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Extent and causes of forest cover changes in Vietnam's provinces 1993-2013: a review and analysis of official data

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Abstract

Within a region plagued by deforestation, Vietnam has experienced an exceptional turn-around from net forest loss to forest regrowth. This so-called ‘forest transition’, starting in the 1990s, resulted from major changes to environmental and economic policy. Investments in agricultural intensification, reforestation programs, and forestland privatization directly or indirectly promoted natural forest regeneration and the setting-up of plantation forests mainly stocked with exotic species. Forest cover changes, however, varied widely among regions due to specific socio-economic and environmental factors. We studied forest cover changes (including ‘natural’ and ‘planted’ forests) and associated drivers in Vietnam’s provinces in between 1993-2013. An exhaustive literature review was combined with multivariate statistical analyses of official provincial data. Natural forest regrowth was highest in northern mountain provinces, especially 1993-2003, whereas deforestation continued in the Central Highlands and Southeast Region. Forest plantations increased most in mid-elevation provinces. Statistical results largely confirmed case study-based literature, highlighting the importance of forestland allocation policies and agroforestry extension for promoting small-scale tree plantations and allowing natural forest regeneration in previously degraded areas. Results provide evidence for the abandonment of upland swidden agriculture 1993-2003, and reveal that spatial competition between expanding natural forests, fixed crop fields and tree plantations increased 2003-2013. While we identified a literature gap regarding effects of forest management by para-statal forestry organizations, statistical results showed that natural forests increased in areas managed for protection/regeneration. Cover of other forests under the organizations’ management, however, tended to decrease or stagnate, especially more recently when the organizations increasingly turned to multi-purpose plantation forestry. Deforestation processes in the Central Highlands and Southeast Region were mainly driven by cash crop expansion (coffee, rubber) and associated immigration and population growth. Recent data trends indicated limits to further forest expansion, and logging within high-quality natural forests reportedly remained a widespread problem. New schemes for ‘payments for forest environmental services’ should be strengthened to consolidate the gains from the ‘forest transition’, whilst improving forest quality (in terms of biodiversity and environmental services), and allowing local people to actively participate in forest management.

Keywords: forest transition, land allocation policies, reforestation programs, small-scale plantations, forestry organizations, shifting cultivation

1. Introduction

Vietnam is the only country in Southeast Asia which, in recent decades, experienced a so-called 'forest transition' from rapid net deforestation to net reforestation (Meyfroidt and Lambin 2008*a*). This transition was largely a consequence of fundamental policy changes and structural reforms in the agricultural and forestry sectors, beginning with broader nation-wide economic reforms (Đổi Mới) in 1986, and gaining momentum after the second land law revision in 1993. The transition has sometimes been heralded as the successful outcome of pro-forest policies and programs, but improvements in terms of forest quality varied, particularly as reforestation largely relied on mono-crop exotic plantations (McElwee 2016). Furthermore, forest cover changes were far from uniform across the country (Meyfroidt and Lambin 2008*b*).

The Vietnam Forestry Development Strategy 2006-2020 (VFDS 2006) set a target to further increase the national forest cover and to strengthen the inherent 'forest environmental services' (FES). To reach such target, the VFDS (2006) promoted 'payments for FES' (PFES) as a key mechanism for funding, with revenues projected to bring in around US$ 2 billion by 2020. Evidence for the actual contribution of policies and government-sponsored programs to the forest transition, however, remains limited (cf. McElwee 2012, 2016, Catacutan et al. 2012). Despite many case studies conducted since the 1990s, the overall picture remains sketchy. There is a need to bring together and synthesize the disjointed information.

The aim of this paper is to review forest cover dynamics and their associated drivers in Vietnam's provinces in the two decades between 1993 (second Land Law revision) and 2013 (advent of PFES program), including both 'natural' forests as well as 'new' plantation forests. The study was based on an exhaustive literature review twinned with statistical analyses of official provincial data. Multivariate statistical modelling was used to explore the power of diverse variables (pertaining to the provinces' physical, demographic, ethnic, economic and forestry-related political-organizational characteristics) to explain overall changes in Vietnam's natural/planted forest cover. As will be shown, the statistical results broadly reflected the image provided by the literature. Certain biases in thematic and regional focus (and associated analytical limitations) were, however, apparent, and the data indicated shifting trends and limits to forest cover expansions.

2. Background

2.1. Historical perspectives - causes of forest decline in Vietnam until the 1990's

In Vietnam deforestation has occurred since colonial times from logging and land conversion

(McElwee 2016). Forest losses of ~15-23% (mainly in Central and Southern Vietnam) occurred from aerial herbicides and fires during the Indochina wars (1945-1975) (de Koninck 1999, Brauer 2009). Deforestation rates were highest, however, post-war. During the 1970s-1980s all forests were nationalized and managed by more than 400 state forest enterprises (SFEs) to extract timber and other resources (FSIV 2009, McElwee 2016). Furthermore, land conversion rates multiplied, including an expansion of slash-and-burn field cultivation (swiddening) in ethnic-minority dominated upland forests. The associated driving factors were diverse and included population growth due to resettlement programs to mountain areas (the so-called 'New Economic Development Zones') and natural increase (Vu et al. 2013, Jamieson et al. 1998); forced collectivization of agriculture in the lowlands and valleys, leading to decreasing crop productivity and added incentives to cultivate individual parcels in remote areas (Meyfroidt and Lambin 2008*b*, Castella et al. 2005*a*, 2006, Tachibana et al. 2001); and state appropriation of forestlands and disruption of customary use rights, leading to poor regulation and unrestrained resource access, and in some cases land conflicts (Tachibana et al. 2001, Nguyen et al. 2010, McElwee 2004, To et al. 2015). As a consequence, national forest cover declined from perhaps ~43% in 1943 to 16-27% in 1993 (estimates vary; De Koninck 1999). In combination with non-sustainable agricultural practices, this deforestation resulted in extensive denuded land areas, especially in the uplands (up to an estimated 40% national area; Vo and LeThac 1994), with detrimental knock-on effects such as nutrient losses, erosion, landslides, siltation of waterways and reservoirs, and recurrent flooding (Lippe et al. 2011, Clemens et al. 2010, Tran and Shaw 2007, Ziegler et al. 2004, Wezel et al. 2002*a*, *b*, Sikor 1995, cf. Cochard 2013). In the late 1980s the depletion of forest and land resources, rising costs of natural disasters, and the recognition of environmental degradation joined with evolving political and economic ideas to promote a variety of paradigm changes in forestry and land resources management (Jamieson et al. 1998, Vo and LeThac 1994, McElwee 2016).

2.2. Theorized forest transition pathways – in general and in Vietnamese context

A 'forest transition' describes an incisive change from historical forest loss to forest gain. Two general transition pathways have been described (Rudel et al. 2005). The first, termed 'economic development pathway', posits that technical and socio-economic changes related to development – such as agricultural intensification on the best lands, industrialization, and urbanization – lead to abandonment of less productive agricultural lands, which then revert to forest (Meyfroidt and Lambin 2008*b*). Here forest regrowth is mainly a side effect of economic growth and modernization.

The second, termed the 'forest scarcity pathway', is dependent on targeted policies in forestry and natural resource management. Under this pathway, increasingly pressing deficits of forest goods and services lead to the recognition that investments in forest maintenance and restoration would be economically rewarding. This can lead to both government and private initiatives to protect existing forests, plant new forests, and manage forests sustainably.

In Vietnam, both pathways played a certain role: economic modernization was concurrent with major state-led forest initiatives (Meyfroidt and Lambin 2008*a*, *b*). The causes of forest transition were, however, non-trivial and highly contextual (Pham et al. 2015, Meyfroidt 2013, Lambin and Meyfroidt 2010, Clement and Amezaga 2008), and, as will be illustrated, several regions have not gone through a forest transition. A large part of the variation in local or regional outcomes may be explained from the variation in 'predisposing environmental factors' (*sensu* Geist and Lambin 2002; e.g. terrain, elevation, soils, etc.) which differ markedly along various geographical gradients and distinct regions (Fig. 1a, b; cf. Sterling et al. 2006, Olson et al. 2001, Epprecht and Heinimann 2004). Another part may be attributable to locally/regionally differing 'underlying forces' (e.g. governance, policies, demographic and economic context; Fig. 1c, Table 1) and associated 'proximate causes' (e.g. effective state-sponsored reforestation, land conversion for farming). Within historical context and conventional interpretations, land uses by ethnic minority groups have often played a significant role (justified or unjustified) to explain forest dynamics, especially in remote mountainous provinces (Castella et al. 2006; cf. Fig. 1d). Fifty ethnic minority groups were known to practice shifting cultivation in forestlands. An estimated 7% of the Tày, 45% of Thái, 16% of Nùng and almost 100% of the H'Mong, Dao and other mountain ethnic minority groups practiced swiddening in 1989 – in total almost 3 million people with ~3.5 million ha under shifting cultivation (Do 1994).

2.3. Transformations in land management, and forest regrowth since the early 1990s

Several important changes were initiated within the course of broader national economic policy reforms starting in 1986 (cf. policy landmarks, Table A1, Appendix A, Supplementary Materials). In the agricultural sector, de-collectivization, market liberalization, and technical innovations radically increased productivity (Kirk and Nguyen 2009, Sikor and Vi 2005, Fatoux et al. 2002). Employment in lowland agriculture and fast growing industries released pressure on marginal lands, contributing to slowing deforestation (Meyfroidt and Lambin 2008*b*). Land laws were revised in 1988, 1993, and 2003, which developed and strengthened private property rights (Beresford 2008).

The forestry sector was also substantially restructured. Forest management authorities and responsibilities were transferred to provincial and district levels. State forest enterprises (SFEs) were reformed, through a shift in scope and function from pure extractive to more protection-oriented forestry, and/or industrial plantation forestry. Some SFEs were completely dissolved; the remaining were restructured or were transformed into either profit-oriented 'state-owned forest companies' (SFCs) or 'forest protection management boards' (FPMBs) mandated with the management of designated 'protection forests' or 'special use forests' (McElwee 2012).

Rural households and communities could gain forest tenure after the 1993 Land Law provided a legal basis for forestland allocation (FLA). The nature of FLA rights, however, depended on provincial contexts, and was typically managed by SFEs or FPMBs (McElwee 2012, Clement and Amezaga 2008, Dang et al. 2010, Ngo and Webb 2008, Castella et al. 2006). Initially, FLA was provided on degraded forestland or barren land to promote reforestation for land improvements and economic gain. Technical support was provided via extension through tree nurseries (mostly using exotic species such as acacia), as well as payments for labour, food and equipment. At later stages natural forestland was made available for FLA, whereby the focus was on protection, maintenance and upgrading of natural forests for specific purposes (mainly watershed protection) (Ngo and Webb 2008, Thiha et al. 2007). Reforestation activities were largely financed through Program 327 (*Greening the Barren Hills Program*; 1993-1998) and Program 661 (*Five Million Hectares Reforestation Program*; 1998-2010). Program 661 mostly aimed at protecting and upgrading forests in critical watersheds, including forest rehabilitation in upland regions (McElwee 2009, To 2007).

As a consequence, national forest cover (as shown by official data) had by 2013 increased to similar levels as in 1943, i.e. 41% of land cover (13.96 million ha). Of these forests, 25.5% (3.56 million ha), however, consisted of plantations with mostly exotic species such as acacias, eucalypts, pines, and rubber. Only 74.5% (10.40 million ha) were classified as natural forest (MARD 2015), but it is debatable how 'natural' these forests really are as they may range from impoverished bush- or thicket-like 'forests' to fairly intact and species-rich types of secondary forests (Meyfroidt and Lambin 2008*a*, Nicolic et al. 2008, Ankersen et al. 2015, Van and Cochard 2016). Many valuable forests continue to be degraded (Sikor and To 2011, Meyfroidt 2013, Jadin et al. 2013, McElwee 2004, 2016). According to FAO (2016) the cover of primary forests decreased almost by a factor of five from 384'000 ha (~4.4% of natural forest area) in 1990 to 85'000 ha (~0.8%) in 2005, but the cover has since stabilized.

2.4. Forestland allocation (FLA): socio-economic effects and consequences on forests

FLA programs exerted differing effects on people's livelihoods, and associated feedbacks on forest cover changes, depending on the context. FLA and accompanying legal constraints, and state control of forests via SFEs/SFCs, hindered shifting cultivation practices and other forest uses by farmers (Clement and Amezaga 2008). Natural forest grew back on abandoned swiddens, but the decline of land area for cropping in combination with the somewhat experimental introduction of new and more intensive farming technologies in sensitive environments incurred additional risks of crop failures and food shortages to the poor (Meyfroidt 2013, Castella et al. 2006, Bayrak et al. 2015, Jakobsen et al. 2007). This sometimes evoked resistance by traditional swiddener communities and occasionally the suspension of FLA plans (Vu et al. 2013, Alther et al. 2002). In other cases, land registration failed because new land rights conveyed less security than traditional systems which had more layers of social control (Sikor 2006). As a consequence, 'top-down' FLA programs were often remolded 'bottom-up', and adjusted to accommodate local realities. Traditional land tenure by relatively strong ethnic groups (e.g. Tày, Thái and Mường) were partly recognized (Castella et al. 2006), or some communities' autonomous land appropriation (asserted via exotic tree plantations during pre-FLA legal limbo) were condoned (Sikor 2012). However, concessions to dominant local stakeholders meant that poor households dependent on open-access natural resources (e.g. for swiddening), or immigrants not integrated into local communities, often got the 'shorter end' of FLA (Castella et al. 2006, Vu et al. 2013, Thiha et al. 2007, Sikor and Nguyen 2007, Gomiero et al. 2000). Many rural poor also lost land resource access as a consequence of state-sponsored reforestation with exotic plantations (McElwee 2009), rapid expansion of cash-crop plantations (e.g. coffee or rubber; Meyfroidt et al. 2013), or exclusion from protected areas (McElwee 2008, Sowerwine 2004, Zingerli et al. 2002).

Households' labor resources, social networks and access to finances were also important to determine whether (or at what rate) available lands could be planted with tree crops. Many households who obtained land rights lacked the means to plant trees, especially given the 3-7 years delay until harvest (Sikor 2012, Nguyen et al. 2010). In production forest areas FLA policies, however, usually required the planting of trees. Consequently, many poor farmers sold their land and became contracted laborers on the same lands (Sikor and Baggio 2014, Bayrak et al. 2015). There were also disparities between communities, some of which were well-connected to the state apparatus, and quick to innovate and mobilize resources to set up plantations. Other communities (often ethnic minority groups) took longer to tap into these new opportunities (Thulstrup 2015, Meyfroidt et al. 2013).

Resource disfranchisements, in addition to continuing rural population growth, led to some renewed pressures on natural forests. While many people found alternative incomes from emerging industries either locally (e.g. at pulp and paper mills) or in peri-urban areas, some relocated to weakly controlled upland areas and resorted to clear new swidden fields, thus reducing forest regeneration (Castella et al. 2006, Alther et al. 2002, Vu et al. 2013). Increases in natural and planted forest cover, furthermore, conceal the fact that many natural forests were still being degraded in quality via 'illicit' selective logging (cf. Sikor and To 2011, McElwee 2004); in some cases traditional protection controls of sacred forests were weakened by FLA interventions (Bayrak et al. 2015).

2.5. Reforestation programs and the role of para-statal forestry organizations

The 'achievement' of the 'forest transition' came at a major price. Reforestation programs cost more than 2 billion USD – funds which were acquired from the state budget, aid loans, donor support, and the private sector (McElwee 2009). Furthermore, while commercial logging in Vietnam's forests was largely banned during the programs, domestic demand for timber remained high and was only partially met by increases of plantation forestry. As a result, much timber exploitation was exported to neighboring countries, especially Cambodia and Laos (Meyfroidt and Lambin 2009, McElwee 2004, 2016).

Within this context, the roles of SFEs, now converted into SFCs and FPMBs, remained controversial. Endowed with state funds and official sanction, these para-statal forestry organizations continued to compete with local communities for land resources, lucrative afforestation programs, and access to commodity markets (To et al. 2015). They still drew prolific resources from state budgets for large-scale forest protection and development projects (including Programs 327 and 661), but were often seen to be relatively 'ineffective' in regards to improving land uses and economic performance (To et al. 2015).

In 2005 SFEs/SFCs controlled ~40% of Vietnam's forestlands (World Bank 2005). In addition, forestlands were variously contracted out to farmers whereby SFEs/SFCs managed and issued specific land contracts, e.g. for purposes such as forest restoration or protection. Many SFEs/SFCs were also charged with implementing FLA. In several provinces SFEs/SFCs were noted as notorious for continuing exploitative and profiteering practices (McElwee 2004). In districts well-endowed with natural forest, SFEs/SFCs reportedly delayed FLA in order to extract timber (Thiha et al. 2007, Ngo and Webb 2008). In other cases, extensive forestlands were assigned as 'protection forest', presumably partly so that SFEs/SFCs could benefit from state funds provided by reforestation programs targeted at watershed protection (Clement and Amezaga 2009). Conflicts have recurrently arisen about land contracted to SFEs/SFCs. In some cases, where local farmers had encroached on SFCs' lands, a so-called 'joint-venture' contract (*liên doanh*) between SFCs and occupants was negotiated (To et al. 2015). There is a gap in the literature as to what degree variable efficiencies of reforestation programs and forest management by SFEs/SFCs or FPMBs may explain overall forest cover changes.

3. Comprehensive review and data analyses

3.1. Conceptual-analytical approach and compilation of database

We first conducted a comprehensive literature review on the extent and causes of forest cover changes in Vietnam (summary Table A2, Appendix A, Supplementary Materials). Insights were used to compile a database with relevant and sufficiently reliable variables available from official sources. We then examined correlative patterns in the data via multivariate regression analyses, specifically focusing on how variables representing agricultural, forestry and land policy changes, and 'predisposing environmental factors', influenced the extents and changes of natural and planted forest cover in the provinces in between 1993-2013. Forest cover (areal extent) was assessed for 1993 and 2013 in the case of natural forest, and for 1999 and 2013 in the case of planted forest (reliable data for 1993 were unavailable). Relative cover changes were assessed for two periods (1993-2003 and 2003-2013) in the case of natural forest, and one period (1999-2013) in the case of planted forest (*F* variables, Table 2).

We tested 135 indicator variables ('independent predictors') which potentially influenced forest cover ('dependent *F* variables') within the 63 provinces. The indicator variables reflected information on geography and terrain (*G* variables), population and ethnicity (*P*), labor and poverty (*L*), infrastructural development (*I*), education (*E*), cereal staple crops agricultural land area and productivity (*A*), forest resource exploitation (*C*), and forest land under tenure or contracts (*T*). The data were mostly collected from official sources, but some data were compiled using Google Earth™. A summary of the 64 variables which turned out to be significant predictors in statistical models is provided in Table 2, including listing of data sources. In Appendix B (Supplementary Materials) a complete listing of all 144 tested variables is provided (Tables B1 and B2), including a PCA loading plot of important variables (Fig. B2), as well as a discussion of data quality.

3.2. Statistical analyses and interpretation

MS Excel and Minitab 17 statistical software (Minitab Inc., State College, PA) were used for calculations and multivariate statistical analyses. Before analyses all data variables were checked for normality; if necessary, data were transformed as appropriate (natural logarithm, square root, Box-Cox or Johnson transformation, or in some cases normal score function). Multivariate linear regression (MLR) was used to assess variable interrelationships. To work out optimal subsets of predictors in MLR models the 'best subsets regression' (BSR) tool in Minitab was used. Severe outlier or leverage points were identified using residual, Cox's distance and DFIT plots, and if considered necessary observations were deleted to improve MLR models. Non-significant predictors (p-value >0.05) were dropped from models in a step-wise mode (if not previously excluded by BSR selection). Principal components analysis was another aid used to better interpret data correlations, and separate relevant from irrelevant factors. While the data of most variables evidently followed spatial patterns according to Vietnam's geography (cf. Fig. 1), the residuals data of final regression models did not show statistically significant spatial autocorrelation (determined via testing the correlation of residuals with between-provinces spatial distance data). MLR model equations and relevant statistics are provided in Table 3.

4. Forest change in Vietnam and its causes

4.1. Natural and planted forest extent and change

The nature of the 'forest transition' in Vietnam, even whether it can be confidently asserted to have occurred or not, can only be partly resolved from official forestry and land use data due to quality issues and data gaps (e.g. upland swiddening and land tenure by para-statal forestry organizations). However, as detailed in our discussion of data quality (see Part 2 of Appendix B, Supplementary Materials; cf. also Nguyen et al. 2009*a*, Phan et al. 2011, McElwee 2004, 2016), we deem that the forest cover (*F*) data can be trusted to represent passably reliable figures, especially as regards their relative inter-provincial variability. This trust is based on the observations that the *F* data generally correspond with large scale and case-study based remote sensing analyses, and that the results of our statistical analyses agree with trends identified in the literature review.

According to official data, total natural forest cover in Vietnam increased from 26.1% of land area in 1993 to 31.4% in 2006; net cover subsequently remained more or less constant (cf. Fig. B3a, Appendix B, Supplementary Materials). At regional level there were, however, divergent trends (Fig. 2, Table 1). In the Northern Mountains Region, natural forests covered only 16.6% in 1993, but until 2013 more than doubled to 38.0%. Lesser increases were observed in the Central Coast Region. In contrast, in the Central Highlands and Southeastern Region, natural forests declined from 49.7% to 35.7%. Remnant forests (< 2% cover) increased marginally in the Red River and Mekong Deltas 1993-2003, but decreased again 2003-2013 (Fig. 2, Table 1).

Total planted forest cover in Vietnam increased relatively steadily from an estimated 4.4% of land area in 1999 to 10.6% in 2013. Highest increases were recorded in mid-elevation ('midland') provinces of the Northeast and Central Coast Regions (14-20% cover in 2013; Fig. 3, Table 1). Plantation cover in the lowlands remained minor (< 5%); it increased slightly in the Red River Delta but decreased in the Mekong Delta. Cover more than doubled in the remote, mountainous Northwest and Central Highlands Regions, but remained below 8% of land area in 2013 (Fig. 3, Table 1).

Forest change patterns, as shown by official data (Figs. 2-3), are mirrored in the literature. Meyfroidt and Lambin (2008*a*, *b*) documented forest cover changes in Vietnam 1993-2002. They verified that information on forest cover on official maps was 'consistent' with the most reliable data from remotely sensed sources; equally, reported forest changes were largely congruent with changes reflected in official district data. These patterns were, furthermore, corroborated by large-scale analyses of NDVI (Normalized Difference Vegetation Index) time series 1982-2006 by Vu et al. (2014*a*, *b*) as well as by a review of 54 publications on local or regional/provincial case studies which reported on forest changes (listed below Table 1; details in Table A2, Appendix A, Supplementary Materials). It should be noted, however, that there were geographical imbalances in case studies, as 71% were conducted in mostly mountainous provinces in the northern half of Vietnam. Most of these 'northern' studies (28) reported increases in natural forest cover (at annual rates of maximally 16%, Lào Cai Province), but some reported data (6) or qualitative observations (5) that indicated decreases. In contrast, only three studies in southern provinces documented natural forest regrowth, whereas nine studies reported net deforestation. Changes to swidden agricultural systems were a subject of 35 studies, and 38 studies described the establishment or expansion of various types of tree plantations, ranging from intercropping stands of fruit trees (often at higher altitudes) to small-scale acacia woodlots (mostly at mid-altitudes), and large rubber plantations (in the south). No studies reported decreases of plantation forests. Sections 4.2 through 4.8 present our analyses of causes of forest cover distribution and changes, based on regression models *M1-M11* (Table 3), and supported by the available literature.

4.2. Forest cover in relation to spatial and topographical factors

The distribution of natural forest largely reflects historic patterns of agricultural expansion. In the flat deltas of the Mekong and Red River, native forests have almost entirely disappeared. While a few lowland forest remnants persist along rivers (Vu 2006) or in protected locations on hills, islands or in home gardens (Trinh et al. 2001, Van and Cochard 2006), relict forests were further decimated 1993-2013, probably due to pressures emanating from urban growth and development (cf. Saksena et al. 2014, Castrence et al. 2014). With few exceptions (e.g. protected areas of Hà Tĩnh and Kiên Giang Provinces; McElwee 2010, Tanaka 2001) extensive forested areas are now only found at higher elevations, especially in large upland provinces, where also the largest changes (in absolute and relative terms) in natural forest cover have taken place in recent times (+*elevation***(*), *M1-3*, *M4a*, *M5d*, *M6a-c*; +*provarea****, *M1-4*, *M5d*; cf. variables in Tables 2 and 3 for details)[1]. As already outlined, forests in the northern mountainous provinces were severely degraded up to the early 1990s, and particularly so on steep and rugged terrain (–*mtrugged***(*), *M1*, *M3a-b*; cf. Meyfroidt and Lambin 2008*b*). In contrast, by 2013 forests had increased mainly in the northern mountains (Fig. 2), and mostly in areas of relatively unproductive and difficult-to-access, steep terrain (hence, positive association in *M4b*, +*mtrugged****; not significant in *M2* and *M4a*).

Between 1993 and 2003, major increases in natural forest cover occurred along latitudinal and poverty/developmental gradients (+*latitude****, +*hpoverty99***, *M5a*). The latitudinal effect (which also was significant in more elaborate models; +*latitude***(*), *M5a-d*, *M6b*; +*latitude**, *M2*, *M4a*) may be partly due to the more mountainous nature of northern provinces, but it may also be explained by proximity to Vietnam's political center Hà Nội. Since the 1990s many development and reforestation programs were concentrated on the relatively poor and environmentally degraded 'hinterland' of Hà Nội, and specific policies and laws may have been enforced more stringently than in other regions. In contrast, the Central Highlands (which were still a major repository of relatively untouched natural forests in 1993; Fig. 2) continued to supply timber and serve as a frontier for agricultural expansion (Meyfroidt et al. 2013; cf. Section 4.8.).

