REPORT

Drivers of Forest Cover Dynamics in Smallholder Farming Systems: The Case of Northwestern Vietnam

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Abstract The national-scale forest recovery of Vietnam started in the early 1990s and is associated with a shift from net deforestation to net reforestation. Large disparities in forest cover dynamics are, however, observed at the local scale. This study aims to unravel the mechanisms driving forest cover change for a mountainous region located in northwest Vietnam. Statistical analyses were used to explore the association between forest cover change and household characteristics. In Sa Pa district, deforestation rates are decreasing, but forest degradation continues at similar rates. Deforestation is not necessarily associated with impoverished ethnic communities or high levels of subsistence farming, and the largest forest cover dynamics are found in villages with the best socio-economic conditions. Our empirical study does not provide strong evidence of a dominant role of agriculture in forest cover dynamics. It shows that empirical studies on local-scale forest dynamics remain important to unravel the complexity of human–environment interactions.

Keywords Forest transition · Vietnam · Ethnic minorities · Subsistence agriculture · Poverty

INTRODUCTION

In tropical regions, deforestation has been one of the most important processes of land cover changes in recent decades (Lambin et al. 2003). In Vietnam, forests were still abundant in the mid-twentieth century in the mountainous areas (Tugault-Lafleur 2007). This period was followed by a phase of rapid deforestation to reach a minimum forest cover in the late 1980s (Meyfroidt and Lambin 2008a). In the early 1990s, the nation-wide forest cover was estimated at 25–31 %. According to Meyfroidt and Lambin (2008b),

deforestation was mainly caused by agricultural expansion following population increase from both natural population growth and migrations. Since the mid-1990s, this trend has been reversed. The nation-wide forest cover has increased through natural regeneration and tree plantations to reach again 32–37 % in 1999–2001 and 34–42 % in 2005 (Meyfroidt and Lambin 2008a). Reforestation would be the result of a combination of economic and political responses to (i) lack of forest, (ii) economic growth, and (iii) market integration at the national level.

However, the rapid recovery of Vietnamese forests during the last two decades was not only the result of domestic efforts, but also of the displacement of wood extraction to neighboring countries (Meyfroidt and Lambin 2009). According to Meyfroidt and Lambin (2009), the equivalent of 39.1 % of the volume of wood regrowth would have been extracted from forests abroad to supply Vietnam's needs. Since logging was severely restricted in natural forests by forestry policies throughout the 1990s, the domestic supply of wood became insufficient to meet the domestic demand, especially to feed the growing processing industry in round wood. As neighboring countries also implemented bans on raw wood exports, the raw material was increasingly supplied by illegal imports from other countries, mainly from Cambodia in the early 1990s (Global Witness 1999) and Laos since the early 2000s (EIA-Telapak 2008), but later also from Malaysia, Myanmar, and Indonesia (EIA-Telapak 2008; Meyfroidt and Lambin 2009).

The recognition of a forest transition, i.e., a change from shrinking to expanding forests (Mather 1992), in Vietnam is associated with a shift from nation-wide decrease to increase in forest cover, and may mask large disparities at local and regional scales (Meyfroidt and Lambin 2008b). Moreover, the main drivers of nation-wide deforestation

and reforestation do not necessarily apply to local levels as drivers of forest cover change interact differently at various spatial scales. In the mountainous area of northern Vietnam, for example, Vu et al. (2012) suggests that ethnic factors play an important role in forest cover dynamics. Other studies highlight the importance of socio-economic and demographic settings on forest cover change (Shortle and Abler 1999; Tugault-Lafleur 2007). The nature of these relationships is not always well understood.

In rural areas, the poorest segments of the population often rely on forests for survival (Tugault-Lafleur 2007; Coulibaly-Lingani et al. 2009). A growing body of literature suggest that forest products often act as a ‘safety nets’ or a form of insurance for the rural poor, as a large proportion of people in developing countries obtain an important part of their subsistence and some cash income from a wide set of forest products and forest-related activities (Vanacker et al. 2003; Coulibaly-Lingani et al. 2009). The use of forest products allows livelihood diversification, but may lead to forest degradation and/or net deforestation when it is not (well) controlled. In the highlands of northern Vietnam, ethnic minorities living in or nearby forests for many generations are the most dependent on forests as infrastructure, education and information are often lacking (Frontier Vietnam 1997). Forests have played a key role in sustaining their livelihoods and reducing their vulnerability to crop failures or other hardships, supplying households with fodder, fuel, wood construction materials, herbal medicines, honey, and game (Tugault-Lafleur and Turner 2009). Ethnic groups are usually thought to be the greatest destroyers of forests with their customs, and their cultural and socio-economic characteristics differing sharply from those of the numerically dominant Kinh, what causes mutual misunderstanding and dislike (Fox et al. 2000; Delang 2002). According to Frontier Vietnam (1999), their low socio-economic conditions force marginal households to exploit forest resources. Yet, being highly dependent on the natural resources, they are also the most intensely and directly affected by negative impacts of forest degradation and deforestation. In contrast to traditional thinking, this could encourage them to take care of the natural resources they rely on.

