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Modelling of land cover changes with CLUE-S in Bac Kan province, Vietnam

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Abstract

This report describes simulations of near-future land use changes with the CLUE-S (Conversion of land use changes and its Effects at Small regional extent) modelling framework for Bac Kan province in Vietnam. CLUE-S consists of a spatial and non-spatial component in which spatial relations between land use and its driving factors as well as scenarios representing developments and policies are included. In this study the CLUE-S model is applied for three different scenarios based on the provincial policies of Bac Kan, Vietnam. Hot-spot maps where compiled to indicate area in which land cover changes will occur in the future. The results of this study are useful for policy makers and land use planners. The provided scientific information can be used as a basis to formulate so-called focus policies on the hot spots and to evaluate alternative policies.

CLUE-S is successfully implemented for the heterogeneous landscape of Bac Kan province. Three different scenarios reflecting the policies of the province; rice sufficiency, livestock development and an increase and protection of the forest area, where compiled. The first two scenarios represent different combinations of these policies while the third scenario provides a picture of future land use configurations without these land use policies. These scenarios result in very different spatial patterns of land use change that can help the communication of the possible effect and impact of the policies for different parts of the province.

1. Introduction

This report describes the implementation of the CLUE-S model (the Conversion of Land Use and its Effects at Small regional extent, Verburg *et al.,* 2002) for Bac Kan province in the north of Vietnam. This research a collaborative effort of the CLUE group at Wageningen University and the Mountain Agrarian Systems Program (SAM), a project of the Vietnam Agricultural Science Institute (VASI, Vietnam), the International Rice Research Institute (IRRI, Philippines), and the Institute de Recherche pour le Développement (IRD, France).

1.1. Background

The SAM program started in 1997 with the main objectives to improve (i) agricultural productivity, (ii) natural resource management and (iii) living standards of the highlands' ethnic minority groups. The "Regional" component of the project (Castella et al., 1999) aims at achieving a good understanding of the processes of land use changes and their main driving forces from farm to provincial levels prior to introduction of technical and organisational innovations. A good understanding of the processes and potential dynamics of land use in the near future will help to design and implement appropriate technical and organisational innovations.

1.2. Objectives

The main objective of this study is to simulate near-future land use changes with the CLUE-S model based on the available data for Bac Kan province in Vietnam. The CLUE-S model will be applied for several different scenarios based on provincial policies. The results of this study are intended to be useful for policy makers and land use planners. The provided scientific information can be used as a basis to formulate so-called focus policies for locations where expected land use developments might harm sustainable development.

1.3. Study area description

The study area, Bac Kan province is situated in the hills of the Red River basin, approximately 200 kilometres north of Hanoi. Before 1996 Bac Kan was part of Bac Thai province together with today's province Thai Nguyen. In 1996 the districts of Bac Thai and two districts of Cao Bang province were grouped together to become the new province of Bac Kan. Bac Kan province is divided into seven districts (see Figure 1), which entail 122 communes. The total population of 272,500 consists mostly of ethnic groups. The majority of the population is from Tay origin. Bac Kan is classified as one of the poorest province of Vietnam (Castella et al., 2002).

The total area of the province is 4871 km², of which 304 km² is used for agricultural purposes. The majority of the population (83%) is rural and dependent on agriculture (Bui *et al.*, 2001).

The increasing population, however, causes pressure on the use of the land and its natural resources. Because of the mountainous terrain, only about 5% of the land area is considered suitable for agricultural production (Bui *et al.*, 2001). This causes an increasing area of sloping land being converted into agricultural land for food production, which rises the concern about long-term sustainability of the natural resource base to support the demands for food production and income generation. To protect the upland systems the Vietnamese government has banned the slash and burn system recently, based on the assumption that this system is the main reason for deforestation (Husson *et al.,* 2001).

In the last decades Vietnam has undergone a lot of changes, one of the most important is the implementation of new economic policies renovations, called *doi moi*. As part of these renovations large-scale land distribution has taken place. In Bac Kan province all land is distributed among farming households, which means that someone is responsible for every plot of land in the province.