The productivity and range of acacia and rubber plantations in Vietnam is largely determined by soil

[1] The listed predictor variables (cf. Table 2 for description) which support the text statements (*elevation* and *provarea* in this case), including the corresponding regression model numbers (*M1-4*, *M5d* in this case), refer to the results presented in Table 3; the coefficient signs (+/–) and p-value significance levels (from strongly*** to medium** and marginally significant*; cf. Table 3) of the predictors in the models are also indicated.

water and fertility, and temperature (Trieu et al. 2016, Nguyen and Dang 2016). Statistical results show that plantation forests were mostly set up in the larger mid-elevation provinces less characterized by rugged terrain (dummy variable _+nodelta***_, _M7-11_; _–mtrugged**_(*), _M7-8, M10a_, _M11_; _+provarea***_, _M7-8_; _+provarea*_(*), _M9_, _M11_), but which were characterized by a relatively high population density (in 1999) and a high share (in 2013) of the population working in agriculture (_+rurpopd95***_, _M9_; _+workagri09**_(*), _M10a_, _M11_). Like natural forests, planted forest cover increased northward (_+latitude***_, _M7-8_), but plantations were more concentrated near the coast (_–distcoast*_, _M7-8_) and near centers of paper and/or pulp production (_+pulpcap04**_, _M10b_). Land accessibility and spatial proximity to wood buyers (paper/pulp facilities, Hà Nội, the Chinese border, coastal hubs) presumably stimulated the setting-up of plantations (cf. Sikor 2012, Sandewall et al. 2010, Clement et al. 2009). The predictors _pulpcap04, latitude_ and _distcoast_ were, however, insignificant in other models, which suggests that over the period 1999-2013 (and at larger 'provincial' data scales) factors relating to land tenure and agriculture were more dominant drivers of plantation establishment (_M9_, _M10a_, _M11_; cf. Section 4.9.).

4.3. Upland forests, ethnic minorities, shifting cultivation, and protected areas

In addition to topographical/spatial patterns, the distribution of natural forests in 1993 (but less so in 2013, cf. Sections 4.4. and 4.6.) appeared to reflect significant agricultural influences. Cover was negatively associated with land area cultivated permanently with cereal crops at the time (data available for 1995, _–cerland95**_(*), _M3a-b_); the association presumably reflects patterns mainly in the better developed provinces where most field plots were officially registered. In contrast, no reliable data were available on the extent of shifting cultivation fields in upland provinces. A negative association between forest cover and provincial population share of the H'Mong ethnic group (_–H'Mong**_(*), _M3a-b_), however, lends support to the notion (cf. Section 2.1.) that intensive shifting cultivation practices in the northern uplands had contributed to deforestation prior to 1993. The H'Mong and other minorities were noted for subsisting on traditional swidden farming in remote upland mountainous areas at least until the 1990s (Turner 2012, Castella and Dang 2002, Leisz 2009, Folving and Christensen 2007). Caution is, however, advised with 'ethnic' interpretations. Especially during the 1980s the populations of upland swiddeners had partly swelled (in addition to natural population growth) and/or been displaced by 'new' swiddeners who had immigrated from the lowlands, and who often ignored local land management rules (Castella et al. 2006). This often went hand in hand with uncontrolled logging by SFEs and other powerful networks and players (McElwee 2004, 2016; cf. Section 2.1.). In addition, traditional swiddening groups such as the H'Mong mainly occupy the remote northern uplands, which in the 1980s were particularly poor and underdeveloped and were generally less effectively controlled and administered by the state (cf. Epprecht et al. 2011). Hence, degradation may be mainly explained by the distance to Hà Nội and other administrative centres (possibly reflected by variable *–distcoast****, *M3a*, *M1*). Ethnic minorities were often blamed for deforestation (Castella et al. 2006), even though in earlier times 'traditional' swiddening was probably practiced in sustainable ways, with long fallow cycles allowing for forest regeneration (cf. Tran et al. 2006, Fox et al. 2000, 2001, Wangpakapattanawong et al. 2010).

The Tày, Nùng, Thái, and Mường traditionally occupied and cultivated fertile, alluvial basements and terraces within mountain valleys. These groups were generally less dependent on shifting cultivation (Castella and Dang 2002, Clement and Amezaga 2008). In order to ensure steady supplies of irrigation water, forests important for protecting watersheds were often maintained and managed in relatively sustainable ways. Furthermore, because of their sedentary lifestyles, communities were often better placed to uphold local rules of forest uses within changeable socio-political contexts (Nguyen et al. 2004, Sikor 2006, Meyfroidt 2013, Folving and Christensen 2007). This can explain the positive association of the variables *Tay* and *Muong* with natural forest cover in 1993 (*+Tay***, *+Muong*** *M3a*; lesser so in 2013, *+Muong**, *M4a-b*), as these minorities' land occupancy presumably provided a certain 'buffer' against excessive pressures on forests.

Correspondingly, areas protected by the state partly explained persistent forest cover in the provinces in 1993 (*+protect93***, *M3b*) and 2013 (*+protect02**, *M4b*). The first protected areas (PAs) were often set up to maintain the remaining forests in the hinterland of urban centers and in already largely deforested and intensively cultivated provinces (cf. ICEM 2003). Notably, this often lead to resource conflicts with local traditional land users, whereby timber resource extraction often significantly increased before a decently adequate PA management regime could be set in place (cf. McElwee 2008, Zingerli et al. 2002, Sowerwine 2004, Hoang et al. 2014). In some cases, extensive logging was even conducted by SFEs in forestlands which were in the process of becoming part of a PA (McElwee 2004, 2016). Despite of these impacts, the negative associations of PAs with forest cover changes in between 1993-2003 (*–protect93**, *–protch93-02**, *M5b*) probably primarily derive from the spatial limitations to forest increases in provinces with high PA cover, rather than actual large-scale deforestation within PAs (cf. spatial 'self-limitation' effects, Sections 4.4. and 4.6.; cf. forest degradation effects, Section 4.7).

4.4. The 'economic development pathway' of forest transition and its limits

Agricultural productivity was stimulated through commodity market formation and expansion, and increased via technical advances such as the introduction of new varieties of rice and maize, subsidies for fertilizers and pesticides, infrastructure improvements, the establishment of new permanent fields on alluvial lands or fixed terraces, or the improvement of upland fields by using sloping agricultural land technologies (Sikor 2001, Fatoux et al. 2002, Sikor and Vi 2005, Pingali et al. 1997, Wezel et al. 2002*b*, Folving and Christensen 2007, Jourdain et al. 2014, Leisz 2009). Agricultural intensification was described as a significant cause for the abandonment of marginal lands (followed by forest regeneration, often natural, sometimes aided) by seventeen studies (and was implied in a further six studies) conducted in the northern mountain provinces, and by two studies in the south (cause *agro-intensification*; Table 1). Since clear causal links were difficult to establish, substantiation was commonly qualitative in nature (studies providing data-based indications were Meyfroidt and Lambin 2008*b*, Vu et al. 2014*b*, Müller and Zeller 2002). Nonetheless, much literature supported the 'economic development pathway of forest transition', especially in remote, underdeveloped rural mountain areas where population pressures were high in relation to low land use potentials. Opposite patterns were reported by seven studies conducted in highly productive regions (Mekong and Red River Deltas, Southeast Region) or 'frontier' provinces (Central Highlands). In these regions increasing land rents, spurred by population growth (in an often already densely populated area) and economic development, exerted increased pressures on remaining forests.

Regional data partly reflected patterns characteristic of forest transition phases. Despite the fact that the rural population increased 1995-2010 in most mountain regions (up to 45% in the Central Highlands; cf. Meyfroidt and Lambin 2008*b*, Meyfroidt et al. 2013) the initially high average fertility rates (during 1970's ~6, in 1990 ~4 children per woman; Allman et al. 1991, GSO 2015) markedly declined to only 1.8-2.6 children per woman in different regions (annual average 2005-2015, Table 1). While populations in the Central Highlands and Southeast Region (which includes Hồ Chí Minh City metropolitan area) partly grew due to net immigration spurred by agricultural and industrial development (Table 1; cf. Meyfroidt et al. 2013, D'haeze et al. 2005, Grogan et al. 2015), the other regions experienced net emigration during 2005-2013. Along with population growth, land area under fixed-field rice and maize crops (the latter especially in mountain regions) expanded and productivity increased. Advances in cereal yields per hectare were highest in mountainous regions (increases of 53-92% as compared to 37-41% in the alluvial lowlands; Table 1; cf. Müller und Zeller 2002, Vu et al. 2014*a*, Castella and Dang 2002, Keil et al. 2009).

Statistical results appear to provide some evidence of the 'economic development pathway' in mountain provinces for 1993-2003, and to a lesser extent for 2003-2013. During 1993-2003 population densities and further population increases, apparently still limited natural forest regrowth and/or contributed to continued deforestation (*–popdens95****, *M5b*; *–rurpopd95**, *M5c*; *–rurpch95-03**, *M5d*; cf. Vu et al. 2014*a*, *b*), but model *M5d* suggests that the expansion of fixed agricultural land under cereal staple crops (mainly rice and maize, but also other cereals, cf. Ho 2014) exerted positive effects on forest changes (*+cerlrch95-03***), especially in higher-lying mountain provinces (*+elevation****). This may be a consequence of the direct economic 'pull' of land labor to more productive sites, and/or programs for agricultural land reclamation and improvement connected to FLA programs (cf. Section 4.5.). Since official statistics did not capture information on swiddens, the negative association of forest changes with increases in maize productivity (*–mapch95-03**, *M5d*) possibly reflects the circumstance that upland swidden fields were largely maintained (not replaced by forest) in provinces where productivity increases of maize were particularly high (cf. Meyfroidt and Lambin 2008*b*, Meyfroidt et al. 2013, Wezel et al. 2002*a*, *b*, Keil et al. 2009).

Natural forest cover changes during 2003-2013 (*natfrch03-13*) were only weakly explained (adjusted R^2 of 11.2%) by the changes in the preceding decade (+*natfrch93-03***, *M6a*), indicating that changes proceeded along largely divergent trajectories. Whereas labor was retracted from swiddens to more productive fields during 1993-2003, this trend apparently weakened during 2003-2013. Forests still tended to increase in the more mountainous and comparatively sparsely populated and poorer provinces (+*elevation****, –*rurpopd03***, *M6b*; +*elevation***, +*poverty09****, *M6c*). On the other hand, the expansion of lands under cereal crops no longer exerted positive effects; in fact, the association with forest cover changes turned significantly negative (–*cerlrch03-13****, *M6b-c*), and forest losses (or diminished increases) were especially observed in provinces where productivity of cereal fields was much improved since 1995 (–*cerprc95-13***; *M6c*). This indicates that further expansion of fixed cereal lands increasingly competed with space that could be occupied by forests (cf. Jakobsen et al. 2007). Natural forest increases, however, tended to be higher in provinces which were characterized by large areas of cereal (especially maize) crop fields in 2003 (+*cerland03****, *M6b*; +*maland03**, *M6c*). In those provinces the 'hunger' for additional cereal lands presumably had already been largely satisfied, and production increases were possible on already established fields.

From our data there was little overt evidence of direct competition for space between natural and planted forests (but see Sections 4.5-4.9.). The change ratios of natural forests were, however, negatively associated with the initial natural forest cover (–*natforest93****, *M5d*; –*natforest03****, *M6b*), and correspondingly for planted forests (–*plantfor99****, *M11*). Apart from this spatial 'self-limitation' effect, there were strong indications that planted forests increasingly competed with expanding agricultural cereal fields (–*cerlrch03-13***, *M11*), especially where adaptable new varieties of maize (often planted for commercial animal feed; Sikor 2001) allowed the extension of permanent fields on lesser productive terrain (–*mailch03-13****, *M11*; –*maland13****, *M10a*; cf. Meyfroidt and Lambin 2008*b*, Wezel et al. 2002*a*, *b*, Castella et al. 2005, Ankersen et al. 2015, Keil et al. 2009). In contrast, more land was available for the extension of tree plantations in provinces where relatively high improvements in cereal field productivity were achieved (+*cerprc95-13***, *M11*), especially in intensive rice productivity (+*ripch95-13***, *M10a*). This lends additional support for the economic development pathway.

In the fertile rice production regions of the Red River and Mekong Deltas, and other alluvial lowland areas, not much space was left for increases of forest plantations on remaining peripheral lands (dummy variable +*nodelta****, *M7-11*). Woodlots were often displaced by increasing urban sprawl and industrial developments (cf. Saksena et al. 2014, Phuc et al. 2014). Only in former rice production areas in lesser productive, ephemerally inundated regions in the Mekong River Delta (An Giang and Kiên Giang Provinces; cf. Figs. 2-3) some increases in *Melaleuca* swamp forests were possible. These forests partly regenerated naturally, or they were set up as economic plantations (Tanaka 2001).

4.5. Land allocation, management changes, and overall effects on natural forests

A major explanation for the abandonment of marginal lands was the hindrance of shifting cultivation practices in conjunction with FLA policies. This was mentioned as a cause for natural forest regrowth by eleven studies (and implied by a further six studies) conducted in the northern mountain provinces and by one study in the Central Highlands (cause *FLA / swidden stop*, Table 1). One study conducted in the Central Highlands (Sikor and Nguyen 2007) reported how FLA lead to an increase in deforestation due to deteriorating traditional land management regimes and ensuing resource conflicts. Within the context of FLA policies and reforestation programs, laws for forest protection were often set in place and enforced to various degrees via mechanisms, such as logistical support and payments for forest patrolling. These measures were noted by thirteen studies (and implied by a further four studies) as relevant factors for forest regrowth, whereas three studies noted negative influences on forests mostly due to weakening traditional forms of management (cause *policies / laws / control*, Table 1). Only one known study (Meyfroidt 2013) explicitly investigated whether perceived qualitative decreases in FES and/or newly internalized environmental value systems (e.g. through government awareness programs) influenced communities to change their forest management. At least seven other studies, however, mentioned communities' changed environmental perceptions and/or values, noting potential positive changes towards effective pro-forest management. Any of these policy-driven causes of forest regrowth may represent the 'forest scarcity pathway', but it is not always clear whether changes such as swidden abandonment would not have occurred also in the absence of policy interventions.

Between 1993 and 2003, natural forest cover increased in provinces where large areas of land were allocated for household tenure (i.e. 'Red Book' semi-permanent land use certificates; cf. Barney 2005, Nguyen et al. 2009*a*), either at the beginning (in 1995; *+hhften95***, *M5b*, *M5d*) and/or during the considered period (FLA until 2004, including community tenure; *+hhcften04***, *M5c*). Household forest tenure increased from 1995 (average 3.2%) to 2004 (10.0%), however predominantly in the Northern Mountains Region (19.3% in 2004) and Central Coast Region (13.5%), but remained very low in the Central Highlands and Southeast Region (0.8%; Table 1). FLA to entire communities (often ethnic minority villages) became possible in 2004 (Tran et al. 2010; Table 1).

In contrast to 1993-2003, increases in natural forests 2003-2013 could not be related to household tenure (*M6b-c*). Indeed, forest changes were negatively associated with forestland area allocated to households in between 1995-2004 (*–hhftch95-04***, *M6c*). This may be explained by several developments. FLA focusing on highly degraded forests in mountain areas generally contributed to forest regrowth 1993-2003, but FLA programs subsequently focused on relatively intact natural forests for management and sustainable livelihood improvements (cf. Section 2.3.). Legally required protective measures (e.g. patrolling) were sometimes only maintained during initial program phases, and regulations were relaxed, occasionally leading to cycles of excessive resource extraction, forest degradation and piecewise clearance (e.g. Thiha et al. 2007, Dien et al. 2013). In some cases, FLA led households to directly clear parts or all of the endowed forest plots for crops or acacia plantations, in order to secure land entitlement and tangible benefits (cf. McElwee 2009, Tran and Sikor 2006, Ngo and Webb 2008).

4.6. Changes in land management and natural forests within provincial contexts

During 1993-2003, and especially 2003-2013, natural forest increases were comparatively smaller (controlled for other factors) in provinces with large population shares of Tày (*–Tay***, *M5b-c*; *–Tay****, *M6b-c*), Thái (*–Thai**, *M5c*; *–Thai****, *M6b*) and Mường (*–Muong***, *M6c*) ethnic minorities. This may be partly explained by traditional systems of forest tenure, and reflect higher initial provincial forest cover (allowing for lesser subsequent forest increase; Sections 4.3. and 4.4). Tày, Thái and Mường communities were partly successful in maintaining traditional forms of land management, and sometimes obtained corresponding official legal tenure via FLA (Castella et al. 2006, Sikor 2006, Clement and Amezaga 2008). During 1993-2013 paddy/maize fields expanded, and these as well as many other (*–ethnother***, *M6b*; mainly Central Coast/Highlands Regions, Fig. 1d) mountain ethnic minorities became increasingly engaged in small-scale acacia and rubber forestry, limiting natural forest increase on allocated lands (cf. Wezel et al. 2002*a*, Castella et al. 2005*a*, Clement and Amezaga 2008, Sikor and Vi 2005, Thiha et al. 2007, Thulstrup 2015, Dien et al. 2013). Reduced forest regrowth may partly also have resulted from the exclusion of immigrant households from FLA, whereby some of the disfranchised turned again to swidden agriculture on non-allocated lands (Section 2.3).

In upland areas, FLA policies impeded the swidden practices of ethnicities such as the H'Mong and Dao, resulting in natural forest regrowth (*+H'Mong**, *M5d*; *+H'Mong****, *M6b*). This effect was possibly weaker in distant borderlands where FLA policies were less stringent and some communities maintained swidden practices (*–distcoast****, *M5d*; *–distcoast***, *M2*, *M4a*; cf. Folving and Christensen 2007, Alther et al. 2002, Jadin et al. 2013, Leisz 2009). In contrast to 1993 (Section 4.3), the ethnic composition of provinces was unimportant to explain forest cover in 2013 (minor exception *+Muong**, *M4a-b*), but forest cover was still marginally lower in provinces characterized by comparatively higher rural population densities (*–rurpopd13**, *M4a*) and higher levels of poverty (*–bpoverty09**, excluding variable *distcoast*, *M4b*).

4.7. Influences of forest management institutions on natural forest cover

In addition to forests devolved to households and communities, extensive forestland areas remained under tenure and management by para-statal or (to far lesser degrees) semi-private or private forestry organizations. We found no study which specifically investigated the differential influences of these organizations' land tenure and management on forest changes, but some qualitative inferences can be drawn from the literature (cf. Section 2.5.; cf. McElwee 2004, 2016, To et al. 2015, Clement and Amezaga 2009). Policy directions since the late 1980's shifted the scope of state forest enterprises (SFEs) and successor organizations (economically oriented state forest companies, SFCs, and forest protection management boards, FPMBs) towards more protection-oriented forestry, and large investments in reforestation were made via Programs 327 and 661 (Section 2.3.). None of the reviewed studies specifically focused on reforestation programs which were directly managed by SFEs, SFCs or FPMBs, but thirteen studies noted that larger-scale reforestation of watersheds or other target zones had been undertaken or supervised by respective para-statal organizations in the study area. On the other hand, unsustainable exploitation of forest resources reportedly continued in other forestlands managed by para-statal organizations with the consent or toleration of responsible authorities. Logging for high-value timber continued to be a serious issue, even within protected areas (Sikor and To 2011, McElwee 2004, 2008, 2016, Jadin et al. 2013). Twenty-three studies (of which eight actually documented net increases in forest cover) noted decreases in forest quality and integrity due to largely uncontrolled resource extraction (cause *forest resource exploitation*; Table 1). Furthermore, conflicts over forest resources between stakeholders (mainly between different communities or between communities and para-statal organizations) with negative outcomes for forest management were reported by six studies (and implied by eight), four of which were conducted in the Central Highlands.

Large forested areas were managed by SFEs/SFCs/FPMBs, but no official data has been published on their respective land tenure, much of which presumably goes under the lumped-up category 'other forest tenure' in Table 1 (cf. Nguyen et al. 2009*a*). In contrast, specific data were available on forests contracted by SFEs/SFCs (no distinction made between SFE and SFC) or FPMBs (distinction made between management boards for protection forests, MB-PFs, and for special use forests, MB-SUFs). As can be seen in Table 1 'other forest tenure' (average 12.3% in 2004) as well as 'forestlands contracted' by either SFEs/SFCs (13.2%) or MB-PFs (6.8%) increased from 1995 to 2004 (by ~22-119%), and areas under tenure/contracts were highest in mountainous provinces, especially in the Central Highlands and Coast Regions. Data were, furthermore, available on forestland contracts issued to households by SFEs/SFCs (Table 1). In most regions forestlands 'contracted to households' first decreased (average of 4.5% in 1995; 2.5% in 1999), but then rose again (4.3% in 2004), probably in conjunction with the dynamics of specific programs for reforestation and forest management (e.g. Programs 327 and 661; cf. Section 2.3). Relatively fewer households were contracted in the Central Highlands, resulting in generally larger areas managed per household (23.6 ha as compared to <11.5 ha in other regions; Table 1). Forests contracted for the purpose of 'protection' (data from 1999; contractors not specified but presumably mostly SFEs/MB-PFs) were found at similar levels in all mountain provinces (average 6.3% land), whereas forests 'contracted for regeneration' were mostly concentrated in the Northern Mountains Region (3.7% compared to <1.1% in other regions; Table 1).

In addition to these data on para-statal organizations' forest tenure and management (and including sub-contracting to households), data were available on land tenure by communal people's committees (CPCs), economic organizations (EOs) and 'foreign organizations' or 'joint ventures' (FOs/JVs). CPCs are temporary owners of forestlands that are in the process of being transferred from other owners (mainly SFEs/SFCs) to households or communities. While CPCs have tenure rights during the transitional period, CPC-managed forests (which were seldom of high timber quality in the beginning) have often become informal 'open access zones' due to weakly enforced controls (Nguyen 2011). At the beginning of FLA in 1995 CPCs still held substantial forestlands (7.1% total land area), especially in the Central Coast Region (17.0%), whereas CPC tenure decreased to only 1.0% area in 2004 (Table 1). EOs were mainly operators of hydro-electric dams and providers of freshwater for large cities, whereas some FOs/JVs were engaged in nature conservation and ecotourism projects (cf. McElwee and Nguyen 2014). Hence, EOs, FOs or JVs often had an interest in effective watershed management (steady water supplies, prevention of siltation) and forest protection. Land tenure by EOs varied by region but decreased nationally from 15.1% in 1995 to 11.9% in 2004 (Table 1). Tenure by FOs/JVs was only 1.5% in 2004.

The influences of different institutions' forest management varied widely, with some gradual changes over time (cf. also Section 4.9). Forest cover changes during 1993-2003 were marginally negatively associated with 'other forest tenure' in 1995 (–*otherften95**), but positively with forestlands contracted by SFEs/SFCs in 1999 (+*sfefcon99**, *M5d*). This suggests that during the 1990's natural forests did not fare well under the tenure of para-statal organizations, except if specific management directives were issued (and correspondingly sufficient state funding provided) under forest protection or reforestation contracts. In particular, forest cover changes were negatively associated with CPC tenure in 1995 (–*cpcften95****, *M5d*) and with the number of households contracted by SFEs in 1995 (–*nhhcon95**$^{(**)}$, *M5b-c*). Presumably, exploitation of scarce timber resources was initially still a dominant activity of SFEs and contractors. Reforestation of 'bare' forestlands (such as under Program 327, and using contracted labor) was largely undertaken by planting exotic species, rather than allowing the regeneration and improvement of 'natural' forest. Furthermore, in many cases where degraded natural forestlands were involved, time-limited legal rights endowed by contracts, and/or situations of quasi-open access (such as under transitional CPC tenure), probably encouraged the planting of exotic trees, which conveyed clearer signs of land resource entitlements as compared to native trees. Hence, some natural forests may have been replaced by acacias also on lands designated as 'protection forest' (cf. Section 4.9.; McElwee 2009, 2016, Thiha et al. 2007, To et al. 2015, Sikor and Baggio 2014, Thulstrup 2014).

During 2003-2013 natural forests increased in provinces where large areas were under contracts for purposes of forest regeneration or protection in 1999 (+*prorefcon99****, *M6b*; +*regenfcon99***, *M6c*). Some of these areas were probably contracted and directly managed by SFEs/SFCs or FPMBs. The positive association of forest cover changes with new forestland contracts to households during the periods 1995-1999 (i.e. start phase of Program 661; *+hhfcch95-99****) and 1999-2004 (expansion of Program 661; *+hhfcch99-04***, *M6b*) suggest, however, that the cooperation of households (many of which were probably already engaged in forestry tasks in 1995; *+nhhcon95**, *M6b*) played an important role for achieving specific reforestation targets (cf. McElwee 2016). Forest regrowth (natural, and possibly aided) was apparently also achieved in watersheds which until 2004 fell under the management EO's and FOs/JVs (*+ecofjvften04****, *M6b*; *+ecoftc95-04***, *M6c*). In contrast, natural forests designated for purposes other than forest regeneration or protection apparently mostly declined in cover under the management by para-statal organizations: cover changes were negatively associated with forestlands under contracts by SFEs/SFCs or MB-PFs in 2004 (*–sfefcon04****, *M6b*; *–mbpfcon04****, *M6c*), and also with forestlands which came under CPC tenure between 1995-2004 (*–cpcftrch95-04***, *M6c*). This points at an increasing emphasis by SFEs/MB-PFs away from management for protection/restoration of native-species forests towards more lucrative plantation forestry with exotics (cf. Section 4.9.; *–pltfrch99-13**, *M6a*).

