beyond expenses for staple food) and changes in above-ground carbon stocks. The land use policy options were derived on the Upper Konto Designated Land Use map (Figure 1). We run the model for 30 years starting from year 2000. For model outputs, we focused on land cover dynamics over the simulated period as well as trade-offs between farmers' welfare non-staple food consumption above-ground carbon sequestration.

To evaluate the performance of the FALLOW model, we compared land cover resulting from model simulation of baseline scenario with reference land cover map produced from LANDSAT™ 2005. We used two criteria: (1) area inaccuracy and (2) spatial accuracy. The in accuracy of area was obtained from calculating relative area size differences:

$$AS_i = 100 \times \left(\frac{A_s - A_r}{A_r} \right) \quad \text{......} \quad (1)$$

where AS = area size difference of land cover type *i* (%), A_s = total area of land cover type *i* in simulation result and Ar = total area of land cover type *i* in reference map.

Table 2. Scenarios (baseline and prospective) of landscape dynamics in Upper Konto catchment developed for FALLOW model application based on the Designated Land Use map in Figure 1.

No.	**Scenarios**	**Description**
0	Baseline	Conservation scheme: Forest Reserve and Protection Forest of State Forest Land are not accessible to farmers
1	Full access	Farmers have full access to land in the whole catchment
2	Conserving Forest Reserve	Forest Reserve are not accessible to farmers, the rest of area including State Forest Land are accessible
3	Limited Access to Production Forest	Similar to Baseline scenario with limited access to Production Forest of State Forest Land (only tree-based allowed to grow)

Spatial accuracy indicator was calculated using the following equation:

$$SA_i = 100 \text{ x } \left(\frac{A_s \cap A_r}{A_s \cup A_r} \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where SA = spatial accuracy indicator of land cover type *i* (%), $A_s \cap A_r$ = total area of land cover *i* that was found in exactly the same position in both simulated and reference land cover maps (intersection) and A_s U A_r = total area of land cover i that was found in both simulated and reference land cover maps (union).

2. Results and discussion

2.1. Baseline scenario

The baseline scenario refers to current situation where Forest Reserve area and Protection Forest of State Forest Land are not accessible to farmers while other areas in the Upper Konto catchment, including the Production Forest of State Forest land, can be accessible.

Preliminary results showed that at after 30 years of simulation, horticulture systems became the dominant land use in the area with cacao systems emerging as a prominent land use (Figure 3A). Dairy cattle were the main income generation in the area, contributing to 50% - 80% of total gross income (Figure 3B). However, the livelihood options was unable to sustain farmers livelihood causing farmers' welfare per capita to decline by 30% over the simulation period. The average aboveground landscape carbon also dropped from 75.6 $Mg.ha^{-1}$ to 65.7 $Mg.ha^{-1}$ or equivalent carbon loss of 0.3 $Mg.ha^{-1}.year^{-1}$(Figure 3C).

The values of simulated average aboveground carbon stocks of Konto catchment (66 – 76 $Mg.ha^{-1}$) was equivalent to a 4-5 year old plantation of *Albizia falcataria*, a fast-growing tree species commonly planted by farmers in Asia or 19% of primary forest (Lasco, 2005).

The large contribution of dairy production systems towards gross income of Upper Konto catchment reflected the importance of the systems for this area.

Earlier results (presented at LANDMOD workshop) were obtained in the absence of fertilizer use, suggested a rapid decline of soil fertility and loss of profitability

2.2. Model performance evaluation

To evaluate FALLOW model performance in simulating baseline condition of Upper Konto catchment, we compared the simulated land cover map of year 2005 with reference land cover map of the same year classified from LANDSAT™ image. The result showed that the spatial accurracy of FALLOW ranged between 52-71% and area inaccuracy of 7 to -45%. (Figue 4) The highest spatial accuracy was obtained for forest while the least area accuracy was obtained for agriculture systems. FALLOW has underpredicted the area of agriculture systems in Upper Konto catchment. This suggest that the new plot establishment module within FALLOW need further improvement.

