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Driving forces of forest cover rehabilitation and implications for forest transition, environmental management and upland sustainable development in Vietnam

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Abstract
Since the 1990s, forests have changed dramatically, transitioning from net forest loss to net forest increase in Vietnam. This study aims to advance the understanding of the factors driving forest transition at local scales. We employed GIS tools and a structural regression model to quantify the areas of rehabilitated forests and their determinants at the commune scale in Dien Bien province. We found that approximately 118,000 hectares of forest were rehabilitated during 1990 and 2010. Rehabilitated forests accounted for a large share of total forest gain (i.e., above 84%), and this proportion increased from 1990 to 2010. The presence of these rehabilitated forest was associated with both biophysical and accessibility factors. While no evidence regarding the effect of smallholder land use intensity or economic development was found, we did find that forestry land tenure policies facilitate the expansion of rehabilitated forests. The findings of this study can inform the development of policies that support small scale forest transition, environmental management, and upland sustainable development in Vietnam and other countries.

Keywords Local-scale forest transition · Socio-economic drivers · Structural regression model · Rehabilitated forests · Rural livelihood · Vietnam

1 Introduction

Forests provide cultural and social benefits, food, fuel, timber, bioproducts, and ecological functions (such as water and air purification, carbon storage, and nutrient cycling), all of which contribute to human wellbeing (Chhatre & Agrawal, 2009; Griscom et al., 2017; Hogarth et al., 2013; Khuc et al., 2016; Vuong et al., 2021). Increased forest cover through rehabilitation and/or restoration improve the livelihoods of nearby rural communities, improve biodiversity and environmental services, and mitigate the effects of climate change (Bui et al., 2019; Martin & Watson, 2016; Miles & Kapos, 2008; Pirard, 2012; Sunderlin et al., 2005). Thus, improving the understanding of factors driving forest change is necessary for better forest management and forest transition.

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Although the concept of a transition forest has been around for over two decades, it has only recently gained attention in the context of global warming. The transition from deforestation to reforestation describes the trend toward increased forest cover (Hosonuma et al., 2012). Economic growth, forest scarcity, globalization and displacement, smallholder land use intensification, and state forest policy are all potential drivers of forest transitions (Meyfroidt et al., 2018a; Trædal & Angelsen, 2020). The majority of the world's forests are now in the post-stage of forest transition, though many are still in the pre-forest or the early stages of forest transition (Hosonuma et al., 2012).

Regarding this, the transition to forest from farmland in Vietnam is instructive for the rest of Asia. The percentage of land covered by national forests increased dramatically, from 28.7 to 42.1% between 1990 and 2020 (MARD, 2021). Each year, approximately 160,000 hectares of forestland, including both natural and plantation forests, are restored or added. Several studies have been conducted over the last two decades to identify factors that affect forest changes in Vietnam. Meyfroidt and Lambin (2008a; b), for example, identified economic development and forest scarcity as the main drivers. In particular, using cross-sectional data at the district-local scale, they found that agricultural intensification can accelerate reforestation while forestry policy has an impact on forest change. In another study, De Jong et al. (2006) identified a set of biophysical-socioeconomic factors influencing forest rehabilitation. Similarly, Cochard et al. (2017), with support from a dataset in 1993–2013, confirmed that biophysical variables, population, agricultural productivity, wood processing, and forest land tenure affect forest cover change to some extent. Although most studies examine reforestation and deforestation (for example, see also studies such as Clement et al. (2009); Cochard et al. (2017); Khuc et al., (2018, 2020), these studies have either used simple models with cross-sectional data or relied heavily on official data. The majority of research has been done at broad levels (i.e., province, district). As a result, we learn little about how different technological, political, cultural, and economic factors influence forest change.

This study contributes to the literature on the theory of forest transition and upland rural development as well as analytical techniques. First, it improves the understanding of factors driving forest transition at small scales, which is very useful for policymakers and relevant stakeholders, who will then have better and/or appropriate practices and ecological management policies. Second, it fills research gaps in a country where a large population relies on forests as a main income source; related studies are quite limited. Hence, social and economic welfare, particularly of the poor, can be improved significantly with appropriate supporting policies, which can also be applied to other regions with similar socioeconomic and forest transition conditions. Third, it is based on a panel dataset associated with a structural model, which helps capture more information on the complex interactions among social, ecological, and economic processes that influence rehabilitated forests and reduce endogeneity.

In this study, we set out to answer two key research questions: (i) where and how much forest rehabilitation has occurred in Dien Bien, and (ii) what are the driving causes of forest rehabilitation? Based on the aforementioned research questions and research objectives, our assumption is that livelihood characteristics and biophysical and accessibility conditions are associated with forest expansion. Hence, we proposed specific hypotheses to test as follows:

- Hypothesis 1 (H1): Higher income, lower population density, presence of forestland allocation policy, and lower elevations lead to an increase in rehabilitated forests area.

