Trajectories of deforestation, coffee expansion and displacement of shifting cultivation in the Central Highlands of Vietnam

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Research highlights:

- Deforestation rates increased in the Central Highlands of Vietnam in the years 2000
- Direct cause was shifting cultivation by marginalized ethnic minorities
- Indirect cause was coffee and other commodity crops expanding on agricultural lands
- Understanding indirect land use changes require analyzing local socio-economic dynamics

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Abstract:

Production of commodities for global markets is an increasingly important factor of tropical deforestation, taking over smallholders subsistence farming. Measures to reduce deforestation and convert shifting cultivation systems towards permanent crops have recently been strengthened in several countries. But these changes have variable environmental and social impacts, including on ethnic minorities. In Vietnam, although a forest transition – i.e. shift from shrinking to expanding forest cover – occurred at the national scale, deforestation fronts and agricultural colonization for commodity crops – a.o. coffee – still dominated the Central Highlands plateaus. Previous studies suggested that the dominant land use changes in that region were on the one hand the acquisition and conversion of agricultural lands to perennial crops for external markets by capital-endowed Kinh households – the majority ethnic group in Vietnam – , and on the other hand the corresponding displacement of poor households of ethnic minorities relying on shifting cultivation towards the forest margins. This study tested this hypothesis by using remote sensing to analyze land use and cover changes and deforestation trajectories in the coffee-growing area in Dak Lak and Dak Nong provinces over 2000-2010. Land use changes were linked with socioeconomic dynamics using secondary statistics and spatial modeling. Net deforestation reached -0.31% y^{-1} of the total area between 2000 and 2010. Deforestation was indeed mainly directly caused by shifting cultivation for annual crops, but this was partly driven indirectly by expansion of coffee and other perennial crops over agricultural lands. Displacement of shifting cultivation into the forest margins, pushed by market crops expansion, was the spatial manifestation of the marginalization of local ethnic minorities and poor migrants, pushed by capital-endowed migrants. This marginalization is a long-standing process rooted in the colonization and development strategy for the highlands followed since colonial times. Over the late 2000s, rapid deforestation was strongly reducing the benefits of national-scale forest recovery, and might shift the country back to net losses of natural forest. Implications for policies that may affect deforestation are discussed.

Keywords:

REDD+ ; Land use policies ; Agricultural commodity booms ; Ethnic marginalization; Remote sensing

1. Introduction

Tropical forests support human livelihoods, constitute sources of raw materials, harbours of biodiversity and carbon reservoirs (Millenium Ecosystem Assessment 2005). Tropical deforestation is a crucial part of global environmental change and a challenge for sustainability of human societies (FAO 2010). Smallholders cultivating food for subsistence or for local markets, usually using shifting cultivation, were often held as the primary agents of deforestation throughout the 1960s to 1980s (Rudel et al. 2009). Over the recent decades, agricultural expansion to produce commodities for global markets became an increasingly important factor of tropical deforestation (DeFries et al. 2010, Lambin and Meyfroidt 2011). Political efforts to control and reduce deforestation have recently been strengthened in several countries, e.g. in Brazil and Indonesia (Macedo et al. 2012, Edwards et al. 2011) and coordinated internationally, among others through the impulse of the proposed REDD+ mechanisms (Venter and Koh 2012). In Southeast Asia in particular, land zoning policies that restricted agricultural activities on forestry lands have contributed to the conversion of uplands agricultural systems towards permanent crops, and to decreasing deforestation in several places (Fox et al. 2009, Meyfroidt and Lambin 2011). But agricultural commodity booms, policy schemes to reduce deforestation and transitions from shifting cultivation towards permanent crops may have important social impacts on livelihoods of specific groups, including uplands dwellers and ethnic minorities (Cramb et al. 2009). These changes may contribute to raise average incomes but also to widen inequities, to marginalization of already poor communities, and increased insecurity of livelihoods through exposure to unstable global markets. Conversion of shifting cultivation mosaics to permanent crops also creates significant environmental impacts, including sometimes increasing deforestation (Ziegler et al. 2009a). If labor demand in expanding crops is small, shifting cultivators may move their fields elsewhere, possibly encroaching into forest in what is known as “indirect land use change” (Lapola et al. 2010). Thus, in order to be effective and equitable, policies to promote sustainable land uses have to be grounded on accurate understanding of the land use processes and social dynamics involved in deforestation and of their possible effects on livelihoods. Despite the vast literature on tropical land uses, surprisingly few studies focus on land sources for the different types of expanding agricultural lands (Gibbs 2012), although this constitutes a prerequisite for understanding the land use dynamics in an area.

In Vietnam, after decades of deforestation, a forest transition – i.e. a shift from shrinking to expanding forest cover – occurred in the early 1990s at the national scale (Meyfroidt and Lambin

2008a,b). But reforestation occurred mainly in the northeastern and northwestern mountains and midlands, the central Annamite Mountains, as well as in some rehabilitated mangroves, while active deforestation fronts still dominated the plateaus of the Central Highlands region (Meyfroidt and Lambin 2008a). High deforestation rates were attributed to important immigration, through state colonization programs in the 1970s and 1980s and then spontaneously in the 1990s and 2000s, and the development of market crops (coffee, rubber, pepper, cashew, and others) (De Koninck 1999). The Central Highlands hold most of the remaining forests with high biomass and biodiversity value in Vietnam (Meyfroidt and Lambin 2008a). Forest transitions often involved displacement of land uses from reforesting countries towards other countries through imports of agricultural and wood products (Meyfroidt et al. 2010). Such international displacement of land uses indeed contributed to the forest transition in Vietnam (Meyfroidt and Lambin 2009). This displacement can also occur domestically, from reforesting regions towards so-called "facilitating regions" supplying increasing amounts of resources and goods (Pfaff and Walker 2010). The potential role of the Central Highlands of Vietnam as a facilitator for the reforestation of the rest of the country remains unclear.

The main objectives of this study are (i) to measure and characterize land cover changes and especially deforestation trajectories in a study area in the Central Highlands of Vietnam for the period 2000-2010, and (ii) to understand the land use change processes in that area and their links with deforestation and socioeconomic development. Based on that, the process of marginalization of some farmers – especially from ethnic minorities –, the role of the Central Highlands in the broader context of Vietnam's forest transition, and policies aiming at sustainable land uses and deforestation reduction will be discussed. Remote sensing data were used to map land cover changes, and combined with secondary statistics and spatial modeling to analyze drivers of land use changes and socio-economic dynamics.

Two main hypotheses from the literature about deforestation in the Central Highlands during the years 2000s were tested. First, several studies suggested that the dominant land use changes were on the one hand the acquisition and conversion of agricultural lands to perennial crops for external markets (coffee, rubber and others) (called "industrial crops" in Vietnam) by capital-endowed households, often Kinh – the ethnic majority group in Vietnam –, and on the other hand the corresponding displacement of poor households of ethnic minorities relying on shifting cultivation towards the forest margins (De Koninck 2000, Doutriaux et al. 2008, Fortunel 2008, Hall 2011). Studies explored these processes using interviews and socio-economic household surveys, but their aggregate effects on the landscape have not been quantified and mapped. This first hypothesis can be subdivided in several testable sub-hypotheses: 1.1: expansion of shifting cultivation and annual

crops was the main direct cause of deforestation; 1.2: perennial crops expanded mainly over current agricultural areas rather than on forest; 1.3: areas of shifting cultivation were pushed further from the population and economic centers, and over marginal lands; 1.4: there was a causal link between changes in perennial and in shifting cultivation crops. The second hypothesis explains that land use zoning regulations, allowing to expand rubber plantations over degraded forest, encouraged or at least sanctioned a sequence of land use where agents – mainly forest enterprises – first logged forestland until it could be considered as degraded, and then expanded plantations of perennial crops on these lands (Hoang et al. 2010). Testing this second hypothesis requires showing the following sub-hypotheses 2.1: forest degradation was usually followed by clearance, and 2.2: perennial crops expanded mainly over degraded forests, and even more over forests that had been degraded recently.

