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Mapping mountain diversity: Ethnic minorities and land use land cover change in Vietnam's borderlands

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ABSTRACT

In the complex agro-ecological conditions of Vietnam's northern borderlands, attempts by ethnic minority farmers to create sustainable livelihoods, along with the impacts of state development policies, have direct consequences for land use and land cover (LULC) change. In this paper we analyse the degree to which LULC has changed and diversified from 1999 to 2009 in Lào Cai Province and the underlying relationships with ethnic minority livelihood diversification strategies. We examine the correlation between LULC diversity and various socioeconomic and biophysical proxies using a spatial autoregressive model. Our findings indicate two major changes in LULC: an increase in closed canopy forest and substantial urban growth. LULC diversity increased between 1999 and 2009, suggesting a transition between land uses and/or a diversification of livelihood strategies. Socioeconomic proxies are significant predictors of LULC diversity in both years, while biophysical proxies are only effective predictors in 2009. In-depth interviews regarding state-led policies and ethnic minority livelihoods reveal some of the underlying mechanisms of such LULC transitions and associations.

Introduction

At the global scale, land use changes such as agricultural expansion, deforestation and urbanization are taking place at record speed, with important consequences for human well-being. These changes often influence weather patterns and contribute to land degradation, while also impacting food security, disease prevalence and water quality (Foley et al., 2005). Since the early 1990s, land use land cover (LULC) changes have drawn significant attention from researchers and funding institutions, including the Global Land Project and the International Geosphere–Biosphere Programme. The result is an important body of research on LULC conducted in various geographic regions and socio-political contexts (e.g. Chowdhury and Turner, 2006; Gray et al., 2008; Wasige et al., 2013).

Since land use has a direct relationship with rural household livelihoods, the interactions between land use change and local livelihoods merit detailed attention (Makalle et al., 2008; Xu et al., 2006). The agrarian transition underway in Southeast Asia, fuelled in part by globalization and multi-national agricultural industries, has resulted in numerous diversification strategies as rural households attempt to maintain or develop sustainable livelihoods (Caouette and Turner, 2009; Rigg, 2005). Land use diversity is an increasingly common strategy for rural households dealing with market integration, environmental change and other external stresses (Ellis, 2000; Rigg and Vandergeest, 2012). To examine such interrelations, calls have been made for closer collaborations among researchers linking both quantitative and qualitative data (Crews and Walsh, 2009; Hett et al., 2012; Rindfuss et al., 2004).

More specifically, there is an urgent need to refine our understandings of the causal mechanisms of LULC change, be they ecological, socio-economic or political. Not only do we need to better comprehend how specific land policies and market-led changes drive change, but also how household agricultural knowledge and livelihood decision-making could trigger such changes (Lambin and Meyfroidt, 2010). The importance of understanding these drivers with regards to indigenous and ethnic minority livelihoods has been acknowledged in Africa (Makalle et al., 2008) and Latin America (Chowdhury and Turner, 2006; Gray et al., 2008), yet in Southeast Asia such studies of these complex mechanisms are still relatively rare (Overmars and Verburg, 2006; Tan-Kim-Yong et al., 2004).

In Vietnam, studies of upland LULC change have been conducted in the central highlands, northern midlands and northern uplands (e.g. Castella et al., 2005; Clement et al., 2009; Sikor, 2001; Vu et al., 2013). However, no study has addressed these aspects in the

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mountainous Sino-Vietnamese borderlands, nor has any study examined the relationships between LULC diversity and livelihood diversification. In these borderlands, state directives such as afforestation policies, agricultural extension programmes, market integration and the trans-national Greater Mekong Subregion initiative, have important influences on livelihoods among ethnically diverse populations (McElwee, 2004; Turner, 2013).

Our aim is to explore LULC change and LULC diversity from 1999 to 2009 in the border districts of Lào Cai Province. We put forward two research questions. First, to what extent have LULC and LULC diversity changed from 1999 to 2009? Second, what are the associations between LULC diversity and socio-ecological factors and how do these associations differ over time? We consider the geophysical factors of elevation and slope, along with distances to roads, markets and the Sino-Vietnamese border as proxies of socioeconomic factors. We begin with a brief discussion of key concepts underlying our study, followed by an overview of the unique political and ethnic situation in uplands. The following two sections provide an outline of our methods and results. We conclude with a discussion of the associations among LULC change, state policies and livelihood strategies.

Conceptualizing LULC, diversity and livelihoods

Our conceptual framework builds on three bodies of literature: (i) LULC, (ii) the relationship between LULC diversity and livelihood diversification and (iii) the underlying proximate and distal causes of LULC change and its diversity.

(i) While land use and land cover are different concepts, studies of landscape patterns increasingly bring these together (e.g. Anderson, 1976; Cassidy et al., 2010; Fox and Vogler, 2005; Leisz et al., 2005; Meyfroidt, 2013; Vu et al., 2013). Land use is any human activity that alters the earth's surface. It may include activities such as swidden cultivation, permanent agriculture, non-timber forest product cultivation, pastureland or plantations. Land cover is any vegetation or feature present on the earth's surface such as shrubs, open canopy trees, closed canopy trees, water or bare soil (Ellis, 2013). In this paper we combine both land use and land cover classes in order to develop a comprehensive evaluation of diversity in the northern uplands of Vietnam.

(ii) In rural locations, important associations exist between LULC change and livelihood decisions, and more specifically between LULC diversity and livelihood diversification (Caviglia-Harris and Sills, 2005; Koczberski and Curry, 2005; McCusker and Carr, 2006; Soini, 2005). Livelihood diversification is "the process by which rural households construct an increasingly diverse portfolio of activities and assets in order to survive and improve their standard of living" (Ellis, 2000, p. 15). The underlying causes of livelihood diversification are highly variable, such as taking advantage of opportunities, namely progressive diversification, or diversification to overcome barriers and withstand shocks and stresses, known as distress diversification (Bouahom et al., 2004; Ellis, 2000; Niehof, 2004; Turner, 2007). A household diversification approach may include engaging in new income opportunities, experimenting with different crops or combining agricultural, livestock and off-farm activities (Chambers and Conway, 1992; Rigg, 2006a; Turner, 2012).

Not surprisingly, livelihood diversification often results in direct or indirect LULC change through adjustments to on-farm or off-farm activities (McCusker and Carr, 2006; Niehof, 2004). On-farm activities directly linked to LULC change may include agricultural intensification, deforestation or crop diversification. Improved access to opportunities for off-farm activities may lead to an increase in labour allocation to non-farm activities and a decrease of on-farm labour (Koczberski and Curry, 2005; Magliocca et al., 2013). This can lead to rural–urban migration and deagrarianization. In this study, we use LULC diversity as a proxy for understanding how livelihood diversification strategies have changed over time.

(iii) Political, social and environmental processes introduce opportunities or constraints for livelihood diversification and LULC change (McCusker and Carr, 2006). One example of this is land reform policies that can constrain existing LULC or create opportunities for change and growth (e.g. crop restrictions, reforestation programmes, land allocation). Similarly, an expansion of local, regional and international markets can create a range of opportunities (or pressures) for livelihood diversification. Areas with highly accessible markets may offer more opportunities for off-farm diversification and on-farm specialization while remote regions tend to be subsistence-based with small, diversified production systems (Barrett et al., 2001). One exception may be national border regions, which can provide additional opportunities for remote market-based activities and cross-border trade (Turner, 2013). Roads can facilitate market access while increasing the exchange of goods, information and people. They can however, also be used as a state tool or 'distance demolishing technology' to extend state propaganda and increase the 'gaze' of the state over remote ethnic minority populations (Scott, 2009). Environmental variables may also present constraints for livelihood and land use decisions, as the expansion of various land uses is limited by geophysical conditions such as slope and elevation.