- Hypothesis 2 (H2): Larger rehabilitated forests area, presence of industrial trees, higher literacy, and larger paddy land area can lead to higher income.
- Hypothesis 3 (H3): Literacy and paddy land are positively associated with higher food production.

2 Definition of forests and rehabilitated forests

The legal definition of "forests" in Vietnam, which is enforced through forest conservation and development laws, has existed for many years. This analysis was based on the definition given in Vietnam's legal forestry document (MARD 2009). Accordingly, a forest is characterized by a densely wooded area with a canopy cover of at least 10% and a minimum continuous area of 0.5 hectares. It must be dominated by woody perennial trees, areca palms, or bamboo, and it must be capable of providing a variety of benefits such as wood, non-wood forest products, biodiversity conservation, and environmental protection.

Forests are classified into two main types based on their origin: natural and planted. Natural forests are those that have grown and renewed themselves without human intervention, while planted forests are those that have been created by humans. Forests are separated into protection forests, special-use forests, and production forests based on their intended use. Protection forests are primarily utilized for their environmental benefits. Special-use woods are used primarily for scientific and educational purposes. Production forests serve primarily economic functions. The categories of protection forests, special use forests, and production forests include both natural and plantation forests.

There are three main techniques for forest rehabilitation in Vietnam: artificial regeneration, natural regeneration, and a combination of the two. Artificial regeneration represents the highest amount of investment in labor capital and financial capital, followed by a combination of artificial regeneration and natural regeneration, and then natural regeneration. In practice, protection and special-use forests are frequently restored through natural regeneration, whereas production forests are frequently rehabilitated using a combination of natural and artificial regeneration. To restore forests, one may utilize one or more strategies, depending on the biophysical and financial conditions.

This study focuses on rehabilitated forests, a type of secondary forest that is part of the natural forest ecosystem. Rehabilitated forests are those that have naturally regrown on land that has lost its forest cover due to slash-and-burn agriculture, forest fires, or low-level logging. Dien Bien province has rehabilitated forests that in all three categories of forest: protection forests, special use forests, and production forests. These forests have been rehabilitated through natural regrowth with the help of local residents.

3 Methods

3.1 Study region

Our research focuses on Dien Bien province (Fig. 1) due to the significant role forestry plays in local subsistence and economic growth. Because of its enormous amount of forestland and undeveloped land, this province possesses excellent potential for forest management. There are forests encompassing 602,566 ha (18.41% of the province's total land area) and agricultural land comprising 176,097 hectares (63.19%) of the province's land

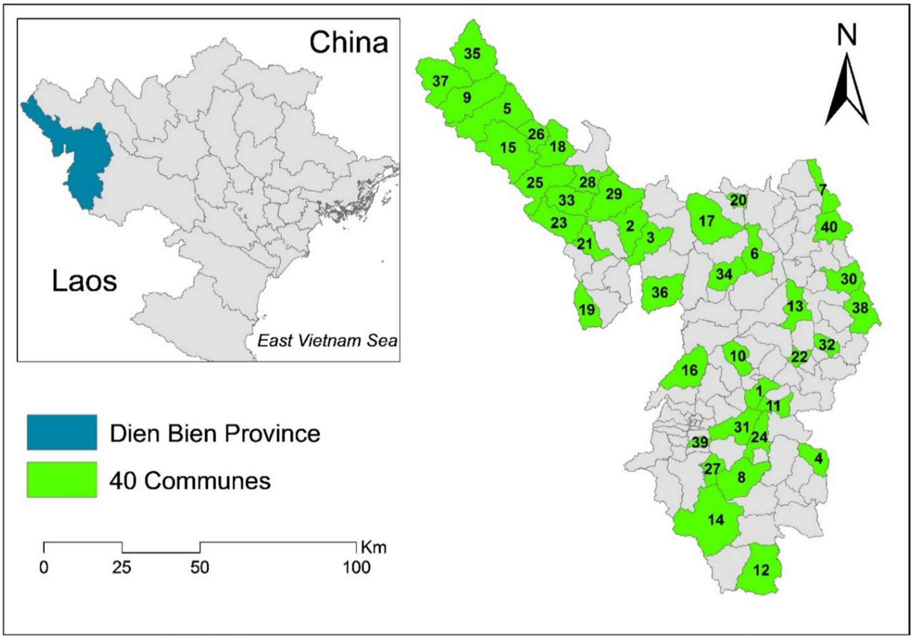

Fig. 1 Map of study region

area. In the 1990s, a plan for allocating forest acreage was devised (To & Tran, 2014). In 2009, the average quantity of forest land provided to commune families for long-term use was 5904 ha. In Dien Bien, numerous comprehensive forest development projects have been performed as part of national initiatives. 45% of the province's communes have participated in an industrial tree (rubber) development initiative since the turn of the century. Dien Bien province and the Vietnam Rubber Corporation's northwest region view the expansion of rubber plantations as important to their socioeconomic prospects. Rubber plantations can utilize a wide range of terrain types; however, the vast majority of land is either underdeveloped or highly deforested.