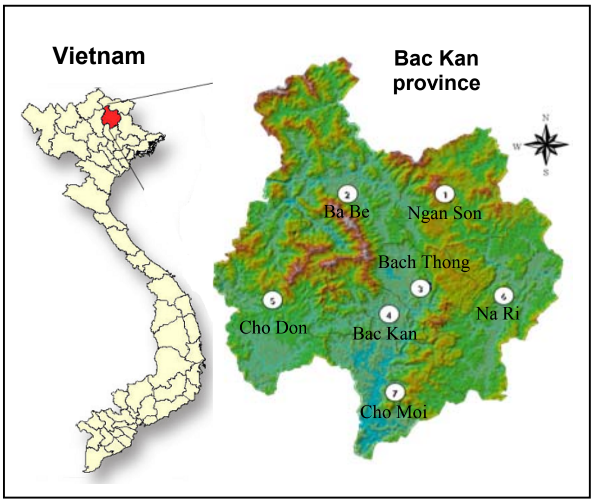

Figure 1. Location of Bac Kan province, and the location of the 7 districts

2. Methodologies

2.1. General land cover change methods

Land use systems are complex and operate at the interface of multiple social and ecological systems. Land use change can be seen as directly or indirectly driven by a set of so-called driving factors of change. These driving forces can be subdivided into two categories (Verburg *et al.*, 2002);

- Drivers that are directly responsible for the rate and quantity of land use change (e.g. forest cleared for agricultural land due to population growth)

- Driving forces determining the location of land use change (e.g. soil suitability for lowland rice)

So driving factors can have an influence on both the quantity and allocation of land use change.

To unravel these interactions between land use change and driving factors it is possible to use empirical methods. The CLUE-s model combines such an empirical analysis with the dynamic simulation of the interactions between land use types.

2.2. CLUE-S modelling approach

CLUE-S is specifically developed for regional applications with a high spatial resolution.

CLUE-S consists of a non-spatial and spatial model, operating at respectively the regional and pixel level. The regional level is in this application the province level, whereas the pixel level consists of a grid with, for this case study, a pixel size of 250 x 250 meter.

In this paper we will give a short overview of the functionality of the CLUE-s model, a more detailed description of the model is provided by Verburg *et al*., 2002. Figure 2 shows the components of the CLUE-s model. Together, these components create the set of conditions on which the calculation of the changes in land use pattern is based.

Land use requirements (demand) are calculated at the aggregate level (the level of the case-study as a whole) as part of a specific scenario. The land use requirements constrain the simulation by defining the totally required change in land use, i.e. all land requirements defined at the aggregate level are allocated at the pixel level. All changes in individual pixels should add up to these requirements. In our approach, land use requirements are calculated independently from the CLUE-s model itself and can be based on a range of methods, depending on the case study and the scenario, e.g. the extrapolation of trends in land use change of the recent past into the near future is a common technique to calculate land use requirements.

Location characteristics determine the relative suitability of a location for the different land use types. The relative probability of finding a land use type at a particular location is related to the biophysical and socio-economic conditions of that location. The relation between the relative probabilities and the biophysical and socio-economic location characteristics is defined in a logit model. The coefficients are estimated through logistic regression using the actual land use pattern as dependent variable. This method is similar to econometric analysis of land use change, which is common in deforestation studies. In our case studies we assume that locations are devoted to the land use type with the highest ‘suitability’. 'Suitability' includes the monetary profit, but can also include cultural and other factors that lead to deviations from (economic) rational behaviour in land allocation. This assumption makes it possible to include a wide variety of location characteristics to estimate the logit function that defines the relative probabilities for the different land use types.

Spatial policies and restrictions indicate areas where land use changes are restricted through spatial policy or tenure status. Case studies have shown that spatial policies and land tenure can influence the pattern of land use change. Maps that delineate the area for which the spatial policy is implemented must be supplied. Some spatial policies restrict all land use change in a certain area, e.g., a log-ban within a forest reserve. Other land use policies restrict a set of specific land use conversions, e.g., residential construction in designated agricultural areas or permanent agriculture in the buffer zone of a nature reserve. The conversions that are restricted by a certain spatial policy can be indicated in a land use conversion matrix: for all possible land use conversions it is indicated if the spatial policy applies.