4.8. Central Highlands and Southeast Region: Forests, societal shifts, and cash crops

Our statistical results probably do not adequately reflect the driving forces behind continuing deforestation in the Central Highlands and Southeast Region (Fig. 2). In Đắk Lắk Province, locally implemented FLA exerted mixed effects. One case study (Müller and Zeller 2002) reported improving forest conditions mainly due to agricultural intensification and strengthened controls on forest resources. Another study (Tran and Sikor 2006, Sikor and Nguyen 2007), however, described how FLA led to increased pressures on forest resources because of conflicting interests by new owners and neighboring villagers claiming traditional use rights. As described by Meyfroidt et al. (2013), the situation in the Central Highlands is complex, partly owing to historical legacies. The region, originally populated by ethnic minorities (primarily Ê Đê and M'Nông people), was the focus of resettlement programs from the late 1970's, often in conjunction with extensive forest exploitation by SFEs (cf. McElwee 2016). Liberalization in the 1990's spurred unplanned immigration (cf. Table 1) and further marginalization of many original inhabitants. During the 1990's deforestation was mainly driven by a coffee cash-crop boom, whereby plantations encroached on lands previously cultivated with staple crops (see also D'haeze et al. 2005, Dien et al. 2013). Many minority people were displaced and took to clearing new forestlands (see also Doutriaux et al. 2008). This detrimental cycle (plantation expansion - social displacement - forest clearing - plantation expansion) in many areas has continued until recently. With profits from rubber now exceeding those of coffee the deforestation focus has, however, shifted from the Highlands to lower-lying provinces in the adjacent Southeast Region (Meyfroidt et al. 2013; cf. Fig. 2). The rubber 'boom' is partly driven by expansion of small-holder plantations, but state-sponsored and private industrial plantations play an increasingly important role (Grogan et al. 2015, To and Tran 2014).

4.9. The plantation ‘boom’ as evidence for the ‘forest scarcity pathway’

Restrictions on shifting cultivation or contracts issued for forest protection/regeneration are motivated by the estimation of policy makers and other stakeholders that forests maintain vital functions and provide important FES. Nonetheless, despite apparent causal links, it is possible that some forests would have regrown in degraded areas even in the absence of policy measures. Data on planted forests, in contrast, provide unequivocal evidence for the ‘forest scarcity pathway’, since actively planted woodlots result from concrete demands for forest products and services which are economically driven and facilitated by land use policies.

FLA and forestland contract schemes significantly facilitated the planting of fruit tree gardens (especially in remote mountain areas) or the setting up of small-scale exotic tree plantations (mainly in the midlands). The factors that spurred the setting-up of private plantations was the focus of several studies conducted in the midlands (Sikor and Baggio 2014, Sikor 2012, Thulstrup 2014, 2015, Nguyen et al. 2010, Sandewall et al. 2010, Gomiero et al. 2000), but smallholder plantations were also mentioned in other studies as a factor of planted forest cover increase (overall 26 studies, and implied in another four studies; cause *FLA / tree planting*; Table 1). A few studies (6) also reported the setting-up of large-scale industrial tree plantations (mainly acacia or rubber) owned by private or state-owned companies.

Land tenure, and especially land contracts (by households, SFEs/SFCs, CPCs), fostered the fast establishment of plantations. In 1999 planted forest cover was associated strongly positively with the number of households having forestland contracts issued by SFEs in 1999 (+*nhhcon99****) and with the forestland area under household contracts in 1995 (+*hhfcon95***, *M9*). The pattern may be explained by the delay from the issuance of contracts to the setting up and expansion of plantations. Contracts issued in between 1995-1999 had only partly materialized into plantation cover in 1999 as compared to contracts issued earlier until 1995. Contracts issued until 1999, however, also partly explained plantation increases in between 1999-2013 (+*hhfcon99***, *M11*; +*nhhcon99**, *M10a*).

The establishment of tree plantations by households depends on many factors, such as security in land tenure, total agricultural/forest assets and income, household labor and family networks, availability of loans, agricultural extension support (e.g. local tree nurseries), and local market prices for wood products (influenced by factors such as regional market prices, transport access and vicinity of wood processing industries) (Nguyen et al. 2010, Sikor and Baggio 2014, Sandewall et al. 2010). As farmers tend to be budget-constrained and risk-averse there can be a delay of several years from FLA to the setting-up of plantations. Furthermore, re-allocation of land resources from poorer to more powerful households frequently occurred, partly explaining a time lag before plantation establishment (cf. Sikor and Baggio 2014, Thulstrup 2014, 2015; Section 2.4.).

It is notable that variables of household forestland tenure (*hhften95*, *hhften99*) were not significant predictors of plantation cover in 1999 (*M9*). This probably partly reflects the circumstance that many households who received forestlands via FLA, mainly in the Northern Mountains Region, were poor compared to other regions (cf. Fig. 1, Table 1); also agricultural extension programs initially mainly focused on improving the output of staple crops such as rice and maize (cf. Jakobsen *et al.* 2007, Folving and Christensen 2007, Sikor and Vi 2005, Nguyen et al. 2004, Keil et al. 2009). Furthermore, the remoteness of these regions increased transport costs of wood products to processing facilities, limiting profit margins (Nguyen et al. 2010, Alther et al. 2002, Gomiero et al. 2000). Household tenure (year 2004) was, however, highly important to explain plantation increases 1999-2013, and the cover in 2013 (*+hhften04****, *M11*, *M10a-b*). Hence, the plantation 'boom' eventually reached the northern mountains. To some degree the 'boom' also reached various relatively marginalized communities of ethnic minorities in the Central Highlands and Coast Regions (*+ethnother**, *M11*; cf. Thulstrup 2014, 2015, Thiha et al. 2007, Meyfroidt et al. 2013, Bayrak et al. 2015). Provinces with a high plantation cover in 2013 were generally characterized by net population emigration (*–migrat05-14****, *M10b*; cf. Table 1) which may have been partly due to a market-driven redistribution of labor and land resources. Farmers who successfully gained profits from plantation forestry were able to acquire additional lands and increase plantations, whereas other farmers became contract laborers or emigrants to industrial centers (cf. Sikor and Baggio 2014).

The plantation 'boom' is also reflected in a change of focus by para-statal forestry organizations. In 1999 planted forest cover was marginally negatively correlated with forestlands contracted by MB-PFs (*–mbpfcon99**, *M9*). This indicates that plantation expansion was possibly limited in provinces where extensive natural forestlands were assigned for protection under management by MB-PFs. Similarly, the expansion of plantations 1999-2013 apparently met limitations by forestlands managed by EOs since 1995 for watershed protection or other purposes (*–ecorgften95**, *M11*). In contrast, plantation increases after 1999 were positively related to forestlands contracted to either SFEs/SFCs, FPMBs or households (*+allfcon04***, *M11*), and plantations grew in provinces where until 2004 comparatively large proportions of forestlands remained under CPC tenure (*+cpcftrch95-04***, *M11*). This suggests that para-statal organizations (including sub-contracted laborers and other temporary forestland custodians) increasingly opted for plantations with fast-growing species in order to meet reforestation targets and/or increasing demands for economic self-sufficiency (cf. Amat et al. 2010, De Jong et al. 2006, Thiha et al. 2007, Dao et al. 2009, McElwee 2009). Especially in the case of CPC tenure, plantations may also have been set up by local communities (i.e. forest landholders *in spe*) in order to expedite the transfer process and/or preempt FLA through factual entitlements via plantations (cf. Section 2.4.; Sikor 2012, To et al. 2015). In 2013 the cover of planted forest was strongly positively associated with forestland area contracted by SFEs/SFCs in 2004 (*+sfefcon04****, *M10a-b*), and to lesser degrees with forestland area under tenure by CPCs and 'other' landholders in 2004 (*+cpcften04**, *+otherften04***, *M10a*).

Not all planted forests were, however, set up merely for wood production. In some regions, exotic trees (acacias, eucalypts, pines) as well as native trees (more than 28 species; Nguyen 2007) were used to establish forests on sites identified for regeneration. These were sometimes planted with the purpose to facilitate the re-colonization of native tree species, and hence ultimately re-establish quasi-natural forests, mostly managed for watershed protection and/or the rehabilitation of soils (cf. De Jong et al. 2006, Amat et al. 2010, Tran et al. 2005, McNamara et al. 2006, Millet et al. 2013). The boundaries between 'planted' and 'natural' forests are thus often somewhat fluid not only in official data, but also in reality (cf. Part 2, Appendix B, Supplementary Materials).

5. Final remarks

To explain the particularities of recent forest transitions in Asian countries, several recent national-level comparative studies have stressed the importance of private entrepreneurship in forest management (facilitated by arrangements for effective forestland ownership), sufficient provisioning of timber products to cover local demands (facilitated by cross-border timber trade and the setting-up of plantations), shifts in the national economy towards export-oriented manufacturing and service industries (facilitated by foreign direct investments), and strong pro-forest state interventions and policies (facilitated by international aid and expertise, and capacities generated from economic growth) (Youn et al. 2016, Li et al. 2015, Liu et al. 2016). However, broad inter-country comparisons focusing on the end state, ignore the complex, long and dynamically shifting pathways which may effectively lead to a so-called 'forest transition' within any particular country. Such pathways are strongly intertwined with a country's specific history, culture and geography, and the development trajectories and sequences may be multifarious within smaller-scale regional contexts. The outcomes of transition processes are neither deterministic nor irreversible (cf. Lambin and Meyfroidt 2010, Singh et al. 2015). While country comparisons tend to focus on differences in current forest governance, each country's broader realities and conditions are also singular.

Vietnam's story is unique within Southeast Asia, and so is the case of its recent forest cover changes (cf. McElwee 2016). Vietnam's forest transition occurred at a time of an increasingly pressing environmental crisis (cf. Jamieson et al. 1998); in this regard it bears resemblances to the case of several western countries in the 19th century (e.g. Switzerland, France, or others; cf. Mather 1992, Mather et al. 1999, Mather and Fairbairn 2000, Walker 1993). Widely perceived forest resource 'scarcity' (and associated effects) towards the end of the 1980's played an important role to trigger significant adjustments in Vietnam's forest policies and management. Until now, this is a major difference to other countries in Southeast Asia (e.g. Indonesia, Malaysia, Laos) where forest resources until recently were still perceived to be available in relatively ample quantities, and/or where the economy is characterized by lesser dependencies on national land resources in upland regions (e.g. Thailand). Even within Vietnam differences between the Northern Mountains Region (with fast net forest regrowth) and the

Central Highlands Region (with continuing net deforestation) suggest that the regional abundances of forest resources fundamentally influence patterns of resource uses and management. In this regard the Kingdom of Bhutan represents a rare exception; it has been noted as the only country in Asia where stringent conservation-inspired state forest policies led to an increase in forest cover under conditions of still-abundant forests (more than 60% cover; Bruggeman et al. 2016).

The Vietnamese forest transition also bears resemblances to earlier examples of transitions in Europe and North America (as well as more recent transitions in neighbouring provinces of China; cf. He et al. 2014, Xu et al. 2007, Mather 2007) as it coincided with the onset of strong national economic growth and modernization; this facilitated the efforts of the state and landholders to achieve a turn-around in forest management. Vietnam was characterized by levels of poverty similar to Ethiopia in the early 1980's, but the country has since achieved middle income status and currently features the second-fastest economic growth rate worldwide (after China) (Economist 2016). Compared to historical Euro-American forest transitions, however, significant differences exist in terms of the country's integration within globalized economic, political and ideological networks, including having access to ideas, tested experiences, technologies and sources of information which are now much advanced (cf. Kull et al. 2007, Lambin and Meyfroidt 2010, Li et al. 2015). For example, various agricultural innovations such as improved genetic varieties of key crops (including rice, maize and acacia trees; Tran and Kajisa 2006, Keil et al. 2009, Griffin et al. 2015), combined with high demands for agricultural and forestry products on international markets (e.g. staple crops, rubber, wood chips; To and Tran 2014, Barney 2005), contributed to rapid land use intensification which (as demonstrated in this and other studies) facilitated reforestation of marginal lands, especially in upland regions. Hence, as was earlier conjectured by Mather (2007), and as has recently been stressed by FAO (2016), the so-called 'Borlaug hypothesis' (which posits that agricultural intensification provided room for reforestation) is partly confirmed for the case of Vietnam. Our study, however, showed that agricultural modernization and land use transformations proceeded in contextually highly disparate ways, with certain regions actually experiencing continuing net deforestation as a result of expanding cash crop plantations (especially coffee and rubber).

More recently emerging trends in forest changes raise questions as to what degree the targets set by VFDS (2006) for the year 2020 can be reached. A further increase of the forest cover to 48% of national land area is presumably only possible in a scenario of furthered expansion of mainly exotic-species planted forests, and the upholding of tight restrictions on swidden farming. It remains unclear how a forest transition strongly shaped by exotic plantations can achieve targets to improve forest biodiversity and FES (including aspects pertaining to improvements of food security of the rural poor). Compared to natural forests, exotic plantations hold little value for biodiversity conservation (cf. Wang et al. 2011, McShea et al. 2009); they also differ in terms of ecosystem functions and services (cf. Chazdon 2008, Sidle et al. 2006, Jackson et al. 2005), and single-species plantations may be vulnerable to diseases and pests (Nambiar et al. 2015). Information on the composition and status of Vietnam's natural forests remains fragmentary; hence it will be difficult to adequately estimate FES over large areas - despite contrary assertions made by new PFES schemes (cf. McElwee et al. 2014, 2016, Ankersen et al. 2015). This situation is particularly disconcerting given additional uncertainties arising from impacts of climate change, invasive species and biodiversity losses (cf. Cochard 2011, 2013, Richardson et al. 2015, Rijal and Cochard 2016).

The high expenditures for forest management, including investments for reforestation such as under Programs 327 and 661, are probably difficult to maintain in the longer-term. Forest management (and the associated organizations) will therefore need to become more cost-effective in order to maintain and consolidate the gains made during the recent forest transition phase. This needs to be achieved within the context of newly rising pressures on forests. Even though natural forest degradation may potentially be reduced by substituting wood extraction from natural forests with wood cultivated in timber plantations (Pirard et al. 2016), natural forests in Vietnam are still under considerable logging pressure (Sikor and To 2011). With an increased pressure on forest resources in neighboring countries (Laos and Cambodia) the appetite for timber in Vietnam's remaining old-growth forests may further increase. The population is still increasing in several upland regions, and our results indicate that the 'economic development pathway' of forest transition may have reached a limit. Furthermore, the implementation of FLA has not led to satisfactory outcomes everywhere, with inequalities arising within as well as between certain communities. The resulting renewed pressures on forest resources may not be easily controlled and managed (cf. McElwee 2016).

PFES schemes can play important roles in increasing incentives for the protection and qualitative improvement of natural forests. Given current information gaps, new programs should, however, be accompanied by research that can foster a better grounding of PFES programs in ecological and socio-economic understanding. More information is, for example, needed about the sustainability of exotic plantation forestry, in particular the alien trees' long-term impacts on soils and local climate, including changes in ecological dynamics and risks of invasion and fire. More research is needed on the effects of natural forest fragmentation on biodiversity and vegetation stability, novel biological threats such as tropical vine invasions that smother forest regeneration, and the functions of exotic plantations to serve as wildlife corridors (cf. Gérard et al. 2015, Le et al. 2012, Cochard 2011, Dickinson and Van 2006). Better protection should be afforded to remaining primary forests within conservation areas, and particular efforts should be directed to the last remnants of lowland forests; these forests are composed of unique sets of potentially highly endangered species (cf. Sterling et al. 2006, McElwee 2010, 2016, Cochard 2016, Webb and Kabir 2009). Research should also address the question how local people can be adequately empowered in conservation-oriented forest management, and in how fast-changing traditional land use systems can contribute to natural forest protection (cf. Boissière et al. 2009, McElwee 2008, Bayrak et al. 2015). In many constellations, investment in the building of permanent field terraces is likely more cost-effective and sustainable than shifting cultivation (cf. Jourdain et al. 2014). If it is, however, found that some forms of traditionally practiced shifting cultivation represent a sustainable and locally appropriate form of land management (cf. Fox et al. 2000, Jakobsen et al. 2007), FLA schemes could also be adjusted to legalize certain flexible forms of land ownership and management.

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Fig. 1. Maps of Vietnam. **(a)** The overall terrain. **(b)** The provinces located within eight regions, i.e. 1.) Northwest (4 provinces), 2.) Northeast (11), 3.) Red River Delta (10), 4.) North-Central Coast (6), 5.) South-Central Coast (6), 6.) Central Highlands (5), 7.) Southeast (8), and 8.) Mekong River Delta (13). Northwest and Northeast Regions are conjointly referred to as the Northern Mountains Region. Source of maps: Wikipedia.com. **(c)** The provinces' population density (indicated by red colours) and poverty share (bubble size; i.e., percentage in the national 40% income bottom, ranging from 9% in TP HCM to 87% in Lai Châu Province). **(d)** The relative ethnic composition of the provinces (indicating the majority Kinh and the five most populous minority groups). The bubble size represents the land area (km^2) of each province. Data sources: World Bank (2015) and UNFPA (2011).

Fig. 2. Relative 'natural' forest cover and forest cover changes within Vietnams' provinces (area of bubbles representing officially reported absolute values in hectares). From right to left: forest cover in 1993 in the 63 provinces (dark green bubbles); changes in forest cover in between 1993-2003; and between 2003-2013 (light green colour: net forest increase; red colour: net deforestation); and forest cover in 2013. Data sources: MARD (2015) and Nguyen et al. (2009).

Fig. 3. Relative 'planted' forest cover and forest cover changes within Vietnams' provinces (area of bubbles representing officially reported absolute values in hectares). From right to left: forest cover in 1993 in the 63 provinces (dark blue bubbles); changes in forest cover in between 1999-2013 (light green colour: net forest increase; red colour: net deforestation); and forest cover in 2013. Data sources: MARD (2015) and Nguyen et al. (2009).

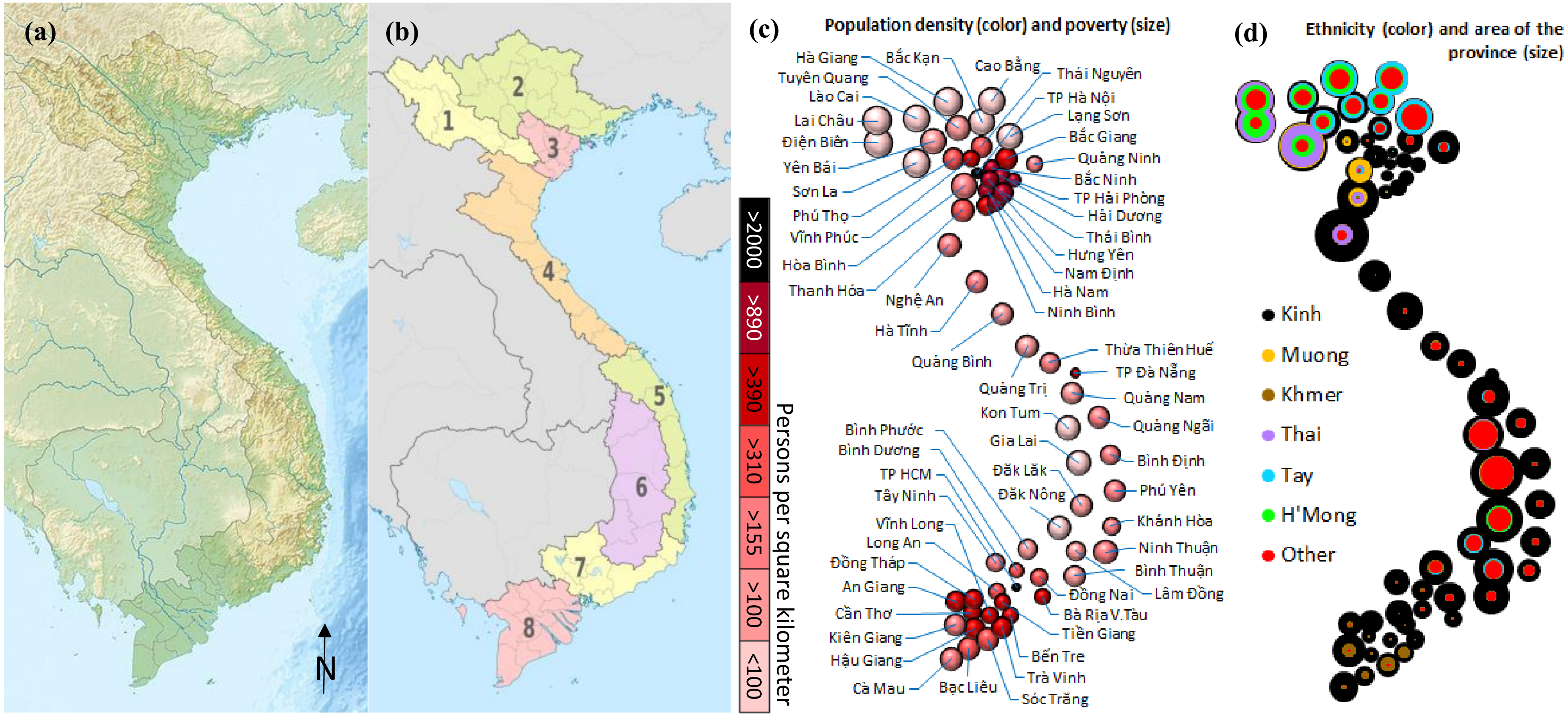
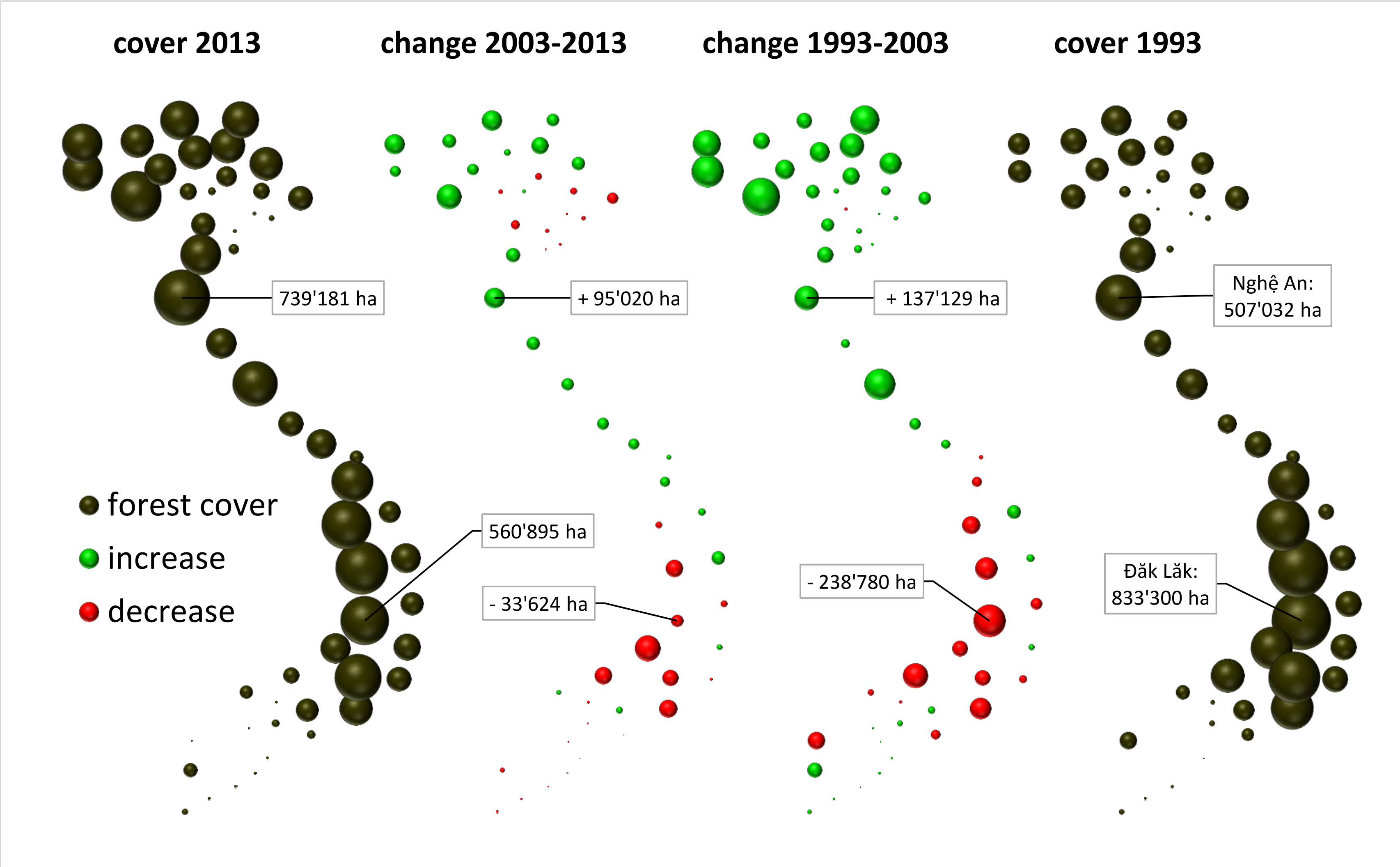

(a)
N
(b)
1
2
3
4
5
6
7
8
(c)
Population density (color) and poverty (size)
>2000
>890
>390
>310
>155
>100
<100
Persons per square kilometer
Hà Giang
Bắc Kạn
Cao Bằng
Thái Nguyên
Tuyên Quang
Lào Cai
TP Hà Nội
Lạng Sơn
Lai Châu
Điện Biên
Bắc Giang
Quảng Ninh
Yên Bái
Bắc Ninh
Sơn La
TP Hải Phòng
Phú Thọ
Hải Dương
Vĩnh Phúc
Thái Bình
Hưng Yên
Hòa Bình
Nam Định
Thanh Hóa
Hà Nam
Nghệ An
Ninh Bình
Hà Tĩnh
Quảng Bình
Thừa Thiên Huế
TP Đà Nẵng
Quảng Trị
Quảng Nam
Kon Tum
Quảng Ngãi
Bình Phước
Gia Lai
Bình Dương
Bình Định
TP HCM
Đăk Lăk
Tây Ninh
Đăk Nông
Phú Yên
Khánh Hòa
Vĩnh Long
Ninh Thuận
Long An
Bình Thuận
Đồng Tháp
Đồng Nai
Lâm Đồng
An Giang
Bà Rịa V.Tàu
Cần Thơ
Tiền Giang
Kiên Giang
Bến Tre
Hậu Giang
Trà Vinh
Cà Mau
Bạc Liêu
Sóc Trăng
(d)
Ethnicity (color) and area of the province (size)
Kinh
Muong
Khmer
Thai
Tay
H'Mong
Other

Fig. 1.



cover 2013
change 2003-2013
change 1993-2003
cover 1993
739'181 ha
+ 95'020 ha
+ 137'129 ha
Nghệ An:
507'032 ha
forest cover
increase
decrease
560'895 ha
- 33'624 ha
- 238'780 ha
Đăk Lăk:
833'300 ha

Fig. 2.

