Human-Environment Interaction in a Slash-and-Burn Agriculture Setting : Perspectives Gained from Computer Simulation

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1. Introduction

Environment has been an integral part of human life since the beginning of human history. Environment provides space for living and resources including foods and many kinds of materials. Those materials are made available through the various ecological processes occurring at local, regional and global scales. The Millennium Ecosystem Assessment (MA) Report uses the term "ecological services" in depicting a direct connection between human system and ecosystem or environment. According to MA, ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other nonmaterial benefits (Copra et al., 2005).

The extent to which human exploits the environment will affect the quality and quantity of services provided by the ecosystem. In this respect, I view the interaction between human system and ecosystem as mediated by "agents" who conduct decision-making process on how to use ecosystem for their purposes. This perspective is depicted in Figure 1. The agent in this sense can be performed by individuals, households, government bodies or companies. During the decision-making process, the agents take into account the state of human system, e.g.

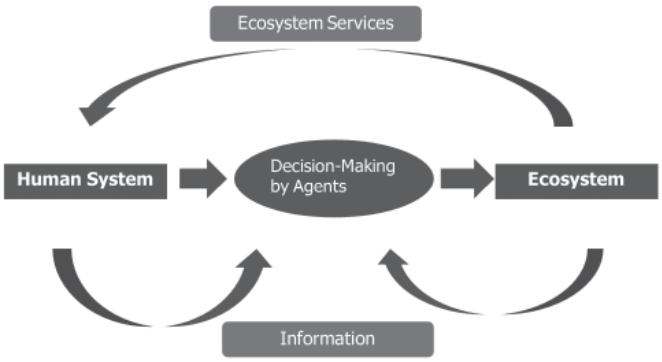

Figure 1. Interaction between human system and ecosystem as mediated by "agents" (modified from Marten, 2001).

level of resource demand, technology available, as well as the state of ecosystem, e.g. fertility level. Once the human action is performed, the ecosystem responds in terms of delivering the ecosystem services sought by the agents. The state of the ecosystem (or environmental condition) will determine the magnitude of service provided. The state of the ecosystem at which the service is delivered then serves as information to the agents for consideration in the next decision-making process. In the human system side, the accumulated knowledge gained from long-term human-environment interaction will constitute part of culture of the human system.

In this paper, I describes how the perspective explained above is implemented in a computer model used for simulating human-environment interaction in a slash-and-burn (or swidden) agriculture setting. The model is then used specifically to examine the implications of land-use decisions on the dynamics of landscape. The case used in this study is the Kantu' community, a slash-and-burn agriculture community living on West Kalimantan, Indonesia near the border with the Malaysian state of Sarawak. The Kantu' has been studied and described in detail by Michael Dove in 1970s (Dove, 1985). Based on the results of his ethnographical research supplemented by data from similar ethnic groups in Kalimantan/ Borneo, I have developed a model to simulate the essential characteristics of the Kantu' on aspects pertaining to how this community used the landscape for agriculture and the associated cultural aspects (Sulistyawati, 2001). This model has been published in Sulistyawati et al.(2005) and Sulistyawati (In press). In this paper, the model is used for slightly different simulation exercise with those previously published.

The following sections will present a short description of the Kantu' people and their agricultural system followed by an introduction to the model and description of the simulation setting used for this paper. Before presented the case study, it is important to note that the description presented here refers to the condition during Dove's study (1970s). Of course, many developments have happened in Kalimantan recently, which may have altered the agriculture system of the Kantu'.

2. Kantu community

Ethnically, the Kantu' belongs to Ibanic ethnic complex. The Kantu' was a largely subsistent community practiced a slash-and-burn agriculture (also called swidden agriculture or shifting agriculture) to produce rice combined with growing rubber trees for tapping. In any one year, the Kantu' household felled a section of forest, slashed the undergrowths & small trees and then burned them to prepare for upland-rice/dry-rice cultivation[1]. The rice

1. The dry-land field used for rice cultivation is also called 'swidden' in some scholarly papers and this term is used in this paper.

was typically cultivated for one year only and then the 'swidden' or field was abandoned. In the subsequent year, the farmer cleared forest in other place and started the cultivation cycle again. The abandoned swidden entered a 'fallow' period for several years, during which natural regeneration to form a secondary forest took place, before it was re-cleared again for swidden. In a certain time, rubber seeds were grown along with rice. In this case, when the swidden was abandoned, rubber trees would dominate the fallow vegetation along with other naturally occurring trees.