Land use type specific conversion settings determine the temporal dynamics of the simulations. Two sets of parameters are needed to characterize the individual land use types: conversion elasticities and land use transition sequences. The first parameter set, the conversion elasticities, is related to the reversibility of land use change. Land use types with high capital investment will not be easily converted into other uses as long as there is sufficient demand. Examples are residential locations but also plantations with permanent crops (e.g., fruit trees).

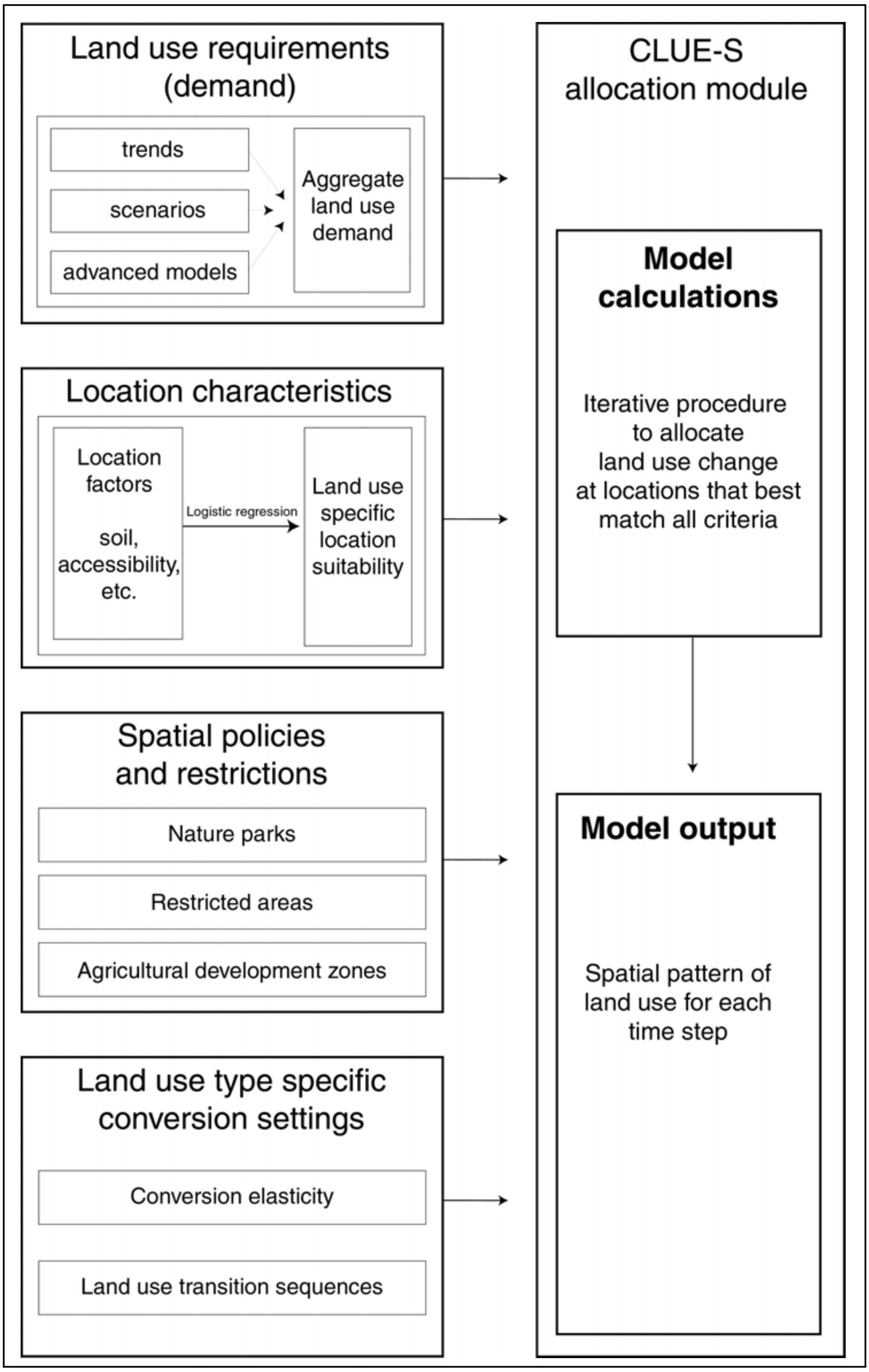

Fig. 2. Structure of the CLUE-s model

Other land use types easily shift location when the location becomes more suitable for other land use types. Arable land often makes place for urban development while expansion of arable land occurs simultaneously at the forest frontier. An extreme example is shifting cultivation: for this land use system the same location is mostly not used for periods exceeding two seasons as a consequence of nutrient depletion of the soil. These differences in behaviour towards conversion can be approximated by conversion costs. However, costs cannot represent all factors that influence the decisions towards conversion such as nutrient depletion, aesthetic values etc. Therefore, for each land use type a value needs to be specified that represents the relative elasticity to change, ranging from 0 (easy conversion) to 1 (irreversible change). The user should decide on this factor based on expert knowledge or observed behaviour in the recent past.

The second set of land use type characteristics that needs to be specified is the allowed land use transition sequence. Not all land use changes are possible or realistic (e.g., arable land cannot be converted into primary forest directly) and many land use conversions follow a certain sequence. Examples include fallow land and forest regrowth following shifting cultivation. These sequences are specified in a land use conversion matrix. For each land use type it is indicated in what other land use types it can change during the next time step.

When all input is provided the CLUE-s model calculates, with discrete time steps, the most likely changes in land use given the above described restrictions and suitabilities. Some changes are irreversible while others are dependent on the changes in earlier time steps. Therefore, the simulations tend to result in complex, non-linear changes in land use pattern, characteristic for complex systems.

3. Data