Ethnic minority livelihoods and land use challenges in northern upland Vietnam

Our case study focuses on the four most northern districts and one city municipality of Lào Cai Province, namely the districts of Bát Xát, Bảo Thắng, Mường Khương and Si Ma Cai and the city municipality (*thành phố*) of Lào Cai (Fig. 1), all bordering Yunnan Province, China. In 2009, the population of these five administrative units was 351,800 (GSO, 2010). In this mountainous terrain, land use along this border is strongly influenced by topography. Elevation ranges from 27 m asl along the Sông Hồng (Red River) to 2990 m in the Hoàng Liên range, while slope varies between 0° to upwards of 50°. Precipitation varies with respect to windward and leeward mountain dynamics, while humidity is often high resulting in frequent fog and cloud cover (Roche and Michaud, 2000). There are two main rivers crossing this region, the Sông Hồng (Red River) and Sông Chảy (Chay River).

The Socialist Republic of Vietnam officially recognizes 54 ethnic groups including the lowland Vietnamese majority (Kinh). This leaves 53 "minority nationalities" (*các dân tôc thiêu sô*) totaling 14.8 percent of the country's population (GSO, 2010). Ethnic minorities comprise 66 percent of Lào Cai Province's population of 614,000, where many of these groups, such as the Hmong (H'Mông, Mông) and Yao (Dao), belong to geographically dispersed, politically fragmented and lineage based populations (GSO, 2010; Michaud, 2006).

Land access and quality play central roles for rural livelihoods in these uplands (Corlin, 2004). While collectivization officially began in the 1950s, it was not consistently nor efficiently implemented in this extreme periphery of the state. Nonetheless, from the 1970s numerous state forestry enterprises were established to extract timber across the region (Poffenberger and Nguyen, 1998). In 1988, Resolution 10 began the dismantlement of collectives and in 1993 land use rights were transferred to the household. A forest transition is now underway due to bans on opium and logging (1992/1993) and reforestation strategies such as the "Greening the Barren Hills" (1992) and the "Five Million Hectare Reforestation"

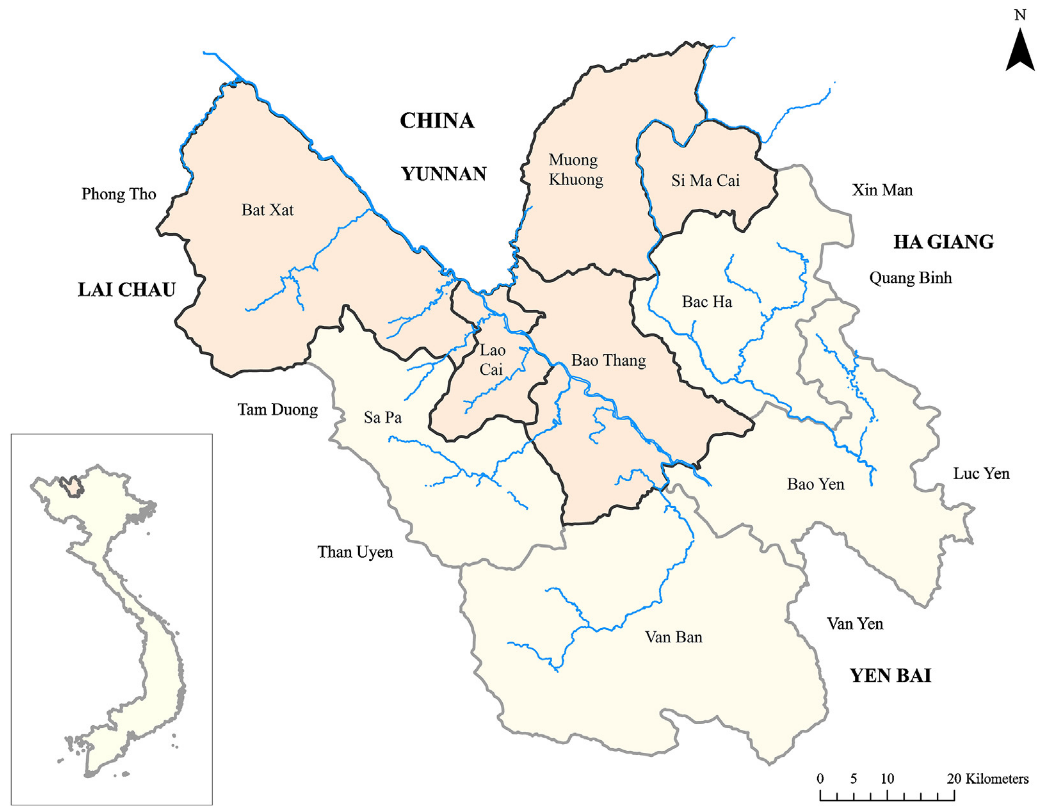

Fig. 1. Study area and surrounding districts in Lào Cai Province, Vietnam.

(1998) Programmes. However, the effects of these reforestation programmes have been mixed, with case studies in the uplands suggesting that forest density and quality are now decreasing (Clement et al., 2009; McElwee, 2009; Meyfroidt and Lambin, 2008a; Sikor, 2001).

Upland ethnic minorities often maintain diverse livelihoods through a composite agricultural system. A mixture of maize and rice fields are incorporated with home gardens, small (officially banned) swidden plots, the collection of firewood, honey and herbs as well as small-scale commercial exchanges of cardamom, livestock, textiles or alcohol (Leisz et al., 2005; Turner, 2012). The past 20 years has witnessed a move from swidden farming to fixed crops, favoured by the granting of long-term land use rights, state discouragement of swiddening and the introduction of hybrid rice and maize seeds since the late 1990s (Bonnin and Turner, 2012). In a few small areas, the expansion of the market economy has led to the introduction of cash crops such as tobacco, tea, pineapples and bananas (Castella et al., 2005; Leisz et al., 2005).

Data and methods

Data and image pre-processing

Land cover maps were derived from Landsat thematic mapper (TM5) and enhanced thematic mapper (ETM+) images obtained from the United States Geological Survey (USGS). Both images were taken during the winter season on 27 December 1999 (ETM+) and 12 November 2009 (TM5) when sparse crops of vegetables were growing. The images were pre-processed to remove distortions caused by sensor errors, atmospheric interference and surface irregularities. An atmospheric correction was conducted using the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH).[2] Four topographic corrections were undertaken to remove reflectance distortions, as recommended for vegetation mapping in mountainous areas: Cosine Correction, Improved Cosine Correction, Sun-Canopy-Sensor and Minnaert (Riano et al., 2003). For each method, we compared spectral changes by evaluating individual band mean and standard deviations before and after the correction.[3] Improved Cosine Correction proved to be the best method and was chosen for this study. Finally, cloud and cloud shadow masking was conducted on the 2009 image using methods outlined by Martinuzzi et al. (2007). There was no cloud cover on the 1999 image.

Three additional quantitative datasets were used to complete the analysis. A 90 m-resolution digital elevation model (DEM) for our study area (path 128, row 44) was obtained from the Global Land Survey Digital Elevation Model collection (2000). Road and market network datasets were obtained for 2009 at a scale of 1:50,000 from Vietnam's Ministry of Natural Resources and Environment (2010). The 1999 road dataset was obtained from the GIS Atlas of Vietnam (2000). Between 1999 and 2009 there were no new markets built, only upgrades of pre-existing markets (Bonnin and Turner, 2014). Field observations and interviews were used to verify land use changes, marketplace networks, market integration approaches and livelihood diversification tactics. These included six semi-structured interviews with state officials and 33 conversational interviews with Hmong, Yao, Nùng and Giáy farmers conducted by the second and third authors in 2013. These observations are underpinned by ethnographic fieldwork in the province since 1999 by the third author.