An expansion of agricultural land through deforestation is often reported for tropical countries dominated by developing economies (Geist and Lambin 2001). The food demand of the rapidly growing population is associated with intensification and expansion of the agricultural land-use (e.g., Angelsen 1999; Barbier and Burgess 2001; Bahadur 2011). Due to shortage of arable land, natural (forested) ecosystems in tropical regions are increasingly converted into grasslands and/or croplands (Barbier and Burgess 2001). In their study on the pathways of agricultural expansion across the tropics, Gibbs et al. (2010) show

that between 1980 and 2000, more than 55 % of new agricultural land came at the expense of intact rainforests and another 28 % from disturbed rainforests. More specifically, Southeast Asia relied on intact forests for nearly 60 % of new agricultural land and on disturbed forests for more than 30 %. In the Vietnamese northern highlands, most ethnic minorities still live on subsistence agriculture generally combining permanent rice cultivation in the valley bottoms and shifting farming on the hillslopes (Fox et al. 2000; Tugault-Lafleur 2007). In past decades, a scarcity of land coupled with a population growth has led to an increasing pressure on forests. As the recently converted agricultural lands are often less appropriate for cultivation, they are prone to rapid decline of soil fertility and/or increased erosion (Frontier Vietnam 1999). The rate of deforestation tends to increase through agricultural expansion. Furthermore, some households grow cash crops such as cardamom under the forest canopy, what might lead to forest degradation (Tugault-Lafleur and Turner 2009). Cardamom cultivation has been identified as one of the main threats to the forest in northeastern Tanzania, the Indian Western Ghats, Guatemala, and in the Central Highlands of Sri Lanka (Reyes et al. 2006; IUCN 2010). In these cases, forest degradation and even long-term disappearance of forest fragments due to cardamom cultivation have been documented. Growing cardamom inside forests requires clearing the understory and middle layer, and thinning the tree canopy, what may hamper regeneration once the crop is abandoned.

It is generally thought that subsistence farmers that are most active in agriculture are the most responsible for rapid forest degradation and/or deforestation (Fox et al. 2000; Geist and Lambin 2001). Since the advent of modern farming practices, subsistence agriculture—often associated to shifting cultivation—has been blamed by many critics, from colonial powers to the FAO, and from academics to the popular press, which consider it as an inefficient use of the forest that ultimately leads to deforestation (Delang 2002). This negative view of subsistence farmers as destroyers of the forest is amplified in regions where they are ethnic minorities, as in the mountainous northwestern Vietnam, because their farming technique are seen as primitive and particularly destructive by the lowland Kinh (Fox et al. 2000; Delang 2002). However, the role of agriculture in deforestation that is reported for developing economies might be far more complex at the local scale. Subsistence farming encompasses a wide range of cultivation practices (Fox et al. 2000), some of which might have limited impacts on forest resources compared to other activities such as timber logging or infrastructure development (Geist and Lambin 2001).

In this study, we aim to unravel the mechanisms underlying forest cover change for a study site in the

Fig. 1 Location of the study area in the Northern Vietnamese Mountains with: **a** the communes of the Sa Pa District belonging to the study area in relation to the HLNP limits; and **b** the villages belonging to the study area. The names of the villages can be found in Fig. 4

mountainous area of northwestern Vietnam. The area is home to several ethnic minorities who settled there some generations ago and practice subsistence agriculture. While they have evolved side by side, these ethnic communities differ strongly by their agricultural and cultural practices, access to market, socio-economic conditions, and educational systems. By linking land cover (1993–2006) and household data, we specifically test (i) if the poorest ethnic communities are associated with the largest forest dynamics and (ii) if agricultural production plays a role in forest cover dynamics at the local scale.

STUDY AREA

The study area is characterized by a rough topography, and the western part is located on the northeast side of Hoang Lien Mountain range. Elevation ranges from 180 m a.s.l. in the easternmost part of the Ban Phung commune up to 3100 m at the southern border of the Sin Chai 2 village (San Sa Ho Commune) (Fig. 1a, b). The climate presents a high seasonality, being subtropical in summer and temperate in winter, and varies considerably within the study area (Van Lanh 2004). The Hoang Lien range acts as a

barrier to atmospheric circulation, and the climate in the southwestern part is particularly cloudy, cold and wet. Further north and at the easternmost part of the area, average temperatures are considerably higher.

The natural vegetation has strongly been influenced by human activities (Frontier Vietnam 1999; Van Lanh 2004). Fire, timber extraction, and land clearing for agriculture have created a mosaic of intact primary forest, degraded forests, shrubs, savannah, secondary forest in regeneration, forest plantations, and agricultural land. The Hoang Lien Mountain comprises probably the last remnants of old natural forests of the uplands of northern Vietnam. It became one of the first areas recognized as a ‘special use forest’ in Vietnam according to Decision 194/CT dated 9/8/1986 from the Chairman of the Ministerial Council, and it was converted into the Hoang Lien National Park (HLNP) in July 2002 following the Prime Minister’s Decision 90/2002/QĐ-TTg to protect biodiversity by preserving the subtropical and temperate forest ecosystems (Van Lanh 2004). The area in and around the HLNP has experienced rapid forest cover change in recent decades. The spatial heterogeneity of these dynamics, coupled with the ethnic, socio-economic and cultural heterogeneity of the area offers the opportunity to address the mechanisms underlying forest cover change.

