

Land Transitions in Northwest Vietnam: An Integrated Analysis of Biophysical and Socio-Cultural Factors

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Abstract This paper discusses transitions in land use evidenced by the case of the Suoi Muoi catchment area in NW mountain of Vietnam. Land use transitions were detected from LANDSAT and SPOT satellite images taken over the last 40 years. The maps showing changes in land use were linked with biophysical properties of the land such as slope gradient, elevation and soil type, and cultural characteristic of various ethnic groups by means of logistic regression model. The combination of research methods and instruments from several disciplines, including statistical spatial analysis such as the multiple logistic regression (MLR) models and the multiple correspondence analysis (MCA) on household interview data, and key informant interviews allowed us to identify and validate a number of

factors that drive land cover and land use changes in Northwest Vietnam.

Keywords Land use change · Shifting cultivation · Ethnic minorities · Vietnam

Introduction

Over the past two decades, land use and land cover changes have been recognized as one of the key driving forces in global environmental changes, which explains why the scientific interest in this subject has been growing. Research has been conducted in temperate, tropical and/or subtropical areas (Meyer and Turner 1992; Turner and Meyer 1994; Geist and Lambin 2001; Becker and Bugman 2001).

Several countries in the Tropics are experiencing forest transitions that mean an end to the net decline in forest cover and the beginning of forest recovery. These forest transitions typically result in relatively complex landscapes with patches of untouched forest, clear cuts and a range of patches with degrading and regenerating forest at various stages. Such transitions and the corresponding landscapes are of high importance because of their positive impact on ecosystem services such as biodiversity preservation, soil and water conservation and carbon sequestration. Rudel *et al.* (2005) suggested two major pathways towards a forest transition. In some places, economic development creates enough non-farm jobs to pull farmers off the land, thereby inducing spontaneous secondary forest establishment in former agricultural plots. In other places, scarcity of forest products has prompted governments and landowners to establish tree plantations on abandoned agricultural lands.

Despite a wealth of research on the dynamics of land use and land cover changes there is still a knowledge gap on this topic in tropical areas, where most of the developing countries are located, as the high costs of conducting field

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and laboratory research are often unaffordable for local institutions. In addition to financial constraints and limited data availability, interdisciplinary research, essential for the study of land use and land cover dynamics, is not yet very common in most developing countries.

One of the major concerns in land use and land cover change in tropical environments is deforestation. During the 1990s, forests grew back in temperate regions, while there was still substantial deforestation in most tropical regions (Lambin *et al.* 2003). FAO estimated that in the tropics, 15.2 million hectares of forest were lost per year during the 1990s (cited in Lambin *et al.* 2003). South East Asia in particular was a hot spot with the highest annual net forest cover change worldwide (i.e. deforestation minus reforestation) of 0.71 %, whereas Africa and Latin America had lower rates (0.36 % and 0.33 %, respectively). Gross deforestation was also very high in Southeast Asia (0.91 % per year), while Africa and Latin America had lower rates of 0.43 % and 0.38 % per year, respectively (Achard *et al.* 2002). The most often cited causes of deforestation in Asia, including Vietnam, are logging, the advancement of the agricultural frontier through ongoing migration into new areas, the intensification of shifting cultivation and a gradual change of areas under shifting cultivation into permanent agriculture (Achard *et al.* 2002; Lambin *et al.* 2000). Tachibana *et al.* (2001) indicate that growing population pressure and unclear ownership rights of forest lands have led to deforestation and the expansion of cultivated lands in the mountainous regions of Vietnam. However, from the end of the 1990s onwards an increase in overall forest cover has been reported in Vietnam (Meyfroidt and Lambin 2008, 2011). The same authors analyzed economic development and forest transition paths in Vietnam during the 1990s and concluded that the establishment of agricultural markets facilitated reforestation by raising agricultural productivity on the most productive lands (Meyfroidt and Lambin 2011). Furthermore, changes in land tenure legislation and environmental policies were also identified as major causes of land use and land cover changes. The Vietnamese government, for example, has paid more attention to forest protection in recent years, which has already led to reforestation in some highland areas (Castella *et al.* 2006; Castella and Verburg 2007; Müller and Munroe 2005; Sikor and Dao Minh 2000, Sikor 2006; Clement and Amegaza 2009; Meyfroidt and Lambin 2011).

It is interesting to note that most research on land use and land cover changes primarily pays attention to bio-physical factors that determine the spatial pattern of land conversions, notwithstanding the well-known fact that economic, socio-cultural and political forces are often the main drivers of land changes. There are a limited number of research projects examining the linkages between both socio-cultural and bio-physical factors. Socio-cultural factors in particular have received little attention. One of the few exceptions is

the research in Bac Can, Vietnam, by Castella *et al.* (2005), which showed that villages have different development potential and emphasized the importance of recognizing these differences when assessing drivers of land use and land cover changes. The research also revealed the significance of considering cultural and agronomic particularities of the ethnic groups living in the villages in land change modeling. Nevertheless, a thorough understanding of the role of socio-cultural factors with respect to land use and land cover changes is still missing in most research.

To fill this gap we undertook an integrated study of bio-physical and socio-cultural variables that influence human-environment relationships, using the upper Suoi Muoi stream catchment in the mountainous area of Northwest Vietnam (Fig. 1) as a case study. The relatively small study area (284 km²) was selected because of its extraordinary diversity of ethnic groups: five of the 54 ethnic groups in Vietnam live in the approximately 200 villages of the catchment. Each of these ethnic groups has particular farming practices linked to socio-cultural characteristics and environmental conditions, which result in different livelihoods.

This paper aims at identifying and improving the understanding of several socio-cultural and bio-physical factors influencing land use and land cover changes by (i) mapping the spatial pattern of land use and land cover changes over the last 40 years, (ii) detecting single variables that are correlated with the spatial pattern of land use and land cover changes and (iii) disentangling the role of bio-physical and socio-cultural factors using multivariate correspondence analysis.