[2] The atmospheric model was set to tropical, the aerosol model was set to rural, the aerosol retrieval was set to the Kaufman–Tanre model (band 3 and band 7) and visibility was estimated to be 25 km.

[3] Values are not shown due to lack of space; see Riano et al. (2003) for further details of the methods followed here.

Image classification

To identify LULC types, we drew on the Level I land cover types proposed by Anderson (1976) and previous LULC mapping studies elsewhere in Vietnam (Clement et al., 2009; Leisz et al., 2005). Using an object-based approach in eCognition we identified six dominant land cover types using segmentations and rule-based classifications: shrubs, open canopy trees, closed canopy trees, water, bare soil and clouds or shadow (Baatz et al., 2008). Two segmentations were undertaken at different scales using the same band composition (bands 1–5, 7), colour/shape ratio (0.2/0.8) and compactness/smoothness ratio (0.3/0.7). Segmentation values of 5, 10, 20, 50, 100 and 200 were tested and visually examined to determine the visibility of the main land cover classes. The first segmentation was conducted at a scale of 50 to obtain objects of large size and classify the *Clouds and shadow*, *Water* and *Bare soil* classes. The second segmentation was conducted at a scale of 10, and a second set of rules was used to classify segments into the three vegetation classes: *Shrubs*, *Open canopy trees*, *Closed canopy trees*.

The six land cover classes were further separated into nine classes using the road network and slope. The *Bare soil* class was divided into two main land use types: *Built-up* and *Agriculture*. Built-up pixels were assigned by evaluating road density. The road network was separated into permanent (gravel or concrete) and seasonal (soil, susceptible to floods during the rainy season) roads. A density map was developed by assigning permanent roads an importance value of 3 and seasonal roads a value of 1. Pixels having high road density (3 m/km^2 in 2000 and 4 m/km^2 in 2010) were visually compared to aerial images of urban areas and renamed as *Built-up*. The remaining *Bare soil* pixels were renamed *Agriculture* and subdivided into field types based on slope: *Paddy fields* (slope < 5°), *Upland fields* (slope from 5° to 25°) and *Steep fields* (slope > 25°) (slope thresholds adapted from Leisz et al., 2005; Ministry of Agriculture and Agricultural Development, 2004).

To measure LULC change we computed the percent change and the annual rate of change for each class (Eqs. (1) and (2)) (Puyravaud, 2003):

$$R = \frac{A1 - A2}{A1} \quad (1)$$

$$Rate = \frac{\ln(A2/A1)}{t} \quad (2)$$

where $A1$ is the cover of arable land at an initial time (t_1) and $A2$ is the cover of arable land at a later time (t_2), $t = t_2 - t_1$. Finally, to identify trajectories of LULC change we overlaid the two classifications using the Tabulate Area module in ArcGIS.

Unit of analysis

We chose a uniform spatial unit of analysis to compute diversity and regress against each socio-ecological factor. Previous studies have suggested that 1 ha, 100 ha and 100 km^2 units could be used to capture characteristics of LULC diversity (Cassidy et al., 2010). Landsat image resolution (30 m) does not provide a high enough spatial resolution to make conclusions about activities at the household level. On the other hand, the 100 km^2 unit is too coarse to show class variations within our study districts (covering 2700 km^2). Hence we opted to conduct our analysis at the 100 ha level (1 km^2). A 2801 grid of cells covering 33 × 33 pixels was superimposed on all regression datasets to generate an average aggregated dataset.

Variable calculation

One dependent and five independent variables were calculated to run a spatial autoregressive model. LULC heterogeneity, or diversity, was used as the dependent variable and was calculated within grid parcels using the Shannon Index (Eq. (3)) (Fédoroff et al., 2005; Jiang et al., 2003; Rescia et al., 2010). Hence, the greater the number of LULC types and the more similar they are in proportion, the higher the diversity value:

$$H = -\sum_{i=1}^{n} p_i ln p_i \quad (3)$$

where H is the diversity value, p_i is the proportion of the ith LULC type and ln is the natural logarithm.

Similarly, the independent variables were calculated and aggregated into grid cells. Slope was derived from the DEM while the socioeconomic variables were calculated using road and market networks. The distance variables incorporated a cost raster and DEM to account for vertical distance travelled. The cost raster was designed following methods outlined by Cassidy et al. (2010) and assigned roads a value of 1 and all other surfaces a value of 10. While economic data such as household income is available for our study area, it is not useful here for an analysis of land use change and ethnic minority livelihoods. As semi-subsistence producers, quantitative measures of 'wealth' or 'poverty' ignore endogenous definitions of wealth while oversimplifying household decision making (Turner, 2012).

Regression analysis

An ordinary least squares model (OLS) and spatially autoregressive (SAR) model were conducted in GeoDA at the 33 × 33 pixel scale (Anselin and Bera, 1998). Spatial autocorrelation occurs if neighbouring data points are correlated in space, being similar (positive autocorrelation) or dissimilar (negative autocorrelation) and must be corrected for prior to preforming a regression analysis (Kissling and Carl, 2008). The SAR models were tested using both a spatial-lag model (assumes spatial autocorrelation occurs in the dependent variable) and an error-lag model (assumes spatial autocorrelation occurs in the residuals of the OLS models due to missing variables). The spatial-error model (Eq. (5)) was proven more robust based on the value of Moran's I, the Lagrange Multiplier test and Robust Lagrange Multiplier test (Bera and Yoon, 1993):

$$y = X\beta + \lambda W(y - X\beta) + \varepsilon \quad (5)$$

where y is the dependent variable, X is independent variables, β is the vector of slopes associated with X, ε is a vector of error terms, W is the spatial lag term, ρ is the spatial lag coefficient, and λ is the spatial error coefficient (Anselin, 2005). Rook distance weight matrices including adjacent neighbouring cells were used since the study area cells are regular and identical.

Results

Independent variables

Statistical results for the independent variable calculations are shown in Table 1 while geographical representations are shown in Figs. 2 and 3. Elevation and slope remain constant over the study period while the distance to roads variable changed from a mean of 900 m (1999) to 250 m (2009), reflecting an increase in the extent and distribution of the road network. Distance to markets remained relatively constant (59 km to 57 km) since no additional markets were established between 1999 and 2009 (Bonnin and Turner, 2014). The distance to border variable was slightly reduced in 2009 (119 km to 112 km) due to changes in the road network.