HLNP consists of two functional zones (1) a central part of 29 845 ha covering the territory of six communes belonging to the districts of Sa Pa (Lao Cai Province) and Than Uyen (Lai Chau Province) and (2) a buffer zone covering an area of 38 874 ha in the territory of 13 communes and one city (Sa Pa Town) belonging to 4 districts in the provinces of Lao Chai and Lai Chau. This study was conducted on 13 communes of the Sa Pa District, of which 8 communes belong at least partly to the National Park (Fig. 1a). The 13 communes are composed of 58 villages constituting the units of the study (Fig. 1b), as the village community is the basic social system that collectively manages local resources (Castella et al. 2005). The use of natural resources is strongly regulated in the central part and buffer zone of HLNP. Although policies related to forest-use are expected to affect forest cover changes, Tugault-Lafleur (2007) has shown that the minority communities in the Sa Pa district are almost indifferent to the growing presence of the State and to markets forces, remaining relatively autonomous both in terms of their modes of economic production and socio-political organization. Most households are not fully aware of the limits of the central part of HLNP and the existing regulation for the buffer zone (Tugault-Lafleur 2007); and field observations suggest that some of them continue to use the forest resources even in strictly protected areas.

The mountainous area of North Vietnam is inhabited by ethnic minorities (Saint-Macary et al. 2010). According to a rural, agricultural, and fishery census realized in 2006 in Sa Pa District, the area counts 30 412 inhabitants or 5019 households belonging to five different ethnic groups: Hmong (66 % of households), Dao (19 %), Tay (7 %), Kinh (6 %) (the Vietnamese majority group), and Day (2 %). All these ethnic groups are settled in the area since at least four or five generations (Michaud and Turner 2000). Apart from the Kinh who are mainly involved in administration, tourism, and education, most of the ethnic minorities practice different variants of subsistence agriculture (Tugault-Lafleur 2007). Local economy is predominantly rural. The farming system is characterized by traditional cultivation of subsistence crops (mostly rice in valley bottoms and terraces, maize and cassava on slopes), vegetables and fruits in small home gardens, and animal husbandry. The villages are not self-subsistent in terms of food production and a number of households are experiencing hunger months (Tugault-Lafleur and Turner 2009). Many households harvest forest products for their domestic consumption or for sale. Some also cultivate cardamom as cash crops, what was encouraged by the authorities after the ban of opium in 1986. Most households have animals like buffaloes, chickens, pigs, goats, cattle, horses, and/or ducks. Some are raised for meat while others are used for agricultural work and transportation. All, however, can be

sold in case of crop failure or resources exhaustion. Live-stock represents thus a kind of insurance for households (Tugault-Lafleur 2007). Tourism is growing in the area and may increase future opportunities.

MATERIALS AND METHODS

Land Cover Dynamics (1993–2006)

Land cover change detection was performed using a time series of Landsat satellite images downloaded from the U.S. Geological Survey archives (<http://glovis.usgs.gov>): Landsat 5 TM 1/02/1993, Landsat 7 ETM + 27/12/1999, and Landsat 5 TM 4/11/2006 (path/row: 128/38). All images were corrected for atmospheric and topographic effects using the MODTRAN-4 code and the semi-empirical topographic correction implemented in ATCOR2/3 (Richter 2011). The SRTM digital elevation model at 90 m resolution was used for topographic correction (Jarvis et al. 2008). Satisfactory results were obtained for bands 3 (red), 4 (PIR), 5 (MIR), and 7 (MIR) only. Land cover maps were created by applying a supervised classification using the maximum likelihood method to the four corrected bands of each image. The classifications were based on training sites from a field campaign conducted in July 2010 and cross-checked with aerial photographs of 2002 (scale of 1:52 000). The air photos were published by the Center for Survey and Mapping Information of the Department of Survey and Mapping; and represent the latest and most reliable source of data that could have been obtained for classification purposes. Five land covers were defined: (1) primary forest, (2) secondary or degraded forest, (3) rice, (4) other crops, and (5) herbs, shrubs, or barren land. The last class contains bare soils, and includes rock outcrops, land set-aside or abandoned, and recently cleared forests. Given some problems of class overlapping, “class biases” were assigned to give more weight to certain classes. The accuracy of the classifications was assessed: (1) qualitatively by comparing land cover maps with field observations and topographic maps of 2009 published by the Vietnam Publishing House of Natural Resources, Environment and Cartography, and (2) quantitatively with the construction of an error matrix based on a pixel-based comparison of the classified land cover map with visual interpretation of satellite images and aerial photographs for a random sample of 180 points.