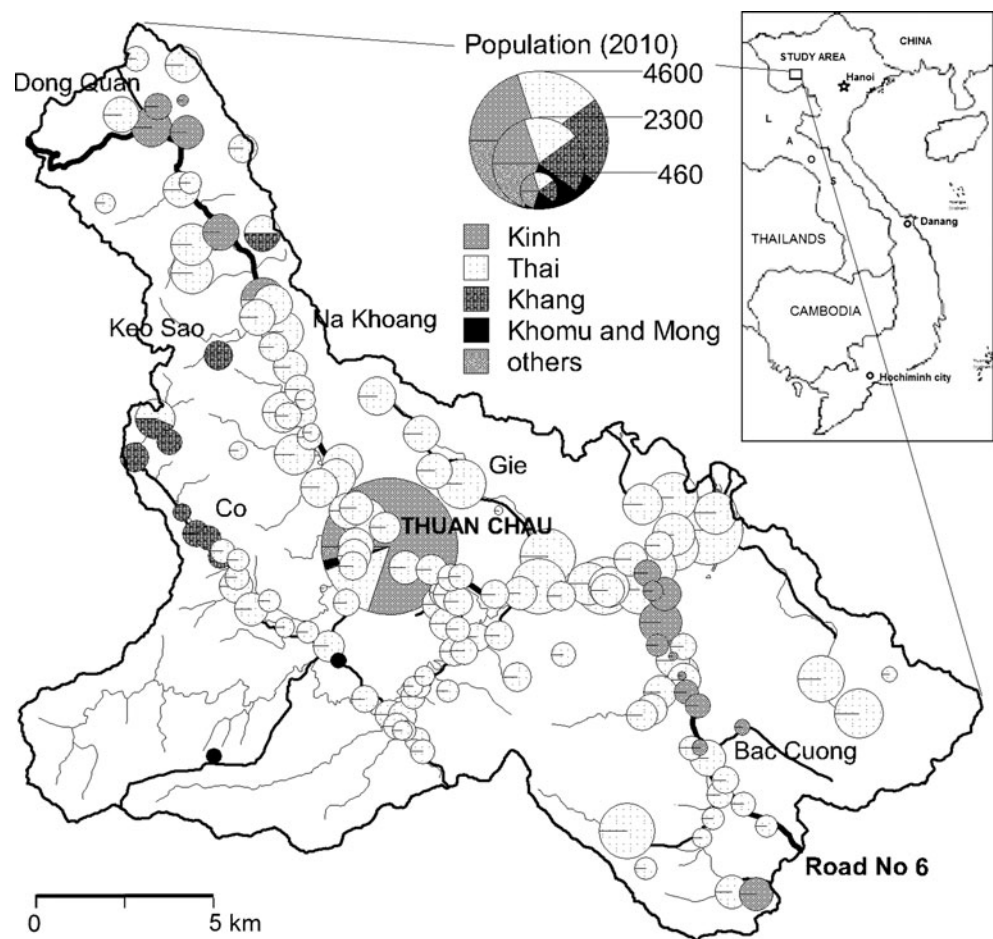
Materials and Methods

Study Area

The study area, the Suoi Muoi catchment, covers 284 km² and is a contributing area of the Suoi Muoi River and located in the Son La Province in the mountainous area of Northwest Vietnam. Two-thirds of the Suoi Muoi catchment is a karst landscape, with closed depressions, sinkholes and no permanent rivers. The spring of the Suoi Muoi River is located in the western highlands of the catchment. The western highlands are terrigenous rock formations ranging in altitude from 800 m to a maximum of 1,800 m and the eastern part is characterized by broad alluvial plains on carbonate rocks at altitudes ranging from 400 m to 600 m. The main river course follows the contact between the terrigenous rocks and carbonate rocks and passes through the Thuan Chau district (Vu Thanh Tam 2003).

The Suoi Muoi catchment has a humid tropical monsoon climate with a relatively cold, dry winter and a warm, rainy summer. The average temperature in Son La Province is 20–

Fig. 1 Settlements of the ethnic groups in the Suoi Muoi Catchment



22 °C, with a maximum of 40 °C and a minimum of 1 °C. Mean annual rainfall in the province is 1,413 mm, with an uneven precipitation distribution. The rainy season, with 80 % of the total annual rainfall, lasts from April to September (Nguyen Trong Dieu 1995).

Forests and shrubby vegetation dominate the natural vegetation in the area. The forests are evergreen humid subtropical broad-leaved forests consisting of two typical canopies: (1) the upper canopy dominated by *Alitga takhtadjanii* with straight trunks up to 35–40 m and (2) the lower canopy consisting mainly of vegetation of the Reed family (Nguyen Trong Dieu 1995). The shrubby vegetation is composed of bamboo and other low growing plants, located on steep slopes and on limestone, which are unsuitable for agriculture. At present, 44 % of the catchment is used for agriculture: paddy fields for rice cultivation on terraces close to the river and upland fields for the cultivation of mainly cassava and maize.

The Suoi Muoi catchment is one of the poorest regions in Vietnam. Inhabitants belong to several ethnic groups with clear socio-cultural differences. Since the 1960s population density in the catchment has increased significantly mainly as a consequence of the state-organized immigration of Kinh people from the Vietnamese lowlands and natural fertility.

Population growth remains high; the number of people recorded in the Suoi Muoi increased from 48,700 in 2002 to 58,000 in 2010 (Thuan Chau district yearbook 2010). In 2010, 81 % of the population belonged to the ethnic group of Thai, 14 % of the population were Kinh, 4 % of the population were Khang, 0.5 % was Mong or Khomu, and 0.5 % belonged to other ethnic minorities, mostly living in the town of Thuan Chau (Fig. 1).

Until a few decades ago, shifting cultivation was a widespread agricultural practice in the area and upland rice was one of the major crops. As the cultivation of upland rice quickly depletes nutrients in the topsoil, shifting cultivators had to move every 2 to 3 years to a new area. After approximately 10 years of fallow, the plot could be cultivated again with upland rice. Today, upland rice cultivation is infrequent in the area, although shifting cultivation is still practiced by some Thai, Khang, Mong and Khmu farmers for the cultivation of cassava and maize. In flat areas near streams or rivers, terraced fields have been constructed for wet rice (paddy) cultivation.

Before 1960, all land in the Suoi Muoi catchment was owned by Thai noblemen. The farmers had to work on their paddy fields and in return received free access to upland fields, where they could grow subsistence crops. In the early

1960s, agriculture was collectivized into a system of cooperative farms, and lands formerly owned by Thai noblemen were declared common property. Around the same time, the government initiated resettlement programs that moved the ethnic Kinh to the so-called New Economic Development Zones. These development zones were established by the central government to encourage people from the densely populated lowlands to settle in the less populous mountain regions. The new immigrants were encouraged by the central government to contribute to the development of these zones by reclaiming land for agriculture and investing in infrastructure, which led to a significant increase in arable land in the area. By the end of the 1970s and the beginning of the 1980s, northern Vietnam went through a severe economic and agricultural crisis caused by, among other factors, severe mismanagement of cooperative farms. This crisis resulted in a dramatic decrease in rice production. The Vietnamese government gradually reformed national agricultural policies in the 1980s by shifting the control over agricultural production from the cooperatives back to individual households. In the early 1990s, an open market economy approach was adapted and farmers were allowed to buy and sell land. The re-privatization of agriculture led to the introduction of new cash crops such as coffee, tea and fruit orchards with oranges, plums and apricots. Additionally, agricultural technologies, such as the application of fertilizers and pesticides and the introduction of improved paddy rice, maize and cassava varieties, led to a significant increase in agricultural productivity. At the same time, the government pushed forward a reforestation program aimed at a re-greening of barren hill slopes (Sikor 2001; Müller and Zeller 2005). To ensure the success of the program farmers were no longer allowed to cut wood from protected areas and received a financial compensation for the establishment of forest plantations on abandoned lands. In the 2000s, the government started to grant land use rights to individual farmers. The objectives of national agricultural policy reforms and the opening of the economy were i) to increase households' subsistence production and simultaneously generate a marketable surplus; ii) to improve the socioeconomic situation of rural households; and iii) to encourage local farmers to engage in sustainable land use practices (Marsh *et al.* 2006).

Socio-Cultural Data Collection and Analysis

To better understand the socio-cultural variables influencing land use and land cover changes and how they are linked to the ethnic groups living in the Suoi Muoi catchment, we undertook an intensive interview campaign in six villages in 2003 and 2004. These villages were selected according to the following criteria: representation of the main ethnic groups in the region, distance to major roads, elevation

and soil properties (Fig. 1). In the six villages all three major ethnic groups are represented.

