# Chapter 30
# An Agent-Based Modelling Application of Shifting Cultivation

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**Abstract** This paper outlines an agent-based modeling application of shifting cultivation for an upland village in Vietnam, which was developed to improve the management of shifting cultivation and aid forest protection. The model consists of household and land agents situated in a dynamic social, economic and political environment. Adaptation of the agents to changes in policy is incorporated through a trade-off between economic gains and social responsibility, which affect the subsequent decision-making process. The basics of the model are described including the validation process and the results in a business as usual scenario.

## 30.1 Introduction

Shifting cultivation is commonly practiced in the tropical areas of Africa, Latin America and Southeast Asia (Do 1994; Kerkhoff and Sharma 2006; Tran 2006). Many different practices fall under the term shifting cultivation but it generally involves an alternation of cropping for a few years followed by a relatively long period of fallow (Angelsen 1995; Conklin 1961; Do 1994; Spencer 1966).

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Shifting cultivation is often viewed negatively (Gilruth et al. 1995) and in developing countries, it is seen as a primary driver of deforestation, with an estimated contribution ranging from 41% to 60% (Angelsen 1995; Geist and Lambin 2001). In the uplands of Vietnam, shifting cultivation is a common method of agricultural production, with more than 340,000 households practicing this type of agriculture across nearly 74% of the national territory (Institute for Ethnic Minority Affairs 2005). As in other countries, shifting cultivation is viewed as highly destructive to the forest and has become the focus of several government policies in Vietnam. Despite large investments, these policies appear to have had little success as shifting cultivation still remains active outside of the areas where it is legally permitted (Institute for Ethnic Minority Affairs 2005; Tran et al. 2005). Several researchers (Fox et al. 2000; Institute for Ethnic Minority Affairs 2005; Shanks et al. 2003; Vuong 2001) have argued that these polices have been implemented with little consideration for the local socio-economic context or the provision of alternative, culturally acceptable livelihoods. As a result, there has been limited adoption by the local people. To develop more realistic policies for land management and to assist policy makers and stakeholders in evaluating different policy options, it is essential to gain a better understanding of shifting cultivation, in particular the interplay between shifting cultivators, household resources and the constraints associated with production. This requires an approach such as agent-based modeling that takes into account the dynamic properties of the system, including the biophysical, socio-economic and political aspects of shifting agriculture in a larger context. The more generic advantages of this approach are already described in detail in Crooks and Heppenstall (2012) but agent-based modeling is particularly suitable for this application because the decision-making process can be captured at a household level in terms of livelihood, as well as at the landscape scale, in terms of land cover change and natural resource management.

This chapter presents the development of an agent-based model (ABM) to the study of shifting cultivation in Vietnam, which captures the relationships between the political power, the community structure and the need to clear the forest for agriculture. Previous modeling work is reviewed to demonstrate the advances of this application over other related work, which is followed by a description of the model. Implementation, validation and scenario development are also discussed.

## 30.2 Previous Work on Modelling Shifting Cultivation

Early research into shifting cultivation (e.g. Conklin (1957), Spencer (1966) and Watters (1971)) was largely descriptive in nature and did not explain its dynamic structure or the driving forces. However, simulation modeling in the 1980s allowed further developments, e.g. the forest regeneration model of Wilkie and Finn (1988), which simulated the long term effects of shifting cultivation in north-eastern Zaire. The results showed that population pressure, land tenure systems and fallow length have a strong influence on the spatial patterns of the landscape. In another study, Dvorak (1992) developed an analytical model that established a relationship between shifting cultivation, the labour economy and the fallow cycle in West Africa. This was followed by GEOMOD1 and GEOMOD2 by Hall et al. (1995), which were designed to estimate the total amount of land use change in Southeast Asia and sub-Saharan tropical Africa. Although these models produced results with a high accuracy, ranging from 74% to 96%, they performed less well in predicting the patterns of shifting cultivation when compared to permanent agriculture. Similar to the GEOMOD application, the dynamic spatial model of Gilruth et al. (1995) was based on forest structure, productivity, elevation and the distance to towns and cities. This model predicted the locations of shifting cultivation at different time steps for an area in the Republic of Guinea, West Africa, but the results did not compare well with remotely sensed data.