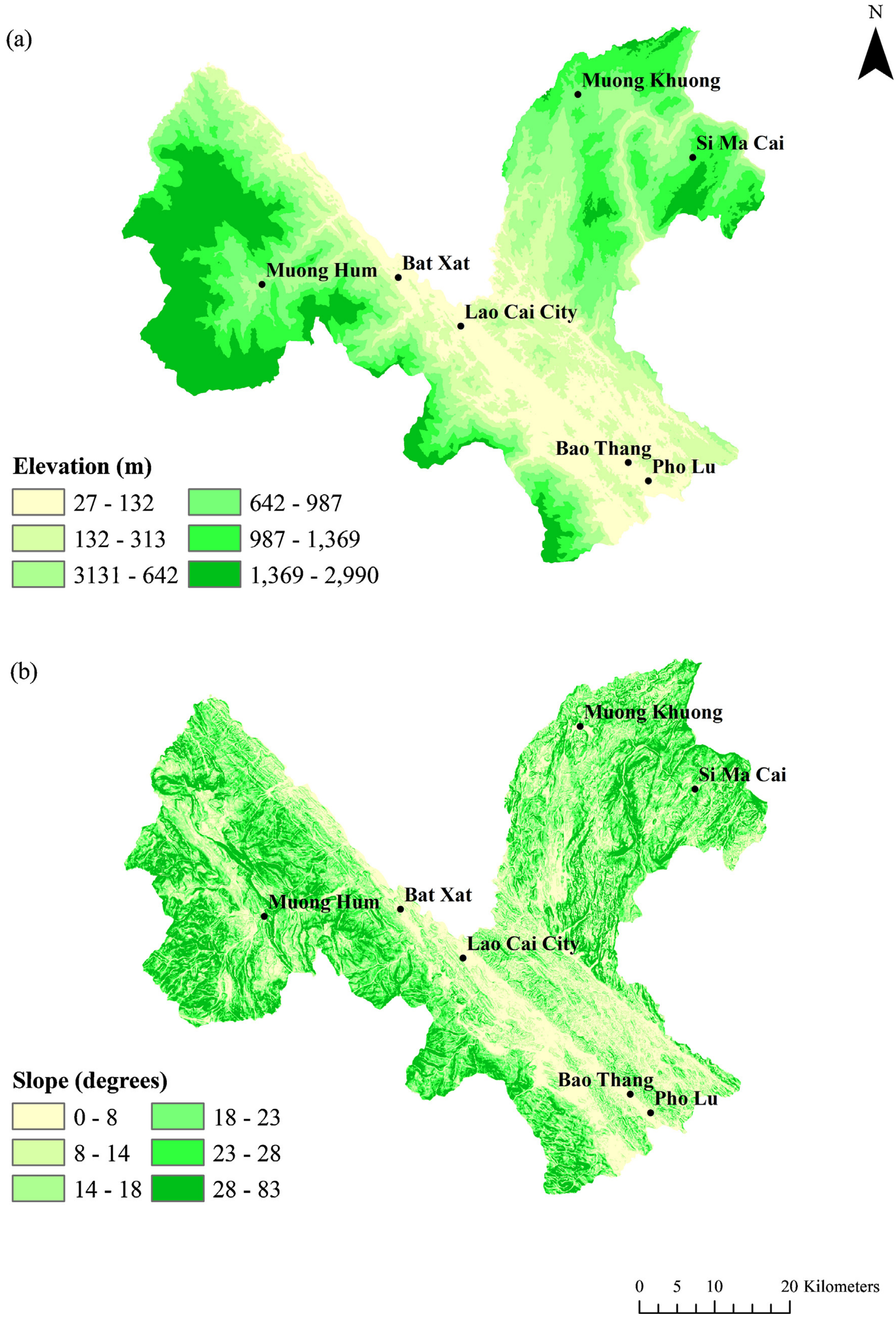

Fig. 2. Ecological independent variables (a) elevation and (b) slope.

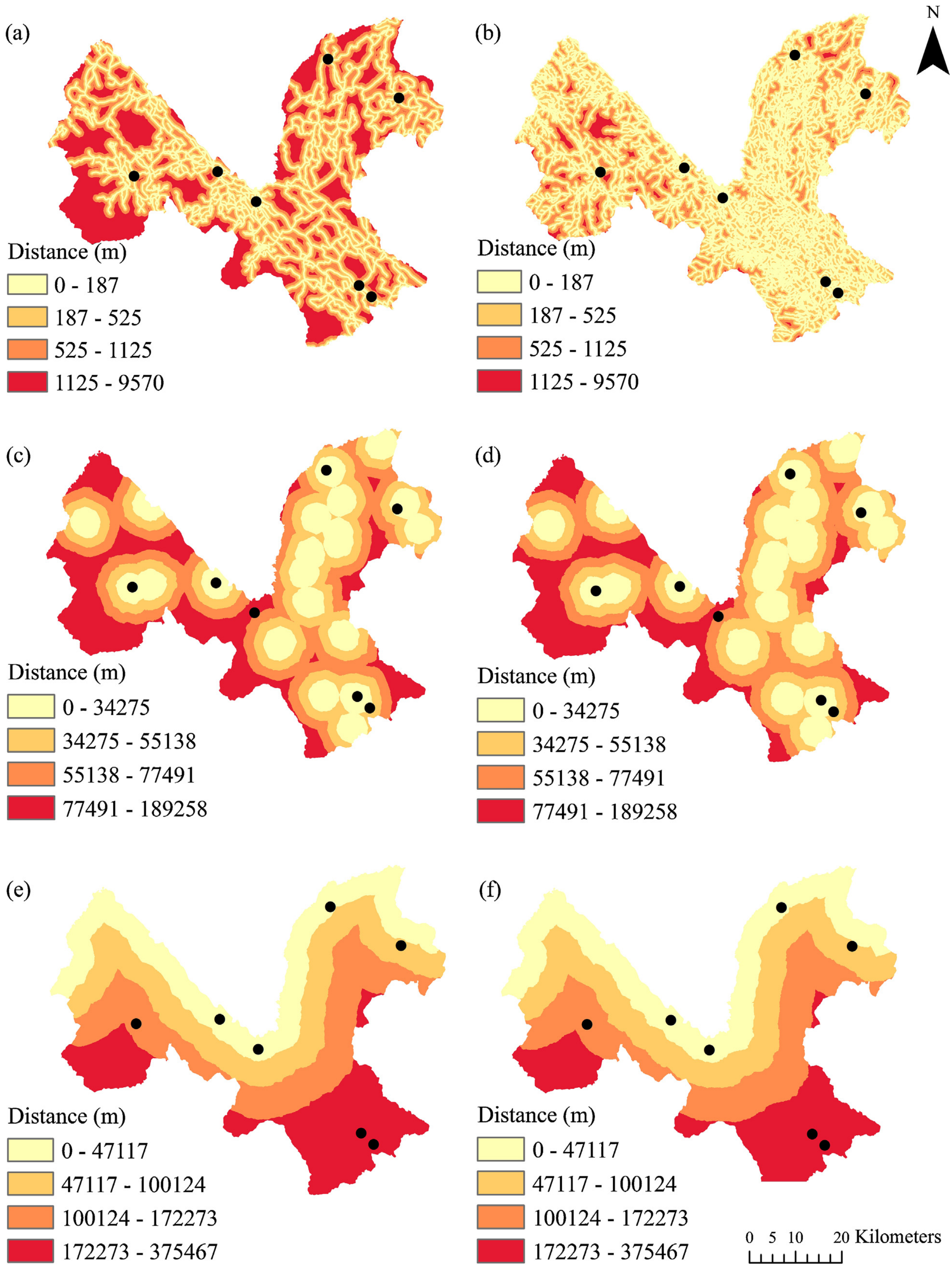

Fig. 3. Socio-economic independent variables: (a) distance to roads 1999, (b) distance to roads 2009, (c) distance to markets 1999, (d) distance to markets 2009, (e) distance to Sino-Vietnamese border 1999 and (f) distance to Sino-Vietnamese border 2009. Black dots represent town locations.