Semi-structured questionnaires were used with both key informants and individual household members in each of the villages and a total of 25 key informants and 35 household members were interviewed (Table 1). Key informants in each village, selected among village heads, deputy heads, party secretaries, and leaders of associations and former cooperatives, provided information on the socio-cultural characteristics of the village and current and past land uses. Key informants also provided valuable insights into the specific cultural context and economic situation of each village and its demographic evolution. Interviewees were selected with the help of key informants to identify and include households from all age classes and economic strata in the village. We aimed at interviewing approximately 10 % of the households in each of the six villages (Table 1). In small villages, like Bac Cuong, we interviewed more than 10 % of the households in order to be able to capture the variability of answers in the village. In some of the bigger villages, like Gie, the 10 % threshold was not achieved due to difficult road access, the language barrier, and time constraints. During household interviews we gathered information on population growth, cultural identity, land access, land use planning, farming systems, household income and other economic indicators.

Interview transcripts were coded using a set of categorical variables for each household (Table 2). As a next step the compiled database was analyzed by applying a multiple correspondence analysis (MCA) to detect dimensions in the dataset that describe a maximum variability of the original variables. The typical output of an MCA is an MCA graph in which the original variables are plotted against the new dimensions according to their mutual correlations.

Land Transition Analysis

Land cover maps were derived from LANDSAT images from different dates (Jan 1973, Dec 1987, Feb 1993 and Dec 1999) and two SPOT images (Feb 1996 and April 2008) using a supervised classification approach. For all six images, training sites were generated using aerial photographs and direct field observations. Figure 2 shows the resulting land cover and land use maps for several years ranging from 1973 to 2008. The following land cover and land use classes were identified: closed canopy forest, open canopy forest, shrubland, grassland, upland fields and paddy fields. Map overlays revealed several land transitions between the classified images: 1973–1988, 1988–1993, 1993–1996, 1996–2000 and 2000–2008.

To understand the underlying drivers of land use and land cover changes, the possible roles of bio-physical and socio-cultural factors were evaluated using Multivariate Logistic

Table 1 Population and number of interviews in the six selected villages

| Village | Ethnic group | Number of | | Number of interviews | |
|-----------|--------------|-----------|------------|----------------------|------------|
| | | Villagers | Households | Key-informants | Households |
| Na Khoang | Thai | 547 | 87 | 7 | 7 |
| Gie | Thai | 650 | 113 | 6 | 8 |
| Dong Quan | Kinh | 250 | 65 | 3 | 6 |
| Bac Cuong | Kinh | 94 | 28 | 3 | 5 |
| Keo Sao | Khang | 317 | 50 | 2 | 4 |
| Co | Khang | 222 | 38 | 4 | 5 |

Regression techniques (MLR). In MLR-models the probability of occurrence of a possible land use and land cover change is linked to a set of categorical and/or quantitative variables. Several studies have used MLR models to demonstrate that deforestation and afforestation patterns are linked to biophysical variables such as lithology (Vanacker 2002), soil fertility (Szillassi *et al.* 2010), topography (Semeels 2001) and neighborhood characteristics such as distance to roads (Etter *et al.* 2006; Castella *et al.* 2005) and distance to villages (Van Dessel *et al.* 2008; Koning 2000). For the purpose of this study we analyzed the spatial patterns of the two most frequently occurring land transitions: from upland fields to shrubland and from shrubland to upland fields. The role of the following variables was evaluated: lithology, elevation,

distance to roads, distance to settlements, distance to Road No. 6, and ethnic groups (Fig. 3).

The lithology layer was created after the digitalization of a geological map compiled by Nguyen Dinh Hop (1994) which was then reclassified into six classes that represent the major bedrock types in the catchment (Fig. 4). The following lithology classes were retained: schist and conglomerate-schist (L1), sandstone and sandy-clayish-limestone (L2), limestone (L3), basalt and siltstone (L4), alluvial sediments, (L5) and schist-siltstone-sandstone and black shale (L6).

Elevation (in m) and slope gradient (in percent) were created from a 20×20 m resolution elevation model (DEM) derived from 1: 50 000 topographic maps with a contour interval of 20 m. The same maps were used to

Table 2 Coding of variables for multiple correspondence analysis

| | Code | Descriptions |
|--------------------------|------|----------------------------------------------------------------|
| Location | GIE | Gie village (Thai) |
| | NK | Na Khoang village (Thai) |
| | DQ | Dong Quan village (Kinh) |
| | BC | Bac Cuong village (Kinh) |
| | CO | Co village (Khang) |
| | KS | Keo Sao village (Khang) |
| Total income | IC3 | Total household income is equal or higher than 1800\$ per year |
| | IC2 | Total household income is between 600\$ and 1800\$ per year |
| | IC1 | Total household income is less than 600\$ per year |
| Income | IF0 | Total household income exclusively from farming |
| Source | IF1 | Total household income from farming and off-farm activities |
| Fuel wood | W1 | Self-collecting fuel wood |
| | W2 | Purchasing fuel wood |
| Industrial plants | I0 | No industrial plants in village |
| | I1 | Industrial plants in village |
| Orchards | O0 | Not having orchards |
| | O1 | Having orchards |
| Forest availability | FR0 | Not having forest |
| | FR1 | Having forest |
| Arable land availability | LA0 | Sufficient agricultural lands |
| | LA1 | Lack of agricultural land |
| Arable land registration | AR0 | Not all agricultural land is recorded |
| | AR1 | All agricultural land is recorded |