The Kantu' traditionally lived in longhouses. A longhouse is a residential building that consists of apartments (bilek), each of which is occupied by a household. Although several households lived together in a longhouse, a household was the primary unit of production, consumption and land appropriation. Swiddens were cultivated largely using household's labour and rice was mainly for household consumption. Ownership of land was firstly acquired by felling a section of 'primary forest' for making swidden. This 'first-feller' principle was basically a form of reward to investment of labour, as in the Kantu' case, the labour required to fell primary forest was three time larger than for secondary forest (forest re-growth during fallow). The felling of primary forest also necessitated the presence of male labour. Therefore, all secondary forest plots were actually owned by households. The right to re-use secondary forest plots can be shared among siblings originated from the same household or lend to others. The ownership of secondary forests could later be transferred to next generation through inheritance.

Marriage was an important phase in household developmental cycle. Newlywed couple usually took up residence in the household of either the wife's parent (uxorilocal) or the husband's parent (virilocal). The post-marital residence had important consequences with regards to rights to household property including land. The departure of an out-marrying child meant that he/she would lose rights to property of the natal household but would acquire rights in the household into which he/she married. After several years staying in the parent's household, married couples would eventually leave the parents' household to establish their own household. This event is called household partition. Upon a household partition, rubber plots and other property were divided between the parents' and the newly-formed child's household, but this did not apply for secondary forest plots. The rights to re-use the secondary plots were shared between the parent and one or more children households created through partitions. The land formal land division among the parent's and the children's households (i.e. land inheritance) took places upon the partition on one of the children's households.

Every year, the Kantu' made land-use decision on where to select sites for swiddens. The selection of sites were generally based on the number of considerations. Location closer to longhouse (settlement) and the river were generally preferable as it could minimize travel time. The Kantu' also considered the distance to last-year swidden, distance to same-year swidden, distance to other households' swidden. Closer distance to last-year swidden facilitated easy access to some non-rice cultigens that could be harvested in the second year as well as re-use of field hut when the swidden was located far away from longhouse. Whereas, if making more than one swidden in a year, the Kantu' tended to spatially separate swiddens in order to diversify the microenvironment among household's swiddens made in the same year. Meanwhile, site closer to other household's swidden was preferable as it could facilitate labour exchanges between households.

Vegetation state was another important consideration as it associated with labour requirement, land acquisition and potential productivity. Clearing primary forest required more labour but rewarded the household with ownership to the land. Therefore, the Kantu' usually cleared primary forest when there was at least one adult male in the household. Alternatively, making swidden in secondary forest required less labour and also gave a higher yield due to the easiness to achieve complete burning. When the Kantu' attempted to make a swidden in secondary forest, the length of the fallow was a primary consideration; generally longer fallow was preferable than shorter one due to its higher potential productivity. As part of the strategy to optimize the benefit from both types of vegetation, each Kantu' household ideally made at least one swidden in primary forest and one swidden in secondary forest each year.

Household state particularly demographic structure also influenced land-use decision-making. The extent of cultivation would depend on the consumption demand, which was a function of household size. In addition, household structure also determined availability of labour including male labour, which was indispensable when a household attempted to clear primary forest. As demographic structure of households changed following birth and death of the members and household partitions, one can expect that the magnitude of agricultural activity of the Kantu' household also changed over time.

3. The Model

The conceptual framework of the model is presented in Figure 2, which is an implementation of the perspective presented earlier (Figure 1) in the Kantu' case. This diagram summarizes the key features of land-use decision-making conducted by households as the main agent in this context. This paper will not provide detail description of the model. Please refers to Sulistyawati (2001) and Sulistyawati et al.(2005) for description of the model. Only features related to the simulation experiment used in this paper will be presented.