The reasons for the high uncertainty in the above simulated models are their simple assumptions about the decision-making process, some of which view shifting cultivation simply as a transformation from forest to agriculture. To better capture the decision-making process, Brown (2005) developed a spatiotemporal model of shifting cultivation and forest cover dynamics in the Congo basin. The basic concept for making a decision in this model is based on utility maximisation. The decision making of the farmers is based on personal preferences, which are represented by the relative importance of the various factors influencing the farmers in making land use decisions. The importance of each factor or criterion was quantified by undertaking a household survey in which the respondents were asked to assign scores to reflect the importance of a given factor to the land use decision-making process. The fields with the greatest net benefit would then be selected in a given year subject to labour constraints. This approach to collecting data on personal preferences has been adapted for use in this research. However, the decision function does not include the influence of the socio-economic circumstances of the local area yet it is clear that these external factors (i.e. markets, policies) have an influence on the land use decisions made by a household (Castella et al. 2007; Fresco et al. 1990; Haggith et al. 2003). Therefore, the model of Brown (2005) cannot be used effectively in its current form for policy analysis. Furthermore, field selection operates separately for each household within the individual landholding but it does not clearly represent the interactions between different households in the decision-making process. It is recognised that farmers are often influenced by their neighbours' choices, e.g. sharing fencing works with neighbours (Jepsen et al. 2006) or other kinship relations (Gilruth et al. 1995) Therefore, a model that allows for the simulation of several households simultaneously and interactively is necessary in order to model shifting agriculture at a village level.

Another relevant study in the literature is the ABM of Sulistyawati et al. (2005). It was developed to compare different land use strategies within a subsistence economy of rice and rubber cultivation under scenarios of fluctuating rubber prices and a changing population in Indonesia. The model consisted of modules to calculate: (i) the population dynamics; (ii) land use decision-making; (iii) vegetation dynamics; and (iv) production. However, there are limitations to this model associated with the way in which the decisions were modeled, and the rules were formulated for swidden field selection. To evaluate the attractiveness of potential sites, weights (or personal preferences) were assigned, but these were applied equally to all households, which means that all households effectively use the same decision function. The socio-economic conditions of the households should be taken into account in the decision making as outlined in the research by Brown (2005). Another limitation of this model is that the potential rice yield is only estimated based on fallow age. However, with the same biophysical conditions in a rice field, different management practices could produce quite different yields. It is possible in ABMs to calculate yield separately for each land parcel as a function of the land characteristics and socio-economic conditions of its owner. This modification to the model would have made it more realistic.

Jepsen et al. (2006) were the first to publish on the direct application of agent-based modelling to shifting cultivation in Vietnam. Household agents make decisions in the model regarding which fields they will cultivate based on expected yields and labour investment. Fallow age, which is used to calculate the potential yield and labour required to work on the field, is used to estimate land productivity. The findings of the research showed that local farmers behave as would be expected according to well established shifting cultivation theory, and the spatial output of the model resulted in a good match with the data derived from remote sensing. The ABM of Jepsen et al. (2006) has an advantage compared to the model of Brown (2005) as it is able to capture the interaction between household agents in decision making. However, the model is still overly simplistic in its assumptions such as ignoring all economic factors, e.g. price or household potential capital that could be important in other regions. Adding more constraints to the choice of agents such as soil condition, water availability or distance to the household would make the model more realistic. The rules governing field selection are also too simple and therefore some important decision-making aspects (e.g. the linkage between production goals, preferences and decisions) could be lost. This limitation means that the model is unable to simulate the changing context of agents such as the change in land use strategies due to the application of new policies. A further limitation noted by the authors is the simplistic yield relationship in the model, which is simply derived from the cell age and the labour cost based on the number of adjacent cultivated cells. Other potential factors such as fertilisers, agricultural extension etc. could be added to the model. However, this would require much more field data and further statistical analysis.