Land cover maps were imported in the ArcGIS 9.3 software to add the delineation of the town of Sa Pa (as it was in 2006) and major rivers extracted from the topographic maps. Then, differences were made for two pairs of successive land cover maps and the land cover changes were grouped into: (1) no change, (2) cultivation, (3)

Table 1 Overview of the variables included in the statistical analyses

	Unit	Abbreviation	Variables
Village	m	ALT	Average altitude
Location	m	DIST	Radial distance to the town of Sa Pa
Population	Inhabitants ha ⁻¹	POPDENS	Population density
		ETHNIC	Main ethnic group
Agricultural activities	Ha/ha	PLUMS	Proportion of surface area occupied by plums
	Ha/ha	AMOMUM	Proportion of surface area occupied by <i>Amomum</i>
	100 kg ha ⁻¹	RICE	Rice production relative to the village area
	100 kg ha ⁻¹	VEGETABLES	Vegetables production relative to the village area
	100 kg ha ⁻¹	PIG	Pig production relative to the village area
	100 kg ha ⁻¹	FOWL	Fowl production relative to the village area
Socio-economic conditions	%	ELEC	Percentage of households with electricity
		TELE	No. of television(s) per household
		RADIO	No. of radio(s) per household
		MOTO	No. of motorbikes(s) per household
Forest changes	Ha/ha	DEFO939	Proportion of surface area affected by deforestation (1993–1999)
	Ha/ha	DEFO9906	Proportion of surface area affected by deforestation (1999–2006)
	Ha/ha	DEGRA9399	Proportion of surface area affected by forest degradation (1993–1999)
	Ha/ha	DEGRA9906	Proportion of surface area affected by forest degradation (1999–2006)
	Ha/ha	REGE9399	Proportion of surface area affected by regeneration/plantation (1993–1999)
	Ha/ha	REGE9906	Proportion of surface area affected by regeneration/plantation (1999–2006)

All variables are calculated at the village level

abandonment or set-aside, (4) error (transition from any other class to primary forest), (5) deforestation, (6) forest degradation, and (7) forest regeneration or tree plantation. The last three categories related to forest change are of particular interest, and the proportions of these changes were later the object of the statistical analysis.

Household Data

Household data were derived from the Vietnam Rural, Agricultural, and Fishery Census conducted in 2006 under the leadership of the Department of Agriculture, Forestry and Fishery Statistics and the General Statistics Office, with the support of the World Bank. The household survey contains very detailed information on population, ethnic composition, agricultural production, and socio-economic conditions of the 85 villages of Sa Pa District. Random testing of the household data was not possible here, as there was no external dataset available for testing and evaluation. However, a randomized experiment by Glewwe and Hoang Dang (2008) in Vietnam shows that the overall rate of errors in the household surveys of 2002 and 2004 is low.

From the census and topographical data, a new dataset of 14 variables was created at the village level comprising 2 variables related to population dynamics, 6 variables to agricultural activities, 4 variables related to socio-economic status, and 2 variables related to the spatial location

of the villages (Table 1). A standard descriptive analysis was first applied, and the variables were submitted to Kolmogorov–Smirnov and Shapiro–Wilk tests to check normality of distributions. Given the under-representation of Tay, Day, and Kinh relative to Hmong and Dao ethnic groups, the statistical analyses were focused on Hmong and Dao populations that were compared based on the Welch *t* test (for variables with normal distribution) or Mann–Whitney–Wilcoxon test (for variables with unknown distribution) (Beguin 1979; Crawley 2005). A threshold of 5 % was chosen for all the statistical tests to reject or not the null hypothesis.

To confront forest cover change with population, ethnic, agricultural, and socio-economic data, six forest cover change variables were added to the dataset (Table 1). A Spearman Ranks correlation analysis was applied to the 19 quantitative variables (all but the main ethnic group). The variables were then scaled to the unit variance to be subjected to a principal component analysis (PCA). This data transformation technique allows the reduction of the set of variables to a smaller, conceptually more coherent set of principal components, which are linear combinations of the original variables (Dunteman 1989). A hierarchical clustering of the 58 villages was done based on the PCA's results, by using the Ward's method which aims to minimize the intra-class variance and maximize the inter-class variance (Beguin 1979). All statistical operations were

Fig. 2 Land cover transitions between **a** 1993 and 1999; and **b** 1999 and 2006

performed in R software. For more details on the methodological aspects of the statistical analyses, we refer to Crawley (2005).

RESULTS

Land Cover Classification

The overall accuracy of the land cover classification was, respectively, 71.1, 67.8, and 68.3 % (kappa values of 0.54, 0.55, and 0.54) for land cover maps of 1993, 1999, and 2006. Three main errors affect the classifications: (i) confusion between primary and secondary or degraded forest, (ii) confusion between rice and other crops in cultivated valleys, and (iii) confusion between the class ‘herbs, shrubs, and barren land’ and other classes due to the variety of land cover types and land units in this class. However, the overall land cover is consistent with topographic maps of 2009 and field observations. The land cover pattern is strongly determined by local topography: Valleys are generally cultivated, with rice grown on the flattest land

located close to the rivers and other crops on slopes further away from water sources. Steeper slopes and mountain peaks are predominantly barren lands or are covered by forests, herbs, or shrubs. Primary forest is mainly present in the Hoang Lien mountain range, where it covers large areas, and on remote steep slopes. Secondary or degraded forest appears in the form of smaller patches scattered throughout the area, particularly at the boundary between cropland and primary forest. Finally, herbs, shrubs, and barren land are found in different places, as much in valleys as on peaks or on steep slopes. Moreover, this last class is much more present on the maps of 1993 and 1999 than on the 2006 one.