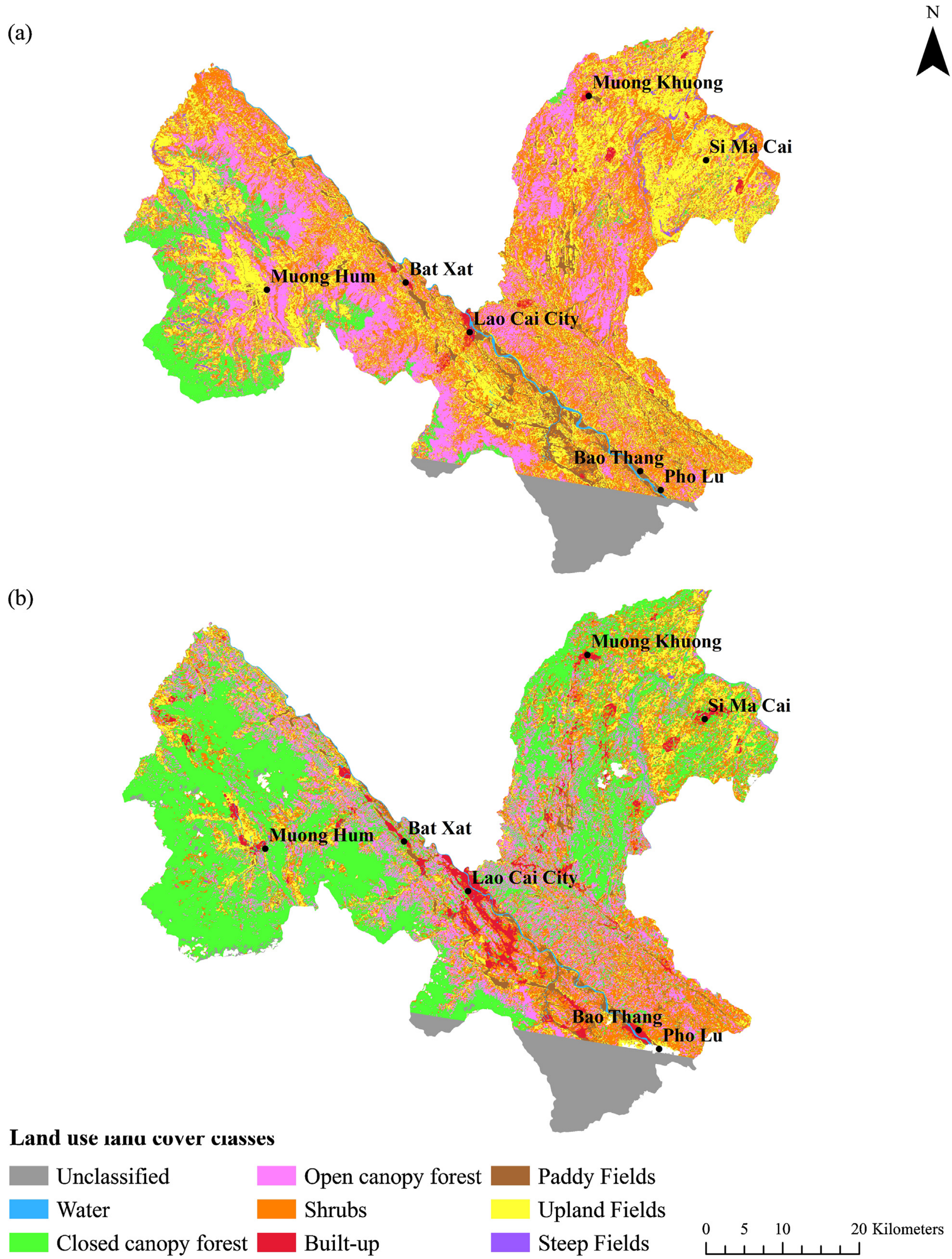

Fig. 4. Results of the LULC classification for (a) 1999 and (b) 2009. White areas in 2009 indicate cloud cover.

Table 1
Summary statistics for the socio-economic and ecological independent variables. Distances are weighted as a function of elevation and the cost raster.

Variable	Minimum	Maximum	Mean	Standard deviation
Elevation (m)	27	2990	757.9	614.1
Slope (°)	0	83.1	18.9	10.3
Distance to roads (m)				
1999	0	9566.3	897.1	1174.5
2009	0	2464.8	249.6	270.2
Distance to markets (m)				
1999	0	190,003.7	58,924.2	32,422.5
2009	0	176,845.8	56,510.1	31,144.3
Distance to border (m)				
1999	0	375,467.2	118,735.5	89,198.0
2009	0	353,770.9	111,865.1	82,936.2

Table 2
Confusion matrix for the 2009 LULC classification (in m^2).

	Reference data							
	Water	Closed canopy	Open canopy	Shrub	Built-up	Agri.	Total	Producer accuracy
Classification								
Water	7200	0	0	0	0	0	7200	100
Closed canopy	0	10,800	900	0	0	0	11,700	92
Open canopy	0	900	10,800	1800	0	1800	15,300	71
Shrub	900	0	1800	14,400	900	0	18,000	80
Built-up	0	0	900	0	10,800	4500	16,200	67
Agri.	2700	0	900	1800	900	19,800	26,100	76
Total	10,800	11,700	15,300	18,000	12,600	26,100	94,500	
User accuracy	67	92	71	80	86	76		78

LULC classification

The classification yielded nine different LULC types (Fig. 4). An accuracy assessment was conducted for the 2009 classification using a reference dataset of 172 plots (Table 2). *Water* and *Closed-canopy* references were obtained from a government generated land cover map while the remaining classes were tested using groundtruth plots acquired in the field (August 2012). The overall accuracy for the classification was 78 percent.[4] Since reference data plots were unavailable for the 1999 classification, an accuracy assessment was not performed. However, the same criteria were used to classify these images and we infer that their accuracy is similar.

Land use land cover change between 1999 and 2009

The dominant class for both 1999 and 2009 was shrubs. The largest change over the 10-year period was a 528 percent increase in built-up areas, predominately along the Red River (Table 3). The second largest change was a 413 percent increase in closed canopy forest occurring primarily in Bát Xát district. There was a decline in all three agricultural categories, the largest of which was an 87 percent decrease in steep fields primarily in Si Ma Cai and Mường Khương districts.

Several important trends and transitions between classes are worth noting (Table 4, bold values in Table 5 and Fig. 5). About 357 km^2 of open forest transitioned to closed canopy forest primarily around Mường Hum, in the east of Bảo Thắng district and southwest of Lào Cai city. Close to 310 km^2 of shrubs transitioned into closed forest, including planted trees that have matured into full canopy trees. These conversions occurred along the Chinese border in Mường Khương, in the east of Bảo Thắng district and in certain areas of Si Ma Cai. Upland fields covering approximately 239 km^2 converted into shrubs west of the Red River valley and in fragmented areas of Bảo Thắng. Approximately 230 km^2 of shrubs transitioned to open forest in small areas throughout the region. Finally, nearly 300 km^2 of upland fields transitioned to closed or open forest. This occurred to the greatest extent in the east of Mường Khương district, the south of Si Ma Cai district and in Mường Hum. Urbanization occurred as the city of Lào Cai and other rural towns expanded.

Land use land cover diversity in 1999 and 2009

The results of the diversity index indicate that in 1999 the highest LULC diversity was along the Red River where there was a mixture of urban, rural and water classes (Fig. 6). By 2009 there was a significant increase in Shannon diversity throughout the entire study area. Following the Red River, the western edge of the Sino-Vietnamese border (northwest of Bát Xát) experienced a large increase in diversity while, in the same district, the mountainous region west of Mường Hum commune had a significant decrease. Between 1999 and 2009 the standard deviation increased from 0.273 to 0.423 indicating an increase in variation of LULC types.