The research that is most similar to the application described in this chapter is the Land use Dynamic Simulator (VN-LUDAS) of Le (2005) and Le et al. (2008). The type of study area is the same and the categorisation of households into groups, that are then assigned a specific land use strategy for selecting fields, has been adapted from this research. This categorisation is dynamic so households may change their strategy during a simulation. This is something that is currently not incorporated into other models such as those developed by Jepsen et al. (2006), Sulistyawati et al. (2005) and Wada et al. (2007). However, Le (2005) classified households into groups and then built separate relationships to determine field selection based on the field characteristics. This approach essentially predicts the probability of land use types based on explanatory variables but it does not explain why farmers make these choices.

Instead the method of Brown (2005), which uses household context to predict the probability of selecting land use strategies (i.e. types of personal preferences), was incorporated into this research. Another aspect of the VN-LUDAS model that has been adapted here lies in the land transition module. A large sample was collected for exploring the relationship between stand basal area and forest development. Le (2005) provided ranges of thresholds indicating the transitions between forest land cover types. This calibration is particularly significant for Vietnamese conditions because the forest is quite area specific, and it might not be suitable to use parameters gathered for other regions. Some of these parameters have been used in this ABM application. Furthermore, the VN-LUDAS model incorporates a response mechanism for policy change but the probability that households will violate constraints, including land use policies (e.g. forest protection regulations), is random and treated equally by all household agents. The VN-LUDAS model is therefore limited in capturing the association between individual accountability and the pressure exerted by local authorities to implement policy in the decision-making process of the land users.

The ABM developed as part of this research has incorporated elements from previous research into the development process but it has also attempted to address some of the shortcomings outlined above.

## 30.3 Study Area and Datasets Used

A model was developed for Binh Son-1 village in Ky Son district, Nghe An province. This village is typical of upland villages in Vietnam, and the ethnicity of the village is almost 100% Kho Mu for whom shifting cultivation is the only agricultural practice. The elevation of the village ranges from 400 to 1,200 m above sea level with a total area of about 7.4 km$^2$. The village contains 88 households, with a total population of 436 people in 2007. There have been several policies and forest protection programmes implemented in the village. However, a considerable amount of illegal shifting cultivation still occurs in the protected forests.

The data used in this research consists of a survey dataset that was collected during 2007 as well as land cover maps derived from TM satellite images in 2000, 2005 and 2006. The survey data collected include maps that were obtained from participatory mapping exercises, and socio-economic data about the households from questionnaires. Participatory rural appraisal (PRA) was used for the mapping tasks (Chambers 1994), including village territory, soil status and land use maps. The questionnaires were carried out randomly on 63 households, and were specifically focused on gathering information about household conditions related to livelihoods and personal preferences for cultivation. The information on personal preferences was collected based on the method proposed by Brown (2006) in which the survey respondent rated land decision criteria on a zero-to-ten scale according to the importance they placed on each factor. Additional interviews were conducted with key villagers and local authorities about the customary laws and the institutional and other rules that govern the land use activities of the local people.

## 30.4 Description of the ABM of Shifting Cultivation

An ABM of shifting cultivation consists of household agents, land agents and global parameters. Household agents represent shifting cultivators, who are capable of autonomous actions in the biophysical environment (i.e. on land patches or fields). Land agents are a set of grid cells representing land patches with their characteristics such as soil, land cover and land use. Global parameters are the set of external conditions that include important socio-economic and policy-related parameters. The global environment is considered as the external driving force of land use change. It varies from year to year but applies across the whole grid and influences all agents. Within the shifting cultivation system, household agents interact and make changes to their biophysical environment (i.e. the land patches) while the environment also constrains the activities of the household. The household agents, the policy response mechanism and the land agents are now briefly described below.

### *30.4.1 The Household Agent*

Each household is an autonomous agent that is embedded within a potential decision routine, where field selection and policy adaptation are the two main components:

**Field selection routine**: this contains the rules that govern the choice of which fields or land patches to cultivate. The rules governing choice are based on the traditional economic behavioural theory of utility maximisation, which is widely applied in the simulation community (Le et al. 2008; Russell and Norvig 1995; van den Bergh et al. 2000; Wooldridge 2002). The main assumption of this theory as applied in this model is that the agent will rationally choose the field that is preferred to or no worse than all the others. The utility represents the ranked personal preferences of a household agent for all possible patches or combination of patches, the set of which is also restricted by labour requirements and accessibility (i.e. physical and tenure accessibility). The utility function ($u_i$) for field selection is formulated as:

$$Max\sum_{s=0}^{S} u_{st};\quad u_{st} = [r_{it}][Z_{st}] \tag{30.1}$$

where *i* is a household, *s* is a field or land patch within the accessible area *S* at time *t*; *Zst* are the land specific factors, and *rit* are the preference parameters of the household, which can be derived from the household context (Brown 2005). There is also a stochastic component, which captures the uncertain nature of the perceptions. By multiplying the vector of land variables with the vector of personal preferences of a particular household, the utility function represents the suitability of a given field to the household. Fields with the largest utility values are, therefore, the ones that will be potentially selected by the agent. The general algorithm of the field selection routine is shown in Fig. 30.1.

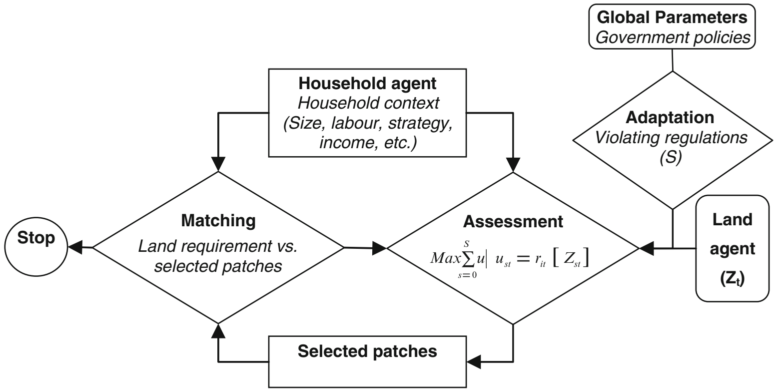


**Fig. 30.1** Field selection algorithm

**Adaptation routine**: this contains the simulation of responses by individual households to policies. The general response mechanism is adopted from the Institutional Analysis and Development (IAD) framework (Ostrom 1999), which has been specifically developed for organising research on institutions and governance structures. The factors that drive an agent's decisions are a combination of incentives (e.g. likely economic benefits) and beliefs (e.g. political accountability) (Clement and Amezaga 2009). The policy response is, therefore, based on the assumption that an individual will behave by trading off their vested interests against their individual accountability or social responsibility (Crano 1995). The general response mechanism is formulated as:

$$Response(R) = f\left\{\left(vestedInterests, accountability\right) * \ pressure\right\} \tag{30.2}$$

where vested interests comprise the expected economic outcome that the policy implementation will bring to the household. This variable can be expressed by the rate of expected income after and before policy implementation. The accountability is quantified based on a farmer's background and the influence of the body that implements the policy, while the pressure is based on the priority with which the policy is implemented.

The response of an agent to a policy is in the form of a response index that indicates how related policies satisfy each individual. The minimal response index is zero, which indicates no policy is to be implemented or both vested interests and accountability are at the lowest level. Low values indicate potential opposition to the policy while higher values indicate support. The response does not directly change the land use decision of an agent but it contributes to the probability that the agent will undertake activities that support or oppose a given policy and to then act accordingly, e.g. cultivate in the protected forest.

The response affects the *field selection* routine by modifying the definition of total accessible land *S*. For example, land allocation policies are intended to encourage farmers to cultivate only inside the allocated areas. If these policies are implemented, then farmers that respond positively will only choose fields within the total accessible land *S* that fall within the allocated areas. In contrast, farmers that respond negatively to the policy will extend their search to land patches outside the allocated areas and broaden the definition of total accessible land *S*. Similarly, forest protection policies do not allow farmers to cultivate inside any protected forests. Farmers that respond negatively to this policy will not consider the boundary between protected and non-protected areas in their field selection.