The different components of the CLUE-S model require different data as input. Therefore a suitable data set needs to be prepared.

3.1. Data set

Several data sources are available for the construction of the data set. A land cover map from 1998 was used together with data representing possible driving factors of land use change. The independent variables comprised soil, geology & landscape, socio-economic, accessibility and climate data selected based on knowledge of the ongoing processes in the study area. In table 1 the variables, type of variable (i.e. discrete, binary, and continuous), units (e.g. %, meter) and classes are presented.

Table 1. Land use types and variables used in the model

Variables	Type	Unit	Classes
Dependent			
Land Cover 2)	Binary	0-1	Lowland rice
			Terraces
			Upland crop
			Closed forest
			Open forest
			Shrubs
			Grassland
			Mosaics
			Others
Independent			
Soil, geology & landscape			
Soil type 4)	Binary		Class 1
			Class 2 *
			Class 4
			Class 5
			Class 6

			Class 8
			Class 10
Geology 4)	Binary	0-1	Schist *
			Granite
			Sediment
			Sandstone
			Limestone
			Colluvial
			Rhyolite
Soil degradation 4)	Binary	0-1	None
			Slightly *
			Moderate
Elevation 2)	Discrete	Meter	
Slope 2)	Discrete	%	
Socio-economic			
Rural labour force 1)	Discrete	% per commune	
Rural labour force density 1)	Discrete	Number per ha agricultural land per commune	
Poverty 1)	Discrete	% per commune	
Population 1)	Discrete	Number per commune	
Variables	Type	Unit	Classes
Population density 1)	Discrete	Number per km² lowland & residential land per commune	
Illiteracy 1)	Discrete	% per commune	
Accessibility			
Distance to nearest village 2)	Continuous	Meter	
Distance to nearest A road 2)	Continuous	Meter	
Distance to nearest B road 2)	Continuous	Meter	
Distance to nearest C road 2)	Continuous	Meter	
Distance to nearest stream 2)	Continuous	Meter	
Distance to nearest river 2)	Continuous	Meter	
Distance to nearest commune market 2)	Continuous	Meter	
Distance to nearest district market 2)	Continuous	Meter	
Distance to province market 2)	Continuous	Meter	
Travel time to nearest market	Continuous	Minutes	
Travel time to province capital	Continuous	Minutes	
Isolation index	Continuous	-	
Climate			
Mean rainfall rainy season 3)	Discrete	Millimetre	
Mean rainfall dry season 3)	Discrete	Millimetre	
Number of dry months 3)	Binary	0-1	3 dry months *
			4 dry months
			5 dry months
Number of cold months 3)	Binary	0-1	1 cold month
			0 cold month *

Used data sources 1) SAM-Regional statistical data set 2) SAM-regional spatial data set 3) LUPAS data set 4) Geographic database of Bac Kan province