2. Study area and background

The Central Highlands (Tay Nguyen in Vietnamese) is both an area of plateaus located westward of the Annamite mountains range, and an administrative region corresponding to the provinces of Kon Tum, Gia Lai, Lam Dong, Dak Lak, and Dak Nong (Fig. 1a). Binh Puoc province is not officially considered as part of the Central Highlands, but has many similar biophysical and socioeconomic characteristics.

The study area covers 747,800 ha in the provinces of Dak Lak, Dak Nong and Lam Dong (Fig. 1a, 1b). The geomorphology, with basaltic soils and flat or gently hilly relief, creates favorable conditions for agriculture. The area overlaps several ecoregions (UN-REDD Vietnam 2011). The northern and center of the area is part of the Buon Ma Thuot basaltic plateau ecoregion (also called Dak Lak plateau), with altitude ranging between 350 and 900 m and abundant ferralsols highly suitable soils for agriculture and especially for coffee (Berding et al. 1999, UN-REDD Vietnam 2011) (Fig. 1c). The dry season lasting from November / December to April constrains coffee cultivation by imposing irrigation to initiate the growing season earlier (D'haeze et al. 2005). The northwestern part, the peneplains of Che Reo, Phu Bon and Ea Sup ecoregion (UN-REDD Vietnam 2011), is the lowest area, with the warmest and driest conditions of the study area, and altitudes ranging between 150-400 m. The south-center of the study area is part of the M'Drak mountain range ecoregion, and structured by the lower watersheds of the Srepok river and its two main tributaries, the Krong Ana and Krong No rivers. Flat lands are intersected by hills with steep slopes. The dominant soil types are less suitable for cultivation, except for patches suitable for paddy rice

cultivation. Altitude ranges between 300-800 m, except for some granitic peaks emerging above 1000 m. At a similar elevation, rainfall and temperatures are slightly higher than over the Buon Ma Thuot plateau. The southwestern part is the Dak Nong – Dak Mil plateau ecoregion, with altitude ranging between 400-1000 m and topography ranging from gently undulating to steeply dissected. The southeastern part is covered by the Chu Ang Sin granitic mountains ecoregion, with elevation between 600-1600 m and the highest rainfall of the study area. Natural vegetation over the study area is mainly composed of evergreen to semi-evergreen broadleaf forest, except in the northwestern part where dry and open deciduous dipterocarp forests dominate (Sterling et al. 2006). The capital of Dak Lak province, Buon Ma Thuot, occupies the center of the study area.

This study area was originally settled by several ethnic groups traditionally practicing shifting cultivation, mainly the Ede, and the Mnong in the southeastern part (Lak district) (Khong 2002). Although some settlers came before, colonization by Kinh population started effectively in the late 1970s, when the Vietnamese government initiated large-scale resettlement programs, to colonize and develop New Economic Zones (NEZ) established throughout the northern mountains and Central Highlands (Dery 2000, De Koninck 2000, Doutriaux 2008). Agriculture was collectively organized under cooperatives, whose productivity remained low, threatening the food security of the country during the late 1970s and 1980s (Kerkvliet and Porter 1995). Starting in the 1980s and especially with the initiation of the Doi Moi reforms in 1986, the government progressively liberalized and de-collectivized agriculture, and allocated rights on long-term use of agricultural and then forestry lands to households (Kerkvliet and Porter 1995, Meyfroidt and Lambin 2008b). With the general liberalization of the society, unplanned migration towards the Central Highlands accelerated (Hardy 2000, 2003, Zhang et al. 2006, Phan and Coxhead 2010). Migration was driven by and at the same time fuelled the rapid agricultural development of the Central Highlands, especially through coffee production. Almost insignificant in 1975, coffee cultivation boomed in Vietnam over the late 1980s and 1990s thanks to economic liberalization and privatization of agricultural production means, and rises in world coffee prices reinforced by the 1994 frost in Brazil (Ha and Shively 2008, Doutriaux et al. 2008). Vietnam thereby became the world's second largest exporter of coffee. Yet, despite coffee boom and general economic growth in the area, poverty remained severe among the ethnic minority populations in the Central Highlands, compared to Kinh migrants (Baulch et al. 2010). Price collapses between 1999 and 2001 then created a coffee bust, impoverishing many farmers which had contracted debt to invest in irrigation and inputs needed for coffee cultivation (Ha and Shively 2008). More recently, rubber started to expand rapidly throughout mainland Southeast Asia, including in the Central Highlands of Vietnam (Ziegler et al. 2009b, Li and Fox 2012). Facing the rapid deforestation of the country in the 1980s, the

government promulgated the Law on Forest Protection and Development in 1991, which defines forestry land as land covered by forest or planned for forestry uses, and subdivides it in three categories according to the planned use: special-use forest (forests of high biological or cultural value), protection forests (for protection of water and soil resources), and production forests intended for exploitation of timber and non-timber forest products, and where some agriculture is allowed in certain conditions (Clement and Amezaga 2009). In the study area, the main special-use forests are the Nam Nung, Nam Ka and Ho Lak forests (Fig. 1c). Two national parks are also located inside or close to the study area: Yok Don park covered by dry deciduous forests and Chu Yang Sin park in the Southern Annamite mountains. Some questions arising from this short socio-economic outline will be discussed in this paper: why do ethnic minorities remain impoverished and marginalized despite economic development of the area, and what effects does this have on land use and forests?, do the coffee and rubber booms have similar effects on the landscape?, and how effective are policy measures to control deforestation?

3. Data and Methods

3.1 Remote sensing processing

The time series of remote sensing data consists of Landsat TM images – path/row 124/51 and 124/52 – of 2000-2001 (February-March) and 2004-2005 (December-January) and ASTER images of 2010 (March), which were mosaicked, coregistred and georeferenced. 71 ground control points, collected by fieldwork in April 2010, were used in combination with topographic maps, Google Earth images, and expert knowledge to train supervised classifications of land cover by maximum likelihood. Classifications were initially realized with many detailed classes, which were subsequently aggregated into a few broad classes: (i) evergreen forest (including bamboos, mixed forests and different broadleaf forest qualities), (ii) open deciduous dry forest, (iii) shrubland (including fallows and degraded open forest), (iv) bare and residential land, (v) annual crops, including shifting cultivation crops like rice, maize and cassava – despite being actually a perennial crop – , as well as some irrigated rice, and (vi) agricultural farm with perennial crops (mainly coffee but also pepper, cashew and rubber). Change detections were realized by combining a post-classification comparison reclassified into the main trajectories of land use/cover changes, with an image differencing of the Normalized Difference Vegetation Index (NDVI) with thresholds at +/- 1 standard deviation (SD) around the mean (Coppin et al. 2004). The trajectories of change considered were: (i) deforestation for annual crops, (ii) deforestation for perennial crops, (iii) forest

degradation (i.e. change from evergreen forest to shrubs or open deciduous forest, (iv) reforestation (i.e. change from any other class to a forest class), (v) agricultural change to perennial crops (i.e. from annual crops, residential or bare land), (vi) conversion of shrubs / open deciduous forest to annual crops, (vii) conversion of shrubs / open deciduous forest to perennial industrial crops. Because of their insufficient separability, shrubland and open deciduous forests were merged for the analyses of land cover trajectories. By using NDVI differencing, the land cover trajectories maps were thus constructed to be conservative – i.e. not falsely detect pixels as change due to classification errors. Majority filters were used to remove noise and speckle. 350 points for the land cover maps and 210 points for the 2005-2010 land cover trajectories map, selected by structured random sampling, were used for validation, using aerial photographs, Google Earth images and colour composites of the satellite images as references. Because of the available data, reliable validation of the 2000-2005 land cover trajectories map was not possible.