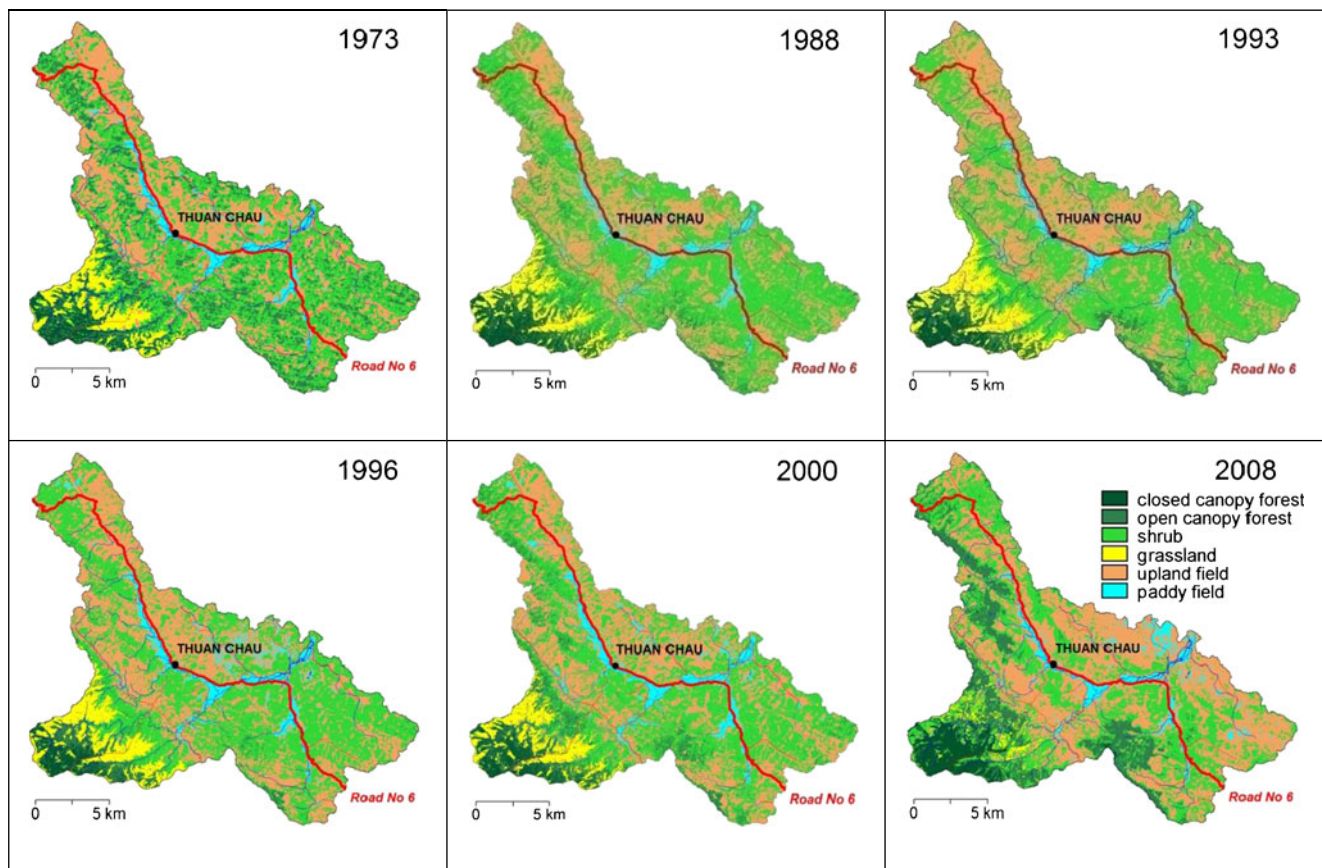


Fig. 2 Land cover and land use maps of the Suoi Muoi catchment

digitize the location of permanent rivers, roads and settlements which were used to quantify the distance of neighborhood variables to roads and settlements.

We also created a map showing the spatial distribution of the four main ethnic groups on the basis of the census data published in the Thuan Chau district yearbook (2010). The territory of each settlement was delineated by constructing Thiessen polygons around the centre of the settlements. The territory of the following ethnic groups was mapped: Thai (E1), Kinh (E2), Khang (E3) and Mong-Khomu (E4).

As a next step the coefficients of the following logistic regression equation were calibrated for each of the time periods studied (Eq. 1):

$$p(AB) = \frac{e^{(a+b_1X_1+\dots+b_nX_n)}}{1 + e^{(a+b_1X_1+\dots+b_nX_n)}} \quad (1)$$

In which: $p(AB)$ is the probability that land use type A will change into land use type B

$X_1 \dots X_n$ explanatory variables
 $a, b_1 \dots b_n$ calibration coefficients

The MLR equation was calibrated with SAS/STAT procedures using 5,000 data points sampled randomly throughout

the study area. For each sample point the following data were collected: (1) the value of the dependent variable $p(AB)$ (which has a value of 1 if the land use changed from type A to type B and a value of 0 if an AB conversion did not occur) and (2) a value for each of the explanatory variables.

The MLR models were validated by constructing a Relative Operation Characteristic (ROC), also known as a Receiver Operation Characteristic. The ROC procedure is used to measure the relationship between simulated change and real change (Pontius and Schneider 2001). A ROC curve is based on the relative ranking of all the land units, according to their relative land cover change probability values. The validation was also tested with and without ethnicity variables.

Results

Socio-Cultural Characteristics of the Ethnic Groups

Results from key informant interviews showed that, apart from a few exceptions, only one ethnic group lives in each village. For the purpose of this study, we report only the main socio-cultural characteristics of three major ethnic groups (Thai, Kinh, Khang) living in the catchment area.

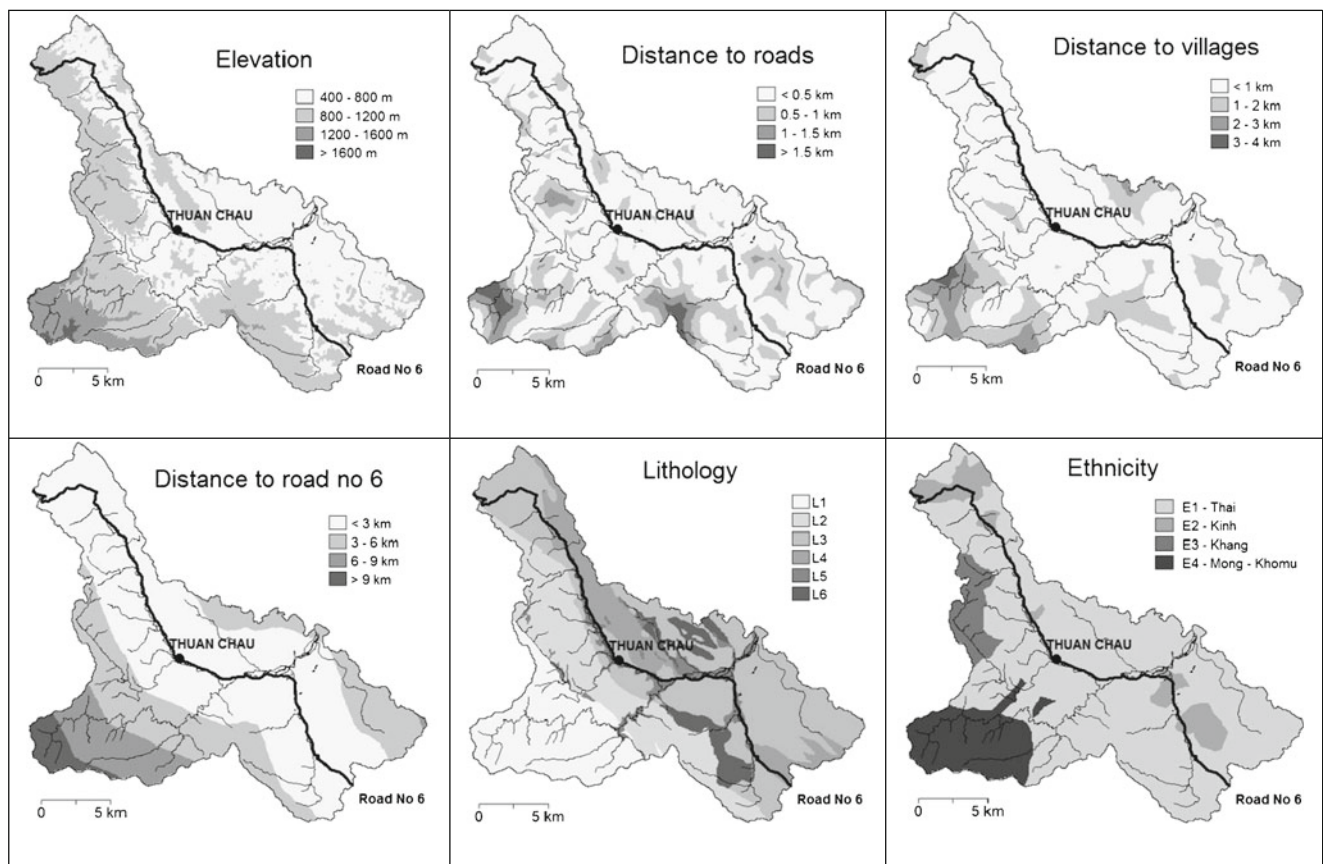


Fig. 3 Prediction variables for land use change

The Thai (Black Thai) form the largest ethnic group in the area. They migrated to Northwest Vietnam about 700 to 800 years ago (Cam Trong 1978) and settled in fertile valleys, near springs. They live in clearly delineated villages, with houses built close to each other. Irrigated rice cultivation forms the core of their agricultural system, but the Thai also cultivate upland rice, maize, cassava, taro and cotton on upland fields.