The commune, the smallest level of administrative division in Vietnam, was chosen as the unit of analysis in order to better explore the factors that have led to Vietnam's successful reforestation. The research team interviewed foresters and managers from Dien Bien's Agricultural and Rural Development, Forestry, and Forest Protection departments in order to determine which communes are reflective of the province's typical economic and ecological conditions. Forty communities were chosen for a thorough examination of regenerated forest (Fig. 1). The communes in question contain more than half (56.49%) of the province's land area and 63.18% of the province's forest cover (Vietnamese law distinguishes between "forestry land" and "forest land").

3.2 Forest rehabilitation model

Based on our hypotheses, we developed a theoretical model of rehabilitated forests that includes key factors that could explain changes in rehabilitated forests in the study area. We first reviewed numerous relevant publications on land use and land cover change, restoration, and its factors in many parts in the world (Call et al., 2017; Hosonuma et al., 2012; Khuc et al., 2016; Lambin et al., 2003; Magliocca et al., 2019, 2020; Nguyen et al., 2018; Noszczyk, 2018; Shi et al., 2020; Stibig et al., 2014; Verburg et al., 2004; Yin et al., 2010). We subsequently narrowed the review down to several research articles that are closely associated with Vietnam.

We discovered that there were numerous elements that could have an impact on recovered forests in Dien Bien province, and we divided them into five categories: biophysical and attainable elements; socioeconomic issues; food security; population growth; and forest policy. The following section provides justifications and/or assumptions for including these variables in the rehabilitated forests, income, and food equations. Biophysical and accessibility characteristics are frequently included as critical factors to consider in reforestation, forest recovery, and forest change models (Cochard et al., 2017; Meyfroidt & Lambin, 2008a). For example, we hypothesized that, given the same set of conditions, recovered woods would be more abundant in areas farther from urban centers. Following that, socioeconomic variables were considered. Among these are several critical factors incorporated into forest-change models (Cochard et al., 2017; Meyfroidt & Lambin, 2008a). Two potential key elements in this category are population and disposable income. The first assumption is that rising populations and economies will increase demand for wood goods. The increased risk of harvesting, rather than protection, may impact forest restoration. Furthermore, the study area is home to a variety of ethnic minority groups, each of which uses land and forest resources in their own unique ways. The international community has recognized Vietnam's early forest rehabilitation success (De Jong, 2010), which may be linked to national forestry policy (i.e., forest land allocation policy) (Cochard et al., 2017). As a result, the forest restoration model may take into account national forestry policy.

Vietnam, like many other growing Southeast Asian countries, is quickly urbanizing. Nonetheless, the country has long been a country where the vast majority of the population lives and works in rural areas, with agriculture accounting for a sizable portion of the national economy (Pham et al., 2019; VUSTA, 2011). Because land is such an important component of agriculture, its price can have a significant impact on the industry's ability to produce food and profit. The ability of a family to provide for itself is heavily influenced by its human resources. A program for the development of industrial trees was implemented in a well-known upland area of Dien Bien province in 2008. Restoring forests can provide people with multiple income streams. Some may make a living by selling timber and non-timber forest products, while others are paid by the local government to protect the forests. As a result, in the income generation model, we include land capital, human resources, and forest productivity, whereas in the food generation model, we include land and human resources.

Based on this reasoning, we developed a structural model to discern the complex interactions among the drivers of rehabilitated forests, income, and food in Dien Bien. The theoretical structural model of rehabilitated forests (FR) is expressed as follows:

$$\text{Model I}: \mathrm{RF}_{it} = f\left(\mathrm{BI}_{it},\ \mathrm{AC}_{it}, \mathrm{SO}_{it}, \mathrm{IN}_{it}, \mathrm{FD}_{it}, \mathrm{POP}_{it},\ \mathrm{FP}_{it}\right)$$

$$\text{Model II}: \mathrm{IN}_{it} = f\left(\mathrm{LA}_{it},\ \mathrm{HU}_{it},\ \mathrm{FP}_{it}, \mathrm{RF}_{it}\right)$$

$$\text{Model III}: \mathrm{FD}_{it} = f\left(\mathrm{LA}_{it}, \mathrm{HU}_{it}\right)$$

where RF_{it}, IN_{it}, and FD_{it} are dependent variables while BI_{it}, AC_{it}, SO_{it}, POP_{it}, FP_{it}, LA_{it}, and HU_{it} are independent variables. RF_{it} represents rehabilitated forests in commune i at time t. BI_{it}, AC_{it}, SO_{it}, IN_{it}, FD_{it}, POP_{it}, FP_{it}, HU_{it}, LA_{it} is short for biophysical, accessibility, social, income, food, population, forest policy, land, and human resource variables respectively.