Land Cover Changes

Differences made between pairs of successive land cover maps allow the identification of land cover trends that are consistent for the entire period 1993–2006 (Fig. 2). No change mostly concerns primary forests in Hoang Lien Mountains and very steep slopes; change in cropland is concentrated in valleys bottoms and on gentle slopes,

especially for 1999–2006; and forest cover change appears as smaller parcels spread over the study area. The land cover maps also indicate stronger land cover dynamics in the period 1993–1999 compared to 1999–2006. Deforestation was higher in 1993–1999 (Fig. 2a), in the whole area and the majority of villages, and was present throughout the area while it was concentrated on the outskirts of fields during 1999–2006 (Fig. 2b). Forest degradation was limited to small patches during the entire time period 1993–2006. Even if the overall proportion of regeneration/plantation is somewhat larger during the second period, there is not a significant tendency at the village level.

Villages' and Populations' Characteristics

In the study area, there are 34 Hmong villages, 20 Dao villages, 2 Tay villages, 1 Day village, and 1 Kinh entity (Sa Pa Town): Tay villages are clustered in the lower part of the Muong valley (main valley crossing the study area from the northwest to the southeast), Dao villages are located at various altitudes in the northern and eastern most parts of the area, Hmong villages are mainly found at higher altitude with some concentration along the southern part of the Muong valley. Kinh are clustered in Sa Pa town

and are present in minority in Hoang Lien village. The only village with a majority of Day people is located along the Muong valley.

Statistical tests revealed a significant difference between Hmong and Dao villages for all the 13 quantitative variables, with the exception of two variables related to fruit and vegetable production (Table 2). Hmong villages are located at a significantly higher altitude and smaller distance from Sa Pa Town; and are more densely populated than Dao villages. They are characterized by a greater proportion of area occupied by *Amomum* and higher production of rice, pig, and fowl per unit surface area. On the other hand, the percentage of households having electricity and the numbers of TV, radio(s), or motorbike(s) per household are significantly higher in Dao villages. Hmong and Dao ethnic groups are also significantly different with regard to forest dynamics (Table 2). Proportion of deforestation between 1999 and 2006, as well as proportions of degradation and regeneration/plantation on the two periods are significantly smaller in Hmong villages than in Dao ones.

Multivariate Statistical Analysis: Hierarchical Clustering of Principal Components

Six principle components were extracted from the dataset, accounting together for 76 % of the total variance. Table 3 displays the percentage of total variance explained by the different components, as well as correlation coefficients between these components and each variable. The correlations with the two first components, which together account for nearly 50 % of the total variance of the dataset, are illustrated in Fig. 3. The Ward's hierarchical clustering was made on basis of the six components selected in the PCA. Three clusters were chosen based on the dendrogram. The results both of the PCA and of the clustering show a pattern closely linked with the ethnicity (Fig. 4). In the first vector space, there is a clear separation along the first component between Hmong and Kinh on the one side, and Dao, Tay, and Day people on the other side. Only six villages are exceptions to this overall pattern: three Dao villages located in the third quadrant and three Hmong villages present in the fourth quadrant. The town of Sa Pa as well as the Hmong village of Sau Chua appear as outliers. The separation is reinforced by the clustering, with the formation of two distinct groups from both sides of the first component, except for Lech Mong. It is interesting to put Figs. 3 and 4 in parallel in order to link the position of villages—belonging to different ethnic communities and grouped within three clusters—in the individuals' space formed by the first two components with the correlations between these components and the 19 quantitative variables.

Table 2 Results of comparison tests between the Hmong and Dao populations for each variable

Variables	<i>t</i> / <i>W</i> statistic
ALT ^t	−3.22**
POPDENS ^t	−6.01***
AMOMUM	587.00***
PLUMS	442.00
RICE	536.00***
VEGETABLES	388.00
PIG	517.00**
FOWL	544.00***
ELEC	67.00***
TELE ^t	3.46**
RADIO	104.50***
MOTO	136.00***
DIST	84.00***
DEFO9399 ^t	−1.17
DEFO9906	187.00**
DEGRA9399 ^t	3.09**
DEGRA9906	141.00***
REGE9399	166.00**
REGE9906 ^t	3.91***

The Welch *t* test was used for variables with normal distribution (indicated with index *t*), while the Mann–Whitney–Wilcoxon test was used for all the other variables. For more details on the statistical techniques, we refer to Crawley (2005)

Significant at * 5 % level, ** 1 % level, *** 1 % level

Table 3 Percentage of total variance of the dataset explained by the principal components and saturation matrix