The Kinh are the major ethnic group in Vietnam, and the second largest ethnic group in the Suoi Muoi catchment. Most of the Kinh live in towns, along the national road or in broad flat areas. Kinh originally settled in the lowland areas. Most of the Kinh in the Suoi Muoi catchment originate from the populous province of Thai Binh and moved to the area in the early 1960s, supported by a national settlement program to help establish the “New Economic Development Zone” in the Vietnamese highlands. The second generation of Kinh migrants was born and brought up in the highlands and regards the catchment as their homeland. Most Kinh people living in rural areas cultivate crops and practice animal husbandry. Kinh people are known as early adopters of agricultural innovations such as improved crop varieties and chemical fertilizers. Since the introduction of the market economy, the Kinh have invested in tree plantations and

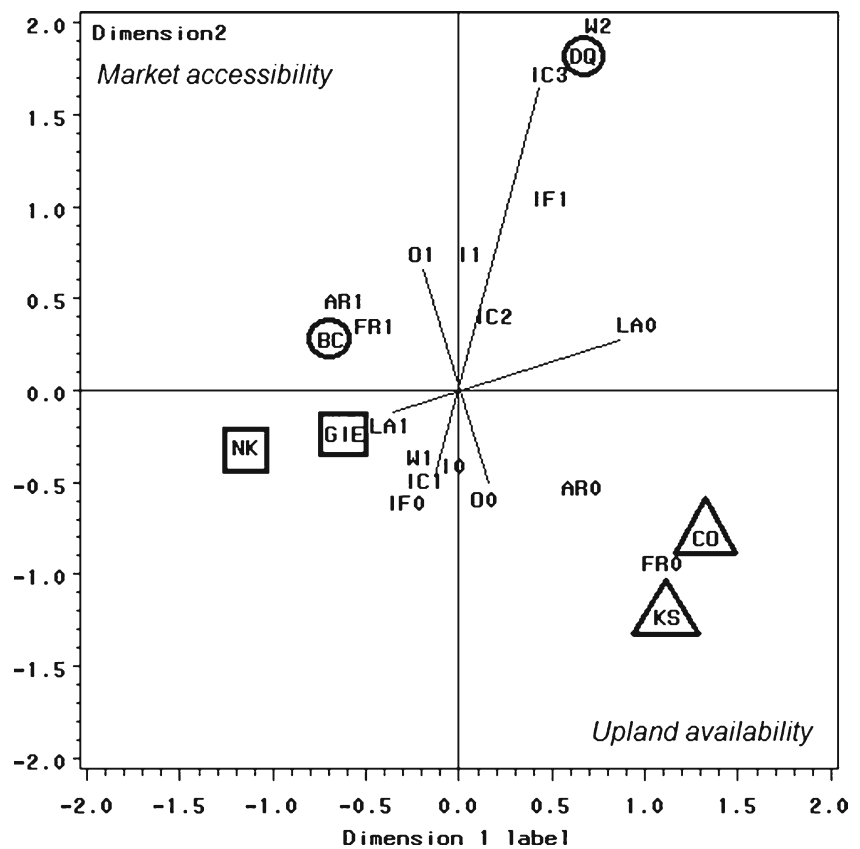
cattle breeding farms. Most Kinh farmers generate off-farm income from transportation of and trade in agricultural products.

Like the Thai people, the Khang have settled in the area for centuries. They cultivate paddy rice and practice shifting cultivation with upland rice, maize and cassava. In the Suoi Muoi catchment, the Khang live in the remote northwest. Khang villages are mostly isolated from markets as road access is limited in these remote areas. The state recognizes Khang people as an ethnic minority, which gives them priority in economic development plans. For instance, Khang receive an extra subsidy for growing maize and rice.

Data gathered during household interviews were analyzed using multiple correspondence analysis and results are presented in a two-dimensional scatter plot. Each original response category is plotted against the two principal components derived from the initial dataset (Fig. 4). The first and second dimensions (horizontal and vertical axes) explain 26 % and 16 % of the original variance, respectively.

Figure 4 suggests that the vertical axis is an indicator of market accessibility. A high score on this dimension is related to a greater than average presence of industrial plants (I1), presence of fruit orchards (O1), and purchase of firewood (W1). Households with market access seem to have a higher

Fig. 4 MCA-graph derived from household interviews in the six villages



income (IC3) than households scoring low on this dimension. Households that score above average on the market accessibility dimension typically live in the Kinh village of Dong Quan and to a lesser extent in the Kinh village of Bac Cuong. The Thai villages of Na Khoang and Gie have an average score, while the Khang villages of Co and Keo Sao score below the average for market accessibility.

The horizontal axis in Fig. 4 is related to land availability. Lack of land (LA1) was rarely mentioned by households as a problem in the Khang villages of Co and Keo Sao, while the majority of households in the Thai villages of Gie and Na Khoang stated that access to agricultural lands is problematic. Kinh villages take an intermediate position on the land availability dimension. The village of Dong Quan scores higher than average, while the village of Bac Cuong scores similar to the Thai villages.

Results from the household interviews (Fig. 4) also show that there is a difference between ethnicities in terms of economic development and land management. The Kinh people of Dong Quan, who live close to the national road, have the best access to markets and industrial plants. Farmers in Dong Quan have access to sufficient agricultural land for crop cultivation and many of them additionally cultivate fruit orchards for commercialization which allows for a higher income from farming and off-farm activities than that of households in the other villages. Another important feature in this village is, as reported by key informants, that land

policy rules are respected by all community members. The other Kinh village, Bac Cuong, is situated at a much less favorable location for market agriculture, and household income is significantly lower than that of the inhabitants of Dong Quan. The economic situation is comparable to that of the Thai villages, with households having a medium income. The Khang villages of Keo Sao and Co have low market accessibility, low income, no industrial plantations and no orchards, but there is still land available for further exploitation. This fits with the interviews of key informants, which made it clear that the two Khang villages did not implement forest land allocation. Moreover, the issuing of land certificates has not yet been completed. Both villages still have a significant area available for upland field expansion. Particularly in Keo Sao, which is very difficult to access, farming products are rarely sold on the market and most of the agricultural production is subsistence oriented. In Keo Sao and Co, only a few households have started orchards and coffee plantations.