3.2 Trajectories and spatial patterns of perennial and annual crops expansion

Sub-hypothesis 1.2 suggests that perennial crops expanded mainly over existing agricultural areas rather than on forest. Because perennial crops like coffee or rubber may take several years before growing enough to be spectrally separable from annual crops, a time lag was necessary to reliably identify the sources of land used for perennial crops expansion over the 2005-2010 period. The trajectories over 2005-2010 were thus compared to the land cover of the pixel in 2000. To verify the sub-hypothesis 1.3 proposing that shifting cultivation areas were pushed further from population and economic centers and over marginal lands, several indicators were computed for the plots newly put under cultivation of annual crops, for 2000-2005 and 2005-2010: average distance to human infrastructures (settlements, towns and roads), average slope, and percentage of land on marginal soils. The spatial pattern of newly opened plots was supposed to be more representative of shifting cultivation dynamics than the spatial pattern of active areas in a given year, because the latter merge shifting cultivation with permanent cropping – mainly irrigated rice. Finally, the causal link between changes in perennial and in annual crops was explored by comparing the area of annual crops lost because of perennial crops expansion with the area of annual crops expanding into forest, for the period 2005-2010.

3.3 Spatial determinants of deforestation and crops expansion 2005-

2010

Logistic regression models were used to analyze proximate causes and spatial determinants for each of the five main land use/cover changes for the period 2005-2010, namely (i) deforestation, (ii) forest degradation, (iii) clearance of shrubs / open forests, (iv) expansion of annual crops, (v) expansion of perennial crops. For each model, stratified random sampling was used to select 1000 points which experienced the corresponding change, and 1000 points which could potentially have experienced that change but have not, with a minimum distance of 150 m – determined using variograms – to minimize spatial autocorrelation (Müller et al. 2009). Due to this constraint, the actual number of sample points in each model was lower than 2000. The predictors were: (i) biophysical variables, i.e. mean annual temperature, elevation (a.o. as a proxy for annual temperature gradient), slope, aspect (calculated from the ASTER GDEM v.2 by METI and NASA, Tachikawa et al. 2011), ecoregion (UN-REDD Vietnam 2011), presence of ferralsols (from the provincial soil maps), (ii) variables related to accessibility for human activities, i.e. distance to settlements (digitized from the topographic maps), to roads, and to the main towns (Buon Ma Thuot, and Da Lat and Bao Loc in Lam Dong province) (all in meters), (iii) policy variables, i.e. zoning of the land as forest or not, and zoning of the land as protection or special-use forest or not, (iv) socio-economic indicators at commune level for 2010, i.e. rural population density (in people per hectare) and yields of the main crops – i.e. coffee, rice and maize. Variance Inflation Factor (VIF) indices above 5 were used to remove variables presenting collinearity. X and Y coordinates (in UTM projection) were initially added to control for remaining spatial autocorrelation (Müller et al. 2009), but Y coordinates were removed because of collinearity.

3.4 Regional perspective

To assess the dynamics in the study area in the light of the broader context of the Central Highlands and national dynamics in Vietnam, statistics on land use, forest cover and ethnic group composition for selected districts and provinces were compiled from official sources (General Statistical Office, Ministry of Agriculture and Rural Development, Forestry Protection Department, and provincial administrations). Following the flow of the argument, these tables will be presented in the discussion.

4. Results

4.1 Land use/cover and land use/cover changes

The overall accuracy of the land cover maps remained relatively low (respectively 69%, 68% and 64% in 2000, 2005 and 2010), but the main confusions occurred (i) with perennial crops being uncorrectly classified as bare, shrub or annual cropland because of their young age, and (ii) between shrubland and open deciduous forests. Misclassifications of young perennial crops plantations were addressed in the analysis of cropland sources by observing the land cover in 2000 for pixels converted to perennial plantations in the period 2005-2010. Validation of the 2005-2010 trajectories map showed that (i) omission errors were indeed larger than commission errors, (ii) no other particular bias in the detection of changes existed, and (iii) the accuracy reached 86%, thanks to the NDVI image differencing and the merging of shrublands and open deciduous forests. The results and discussion are thus based primarily on the land cover trajectories map, which was considered reliable. In 2010, the north and center of the study area were largely covered by coffee, with few forests (Fig. 2, Tab. 1). Forested areas remained mainly in the northwest – open dry deciduous forests – and in the southern and eastern plateaus and mountains (Figs. 1b, 2a). Forest cover (excluding open deciduous forests) declined from 26.6% in 2000 to 22% in 2010. Because of the low separability between shrubs / fallows and dry forests, decline in dry forests was more difficult to observe. Deforestation rates were high, with gross deforestation of -2,848 ha per year between 2000 and 2010, thus annual gross and net deforestation rates of respectively -0.38% and -0.31% y^{-1}, both calculated over the total study area (Tab. 2). Deforestation accelerated over 2005-2010 compared to 2000-2005, and was concentrated in the south (Fig. 2b). The main land use after deforestation was annual crops (mainly rice and maize) (Tab. 2). Forest degradation rates were lower than for deforestation.

4.2 Trajectories and spatial patterns of perennial and annual crops expansion

The most widespread successive trajectories of change over the 2000-2005-2010 periods were (i) no change followed by clearance of natural vegetation for annual crops (31.9% of the changes), (ii) early or late conversion of agricultural lands to perennial crops (24.6% of the changes), and (iii) clearance of natural vegetation for annual crops followed by no change (15.5% of the changes) (Tab. 3). Most of the 11,142 ha of perennial crops expansion over 2005-2010 occurred over areas which were already agricultural lands in 2000 (Tab. 4). Only 13.2% was realized over areas covered

by natural vegetation in 2000. 53% of the perennials expansion over shrubs was preceded by forest degradation over the period 2000-2005, but this represents only 13.7% of the forest degradation which occurred between 2000 and 2005. The sequence (1) deforestation or clearance of shrubs / dry forest for annual crops in 2000-2005 followed by (2) conversion to perennial crops in 2005-2010, as proposed by hypothesis 2, was infrequent and represented a very small share of both the deforestation over 2000-2005 (2.1%) and the perennial crops expansion over 2005-2010 (3.9%). Perennial crops thus expanded mainly on previously existing agricultural areas rather than on recently cleared ones, in line with sub-hypothesis 1.2. Furthermore, the distance from newly opened plots of shifting cultivation to settlements, large towns (primarily Buon Ma Thuot) and roads increased markedly (Tab. 5): compared to the period 2000-2005, the plots opened during the period 2005-2010 were respectively 25%, 5% and 16% further from settlements, towns and roads. Newly opened plots were also located on steeper slopes and poorer soils (Tab. 5).

Between 2005 and 2010, perennial crops expanded over 9,554 ha of agricultural lands, or 10,466 ha if shrubs – that can represent fallows – are also taken into account (Tab. 2). This area has thus been removed from the production pool for annual crops. Over the same period, annual crops expanded over forests by 17,799 ha, and over shrubs or dry forest by 11,491 ha – some of this being part of the usual cycle of shifting cultivation. Active annual croplands (thus excluding shrubs and fallowing) lost to perennial crops represented 54% of the expansion of annual crops over forests. Yet this might underestimate the effect of perennial crops expansion, given that, as shifting cultivation is pushed towards marginal lands, each hectare lost requires more than one additional hectare to produce the same amount. Expansion of annual crops over forests thus did more than compensate the areas lost to perennial crops, but nevertheless a significant share of the deforestation caused by shifting cultivation could be considered as driven by the need to replace areas lost to perennial crops and thus being indirectly driven by the expansion of these perennial crops.