The model was built using a rule-based approach. In this case, the dynamics of system are represented as a series of IF-THEN-ELSE statements in computer codes written using Borland DELPHI software package. The rules basically represent a simplified form of the

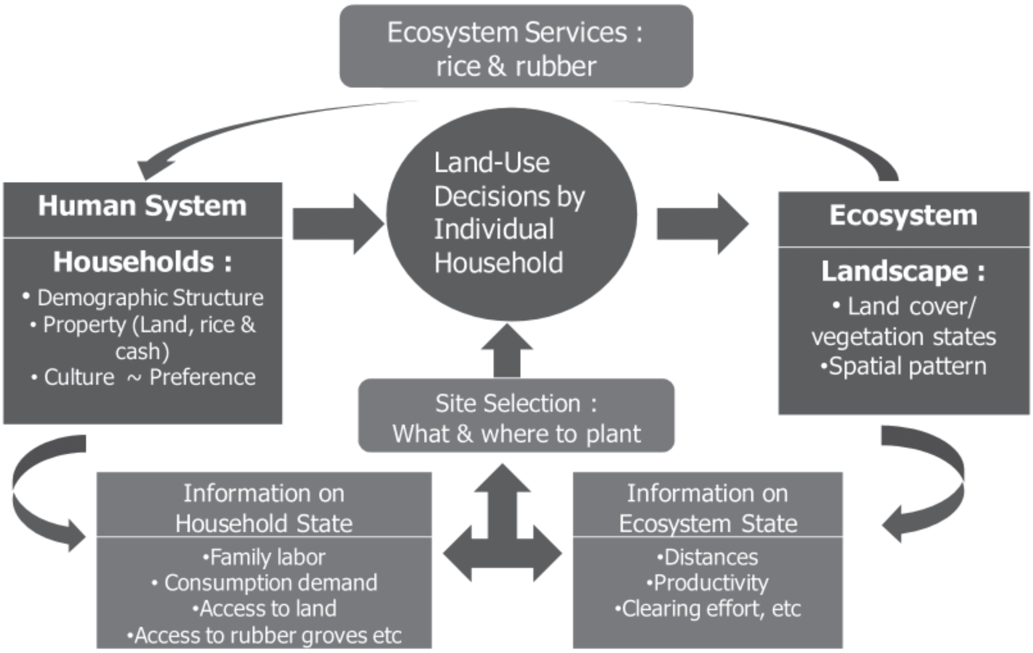

Figure 2. Conceptual framework of the model

characteristics of Kantu' community. The model simulates the development of a hypothetical Kantu' community along with the landscape where the slash-and-burn cultivation is carried out.

The development of community is simulated by 'creating' person (i.e. birth) as well as new households through household partition. The process of aging, marriage and death of each person is simulated taking into account the prevailing social custom such as incest taboo. The model simulates land-use decision of each household on what agricultural activities to perform and where they are performed. The model deals with three agricultural activities – making swiddens for growing rice only, making swiddens for growing rice intercropped with rubber, and tapping rubber. The extent of rice cultivation is determined on household's consumption demand for rice and availability of household's labour. Whereas, the extent of rubber tapping is a function of cash demand for purchasing basic goods.

Site selection process by each household is simulated spatially taking into account criteria expressed by the Kantu', i.e. distance to longhouse, distance to river, distance to the household's last-year's field(s), distance from the household's other current field(s), distance to other households' fields, site ownership, vegetation and topography. Technically, each potential site is evaluated according to those criteria and the best potential site from the perspective of searching household is then selected. Numerically, the 'attractiveness' of potential sites is in the form of 'site index' (Box 1). F1 to F8 refer to the value of each selection criteria expressed on 1-to-5 scale with the order of scale corresponds to increasing preference. There are a set of rules for assigning the values of F, which are described in detail in Sulistyawati (2001). Meanwhile, W1 to W8 refer to 'relative importance' of each factor; all weight values sum to one. The value of each selection criteria (F) depends on the condition of site and searching household. The set of weights (W) is fixed and reflects general strategy of community as a whole in selecting sites.