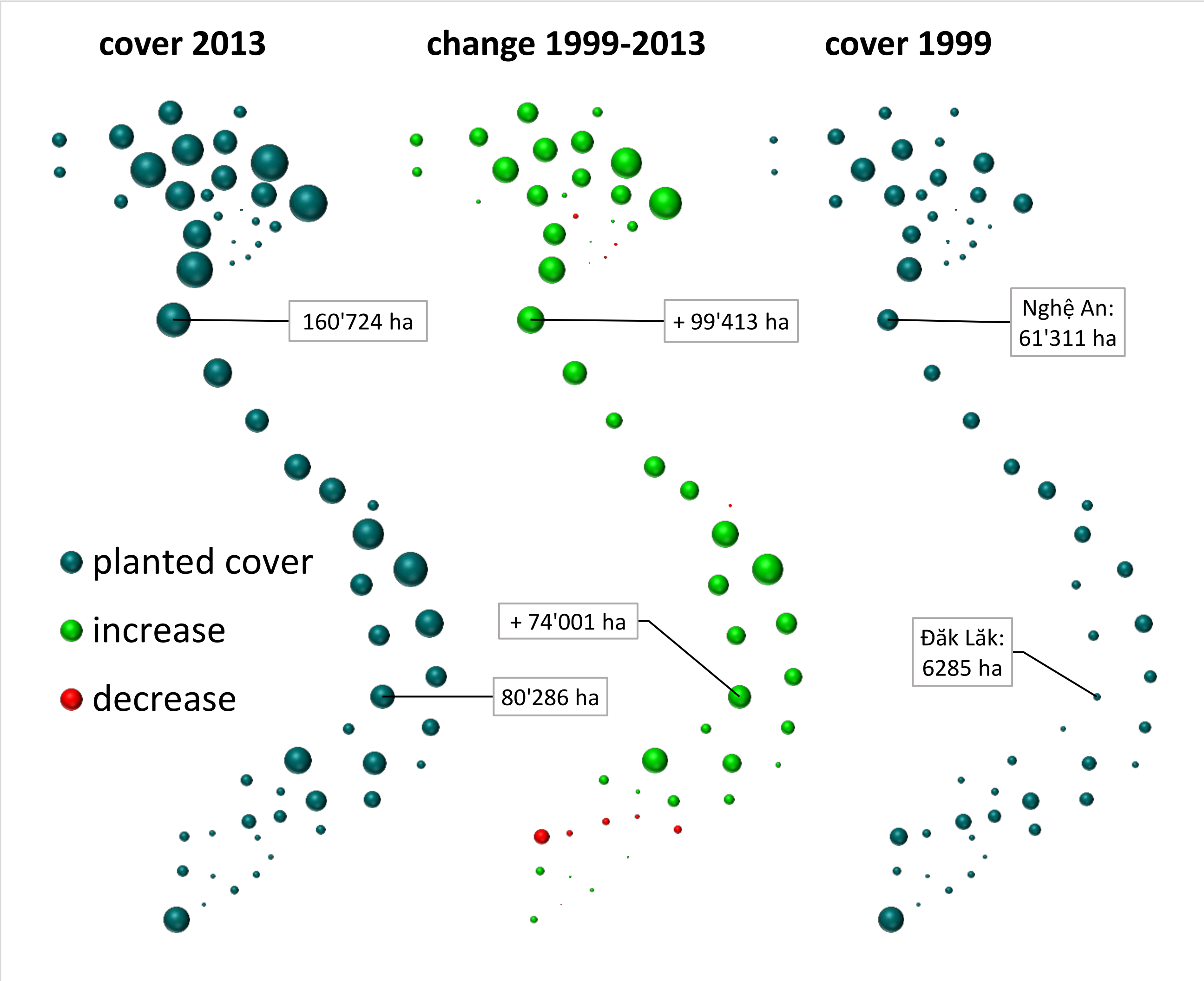

cover 2013
change 1999-2013
cover 1999
160'724 ha
+ 99'413 ha
Nghệ An:
61'311 ha
planted cover
increase
decrease
+ 74'001 ha
Đăk Lăk:
6285 ha
80'286 ha

Fig. 3.

Table 1. Regional summaries of relevant statistics of forest extents and changes, socio-economic and agricultural indicators, and statistics of forest land tenure and contracts. Included are triangle indices illustrating causal factors which in the literature were used to explain forest changes in different regions. The relevant literature references are listed below the table. For more details of literature review see Table A2, Appendix A; for data sources see Tables B1 and B2, Appendix B, Supplementary Materials. The data colouring indicates increases (light green) and decreases (red) during the time periods in between the indicated years.

Legend for qual. forest change causes:
- ▲ important cause of forest increase
- ▴ minor cause of forest increase
- ▼ important cause of forest decrease
- ▾ minor cause of forest decrease
- ♦ +/- no change of forest cover

Variables measured ∨		*Region* >	**All Vietnam**	Northern Mountains: Northwest Region	Northern Mountains: Northeast Region	Red River Delta	North-Central Coast	South-Central Coast	Central Highlands	Southeast Region	Mekong River Delta
Land	Total land area (km²)		**330'972**	37'415	63'962	14'957	51'459	33'205	54'641	34'762	40'572
Forest cover extent/change	Natural forest land (% of total land area)	in 2013	**31.4**	40.3	36.7	3.2	42.3	31.8	46.6	18.5	1.5
		in 2003	**30.2**	33.8	32.6	3.7	37.1	29.5	52.5	22.2	1.6
		in 1995	**26.1**	12.9	18.8	1.8	27.7	29.3	62.2	30.1	1.9
	Planted forest land (% of total land area)	in 2013	**10.6**	4.9	19.8	4.7	14.0	16.0	5.5	7.7	4.5
		in 2003	**6.3**	2.6	11.2	3.5	8.1	7.2	2.4	5.5	5.6
		in 1999	**4.4**	2.1	7.2	3.7	5.8	5.1	1.1	3.9	5.1
Causes of for. change	*agro-intensification*		▲	▲	▲	▾	▲	▴	▾	▾	▾
	forest land allocation (FLA) / swidden stop		▲	▲	▲	-	▲	▴	(▴)	?	-
	policies / laws / control		▴	▴	▴	-	▴	▴	?	?	(▴)
	forest land allocation (FLA) / tree planting		▲	▲	▲	♦	▲	▲	▴	▴	♦
	forest resource exploitation		▼	▾	▾	?	▾	▾	▼	▼	?
Socio-economic indicators/change	Rural population density (people km^{-2})	in 2010	**183**	63	118	884	163	142	68	210	325
		in 1995	**172**	48	110	899	166	143	47	167	323
	Fertility: mean no. children/woman	2005-2015	**2.1**	2.5	2.2	2.1	2.4	2.2	2.6	1.8	1.9
	Migration: annual pop. change (%)	2005-2013	**0**	-0.7	-2.8	0.5	-4.4	-2.3	0.6	12.0	-5.3
	Agricultural sector labor share (%)	in 2009	**48.8**	81.3	70.6	47.4	64.7	49.2	69.7	17.7	47.5
	Poverty: people below poverty line (% of total population)	in 2009	**19.6**	62.2	35.0	10.5	25.0	17.8	33.2	9.1	17.5
		in 1999	**34.4**	71.3	52.5	28.4	46.4	36.3	44.1	12.2	35.8
Agricultural indicators/change	Land area under rice crops (% of total land area)	in 2013	**23.9**	4.7	8.7	70.2	13.5	11.3	4.3	13.7	96.0
		in 1995	**20.4**	3.2	8.2	76.4	13.3	12.7	3.2	14.3	78.6
	Land area under maize crops (% of total land area)	in 2013	**3.5**	6.7	4.1	5.5	2.4	1.4	4.6	3.3	1.0
		in 1995	**1.7**	1.8	2.3	6.4	1.2	0.6	0.9	2.7	0.5
	Mean field productivity of cereals (tons of grains per hectare per year)	in 2013	**4.6**	3.3	4.3	5.8	4.6	5.2	4.6	4.4	5.2
		in 1995	**2.8**	2.0	2.5	4.1	3.0	3.3	2.4	2.7	3.8
	Mean pulp and paper capacity index ⌈[1]	in 2004	**5.0**	4.6	6.6	7.5	4.4	2.4	3.4	6.5	3.0
Prot. areas	Land area under nature protection ⌈[2] (% of total land area)	in 2002	**7.2**	8.3	7.0	3.8	12.0	4.7	8.6	7.4	1.8
		in 1993	**2.3**	3.5	1.5	1.9	2.6	1.5	3.9	3.2	0.2
Forestland tenure (% of total land area)	Household (HH) forest tenure (% of total land area; ~Red Book)	in 2004	**10.0**	22.4	17.6	2.0	15.5	10.3	0.6	1.1	2.7
		in 1995	**3.2**	3.8	6.8	0.6	3.6	2.0	1.1	2.7	1.6
	Community forest tenure (% land area)	in 2004	**0.5**	1.4	1.7	0.2	0	0.1	0.04	0	0.1
	'Other' (≠ HH, CPC, EO) forest tenure (% of total land area)	in 2004	**12.3**	3.0	13.7	2.9	14.2	9.5	20.3	21.9	3.1
		in 1995	**6.7**	4.5	3.7	0.9	7.3	7.3	16.4	7.0	1.0
	Communal people committees' (CPC) forest tenure (% of total land area)	in 2004	**1.0**	0.1	2.1	2.0	1.1	1.8	0.7	0.05	0.03
		in 1995	**7.1**	3.7	7.7	0.7	13.4	22.6	3.8	1.1	0.2
	Economic organizations' (EO) forest tenure (% of total land area)	in 2004	**11.9**	2.9	10.1	0.5	16.5	12.1	25.5	11.7	3.0
		in 1995	**15.1**	6.3	9.4	1.8	12.9	9.3	38.9	25.0	3.9
Contracted forestlands (% of total land area)	Forests (%) contracted by state forest enterprises or companies (SFEs/SFCs)	in 2004	**13.2**	1.6	8.9	1.1	20.8	14.7	29.2	11.4	4.0
		in 1999	**10.8**	0.5	5.8	1.2	13.4	13.1	28.8	10.9	2.3
	Forests (%) contracted by management boards of protection forests (MB-PFs) ⌈[2]	in 2004	**6.8**	1.3	3.4	2.5	3.2	10.3	15.3	15.0	2.1
		in 1999	**3.1**	1.0	1.1	0.7	1.5	2.6	7.4	8.5	1.2
	Forests contracted to households by SFE/SFCs (% of total land area)	in 2004	**4.3**	1.8	5.5	0.09	6.7	3.4	4.3	5.8	2.5
		in 1999	**2.5**	0.7	4.3	0.08	2.3	3.2	4.0	2.3	0.3
		in 1995	**4.5**	1.3	3.3	0.5	5.7	7.5	7.6	4.7	2.3
	Av. area (ha) per household contracted	in 2004	**9.5**	7.0	8.7	3.0	11.4	9.5	23.6	6.1	7.9
	Forests contracted for protection (%)	in 1999	**6.3**	5.1	7.1	1.4	8.1	4.1	8.2	8.4	3.0
	Forests contracted for regeneration (%)	in 1999	**1.6**	5.6	2.5	0.8	1.1	0.6	0.3	0.8	0.3

Footnotes: ⌈[1] The mean pulp and paper capacity index combines information of wood processing and transport capacities in the region (see Table B1c, Appendix B, Supplementary Materials). ⌈[2] Areas contracted by MB-SUFs (management boards for special use forest; cover not shown) corresponded approximately to the areas of nature protected areas. _Literature providing information and causal explanations of forest changes:_ **All Vietnam:** Meyfroidt et al. (2008*a*, *b*), Vu et al. (2014*a*, *b*); **Northwest Region:** Clement and Amezaga (2008, 2009), Clement et al. (2009), Folving and Christensen (2007), Lippe et al. (2011), Meyfroidt (2013), Nguyen et al. (2004, 2009*b*), Saint-Macary et al. (2010), Sikor (2001, 2006), Sikor and Dao (2002), Sikor and Vi (2005), Tachibana et al. (2001), Vu et al. (2013), Wezel et al. (2002*a*); **Northeast Region:** Castella et al. (2005*a*, *b*, 2006), Castella and Dang (2002), Hoang et al. (2014), Jadin et al. (2013), Meyfroidt (2013), Nguyen et al. (2010), Pham et al. (2015), Sandewall et al. (2010), Sikor (2012), Sikor and Baggio (2014), Tachibana et al. (2001), Trincsi et al. (2014), Turner and Pham (2015); **North-Central Coast:** Ankersen et al. (2015), Bayrak et al. (2015), Disperati and Virdis (2015), Jakobsen et al. (2007), Leisz (2009), McElwee (2008, 2009), Müller et al. (2014), Thiha et al. (2007), Tran et al. (2010), Dao et al. (2009); **South-Central Coast:** Sikor (2012), Sikor and Baggio (2014), Thulstrup (2014, 2015); **Central Highlands:** D'haeze et al. (2005), Dien et al. (2013), Heinimann (2006), Leinenkugel et al. (2015), Meyfroidt et al. (2013), Müller and Zeller (2002), Sikor and Nguyen (2007), Sikor and Tran (2007), Tran and Sikor (2006); **Southeast Region:** Grogan et al. (2015); **Mekong River Delta:** Heinimann (2006), Leinenkugel et al. (2015), Tanaka (2001)

Table 2: Summary of the dependent (*F*) variables and significant predictors (*G*/*P*/*L*/*A*/*C*/*T*) in multivariate models (Table 3). References for data sources are listed at the table bottom.

Variable name	Variable description	Source
Geographical and terrain (G) variables		
nodelta	Whether [0] or not [1] the province lies in the Red River or Mekong Delta	GEA
latitude	Latitude: north UTM coordinates (m) at approximate centre of the province	GEA
elevation	An index of the estimated mean elevation (metres a.s.l.) of the province	GEA
distcoast	The nearest distance from the province border to the coast (km)	GEA
mtrugged	An index of estimated mountainous rugged terrain cover (%) of the province	GEA
provarea	The provincial area cover (km^2)	WB
Forest cover extent and change (F) variables		
natforest93 / 03 / 13	Natural forest cover (ha) in 1993; respectively 2003; respectively 2013	MAR
natfrch93-03 / 03-13	Relative (%) natural forest cover change 1993-2003; respectively 2003-2013	MAR
plantfor99 / 13	Planted forest cover (ha) in 1999; respectively 2013	MAR
pltfrch99-13	Relative (%) planted forest cover change 1999-2013	MAR
Population indicator (P) variables		
popdens95	Population density (people km^{-2}) in 1995	GSO
rurpopd95 / 03 / 10	Rural population density (people km^{-2}) in 1995; respectively 2003; resp. 2010	GSO
rurpch95-03	Rural population change: population density in 2003 as a ratio of density in 1995	GSO
migrat05-14	Mean annual net migration (%) 2005-2014	GSO
Tay, *Thai*, *Muong*, *H'Mong*, *ethnother*	Tày, Thái, Mường, H'Mong, respectively 'other' ethnic mountain minority populations in provinces (% of total population) in 2009	UNP
Labor / economic development indicator (L) variables		
workagri09	Labor force (% of all labor forces) working in agriculture in 2009	WB
hpoverty99	Households (% of population) below poverty line in 1999	WB
bpoverty09	Population (%) in national 40% income bottom in province in 2009	WB
Agricultural productivity (A) and wood processing (C) indicator variables		
cerland95 / 03	Land area (1000 hectares) planted with cereal staple crops in 1995 / resp. 2003	GSO
cerlch03-13	Cereal crops land area change: 2013 cover minus 2003 cover	GSO
cerlrch95-03 / 03-13	Cereal relative (ratio) land area change 1995-2003; respectively 2003-2013	GSO
cerprch95-13	Cereal field productivity change: 2013 output ha^{-1} as a ratio of 1995 output	GSO
riprch95-13	Rice field productivity change: 2013 output ha^{-1} as a ratio of 1995 output	
maland03 / 13	Land area (1000 hectares) planted with maize in 2003; respectively 2013	GSO
mailch03-13	Maize crops land area change: 2013 cover minus 2003 cover	GSO
maprch95-03	Maize field productivity change: 2003 output as a ratio of 1995 output	GSO
pulpcap04	Index for provincial pulp-and-paper wood processing capacities in 2004 ⌈[1]	NSY/GEA
Forest land tenure and contract indicator (T) variables		
hhften95 / 04	Forest tenure (ha) by 'households and individuals' in 1995; respectively 2004	NSY
hhftch95-04	Change in forest area (ha) under household tenure 1995-2004	NSY
hhcften04	Forest tenure (ha) by 'households, individuals or communities' in 2004	NSY
cpcften95 / 04	Forest tenure (ha) by 'communal people's committees' in 1995; resp. 2004	NSY
cpcftch95-04	Change in forest area (ha) under tenure by CPCs 1995-2004	NSY
ecorgften95 / 04	Forest tenure (ha) by 'economic organizations' in 1995; respectively 2004	NSY
ecoftch95-04	Change in forest area (ha) under tenure by 'economic organizations' 1995-2004	
forjovften04	Forest tenure (ha) by 'foreign organizations and joint ventures' in 2004	NSY
ecofjvften04	*ecorgften04* plus *forjovften04*	NSY
otherften95 / 04	Forest tenure (ha) by 'other' non-specified owners in 1995; respectively 2004	NSY
regenfcon99	Forest area (ha) contracted for 'zoning for regeneration' in 1999	NSY
protfcon99	Forest area (ha) contracted for 'protection and management' in 1999	NSY
prorefcon99	*regenfcon99* plus *protfcon99*	NSY
allfcon04	Forest area (ha) contracted by any contractor (SFE, households, FPMB) 2004	NSY
sfefcon99 / 04	Forest area (ha) contracted by SFEs/SFCs in 1999; respectively 2004	NSY
nhhcon95 / 99	Number of households contracted by SFEs/SFCs in 1995; respectively 1999	NSY
hhfcon95 / 99 / 04	Forest area (ha) contracted to households by SFEs/SFCs in 1995; 1999; 2004	NSY
hhfcch95-99 / 99-04	Change in area (ha) contracted to househ. by SFEs/SFCs 1995-1999; 1999-2004	NSY
mbpfcon99 / 04	Forest area (ha) contracted by MB-PFs in 1999; respectively 2004	NSY
protect93 / 02	Nature protected area (ha) in the province in 1993; respectively 2002	ICE
protch93-02	Change in area (ha) covered by nature protected areas 1993-2002	ICE

<u>*Footnotes:*</u> ⌈[1] Index calculated using original NSY data and UTM coordinates, cf. Table B1c, Appendix B
<u>*List of data sources*</u>: GEA - compiled manually from Google Earth™; GSO - GSO (2014); ICE - ICEM (2003); MAR - MARD (2015); NSY - Nguyen et al. (2009*a*); UNP - UNFPA (2011); WB - World Bank (2015)

Table 3. Listing of multivariate regression model equations (*M1-M11*) for forest cover variables (natural forest in 1993, *natforest93*, and 2013, *natforest13*; correspondingly planted forest in 1999, *plantfor99*, and 2013, *plantfor13*), respectively the relative forest cover changes during time periods 1993-2003 (*natfrch93-03*), 2003-2013 (*natfrch03-13*) and 1999-2013 (*pltfrch99-13*). Statistical significance of the predictors is indicated by underlining as strong ($p<0.0005$), medium ($0.0005<p<0.005$) and rather marginally significant ($0.005<p<0.05$; no underlining). The adjusted R^2 and number of observations used for models are indicated in brackets below the equation. The function nscor indicates a normal score transformation, JT a Johnson transformation (cf. Tables B1 and B2, Appendix B, Supplementary Materials).