4.3 Spatial determinants of deforestation and crops expansion 2005-2010

As logistic models constitute but one aspect of this study, we focus only on results useful for our analysis. Elevation and temperature had a negative influence on deforestation (Tab. 6). Presence of ferralsols and higher mean temperature were positively linked with deforestation. Increasing distance to settlements exerted a negative influence on deforestation likelihood, but forest patches in the surroundings of towns were less likely to be cleared than plots further away. Being classified as forestry land did not decrease the likelihood of deforestation, but the strictest levels of forest

protection (i.e. protection and special-use forest) effectively hindered deforestation. For forest degradation, elevation and zoning of the land as protection or special-use forest also had negative influences, and distance to towns a positive influence. Forest degradation was also more likely in the northwestern peneplains. Clearance of shrubs and dry forests was negatively influenced by temperature and distance to settlements, and less likely in the northwestern peneplains and in protection / special-use forests. Higher population density increased the likelihood of shrubs and dry forest clearance. Expansion of annual crops was negatively influenced by elevation, presence of ferralsols, and also less likely in the Buon Ma Thuot plateau and northwestern peneplains ecoregions – thus more likely in the southern and eastern plateaus and mountains ecoregions. Expansion of annual crops was less likely when going further from settlements and in protection / special-use forests, but more likely when going further from roads and towns. Expansion of perennial crops was positively influenced by elevation and presence of ferralsols, but negatively influenced by temperature and distances to towns. Perennial crops expansion was more likely in the northwestern peneplains and Buon Ma Thuot plateau, and in densely populated areas. Finally, zoning of land as protection / special-use forest had a negative influence on expansion of perennial crops. Overall, forestry land classified as protection and special-use forest was thus indeed relatively protected, controlling for accessibility and biophysical factors. Annual crops expanded more on lands relatively close to settlements, thus to labour force, but not on lands close to roads and on ferralsols. This suggests that a more competitive land use expanded over these most suitable lands. Perennial crops – i.e. coffee here – indeed expanded more on lands with suitable soils and climate, and markets accessibility, in place of annual crops.

5. Discussion

5.1 Displacement and marginalization of shifting cultivation farmers

The results support the sub-hypotheses 1.1, 1.2 and 1.3. Annual crops were the main direct cause of deforestation (Tab. 2), perennial crops expanded mainly over existing agricultural areas rather than on forest (Tabs. 2, 4), and areas of annual crops were pushed further from the population and economic centers, and over marginal lands (Tab. 3, 5). The sub-hypothesis 1.4, positing a causal link between changes in perennial and in annual crops could be partly supported by analyses of spatial pattern of annual croplands – about at least 35% of the annual croplands expansion could be attributed to the displacement caused by perennial crops expanding over annual croplands –, and of spatial determinants of agricultural expansion, but not directly proved. Thus, overall, the main

hypothesis – i.e. that deforestation was mainly caused by the acquisition and conversion of agricultural lands to perennial crops by capital-endowed households, often from the Kinh ethnic majority, and corresponding displacement of poor households of ethnic minorities relying on shifting cultivation towards the forest margins – was largely supported by the data. By contrast, hypothesis 2 and its sub-hypotheses were not verified in this study area (but see section 5.2.1).

Understanding the social dynamics leading to this displacement and marginalization of local ethnic minorities – mainly Ede and Mnong in the study area - requires a historical perspective (De Koninck 2000, Dery 2000, Fortunel 2008, Hall 2011). Migration and infrastructures development were undertaken with limited results under the French colonial rule. Throughout the Indochina Wars, the Central Highlands were increasingly recognized as a strategic area. Ethnic minorities had started to organize under the FULRO (United Front for the Liberation of Oppressed Races), a nationalist movement and insurgent group, initially against the French, then against the South Vietnam government. Although Americans partly succeeded in using the FULRO against North Vietnam, the communists gained many supporters among ethnic minorities through intensive presence on the field (Guérin et al. 2003). This strong position in the highlands proved crucial for conquering the plains of South Vietnam.

After the reunification, with continuing instability related to ethnic minorities and fear from external threats, the Vietnamese government regarded the Central Highlands as critical for national security. Colonization programs aimed at fulfilling multiple objectives: solving overpopulation and poverty issues in lowlands, and addressing the difficulties to integrate and assert control over remote highlands and minority ethnic groups (Dery 2000, De Koninck 2000, Guérin et al. 2003, Hardy 2003, Doutriaux 2008). The socialist ideology promoted a productivist and rationalist view in which highlands were underused by backwards populations with inefficient agricultural techniques (Sowerwine 2004). Through contacts with Kinh people, ethnic minorities were expected to become civilized, adopt modern practices and lifestyles, and take part to a unified nation. Although official policy promoted the multiethnic character of the country, in practice, Kinh customs were usually considered as the most advanced, to which other people should assimilate (McElwee 2008). Over the 1970s and early 1980s, most migrations were planned, i.e. they occurred in areas determined by the government and with support from the state. Through ideological mobilization campaigns, migrants were motivated to improve their own economic situation while simultaneously participating to a patriotic effort to build the Vietnamese socialist nation (Hardy 2003). Initially, Kinh migrants were not always conflicting with local populations. In many cases, local ethnic population welcomed migrants, helping them to settle (Hardy 2003). Although local populations

often had to abandon their land to migrants, extension support from state enterprises for developing irrigated rice and perennial crops, and collaboration in cooperatives also provided opportunities for ethnic minorities. In the early 1990s the coffee boom fuelled a rapid agricultural development providing benefits to many farmers, both Ede and Kinh (Fortunel 2008, Phan 2009).

But in the 1980s, with economic liberalization, abandonment of controlled household registration limiting movements – the "ho khau" –, development of private transport systems and decline of colonization programs, unplanned migration became dominant, by Kinh from the Red River delta and the central coast but also by other ethnic groups from the northern mountains, including Nung, Tay, Thai, Dao, Hmong and Muong (Hardy 2000, 2003, Zhang et al. 2006, Phan and Coxhead 2010). With decreasing state's material and ideological supports to resettlement, the typical profile of migrants in the 1990s and 2000s changed, towards people with more resource and capital than before, and motivated by economic opportunities and perspectives of becoming rich more than the building of national economy (Hardy 2003). Absent state programs, many migrant relied on relatives already living in the Central Highlands to find land to settle. Some people started to make their living by providing such land through various ways, including clearing and claiming forest fallows or acquiring land from ethnic minorities at cheap price, relying on their lack of knowledge of language, administrative procedures and official land tenure systems.

In the initial migration waves, small groups of Kinh arriving in an unknown and hostile environment often had to adapt, partly by integrating with local ethnic population and adopting some of their practices (Hardy 2003). But after the 1990s, with progressive development of infrastructures and relations with external markets, as well as balance of population more strongly shifting towards Kinh, local ethnic population became increasingly marginalized (Guérin et al. 2003, Hardy 2003). Although free migrants were often held responsible for social and environmental problems in the highlands, government's attitude towards them remained ambiguous as they actually contribute to state's objectives of national consolidation (Hardy 2003). With changes and fuzziness in policies since the 1980s, public organizations, including state farms and others, sometimes expropriated ethnic communities from their land to sell it to migrants (Guérin et al. 2003). Ethnic population dispossessed of their land had few options other than moving further into the forest, except possibly moving to town in hope for jobs. As long as the coffee boom was providing at least some benefits to many people, this marginalization remained hidden, but the coffee crisis acted as a trigger to reveal the tensions between local ethnic groups, Kinh and other migrants (Fortunel 2008, Phan 2009). Actually, unequal powers between Kinh and minorities, prejudices, and inappropriate policies have contributed to maintain ethnic minorities of the Central

Highlands among the most isolated, poor and less formally educated populations of the country (Baulch et al. 2010). For example, although production of cereals per capita was multiplied by 350% in Dak Lak between 1995 and 2010 (GSO 2012), nutritional status of ethnic minority children in the Central Highlands worsened between 1998 and 2006 (Baulch et al. 2010).

Besides spatial aspects explored in our study, other studies described in more details the social aspects of displacement (Doutriaux et al. 2008). Along with dispossessed Ede and Mnong, other groups including poor newcomers – especially from other ethnic minorities from the North – , and some settlers from earlier waves – in particular farmers indebted after the coffee crisis – are also being marginalized, but local ethnic minorities represent by far the largest share of the marginalized farmers encroaching forests with shifting cultivation. This marginalization, coupled with economic opportunities in agriculture in the region, creates a dualization between capital-endowed farmers and traders involved in commodity crops markets and subsistence smallholders forced to rely on increasingly marginal land (Phan 2009). Such dualization is a typical process of contemporary frontiers (Barbier 2012).