Site Index = F1W1 + F2W2 + F3W3 +... +F8W8

Box 1. Site index for summarizing the value of all site selection criteria

Given the level of rice demand and the size of available labour, each household decides the number, type, and location of swiddens to be made. The type of swidden can be swidden for rice only or swidden for rice intercropped with rubber. Once a site is selected, then it is converted into swidden for one year. After that, the site is abandoned and the fallow plot undergoes vegetation changes (succession), which is simulated simply as a function of duration since the abandonment. The vegetation changes in the following states : swidden (year 0), old-swidden (year 1), shrub (year 2-5), young secondary forest (year 6-20) and old secondary forest (year 21-100).

The model runs at an annual time step for most processes, with the exception of cultivation tasks (e.g., slashing, felling and harvesting), which use a daily time step. The current version of the model initially runs with nine hypothetical households and simplified landscape of 12.5 km2 consisting of primary forest, river and longhouse (Figure 3-a). The topographical variation is also presented in simplified form in which the altitude increases as location is further away from the river (Figure 3-b). Many part of this model is simulated using stochastic or random approach. The result analysis of such model is usually based on output from several runs.

4. Simulation Setting

This model can be used as a tool for ‘experiment’ involving both human and ecosystem. Such experiment usually takes a form as ‘what-if’ exercise in which one phenomenon being investigated is varied whereas other components are held constant. In this paper, the model is used to examine the implication of different site selection strategies on landscape dynamics.

For this purpose, I developed two contrasting scenarios differing on how households consider the relative importance among the eight selection criteria expressed as weight (W) in the site index (Box 1). The first scenario reflects a strategy that considers vegetation is more important than other criteria. Vegetation factor in this model setting is associated with opportunity to acquire more land (i.e. clearing primary forest) and higher rice productivity in older fallow plots. However, availability of household’s labour acts as constraint to the type of vegetation that can be cleared by a household. One can view the first scenario as represent a community that tends to accumulate land whenever the situation allows. Technically, it was done by setting the value of W associated with vegetation arbitrarily higher than other selection criteria, i.e. 0.3750 compared with 0.0892 for each of other factors. This scenario is called **Veg-More** mode thereafter. The second scenario, reflects a strategy that considers minimizing travel time by making swidden closer to longhouse is more important than other criteria. Technically, it was done by setting the value of W associated with distance to longhouse arbitrarily higher than other selection criteria, i.e. 0.3750 compared with 0.0892 for each of other factors. This scenario is called **CloseLH-More** mode thereafter.

With this model, it is possible to view many aspects of the simulated community and landscape. However, for the purpose of this paper, I presents only the outputs on population size, extent of each vegetation type and average fallow duration. The results presented are average values from 20 runs. The model was run for 75 years to allow long-term consequence of land-use decision-making being investigated.

5. Results & Discussion

Before presenting the quantitative analysis of simulation outputs, snapshots of the simulated landscape condition on year 50 are presented in order to provide illustration on the spatial implication of land-use decisions (Figure 3-c and -d). In those figures, grids varying in colour and shape are plots once cleared for swidden and be in one of the following vegetation states : swidden, old swidden, young secondary forest or old secondary forest. Meanwhile, the continuous grids are the remaining primary forest. It is clear from those figures that **Veg-More** mode results in faster agricultural expansion into primary. Almost all primary forest has gone by year 50. In contrast, primary forest is cleared at slower rate as households tend to re-