### 30.4.2 The Land Agent

The land agents represent the biophysical environment as a series of grid cells, each of which has associated properties such as land cover, soil, slope, etc. The land patches are updated through direct interaction with the household agents, neighbouring land agents and natural succession processes. The routine that controls the dynamics of the land agents is responsible for regularly updating the dynamic status of the land patches. The land use is simply updated after each field selection since it is a direct driving force of land use change in the uplands (Jakobsen et al. 2007; Jepsen et al. 2006). However, updating land cover is much more complicated as it is driven not only by human intervention but also by natural succession, which is beyond human control. The basic transition model used in this research is expressed as:

$$S_{t+1} = f\left(S_t, P_t, T_t\right) \tag{30.3}$$

where $S_{t+1}$ and $S_t$ are the vegetation state of patch *S* at time $t+1$ and $t$; $P_t$ is the collective gross development at time *t* depending upon both internal and external forces acting on patch *S*; and $T_t$ are the transition rules. $P_t$ is determined from the fallow age and ground basal area, which is estimated from the parameters and empirical models in the literature (Le et al. 2008). The transition rule *T* is estimated using fuzzy sets (see Ngo et al. (2009) for more details).

### 30.4.3 Model Implementation

The model operates iteratively on an annual production cycle. Each simulation starts with an initialisation stage and continues with cycles of three main phases: categorisation, field selection and update (see Fig. 30.2).

**The initial phase**: The land patch attributes are imported to the model directly as GIS data layers, which include land cover, fallow age, ground basal area, land use, soil, slope and maps of buffered areas (i.e. distance to settlement areas, roads and streams). Household agents are then created, where the number of agents is equal to the number of households in the study area. Household profiles are assigned based

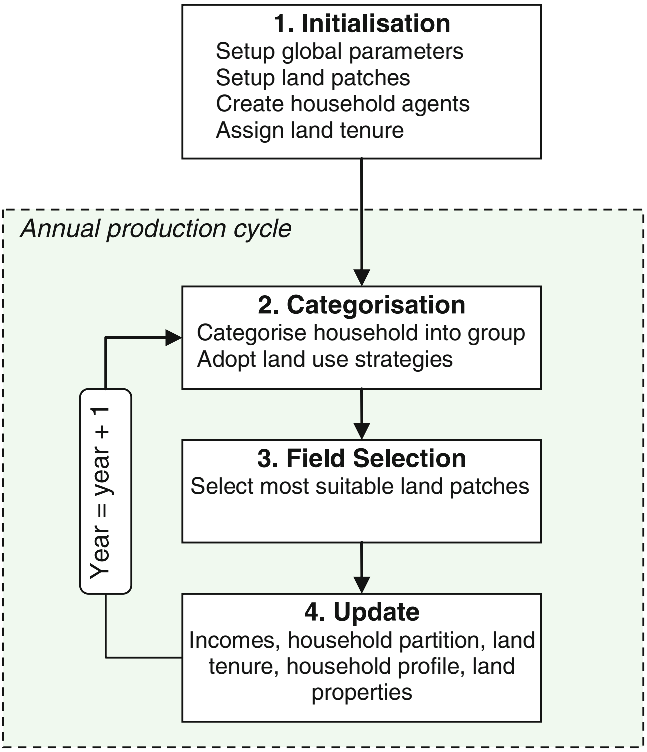


**Fig. 30.2** A general simulation cycle of the SCM

on the household survey samples (i.e. mean and standard error). Each household is located randomly in the settlement area. Finally, fields for cultivation are allocated to the households according to the land tenure status that is identified by the global parameters at the time of the simulation.

**Household categorisation phase**: This phase categorises households into groups based on their characteristics and assigns the field selection strategies (i.e. personal preferences [$r_{it}$]) to the individual household agents based on the probability that the household will select a certain strategy. During a single iteration of the model, if a household agent changes the group to which it belongs, the field selection strategies will be updated accordingly.

**Field selection stage**: This phase involves field selection, policy adaptation and prediction of possible outcomes of human activities. The simulation steps are as follows:

- Adopt policies by estimating the policy response index for each household agent, and determine whether or not the agent will violate the land use regulations.
- Search for the most suitable fields based on the perception of the household about land resources and accessibility. The accessibility of land is determined based on the response to the policy in the previous step.

- Decide on the number of patches to be selected based on basic food requirements and the availability of land.
- Record the human interactions (e.g. tenure) for each of the land patches.