5.2 Spatial heterogeneity inside and across regions, and extra-local displacement

5.2.1 Intra-regional differences in deforestation patterns within the Central Highlands

This section expands the focus beyond the study area, to contrast the dynamics there with dynamics in neighboring areas of the Central Highlands, and highlight the context-specificity and spatial heterogeneity of land use and deforestation dynamics. The study area covers the largest part of the coffee basin in Dak Lak, and extends further south in Dak Nong (Fig. 1a). With the coffee boom, Dak Lak was a deforestation hotspot during the 1990s (D'haeze et al. 2005, Tab. 7). Deforestation then decreased strongly during the coffee bust period of 2000–2005. Coffee area slightly contracted over the early 2000s (Ha and Shively 2008, Agergaard et al. 2009), but started to recover since 2004. Cashew served as a refuge crop in Dak Lak during the coffee bust, then declined after 2007 (Ha and Shively 2008). Over 2005–2010, perennial crops – still mostly coffee – expanded mainly over already existing agricultural areas (section 4.2), and deforestation rebounded but remained below the 1990s figures (Tab. 7). The main hotspot of deforestation in the Central Highlands moved southwards, to Dak Nong and Binh Phuoc provinces (Tab. 7, Fig. 1a). There, by contrast, perennial crops plantations, mainly rubber, expanded mostly over forest, constituting the main direct cause of deforestation (Hoang et al. 2010).

Deforestation was thus driven mainly by an indirect pressure from coffee in Dak Lak and by a stronger and direct pressure from rubber in Dak Nong / Binh Phuoc. The causes of these differences in land use and deforestation trajectories can be traced to several factors. First, the spatial distribution of crops – coffee in Dak Lak and northern Dak Nong, versus rubber in Binh Phuoc and southern Dak Nong – corresponds to their respective requirements. Coffee requires higher elevation and cooler temperatures, and is less suited in the lower elevations of Binh Phuoc compared to Dak Lak. In fact, with plateaus under 1000 m high, even Dak Lak is only suited for the low-value Robusta and not for the higher-value Arabica (Jürgen Pohlan and Janssens 2010). On the contrary, rubber is typically an equatorial crop grown under 400 m of elevation, and temperatures below 18°C reduce yield (Verheye 2010). The conditions in Binh Phuoc and southern Dak Nong are thus more favourable for rubber compared to Dak Lak, despite the successful trials and developments of hybrids in China allowing for expansion of rubber plantations in non-traditional growing areas (Li and Fox 2012). Second, rapidly increasing global demand for rubber, including from China, contributed to an ongoing rubber boom in mainland Southeast Asia (Ziegler et al. 2009b, Li and Fox 2012). Third, large forested areas remained in Dak Lak even in the 2000s, while forests were almost exhausted in Binh Phuoc (Tab. 7). The contrast between decreasing deforestation rates in Dak Lak and deforestation hotspot in Binh Phuoc and Dak Nong could thus not be attributed to a scarcity of forests to cut in Dak Lak. Furthermore, policies and governmental support regarding rubber and coffee differ. Rubber is part of the national strategy and is allowed to expand over "poor" forests (Hoang et al. 2010), to benefit from the booming global demand. With an already very high coffee production in Vietnam, the collapse of the coffee prices in the early 2000s caused severe economic difficulties for households engaged in mono-cropping (Ha and Shively 2008, Agergaard et al. 2009), and in turn political unrests (Fortunel 2008). Market situation did not favour further expansion of coffee, government incentives were scaled down and policies prohibited expansion of coffee over forests. The difference in land use trajectories across the Central Highlands, with the southern margins (Binh Phuoc / southern Dak Nong) constituting the recent deforestation hotspot compared to the core of the Central Highlands (Dak Lak / northern Dak Nong), might therefore be primarily due to differences in suitability of land, global markets and national strategy towards coffee and rubber. Policies played an important role in displacing these deforestation fronts and modifying the land use trajectories, but in turn these policies were strategically tailored to respond to global demand for commodities.

5.2.2 Migration and the role of the Central Highlands in the forest transition of Vietnam

Expanding the focus even more broadly, we discuss here whether agricultural expansion and migration in the Central Highlands caused or facilitated the reforestation elsewhere in the country – mostly in the northern and central mountains, as suggested by some authors (Leblond 2011). Since the 1980s, land scarcity and degradation in the North caused both outmigration – to the Central Highlands and elsewhere – and decline in shifting cultivation. Migrants from upland ethnic groups, being traditionally farmers and highly valuing that activity, were likely to look for places where they could continue agriculture (Pham 2009). In northern mountains villages well-connected to main roads and for households having both enough money to migrate and not enough land to expand cultivation, migration to the Central Highlands was indeed among the diversification strategies pursued (Alther et al. 2002). Villages established entirely by migrants from northern uplands ethnic groups have been described (e.g. Lindskog et al. 2005), as well as Kinh having moved initially from the plains to the northern mountains, then to the Central Highlands (Hardy 2003). But on aggregate, despite uncertainties in official statistics (Pham 2009), most migrants to the Central Highlands were Kinh, coming overwhelmingly from the plains and deltas of the Red River and Mekong (Winkels 2008, Hardy 2000, 2003). Immigrants from northern and central uplands ethnic groups – e.g. Thai, Tay, Hmong, Muong and others – constitute only up to 10% of the population of the Central Highlands (Hardy 2000, Doutriaux et al. 2008, Tab. 8). In a country-wide statistical analysis, district-level changes in population density did not contribute to the reforestation between 1993 and 2002, and the net population change in the northern mountains and midlands was still positive (Meyfroidt and Lambin 2008b). Thus, although locally, for farmers with sufficient resources, migration and agricultural colonization in the Central Highlands likely contributed to reforestation and mitigation of land degradation in some places, massive outmigration of population from the northern and central uplands was not the primary driver of reforestation in these regions, contrasting with other cases of forest transitions (Meyfroidt and Lambin 2011).

5.2.3 Recent trends and balance of between forest cover changes among regions of Vietnam

Agricultural development in the Central Highlands contributed to exports and economic growth in Vietnam, thus supporting the restructuring of the economy and government investments which constituted the socioeconomic context of the forest transition (Meyfroidt and Lambin 2008b,

Meyfroidt and Lambin 2009, Lambin and Meyfroidt 2010). But deforestation in the Central Highlands reduced the net country-wide effects of the forest transition. Most primary forests remnants are in the Central Highlands and ongoing deforestation has important impacts on biodiversity and carbon storage (Meyfroidt and Lambin 2008b). Over the last decade, net reforestation rates at the country level declined (Tab. 9). With coffee recovery and rubber boom, rates of clearance of natural forests in the Central Highlands increased during the period 2005-2009 compared to 1999-2005, while natural forest expansion in the rest of the country slowed down. Net increases in natural forest area were therefore greatly reduced. Most of the recent reforestation in Vietnam was thus due to increases in plantations (Tab. 9), compared to the relatively equal contribution of plantations and natural regrowth between 1991-1993 and 2005 (Meyfroidt and Lambin 2008a). Continuing the same trend, deforestation in the Central Highlands might shift the country back to net losses of natural forest over a few years.

5.3 REDD+ policies

This section discusses implications on policies to reduce deforestation and forest degradation in Vietnam, e.g. as could be supported by a REDD+ scheme. Some implications hold across the Central Highlands. First, given the high value of the currently booming crops such as rubber, and thus the high opportunity cost of conserving forests, policies based only on payments for forest preservation are unlikely to be competitive enough to significantly affect deforestation (Hoang et al. 2010). Furthermore, in that region very few households hold title on forestlands, thus making them legally unable to receive payments except as contract for labour (McElwee 2012). Second, policies need to acknowledge sub-regional heterogeneity in deforestation contexts, even across a few dozens of kilometres. Although the Central Highlands are often regarded as one broad homogeneous deforestation front, important differences in land use and deforestation processes exist between the rubber area in Binh Phuoc and southern Dak Nong and the coffee basin in Dak Lak and northern Dak Nong. These differences call for subtle spatial targeting of policy measures. Controlling migration represents a huge challenge for local authorities (Hardy 2003), and might actually come as a consequence of tightened land use control rather than a tool to reduce deforestation. Suggestions to revise land zoning policies to direct rubber expansion on so-called underutilized lands – i.e. already cleared and degraded, fallows lands (Hoang et al. 2010) – might drive land use displacement and further deforestation similar to the coffee area, as these “unused” lands often belong to shifting cultivation systems (Fox et al. 2009, Lambin and Meyfroidt 2010).