Based on a theoretical framework that incorporates these hypotheses, we developed an empirical model for replanted forests. The study considered the complex relationships between the factors that drive forest rehabilitation. To reduce the possibility of endogeneity, the study used a structural model with estimates based on the three-stage least squares method. Model specification is central to the development of any structural model (Shi et al., 2020; Yin & Xiang, 2010). We used a three-stage least squares (3SLS) estimator to estimate socioeconomic variables related to changes in rehabilitated forests. We also used ARCGIS software and GEODA v1.6 to test for spatial autocorrelation, which can influence spatial data-based models (Anselin & Rey, 2014; Anselin et al., 2006). Unfortunately, there was no evidence of spatial autocorrelation in our tests. The empirical estimation for this study is presented using a structural model. Our model's input variables were clearly defined (Table 1).

3.3 Data

Our research focuses on three sets of data spanning the years 1990–2010: (i) biophysical and accessibility data, (ii) forest data, and (iii) socioeconomic data. We consulted MONRE for collecting data on the biophysical and accessibility variable. Regarding the forest variable, we used forest distribution maps prepared by the Ministry of Agriculture and Rural Development (MARD) and the Japan International Cooperation Agency (JICA). The Forest Inventory and Planning Institute (FIPI), a sub-agency of MARD, conducts a national forest inventory every five years and produces the data used to create the forest distribution maps. JICA and FIPI developed forest distribution maps for 1990, 2000, and 2010 using a forest classification system with 17 categories (e.g., "rehabilitated forests" has a code of 4). The quality of the forest data was ensured by using both satellite imagery and ground truthing method. Specifically, the forest distribution maps were cross-checked to ensure a categorization consistency of 89%.

Data for socioeconomic variable (iii) was collected by a team from the Vietnam National University of Forestry through a field survey conducted in 2012 and 2013. Forty of the seven districts in Dien Bien province were surveyed (Fig. 1). The data were compiled through both individual and focus group interviews. Interviewers (researchers, lecturers), respondents (local commune personnel, farmers), and organizing elements were all within the control of the research team in order to improve data quality and reduce bias (pre-survey, final survey). Interviewers participated in the creation of a questionnaire that was piloted with a focus group prior to modifications. In addition, the interviewers received brief, in-person training on a variety of interviewing techniques.

Similar to the forest map data, the collected socioeconomic data were organized in a panel format (panel data) that combines observations of many dimensions obtained across two time periods for the same commune. Using forest distribution maps as input, the area of reforestation during 1990–2000 and 2000–2010 was determined. These statistics were used as dependent variables in the subsequent study. As dependent variables, we selected two measures of forest restoration success: forest restoration area per inhabitant and forest restoration area as a percentage of total commune land area. The proportion of a province's

Table 1 The definitions of the variables used in the Dien Bien forest rehabilitation model

Group	Variable	Variable description	References
(Group 1) Rehabilitated forests extent and change (RF) variables	Rehabilitated forests	Percentage of restored forests in relation to the corresponding commune area (%)	Cochard et al. (2017); De Jong et al. (2006); Meyfroidt and Lambin (2008a)
(Group 2) Biophysical (BI) and accessibility (AC) variables	Elevation	Elevation on average (m)	Cochard et al. (2017); Meyfroidt and Lambin (2008a); Viña et al. (2016)
	Road density	Road density (km.km^{-2})	Cochard et al. (2017); De Jong et al. (2006); Meyfroidt and Lambin (2008a)
	Distance	Distance from commune centroid to province center (km)	Cochard et al. (2017); Viña et al. (2016)
	Forest cover 90	Initial forest cover in 1990 (%)	De Jong et al. (2006)
(Group 3) Income and economic (IN) variables	Income	Per capita income (million VND per person)	Cochard et al. (2017); De Jong et al. (2006)
	Forest income	The average percentage of household income that comes from forest-based activities in a commune (%)	Cochard et al. (2017); De Jong et al. (2006)
(Group 4) Social variables (SO, POP)	Ethnicity	Percentage of minority ethnic in selected commune (%)	Cochard et al. (2017); De Jong et al. (2006)
	Population density	Population density (people km^{-2})	Cochard et al. (2017); Meyfroidt and Lambin (2008a)
(Group 5) Agricultural (LA) and food variables (FD)	Paddy land	Percentage of agricultural land in paddy rice (%)	Cochard et al. (2017); Meyfroidt and Lambin (2008a)
	Food capacity	Average percentage of households having enough food within a year (%)	Cochard et al. (2017)
(Group 6) Human resource (HU) variables	Literacy	Percentage of literate population at 15 years of age and above (%)	Cochard et al. (2017)
	Immigrants	Binary variable (the presence of immigrants takes 1; otherwise is 0)	De Jong et al. (2006)

Table 1 (continued)

Group	Variable	Variable description	References
(Group 7) Forestry policy and production (FP) variables	Redbook	The proportion of forestland that has been certified and allocated to households, expressed as a percentage. (%)	Cochard et al. (2017); De Jong et al. (2006)
	Industrial tree	Binary variable (1 indicates the presence of an industrial tree development program, while 0 indicates its absence)	Cochard et al. (2017); De Jong et al. (2006)

Independent (RF/IN/FD) variables and predictors (BI/AC/IN/SO/POP/FD/LA/HU/FP) in structural model (Table 4). The 40 communes in Dien Bien province were used as the units of analysis in this study (see Table S1) forest that has been recovered has been well studied (Cochard et al., 2017). Secondly, while it is well acknowledged that population growth is one of the key causes of deforestation, it is also well established that other factors, including socioeconomic and policy issues, significantly affect the relationship between population and forest cover. Thus, the change in restored forest area per capita is a helpful indicator of how policy, income, and other factors have interacted with population expansion over time to influence repaired forests. We rely on this data because they represent forest changes that are consistent with forest-protection and management actions by a variety of organizations. We researched and measured plantation forest, forest area expansion, and forest area loss throughout the same time period as restored forests in order to have a better understanding of their interdependence.