Role of independent variables in 1999 and 2009

The regression results for both the OLS and SAR (spatial error) models are shown in Table 6. The SAR models prove to be more robust, with lower AIC values and no spatial autocorrelation in the residuals (non-significant Moran's I). Using the SAR models for interpretation, elevation and slope are significant variables only in 2009 ($p < 0.05$ level with T-values = −11.756 and −6.229, respectively). In 2009, they exhibit negative relationships indicating that areas with high elevation and high slope had low diversity. An increase of 100 m in elevation means a reduction of 0.03 in the diversity index while an increase 10° in slope means a reduction of

[4] Confusion between *Built-up* and *Agriculture* (33 percent of built-up classified as agriculture) may be due to our method of separating these classes using road density. Likewise, confusion between *Agriculture* and *Water* (33 percent of water classified as agriculture) may be due to changes in water levels between the date of image acquisition and reference map.

Table 3
Class area, percent change and annual rate of change.

Class	1999		2009		Percent change (%)	Annual rate of change (%)
	Area (km²)	Percent total	Area (km²)	Percent total		
Water	17.3	0.6	20.7	1.2	19.2	1.79
Closed canopy forest	19.5	7.4	105.1	5.9	412.7	16.84
Open canopy forest	564.5	20.5	486	27.2	−13.9	−1.50
Shrubs	869.8	31.6	552.5	31	−36.5	−4.54
Built-up	12.7	0.5	79.6	4.5	528.4	18.35
Paddy fields	135.9	4.9	76.6	4.3	−43.7	−5.73
Upland fields	756.3	27.5	280.6	15.7	−62.9	−9.92
Steep fields	38.7	1.4	5	0.3	−87.2	−20.46
Unclassified	153.6	5.6	178.1	10	15.9	1.48

Table 4
LULC change between 1999 and 2009 by district (unit: km^2, district location on Fig. 1).[a]

LULC type	Bảo Thắng	Bát Xát	Lào Cai	Mường Khương	Si Ma Cai
Unclassified	11.1258	8.5482	3.888	0.3456	0.2826
Water	−1.5984	3.3057	−0.637	1.134	0.5274
Closed canopy forest	75.4947	418.444	53.085	221.733	72.996
Open canopy forest	49.5108	−105.84	−9.135	−20.0385	7.1316
Shrubs	−24.4377	−176.84	−17.01	−89.5365	−6.4458
Built-up	13.752	14.3955	26.051	7.7571	4.8726
Paddy fields	−28.6146	−8.9712	−13.42	−6.354	−2.0007
Upland fields	−94.4073	−147.88	−43.44	−113.5017	−70.303
Steep fields	−1.908	−16.409	−0.567	−5.6547	−8.6625

[a] Interpretation of LULC transitions should be done with caution due to the complex swidden-fallow system in the upland region.

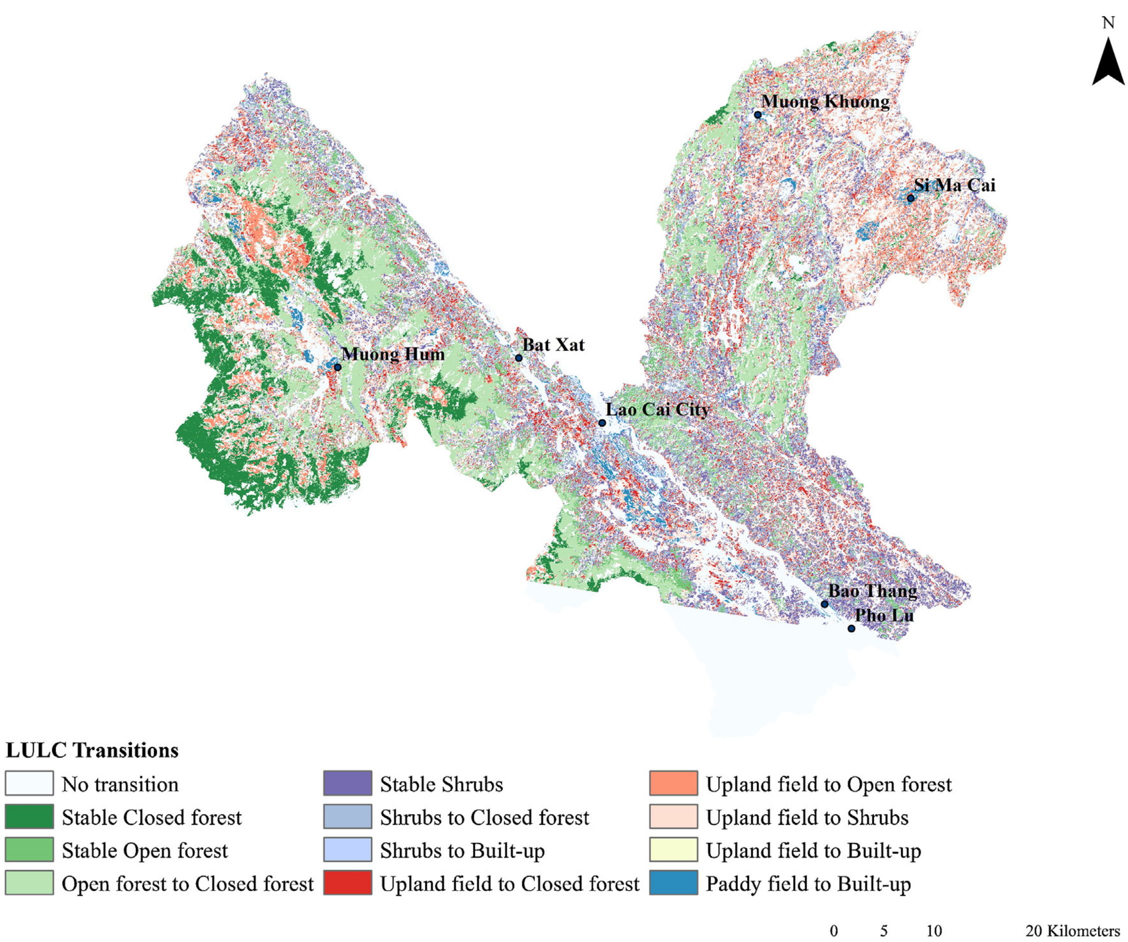

Fig. 5. Land use land cover transitions between 1999 and 2009.