* This class is excluded in the logistical regression analyses

3.2. Data sources

The data set for the CLUE-S application for Bac Kan province is based on four different data sources;

1. statistical data gathered/derived by the SAM-Regional project, all data were available on commune level for 1999
2. spatial data derived by the SAM-Regional project
3. data gathered/derived by the LUPAS research team (Kam *et al.*, 2000)
4. data gathered/derived by the research group of the Geographic database of Bac Kan province (Brabant *et al.*, 1999)

4. Scenario development

For CLUE-S simulations, scenarios need to be defined. These scenarios contain assumptions and calculations of the demand at provincial level. A scenario is characterised by projections of the total area required for each land use type and area restrictions, which are, based on both current and assumed policies. For the policies in Bac Kan province the following demand and area restriction components were developed to visualise the effects of these policies on land cover.

4.1. Policies

Bac Kan is one of the poorest provinces in Vietnam. The economy depends largely on finances supplied by the national government. The provincial government has designed a number of policies to improve the province's welfare by income generation. Supplementary to more income, self-sufficiency in rice and environmental development are described as major objectives in the policies for the province's future.

These policies are specified at two levels; the province level and the household level. This CLUE-S application is based on the policy objectives at province level, which are:

1. Intensification of the lowlands, and a restriction in expanding the lowland area. The government is stimulating the intensification with special subsidies for farmers who increase the number of cropping cycles on their land.
2. Increasing the number of livestock to fulfil the increasing demand for meat.
3. Reforestation of the hills in the province for environmental concern and production forests. The provincial objective is to have 50 % the province covered with forest in 2010. The reforestation policy can be seen as a part of the national policy to establish 5 million ha of forest in Vietnam in 2005.

4.2. Demand

Three different scenarios for this CLUE-S application were made based on different projections of the demand for land use types and different forest protection and reforestation policies. It is not possible to totally fulfil both livestock development and reforestation, because both policies claim much of the available land resources.

<u>Scenario 1</u>. The first scenario aims at subsistence in rice at the current input level, livestock growth by an increased meat demand and some forest development, with a higher priority for pasture land. Furthermore, existing and newly planted forests are assumed to be well protected.

<u>Scenario 2</u>. The second scenario aims at subsistence in rice at the current input level and forest development according to the provincial policy.

<u>Scenario 3</u>. This scenario is a projection of the situation which might be realistic when policies would not aim at a sustainable development of the province and historic developments would continue in the future. Forest area is assumed not to be expanded and the increasing population pressure is expected to put much claim on the upland land resources.

In all scenarios upland crops and mosaics are treated as competitive land covers for forest development and supportive for livestock development. These land cover types occur on the higher part of the slopes and can be used as fodder production land. In the first scenario there is a small growth for both land cover types and in the second scenario a small decrease.