% of variance explained	Components					
	1 29.86	2 14.87	3 11.42	4 8.02	5 6.37	6 5.75
DEFO9399	−0.47***	0.11	−0.30*	0.32*	−0.49***	0.16
DEFO9906	0.78***	0.11	0.40**	0.21	−0.08	0.01
DEGRA9399	0.73***	−0.08	0.23	0.24	0.31*	0.17
DEGRA9906	0.74***	0.07	0.22	−0.05	0.18	0.37**
REGE9399	0.83***	0.19	0.25	−0.11	−0.18	−0.05
REGE9906	0.53***	0.34**	−0.19	−0.15	−0.61***	0.14
POPDENS	−0.46***	0.12	0.56***	−0.48***	0.05	−0.07
ALT	−0.77***	−0.23	−0.37**	0.35**	0.10	0.00
PLUMS	−0.27*	0.72***	−0.22	−0.02	0.09	0.49***
AMOMUM	−0.51***	0.04	0.61***	0.08	0.15	−0.08
RICE	−0.28*	0.71***	0.25	−0.28*	0.09	−0.09
VEGETABLES	−0.25	0.56***	0.02	−0.23	−0.31*	−0.42***
PIG	−0.44***	0.63***	−0.002	0.11	0.13	0.42***
FOWL	−0.42***	0.51***	0.37**	0.40**	0.08	−0.11
ELEC	0.44***	0.43***	−0.15	0.22	0.05	−0.19
TELE	0.26	0.53***	−0.45***	0.09	0.37**	−0.28*
RADIO	0.37**	0.21	0.26	0.70***	−0.15	−0.25
MOTO	0.30*	0.19	−0.57***	−0.17	0.31*	−0.27*
DIST	0.80***	0.13	−0.21	−0.17	0.04	0.06

Significant at * 5 % level, ** 1 % level, *** 1 % level

Fig. 3 Orientation of quantitative variables in the vector space formed by the first two principal components (DIM1 and DIM2). The first component (DIM1) accounts for 29.86 % of the total variance of the dataset, and the second component (DIM2) for 14.87 %. The unit circle represents the upper limit of the variables' coordinates. Its representation on the graph shows how each variable is represented in the first principal plan. The closer a variable to the circle is, the better its representation is in the plan formed by these two first components

The first cluster includes only Sa Pa Town and Sau Chua (Fig. 4). Since many Kinh of the Sa Pa Town work in the sectors of administration, education, or tourism, it may be surprising that the town is associated with high proportion

of its area occupied by plum trees and high relative productions of rice, vegetable, pig, and fowl. However, this entity extends well outside the city itself and includes farmers who have better access than the ethnic minorities

Fig. 4 Distribution (factor scores) of villages in the individuals' space formed by the first two principal components (DIM1 and DIM2). The *symbols* are colored according to the main ethnic group in the village. The *symbols* refer to the three groups that were recognized by the statistical procedure

1: Sa Xeng	13: Giang Tra	25: Lao Chai San 2	37: Seo Trung Ho	49: Phung Dao
2: Can Ngai	14: Ma Tra	26: Ly Lao Chai	38: Hau Tru Ngai	50: Phung Mong
3: Suoi Thau	15: Sau Chua	27: Lao Hang Chai	39: Hang Da	51: Ban Sai
4: Lu Khau	16: Sa Xeng 2	28: Ta Van Day	40: Thao Hong Den	52: Nam Si
5: Ta Chai	17: Sa Pa	29: Ta Van Mong	41: Ban Pho	53: Ban Pho 2
6: Po Si Ngai	18: Suoi Ho	30: Ta Chai Dao	42: Hao Su Pan 2	54: Ban Tong
7: Mong Sen 2	19: Sa Pa Town	31: Den Thang	43: Hao Su Pan 1	55: Muong Bo
8: Mong Sen 1	20: Sin Chai 2	32: Ta Chai Mong	44: Van Den Su 1	56: Sin Chai B
9: Si Chai	21: Cat Cat	33: Hoang Lien	45: Van Den Su 2	57: Sin Chai A
10: Chu Lin 2	22: Y Linh Ho	34: Ban Den	46: Lech Mong	58: Nam Cum
11: Vu Lung Sung	23: Lo Lao Chai	35: Nam Tong	47: Ban Kim	
12: Chu Lin 1	24: Lao Chain San 1	36: Ta Trung Ho	48: Lech Dao	

to information, to new and more profitable varieties of crops and to the market of Sa Pa, where they can buy various agricultural inputs and/or sell their produce. They may thus obtain better yields and produce a lot on a small agricultural area.

As Sa Pa Town, the Hmong village of Sau Chua is characterized by high relative productions of pig and fowl and high proportion of its area occupied by plum trees, but also by high proportion of *Amomum* and relatively high average altitude and population density. This village has a quite small area with a relatively high number of households and a large proportion of forest, barren land, herbs, and shrubs (more than 50 %). The abundance of herbs, shrubs, and barren land may be due to clearing of forest by Hmong households for growing cardamom in order to compensate for the small area of arable land. Moreover, the relatively small area of cultivation compared to the population size may explain the high relative productions of pig and fowl, which do not need specific land, as well as the abundance of plum trees that households may plant in their garden.

The second cluster consists of 34 villages; 31 Hmong and three Dao (Fig. 4). Hmong villages appearing in the first quadrant and belonging to this cluster are associated to a high population density and a large proportion of their area dedicated to the cultivation of *Amomum* like Sau Chua, but also by high deforestation rates between 1993 and 1999. Some of them present a relatively large proportion of area occupied by plum trees and high relative productions of rice, vegetable, pig, and fowl. Villages that are located in the third quadrant are characterized by a high average altitude, in addition to high deforestation rates, high population density and a relative abundance of *Amomum*.