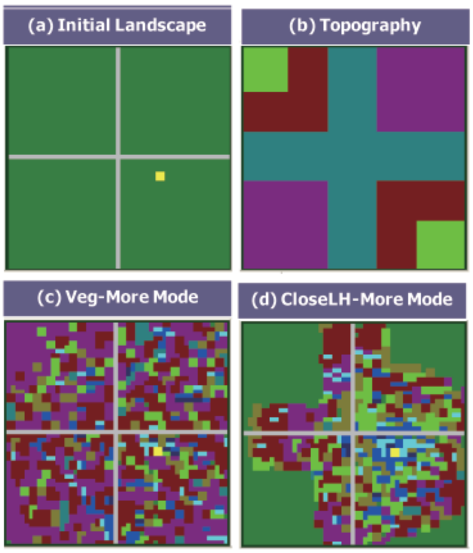

Figure 3. Initial landscape (a), topography (b) and landscape composition at year 50 in each simulation mode (c-d)

clear fallow plots closer to longhouse in **CloseLH-More** mode. The implications of difference in site selection strategy on each landscape component and length of fallow period will be presented by graphs (Figure 4).

The magnitude of population pressure driving the simulations can be seen in Figure 3(a). Note that the population increase is similar in both modes. This suggest that all simulation modes operates on similar population pressure and, therefore, any differences found could be largely attributed to differences in site selection strategy. The population grow from initially about 5 to 35 persons/km2 which encompasses the range of density where slash-and-burn agriculture in a ‘traditional form’ has been reported in Kalimantan/Borneo (see Sulistyawati, 2001). The simulation ends at a higher density than those reported figures, which implies that the situation at the final year represents a very high pressure on the land.

As the population increases, the amount of land cultivated as swidden also increases (Figure 3(b)). The pattern are also similar in all modes. In this model, the magnitude of