For the proper measurement of reforested regions, plantation forests, forest gain, and deforestation in Dien Bien, multiple stages were essential, such as the production of forest distribution maps. We relied on this forest distribution map for our research, as it represented the most reliable and publicly available forest data in Vietnam. This map was constructed and verified at a national size (JICA, 2012). Between 1990 and 2010, forest distribution maps included a land classification system that distinguished 13 land use types (Table S2). Rehabilitated forests are forests that were reestablished on previously deforested land, whereas forest gain refers to land that went from being unforested to forested and forest loss refers to area that went from being forested to unforested. We then determined the percentage increase or decrease in forest cover, as well as the total area of reforested land, plantation forest, forest gain, and forest loss in a variety of localities.

We used ARCGIS v10.2 to determine the total area of forested land that has been regrown, planted, gained, or lost as a result of deforestation (ESRI, CA, USA). The multiple GIS map layers displayed 13 distinct land use codes (1 through 4, 6 through 7, and 11 through 17). We were able to construct both forest and non-forest maps by initially specifying query conditions. Using query conditions, we later created a map depicting the locations of restored forests, planted forests, and forested land. We generated information and a map of replanted forests, natural forests, lost forests, and gained forests using the "intersect" and "dissolve" commands in ArcGIS version 10.2. Since the distribution of some forest data (rehabilitated forests, plantation forests, forest gain, and deforestation) was non-normal, a non-parametric test (Wilcoxon signed rank test) was used to compare forest rehabilitation and its relationship to other variables between 1990 and 2010. (Table S3-4).

4 Results

4.1 Forest change and rehabilitated forests

According to our investigation, medium evergreen forests were the most common forest type in Dien Bien in 1990, followed by poor evergreen forests, mixed bamboo forests, and rehabilitated forests. Between 2000 and 2010, the area of rehabilitated forests increased significantly, becoming the most common forest type, followed by mixed bamboo forests and medium and poor evergreen forests. For example, the area of rehabilitated forests increased from 21,000 hectares in 1990 to 101,000 hectares in 2000 and 161,000 hectares in 2010 (Fig. 2).

The share of plantation forests relative to the total forest area is small (7%), while the share of restored forests to the total forest area is substantial (84%). There was a definite rising trend in the proportion of forest land that had been restored from 1990 to 2010.

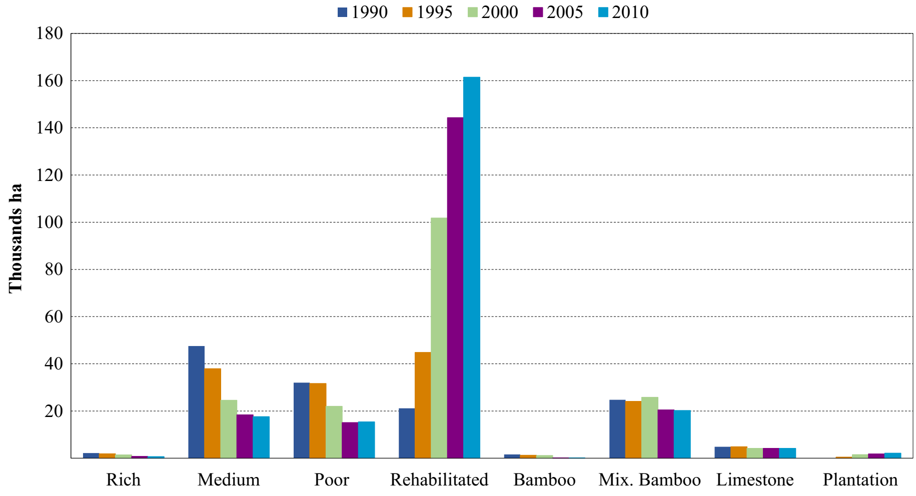

Fig. 2 Difference in forest cover between 1990 and 2010 across a range of forest types in Dien Bien province, Vietnam. There are many different types of forests, such as rich (evergreen), medium (deciduous), poor (deciduous), rehabilitated (forests that have been restored), mixed (bamboo and mixed bamboo), limestone (evergreen), and plantation (non-forest land) (plantation forest)

Between 1990 and 2000, as well as between 2000 and 2010, the area of rehabilitated forests increased considerably, whereas the area of plantation forests decreased. In addition, the overall forest growth in Dien Bien and all of the study's communes consists of almost the same area of rehabilitated and plantation forests (>90%). The remainder of forest growth is comprised of the remaining six forest types (rich evergreen forest, medium evergreen forest, poor evergreen forest, bamboo forest, mixed bamboo forest, and limestone forest) (Table 2). In general, the major changes recorded in forests since the 1990s can be attributed more to reforestation than to forest plantations. As will be demonstrated in the following section, there appears to be a relationship between land tenure policies (Redbook) and the size of the regenerated forest, consistent with the role of state policy in forest transition theory. The following section provides additional clarification.