The third cluster contains the 22 other villages of the study area; 17 Dao villages, 2 Hmong villages, the Day village, and the two Tay villages (Fig. 4). These villages are associated with a large proportion of deforestation on the second period and large proportions of forest degradation and of regeneration/plantation on the two transition intervals. They are also relatively distant from Sa Pa Town

and relatively well equipped in terms of electricity, televisions, radios, and motorbikes. Furthermore, villages appearing in the fourth quadrant are characterized by a particularly large proportion of regeneration/plantation during 1999–2006.

DISCUSSION

The Vietnamese Forest Transition: What Is Observed at Local Scale?

At national scale, a shift from a net deforestation to a net reforestation occurred at the beginning of the 1990s (Meyfroidt and Lambin 2008a). At the local scale, we do not observe the forest transition, as the rate of regeneration and/or plantation is smaller than the rate of deforestation and forest degradation during the study period (Fig. 2). However, the net loss in forest cover (i.e., taking into account forest cover decrease and increase) is smaller in 1999–2006 compared to 1993–1999. There seems to be a decrease in the clearing of large forested areas like those in Hoang Lien Mountains after 1999, as deforestation is more concentrated along cultivated lands. The rate of forest degradation is approximately the same on the two intervals probably because of a continuation of the collection of forest products for consumption or sale, and/or slash and burn on small parcels despite its ban by the State in 1992 (Michaud and Turner 2000). Large campaigns of reforestation were launched in the early 1990s, but it seems that they have not been sufficient to initiate the shift to a net reforestation. The pattern of forest cover change differs significantly between ethnic groups: statistical tests show that Hmong villages are generally associated with lower rates of forest cover change than Dao villages (Table 2). Our data therefore suggest that the Dao villages use forest resources more intensively.

Is Rural Poverty Driving Deforestation?

The percentage of households having electricity is a good indicator of the average socio-economic conditions of villages. Access to electricity is not only dependent on the socio-economic position of individual households, but highly depends on the organization of the village. Households that are settled in an area with a power distribution network set up by the community have a clear advantage compared to others located in remote areas without established electricity network. Access to electricity will therefore be higher in villages where the community has paid for the set-up of a distribution network or where households have invested in generators. Our analyses show that lowest percentages of access to electricity are found in Hmong

villages while all households of Sa Pa Town have electricity, as well as more than 70 % of households in Tay or Day villages. Kinh, Dao, Tay, and Day villages also seem to be better equipped in terms of televisions, radios, and motorbikes than Hmong villages. Not surprising, the numbers of radio(s) and television(s) per household are strongly correlated with the availability of electricity. Dao villages located at the northernmost and easternmost parts of the area would yet not be connected to the national grid, but most households have generators.

The results of our statistical analyses confirm earlier statements from the Frontier Vietnam report (1999) that the Hmong are the most socio-economically disadvantaged of all the ethnic minorities living in the study area. Statistical analyses of the socio-economic data show that they have poorer socio-economic status than the other ethnic groups in the study area. Hmong villages are much less equipped in terms of electricity, TV, radio(s), and motorbike(s) than Dao villages, even if they are located at a significantly shorter distance from Sa Pa Town where living conditions of the Kinh are much higher (Table 2). These results are consistent with the study conducted by UNFPA on national data from the 2009 Vietnam Population and Housing Census (UNFPA 2011). Based on information on housing, living conditions, and household amenities, the UNFPA used principle component analysis to obtain an indirect indicator of the household socio-economic status. Their results show that the Kinh ethnic group has the best socio-economic conditions while the Hmong experience the lowest socio-economic conditions among the 6 ethnic groups that were included in their study. According to Frontier Vietnam (1999), the Hmong communities of the Lao Cai Province are characterized by the lowest literacy rates and shortest life expectancy compared to the other ethnic groups, as it is also the case at the national level (UNFPA 2011). Using wood to build the bulk of their houses, for heating, cooking or drying the cardamom, which they furthermore grow in forests, the Hmong are also reported to consume a lot of wood compared to other ethnic communities (Frontier Vietnam 1999). For example, while the houses of all ethnic communities have timber frames, a much larger proportion of Hmong houses has wooden roofs and wall materials compared to Dao, Day, or Tay houses. In addition, during the winter months, many Hmong households harvest various forest products for food or to sell on the Sa Pa market. And some of them go into the forest to make charcoal.

However, our results contradict the hypothesis that the poorest rural communities are associated with the highest rates of deforestation and forest degradation. The results suggest that Hmong villages that have been forest-dependent for many years have learned to manage them in a more or less sustainable way. The small-scale activities

that they have in or around the forests seem not to have a major impact on deforestation rates. Furthermore, the Hmong usually lack of means to deforest large areas, as they lack of arable land and of contacts with the authorities to participate in large reforestation or plantation campaigns.

Is There a Trade-Off Between Agricultural Activities and Deforestation?