In areas where deforestation is mostly caused by smallscale farmers marginalized and displaced

554 from the core agricultural areas, as in the coffee region, policies to control deforestation need to
555 address these socio-economic dynamics. Ensuring more equitable sharing of the benefits of
556 agricultural development, especially among ethnic groups, might contribute to reduce deforestation.
557 Paternalistic policies, designed to protect local ethnic minorities like the Ede from loosing their
558 main production asset in poorly negotiated deals with Kinh inmigrants, maintain them outside of the
559 land markets by not allowing them to sell their land titles (Phan 2011). But thereby, Ede and Mnong
560 having to sell their land for any reason have to rely on illegal land transactions, which are less
561 secure and bring few benefits (Phan 2011). Revising these policies to integrate local ethnic groups
562 into the mainstream economy might allow for more transparency and control over land transactions,
563 and more possibilities to equalize their bargaining power with Kinh and other immigrants (Phan
564 2011). Agricultural intensification might have various effects on deforestation. Increasing
565 productivity of coffee, rubber and other commodity crops for which global demand is elastic is
566 likely to increase incentives for deforestation, in a so-called rebound-effect (Lambin and Meyfroidt
567 2011, Pirard and Belna 2012). Demand for staple crops being likely to be less elastic, rebound-
568 effect would thus be less strong. Extension efforts for intensification of staple crops, especially in
569 shifting cultivation systems, might thus contribute to improve the socio-economic conditions of
570 ethnic minorities while reducing deforestation, as it occurred elsewhere in the Central Highlands
571 (Müller and Zeller 2002) and the northern mountains of Vietnam (Sikor 2001, Meyfroidt and
572 Lambin 2008b). Certification of coffee production for environmental and/or social standards might
573 allow farmers to benefit from more stable prices (Rueda and Lambin 2013), constituting a useful
574 way to counterbalance the fluctuating prices of coffee and their harmful effects on livelihoods (Ha
575 and Shively 2008). But the very intensive coffee cultivation system predominant in Vietnam, with
576 sun-grown Robusta, important fertilizers inputs and irrigation, makes it difficult for smallholders to
577 comply with most certification standards (Neilson et al. 2010, Jha et al. 2011). Large-scale
578 certification of Vietnamese coffee thus presents serious challenges, and does not directly address the
579 displacement shown to be the main direct cause of deforestation. Further, any policy to intensify or
580 certify agriculture is limited by the near nonexistence of extension services in the region.

581 The spatial pattern of deforestation does not correspond to locations with the highest agro-
582 ecological potential for crops (D'Haeze et al. 2005). Due to its informal nature, deforestation caused
583 by displacement of marginalized smallholders is not integrated into land use planning. Occasionally,
584 pressed by an increasing population facing land scarcity, local authorities grant rights to extend
585 agricultural lands over forests or officialise the existence of newly expanded cropland, in an ad-hoc
586 manner (Phan 2011). Based on the agro-ecological potential of land, and habitat and corridors
587 conservation, spatial planning of production forestry lands destined to remain forested, versus those

588 which might eventually be cleared for agriculture, might be used to open new areas for smallholders
589 and ethnic minorities. If not integrated with a policy to support marginalized smallholders, land
590 zoning can eventually be mainly restrictive for subsistence agriculture, as market agriculture
591 progressively displaces the former. Eventually, all these policies would face huge constraints related
592 to multiple and sometimes competing layers of administration, and organizational dysfunctions
593 (Kerkvliet and Marr 2004, Chong 2012). Strong enforcement of land zoning policies, for example,
594 has been shown to significantly affect its effectiveness (Gaveau et al. 2009). Progresses towards
595 sustainable land uses might thus emerge not only from government's efforts but also from agency of
596 local populations and ethnic minorities struggling to shape their lives amidst the incoming forces of
597 globalization (Hardy 2012).

598

599 # 6. Conclusion

600 Deforestation in the study area was important over the 2000s, with gross rates reaching -0.38% y^{-1}
601 of the total area between 2000 and 2010, and -0.50% y^{-1} over 2005-2010, and corresponding net
602 rates of -0.31% y^{-1} and -0.33% y^{-1}. Deforestation was mainly directly caused by shifting cultivation
603 by smallholders, but this was partly driven indirectly by expansion of coffee and other commodity
604 crops over agricultural lands. This displacement of shifting cultivation into the forest margins,
605 pushed by market crops expansion, was the spatial manifestation of a process of marginalization of
606 households from local ethnic minorities, pushed by Kinh and other migrants. The contrast with
607 other areas of the Central Highlands where deforestation was directly caused by rubber expansion
608 highlights the importance of refined spatial knowledge and place-based policies. The relations
609 between this colonization, deforestation and agricultural expansion front in the Central Highlands
610 and the national-scale reforestation in Vietnam calls for further studies exploring the role of
611 facilitating regions in forest transitions. Yet, over the most recent years, deforestation of the major
612 remaining old-growth forests in Vietnam has started to shift the balance of natural forests back
613 towards the negative on country level. Policies that could affect deforestation include improving
614 inclusion of the ethnic minorities into the socio-economic, political and agricultural markets
615 spheres, intensifying staple crops, and optimizing land zoning to identify forested land with the
616 lowest tradeoffs between environmental services and agricultural development for marginalized
617 smallholders. Controlling deforestation in the Central Highlands of Vietnam will remain an arduous
618 task, given the high profitability of agriculture and the comparatively low population density which
619 continues to attract migrants, as in other frontiers with comparatively little labour and abundant land

(Barbier 2012), as well as the poor governance environment. Proper understanding of the land use trajectories and underlying social dynamics at play may contribute to designing more effective and equitable interventions. With looming global land scarcity and growing recognition of indirect and cascading land use changes (Harvey and Pilgrim 2011, Lambin and Meyfroidt 2011), the competition between extensive systems – such as traditional shifting cultivation for subsistence or local markets and extensive pasture on the one hand –, and industrial plantations of commodity crops on the other hand bears increasing importance on deforestation. In the Peruvian Amazon, high-yielding, large-scale industrial oil palm plantations expanded preferentially over forests compared to low-yielding, smallholders oil palm plantations (Gutiérrez-Vélez et al. 2011). By contrast, in the southern Amazon of Brazil, recent soybean expansion occurred mainly over former pastures, allowing for simultaneously increasing agricultural production and reducing deforestation (Macedo et al. 2012). Yet, this expansion of soybean may have driven deforestation indirectly by displacing pastures further in the Amazon forest (Barona et al. 2010, Arima et al. 2011). This study showed that displacement of land use is a cross-scale process, occurring not only at international (Meyfroidt et al. 2010) and inter-regional (Pfaff and Walker 2010) but also at local level. In any case, to avoid displacement, policies to control deforestation and promote sustainable land uses require the combination of measures to increase supply, such as ecological agricultural intensification, with measures to control land use expansion, such as land zoning, and measures to control the demand (Meyfroidt and Lambin 2011). Both the conditions under which such displacement of land uses and indirect deforestation occurs, and the appropriate policies to control it, deserve further analyses.

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Figure 1. Study site in the Central Highlands of Vietnam. (a): location of the study site with identification of the Central Highlands provinces. (b): Infrared color-composites of the 2010 Aster images, with outlines of the district boundaries. (c) Forestry land zoning, ecoregions and elevation in the study area.

Figure 2. Land cover and land cover changes maps. (a) Land cover map in 2010. (b) Land cover changes 2005-2010, reclassified in the main trajectories.