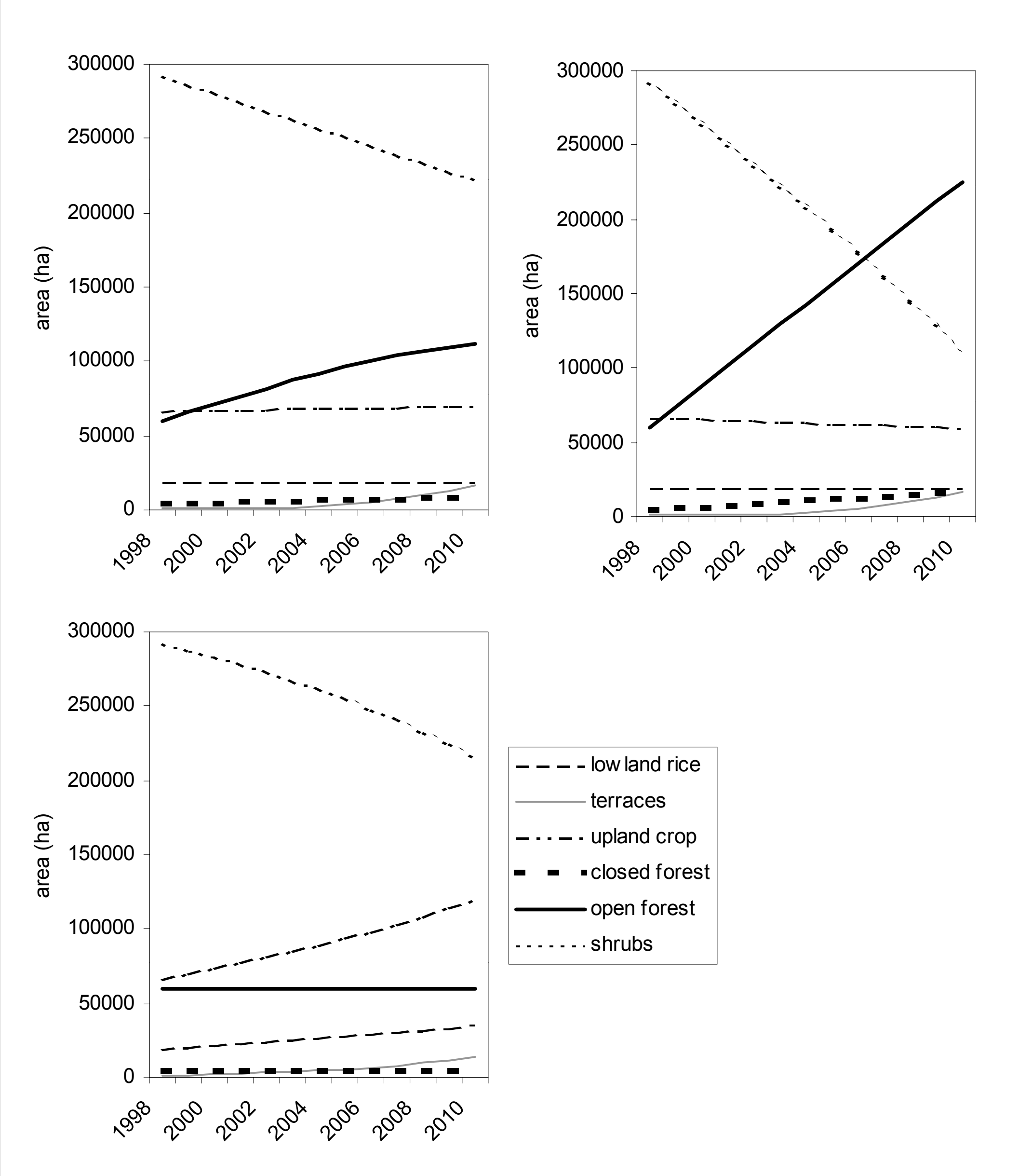

Figure 3. Demand projection of the three scenarios (upper left: scenario 1; upper right: scenario 2; bottom: scenario 3)

4.3. Time period

The CLUE-S model was set on a timeframe of 12 years, from 1998 to 2010. The period was chosen because policy makers use 2010 as a milestone for their policies. The relative short period of 12 years also limits the extent that certain driving factors will change over time. In the CLUE-S modelling framework driving factors are assumed to be constant in time, while the land use in Bac Kan is changing fast.

5. Model outputs

For the three scenarios presented above the CLUE-S was used to simulate the future changes in land use pattern. The simulation results are based on yearly time steps. In Figure 4 we have, however, only presented the initial land use configuration in 1998 and the resulting land use pattern at the end of the simulation. Scenario 1 aims at rice subsistence, enough pasture land for livestock development and some reforestation and forest re-growth.