**Update phase**: The phase consists of updating the land tenure, land cover and other household characteristics. Land tenure is regularly updated according to the land use rights in place after each field selection and after changes to the characteristics of the household agents, which are updated using survey information collected at the study site. If the simulation runs long enough, it is possible to produce new household agents based on the demographic attributes of the local population. New households are created when a household immigrates or a newly married couple moves to a new household (i.e. household partitioning). This partitioning can occur when parents are too old or the household size becomes too large. New household profiles are created stochastically based on the mean value and standard errors of the survey data set. The newly created household acquires land tenure based on the global parameters set by the model user.

Each simulation cycle ends when the update phase finishes. However, the simulation can continue to run for other simulation cycles as long as required by the model user. The ABM developed as part of this research operates in NetLogo (Wilensky 1999) with extensions written in Java.

### *30.4.4 Model Validation*

Validation is an essential process to ensure that the model can be applied to examine the patterns of shifting cultivation and produce reliable data for policy analysis. Part of the validation process involves calibrating the model. Some of the parameters in the model were determined from the survey data and a statistical analysis. These include the personal preferences $r_{it}$ and the policy response. The rest of the parameters were determined using a genetic algorithm. Details of how these parameters were obtained can be found in Ngo (2009).

Validation was also applied to the field selection and policy response routines as well as to the final model outputs of land cover change. The Mean Nearest Neighbour distance (MNN) (Campbell 1995) was used to test the hypothesis that the field selection routine behaves differently from a random selection. The test results showed that the selected fields were significantly different from a random selection and the clustering tendency in the simulated maps is quite similar to that of reference maps, which were derived from TM Landsat satellite images.

The policy response was validated by examining the amount of illegal cultivation predicted by the model, which is indicated by the number of land patches cultivated inside the protected forests. The simulated results were comparable with the results from reference maps (i.e. 20.5% compared to 24.6%).

The overall operation of the model was validated by comparing the spatial structure of land cover maps and reference maps derived from satellite images.

**Table 30.1** Policy setting for the baseline scenario

| Type of policy | Start | Term | Implemented body | Pressure |
|---|---|---|---|---|
| Land allocation | NA | – | – | 0 |
| Techn. support | NA | – | – | 0 |
| Credit support | 2000 | 30 | Headmen, VCP | 4 |
| Extension training | 1999 | 30 | Headmen | 5 |
| Forest protection | 1996 | 50 | Headmen, VCP | 8 |
| Population | 2000 | 30 | Women's Union | 4 |

Note: *NA* not applicable, *VCP* Vietnam Communist Party cell

**Table 30.2** Percentage change in land cover type in the baseline scenario in 2020

| Scenarios | Swidden | Bare soil | Grass-shrub | Open forest | Dense forest |
|---|---|---|---|---|---|
| Land cover in 2006 | 10.8 | 8.8 | 9.9 | 53.8 | 15.9 |
| Baseline ($S_0$) | 13.7 | 16.7 | 25.7 | 31.9 | 11.6 |

This evaluation was conducted using a Multiple Resolution Goodness-of-fit index, $F_t$ (Costanza 1989). The result produced an $F_t$ of 80%, indicating a good fit between the model outputs and the reference data, and the model can now be used for further analysis. Details of the validation process of the model can be found in Ngo (2009).

### 30.4.5 Building a Baseline Scenario

The application of the model in assessing policy impacts is based on formulating a scenario that quantifies the possible transitions and the approximate processes leading to the changes in shifting cultivation in the study site. As an initial start, a baseline scenario was applied to the model which assumes that the development context of the village follows the current trend (i.e. 2007) and remains stable during the simulation. The parameter settings, which are based on the survey in 2007, are shown in Table 30.1. The term of the simulation is 14 years, from 2006 to 2020, which coincides with the time frame of the current forest development strategy (District People Council of Ky Son 2007; MARD 2007). It also approximates a time period suggested in previous research (i.e. 10–20 years) (Huss 1988). The starting point is 2006 because the latest available land cover map (derived from satellite images) is for the year 2006. All scenarios were run ten times and the results were averaged.