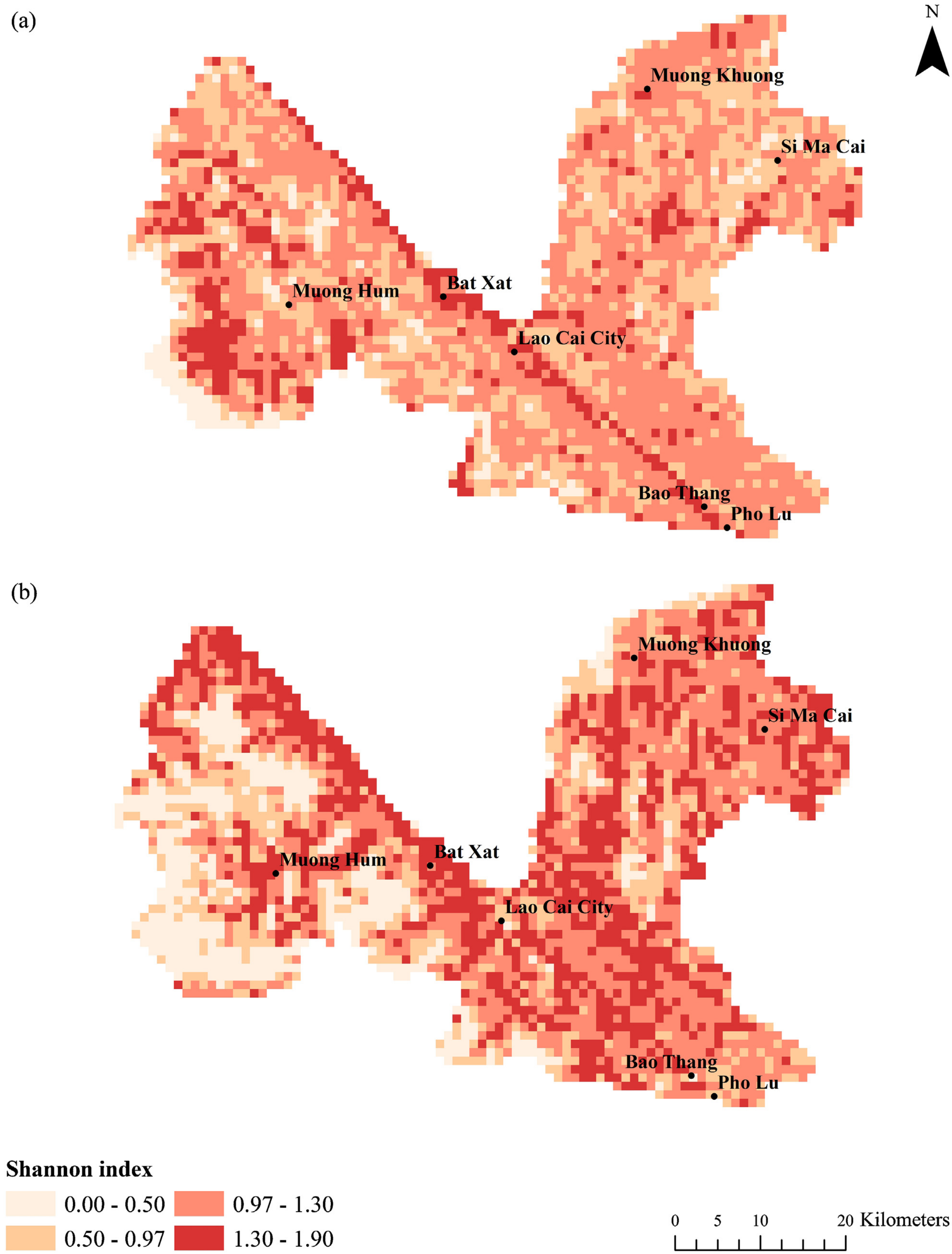

Fig. 6. Values of the Shannon diversity index for (a) 1999 and (b) 2009 at a meso-scale resolution (1 km² cells).

Table 5
Transition between classes. Grey areas indicate no change between classes while white areas indicate a conversion from 1999 to 2009 (in km^2).

	1999 classes								
	Unclassified	Water	Closed canopy	Open canopy	Shrubs	Built-up	Paddy fields	Upland fields	Steep fields
2009 classes									
Unclass.	152.99	0.29	8.07	4.66	6.93	0.05	1.33	3.59	0.16
Water	0.27	8.89	0.01	1.17	3.28	0.18	3.58	3.23	0.09
Closed canopy	0.22	0.65	180.06	**357.13**	**310.32**	1.42	5.06	**176.71**	19.02
Open canopy	0.02	0.53	2.58	115.24	**230.25**	1.00	8.94	**120.10**	7.39
Shrubs	0.03	1.09	2.88	55.63	209.43	2.76	32.88	**238.83**	8.96
Built-up	0.00	1.77	0.08	2.93	15.32	6.34	23.75	29.34	0.05
Paddy fields	0.02	2.42	0.04	2.60	12.18	0.11	59.19	0.00	0.00
Upland fields	0.03	1.32	1.15	21.47	75.37	0.80	0.00	180.45	0.00
Steep fields	0.00	0.00	0.14	0.25	1.81	0.00	0.00	0.00	2.75

0.8 in the diversity index (which varies from 0 to 1.845 in our study area).

Distance to roads and distance to markets were significant in predicting diversity in both 1999 and 2009. Both relationships are negative indicating that areas further from markets and roads had less diversity. An increase of 1 km in the distance to roads may decrease the diversity index by 0.68 and 1.64, in 1999 and 2009 respectively. An increase of 1 km in the distance to markets may reduce the diversity index by 0.001 and 0.002, in 1999 and 2009 respectively.

Distance to border was only significant in 2009; however the association is weaker than the other distance variables. The relationship was negative which suggests that areas closer to the Yunnan border tend to have higher LULC diversity. An increase of 1 km in the distance to border may reduce the diversity index by 0.0005.

Discussion and conclusion

Transitions in LULC and LULC diversity

By analysing LULC transitions and evaluating the role of socio-ecological proxies on diversity, we are able to propose the impact of regional policies on LULC diversity and livelihood diversification. First, we outline the possible relationships between our observed changes and state policies. Second, we discuss in greater detail the two largest LULC transitions we found, namely an increase in closed canopy forest and urban growth, noting how these may be linked to specific livelihood diversification strategies. Finally, we conclude with a discussion on the relative importance of socio-ecological proxies and the importance of scale.

Market integration, state policies and land use change

The impacts of state-led land use policies such as Resolution 10, the 1993 Land Law, and different reforestation programmes vary throughout the region and are further complicated by local politics and ethnic minority–majority relations. We found evidence that the infrastructure required for upland integration significantly increased between 1999 and 2009, notably an expanded road network and reduced distance to markets. These changes provide local residents more opportunities to sell agricultural surplus, obtain access to market knowledge or resources and secure non-agricultural income (Alther et al., 2002). Nonetheless, new upland marketplace regulations favour lowland traders by setting fixed market days and demanding market fees and taxes. The decline of this 'friction of distance' (Scott, 2009), has also brought increased pressure for ethnic minority households to reduce swiddening and follow state endorsed farming practices such as the adoption of hybrid seeds (interviews 2013).

Outside our study region, in Bắc Kạn Province, Castella et al. (2006, p. 16) found that most upland households were hesitant to pursue state-endorsed plantation cash crops as a livelihood strategy as they were "a highly uncertain source of income because of village remoteness and market uncertainty". This was the case in our study locale as well, with little evidence of plantation crops, such as coffee or rubber overtaking composite agricultural systems as the primary livelihood approach of rural upland residents. We did observe pineapples being grown as a cash crop in

Table 6
Results of the global regression analysis for the OLS and SAR model. SAR-error values are used for interpretation.

Parameter	1999				2009			
	OLS		SAR-error		OLS		SAR-error	
Variable	Coef.	*T*-value	Coef.	*T*-value	Coef.	*T*-value	Coef.	*T*-value
Intercept	1.157	69.83***	1.083	35.69***	1.606	79.96***	1.594	42.87***
Elevation	0.0000	4.53***	0.0000	0.01	−0.0003	−21.16***	−0.0003	−11.76***
Slope	−0.005	−6.18***	0.001	1.08	−0.007	−6.59***	−0.008	−6.23***
Dist. roads	−0.000067	−11.94***	−0.000068	−6.88***	−0.000273	−8.89***	−0.000164	−5.07***
Dist. markets	−0.000001	−3.40**	−0.000001	−2.22*	−0.000002	−7.48***	−0.000002	−3.14**
Dist. border	0.000000	3.02**	0.000000	1.64	−0.000001	−6.44***	0.000000	−2.31*
Spatial autoreg.			0.068	40.43***			0.693	42.65***
(Adjusted or pseudo) R^2	0.120		0.482		0.421		0.675	
AIC	326		−760		1610		412	
Moran's *I*	0.460		−0.044		0.486		−0.042	
LM (lag)	1139.520				1201.227			
Robust LM (lag)	25.479				0.022			
LM (error)	1116.251				1247.242			
Robust LM (error)	2.211				46.037			

LM: Lagrange Multiplier test, Robust LM: Robust Lagrange Multiplier test.
* Significant at *p*-value <0.1.
** Significant at *p*-value <0.05.
*** Significant at *p*-value <0.01.