The patterns of forest cover change observed in rehabilitated forests during the course of the study period relative to the various biophysical variables present on the landscape are shown in Table 3. Rehabilitated forested areas tended to be larger in size and located farther from the provincial capital. In the meantime, there was a linkage between restored forests and proximity to the provincial capital, whereas a higher road density was associated with fewer restored forests. These findings suggest that biophysical circumstances may be a substantial factor in influencing the location and rate of forest expansion.

4.2 Estimated results of rehabilitated forests model

Table 4 presents the structural model's empirical results. All models with a P-value less than 0.05 were deemed statistically significant in terms of their ability to explain observed variance in the dependent variable. Distance, road density, altitude, allocation of forestland,

Table 2 The changes in rehabilitated and planted forests over different periods

Period	Unit	Rehabilitated forests (RF)		Plantation forests (PF)		Total area of rehabilitated forests and plantation forest (RFP)	
		Sampling (n = 40)	Province (n = 124)	Sampling (n = 40)	Province (n = 124)	Sampling (n = 40)	Province (n = 124)
1990–2000	Ha	69,054	100,117	1,432	8,361	70,486	108,478
	%	84.17	82.47	6.11	6.89	90.28	89.36
	%	12.62	10.47	0.37	0.87	12.99	11.34
2000–2010	Ha	90,106	161,240	1,311	7,121	91,417	168,361
	%	96.37	94.29	1.82	4.16	98.19	98.45
	%	16.15	16.87	0.33	0.74	16.48	17.61
1990–2010	Ha	118,753	203,923	1,785	9,843	120,538	213,766
	%	92.72	90.60	1.67	4.37	94.39	94.97
	%	20.94	21.33	0.41	1.03	21.35	22.36

Each interval is comprised of three rows. In the first column, the total forest area in hectares is listed. In the second column of the table, percentages represent the ratio of forest expansion to total area. The third column represents the percentage of land covered by forest

Table 3 Correlations between rehabilitated forests area and biophysical variables

Variables	Initial rehabilitated forests (ha)			Rehabilitated forests by periods (ha)		
	1990	2000	2010	1990–2000	2000–2010	1990–2010
Elevation	0.377**	0.375**	0.042**	0.186	0.125	0.198
Road density	−0.104	−0.449***	−0.496***	−0.555***	−0.563***	−0.532***
Forestland area	0.298*	0.850***	0.861***	0.790***	0.717***	0.778***
Distance	0.382**	0.584***	0.419***	0.447***	0.146	0.278*

***, **, * correlation is significant at the levels of 0.1, 0.05, and 0.01 (2-tailed)

and ethnicity are among the factors that can be used to distinguish between the complete and restricted models.

In models I, II, and III, the "Redbook" variable is statistically associated with rehabilitated forests, as shown in Table 4. A 1% increase in forestland would lead to a 0.14 percentage point increase in recovered forests. This shows that forestland allocation strategy (FLA) may have a direct, positive impact on forest expansion following rehabilitation.

The first model suggests that the variables "Industrial tree", "Paddy land", "Literacy" and "Rehabilitated woods" all have a beneficial impact on income. The presence of rehabilitated forests contributed to a 3.0% increase in per capita income; the development of industrial trees contributed to a 14.5% increase in per capita income; and a 1% increase in literacy contributed to a 1.8% increase in per capita income. These findings illustrate the significance of planted forests in bolstering the local economy. In addition, spreading rehabilitated forests and improving educational standards may help improve income in the study area.

Regarding the food dimension, the impacts of the variables "Literacy" and "Paddy land" in the food equation were as expected; both the amount of available land and the level of education had a favorable impact on food production. When the area of land used for paddy rice increased by 1% and the literacy rate doubled, food production capacity increased by 1.2% and 0.4%, respectively. These results confirm the significant support for the government's current efforts to increase food security, reduce poverty, and promote sustainable livelihoods in the mountainous regions of Vietnam.

5 Discussion

In this section, we discuss the key results of forest changes and its factors in Dien Bien province in light of forest transition theory, socio-ecological systems, semiconducting principle, and sustainable livelihood framework (Meyfroidt et al., 2018b; Partelow, 2018; Serrat, 2017; Vuong, 2021).