For most key informants it was easier to remember the number of households at certain points of time rather than the total number of people living in the village. We therefore used the number of households to present the demographic evolution of the villages (Fig. 5). In all villages the number of households, with the exception of the Kinh village of Bac Cuong, has steadily increased over the last 60 years. The Thai villages of Na Khoang and Gie have experienced the greatest

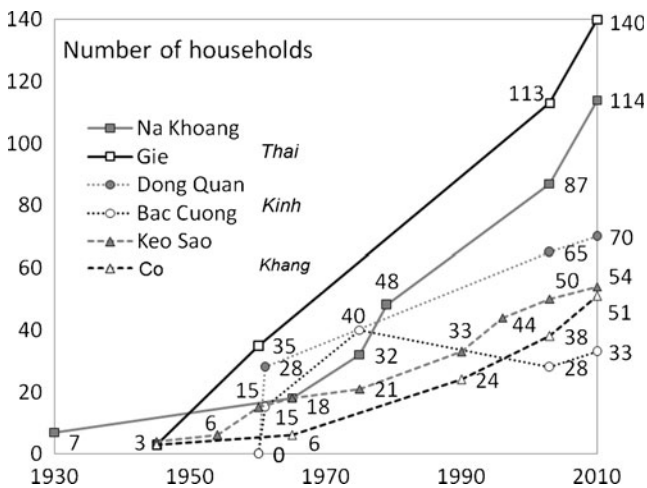


Fig. 5 Demographic evolution of the six selected villages (source: key-informant interview)

increase in households, followed by the Kinh village of Dong Quan and the Khang villages of Keo Sao and Co. In the Kinh village of Bac Cuong, the demographic evolution has not been as straightforward. The initial increase in the number of households up until the 1970s was followed by a decline from 40 to 28 households by 2000 and a recovery by 2010 to 33 households. Interviewees attributed this fluctuation to the lack of infrastructure, including water access, and a high rate of crimes around the village, which caused many of the original inhabitants of the village to move out.

Analysis of Land Transitions

The land transitions are described and analyzed based on the spatial analysis and information provided by the key informants. In Table 3 we present land cover and land use conversions in hectares per year, resulting from spatial analysis. We display the major land use changes for different time periods between 1973 and 2008 in the Suoi Muoi catchment. The most frequent change trajectories are those from shrubland to upland fields (SH-UP) and from upland fields to shrubland (UP-SH).

Figure 6 shows that the total area of forest cover, including closed canopy forest and open canopy forest, remained unchanged between 1973 and 2008, and that forests cover 15 % of the total area of the Suoi Muoi catchment. There was a reduction in forest cover during the mid-1990s, but forests recovered afterwards. The area of upland fields in the catchment has expanded over the last 40 years; however, the patterns of changes vary from one ethnic group to another. The Kinh reduced the area of the upland field from 2000 to 2008; the Khang, after decades of ups and downs in the area of upland fields, also decreased their upland fields from 2000 to 2008, while the Thai communities, after decades of only modest increases, substantially increased the area of upland fields.

Tables 4 and 5 show the results of the MLR model calibration using the observed shrubland to upland field and upland field to shrubland conversions for the time periods studied. Positive coefficients indicate that the probability of a conversion increases with increasing parameter values.

The calibrated models were used to map the UP-SH and SH-UP conversion probabilities at a pixel level of 20×20 m resolution (Fig. 7).

The calibration parameters show that the probability of a shrubland to upland field conversion is negatively correlated with slope gradient (in five out of five time periods) and elevation (3/5). New upland fields are preferentially installed on sandstone (4/5) or basalt (4/5), while schist (5/5), limestone (2/5) and alluvial soils (1/4) seem to be avoided. The upland field to shrubland conversions shows an opposite pattern. Land abandonment occurs more frequently on steep slopes (5/5) at higher altitudes (4/5) and on schist (3/5) and limestone (2/5) lithologies.

The location of the land units is also a significant factor: at remote locations at a relatively large distance from the national road, the probability of shrubland-upland field conversions is significantly higher (3/5) which suggests that shifting cultivation is practiced more frequently in isolated villages. The distance to minor roads is, on the other hand, negatively correlated with the occurrence of SH-UP conversions (4/5) and positively correlated with UP-SH conversions (2/5).

A remarkable result shown in Tables 4 and 5 is the role of the variable ‘ethnic group’. The results indicate that land units with the same biophysical and neighborhood characteristics have a higher probability of being taken into production if they belong to the territory of a Khang village (3/5) and a lower probability if they belong to the territory of a Kinh village (2/5). The villages of Thai and Mong-Khomu take an intermediate position. In the whole period between 1973 and 2008, the odds ratio for a shrubland-upland field conversion on Khang territory is 1.638 ($=1/0.6104$) higher than the odds ratio on land of the Mong-Khomu. The odds ratio for a shrubland-upland field conversion on land of the Kinh is 2.334 times ($=1/0.4284$) lower than the odds ratio on land of the Mong-Khomu. This means that land units with the same physical properties have a 1.638 times higher probability of being converted into upland fields when they belong to the territory of the Khang and a 2.334 times lower probability of being converted into shrubland when they belong to the territory of the Kinh.

The ROC validation was carried out for the models with the ethnic group and without this variable. Figure 8 shows that the model that includes the ethnic group variable gives a better prediction for land use transition than a model that ignores this variable.

Table 3 Land use change rates (in hayr⁻¹)

| | Major land use changes | 1973–1988 | 1988–1993 | 1993–1996 | 1996–2000 | 2000–2008 |
|----|--------------------------|-----------|-----------|-----------|-----------|-----------|
| 1 | Closed f. to open forest | 17 | 60 | 72 | 54 | 8 |
| 2 | Open forest to shrub | 165 | 141 | 112 | 42 | 73 |
| 3 | Shrub to upland field | 185 | 549 | 1029 | 698 | 557 |
| 4 | Upland field to shrub | 174 | 404 | 802 | 694 | 359 |
| 5 | Shrub to open forest | 43 | 51 | 59 | 245 | 204 |
| 6 | Open f. to closed forest | 18 | 33 | 65 | 67 | 72 |
| 7 | Grassland to open forest | 17 | 25 | 51 | 78 | 53 |
| 8 | Grassland to shrub | 5 | 13 | 67 | 23 | 64 |
| 9 | Paddy to upland field | 21 | 47 | 67 | 113 | 93 |
| 10 | Upland field to paddy | 21 | 29 | 210 | 114 | 44 |

Discussion

The combination of research methods and instruments from several disciplines, including statistical spatial analysis such as the multiple logistic regression (MLR) models and the multiple correspondence analysis (MCA) on household interview data, and key informant interviews allowed us to identify and validate a number of factors that drive land cover and land use changes in Northwest Vietnam.