Equations for natural forest cover extent and changes	
M1	$[\textit{natforest93}]^{0.18} = -18.05 + 9.05 \times [\underline{\textit{elevation}}]^{0.13} - 0.937 \times \mathrm{nscor}[\underline{\textit{distcoast}}] - 1.69 \times \mathrm{nscor}[\underline{\textit{mtrugged}}] + 2.346 \times [\underline{\textit{provarea}}]^{0.16}$ (adj. R^2: 88.0%; 62 observations)
M2	$\mathrm{JT}[\textit{natforest13}] = -6.55 + 0.00000016 \times [\textit{latitude}] + 1.054 \times [\underline{\textit{elevation}}]^{0.13} - 0.202 \times \mathrm{nscor}[\underline{\textit{distcoast}}] + 1.153 \times [\underline{\textit{provarea}}]^{0.16}$ (adj. R^2: 88.7%; 62 observations)
M3a	$[\textit{natforest93}]^{0.18} = -11.66 + 5.18 \times [\underline{\textit{elevation}}]^{0.13} - 0.81 \times \mathrm{nscor}[\underline{\textit{distcoast}}] - 1.412 \times \mathrm{nscor}[\underline{\textit{mtrugged}}] + 3.79 \times [\underline{\textit{provarea}}]^{0.16} + 0.622 \times \mathrm{JT}[\underline{\textit{Tay}}] + 0.462 \times (-[\underline{\textit{Muong}}]^{(-0.33)}) - 0.638 \times \mathrm{JT}[\underline{\textit{H'Mong}}] - 0.9 \times \ln[\underline{\textit{cerland95}}]$ (adj. R^2: 93.6 %; 60 observations)
M3b	$[\textit{natforest93}]^{0.18} = -15.61 + 6.86 \times [\underline{\textit{elevation}}]^{0.13} - 2.304 \times \mathrm{nscor}[\underline{\textit{mtrugged}}] + 4.03 \times [\underline{\textit{provarea}}]^{0.16} - 0.575 \times \mathrm{JT}[\underline{\textit{H'Mong}}] - 1.15 \times \ln[\underline{\textit{cerland95}}] + 0.61 \times \mathrm{nscor}[\underline{\textit{protect93}}]$ (adj. R^2: 92.4%; 59 obs.)
M4a	$\mathrm{JT}[\textit{natforest13}] = -4.49 + 0.00000018 \times [\textit{latitude}] + 0.742 \times [\underline{\textit{elevation}}]^{0.13} - 0.203 \times \mathrm{nscor}[\underline{\textit{distcoast}}] + 0.85 \times [\underline{\textit{provarea}}]^{0.16} - 0.17 \times \mathrm{JT}[\textit{rurpopd10}] + 0.12 \times (-[\textit{Muong}]^{(-0.33)})$ (adj. R^2: 91.3%; 62 obs.)
M4b	$\mathrm{JT}[\textit{natforest13}] = -3.124 + 0.494 \times \mathrm{nscor}[\underline{\textit{mtrugged}}] + 0.954 \times [\underline{\textit{provarea}}]^{0.16} - 0.0068 \times [\textit{bpoverty09}] + 0.084 \times (-[\textit{Muong}]^{(-0.33)}) + 0.139 \times \mathrm{nscor}[\textit{protect02}]$ (adj. R^2: 90.5%; 60 observations)
M5a	$\mathrm{JT}[\textit{natfrch93-03}] = -1.98 + 0.00000098 \times [\underline{\textit{latitude}}] - 0.269 \times \mathrm{JT}[\underline{\textit{hpoverty99}}]$ (adj. R^2: 62.3%; 55 obs.)
M5b	$\mathrm{JT}[\textit{natfrch93-03}] = -0.337 + 0.00000148 \times [\underline{\textit{latitude}}] - 0.406 \times \ln[\underline{\textit{popdens95}}] - 0.37 \times \mathrm{JT}[\underline{\textit{Tay}}] - 0.224 \times \mathrm{nscor}[\textit{protect93}] - 0.087 \times \ln([\textit{protch93-02}]+1000) + 0.166 \times [\underline{\textit{hhften95}}]^{0.15} - 0.232 \times \mathrm{nscor}[\textit{nhhcon95}]$ (adj. R^2: 70.5%; 57 observations)
M5c	$\mathrm{JT}[\textit{natfrch93-03}] = -3.46 + 0.00000135 \times [\underline{\textit{latitude}}] - 0.28 \times \mathrm{JT}[\textit{rurpopd95}] - 0.296 \times \mathrm{JT}[\underline{\textit{Tay}}] - 0.11 \times (-[\textit{Thai}]^{(-0.4)}) + 0.126 \times [\underline{\textit{hhcften04}}]^{0.17} - 0.325 \times \mathrm{nscor}[\underline{\textit{nhhcon95}}]$ (adj. R^2: 69.5 %; 57 obs.)
M5d	$\mathrm{JT}[\textit{natfrch93-03}] = -3.315 + 0.00000055 \times [\underline{\textit{latitude}}] + 1.98 \times [\underline{\textit{elevation}}]^{0.13} - 0.284 \times \mathrm{nscor}[\underline{\textit{distcoast}}] + 1.1 \times [\underline{\textit{provarea}}]^{0.16} - 0.682 \times [\underline{\textit{natforest93}}]^{0.18} - 0.177 \times \mathrm{JT}[\textit{rurpch95-03}] + 0.185 \times \mathrm{JT}[\textit{H'Mong}] + 0.13 \times \mathrm{JT}[\underline{\textit{cerlrch95-03}}] - 0.074 \times \mathrm{JT}[\textit{maprch95-03}] - 0.434 \times [\underline{\textit{cpcften95}}]^{0.08} + 0.18 \times [\underline{\textit{hhften95}}]^{0.15} - 0.031 \times \ln[\textit{otherften95}] + 0.015 \times [\textit{sfefcon99}]^{0.26}$ (adj. R^2: 97.7 %; non-delta provinces, 34 obs.)
M6a	$\mathrm{JT}[\textit{natfrch03-13}] = -2.44 + 1.39 \times [\underline{\textit{elevation}}]^{0.13} + 0.298 \times \mathrm{JT}[\underline{\textit{natfrch93-03}}] - 0.32 \times \mathrm{JT}[\textit{pltfrch99-13}]$ (adj. R^2: 39.6 %; 60 observations)
M6b	$\mathrm{JT}[\textit{natfrch03-13}] = -8.215 + 0.000000413 \times [\textit{latitude}] + 3.05 \times [\underline{\textit{elevation}}]^{0.13} - 0.122 \times [\underline{\textit{natforest03}}]^{0.2} - 0.32 \times \mathrm{JT}[\underline{\textit{rurpopd03}}] + 0.34 \times \ln[\underline{\textit{cerland03}}] - 0.38 \times \mathrm{JT}[\underline{\textit{cerlrch03-13}}] - 0.64 \times \mathrm{JT}[\underline{\textit{Tay}}] - 0.26 \times (-[\underline{\textit{Thai}}]^{(-0.4)}) + 0.34 \times \mathrm{JT}[\underline{\textit{H'Mong}}] - 0.28 \times \mathrm{JT}[\textit{ethnother}] + 0.258 \times [\underline{\textit{ecofivften04}}]^{0.16} + 0.119 \times [\underline{\textit{prorefcon99}}]^{0.2} - 0.239 \times [\underline{\textit{sfefcon04}}]^{0.16} + 0.133 \times \mathrm{nscor}[\textit{nhhcon95}] + 0.26 \times \mathrm{nscor}[\underline{\textit{hhfcch95-99}}] + 0.137 \times \mathrm{nscor}[\underline{\textit{hhfcch99-04}}]$ (adj. R^2: 91.4 %; 57 observations)
M6c	$\mathrm{JT}[\textit{natfrch03-13}] = -18.2 + 1.69 \times [\underline{\textit{elevation}}]^{0.13} + 0.037 \times [\underline{\textit{bpoverty09}}] - 0.67 \times \mathrm{JT}[\underline{\textit{cerlrch03-13}}] - 2.15 \times \ln[\underline{\textit{cerprch95-13}}] + 1.77 \times [\textit{maland03}]^{0.22} - 0.51 \times \mathrm{JT}[\underline{\textit{Tay}}] - 0.275 \times (-[\underline{\textit{Muong}}]^{(-0.33)}) - 25 \times [\underline{\textit{hhftch95-04}}]^{0.1} - 0.07 \times \ln[\underline{\textit{cpcftch95-04}}] + 34.8 \times [\underline{\textit{ecoftch95-04}}]^{0.08} + 0.92 \times [\underline{\textit{regenfcon99}}]^{0.08} - 0.324 \times \mathrm{nscor}[\underline{\textit{mbpfcon04}}]$ (adj. R^2: 78.9 %; only non-delta provinces; 40 observations)
Equations for planted forest cover extent and changes	
M7	$[\textit{plantfor99}]^{0.33} = -40.0 + 11.02 \times [\underline{\textit{nodelta}}] + 0.0000071 \times [\underline{\textit{latitude}}] - 2.73 \times \mathrm{nscor}[\textit{distcoast}] - 4.88 \times \mathrm{nscor}[\underline{\textit{mtrugged}}] + 11.66 \times [\underline{\textit{provarea}}]^{0.16}$ (adj. R^2: 53.8 %; 62 observations)
M8	$[\textit{plantfor13}]^{0.3} = -50.7 + 10.35 \times [\underline{\textit{nodelta}}] + 0.00000646 \times [\underline{\textit{latitude}}] - 2.22 \times \mathrm{nscor}[\textit{distcoast}] - 4.11 \times \mathrm{nscor}[\underline{\textit{mtrugged}}] + 14.56 \times [\underline{\textit{provarea}}]^{0.16}$ (adj. R^2: 69.6 %; 62 observations)
M9	$[\textit{plantfor99}]^{0.33} = -8.16 + 14.89 \times [\underline{\textit{nodelta}}] + 5.72 \times [\textit{provarea}]^{0.16} + 7.51 \times \mathrm{JT}[\underline{\textit{rurpopd95}}] + 4.743 \times \mathrm{nscor}[\underline{\textit{nhhcon99}}] + 3.13 \times \mathrm{nscor}[\underline{\textit{hhfcon95}}] - 2.35 \times \mathrm{nscor}[\textit{mbpfcon99}]$ (adj. R^2: 75.7 %; 59 observations)
M10a	$[\textit{plantfor13}]^{0.3} = -4.8 + 5.23 \times [\underline{\textit{nodelta}}] - 3.57 \times \mathrm{nscor}[\underline{\textit{mtrugged}}] + 0.013 \times [\underline{\textit{workagri09}}]^{1.41} + 5.27 \times [\underline{\textit{riprch95-13}}] - 7.74 \times [\underline{\textit{maland13}}]^{0.14} + 1.91 \times [\underline{\textit{hhften04}}]^{0.17} + 0.205 \times [\textit{cpcften04}]^{0.17} + 0.57 \times [\underline{\textit{otherften04}}]^{0.19} + 1.87 \times [\underline{\textit{sfefcon04}}]^{0.16} + 1.4 \times \mathrm{nscor}[\textit{nhhcon99}]$ (adj. R^2: 93.2 %; 58 obs.)
M10b	$[\textit{plantfor13}]^{0.3} = -2.78 + 6.36 \times [\underline{\textit{nodelta}}] - 3.01 \times \mathrm{JT}[\underline{\textit{migrat05-14}}] + 3.3 \times \ln[\underline{\textit{pulpcap04}}] + 1.354 \times [\underline{\textit{hhften04}}]^{0.17} + 2.24 \times [\underline{\textit{sfefcon04}}]^{0.16}$ (adj. R^2: 86.8 %; 61 observations)
M11	$\mathrm{JT}[\textit{pltfrch99-13}] = -2.945 + 0.84 \times [\underline{\textit{nodelta}}] - 0.467 \times \mathrm{nscor}[\underline{\textit{mtrugged}}] + 0.663 \times [\underline{\textit{provarea}}]^{0.16} - 0.051 \times [\underline{\textit{plantfor99}}]^{0.33} + 0.0031 \times [\underline{\textit{workagri09}}]^{1.41} + 0.17 \times \mathrm{JT}[\textit{ethnother}] - 0.17 \times \mathrm{JT}[\underline{\textit{cerlch03-13}}] - 1.04 \times [\underline{\textit{mailch03-13}}]^{0.14} + 1.16 \ln[\underline{\textit{cerprch95-13}}] + 0.12 \times [\underline{\textit{hhften04}}]^{0.17} + 0.036 \times \ln[\underline{\textit{cpcftch95-04}}] - 0.075 \times [\textit{ecorgften95}]^{0.14} + 0.05 \times [\underline{\textit{allcon04}}]^{0.24} + 0.23 \times \mathrm{nscor}[\underline{\textit{hhfcon99}}]$ (adj. R^2: 88.4 %; 59 obs.)

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Supplementary Data A: Additional summary information from the literature review

Part 1: Overview over forest-relevant policy landmarks

Table SA1: Summary of important new policies, decrees, decisions and documents which influenced the course of forest management within Vietnam. Information sources were Castella et al. (2006), De Jong et al. (2006), McElwee (2012), McElwee et al. (2014), Meyfroidt and Lambin (2008*a*), Nguyen (2008), Pham (2006), Pham et al. (2015), Sandewall et al. (2010), Thiha et al. (2007), VFDS (2006).

Year	Policies, decrees, decisions, documents	Description
Era: State forest management and collectivization		
1960	Forest collectivization in North Vietnam	All forests were managed by state forest enterprises (SFEs).
1975	Forest collectivization in South Vietnam	All forests were managed by SFEs and cooperatives.
1981	Directive 100 CT/TW	Improvement and expansion of contract system targeted at labor groups of agricultural cooperatives, improving management and distribution mechanism of cooperatives based on labor productivity. Preparation of issuance of land use rights.
Era: Shift to market economy and devolution of forest resources management		
1986	Đổi Mới policy	Đổi Mới (economic renovation) policy launched after the determination of the Sixth National Congress of the Vietnamese Communist Party. The decision paved the way for the introduction of a 'free market' economy.
1988	Resolution 10 NQ/TW	Agricultural land was allocated on a long-term lease to individual households. In effect the end of the collectivization period.
1988	The Land Law revision 1	First time defined three forms of land allocation: land allocation for long term and permanent use, land allocation for time-fixed term use, and land allocation for temporary use.
1991	Law on Forest Protection & Development	Opening places for local people's participation in forest protection and management. A shift towards forest privatization.
1992	Decree 327	Re-greening barren hills and socio-economic development programs through plantations.
1993	The Land Law revision 2	Formalized allocation of agricultural and forest lands to individual households through provision of permanent land certificates.
1994	Decree 02/CP/1994	Forest land allocation to organizations, households, and individuals.
1995	Decree 01/CP/1995	Forest land contracts (leasing-out of SFE-lands to households) for the purposes of agriculture, forestry and aquaculture.
1998	Decree 661/QD-TTg	Restoration of 5 million hectares of forest during 1998-2010 (5MHRP - 5 Million Hectare Reforestation Program).
1999	Decree 163/1999/ND-CP	Government decree on land allocation for forestry purposes.
1999	Decision 187/1999/QQ§-CP	On the reorganization and management mechanism of the State Forest Enterprises system.
Era: Socio-economic development and 'natural' forest land allocation		
2001	Decision 178/2001/QD-TTg	On the beneficiary rights and obligations of households and individuals who have forest land allocated, leased or rent.
2003	The Land Law revision 3	Land Law passed by the National Assembly, recognizing the legal status of communities as owners of land resources.
2004	Law on Forest Protection & Development	Law passed by the National Assembly, recognizing common property as a legal forest management arrangement.
2004	Decree 181/2004/ND-CP	Government decree providing a new framework for forestland allocation (replacing Decree 163), following the 2003 Land Law
2004	Decree 200/2004/ND-CP	Reclassification, renovation and development of State-Forest Enterprises (SFEs).
Era: Payments for forest ecosystem services		
2006	Vietnam Forestry Development Strategy 2006-2020	Setting goals and objectives for forestry sector development in Vietnam. Emphasizes the move from state to social and private forestry. Forestry financing is based on new market mechanisms, such as PFES (payments for forest environmental services).
2008	Decision 380/QD-TTg	Decision on piloting PFES in provinces Lâm Đồng and Sơn La before rolling out this program nationwide.
2010	Decree 99/ND-CP/2010	PFES program was officially endorsed at national level.
2010	New Rural Development Program	Setting objectives and work plans for rural development including economy, environment, culture, and food security.

Part 2: Overview over case studies in Vietnam reporting on forest changes and the associated causes

Using literature databases (Scopus®, Google Scholar) and cross-references from published and peer-reviewed articles (including book chapters and monographs), we conducted a comprehensive search on natural and planted forest changes in Vietnam since around 1990. We included publications (year 2000 until recent) concerned with the interactions of forest changes, reforestation programs and policy changes, and people's livelihoods. Through a literature 'comb-out' we identified key causal factors that authors used in order to explain the observed changes in forest cover and/or qualities. Furthermore, we gathered information on the overall effects of policies (and associated changes) on socio-economic conditions in studied communities. A visualized summary of findings from this review is presented in Table SA2 below. The qualitative assessment of literature was used to support the initial data variable selection for the statistical part of the study (cf. Appendix B), and finally as an underpinning for the interpretation and discussion of the results from the analyses of forest cover data.

Causal factors that authors used to explain observed changes in forest cover and/or qualities were:

a) **Agricultural intensification** (factor *agro-intensification*). Positive effect: Devolution of agricultural land ownership and substantial increases in field productivity (fostered by improved extension services and spurred by liberalized markets) alleviated pressures on natural forests. Fields on remote and/or unproductive sites (especially swidden fields in upland areas) were abandoned as labor was bound on increasingly productive agricultural areas and new industries leading to natural forest regrowth. Negative effect: Fields were extended into forest areas due to unrestricted regulations, causing net deforestation.
b) **Disruption of swiddening by forest land allocation policies** (factor *FLA/swidden stop*). Positive effect: FLA lead to the devolution of forest land management responsibilities to the assigned land holders with the result that unrestricted (and potentially unsustainable) swiddening cultivations on open-access forest lands were no longer possible, leading to natural forest regrowth on these areas. Negative effect: Net deforestation resulting from FLA. This may be due to unequal FLA whereby some farmers with insufficient land were forced to set up swiddening plots in more remote forested areas. Or it may be due to local contexts (e.g. contravening traditional rules) whereby legal land titles remained opposed, leading to farmers clearing forest in order to 'occupy' contested forests.
c) **Policy directives, legal constraints and controls** (factor *policy/laws/control*). Positive effect: New policy directives and laws, and associated official controls and monitoring, lead to better protection of the remaining natural forests, and degraded forests generally recovered due to better management by private holders of allocated lands, and/or by SFEs on state-owned lands. Negative effect: Net deforestation resulting from new policy directives and laws which were contravening established local rules, inducing more insecurity thereby weakening controls on forests. Such effects may also have been brought about by powerful influences of state forestry enterprises or companies (SFEs/SFCs), destabilizing locally established rules.
d) **Innate cognition of observed environmental degradation** (factor *cognized degradation*). Positive effect: Communities perceived certain significant qualitative decreases in the provision of FES, e.g. the productivity of swidden fields (due to insufficient regeneration periods) or a decrease of water resources during the dry season. This provided an incentive for them (without necessarily any external influences) to abandon swiddening, protect remaining forests and/or counteract forest degradation. Effects of this factor were only found to be positive.
e) **Internalization of new environmental values** (factor *valued environment*). Positive effect: New policies and associated teaching programs lead communities to 'understand' and/or internalize the (actual or stated) 'values' of certain FES (e.g. for water provision). This influenced communities to change forest management. Effects of this factor were only found to be positive.
f) **Promotion of private tree planting by FLA programs** (factor *FLA/tree planting*). Positive effect: Degraded forest land allocation and associated extension services made it possible for the assigned land holders to set up small-scale plantation forest plots. These plantations were typically stocked with fast-growing exotic tree species such as acacias or eucalypts, but also included the setting-up of fruit tree plantations, especially in upland areas. Effects of this factor were only found to be positive in the literature in regards to planted forests, but a few studies reported the replacement of natural forests by plantations.
g) **Reforestation programs** (factor *reforestation program*). Positive effect: Government-sponsored reforestation activities (such as under Programs 327 and 661) by SFEs on state-managed land, and other actors (e.g. communities, companies) on other types of lands, lead to forest increases (native or exotic species). Effects of this factor were only found to be positive.
h) **Expansion of commercial plantations** (factor *industrial plantations*). Positive effect: Economically managed plantations were expanded by powerful actors (estate owners, companies), possibly at the expense of agricultural land owned by weaker stakeholders (e.g. communities of ethnic minorities). Effects of this factor were only found to be positive in the literature in regards to planted forests, but some studies reported the replacement of natural forests by plantations (factors i, j).

i) **Forest resource exploitation and corruption** (factor *resource exploitation*). Negative effect: Forests were legally or illegally logged for timber and/or converted to plantations by villagers or powerful actors (estate owners, companies), possibly facilitated by weak and/or unclear legal restraints and/or under-resourced and 'corrupt' state authorities. Positive effect: Cardamom plants grow best in the shade of natural forest vegetation. In northern border provinces a cardamom boom (largely driven by market demand from China) resulted in farmers managing their peripheral lands for natural regrowth in order to expand cardamom plantations in the new forests. On the other hand, natural forests even within National Parks were exploited for cardamom production. In terms of forest cover this resulted, however, in a positive effect. It was also suggested that forests regrew in areas which were managed for livestock, especially 'forest' cattle, possibly as a result of higher feed qualities as compared to sensitive open areas.

j) **Displacement and land resource conflicts** (factor *resource conflict*). Negative effect: Weak actors were displaced (e.g. through take-over of land by powerful actors, cf. factors h and i) which forced them to cut natural forest (possibly 'illegally') for new agricultural land. Effects of this factor were only found to be negative.

Reported effects of forest-relevant policies (and associated environmental changes) on socio-economic conditions were:

k) **Livelihood changes** (factor *livelihood changes*). The changes brought about by government policies and/or land use changes lead to a general improvement (positive effect) or worsening (negative effect) of the overall livelihoods of the people of studied communities.

l) **Equitable resource uses** (factor *equity/poverty*). The changes brought about by government policies and/or land use changes lead to more (positive effect) or less (negative effect) equitable uses of resources, respectively prevented the poor from becoming poorer (and the rich becoming disproportionately richer).

m) **Infrastructure development** (factor *infrastructure*). The changes brought about by government policies and/or land use changes lead to significant development of infrastructure for the studied communities (only positive effect). Note that an increase here does not refer to any changes in the forest. The expansion of roads often lead to an associated decrease in forest cover, which is indicated under point i).

n) **Ethnic disparities and tensions** (factor *ethnic disparities*). The changes brought about by government policies and/or land use changes lead to differential profiting by different ethnic groups (negative or neutral effect), potentially leading to ethnic tensions.

o) **Diversification and migration** (factor *diversif./migration*). The changes brought about by government policies and/or land use changes lead to pressures on household members or entire households to diversify labor activities (positive or neutral effect) and/or migrate to seek labor elsewhere (negative effect).

The **Table SA2** (a-d) below lists all the case studies (publications listed, and specific case studies indicated) which reported on forest cover changes. The table indicates 1.) in which province or region the study was conducted; 2.) the time period (years) which was investigated by the study; 3.) the ethnicities of the communities where the study was conducted (i.e. BK – Bru-Vân Kiều, Co – Co, CT – Co Tu, Da – Dao, DL – Đan Lai, Ed – Ê Đê, Gi – Gia-rai, Hm – H'Mong, Ki – Kinh, Kh – Kháng, m – migrants, Mu – Mường, Nu – Nùng, SC – Sa Chi, Th – Thái, TP – Than Y and Than Phan, Ty – Tày); 4.) the scale of the study site (C – commune or village, D – district, P – province, R – wider region); 5.) the relative elevation zone of the study site (H – highlands, M – midlands, L – lowlands); 6.) the methods used in the study (i.e. remote sensing, questionnaires, qualitative interviews, and/or secondary/official data); 7.) whether natural and planted forest cover strongly increased (full green colour), slightly increased (light green colour), did not change (or no indications; no colour), slightly decreased (light red colour), or strongly decreased (full red colour) at the study site (approximate change rates are indicated if relevant data provided by the study); 8.) whether or not the study reported on swidden agriculture (and possible associated changes); 9.) causal factors (a-j, cf. above) by which the study explains the forest changes observed; and 10.) effects of forest-relevant policies (and associated environmental changes) on socio-economic conditions (k-o, cf. above) as reported in the study.

Table SA2a. Studies conducted in entire Vietnam and in the Northwest Region.

Legend	
(green / light green)	forest c. increase
(red / light red)	f. cover decrease
▲	main positive effect
▴	minor pos. effect
▼	main negative effect
▾	minor neg. effect
♦	+/- effects balanced
▴?	not explicit / unclear

Reference Source	Case study site, scale, time period, community ethnicity: Province or region where the study was conducted	Time period under investigation	Ethnicities	Scale of study site	Elevation zone of site	Study methods: Remote sensing	Questionnaires	Qualitative interviews	Official data	Reported net forest change: Natural forest change (annual rate in %)	Planted forest change (annual rate in %)	S: Reporting swiddening	Causal factors that authors used to explain observed changes in net forest cover and/or forest qualities: *a) agro-intensification*	*b) FLA / swidden-stop*	*c) policy / laws / control*	*d) cognized degradation*	*e) valued environment*	*f) FLA / tree planting*	*g) reforestation program*	*h) industrial plantations*	*i) resource exploitation*	*j) resource conflict*	Effects on socio-economic conditions: *k) livelihoods improve.*	*l) equity / poverty*	*m) infrastructure*	*n) ethnic disparities*	*o) diversif. / migration*
All Vietnam																											
Meyfroidt & La. (2008*a*)	all Vietnam	1993-2005	-	R	L-H	(X)			X	~2.2	~22		▲	▲				▲			▼						
Meyfroidt & La. (2008*b*)	all Vietnam	1993-2002	-	R	L-H				X	~2.5	~28	(X)	▲	▲	▴?			▲	▴?		▼	▾?	▲		▲		
Vu et al. (2014*a*)	all Vietnam	1982-2006	-	R	L-H	X				?	?																
Vu et al. (2014*b*)	all Vietnam	1982-2006	-	R	L-H	X			X	?	?		▲	▴?	▴?			▴?									
Northwest Region																											
Clement & Amez. (2008)	Hòa Bình	~1999-2005	Mu	C	M		X	X		?	?	X	▴	▲		▴	▴	▴									
Clement et al. (2009)	Hòa Bình	1993-2000	-	P	M	X			X	~0.8?	?				▾			♦	▲	▲							
Nguyen et al. (2004)	Hòa Bình	1988-2003	Ty	C	M		X	X	X	?	?	X	▾?	▴	♦			▲			▾?		▲	▾	▲		▲
Clement & Amez. (2009)	TN, YB, SL, HB[1]	~1991+	-	4P	M-H			X	X	?	?	X		♦	▾			♦	▲				♦	▾			
Folv. & Chr. (2007): B.D.	Sơn La	1992-2000	Da	C	H	X	X	X		~-10	?	X	▾?	▾?		♦		▴									
Folv. & Chr. (2007): Lem	Sơn La	1992-2000	Th, Mu	C	H	X	X	X		~♦	?	X	♦					▴									
Lippe et al. (2011)	Sơn La	1975-2008	Th	C	M	X		X		~0.2	~all	X	▴?														
Meyfroidt (2013): Hoc	Sơn La	1973-2007	Th	C	H	X	X	X		~4.8	-	X	▲	(♦)	▲	♦	♦		▲		▼						
Meyfroidt (2013): Pa Dong	Sơn La	1973-2007	Hm	C	H	X	X	X		~-0.8	-	X	▴	(♦)	▴		▴				▼						
Nguyen et al. (2009)	Sơn La	1993-2007	?	C	H	X				~-0.9	-		▼								▼						
Saint-Macary et al. (2010)	Sơn La	~1976-2006	Th, Hm, Ki	D	M		X	X		-	~8.0							▲									
Sikor (2001) ⌈[2]	Sơn La	~1990-1997	Th	C	H	X	X	X	X	~5.0	?	X	▲	♦	▴			▴	▴		▼	▾?	▲	▾	▲		▲
Tachibana et al. (2001)	Sơn La	1978-1994	-	P	H				X	~-1.3	?	X	▲	▲	▲			▲			▼						
Chi et al. (2013)	Sơn La	1973-2008	Th, Ki, Kh	6C	H	X	X	X		~5.5	?	X	▲	▴				▲					♦			♦	
Wezel et al. (2002*a*)	Sơn La	~1993-1998	Th	6C	H		X	X		-	?	X						▲									

Footnotes:
⌈[1] TN = Thái Nguyên, YB = Yên Bái, SL = Sơn La, HB = Hòa Bình
⌈[2] There are four publications on Chieng Dong Commune (some of which documenting changes since the 1960s): Sikor (2001), Sikor & Dao (2002), Sikor & Vi (2005) and Sikor (2006)

Table SA2b. Studies conducted in the Northeast Region.

Legend / Reference Source	Province or region where the study was conducted	Time period under investigation	Ethnicities	Scale of study site	Elevation zone of site	Remote sensing	Questionnaires	Qualitative interviews	Official data	Natural forest change (annual rate in %)	Planted forest change (annual rate in %)	Reporting swiddening	a) agro-intensification	b) FLA / swidden-stop	c) policy / laws / control	d) cognized degradation	e) valued environment	f) FLA / tree planting	g) reforestation program	h) industrial plantations	i) resource exploitation	j) resource conflict	k) livelihoods improve.	l) equity / poverty	m) infrastructure	n) ethnic disparities	o) diversif. / migration
	Case study site, scale, time period, community ethnicity					Study methods				Reported net forest change		S	Causal factors that authors used to explain observed changes in net forest cover and/or forest qualities										Effects on socio-economic conditions				
Northeast Region																											
Castella et al. (2006) [1]	Bắc Kạn	1990-2001	Ty, Hm, Da	C	H		X	X	X	?	?	X	▲	▲	▲	▲		▴					▾	▾		▼	▼
Castella et al. (2005*a*) [1]	Bắc Kạn	1960-2000	Ty, Nu, Da	C	H		X	X	X	?	?	X	▴?	▴?	▲			▴	▲				♦?	▼		▾	▼
Castella et al. (2005*b*) [1]	Bắc Kạn	1990-2001	-	P	M-H	X			X	~2.8	?	X	▲	▴?				▴?			▾	▾			▲		
Meyfroidt (2013): Khang	Bắc Kạn	1973-2007	Ty	C	H	X	X	X		~8.0	-	X	▲	▲	▲	▲		▲									
Meyfroidt (2013): Na Da	Bắc Kạn	1973-2007	Da	C	H	X	X	X		~0.4	-	X	▲	(♦)													
Gomiero et al. (2000)	Quảng Ninh	~1992-2000	Ty, TP, SC	C	M-H		X	X		?	?	X		♦?				▲	▲		▼		♦?	▼		▾	♦
Hoang et al. (2014)	Lào Cai	1993-2014	-	D	H	X			X	~0.5	?	X	▲		▲									▲			
Jadin et al. (2013)	Lào Cai	1993-2006	Hm, Da	D	H	X			X	?	-	X	▲	♦	♦						▼						
Trincsi et al. (2014) [2]	Lào Cai	1999-2009	-	D	M-H	X		X		~16	?	X	▲	(♦)	▲						▲				▲		
Pham et al. (2015) [2]	Lào Cai	1999-2009	-	D	M-H	X				~16	-	X	▲	(♦)	▲		▴		▲		▲				▲		
Tachibana et al. (2001)	Thái Nguyên	1978-1994	-	P	H				X	~-5.5	?	X	▲	▲	▲			▲			▼						
Turner & Pham (2015) [2]	N border region	2000-2009	-	R	H	X		X		~10	-	X	▴?		▴?	▴	▴?				▲		▲		▲	▾	▲
Sandewall et al. (2010)	N border region	1980-2006	-	3D	H		X	X	X	?	most							▲		▴	▾		▲	▾	▲		▲
Sikor & Baggio (2014) [3]	Phú Thọ	1989-2008	-	2C	M		X	X		-	most							▲		▴			▲	▾			♦
Nguyen et al. (2010)	Phú Thọ ?	1993-2006	-	5C	M		X		X	-	all							▲					▲				

Legend: forest c. increase (green / light green); f. cover decrease (red / light red); ▲ main positive effect; ▴ minor pos. effect; ▼ main negative effect; ▾ minor neg. effect; ♦ +/- effects balanced; ▴? not explicit / unclear

Footnotes:
[1] Several case studies (published in Castella & Dang 2002; studies not listed here) have been conducted in Bắc Kạn Province during the 1990s which generally reflect the reporting by Castella et al. (2006, 2005*a*, *b*).
[2] Especially Turner & Pham (2015) interpret 'natural' forest regrowth to largely result from the planting of lucrative cardamom plants (seeds traded mainly to nearby China) which only grow beneath the canopies of larger trees. Many areas formerly used for swiddens or other uses were therefore left to regrow for natural forest cover.
[3] There are two publications on the two villages Xom Lam and Village 5: Sikor & Baggio (2014) and Sikor (2012).