Between 1990 and 2010, forest cover increased in the examined communes; however, the increase was mostly related to restored forests rather than plantations. This study suggests that changes in restored forests, not forest plantations, were responsible for the transformation of forests in some highland communes. This demonstrates the success of national forest-development initiatives and policies (McElwee, 2016), but it also demonstrates that upland residents face challenges in extending plantation forests in inaccessible

Table 4 The results of a structural model of the share of rehabilitated forests in regards to respective communal area

Variables	Full model (model I)			Restricted model (model II			Restricted model (Model III)		
	Rehabilitated forests 1990–2010	Income (ln)	Food	Rehabilitated forests 1990–2010	Income (ln)	Food	Rehabilitated forests 1990–2010	Income (ln)	Food
Income (ln)	− 6.388			0.575			− 3.195		
	(12.76)			(9.320)			(11.63)		
Food	0.00516			− 0.0542			− 0.0537		
	(0.192)			(0.169)			(0.181)		
Population density	0.000757			− 0.00633			− 0.0173		
	(0.0324)			(0.0269)			(0.0289)		
Redbook	0.138*			0.0985*			0.129**		
	(0.0751)			(0.0506)			(0.0606)		
Distance	0.0724			0.0395					
	(0.0446)			(0.0302)					
Elevation	− 0.000307			− 0.000735					
	(0.00413)			(0.00345)					
Road density	− 6.944			− 2.202					
	(5.317)			(4.259)					
Ethnicity	− 0.407	− 0.000223	0.0820						
	(0.271)	(0.00702)	(0.254)						
Rehabilitated forests		0.0325***			0.0315***			0.0383**	
		(0.0112)			(0.0121)			(0.0162)	
Industrial tree		0.145*			0.115			0.135	
		(0.0815)			(0.0725)			(0.0865)	
Literacy		0.0180***	0.582***		0.0187***	0.562***		0.0183***	0.561***
		(0.00574)	(0.208)		(0.00545)	(0.198)		(0.00625)	(0.198)
Paddy land		0.0110	1.216***		0.0109	1.203***		0.0118	1.204***
		(0.00678)	(0.238)		(0.00678)	(0.235)		(0.00800)	(0.235)

Table 4 (continued)

Variables	Full model (model I)			Restricted model (model II			Restricted model (Model III)		
	Rehabilitated forests 1990–2010	Income (ln)	Food	Rehabilitated forests 1990–2010	Income (ln)	Food	Rehabilitated forests 1990–2010	Income (ln)	Food
Constant	59.24	1.049	8.849	12.24	1.020***	17.01*	22.75	0.935***	17.02*
	(40.86)	(0.739)	(26.99)	(14.82)	(0.279)	(9.314)	(20.14)	(0.332)	(9.310)
Observations	80	80	80	80	80	80	80	80	80
R-squared	0.063	0.296	0.499	0.142	0.304	0.498	0.048	0.192	0.498
P value	0.0358	0.0000	0.0000	0.0251	0.0000	0.0000	0.0413	0.0000	0.0000

The dependent variables of models I, II, and III are the proportion of rehabilitated woods relative to the entire respective communal area (percent), per capita income (million VND), and the average proportion of families with sufficient food throughout the year (percent), respectively. NI is excluded from the list. In the second and third models, there was no consideration of ethnicity. In model III with full restrictions, characteristics such as distance, elevation, and road density were eliminated. Value absolute of z statistics enclosed by parentheses

*, **, *** indicate significance levels of 10%, 5%, and 1%, respectively

areas due to biophysical and accessibility issues, inadequate infrastructure, and limited markets (Nguyen et al., 2021; Yen et al., 2013).

Vietnam has implemented its forestland allocation (FLA) program for the past two decades (De Jong et al., 2006; Meyfroidt & Lambin, 2008a; Nguyen & Tran, 2018). This policy promoted land privatization and equitable access to financing in order to promote the active participation of locals in forest rehabilitation and reforestation (Dang et al., 2018; To & Tran, 2014). Forestland allocation policies may facilitate the transfer of ownership to farmers and other stakeholders, notwithstanding their dubious impact on naturally regenerated forests (Thanh & Sikor, 2006; Yang et al., 2016). Some upland regions, for example, were found to have a low chance of benefiting from forest extension and improved livelihoods as a result of FLA (Sikor, 2001). Our data corroborate the first hypothesis of our study, which predicted that FLA policy would influence forest recovery (Table 4). Several more studies have come to the same conclusion (De Jong et al., 2006; Meyfroidt & Lambin, 2008a). This finding is important because it could support the government's current forestland allocation program. Although decentralization is a crucial part of forest governance, the rising need for food, biofuels, wood, and environmental services may exceed FLA's capabilities (Agrawal et al., 2008). Keeping and improving the implementation of FLA in inventive ways while expanding the policy to address the continuing limitations, and empowering the community with more education and market actors may yield additional benefits (Nguyen & Tran, 2018; Simelton et al., 2016; Tran & Vu, 2019; Yang et al., 2016). It is essential to resolve the issues that have arisen as a result of the existing FLA policy. Not providing clear and rigorous instructions about FLA, slowing down the pace at which FLA is implemented, not precisely establishing forestland boundaries in the field, and not supporting policy procedures that follow FLA are examples of these issues (To & Tran, 2014).