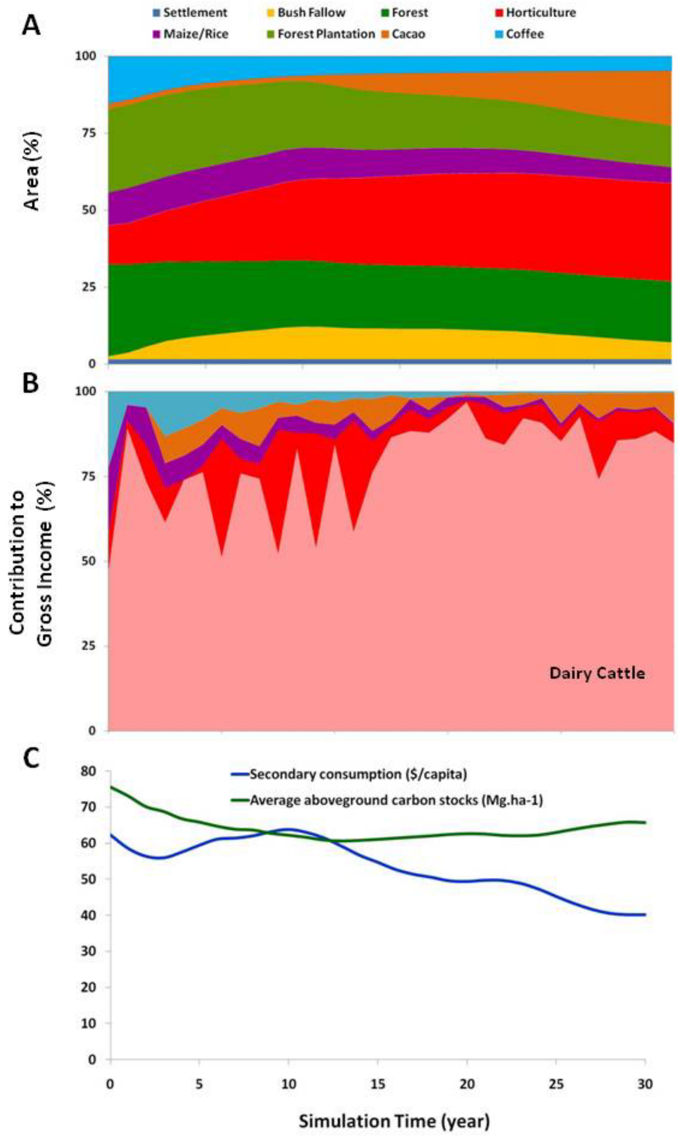

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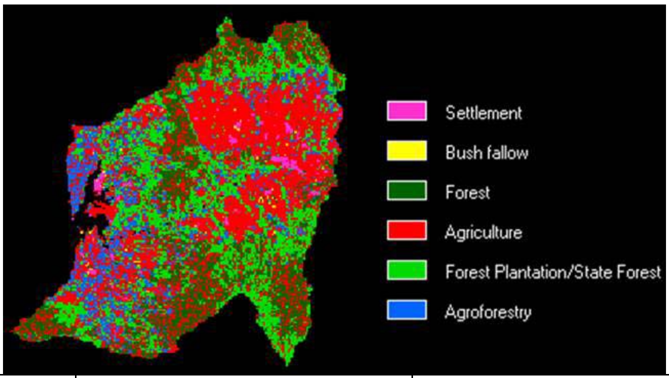
Figure 3. Baseline scenario results of FALLOW model run for the Upper Konto catchment (A) Landcsape dynamics (in % area), (B) contribution of main livelihoods option catchment gross income (in $) and (C) farmers' welfare (in US$ per capita) and average landscape aboveground carbon stocks (in Mg.ha^{-1}).



Land cover	Spatial accuracy (%)	Relative area difference (%)
Agriculture	52	-45
Agroforestry	52	18
Forest Plantation	52	10
Forest	71	7

Figure 4. Land cover map of Upper Konto catchment at year 2005 with its value of spatial accuracy and area inaccuracy when compared with reference land cover map derived from LANDSAT™ image of the same year

2.3. Scenario analysis: prospecting impact of land use policies

We compared the result of three scenarios run after 30 years of simulation to the baseline condition (Table 3). Giving full land access to the farmers (**Scenario 1**) produced a slight decline in secondary consumption /welfare of 8% over the 30-year period. However, as expected the average aboveground carbon stocks decreased substantially by 72% or equivalent to carbon loss of 1.6 $Mg.ha^{-1}.year^{-1}$. The loss of carbon was mainly due to opening forest areas to horticulture and cacao systems. The average aboveground carbon stocks value at the end of the run was equivalent to grassland/bush fallow system (Lasco, 2005).

Conserving Forest Reserve only, without conserving Protection Forest area, (**Scenario 2**) also only slightly reduced farmers' welfare (by 6%) and reduced average aboveground carbon stocks by 42%, equivalent to carbon loss of 0.9 $Mg.ha^{-1}.year^{-1}$.

Conserving all designated area for forest (Forest Reserve and Protection Forest) and providing limited access to Production Forest area for managing tree based systems (**Scenario 3**) slightly increased both farmers' welfare and average aboveground carbons stocks by 13% and 14% respectively. The increase of carbon stocks level from baseline by 14% managed to stabilize the landscape carbon stocks over the 30 years period.

The prospective studies revealed that changing land use policies from the current policy did not change farmers' welfare condition which was going through declining rate (Figure 2). Therefore, to improve farmers' welfare requires additional change in policy beyond land use policies. However, to maintain the landscape aboveground carbon sequestration level, **Scenario** 3 was deemed to be the best option.

Table 3. Result of FALLOW run after 30 years for Upper Konto catchment under various land use policies scenarios (see Table 3).

Scenario	Secondary consumption (US \$ year^{-1} capita-^{1})	Average aboveground carbon stocks (Mg.ha^{-1})
0. Baseline	40,20	65,74
1. Full access to land	37,00	18,64
2. Conserving Forest Reserve	37,90	37,47
3. Limited Access to Forest Production	45,60	75,27

Conclusion

The use of the FALLOW model to explore and prospect the impact of various land use policy scheme in Upper Konto catchment suggested that the current policy may lead to declining farmers welfare and average aboveground carbon stocks. A change in land use policy by giving limited access to manage tree based systems in part of the State Forest Land while still maintaing designated forest areas, could maintain the abovegorund landscape carbon stocks level and reduced the decline of farmer's welfare. To improve farmers' welfare, policy intervention beyond land use policies are required.

The above result showed the value of integrating economic, biophysical and farmers' knowledge dynamics components in a simulation model such as FALLOW to explore various policy scenarios for natural resource management. FALLOW allows exploration of plausible landscape trajctories and its consequences on landscape level indicators such as welfare and carbon stocks. Quantitative results should be taken cautiously as the model could only capture the essential drivers of landscape dynamics at aggregated temporal and spatial scale.

The spatial acuracy and area inaccuracy of FALLOW model in simulating baseline condition of Upper Konto catchment showed the need to further improved the new plots estblishment module of the model. Model performance evaluation such on spatial accuracy and area inaccurracy can indicate the crediblity of a model in simulating the landscape. However, further evaluation/validation of model results involving stakeholders' of the area will be more important to enhance salience and legitimacy of the scenario analysis study.

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