The MLR models show that the variable ‘ethnicity’ is significantly correlated with the spatial patterns of UP-SH and SH-UP conversions. If biophysical and location parameters are similar, land units with shrubland have the highest probability of being converted into upland fields if they belong to the territory of a Khang village and the lowest

probability if they belong to the territory of the Kinh. A multiple correspondence analysis (MCA) made clear that the significance of the factor ‘ethnicity’ can be explained by the differences in economic behavior, agricultural practices, and heritage (practices in former settlements) of the ethnic groups that live in the catchment. The Kinh people, who were used to producing paddy rice for a market economy in the Vietnamese lowlands, have imported their way of life in the Vietnamese mountain area. By modernizing and specializing agriculture, their productivity is significantly higher, which has resulted in a decrease in shrubland-upland field conversions. Moreover, many households receive an additional income from non-farming activities. This explains why less deforestation and even afforestation could be observed despite a significant population increase in the villages. The more conservative Khang, and to a lesser extent, Thai, rely on a subsistence

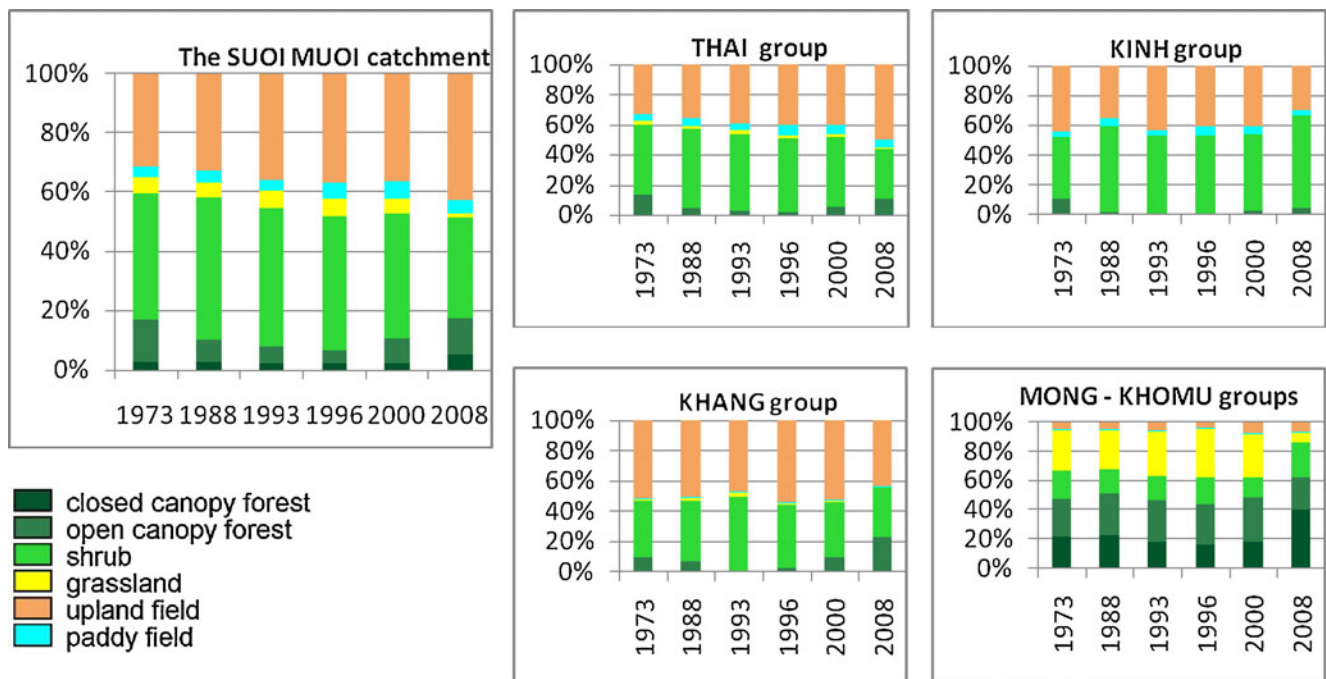
**Fig. 6** Proportion of land cover/land use categories in different years (%)

Table 4 Controlling factors of the shrub to upland field conversions

| Parameter | Cat. | Calibrated MLR-coefficients | | | | | |
|-----------------|--------------|-----------------------------|-----------|-----------|-----------|-----------|-----------|
| | | 1973–1988 | 1988–1993 | 1993–1996 | 1996–2000 | 2000–2008 | 1973–2008 |
| Intercept | | 1.1541 | −0.2117 | −0.3930 | 0.6789 | 4.1411 | 4.5285 |
| Dist to road 6 | | NS | NS | 0.0001 | 0.0002 | 0.0006 | 0.0006 |
| Dist to roads | | NS | −0.0010 | −0.0004 | −0.0004 | −0.0005 | −0.0005 |
| Dist to village | | NS | NS | −0.0006 | NS | NS | NS |
| Elevation | | −0.0021 | NS | NS | −0.0019 | −0.0074 | −0.0072 |
| Slope gradient | | −0.0218 | −0.0316 | −0.0240 | −0.0285 | −0.0062 | −0.0059 |
| Lithology | L1 schist | −0.3378 | −0.8142 | −0.9710 | −0.7873 | −1.3000 | −1.2064 |
| Lithology | L2 sandstone | 0.4176 | 0.3825 | 0.4052 | 0.3439 | NS | NS |
| Lithology | L3 limestone | −0.6986 | NS | NS | NS | 0.2610 | 0.1882 |
| Lithology | L4 basalt | 0.5680 | 0.4744 | 0.6506 | 0.8909 | 0.5619 | 0.5303 |
| Lithology | L5 alluvium | NS | NS | NS | −0.5905 | NS | −0.5146 |
| Lithology | L6 shale | RC | RC | RC | RC | RC | RC |
| Ethnicity | E1 Thai | NS | NS | NS | NS | 0.3382 | 0.2940 |
| Ethnicity | E2 Kinh | −0.4990 | NS | NS | NS | −0.4723 | −0.4284 |
| Ethnicity | E3 Khang | 0.5024 | NS | NS | 0.2897 | 0.7623 | 0.6104 |
| Ethnicity | E4 Mong/Khmu | RC | RC | RC | RC | RC | RC |

NS non-significant at a 5 % confidence level, RC reference category of categorical variable

economy and are reluctant to modernize and specialize their agricultural practices.

The MCA graph shows that the spatial pattern of land use changes in the Suoi Muoi catchment is the result of a complex interaction between physical factors, land policies, cultural

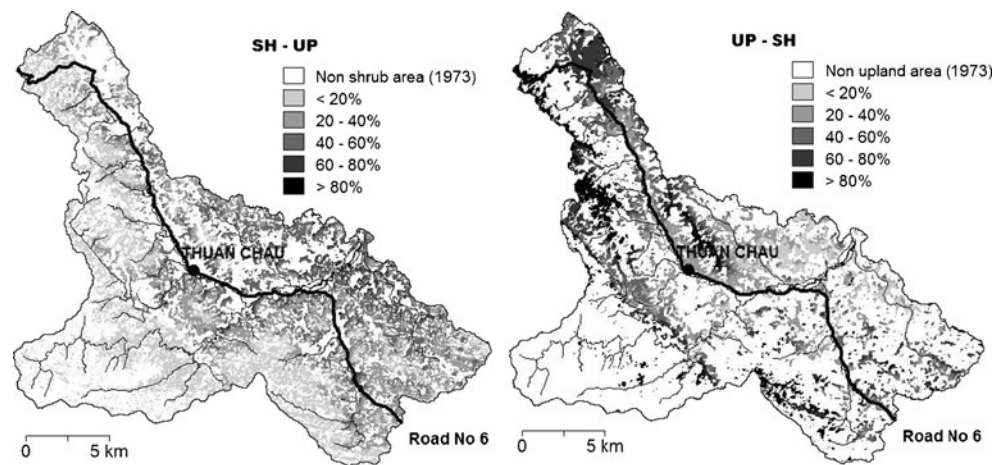
background and market accessibility. The availability of land is an important factor that has an impact on land management and economic development of the different ethnic groups. In the villages that suffer from lack of land, the fallow periods are shorter. Shifting cultivation is still practiced in Khang villages,