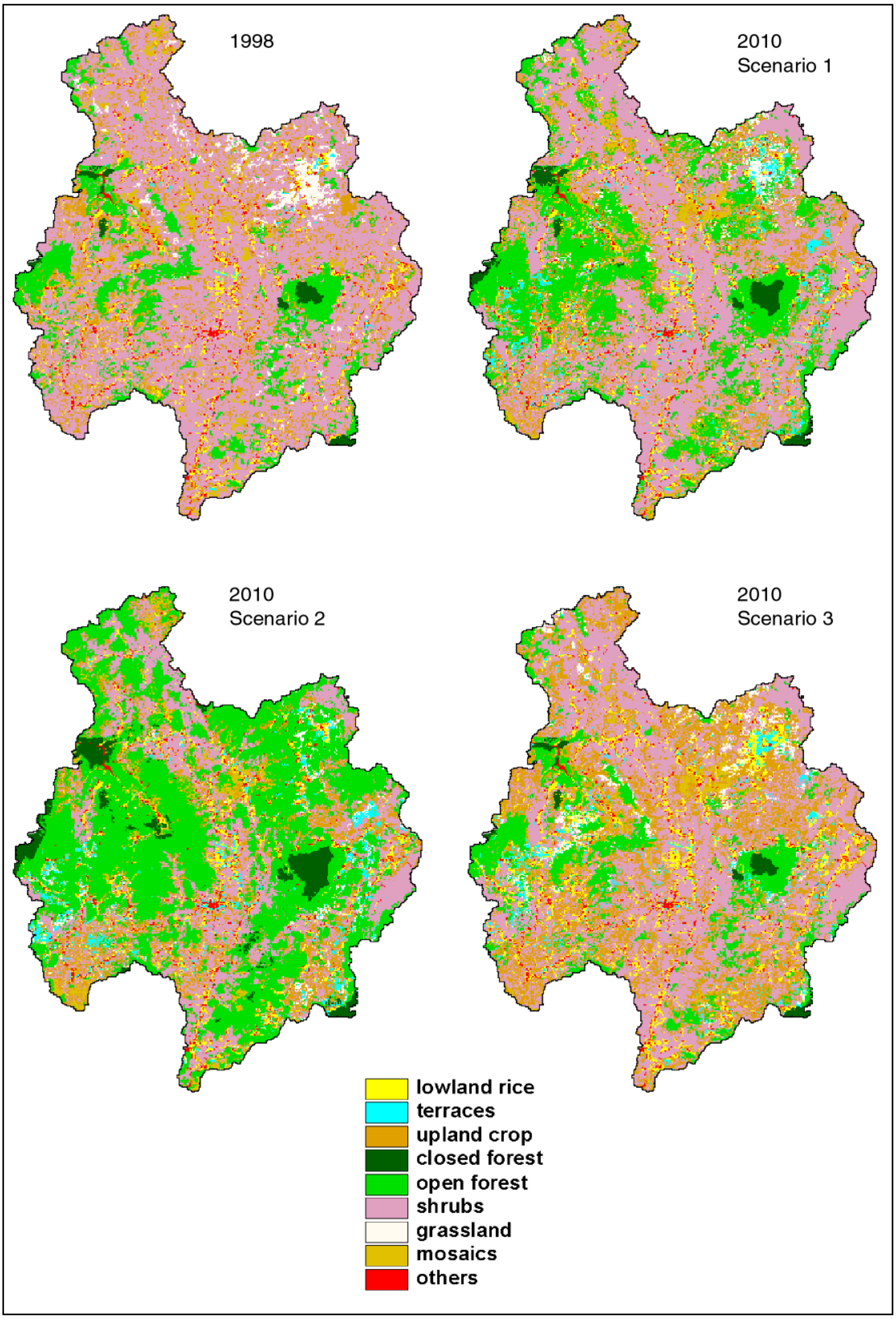

Figure 4. Results of the simulation of the scenarios with the CLUE-s model (initial land use configuration and scenario results for 2010)

According to the simulations most reforestation and forest re-growth is to be expected in the rugged western part of the province. Expansion of the lowland rice area can be found throughout the whole province mainly in the river valleys close to villages.

Scenario 2 aims at rice subsistence and the reforestation policy, 50% of the province under forest cover in 2010. These huge claims on the land resources have a large impact on the province's land cover changes. According to the simulation reforestation and forest re-growth occur all over the province. Only the central valley and southern part of the province remain dedicated to agricultural purposes. In this area population pressure is too high to ensure successful reforestation. Closed forest re-appears at the most remote locations at the boundary of the province and at the highest mountaintops.

The third scenario shows a picture that might become reality when no spatial policies were implemented. The increasing demand for agricultural land causes large areas of formerly bush land to be reclaimed for upland farming and all flat areas are converted into lowland rice.

The three scenarios show three extremes for changes in land cover developments in the province. Most of the changes forecasted might not actually take place at the short time frame addressed in this study. However, the maps show images of potential future developments that can be used as a means of communication of spatial policies to the different stakeholders that actually manage the land resources.

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