Table SA2c. Studies conducted in the Central Coast Region.

Legend:
- forest c. increase (green cells)
- f. cover decrease (red cells)
- ▲ main positive effect
- ▴ minor pos. effect
- ▼ main negative effect
- ▾ minor neg. effect
- ♦ +/- effects balanced
- ▴? not explicit / unclear

Reference Source	Province or region where the study was conducted	Time period under investigation	Ethnicities	Scale of study site	Elevation zone of site	Remote sensing	Questionnaires	Qualitative interviews	Official data	Natural forest change (annual rate in %)	Planted forest change (annual rate in %)	Reporting swiddening	a) agro-intensification	b) FLA / swidden-stop	c) policy / laws / control	d) cognized degradation	e) valued environment	f) FLA / tree planting	g) reforestation program	h) industrial plantations	i) resource exploitation	j) resource conflict	k) livelihoods improve.	l) equity / poverty	m) infrastructure	n) ethnic disparities	o) diversif. / migration
Legend	Case study site, scale, time period, community ethnicity					Study methods				Reported net forest change		S	Causal factors that authors used to explain observed changes in net forest cover and/or forest qualities										Effects on socio-economic conditions				
North Central Coast																											
Ankersen et al. (2015)	Nghệ An	1973-2011	Th	C	H	X				~1.0	all	X	▲	▴?	▴?												
Dao et al. (2009)	Nghệ An	1954-2005	Th, Kh, DL	C	H	X		X	X	~0.4	all	X	▴?	▴?	▲		▲		▴		▾						
Jakobsen et al. (2007)	Nghệ An	1991-2003	Th	C	H	X	X	X		?	?	X	♦	▲	▴						▾?		▼				
Leisz (2009) [1]	Nghệ An	1989-2003	Th, Hm	4C	H	X	X	X	X	~10	-	X	▲	▴?							▲				▲		
Müller et al. (2014)	Nghệ An	1980-2012	-	2C	H		X	X		~6	?	X	▴?	▲	▴?						▼						
McElwee (2008)	Hà Tĩnh	2000-2001	Ki?	5C	L-M		X	X		?	-										▾						
McElwee (2009)	Hà Tĩnh	2000-2001	Ki?	C	L-M		X	X		?	?							▴?	▲	▴?	▾?	▾?	▾	▼			
Bayrak et al. (2015): H.H.	Quảng Trị	~2000-2013	BK	C	H			X		?	?	X		▲	♦		▴?				▼	▾?	▾?	▼			
Bayrak et al. (2015): T.L.	Thừa Thiên-Huế	~2000-2013	CT	C	M-H			X		?	?	X		▲	▼		▲	▲			▼	▾?	▾?	▼			
Disperati & Virdis (2015)	Thừa Thiên-Huế	1965-2014	-	D	L	X				~0.8	?							▴?	▲								
Gomiero et al. (2000)	Thừa Thiên-Huế	~1992-2000	CT	C	M-H		X	X		?	?	X		▾?				▴	▴?		▼	▾?	♦?	▼		▾	♦
Thiha et al. (2007)	Thừa Thiên-Huế	1975-2004	CT, Ki	D	M	X		X	X	~-0.1	all	X	▴?	▾?	▾?			▲			▼	▼			♦	♦	
Tran et al. (2010)	Thừa Thiên-Huế	~2004-2009	CT	C	M		X	X		?	-		♦								▼	▾?	▾				▲
South Central Coast																											
Thulstrup (2015) [2]	Quảng Nam	~1979-2011	Co, Ki	C	M		X	X		?	most		▴?					▲	▲		▾		▲	▼	▲	▼	♦
Sikor & Baggio (2014) [3]	Bình Định	1989-2008	-	2C	M		X	X		-	most							▲		▴			▲	▾			♦

Footnotes:
[1] Noted the effects of livestock (mainly cattle) raising as a potential driver for forest regeneration.
[2] There are two publications on Tam Trà Commune: Thulstrup (2015) and Thulstrup (2014).
[3] There are two publications on the two villages Tan Quang and Thuan Phong: Sikor & Baggio (2014) and Sikor (2012).

Table SA2d. Studies conducted in the Central Highlands and Southeast Region, and in the Mekong River Delta.

Legend:

(green / light green)	forest c. increase
(red / light red)	f. cover decrease
▲	main positive effect
▴	minor pos. effect
▼	main negative effect
▾	minor neg. effect
◆	+/- effects balanced
▴?	not explicit / unclear

Reference Source	Case study site, scale, time period, community ethnicity: Province or region where the study was conducted	Time period under investigation	Ethnicities	Scale of study site	Elevation zone of site	Study methods: Remote sensing	Questionnaires	Qualitative interviews	Official data	Reported net forest change: Natural forest change (annual rate in %)	Planted forest change (annual rate in %)	S: Reporting swiddening	Causal factors that authors used to explain observed changes in net forest cover and/or forest qualities: *a) agro-intensifcation*	*b) FLA / swidden-stop*	*c) policy / laws / control*	*d) cognized degradation*	*e) valued environment*	*f) FLA / tree planting*	*g) reforestation program*	*h) industrial plantations*	*i) resource exploitation*	*j) resource conflict*	Effects on socio-economic conditions: *k) livelihoods improve.*	*l) equity / poverty*	*m) infrastructure*	*n) ethnic disparities*	*o) diversif. / migration*
Central Highlands																											
Müller & Zeller (2002)	Đắk Lắk	1975-2000	?, Ki	2D	H	X	X	X	X	~1.8	?	X	▲	▲	▲			▴							▲		
Sikor & N. (2007)[1]: Cham	Đắk Lắk	1999-2001	Ed, m	2C	H		X	X	(X)	~-7.6	-	(X)	▼	▼	◆						▼	▼	▾	▼		▼	
Sikor & N. (2007)[1]: Diet	Đắk Lắk	1999-2001	Gi, m	2C	H		X	X	(X)	~1.7	-	(X)	▲	▴?	◆						▼	▾	▾	▼		▼	
D'haeze et al. (2005)	Đắk Lắk	1980-2000	-	R	H	X			X	~-1.8	-		▼							▾?							
Dien et al. (2013)	Lâm Đồng	1990-2010	-	P	H			X	X	~-1.6	~10	X	▼		◆			▴	▲	▾?	▼	▼			▲		
Meyfroidt et al. (2013)	DL, DN, LD, BP[2]	1985-2009	-	R	H	X			X	~-0.8	~all	(X)	▼	▾?						▾?	▼	▼	◆?	▼	▴?	▼	▼
Heinimann (2006)	Mekong WS	1993-1997	-	R	H	X			X	~-0.7	?																
Leinenkugel et al. (2015)	Mekong WS	2001-2011	-	R	H	X				~-1.0	?																
Southeast Region																											
Grogan et al. (2015)	BP, TN, BD [2]	2000-2012	-	R	M	X			X	~-2.5	~2.1		▼					▲		▲	▾?	▾?					
Mekong River Delta																											
Tanaka (2001)	An / Kiên Giang	~1980-2000	-	R	L			(X)	(X)	(◆)	?		▼		▴?			▴	▲	▴							
Heinimann (2006)	Mekong Delta	1993-1997	-	R	L	X				?	?																
Leinenkugel et al. (2015)	Mekong Delta	2001-2011	-	R	L	X				?	?																

Footnotes:

[1] There are three publications on the two villages Cham B and Diet: Sikor & Nguyen (2007), Tran & Sikor (2006) and Sikor & Tran (2007)

[2] DL = Đắk Lắk, DN = Đắk Nông, LD = Lâm Đồng, BP = Bình Phước, TN= Tây Ninh, BD = Bình Dương

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Supplementary Data B: Additional information on official data variables used for statistical analyses

Part 1: Summaries of provincial data variables

The following tables provide summaries of all tested official data variables, and corresponding information and descriptive and model statistics. Tables SB1a-g summarize all 'independent' (i) provincial data variables (i.e. indicators on geography and terrain *G*, population and ethnicity *P*, labour and poverty *L*, infrastructural development *I*, education *E*, forest resource exploitation *C*, cereal staple crops agricultural land area and productivity *A*, and forest land under tenure or contracts *T* indicator variables; 63 provinces) which were variously tested as potential predictors of the 'dependent' (d) variables. These 'dependent' variables are listed in Table SB2. In the upper rows the tables summarize the data variable numbers, names, and description (names of variables used in the final models are printed in bold, cf. Tables 2 and 3 in the paper). Any transformation applied to render the data into a normal distribution (i.e. transformation not applicable (-), none (n), natural logarithm (ln X), square root (sqrt X), power function (X^z, as determined from Box-Cox graphs), a Johnson transformation formula (JT X), or a normal score (nscor X) function) is provided in the lower rows left. The data type refers to continuous (CI) or discrete (DI) interval data, respectively binary (B), ordinal (O) or nominal (N) categorical data. Summary statistics (lower row right) are either frequencies (in brackets after the category) or the mean ± the standard deviation (including the data range in brackets). The abbreviation of data sources (as indicated in the table legend) is provided in the lower row at the very right.

Table SB1a. Summary of indicators on geography and terrain *G*. Data were obtained from Wikipedia (Wiki; https://en.wikipedia.org/wiki/List_of_regions_of_Vietnam), from the World Bank (2015; WB), or they were manually recorded using Google Earth™ (GEA).

Var. Code	*Var. Name*	**Data type**	**Variable description**	
	transformation	**Summary stats**		**Data source reference**
Geographical and terrain indicator variables				
iG1	*provname*	N	The name of the province	
	-	Alphabetically (63 provinces): An Giang to Yên Bái		Wiki
iG2a	*provregion*	N	The geographic region where the province is located	
	-	Northeast Region (10 provinces), Northwest (4), Red River Delta (11), North Central Coast (6), South Central Coast (6), Central Highlands (5), Southeast Region (8), Mekong River Delta (13)		Wiki
iG2b	***nodelta***	B	Whether [0] or not [1] the province lies in the Red River or Mekong Delta	
	-	yes - 0 (24 provinces), no - 1 (39 provinces)		Wiki
iG3	*longitude*	CI	E UTM coordinates (Google Earth) at approximate centre of province	
	n	647555 (310334-943650)		GEA
iG4	***latitude***	CI	N UTM coordinates (Google Earth) at approximate centre of province	
	n	1780573 (1001098-2516580)		GEA
iG5	***elevation***	CI	An index of estimated average elevation (meters a.s.l.) of province	
	X^0.13	180 ± 225 (2-800)		GEA
iG6	***distcoast***	CI	An index of the shortest distance from province border to the coast (km)	
	nscor X	53.2 ± 76.0 (0-300)		GEA
iG7	***mtrugged***	CI	An index of approximate 'rugged' mountain terrain areal cover (%)	
	nscor X	41.5 ± 40.7 (0-100)		GEA
iG8	***provarea***	CI	The provincial area cover in square kilometres	
	X^0.16	5254 ± 3683 (823-16493)		WB

Table SB1b. Summary of indicators on population and ethnicity *P*. Data were obtained from GSO (2013), the World Bank (2015; WB), or UNFPA (2011; UNP).

Var. Code	*Var. Name* / transformation	**Data type** / **Summary stats**	**Variable description**	**Data source reference**
Demographic population indicator variables				
iP1a	***popdens95***	CI	Average provincial population density in 1995 (people km^{-2})	
	ln X	395.8 ± 424.8 (28.8-2214.4)		GSO
iP1b	*popdens03*	CI	Average provincial population density in 2003 (people km^{-2})	
	ln X	436.3 ± 483.7 (37.3-2772.0)		GSO
iP1c	*popdens13*	CI	Average provincial population density in 2013 (people km^{-2})	
	ln X	472.3 ± 579.7 (44.7-3731.6)		GSO
iP2a	*popch95-03*	CI	Change in population of provinces: *popdens03* / *popdens95*	
	JT X = -1.93115 + 1.16248 × asinh((X - 1.01353) / 0.0324350)	1.13 ± 0.11 (1.00-1.52)		GSO
iP2b	*popch03-13*	CI	Change in population of provinces: *popdens13* / *popdens03*	
	JT X = -0.383348 + 0.606837 × asinh((X - 1.04483) / 0.0222248)	1.08 ± 0.15 (0.59-1.85)		GSO
iP2c	*popch95-13*	CI	Change in population of provinces: *popdens13* / *popdens95*	
	JT X = -0.654170 + 0.825169 × asinh((X - 1.09347) / 0.0757011)	1.23 ± 0.28 (0.71-2.82)		GSO
iP3a	***rurpopd95***	CI	Average provincial rural population density in 1995 (people km^{-2})	
	JT X = 1.44135 + 0.663488 × ln((X - 15.2205) / (1708.77 - X))	304.7 ± 301.0 (22.3-1090.4)		GSO
iP3b	***rurpopd03***	CI	Average provincial rural population density in 2003 (people km^{-2})	
	JT X = 1.62114 + 0.689181 × ln((X - 20.1116) / (1890.55 - X))	309.2 ± 298.0 (25.1-1065.1)		GSO
iP3c	***rurpopd10***	CI	Average provincial rural population density in 2010 (people km^{-2})	
	JT X = 1.29931 + 0.641132 × ln((X - 27.5763) / (1440.78 - X))	304.8 ± 287.0 (30.1-1138.4)		GSO
iP4a	***rurpch95-03***	CI	Change in rural population of provinces: *rurpopd03 / rurpopd95*	
	JT X = -0.524495 + 0.889075 × asinh((X - 1.00377) / 0.0580235)	1.06 ± 0.12 (0.64-1.40)		GSO
iP4b	*rurpch03-10*	CI	Change in rural population of provinces: *rurpopd10 / rurpopd03*	
	JT X = -0.316291 + 0.864035 × asinh((X - 0.984434) / 0.0464083)	1.02 ± 0.12 (0.78-1.63)		GSO
iP4c	*rurpch95-10*	CI	Change in rural population of provinces: *rurpopd10 / rurpopd95*	
	JT X = -0.495034 + 0.702263 × asinh((X - 0.986894) / 0.0725873)	1.10 ± 0.24 (0.57-2.10)		GSO
iP5	***migrat05-14***	CI	Average annual net migration (in % of population) 2005-2014 in provinces	
	JT X = -0.680684 + 0.826203 × asinh((X + 4.43829) / 1.52923)	-1.26 ± 7.50 (-10.11 to 45.22)		GSO
iP6	*fertility05-15*	CI	Average provincial fertility rate (children per woman) 2005-2015	
	ln X	2.20 ± 0.35 (1.47-3.34)		GSO
iP7	*hhsize09*	CI	Average number of persons per household in the provinces in 2009	
	n	4.04 ± 0.40 (3.24-5.20)		WB
Population ethnic composition indicator variables				
iP8	*Kinh*	CI	The percentage of the Kinh (Vietnamese) majority in the provinces in 2009	
	JT X = -1.01457 + 0.416932 × ln((X - 3.16485) / (99.9228 - X))	78.11 ± 28.48 (5.76-99.87)		UNP
iP9	*mtnethnic*	CI	The percentage of all mountain ethnic minorities in the province in 2009	
	JT X = 0.987549 + 0.333788 × ln((X - 0.120895) / (94.8288 - X))	20.28 ± 28.90 (0.13-94.24)		UNP
iP10	***Tay***	CI	The percentage of Tày ethnic minorities in the province in 2009	
	JT X = -1.43296 + 0.289444 × asinh((X - 0.0130389) / 0.00112231)	3.94 ± 10.40 (0.001-52.93)		UNP
iP11	***Thai***	CI	The percentage of Thái ethnic minorities in the province in 2009	
	(-1)*X^(-0.4)	2.51 ± 9.11 (0.001-53.20)		UNP
iP12	***Muong***	CI	The percentage of Mường ethnic minorities in the province in 2009	
	(-1)*X^(-0.33)	1.71 ± 8.30 (0.001-63.93)		UNP
iP13	***H'Mong***	CI	The percentage of H'Mong ethnic minorities in the province in 2009	
	JT X = -1.05180 + 0.190501 × asinh((X - 0.010484) / 0.000031844)	2.64 ± 7.37 (0.00001-34.80)		UNP
iP14	***ethnother***	CI	Percentage of all other mountain ethnic minorities in the province in 2009	
	JT X = 1.07691 + 0.388978 × ln((X - 0.00769531) / (51.3324 – X))	9.47 ± 13.00 (0.03-50.36)		UNP

Table SB1c. Summary of indicators on labour and poverty *L*, infrastructural development *I*, education *E*, and forest resource uses and exploitation *C*. Data were obtained from the World Bank (2015; WB), the Forest Protection Department (FPD 2014), Nguyen et al. (2009*a*; NSY), or they were manually recorded using Google Earth™ (GEA).

Var. No	***Var. Name*** / transformation	**Data type** / **Summary stats**	**Variable description** / **Statistics model and significant predictors**	
Economic development indicator variables (labour employment and poverty)				
iL1	*labour09*	CI	Percentage of working (economically active) population in 2009	
	n	54.8 ± 4.1 (42.9-62.0)		WB
iL2	***workagri09***	CI	Percentage of labour force working in agriculture in the province, 2009	
	X^1.41	56.2 ± 19.0 (2-85)		WB
iL3	*workself09*	CI	Percentage of labour force working in non-farm self-employment, 2009	
	n	16.0 ± 6.4 (5-31)		WB
iL4	*workwage09*	CI	Percentage of labour force working in dependent wage labour, 2009	
	ln X	27.8 ± 13.5 (10-74)		WB
iL5a	***hpoverty99***	CI	GSO-WB poverty **h**eadcount (below poverty line) ratio (%) in 1999	
	JT X = -0.103224 + 1.03629 ×asinh ((X - 39.6799) / 9.75966)	41.2 ± 16.6 (5-80)		WB
iL5b	*hpoverty09*	CI	GSO-WB poverty **h**eadcount (below poverty line) ratio (%) in 2009	
	JT X = -1.24063 + 1.13818 × asinh ((X - 8.65594) / 8.21476)	25.4 ± 17.2 (2-76)		WB
iL6	***bpoverty09***	CI	Population (%) in national 40 percent income **b**ottom in the province, 2009	
	n	46.1 ± 17.2 (9-87)		WB
Infrastructural development indicator variables				
iI1	*electricity09*	CI	Percentage of households with electricity in the province, in 2009	
	nscor X	95.3 ± 6.3 (71-100)		WB
iI2	*sanitation09*	CI	Percentage of households with flushing toilets at the house, in 2009	
	X^0.1	46.2 ± 20.6 (14-99)		WB
iI3	*water09*	CI	Percentage of households with water (tap or well) in or near house, 2009	
	n	46.5 ± 26.3 (8-98)		WB
Educational development indicator variables				
iE1	*schoolL09*	CI	Percentage people with lower (11-15 y.) secondary school education. 2009	
	X^3.53	84.9 ± 8.2 (68-96)		WB
iE2	*schoolH09*	CI	Percentage people with higher (16-18 y.) secondary school education. 2009	
	n	52.7 ± 12.7 (31-77)		WB
Forest resource exploitation – legal cases indicator variables				
iC1	*conftimb07-10*	CI	Timber (m^3) confiscated monthly during 2007-2010 (bP) in the province	
	X^3.53	58.9 ± 73.7 (0-265.0)		FPD
iC2	*forcase07-10*	CI	All cases (except relating to wildlife) violating forestry laws 2007-2010	
	n	56.3 ± 81.6 (0-496.8)		FPD
Forest resource exploitation – wood consumption indicator variables				
*iC3**	***pulpcap04***	CI	An index for pulp-and-paper wood processing capacities in 2004	
	ln X	5.01 ± 2.76 (1.80-15.27)		NSY / GEA
iC4	*woodcubic04*	CI	Wood cut in 2004 (in cubic meters) in each province	
	X^0.23	38.78 ± 34.78 (1-148.8)		NSY
iC5	*woodVND04*	CI	Wood sold in 2004 (in 1000 Vietnamese Đồng) in each province	
	X^0.11	98.9 ± 91.5 (6.3-432.6)		NSY
*Note: The index variable *pulpcap04* was calculated by first summing up the wood processing capacities (cubic metres wood) for each province, and then adding the summed-up capacities of each other province weighed by (i.e. divided by) the respective inter-province distances (measured on Google Earth™ from approximate province centre to neighbouring province centre in km). The 'distance to processing plant' (to weigh the capacities) within the same province was set at a standard 20 km.				

Table SB1d. Summary of indicators on general cereal staple crops agricultural land area and productivity *A1-6*. All data were obtained from GSO (2013).

Var. No	**Var. Name**	**Data type**	**Variable description**	
	transformation	**Summary stats**	**Statistics model and significant predictors**	
Agricultural land and productivity indicator variables				
iA1a	***cerland95***	CI	Land area (1000 ha) planted with cereal crops in 1995	
	ln X	116.3 ± 94.9 (13.5-402.5)		GSO
iA1b	***cerland03***	CI	Land area (1000 ha) planted with cereal crops in 2003	
	ln X	132.8 ± 119.0 (10.3-563.1)		GSO
iA1c	*cerland13*	CI	Land area (1000 ha) planted with cereal crops in 2013	
	ln X	136.8 ± 130.7 (8.1-642.7)		GSO
iA2a	*cerlch95-03*	CI	Cereal crop land area change: land area in 2003 minus land area in 1995	
	JT X = -0.538366 + 0.653653 × asinh((X - 1.92503) / 6.20167)	16.5 ± 36.2 (-79.8 to 182.8)		GSO
iA2b	***cerlch03-13***	CI	Cereal crop land area change: land area in 2013 minus land area in 2003	
	JT X = -0.309923 + 0.614138 × asinh((X + 2.19013) / 3.93151)	4.0 ± 22.4 (-36.6 to 262.4)		GSO
iA2c	*cerlch95-13*	CI	Cereal crop land area change: land area in 2013 minus land area in 1995	
	JT X = -0.446992 + 0.680666 × asinh((X + 2.58544) / 11.1154)	20.5 ± 53.6 (-61.5 to 262.4)		GSO
iA3a	***cerlrch95-03***	CI	Relative change in area planted with cereal crops: 2003 as a ratio of 1995	
	JT X = -0.299999 + 1.07738 × asinh((X - 1.06399) / 0.171730)	1.15 ± 0.26 (0.57-2.12)		GSO
iA3b	***cerlrch03-13***	CI	Relative change in area planted with cereal crops: 2013 as a ratio of 2003	
	JT X = -0.268200 + 0.865470 × asinh((X - 0.972504) / 0.0838335)	1.02 ± 0.18 (0.43-1.72)		GSO
iA3c	*cerlrch95-13*	CI	Relative change in area planted with cereal crops: 2013 as a ratio of 1995	
	JT X = -0.428736 + 0.837653 × asinh((X - 0.981476) / 0.204509)	1.20 ± 0.46 (0.32-2.79)		GSO
iA4a	*cerprod95*	CI	Average field productivity (tons/ha) of cereal crops 1995 in province	
	n	3.18 ± 0.86 (1.45-5.43)		GSO
iA4b	*cerprod03*	CI	Average field productivity (tons/ha) of cereal crops 2003 in province	
	n	4.24 ± 0.84 (2.32-5.92)		GSO
iA4c	*cerprod13*	CI	Average field productivity (tons/ha) of cereal crops 2013 in province	
	n	4.86 ± 0.88 (2.95-6.57)		GSO
iA5a	*cerpch95-03*	CI	Cereal field productivity change: *cerprod03* minus *cerprod95*	
	n	1.06 ± 0.50 (-0.01 to +2.17)		GSO
iA5b	*cerpch03-13*	CI	Cereal field productivity change: *cerprod13* minus *cerprod03*	
	n	0.62 ± 0.33 (-0.20 to +1.48)		GSO
iA5c	*cerpch95-13*	CI	Cereal field productivity change: *cerprod13* minus *cerprod95*	
	n	1.68 ± 0.51 (0.77-3.32)		GSO
iA6a	*cerprch95-03*	CI	Relative field productivity change of cereal crops: 2003 as a ratio of 1995	
	n	1.37 ± 0.21 (1.00-1.85)		GSO
iA6b	*cerprch03-13*	CI	Relative field productivity change of cereal crops: 2013 as a ratio of 2003	
	n	1.15 ± 0.09 (0.95-1.45)		GSO
iA6c	***cerprch95-13***	CI	Relative field productivity change of cereal crops: 2013 as a ratio of 1995	
	ln X	1.58 ± 0.26 (1.21-2.21)		GSO

Table SB1e. Summary of indicators on rice and maize staple crops agricultural land area and productivity *A7-14*. All data were obtained from GSO (2013).