People's desire for wood for their own existence may potentially affect the growth of sustainable forests. When farmers' earnings increase, they may be more likely to purchase forestland, plant trees, and invest in tree nurseries (Nguyen & Tran, 2018; Sikor & Baggio, 2014), all of which result in a larger forest cover. Our community-level findings confirm the proportional relationship between improved livelihoods and the expansion of restored forests (hypothesis 2). This is illustrated in Table 4. This study suggests that development policies that improve people's incomes and livelihoods can also lead to increased forest cover, especially if these policies are combined with sound land use and land tenure arrangements. Agricultural intensification, which reflects a paradigm shift in land use, has been shown to greatly contribute to reforestation efforts (Dang et al., 2018; Meyfroidt & Lambin, 2008b). Furthermore, it appears that the industrial trees program boosts the average revenue of a commune, but this may have long-term negative impacts on the viability of rural livelihoods (Dao, 2015). This evidence implies that existing government attempts to reduce poverty (such as the "New Rural" program) may be effective, but that expanding the use of industrial tree plantations to achieve so will require adjustment. Some species, for instance, may have detrimental consequences on the ecosystem, and this is a subject that requires additional research.

The exploratory results of forest change and the estimated results of the forest rehabilitation model discussed here suggest that there might still be potential for increasing the forest cover area, including through plantation forests. But this requires not only improving livelihoods but also overcoming enduring constraints such as infrastructure, limited literacy, markets, forestland tenure, forestland fragmentation, sloping farmlands, etc. (Nguyen et al., 2021; Tran & Vu, 2019; Yen et al., 2013). In light of the 3D-mindsponge-serendipity knowledge management system (Nguyen et al., 2023; Vuong, 2023; Vuong et al., 2022), socio-ecological systems (Partelow, 2018), semiconducting principle (Vuong, 2021) along with the sustainable livelihood framework (Serrat, 2017), it appears key to build and apply innovative solutions that are tailored to social-ecological contexts rather than one-size-fits-all scenarios. To be specific, strong collaborations, improved science and technology in agro-forestry, effective communication, and environmental culture are key to enhancing people's awareness, empowering community, improving household livelihood, and enlarging forests.

We acknowledge that our study has some limitations. The first pertains to the low-quality data used in our analysis. The interval between each set of maps is ten years, and each set is based on data from a single year. In addition to possible inconsistencies in the socioeconomic data due to respondents' possible bias, the satellite-derived forests data set acquired from FIPI forest cover maps also contain a certain degree of inaccuracy (JICA, 2012; Putz & Redford, 2010). Our study only included 40 communes, so we cannot be sure that our findings apply to the entire northwest region of Vietnam, which has 600 communes. We also acknowledge that environmental culture (Khuc et al., 2023; Vuong, 2021) is a significant factor that influences how people perceive natural resources and act to protect and develop forests, and that this aspect should be studied further, but this was beyond the scope of our study.

6 Conclusions and policy implications

Vietnam's forest transition has taken place over several years, but further forest expansion and, in particular, improvement in forest quality are essential for enhancing the upland environment, household livelihoods, and reducing carbon emissions in order to reach net zero carbon emissions by 2050. This study demonstrates the significant potential and challenges for increasing forest area and quality. Along with maintaining a forestry policies pathway, Vietnam should particularly consider and follow the smallholder land-use intensification and economic development pathway for further forest expansion. Based on the results and discussions in this study, three key conclusions and/or lessons learned are as follows:

- First, the management of rehabilitated forests poses both opportunities and challenges. This is because rehabilitated forests constitute a local source of forest gain and can ultimately contribute to the acceleration of forest transition. Increases in rehabilitated forests may suggest opportunities for further forest restoration. Regardless, this growth is essential for the expansion of national forests and for continued climate change mitigation efforts targeted at reducing emissions caused by deforestation and forest degradation.
- Secondly, a positive association between "Redbook" proxy and "rehabilitated forest" represents the initial outcomes of a series of forestry preservation laws that were implemented in the 1990s. For instance, under the forestland allocation program, rangers and farmers were responsible for forest protection via forest protection contracts. To ensure that these programs have lasting effects on forest recovery, they must be maintained and evaluated frequently.
- Thirdly, the relationship between forest conservation and improved livelihoods is typically conflicting, making it difficult to fulfill both objectives. In our study, however, forest transition happened simultaneously with substantial economic growth and forest

extension. This indicates that it may be possible to create policies that generate synergy between these two objectives.

These lessons from Vietnam may be applicable to some other developing nations where forest transition is taking place. The policies for sustainable rural development must be developed in local contexts, and it is essential to acknowledge that no single solution will be appropriate in all contexts. Based on the key findings, we hope that this study could help to advance the understanding of how to rehabilitate and/or restore forests at the local level, which could support a faster and more effective forest transition, as well as improved livelihoods for people living in upland rural areas in Vietnam and other countries.

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