The percentage of land cover types and their changes over time are shown in Table 30.2 and Fig. 30.3 respectively. The results show that under a business as usual scenario, the areas under bare land and shrubs increase while open and dense forest decreases by 2020. However, the amount of forest appears to stabilise as the simulation progresses. This finding reflects continued encroachment upon the forest for shifting cultivation and conversion to shrub through fallow and natural succession.

The visual analysis of the land cover maps between the start of the simulation in 2006 and 2020 shows that the greatest change was an increase in the cultivated land

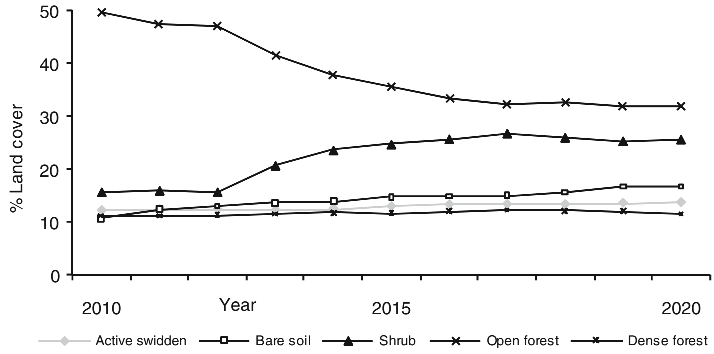


**Fig. 30.3** Land cover change over 14 years from the baseline scenario

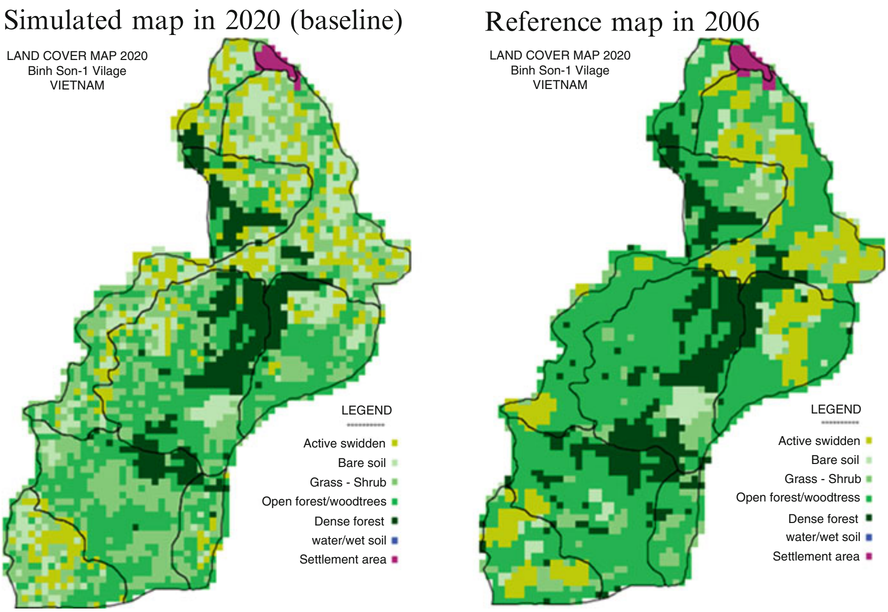


**Fig. 30.4** Land cover maps in 2020 compared to 2006

(Fig. 30.4). Although some dense forests remain at the end of the simulation, these areas are either holy forests or forests located in inaccessible locations such as on steep slopes.

Therefore, under a business as usual scenario, the amount of shifting cultivation will increase. The model was also run for a range of different scenarios related to the implementation of potential government policies in the future. The details of these scenarios and their results are described in Ngo (2009).

## 30.5 Conclusions

This chapter has presented the application of an ABM to study shifting cultivation in an upland village in Vietnam. The application has shown that the relationship between policy implementation and shifting cultivation can be explicitly described using an ABM approach, in particular combining the household context and institutional factors into the land use decision-making process. Given the ability to capture these complex relationships, the model can be used for exploring alternative scenarios and facilitating analysis of policy options towards sustainable forest management.

It is necessary to note, however, that the model has only been validated to date using data from a single village. To develop a really useful and reliable decision support tool for the future, which is the ultimate goal of this research, more data from villages with different types of internal community dynamics and/or policies implemented by the government are required.

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