Table 1

Tab. 1: Land cover proportions (%) in 2010

Land cover proportions (%)	
Forest (broadleaf, bamboo, coniferous, mixed, excluding open dry forest)	22.0
Open dry deciduous forest	2.0
Shrubland	2.6
Bareland (incl. residential)	23.5
Annual crops (including paddylands)	27.8
Perennial / industrial crops	20.6
Water	1.5
Total area (ha)	747,807

Table 2

Tab. 2: Trajectories and rates of land use / land cover changes 2000-2005-2010

	ha			Gross annual change (ha/y)			Gross annual rate (%/y, over the total area)		
Trajectory	2000-2005	2005-2010	2000-2010	2000-2005	2005-2010	2000-2010	2000-2005	2005-2010	2000-2010
Unknown	14,822	17,059	16,083	2,964	3,412	1,608	0.40	0.46	0.22
No change	691,168	681,479	656,646	138,234	136,296	65,665	17.82	16.73	8.03
Deforestation for perennial crops	180	676	804	36	135	80	0.00	0.02	0.01
Deforestation for annual crops	8,338	17,799	27,682	1,668	3,560	2,768	0.22	0.48	0.37
Forest degradation	4,482	1,511	1,609	896	302	161	0.12	0.04	0.02
Reforestation	2,047	6,038	5,476	409	1,208	548	0.05	0.16	0.07
Agricultural changes, to perennial crops	16,882	9,554	22,126	3,376	1,911	2,213	0.45	0.26	0.30
Shrubs / dry forest to annual crops	8,824	11,491	15,425	1,765	2,298	1,543	0.24	0.31	0.21
Shrubs / dry forest to perennial crops	73	912	703	15	182	70	0.00	0.02	0.01
Net forest changes (excl. dry forests)	-6,471	-12,437	-23,010	-1,294	-2,487	-2,301	-0.17	-0.33	-0.31

Table 3

Tab. 3: Eight most frequent successive trajectories for the period 2000-2005-2010, by decreasing order of extent

Trajectories 2000-2005 and 2005-2010	% (of the changed pixels)
No change – Deforestation for annual crops	20.4
Agricultural change, to perennial crops – No change	16.2
No change – Shrubs / dry forest to annual crops	11.5
No change – Agricultural change, to perennial crops	8.4
Shrubs / dry forest to annual crops – No change	7.9
Deforestation for annual crops – No change	7.6
No change – Reforestation	5.0
Forest degradation – No change	4.4
Total	81.4

Table 4

Tab. 4: Sources of land for perennial crops expansion (land cover in 2000 of the land converted to perennial crops between 2005-2010)

Land cover in 2000	ha	%
All	11,142	100.00
Natural vegetation	1,471	13.2
Of which shrubs / open dry deciduous forest	513	4.6
Of which other forest (evergreen, bamboos)	959	8.6
Annual crops	6,249	56.1
Other agricultural areas (bare lands)	3,246	29.1
Other land (including water)	176	1.6

Table 5

Tab. 5: Indicators of marginality of the new areas of annual crops

Indicator	2000-2005	2005-2010
Average distance to settlements (m)	2,472	3,095
Average distance to towns (mainly Buon Ma Thuot) (m)	34,014	35,569
Average distance to roads (m)	2,937	3,417
Average slope (degrees)	9.6	11.8
% of area on marginal soils	44.5	55.4

Table 6

Tab. 6: Spatial determinants of land cover / land use changes 2005-2010

	Deforestation			Forest degradation			Shrubs and dry forest clearance			Expansion of annual crops			Expansion of industrial crops		
N		1596			901			1759			1815			1791	
Coefficients:	VIF	Estimate	Signif.	VIF	Estimate	Signif.	VIF	Estimate	Signif.	VIF	Estimate	Signif.	VIF	Estimate	Signif.
(Intercept)	-	-25.11	***	-	-12.20		-	1.375		-	-8.367	**	-	-4.219	
Elevation (m)	3.1	-0.006341	***	4.1	-0.007154	***	4.0	-0.00006909	.	2.7	-0.005106	***	3.0	0.001796	***
Slope (degrees)	1.2	-0.004668		1.3	0.01541		1.3	0.004438		1.4	0.01282	.	1.3	-0.008718	
Aspect (degrees)	1.0	-0.0003867		1.1	0.0001899		1.0	-0.0001892		1.0	0.0007041		1.0	-0.0003625	
Temperature (Celsius degrees)	2.3	0.1019	*	3.4	-0.03783		1.7	-0.08319	**	1.5	-0.01886		1.4	-0.1145	***
Ecoregion 1	1.8	-0.05347	.	2.9	0.9286	.	3.2	-0.2289		3.7	-0.4921	*	3.2	1.042	***
Ecoregion 2	1.7	0.5199		3.4	1.715	**	3.7	-1.736	***	2.0	-1.228	***	1.9	0.9262	**
Ferralsols	2.4	0.9640	***	2.1	0.4406		1.2	0.07145		2.2	-0.6185	***	1.4	1.271	***
Dist. to settlements (m)	2.0	-0.0002696	***	2.2	-0.00002092		2.5	-0.0001015	**	2.3	-0.0001552	***	2.2	-0.00008209	.
Dist. to roads (m)	2.1	-0.00004494	.	2.0	-0.00009779	.	2.2	0.00001050		1.8	0.00008388	***	1.7	-0.00005088	.
Dist. to towns (m)	3.8	0.00005398	***	3.9	0.00006008	**	3.5	-0.0000004211		2.7	0.00001679	**	3.0	-0.00001555	*
Zoning as forestry land	1.1	-0.2007		1.1	0.1633		1.7	0.07658		2.7	-0.07365		1.7	-0.2445	
Zoning as protection / special-use forest	1.4	-0.9586	***	1.4	-0.6634	*	1.3	-0.5456	***	1.5	-0.3376	*	1.3	-1.033	***
Rural population density in 2010 (people/km2)	2.4	-0.4450	.	2.5	-0.3757		2.1	0.07720	*	2.0	0.06655		1.7	0.2722	***
Coffee yields in 2010 (XX)	3.0	-0.051837		3.6	0.1310		2.1	-0.1408	.	-	-	-	2.0	-0.06503	
Rice yields in 2010 (XX)	-	-	-	-	-	-	-	-	-	2.9	-0.02742		-	-	-
Maize yields in 2010 (XX)	-	-	-	-	-	-	-	-	-	4.6	-0.01813		-	-	-
X coordinate (UTM, m)	2.5	0.00003172	***	2.0	0.00001528		1.6	0.000001956		1.8	0.00001399	***	1.6	-0.000006677	.

Notes: N: number of observations. Ecoregion 1: Buon Ma Thuot basalt plateau. Ecoregion 2: peneplains of Cheo Reo, Phu Bon, Ea Sup. Control ecoregions (aggregated): M' Drak Mountain Range, Dak Nong and Dak Mil plateau, and Chu Ang Sin Mountain and Da Lat mountainous plateau. Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 . - : variable not included because of Variance Inflation Factor (VIF) too high. All models were significant on likelihood ratio test at p<0.0001 level compared to the null model.

Table 7

Tab. 7: Areas and annual changes in areas of forest and the main perennial crops (coffee, rubber, cashew) in several years in selected provinces of the Central Highlands of Vietnam