Var. No	***Var. Name*** / transformation	**Data type** / **Summary stats**	**Variable description** / **Statistics model and significant predictors**	
Agricultural productivity indicator variables				
iA7a	*riland95*	CI	Land area (1000 ha) planted with rice crops in 1995	
	ln X	107.4 ± 95.8 (8.3-391.8)		GSO
iA7b	*riland03*	CI	Land area (1000 ha) planted with rice crops in 2003	
	ln X	118.1 ± 121.3 (8.9-563)		GSO
iA7c	*riland13*	CI	Land area (1000 ha) planted with rice crops in 2013	
	ln X	125.4 ± 151.0 (5.4-770.4)		GSO
iA8a	*rilrch95-03*	CI	Change in planted area of rice crops: 2003 as a ratio of 1995	
	JT X = -0.0918343 + 0.770481 × asinh((X – 1.05846) / 0.0809319)	1.09 ± 0.28 (0.57-2.87)		GSO
iA8b	*rilrch03-13*	CI	Change in planted area of rice crops: 2013 as a ratio of 2003	
	JT X = -0.426694 + 0.772917 × asinh((X - 0.936722) / 0.0797803)	1.03 ± 0.30 (0.40-2.70)		GSO
iA8c	*rilrch95-13*	CI	Change in planted area of rice crops: 2013 as a ratio of 1995	
	JT X = -0.429023 + 0.718850 × asinh((X - 0.960835) / 0.141924)	1.19 ± 0.90 (0.27-7.77)		GSO
iA9a	*riprod95*	CI	Average field productivity (tons/ha) of rice crops in 1995	
	X^0.28	3.30 ± 0.81 (1.53-5.55)		GSO
iA9b	*riprod03*	CI	Average field productivity (tons/ha) of rice crops in 2003	
	X^1.46	4.37 ± 0.80 (2.50-6.07)		GSO
iA9c	*riprod13*	CI	Average field productivity (tons/ha) of rice crops in 2013	
	X^2.8	5.10 ± 0.92 (1.75-6.51)		GSO
iA10a	*riprch95-03*	CI	Field productivity change of rice crops: 2003 as a ratio of 1995	
	ln X	1.35 ± 0.20 (0.98-1.82)		GSO
iA10b	*riprch03-13*	CI	Field productivity change of rice crops: 2013 as a ratio of 2003	
	JT X = 1.73552 + 2.40258 × asinh((X - 1.39353) / 0.229796)	1.18 ± 0.16 (0.62-1.51)		GSO
iA10c	***riprch95-13***	CI	Field productivity change of rice crops: 2013 as a ratio of 1995	
	JT X = -0.417984 + 1.40213 × asinh((X - 0.946027) / 0.377428)	1.59 ± 0.28 (0.83-2.16)		GSO
iA11a	*maland95*	CI	Land area (1000 ha) planted with maize crops in 1995	
	X^0.19	8.8 ± 11.1 (0.1-62)		GSO
iA11b	***maland03***	CI	Land area (1000 ha) planted with maize crops in 2003	
	X^0.13	14.5 ± 17.9 (0.2-79.8)		GSO
iA11c	***maland13***	CI	Land area (1000 ha) planted with maize crops in 2013	
	X^0.14	18.6 ± 27.7 (0.1-162.8)		GSO
iA12a	*mailch95-03*	CI	Change in planted area of maize crops: 2003 as a ratio of 1995	
	JT X = -0.721676 + 0.721837 × asinh((X - 1.15601) / 0.362442)	2.51 ± 3.42 (0.51-24)		GSO
iA12b	***mailch03-13***	CI	Change in planted area of maize crops: 2013 as a ratio of 2003	
	JT X = 0.211560 + 0.976679 × asinh((X - 1.28183) / 0.267577)	1.21 ± 0.41 (0.33-2.52)		GSO
iA12c	*mailch95-13*	CI	Change in planted area of maize crops: 2013 as a ratio of 1995	
	JT X = -1.29412 + 0.891599 × asinh((X - 0.927173) / 0.424236)	3.07 ± 5.02 (0.39-39)		GSO
iA13a	*maprod95*	CI	Average field productivity (tons/ha) of maize crops in 1995	
	X^0.22	2.13 ± 0.96 (0.52-6.57)		GSO
iA13b	*maprod03*	CI	Average field productivity (tons/ha) of maize crops in 2003	
	n	3.40 ± 1.06 (1.57-6.87)		GSO
iA13c	*maprod13*	CI	Average field productivity (tons/ha) of maize crops in 2013	
	X^0.19	4.40 ± 1.18 (2-7.65)		GSO
iA14a	***maprch95-03***	CI	Field productivity change of maize crops: 2003 as a ratio of 1995	
	JT X = -0.888210 + 1.02484 × asinh((X - 1.34491) / 0.270614)	1.75 ± 0.65 (1.00-5.00)		GSO
iA14b	*maprch03-13*	CI	Field productivity change of maize crops: 2013 as a ratio of 2003	
	JT X = -0.878714 + 1.01615 × asinh((X - 1.15352) / 0.121546)	1.35 ± 0.35 (1.00-3.50)		GSO
iA14c	*maprch95-13*	CI	Field productivity change of maize crops: 2013 as a ratio of 1995	
	JT X = -0.675272 + 1.01590 × asinh((X - 1.75422) / 0.465547)	2.35 ± 1.05 (1.10-6.97)		GSO

Table SB1f. Summary of forest land tenure (*T1-5*) and protected areas (*T6*) indicator variables. Data were obtained from Nguyen et al. (2009*a*; NSY) and ICEM (2003; ICE).

Var. No	***Var. Name***	**Data type**	**Variable description**	
	transformation	**Summary stats**	**Statistics model and significant predictors**	
Forest land tenure indicator variables				
iT1	*allften04*	CI	Total forest land (hectares) under any specified tenure in 2004	
	X^0.26	196028 ± 211003 (0-879764)		NSY
iT2a	***hhften95***	CI	Forest tenure (ha) by households (HH) and individuals in 1995	
	X^0.15	16794 ± 27115 (0-121148; 49 data larger than 0)		NSY
iT2b	***hhften04***	CI	Forest tenure (ha) by households (HH) and individuals in 2004	
	X^0.17	52615 ± 94666 (0-437109; 56 data larger than 0)		NSY
iT2c	*hhftch95-04*	CI	Household tenure change 1995-2004: *hhften04* minus *hhften95*	
	JT X = -0.710861 + 0.533257 × asinh((X + 688.650) / 5166.88)	35821 ± 83173 (-45977 to + 421993)		NSY
iT2d	*comtenure04*	CI	Forest tenure (ha) by entire communities in 2004	
	-	2862 ± 14946 (0-110972; 14 data larger than 0)		NSY
iT2e	***hhcften04***	CI	Forest tenure (ha) by households and/or communities in 2004	
	X^0.17	55477 ± 101235 (0-437109; 56 data larger than 0)		NSY
iT3a	***ecorgften95***	CI	Forest tenure (ha) by economic organisations (EO) in 1995	
	X^0.14	79296 ± 144784 (0-1009001; 49 data larger than 0)		NSY
iT3b	***ecorgften04***	CI	Forest tenure (ha) by economic organisations (EO) in 2004	
	X^0.15	62514 ± 99814 (0-445879; 52 data larger than 0)		NSY
iT3c	***ecoftch95-04***	CI	Economic org. tenure change 1995-2004: *ecorgften04* minus *ecorgften95*	
	JT X = 0.152151 + 0.263719 × asinh((X + 1150.78) / 2104.41)	-16782 ± 138366 (-784385 to 296214)		NSY
iT3d	*forjovften04*	CI	Forest tenure (ha) by foreign and joint-venture organisations (F/JV) in 2004	
	-	8031 ± 45818 (0-358304; 14 data larger than 0)		NSY
iT3e	***ecofjvften04***	CI	Forest tenure (ha) by economic organisations and F/JVs in 2004	
	X^0.16	70545 ± 129069 (0-795006; 53 data larger than 0)		NSY
iT4a	***cpcften95***	CI	Forest tenure (ha) by communal people's committees (CPC) in 1995	
	X^0.08	37158 ± 79592 (0-403038; 47 data larger than 0)		NSY
iT4b	***cpcften04***	CI	Forest tenure (ha) by communal people's committees (CPC) in 2004	
	X^0.17	5346 ± 13111 (0-55857; 43 data larger than 0)		NSY
iT4c	***cpcftch95-04***	CI	CPC tenure change 1995-2004: *cpcften04* minus *cpcften95*	
	nscor X	-31897 ± 77809 (-398334 to 36141)		NSY
iT5a	***otherften95***	CI	Forest tenure (ha) by other owners in 1995	
	ln(X+1)	35229 ± 83350 (0-448321; 45 data larger than 0)		NSY
iT5b	***otherften04***	CI	Forest tenure (ha) by other owners in 2004	
	X^0.19	64744 ± 94763 (0-425545; 58 data larger than 0)		NSY
iT5c	*othftch95-04*	CI	Other tenure change 1995-2004: *otherften04* minus *otherften95*	
	nscor X	29514 ± 104022 (-354842 to 389247)		NSY
Protected areas indicator variables				
iT6a	***protect93***	CI	Area covered by nature protected areas (ha) in 1993	
	nscor X	12203 ± 22007 (0-109624; 33 data larger than 0)		ICEM
iT6b	***protect02***	CI	Area covered by nature protected areas (ha) in 2002	
	nscor X	37912 ± 54125 (0-234564; 46 data larger than 0)		ICEM
iT6c	***protch93-02***	CI	Protected areas change: *protect02* minus *protect93*	
	nscor X	25709 ± 48090 (0-233964)		ICEM

Table SB1g. Summary of forest land tenure and contract indicator (*T7-15*) variables. Data were obtained from Nguyen et al. (2009*a*; NSY).

Var. No	***Var. Name*** / transformation	**Data type** / **Summary stats**	**Variable description** / **Statistics model and significant predictors**	
Contracted forest land indicator variables				
iT6a	*allfcon99*	CI	Total forest land (hectares) under any specified contract in 1999	
	X^0.5	41194 ± 52344 (0-253153; 52 data larger than 0)		NSY
iT6b	***allfcon04***	CI	Total forest land (hectares) under any specified contract in 2004	
	X^0.24	160389 ± 198482 (0-873247; 59 data larger than 0)		NSY
iT6c	*allfrch95-04*	CI	Total contracted land changes: *allfcon04* minus *allfcon99*	
	nscor X	119195 ± 175598 (-130629 to 677247)		NSY
iT7	***regenfcon99***	CI	Forest areas (ha) contracted for regeneration in 1999	
	(X+20)^0.08	8145 ± 20494 (0-137689; 44 data larger than 0)		NSY
iT8	*protfcon99*	CI	Forest areas (ha) contracted for protection in 1999	
	(X+20)^0.19	33049 ± 41897 (0-193000; 51 data larger than 0)		NSY
iT9	***prorefcon99***	CI	Forest areas (ha) contracted for protection or regeneration in 1999	
	X^0.2	41194 ± 52344 (0-253153; 52 data larger than 0)		NSY
iT10a	***sfefcon99***	CI	Forest areas (ha) contracted by state forest enterprises SFEs/SFCs in 1999	
	X^0.26	56800 ± 110569 (0-662705; 48 data larger than 0)		NSY
iT10b	***sfefcon04***	CI	Forest areas (ha) contracted by state forest enterprises SFEs/SFCs in 2004	
	X^0.16	69208 ± 103426 (0-405688; 52 data larger than 0)		NSY
iT10c	*sfefrch99-04*	CI	SFE/SFC-contracted land changes 1999-2004: *sfefcon04* minus *sfefcon99*	
	nscor X	12408 ± 70522 (-332127 to 331256)		NSY
iT11a	***nhhcon95***	CI	Number of households contracted by SFEs/SFCs in 1995	
	nscor X	2817 ± 5107 (0-22134; 29 data larger than 0)		NSY
iT11b	***nhhcon99***	CI	Number of households contracted by SFEs/SFCs in 1999	
	nscor X	2539 ± 4300 (0-20000; 32 data larger than 0)		NSY
iT11c	*nhhcon04*	CI	Number of households contracted by SFEs/SFCs in 2004	
	nscor X	2359 ± 3862 (0-21904; 38 data larger than 0)		NSY
iT11d	*nhhcch95-99*	CI	Household no. contract changes 1995-1999: *nhhcon99* minus *nhhcon95*	
	nscor X	-278 ± 6089 (-19989 to 20000)		NSY
iT11e	*nhhcch99-04*	CI	Household no. contract changes 1999-2004: *nhhcon04* minus *nhhcon99*	
	nscor X	-180 ± 5172 (-18652 to 17004)		NSY
iT12a	***hhfcon95***	CI	Forest areas (ha) contracted to households by SFEs/SFCs in 1995	
	nscor X	23543 ± 33150 (0-147495; 47 data larger than 0)		NSY
iT12b	***hhfcon99***	CI	Forest areas (ha) contracted to households by SFEs/SFCs in 1999	
	nscor X	13324 ± 19732 (0-80966; 38 data larger than 0)		NSY
iT12c	***hhfcon04***	CI	Forest areas (ha) contracted to households by SFEs/SFCs in 2004	
	nscor X	22481 ± 32741 (0-136918; 38 data larger than 0)		NSY
iT12d	***hhfcch95-99***	CI	HH forest area (ha) contract changes 1995-1999: *hhfcon99* minus *hhfcon95*	
	nscor X	-10218 ± 27545 (-114825 to 66370)		NSY
iT12e	***hhfcch99-04***	CI	HH forest area (ha) contract changes 1999-2004: *hhfcon04* minus *hhfcon99*	
	nscor X	9157 ± 29552 (-74359 to 103622)		NSY
iT13a	***mbpfcon99***	CI	For. tenure (ha) by management boards for protection forest MB-PFs, 1999	
	nscor X	16375 ± 36872 (0-222844; 32 data larger than 0)		NSY
iT13b	***mbpfcon04***	CI	Forest tenure (ha) by MB-PFs in 2004	
	nscor X	35743 ± 73086 (0-384649; 41 data larger than 0)		NSY
iT13c	*mbpfcch99-04*	CI	MB-PF forest contract changes 1999-2004: *mbpfcon04* minus *mbpfcon99*	
	nscor X	19368 ± 43467 (-35422 to 234860)		NSY
iT14a	*mbsufcon99*	CI	For. ten. (ha) by management boards for special use forest MB-SUFs, 1999	
	nscor X	17889 ± 30698 (0-181545; 42 data larger than 0)		NSY
iT14b	*mbsufcon04*	CI	Forest tenure (ha) by MB-SUFs in 2004	
	nscor X	32957 ± 43698 (0-244608; 53 data larger than 0)		NSY
iT14c	*mbsucch99-04*	CI	MB-SUF forest contract changes 1999-2004: *mbsufcon04-mbsufcon99*	
	nscor X	15069 ± 20572 (-1393 to 95358)		NSY

Table SB2. Summary of dependent (d) forest cover and cover change (F) variables. The data were taken from the Ministry of Agriculture and Rural Development (MARD 2015).

Var. No	**Var. Name**	**Data type**	**Variable description**
	transformation	**Summary stats**	**Statistics model and significant predictors**
Forest cover and forest change variables			
dF1a	***natforest93***	CI	The cover of natural forest (in hectares) in the province in the year 1993
	X^0.18	136998 ± 199329 (0-838567)	MARD
dF1b	***natforest03***	CI	The cover of natural forest (in hectares) in the province in the year 2003
	X^0.2	158735 ± 190037 (0-727740)	MARD
dF1c	*natforest13*	CI	The cover of natural forest (in hectares) in the province in the year 2013
	JT X = -0.620267 + 0.695975 × ln((X^0.2 + 4.63366) / (15.0468 – X^0.2))	164879 ± 197342 (0-739181)	MARD
dF2a	***natfrch93-03***	CI	The change in cover of natural forest (percentage) from 2003 until 2013
	JT X = -0.644359 + 0.657010 × asinh((X + 5.74994) / 17.3147)	36.8 ± 74.3 (-100 to +241.1)	MARD
dF2b	*natfrch03-13*	CI	The change in cover of natural forest (percentage) from 2003 until 2013
	JT X = 0.138255 + 0.695862 × asinh((X - 3.72430) / 10.0073)	-3.3 ± 26.8 (-100 to +35.7)	MARD
dF3a	***plantfor99***	CI	The cover of plantation forest (in hectares) in the province in the year 1999
	X^0.33	23355 ± 22407 (0-89551)	MARD
dF3b	*plantfor03*	CI	The cover of plantation forest (in hectares) in the province in the year 2003
	X^0.34	32970 ± 30219 (0-108365)	MARD
dF3c	*plantfor13*	CI	The cover of plantation forest (in hectares) in the province in the year 2013
	X^0.3	55877 ± 57061 (0-199735)	MARD
dF4	*pltfrch99-13*	CI	The change in cover of planted forest (percentage) from 1999 until 2013
	JT X = -2.25918 + 1.09079 × asinh((X + 67.1539) / 36.4861)	152.5 ± 224.9 (-72.5 to +1177.5)	MARD

Part 2: Discussion of the quality and meaningfulness of the explored data

While official statistics in forestry and other sectors in Vietnam have generally improved in the last three decades, there are still important issues and challenges in terms of data gaps and inconsistencies, methodological standardization in data gathering, and/or in transparency of statistical data (cf. Nguyen et al. 2009*a*, Phan et al. 2011, Clement and Amezaga 2009, McElwee 2004, 2016)[1]. We assume that the non-forestry 'independent empirical' data variables (*G*, *P*, *L*, *I*, *E*) are reasonably accurate and precise, even if some data may not be taken at exact 'face value'. For example, in the GSO (2015) data the summed-up numbers of 'rice' and 'maize' crop land area of certain provinces for certain years slightly exceeded the corresponding numbers of 'cereal' crops land area (which supposedly include rice, maize as well as other cereals; it is possible that the areal mismatches have resulted from double-counting in cases of changing crop systems). Regarding forestry data we only found *T* variables for the years 2004, 1999 and 1995, with some notable gaps especially in the year 1995 (cf. Nguyen et al. 2009*a*, original sources GSO and MARD). It needs to be kept in mind that in some provinces FLA programs continued after 2004. Especially land contracts (mostly issued for periods of a few years), changed to varying degrees throughout the study period (cf. Table 1 in the main article). The *C* data variables must be understood as mere approximate indicators for relative differences of forest resource exploitation/uses among the provinces. Indeed, within the statistical models, only variable *iC3* (*pulcap04*) turned out as relevant.

Controversy surrounding the accuracy of official data of forest cover changes in Vietnam (such as our *F* variables provided by VNFOREST 2015) is not insubstantial. Some of these data have occasionally been found to differ considerably from results obtained by researchers from remotely sensed data. For example, Clement et al. (2009) state that official statistics in Hòa Bình Province have over-estimated the extent of afforestation by two to tenfold versus the 'true' extent established through analyses of satellite images. Similarly, in a remote sensing study of the Lower Mekong Basin, Heinimann (2006) expressed some reservations in regards to the quality of official forest cover data in Vietnam and neighbouring countries. While there may be noticeable differences, the results of most studies (including the one by Heinimann 2006), however do not contradict the general picture shown by official provincial statistics (cf. Table SA2, Appendix A, Supplementary Materials). In the case of the Central Highlands, all larger-scale GIS studies (including Heinimann 2006), as well as the official data, report extensive net deforestation during the study period 1993-2013; in addition, the shift in deforestation focus (as shown by official data, cf. Fig. 2 in the main article) generally corresponds with the descriptions provided by Meyfroidt et al. (2013; cf. Section 4.8. in the main article).

Most recently McElwee (2016) has expressed major doubts regarding the accuracy of official data on forest cover (see in particular the sub-section 'Revisiting the Forest Transition', pp. 165-168 in McElwee 2016). Her argumentation is partly based on her own observations during extensive field research in various parts of Vietnam since 1998. Many of her points cannot be easily brushed away (cf. later notes). Especially her observations and research in regards to continuing natural forest degradation (often occurring simultaneously with major government-sponsored exotic-species afforestation efforts) need to be acknowledged and accounted for when considering changes in the cover of so-called 'forest'. On the other hand, two remote sensing studies (Hansen et al. 2013, Kim et al. 2015)[2, 3], which she refers to in order to underline her argumentation, may also be examined critically and discussed in more detail.

Published in the journal *Science*, Hansen et al. (2013) presented a global map of '21st-century forest cover change'. A closer look at the map (online, see https://earthenginepartners.appspot.com/science-2013-global-forest) reveals that loss of 'forest' in Vietnam mainly occurred in the Central Highlands and Southeast Region, and apparently partly in the Northwest Region (especially Sơn La and Điện Biên Provinces). Areas of forest increase are mainly depicted in provinces of the Northeast Region, whereas in the midlands (including many Central Coast provinces) large areas are found where both gains and losses of 'forest' were recorded. As observed by McElwee (2016), at the national level the 'forest' losses in Vietnam (i.e. 12'289 km^2) indeed exceed 'forest' gains (5643 km^2) as recorded by the study of Hansen

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[1] All references are listed in the Reference section of the main article, except the ones listed specifically in the footnotes.

[2] Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R., Kommareddy, A., Egorov, A., Chini, L., Justice, C.O., and Townshend, J.R.G. 2013. High-resolution global maps of 21st-century forest cover change. Science **342**(6160): 850–853. doi:10.1126/science.1244693

[3] Kim, D.-H., Sexton, J., and Townshend, J.R. 2015. Accelerated deforestation in the humid tropics from the 1990s to the 2000s [online]. Geophys. Res. Lett. **42**(9): 3495–3501. doi:10.1002/2014GL062777

et al. (2013; data listed in their Supplementary Materials). However, the essential question is what the pixels on the map really represent.

In a critique also published in *Science*, Tropek et al. (2014)[4] showed that the data of Hansen et al. (2013) not only represent exotic tree plantations as 'forest' on an equal footing as natural tropical forests; in various cases actually plantations of soybean (in Brazil), bananas and pineapple (in the Philippines), oil palm (in several countries), tea (in Cameroon) and other staple field crops (in Madagascar) were misclassified as 'forest'. In their response Hansen et al. (2014, p. 981)[5] claimed that the 'forest' in their study by definition represent "all vegetation taller than 5 m in height". This however seems an odd 'definition' if one considers that Landsat satellites measure vegetation surface reflectance, but can hardly sense vegetation height. Under the 5-m-definition, for example, extensive densely growing stands of tall *Acacia zanzibarica* in coastal Tanzania (woodlands as described by Cochard et al. 2011, Tobler et al. 2003)[6, 7] would qualify as 'forests'. These so-defined 'forests' do, however, not show up on the map provided by Hansen et al. (2013). This is evidently because *A. zanzibarica* trees are characterized by sparsely foliated tree crowns, and the overall vegetation reflectance much more resembles that of a dry savanna biome rather than that of a 'typical' forest. Conversely, dense moist grass- and shrublands, or irrigated staple plantations, may easily be misclassified as a type of forest (as has obviously happened; Tropek et al. 2014) because of a surface reflectance which may be similar to that of productive forests – irrespective of the heights of the dominant plants. This problem is evidently relevant in the case of upland Vietnam, as is illustrated by the scenes shown in Fig. SB1, representing landscapes covered by dense tropical shrublands interspersed with limited tree stands in Sơn La Province. The map by Hansen et al. (2013) largely misrepresents shrublands as 'forest', and, correspondingly, the clearance of shrublands for new swidden fields is therefore indicated as 'forest loss'. It may well be that – for various reasons – the rates of deforestation in Sơn La Province are not reported accurately by forestry personnel, and that net forest increases are exaggerated. The maps of Hansen et al. (2013) are, however, an unreliable source to support such implications. In upland provinces of the Northwest Region these maps probably largely signal the increasing rate of clearance of shrubland vegetation (but possibly including incipient 'forests') for establishing maize fields prior to 2013, probably occurring under more relaxing socio-political conditions after a period (during the 1990's and early 2000's) when swidden agriculture was most stringently restricted under the encumbrance of reforestation policies and programs.

Are the maps of Hansen et al. (2013) useless to detect changes in forest cover? If we better understand what the maps probably represent (i.e. changes in vegetation cover in terms of biomass, rates of photosynthesis and related parameters, rather than presence/absence of woody plants taller than exactly 5 meters) we can still use the maps to extract valuable information. For example, we may observe selective logging and forest degradation in the buffer zones and even inside protected areas such as, for example, Kẻ Gỗ Nature Reserve (coordinates 18°16' N / 105°45' E), one of the last remaining lowland natural forests where much research has been conducted by McElwee (2016). We may observe how natural forests were cleared before 2013 to make room for acacia plantations, such as at one of our previous study sites in Thừa Thiên-Huế Province (coordinates 16°13' N / 107°42' E; Van and Cochard 2016). And we may observe that the plantation cover in midland provinces has a high turnover rate as in between 2000-2013 areas were planted (blue color), cropped and replanted (violet color) with acacias and other exotics. Insofar plantations are hardly stable 'forests', and, correspondingly, statistics on 'planted forest' cover may partly reflect these dynamics. Observing such changes, it can be questioned whether a land use 'transition' towards a dynamic tree cropping system should indeed be described as a 'forest transition' in the classical sense.

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4 Tropek, R., Sedláček, O., Beck, J., Keil, P., Musilová, Z., Šimová, I., and Storch, D. 2014. Comment on "High-resolution global maps of 21st-century forest cover change". Science **344**(6187): 981-d. doi:10.1126/science.1248753

5 Hansen, M.C., Potapov, P.V., Margono, B., Stehman, S.V., Turubanova, S.A., and Tyukavina, A. 2014. Response to comment on "High-resolution global maps of 21st-century forest cover change". Science **344**(6187): 981-e. doi:10.1126/science.1248817

6 Cochard, R., and Edwards, P.J. 2011. Tree dieback and regeneration in secondary *Acacia zanzibarica* woodlands on an abandoned cattle ranch in coastal Tanzania. J. Veg. Sci. **22**(2011): 475-489. doi:10.1111/j.1654-1103.2011.01276.x.