Table 5 Controlling factors of the upland field to shrub conversions

| Parameter | Cat. | Calibrated MLR-coefficients | | | | | |
|-----------------|--------------|-----------------------------|-----------|-----------|-----------|-----------|-----------|
| | | 1973–1988 | 1988–1993 | 1993–1996 | 1996–2000 | 2000–2008 | 1973–2008 |
| Intercept | | −1.4457 | −3.3817 | −2.6102 | −3.8604 | −5.8443 | −6.6013 |
| Dist to road 6 | | −0.0001 | NS | NS | −0.0001 | −0.0004 | −0.00057 |
| Dist to road | | NS | 0.0007 | 0.0006 | NS | NS | NS |
| Dist to village | | −0.0003 | 0.0041 | NS | NS | NS | NS |
| Elevation | | NS | 0.0010 | 0.0004 | 0.0026 | 0.0076 | 0.00882 |
| Slope gradient | | 0.0445 | 0.0423 | 0.0346 | 0.3540 | 0.0047 | 0.0125 |
| Lithology | L1 schist | NS | 1.0238 | 0.3857 | 0.7351 | NS | 0.9694 |
| Lithology | L2 sandstone | NS | NS | NS | NS | NS | −0.5021 |
| Lithology | L3 limestone | 0.4270 | NS | 0.314 | NS | NS | NS |
| Lithology | L4 basalt | −0.6566 | −0.9872 | −0.5998 | −0.6402 | NS | −0.3333 |
| Lithology | L5 alluvium | NS | NS | NS | NS | NS | NS |
| Lithology | L6 shale | RC | RC | RC | RC | RC | RC |
| Ethnicity | E1 Thai | NS | NS | NS | NS | −0.4822 | NS |
| Ethnicity | E2 Kinh | NS | NS | NS | NS | 0.9132 | 1.0775 |
| Ethnicity | E3 Khang | NS | NS | NS | −0.5739 | −0.8759 | −0.6392 |
| Ethnicity | E4 Mong/Khmu | RC | RC | RC | RC | RC | RC |

NS non-significant at a 5 % confidence level, RC reference category of categorical variable

Fig. 7 Map of transition probabilities from shrubland to upland field (SH-UP) and versus (UP-SH) during the whole observation period (1973–2008)



where there is enough land available. Around the villages of the Kinh and Thai, shifting cultivation is not possible because all the land has been allocated to individual households and the forest land is protected. Therefore, people cultivate their fields intensively.

Interviews showed that market accessibility has become a very important factor since the introduction of the open market system. Kinh villages became the richest villages because of good market accessibility, and land use around their villages has not changed significantly. The economic development of the Kinh villages has had an impact on land use in the neighboring villages: for example, a lot of fuel wood is bought from the Mong and Thai villages for the processing of tea. As a consequence, the Thai have lost a great deal of their forest in recent decades. The Khang villages do not seem to participate in this local economy because of their very poor accessibility. They are therefore trapped in a system of subsistence agriculture. As a consequence Khang villagers have preserved their forest well, even though they are among the poorest inhabitants of the Suoi Muoi catchment.

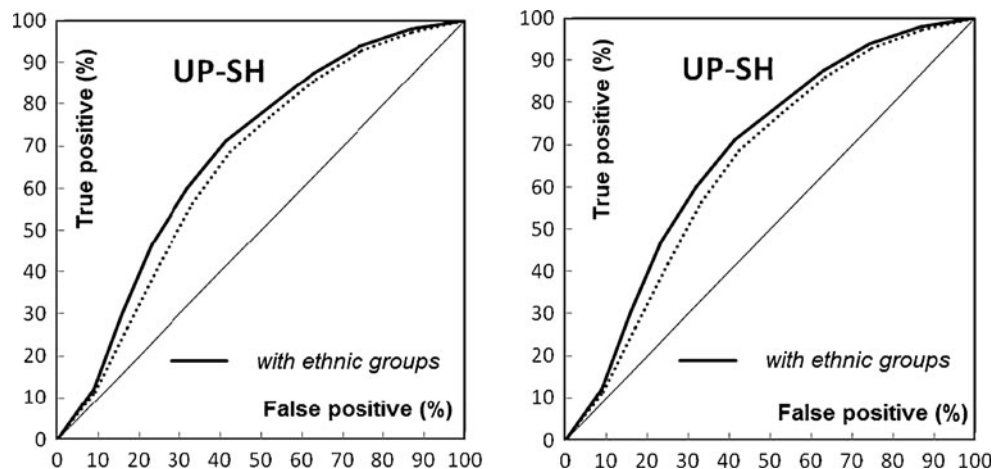
These findings have important consequences for the application of land use change models. Models based on biophysical and neighborhood parameters, such as soil

suitability, topography and distance indicators that do not take into account the differences in ways of life of the ethnic groups, will underestimate deforestation probabilities on the land of the Thai and the Khang and overestimate these probabilities on the land of the Kinh. For example, the probability of shrubland to upland field conversion is clearly underestimated around the Khang villages in the western part of the catchment and overestimated around the Kinh villages in the southeastern part of the catchment.

Conclusion

The objective of this research was to identify and understand the driving and controlling factors of land use change in the Suoi Muoi catchment. Land use change patterns were monitored using satellite imagery from 1973 to 2008. By means of statistical analysis, a number of independent variables correlated with the spatial pattern of land use and land use change were identified. Apart from a set of biophysical parameters, the ethnicity of the households was identified as a significant factor. This correlation was explained by means of a multiple correspondence analysis and further

Fig. 8 Difference between assessed shrubland-upland field conversion probabilities modeled without and with the ethnic factors



sustained by ancillary information from key informants, which showed that ethnicity could be considered a proxy for market integration.

In the Suoi Muoi catchment, market integration led to an increase in productivity and resulted in a decrease in the pressure on the land. The market transition has occurred in different stages in different ethnic communities, depending on the communities' ethnic characteristics as well as their location and local environment. For example, ethnic groups like the Khang, who live in more isolated locations, are more reluctant to adopt a market economy and maintain instead a traditional subsistence economy. The average agricultural productivity of this ethnic group is significantly lower, which results in an increasing pressure on the land and ongoing shrubland-upland field conversions. An important finding of this study is therefore that the promotion and further development of a market economy could be a very effective forest conservation strategy in northern Vietnam. Land managers and policy makers should therefore develop a policy that stimulates farmers to take part in a market-oriented economy while showing no disrespect for their traditional ways of life. The analysis presented above showed that infrastructure and accessibility are important constraints for the development of such a market economy. The example of the Kinh village of Bac Cuong showed that ethnic groups that have a long tradition of producing agricultural products for the market become disappointed if they are forced to carry out their activities at remote locations where potential profits are much lower. To conclude, cultural characteristics of ethnic groups, land availability, and different degrees of market integration depending on the availability of an open market are among the most important driving forces of land use conversion.

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