Units : '000 ha	1985	1993	1999	2005	2009	Annual change 1985-1993 ('000 ha/y)	Annual change 1993-1999 ('000 ha/y)	Annual change 1999-2005 ('000 ha/y)	Annual change 2005-2009 ('000 ha/y)
Forest									
Dak Lak + Dak Nong	1294.0	1153.6	1018.0	974.7	957.2	-17.6	-22.6	-7.2	-4.4
Đắk Lắk	-	672.5	598.6	604.3	633.2	-	-12.3	1.0	7.2
Đắk Nông	-	481.1	419.4	370.4	324.0	-	-10.3	-8.2	-11.6
Lâm Đồng	630.0	599.6	618.5	607.3	602.0	-3.8	3.2	-1.9	-1.3
Bình Phước	248.9	235.9	165.0	172.4	113.9	-1.6	-11.8	1.2	-14.6
Natural forest									
Dak Lak + Dak Nong	1284.0	1150.5	1008.3	946.1	881.4	-16.7	-23.7	-10.4	-16.2
Đắk Lắk	-	669.5	595.9	585.9	571.9	-	-12.3	-1.7	-3.5
Đắk Nông	-	481.0	412.4	360.2	309.4	-	-11.4	-8.7	-12.7
Lâm Đồng	621.0	593.0	591.2	557.9	543.3	-3.5	-0.3	-5.6	-3.6
Bình Phước	248.9	235.9	154.0	117.9	95.2	-1.6	-13.7	-6.0	-5.7
Coffee									
Dak Lak + Dak Nong	25.0	100.0	182.3	241.8	256.8	9.4	13.7	9.9	3.8
Đắk Lắk	-	-	-	170.4	182.0	-	-	-	2.9
Đắk Nông	-	-	-	71.4	74.8	-	-	-	0.8
Lâm Đồng	-	-	87.6	117.5	141.1	-	-	5.0	5.9
Bình Phước	-	-	17.8	10.4	11.5	-	-	-1.2	0.3
Rubber									
Dak Lak + Dak Nong	-	-	26.7	31.3	44.6	-	-	0.8	3.3
Đắk Lắk	-	-	-	22.8	25.1	-	-	-	0.6
Đắk Nông	-	-	-	8.5	19.5	-	-	-	2.8
Lâm Đồng	-	-	0.0	0.0	1.6	-	-	0.0	0.4
Bình Phước	-	-	84.3	99.2	144.0	-	-	2.5	11.2
Cashew									
Dak Lak + Dak Nong	-	-	5.6	42.1	58.7	-	-	6.1	4.2
Đắk Lắk	-	-	-	29.5	36.4	-	-	-	1.7
Đắk Nông	-	-	-	12.6	22.3	-	-	-	2.4
Lâm Đồng	-	-	8.6	10.8	15.6	-	-	0.4	1.2
Bình Phước	-	-	64.8	116.0	156.1	-	-	8.5	10.0
Natural forest (% of total land)									
Dak Lak + Dak Nong	65.4	58.6	51.3	48.2	44.9	-0.8	-1.2	-0.5	-0.8
Đắk Lắk	-	51.0	45.4	44.6	43.6	-	-0.9	-0.1	-0.3
Đắk Nông	-	73.8	63.3	55.3	47.5	-	-1.8	-1.3	-1.9
Lâm Đồng	63.6	60.7	60.6	57.1	55.7	-0.4	0.0	-0.6	-0.4
Bình Phước	36.2	34.3	22.4	17.2	13.9	-0.2	-2.0	-0.9	-0.8

Notes: sources: data on coffee, rubber and cashew: Ministry of Agriculture and Rural Development (MARD). Forest cover data: Forest Inventory and Planning Institute (FIPI), and own calculations based on FIPI maps. Until 2004, Dak Nong was part of Dak Lak province. Until 1997, Binh Phuoc was merged with Binh Duong province into Song Be province. Statistics of agricultural lands for the earlier dates are thus unavailable for these provinces. - : not available.

Table 8

Tab. 8: Percentages of the main ethnic groups in the rural population in Dak Lak in 2009, by districts

districts	Ede	Kinh	Mnong	Other
Buôn Ma Thuột	23.0	70.0	0.1	6.8
Krông Búk	31.3	67.0	0.0	1.2
Cư M Gar	39.0	48.8	0.0	10.5
Krông Pắc	19.5	64.4	0.0	9.8
Krông Ana	22.9	72.7	1.8	2.2
Lăk	6.6	32.6	53.3	7.4

Source: Dak Lak Statistical Yearbooks

Table 9

Tab. 9: Annual rates of forest changes (total and natural) in Vietnam and in the Central Highlands

	Total forest		Natural forest	
	1999-2005	2005-2009	1999-2005	2005-2009
Net change (ha/year)	283,518	160,536	139,829	14,033
Deforestation in the Central Highlands (ha/year)	-9,876	-35,449	-31,431	-43,396

Notes: sources: Forest Inventory and Planning Institute and Forest Protection Department (www.kiemlam.org). Central Highlands here corresponds to the administrative region of the same name (the provinces of Kon Tum, Gia Lai, Lam Dong, Dak Lak, and Dak Nong), and the neighboring provinces which are also part of the same deforestation front and agricultural colonization area (i.e. Binh Phuoc and Binh Thuan).

Figure 1

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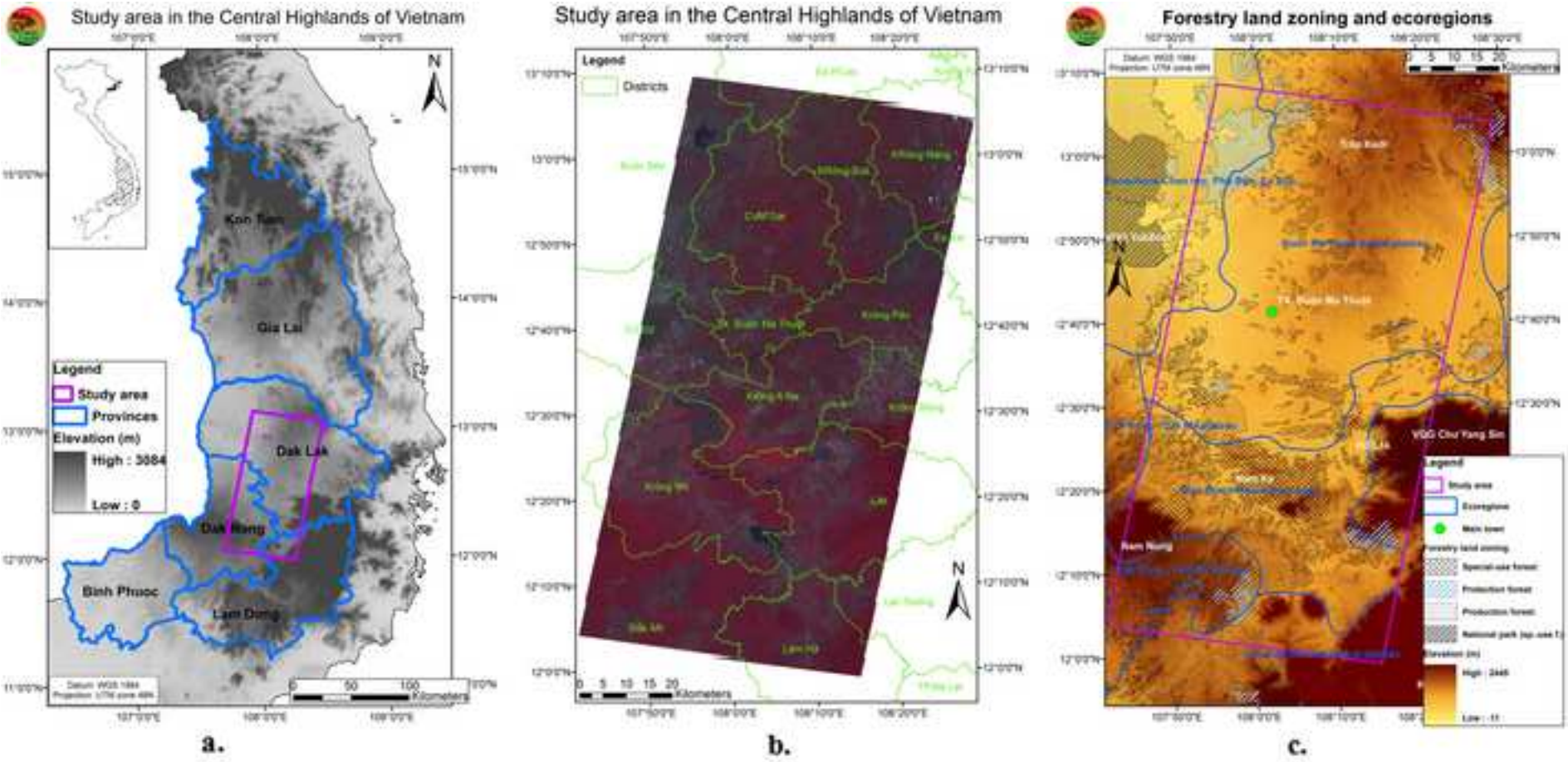

Figure 2

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