Mường Khương district, but this has occurred fairly recently and remains small scaled, with the Hmong farmers involved facing stiff competition from elsewhere (interviews 2013).

Rural change and closed canopy forest increase

Focusing on LULC change in rural areas of the study region, there was an overall 413 percent increase in closed canopy forest. This increase is compatible with a national study that found the extent of the Vietnamese forest network increased during this time period (Meyfroidt and Lambin, 2008b). Our results indicate that the majority of forest change occurred in Bát Xát district, to the southwest of Mường Hum commune, resulting in a significant transition to low LULC diversity. High slope and elevation, a sparse road network and few marketplaces characterize this locale. The dominant ethnic group in Bát Xát is Hmong, at 26 percent of households (GSO, 2007). In 1999, this region was largely classified as upland fields with dry rice and corn production. From our interviews with Hmong uplanders, we suggest that the 63 percent decrease in upland fields occurred concurrently with a move towards state-sponsored high yield hybrid rice. With the state encouraging farmers to stop swidden agriculture, including dry rice and maize, many farmers have switched to more intensive rice farming techniques. This switch has implications for livelihood strategies as hybrid seeds must be purchased annually, requiring chemical pesticides and fertilizers, all at substantial financial cost. This has resulted in semi-subsistence households becoming reliant on the cash economy to a greater extent than in the past (Bonnin and Turner, 2012; interviews 2013).

Linked to this need for more cash income, we suggest that the increase in forest cover in Bát Xát district could be due to a combination of declining agricultural footprint, reforestation policies and a heightened interest in cardamom cultivation to meet the cash needs of local households (interviews 2013). Cardamom, for which there is a high demand in China, is a low-labour crop, grown under the shade of mature forests (Turner, 2012).[5] In Bát Xát, this crop is one of the few means by which ethnic minority farmers can gain cash income. Cardamom is exported from Bát Xát by lowland Kinh traders who purchase it at the 'farm gate', transport it to Lào Cai city and either cross the border to trade directly in China, or are visited in Lào Cai by China-based wholesalers. However, the ability of cardamom to provide a stable income is of concern to ethnic minority farmers due to an increasing reoccurrence of extreme weather events (especially extreme cold and hail storms) resulting in unpredictable yields. Moreover, prices fluctuate considerably from year to year, in part due to changing demand in China, and in part due to volatile relationships with individual intermediary traders (interviews 2013; Tugault-Lafleur and Turner, 2009). Yet, this need for cash income means that in response to a state initiative to increase agricultural uniformity in the uplands using hybrid rice, local ethnic minority households are concurrently supporting reforestation through the protection and restoration of old growth forests for cardamom production. Thus, in Bát Xát district, forest conservation and expansion appear to be unlikely side effects of market integration and agrarian transition in these uplands.

Urban growth and diversity in the Red River valley

Throughout our study area there was a 528 percent increase in urban areas. The majority of this growth occurred in the Red River valley, within the city municipality of Lào Cai. We argue that this growth is directly linked to national plans to facilitate cross-border trade and promote the Greater Mekong Subregion North–South Economic corridor. The Vietnamese government is investing extensively in Lào Cai city, promoting trade and road infrastructure. At the provincial level, the *2020 Lào Cai Economic Development Plan* prioritizes construction, renovation and upgrading of facilities at the Lào Cai-Yunnan international border, as well as the construction of new smaller border crossings (People's Committee of Lào Cai, 2010).

Interestingly, LULC diversity within this corridor increased between 1999 and 2009. This may be related to an increased mix of agricultural land uses on the rural–urban fringe. This increase could also be temporary, due to transitioning land uses, and it is likely that with time diversity will decrease as the valley becomes urbanized. This is supported by the fact that the main LULC shift that occurred in the valley was a transition from paddy fields to urban. Significant urban growth between 1999 and 2009 also occurred near rural towns in the other four districts of our study area. This is not surprising given the increasing market integration of the province as a whole, increasing numbers of lowland Kinh settling in these towns, and improvements in road infrastructure.

Socio-ecological effects on LULC diversity and a question of scale

With market integration, the significance of road and market socioeconomic proxies in both 1999 and 2009 is logical as the majority of farmers in these locales are increasingly drawing on industrial inputs to diversify crops (such as small areas of fruit trees) and to intensify their fields. Distance to the Sino-Vietnamese border was not significant in 1999 since, at this time, the majority of ethnic minority upland populations were more involved in semi-subsistence agriculture than long-distance or cross-border trade of agricultural or industrial goods. However, by 2009 distance to the border became mildly significant. This could reflect reduced trade restrictions, increasing numbers of ethnic minority householders trading a range of agricultural goods (such as maize) to China, as well as increased trade across the Lào Cai city border crossing (interviews 2013).

On the other hand, between 1999 and 2009 there was a shift in the relative importance of ecological variables. Our regression results suggest that in 1999 only socioeconomic variables were significant, however by 2009 slope and elevation became the most effective predictors of diversity, indicating that areas with low slope and elevation tend to have the lowest LULC diversity. Since the biggest predictors of diversity are resources that are the most limited (Fatoux et al., 2002; Lambin and Meyfroidt, 2010), we suggest that large-scale on-farm diversification in the uplands is increasingly limited by the availability of low slope and low elevation regions.

Thus, as farmers draw on resources to diversify land use in highly accessible regions, the remaining low diversity regions remain undiversified due to harsh terrain and difficult access. In our study, these low diversity areas also tend to have the highest populations of semi-subsistence ethnic minority farmers with few ties to the market economy. Yet, we suggest here that scale becomes a factor in our analysis. While a meso-scale analysis (1 km^2) can show large-scale transitions in LULC diversity, it cannot trace smaller changes in the semi-subsistence, composite agricultural livelihoods of upland ethnic minorities living in scattered hamlets. Hence what can be argued to be highly diverse and flexible household land use systems, cannot be captured without ground observations or a high-resolution spatial analysis to resolve concerns of scale.

Conclusions

By combining LULC mapping, statistical analyses and qualitative interviews and observations we have gained a number of insights into different causes of LULC change and diversity in a remote,

[5] Likewise, in neighbouring Laos, the increasing market integration of rural livelihoods has encouraged the intensification of non-timber forest product collection, including cardamom, as well as the infiltration of these products into local and regional markets (Ducourtieux et al., 2006; Rigg, 2006b).

borderland province of upland Vietnam, where such a study has not been undertaken before. Our findings show that in the borderland districts of Lào Cai Province LULC diversity increased between 1999 and 2009. There was evidence of significant relationships between socioeconomic variables, environmental variables and the variety of land uses and/or land covers. There was a large shift between the relative importance of socio-ecological variables between the two study years, suggesting that upland residents as a whole are diversifying their livelihood strategies in order to adapt to socio-economic, political and ecological changes. Far from autarkic, upland households are adopting new initiatives to access supplementary cash incomes. This approach could be called "productive bricolage", encompassing a variety of ways that farmers integrate subsistence agriculture with cultivation for cash income (such as cardamom under the forest canopy) (Batterbury, 2001, p. 438). In sum, these borderlands are in a period of notable flux as market integration and state policies result in upland farmers experimenting with a variety of livelihood diversification strategies, while state policies impact not only rural livelihood decision making, but also the expansion of urbanization and industrial growth in the Red River valley.

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