7 Tobler M.W., Cochard R. and Edwards P.J. 2003. The impact of cattle ranching on large-scale vegetation patterns in a coastal savanna in Tanzania. J. Appl. Ecol. **40**(3): 430-444. doi:10.1046/j.1365-2664.2003.00816.x

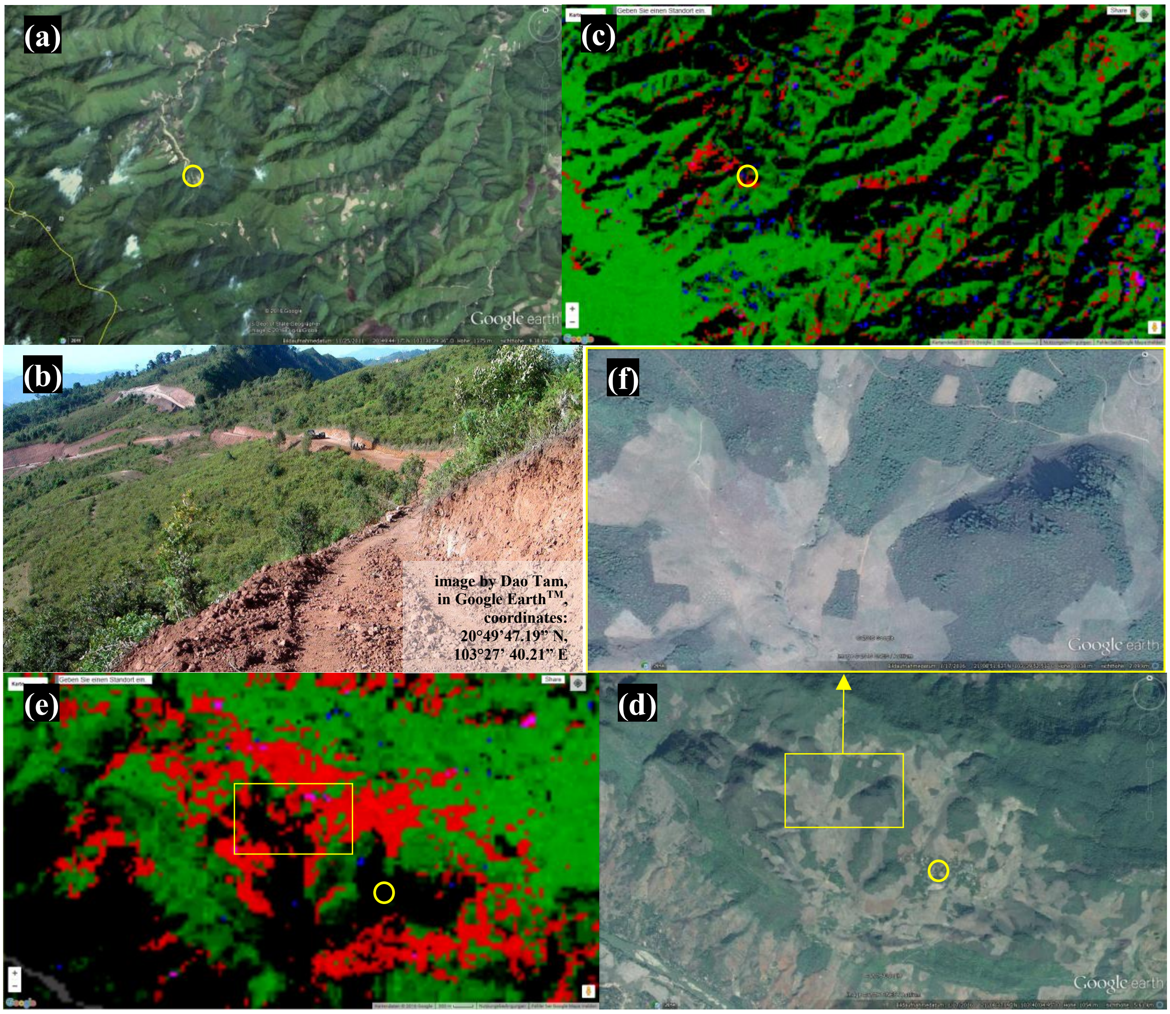

Fig. SB1. Top scenes (a-c) showing the forest cover near Cang Kéo (yellow circle; coordinates: 20°49'38" N, 103°29'49" E) in Sơn La Province. While the high-resolution SPOT satellite image from 25 November 2011 shown in Google Earth™ (image **a**) reveals a 'forest' cover of perhaps maximally 20% (trees are mostly located in shady and moist places along valley bottoms and hillsides; most of the area is grass- and shrubland, cf. middle left image **b**), the map produced by Hansen et al. (2013, image **c**) vastly overestimates tree cover. The map shows 'stable' forest cover (green colour) of around 60%, whereby the computerized classification seems to be strongly influenced by the solar exposure of the hillsides in the Landsat images. Indicated decreases of so-called 'forest' since the year 2000 in some locations (red locations) may, therefore, merely represent the clearing of dense grass and shrub cover (e.g. fires, or swidden field clearing) or higher drought exposures on hillsides compared to the earlier images. In other cases the red pixels in the map of Hansen et al. (2013) may indeed indicate recent forest clearance, e.g. along the hillsides adjacent to hilltop forest as seen in the lower images (**e** and **d**; north of Chiềng Sơ; yellow circle coordinates: 21°08'27" N, 103°40'19" E). A closer look (cf. sub-scene, image **f;** SPOT satellite, 2016), however, shows that it was probably mostly shrub regrowth (or incipient forest regeneration?) which was cleared for new swidden fields. Sources: images a, d and f were obtained from Google Earth™, © 2016 DigitalGlobe, respectively © 2016 CNES/Astrium; images c and e were obtained from https://earthenginepartners.appspot.com/science-2013-global-forest (published by Matthew C. Hansen, University of Maryland, with kind permission to reprint; maps powered by Google Earth™).

Data published by Kim et al. (2015) suggest that the forest cover of Vietnam has actually been decreasing overall in between 1990-2000 (by -60’000 ha y^{-1}) as well as between 2000-2010 (by -172’000 ha y^{-1}), rather than increasing, as suggested by official statistics. Since Kim et al. (2015) have not provided their data as an open source file, we can only make guesses about the accuracy and usefulness of their maps. Based on Landsat images Kim et al. (2015) calculated forest cover maps for all the countries located in the humid tropics. It is quite likely that their maps are affected by similar limitations and classification errors as the maps of Hansen et al. (2013). Calibrating vegetation classes on a global scale almost certainly incurs certain relevant errors, given the vast diversity and variability of climates and vegetation types among different continents. In addition, Kim et al. (2015) note that some regions could not be classified because the satellite images were affected by cloud cover. Depending in which regions the cloud cover was concentrated, this obviously can affect the measurement of forest cover changes of a country. If we however disregard such potential errors and limitations and assume that the maps are reasonably accurate, the difference between their data and the official Vietnamese forestry data may indeed reflect differences in the definitions of ‘forest’. There are numerous accounts (cf. McElwee 2016, 2004, Meyfroidt and Lambin 2008*a*; other literature listed in Table SA2, Appendix A) which suggest that during 1993-2013 forest degradation (due to ‘illegal’ logging and other impacts) remained rampant within Vietnam, irrespective of the simultaneous regeneration of (secondary) forest cover in other parts. If the remotely-sensed data by Kim et al. (2015) more or less correctly captured the decline of tree density and forest biomass, many degraded forests possibly did no longer qualify as ‘forest’ under their more conservative definitions and map calibration, explaining their reported decline of cover.

Given the demonstrated, respectively suspected limitations of the studies by Hansen et al. (2013) and Kim et al. (2015), are the doubts expressed by McElwee (2016) unfounded? The fact remains that no openly accessible vegetation map of high quality exists for Vietnam, even if plentiful satellite images are now available and the capabilities of GIS technologies (in combination with detailed on-the-ground information provided by forestry personnel) are much greater today than just two decades ago. A lot of information on land cover can nowadays even be extracted by using tools such as Google Earth™, and may serve to double-check the trustworthiness of certain data. For example, according to official statistics the forest cover in Sơn La Province has increased from 9.7% in 1993 to 33.1% in 2003 and 43.1% in 2013. Scanning through the province and zooming in at various locations using Google Earth™ (based on Landsat and Spot satellite images of 2016) it appears that overall forest cover is clearly higher than 10%, but a cover of >40% appears too high – except perhaps if certain types of shrub- or bushlands, thickets, open woodlands and/or freshly planted stands of saplings are included to qualify as ‘forest’. If the definition of ‘forest’ is very broad and includes dense bushlands and incipient regenerating forests, we may, however, revert to the question whether the vegetation losses depicted on the map by Hansen et al. (2013) may not indeed largely represent the losses of these same types of ‘forest’ via the clearance of new swidden fields. In any case, it seems clear that most ‘forests’ lost (as indicated in the map by Hansen et al. 2013) in Sơn La Province are probably very different from many forests lost in the Central Highlands provinces, as far as forest qualities such as biomass and species richness are concerned.

Currently we do not have a firm basis to verify the accuracy and reliability of official data on forest cover in Vietnam, nor do we know what types of vegetation various ‘natural’ and ‘planted’ forests exactly represent. The provincial data on forest cover and changes (*F* variables provided by VNFOREST 2015) are compiled from survey data reported by statistical staff working in the communes of different districts (Phan et al. 2011). Even though the forests are assessed using rough qualitative categories (ranging from ‘renascent’ to ‘poor’, ‘medium’ and ‘rich’ forest) the clearest and least equivocal distinction is made between any type of ‘forest’ and ‘bare land’ (Tachibana et al. 2001). Especially in the absence of sufficiently accurate aerial images such data may, nonetheless, variably be afflicted by certain subjective biases and manipulations. In addition, there are also some methodological issues and borderline cases. There is no absolutely clear, unequivocal definition of which vegetation does and which does not represent ‘forest’. Certain types of permanently degraded forest-like woodlands, bushlands and thickets (cf. Nikolic et al. 2008) may thus be or not be considered as ‘forests’ (i.e. technically at the same level as ‘primary’ rainforest), depending on the subjective assessment of the surveyors. There also does not seem to be a sufficiently clear-cut differentiation in regards to what constitutes ‘natural’ or ‘planted’ forest. ‘Planted’ forest is commonly understood to be economically used ‘plantation’ forest which is typically stocked with one or several (typically exotic) types of tree species. In contrast, ‘natural’ forest is usually understood as a forest which is stocked with wild and native trees and has grown (or re-grown) essentially without any direct human influence (‘planting’ activity). There are, however, various intergrading types of forests. Afforestations (~plantations) of shade trees (possibly with exotic species, cf. Amat et al. 2010, De Jong et al. 2006, Van et al. 2005, McNamara et al. 2006) which are meant to facilitate the 'natural' regeneration process of forests on previously bare lands are mostly classified as 'planted' forest. At what stage would such a forest (or similarly abandoned tree plantations) be classified as 'natural' forest, if at all? Conversely, what about the case where economically harvested plants (e.g. cardamom, cf. Jadin et al. 2013, Turner and Pham 2015) are planted in the shade of previously 'naturally' growing trees? Would this be considered a 'plantation' or a 'natural' forest? Such ambiguities can all lead to 'blurriness' of these data. This needs to be kept in mind. The current distinction between 'natural' and 'planted' forest appears to be largely influenced by the efforts for active reforestation during the 1990's. If the objective is to monitor the extents and qualities of forests (such under the new PFES schemes) there is much room for further improvements to be made in official statistics.

Not only are the 'forest' categories vaguely defined, allowing various errors (accidental or wilful) of monitoring and reporting. In addition, given the pressures to report reforestation successes in regions which were the focus of large-scale reforestation programs (such as 5MHRP), it is not unlikely (as is implied by McElwee 2016) that the figures of increasing forest cover may have been somewhat biased upwards in comparison to the areas which in reality regrew into a closed forest cover (this is probably especially the case for 'natural' forest). Especially in the North of Vietnam, some of the *F* data may therefore only partly reflect the cover of actual stable forest; to some degree the data may also reflect bushlands (~incipient 'forests'?), woodlands (~thinned-out 'forests'?), or even just the data manipulations of careless statistical staff trying to hide reforestation failures (e.g. due to droughts or fires) or illegal clear-felling in certain areas.

Given today's remote-sensing capabilities (which guarantee a certain amount of transparency in regards to issues of forest cover changes) as well as various checks and balances within the Vietnamese forestry system, it would be unlikely, however, that all provincial data were manipulated to such a degree so as to represent essentially fictitious numbers. We deem that the *F* data can be trusted to represent passably reliable figures, especially as regards their relative inter-provincial variability (the data are possibly less accurate in their absolute values, which may or may not be variously biased upwards). Part of our confidence is based on the analyses by Meyfroidt and Lambin (2008*a*) who demonstrated that the forest cover data by MARD (respectively subsidiary forest research institutes such as the Forest Investigation and Planning Institute FIPI; cf. Phan et al. 2011) at provincial/district levels in general corresponded to information derived from large-scale remotely-sensed analyses. Furthermore, the patterns of the data generally corresponded to the information derived from the detailed review of literature, as summarized in Table SA2 (Appendix A). Various regional studies on land cover changes using remote sensing techniques (Turner and Pham 2015, Dao et al. 2009, Leisz 2009, and others) indeed confirmed the trends of slowly increasing forest cover in northern provinces (often coinciding with a decrease of the cover of shrublands, partly due to increasing forests, and partly due to the expansion of annual crop fields). Perhaps with the exception of some provinces (e.g. Sơn La Province) the overall patterns of forest cover changes (Figs. 2 and 3 in the main article) also broadly corresponded with vegetation biomass changes as shown by large-scale satellite-based analyses such as those presented by Hansen et al. (2013) and Vu et al. (2014*a*, *b*). Finally, the outcomes of the statistical analyses of the *F* data generally make a lot of sense, especially when compared to all the information derived from the literature review (cf. Section 4.2.-4.9. in the main article). Such an outcome would hardly have occurred, if the *F* data would not indeed reflect a somewhat truthful representation of forest cover and forest cover changes in Vietnam's provinces.

Part 3: Additional data representations

The regression models presented in Table 3 of the main article are the outcome of extensive statistical variable selection procedures. The models are somewhat limited by the types of data which were available, especially for the period 1993-2003. In addition, the reliability of some of the used data may be viewed critically (cf. Part 2, Appendix B). Furthermore, while some patterns within models appear readily explainable, other patterns may be open to more than one interpretation. Pursuant to pertinent logic, models can provide valuable insights into patterns and real processes, but they do not infer ultimate proof of causality. In addition, some predictors may not represent the influences which they may portend within the models. For reference and transparency we therefore here provide a PCA loading plot (Fig. SB2) to show the proximity of major variables within multivariate space. In addition, the trends in forest cover (official data) over the period 1993-2013 are depicted in Figs. SB3a-c.

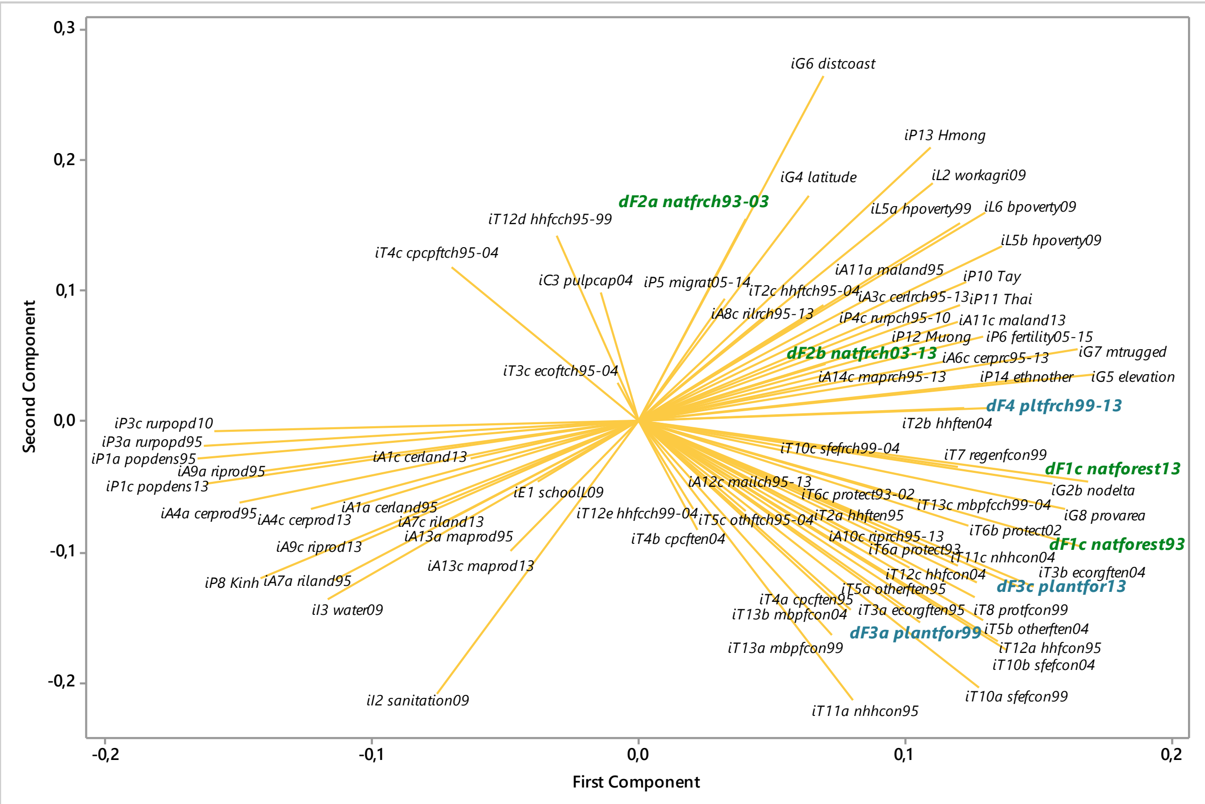

Fig. SB2. Principal components loading plot of main selected variables. For the description of the variables refer to Tables SB1a-g and SB2.

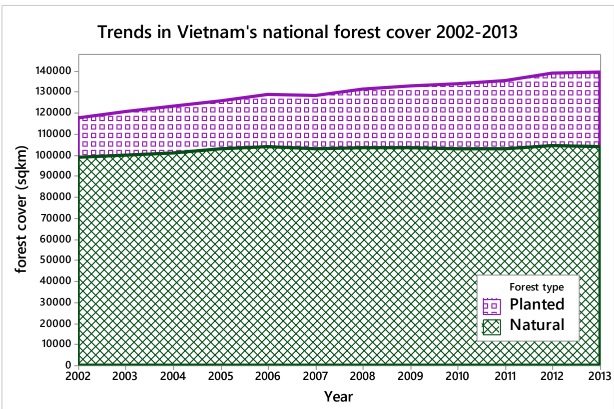

Fig. SB3a. Overall trends in Vietnam's national forest cover in between 2002 and 2013 (official data). While planted forest cover was steadily increasing (19'059 km^2 in 2002; 35'563 km^2 in 2013) the natural forest cover was only increasing marginally in between 2002 (98'606 km^2) and 2006 (102'795 km^2), and varying only slightly thereafter.

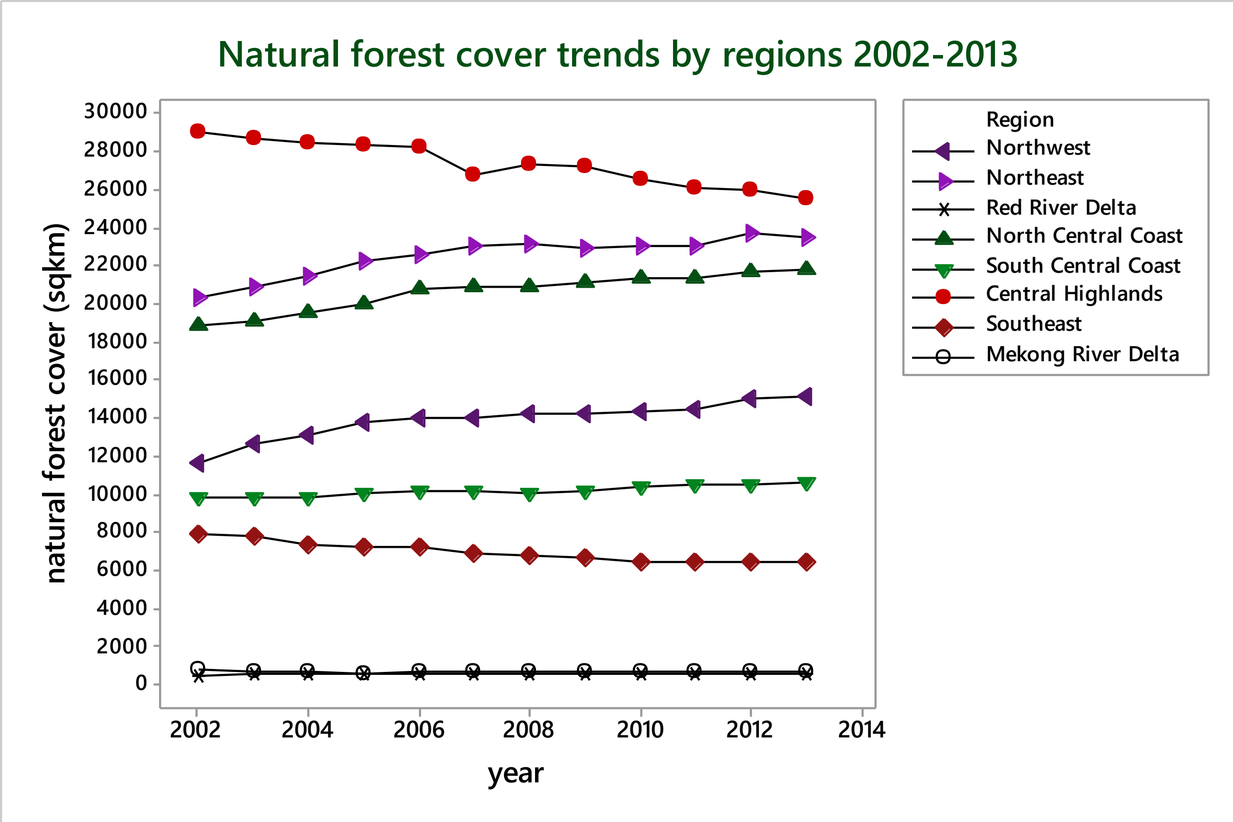

Fig. SB3b. Cover trends of ‘natural’ forests by regions in between 2002 and 2013 (official forest data).

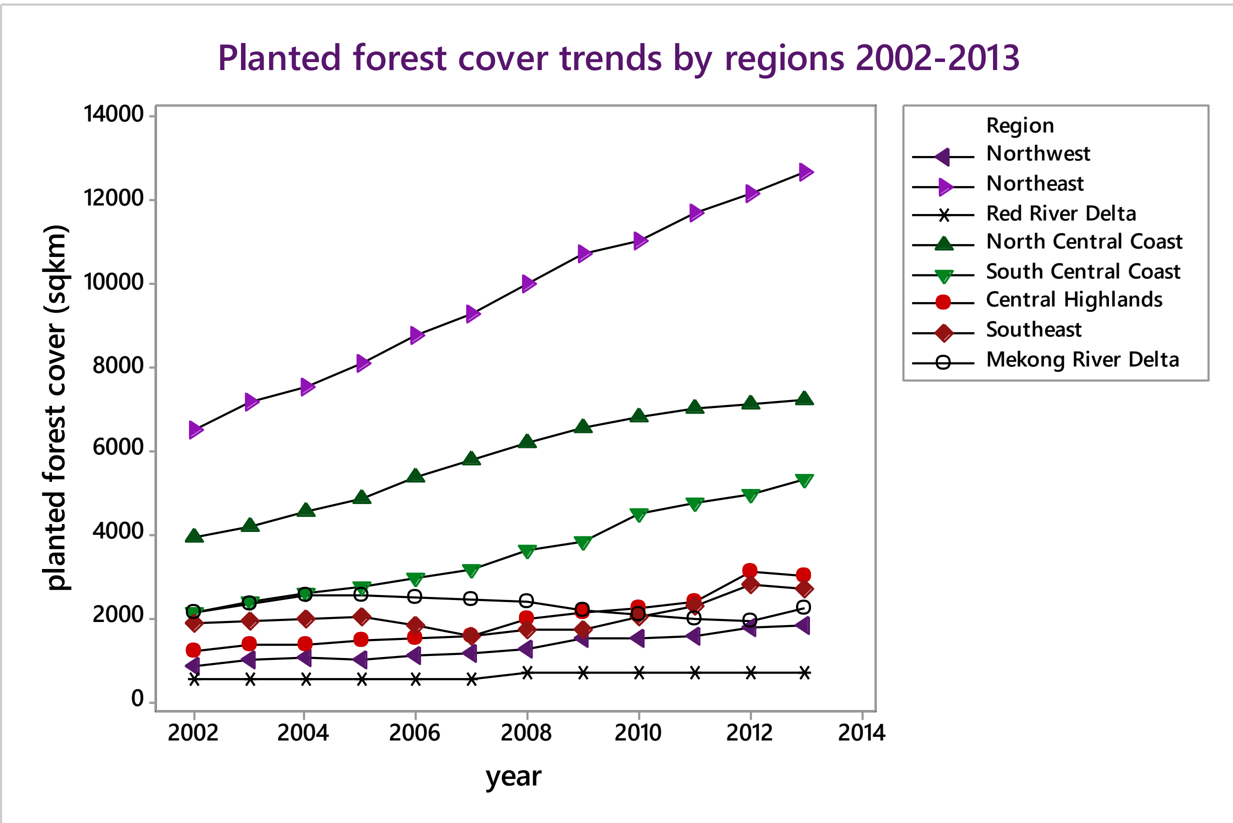

Fig. SB3c. Cover trends of ‘planted’ forests by regions in between 2002 and 2013 (official forest data).