The case of Sa Pa Town aside, the results demonstrate that villages associated with the largest dynamics of forest cover on the time intervals of 1993–1999 and 1999–2006 are those with the best socio-economic conditions in 2006 (Table 3, Fig. 3). At the opposite, villages with the smallest forest cover dynamics are those presenting the highest proportions of area dedicated to farming and the largest agricultural production relative to their area in 2006. Furthermore, these two associations seem to be closely related to the ethnicity of the villages in the study area (Fig. 4).

Agricultural activities are important in the densely populated rural areas, as shown by significantly positive correlations between five of the six variables related to agricultural activity and population density. Sa Pa Town is an exception as it is not densely populated but has a great proportion of its area occupied by plum trees, as well as great productions of rice, vegetables, pig and fowl relative to its area. The greater proportion of area occupied by *Amomum* and the higher relative productions of rice, pig, and fowl characterizing the Hmong villages must be linked to their higher population density, at least compared to Dao villages, rather than to a potential higher agricultural productivity (Table 2). Hmong households are still using traditional practices while other ethnic communities are generally more able to buy fertilizers on the market of Sa Pa Town and cultivate new varieties of crops that are more productive (Frontier Vietnam 1999). Concerning plants of the *Amomum* genus, it is mainly cardamom that households cultivate under the forest canopy after having roughly cleared the ground vegetation and cut around 40 % of the trees (Frontier Vietnam 1999; Tugault-Lafleur 2007). Cardamom is also more frequently grown by Hmong people than by other communities because they are particularly susceptible to the exhaustion of their harvest and need money to buy food during the months of hunger. In such situation, cash crop cultivation is recommendable because it can generate the same income on a smaller land area compared to growing food crops (Hamilton and Bensted-Smith 1989).

Furthermore, population density seems more related to the size of the village than to the number of households. The highest densities are found in Hmong villages because this ethnic group inhabits the smallest villages. This may

be due to its settlement in the highest and more remote regions, where the village extension is limited both by topography and vegetation. The migration history may actually explain the spatial repartition of the different ethnic groups in the area. Dao and Hmong communities have immigrated to northern Vietnam relatively late (in the eighteenth and nineteenth century, respectively), and fertile valleys were already occupied by other ethnic groups (Tugault-Lafleur 2007). They had to settle at higher altitude, often on forested slopes. This is particularly the case of Hmong communities inhabiting the study area.

Figure 4 shows that the Hmong are more active in agriculture than the Dao. The densely populated Hmong village practice agriculture at higher altitude, and close to forested areas. According to the above-stated hypothesis on the trade-offs between agriculture and deforestation, one could expect higher deforestation and forest degradation in Hmong villages compared to Dao ones. Yet, the results show the opposite trend. The Hmong have practiced both rice farming and shifting and/or rotational agriculture together as an integrated system of subsistence for generations. This phenomenon has also been described for rural Tay village in Ban Tat by Fox et al. (2000). As paddy production can be intensified as population grows, this combination of paddy fields with swiddens may relieve some pressure on the forested land. The Hmong villages of Sa Pa district have been in the same location for several hundred years (Michaud and Turner 2000), and their extensive array of terraced wet rice has not undergone great expansion in recent decades. The cultivation of cardamom under the forest canopy seems not to represent a major threat to the forest as it is not practiced extensively. Unlike the well-documented case of the East Usambara Mountains, Northeastern Tanzania, where plots are cleared completely and converted to annual crops once the cardamom cultivation becomes unprofitable (Reyes et al. 2006), the forest is able to quickly recover its natural state in the study area as the tree canopy is left relatively intact by the local households (Frontier Vietnam 1999). Furthermore, there are nowadays new ways for Hmong households to diversify their economic activities and get additional income. Beside the cultivation of cash crops, the current development of tourism in the area of Sa Pa Town offers a number of new opportunities to minorities' households (Michaud and Turner 2000). Many Hmong women go regularly to Sa Pa town to sell handicrafts to tourists. Some young people from ethnic minorities are hired by hotels or agencies of the town as trekking guide. Households who are able to offer minimal comfort in villages surrounding Sa Pa Town also provide bed and board for trekkers. All these activities allow a loosening of the pressure on forest resources.

CONCLUSION

Our data on forest cover change (1993–2006) show that deforestation rates are decreasing, but that forest degradation continues at similar rates. In the Sa Pa district, there was no transition from a net deforestation to net reforestation, as it was observed at the national scale. Spatial analyses of forest cover dynamics in relation to demographic and socio-economic variables allowed us to identify the mechanisms behind the observed forest cover changes. Our data show that high rates of deforestation are not necessarily associated with impoverished ethnic communities or high levels of subsistence farming. On the contrary, the largest forest cover dynamics are found in villages with the best socio-economic conditions. Interestingly, the statistical analyses show that Hmong villages are characterized by significantly lower deforestation rates, despite their high population densities, poor socio-economic conditions, and high implications in agricultural production. A multiplicity of explanatory factors can influence the relationships between humans and their environment. Our results show that the outcomes of national or regional studies have to be confronted with studies on local-scale forest dynamics to better understand the complexity of the human–nature relationship.

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