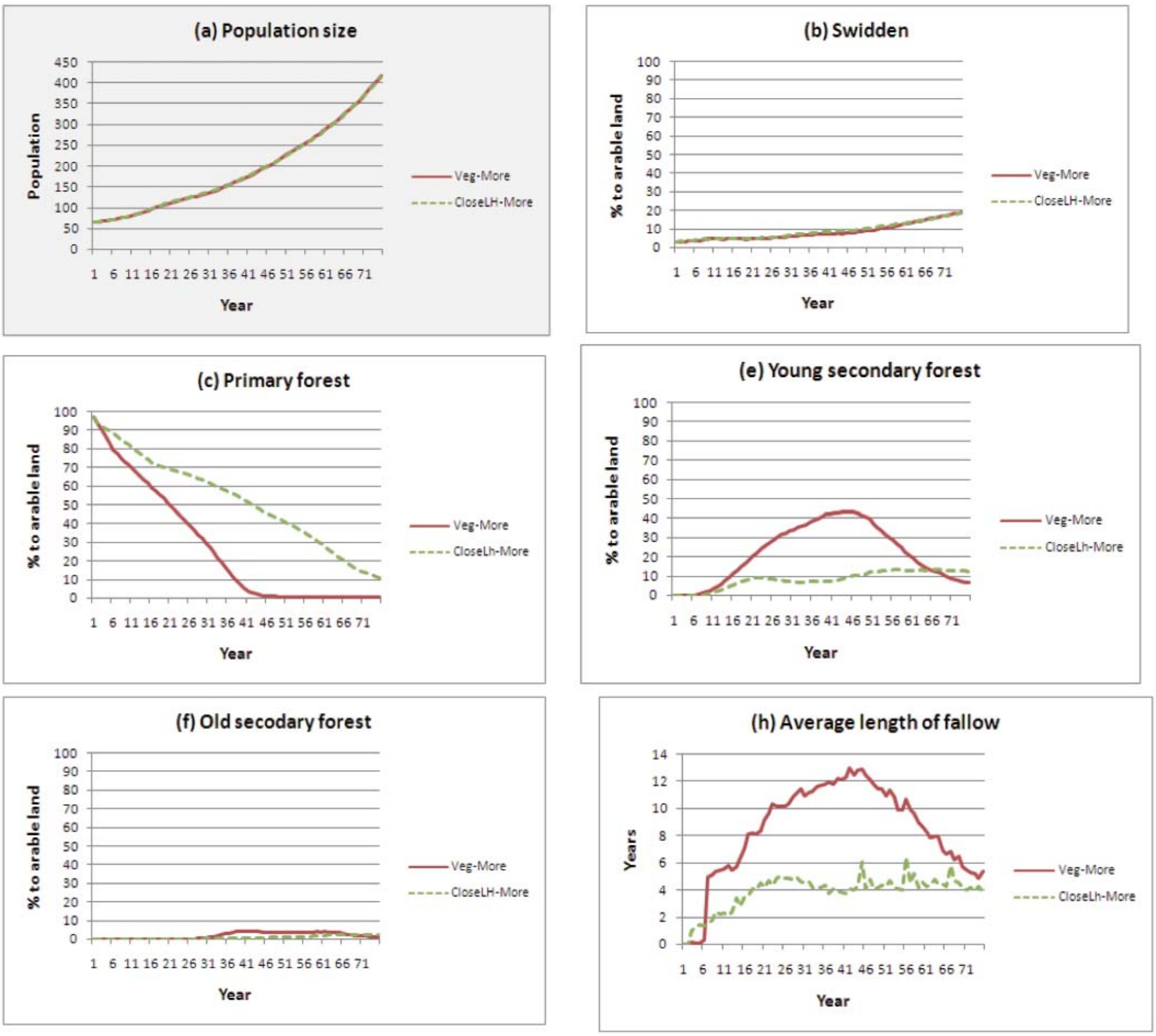

Figure 4. Simulated population (a), landscape composition (b,c,e,f) and average length of fallow from each simulation mode.

swidden cultivation is determined largely by the magnitude of household's rice consumption demand, which is in turn determined by household size. Therefore, similar population size will bring about similar level of swidden cultivation. Despite similarity in the area of cultivated swiddens, there are contrasting difference on what type of vegetation cleared for the swidden. This point can be investigated by looking at the trends of other vegetation types.

Clear differences were found on the trend of primary forest, shrubland and young secondary forests (Figure 4(c), (d) and (e)). Higher concern over vegetation types in **Veg-More** mode results in faster primary forest clearing; no primary forest is left by year 50. Meanwhile, higher concern over locating swiddens closer to longhouse results in slower primary forest clearing in **CloseLH-More** mode. In **Veg-More** mode, for households who need to cultivate multiple swiddens (due to high rice demand), they are likely to open at least one swidden in primary forest when male labour is available. This means that previously abandoned swiddens (or fallow plots) have more time to develop into older vegetation and this explains why the young secondary forest accumulates at faster rate until approximately year 50. In contrast, slower rate of young secondary forest accumulation is observed in **CloseLH-More** mode. This is due to firstly slower formation of new fallow plots as a result of more re-clearing fallows plots rather than primary forest because the fallow plots are located closer to longhouse. Secondly, as soon as fallow plots enter young secondary forest state, they are soon selected for swiddens because young secondary forest is the most preferable fallow vegetation due to its higher rice productivity.

The trend in **Veg-More** mode changes drastically after year 50 coinciding with the disappearance of primary forest. During this period, young secondary forest decline rapidly. This is because now all swiddens have to be made in fallow plots and so, the young secondary forest plots are re-cleared at faster rate than in the previous period.

It is interesting to note that, in both modes, only small area develops into old secondary forest. This indicates that once fallow plots are 'old enough', i.e. reaching >= 10 years old and thus have entered young secondary forest state, they are likely to be re-cleared and do not succeed into old secondary forest. However, despite occurring in small extent, some old secondary forest plots are found. This points to another interesting dynamics from the simulation, i.e. inequality of land holding. The presence of some old secondary plots indicates that there are few households having a large number of fallow plots. Therefore, despite some of their fallow plots continue to be re-cleared, there are others, which are not re-cleared and can be left to develop into old secondary forest. Such household comes into 'existence' in this model due to a specific historical demographic created by random event. This, for example, could happen to a household that has a large number of male children, so that the labour needed to clear primary forest is always available.

Another view on implication of different site selection strategy can be examined from the average length of fallow, that is the duration before a fallow plot is re-cleared. Length of fallow in this model affects land productivity in which longer fallow is simulated to have higher rice productivity. Figure 4(h) shows that the average of fallow length in both modes are initially low because during such stage the fallow plots have just began to be formed, thus their ages are young. Subsequently, the trends between **Veg-More** and **CloseLH-More** modes are strictly different. More primary forest clearing on **Veg-More** creates more fallow plots, some of them can develop into older state. Therefore when household attempts to make swidden in fallow plots, the most-preferable old fallow plots are available and can be selected. The increasing length of fallow trend in **Veg-More** mode occurs until about year 50, after which it declines due to more re-clearing of fallow plots as the population increases in a limited area. In **CloseLH-More** mode, however, due to slower new fallow plot formation and attractiveness of fallow plots due to their closer location to longhouse, the fallow plots tend to be re-cleared at shorther period after they are abandoned. This explains the constant but low average of fallow length in **CloseLH-More** mode.

6. Summary & Conclusions

This paper has described the use of model to study human-environment interaction in a slash-and-burn or swidden agricultural setting. The model simulates land-use decision-making in a dynamic way in that the simulated community changes dynamically as a result of demographic events of aging, birth and death along with the dynamic changes in the landscape as a result of human action and the resulting natural responses. Constructed in this way, the model allows differences in households (e.g. size, labour availability, land holding) and sites (e.g. position, history of land-clearing) to be taken into account.

The results of simulation experiment with different site selection strategy reveal that higher concern over acquiring land (i.e. **Veg-More** mode) results in faster primary forest clearing. In medium-terms, however, it facilitates faster accumulation of fallow plots and subsequently allows longer fallow period to be practiced. In contrast, higher concern over minimizing travel time from longhouse (i.e. **CloseLH-More** mode) can slower primary forest clearing but it results in repeat clearing of fallow plots, thus decreasing fallow length which can have consequence on rice productivity associated with shortening fallow[2]. Therefore, it can be said that on a slash-and-burn agriculture system in which clearing primary forest is a means to establish ownership and longer fallow period is necessary to achieve higher rice productivity, accumulating more lands whenever the labour allows seems to be a plausible strategy at least from a household’s perspective, although it may not necessary be the case

2. Actually this model facilitates assessment on implication of land-use decision on household’s rice production, however, it is not discussed in this current paper (see Sulistyawati, 2001).

from a forest conservation perspective.

This model applies 'preferences' as expressed by the Kantu' consisting of several aspect (e.g. vegetation, distance and ownership) in site selection criteria, which is meant to reflect the Kantu' community's knowledge gained from the long-terms interactions with nature. This simulation exercise demonstrates that those preference will eventually fail to be realized when the land becomes in short supply. It has been shown previously that as the size of simulated population increases, more and more households are in situation where they cannot obtain 'ideal' lands. Eventually, the ideal form of slash-and-burn agriculture breaks down. When seven year is taken as the minimum fallow length for restoring soil fertility, the breakdown of ideal slash-and-burn agriculture simulated by in this paper appears in about year 65 or at population density of around 27 persons/km2.

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8. References

Chopra, K., Leemans, R., Kumar,P., Simons, H. 2005. Ecosystems and human well-being : policy responses : findings of theResponses Working Group of the Millennium Ecosystem Assessment, ISLAND PRESS, Washington.

Dove, M. R. 1985. Swidden Agriculture in Indonesia : The subsistence strategies of the Kalimantan Kantu', Mounton Pub., Berlin.

Marten, G. 2001. Human Ecology : Basic Concepts for Sustainable Development, Earth Scan Publication, London.

Sulistyawati, E., Noble, I. R., Roderick, M. L. 2005. A simulation model to study land use strategies in swidden agriculture systems. Agricultural Systems 85: 271-288.

Sulistyawati, E. 2001. An agent-based simulation of land-use in a swidden agricultural landscape of the Kantu' in Kalimantan, Indonesia. PhD Thesis (Unpublished), Canberra: The Australian National University.

Sulistyawati, E (In Press). The historical demography of resource use in a swidden community in west Kalimantan. In Complicating Conservation: Beyond the Sacred Forest (M. Dove et al.,eds.), Duke University Press.