

**LAND SYSTEM RESILIENCE: LINKING LAND USE CHANGE, STATE POLICY AND
ETHNIC MINORITY RESOURCE MANAGEMENT IN NORTHERN UPLAND
VIETNAM**

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ABSTRACT

In the Socialist Republic of Vietnam, state policies governing land use, market integration, and poverty reduction largely determine the prospects for social-ecological resilience. In turn, land system change in the northern uplands has largely been shaped by market liberalization and the integration of ethnic minority farmers into state development practices and ideologies. Hybrid crops and plantation forestry are increasingly being adopted with important implications for local livelihoods and ecosystems, although the long-term outcomes of such land changes remain poorly understood. The aim of this thesis is to explore the relationships between state policy, land use change, and social-ecological resilience from 1999 to 2014 in Lào Cai Province, Vietnam. To do so, I draw on a conceptual framework integrating social-ecological systems, resilience, land system change, and sustainable livelihoods. Taking a mixed methods approach, I developed 15m resolution object-oriented land cover classifications, which I analyzed for change in landscape structure and function from 1999 to 2014. I also completed qualitative fieldwork including 75 semi-structured and informal interviews with government officials and Hmong, Yao, and Tày farmers. I find that there has been an important increase in plantation forestry, cash crops, and urban areas. Concurrently, total area under agricultural cultivation and secondary vegetation have declined, pointing to a land system regime shift. Farmers described an increase in opportunities to gain financial capital, yet also noted a severe degradation of natural capital. Furthermore, there has been a loss of socio-ecological resilience due to increasing incidents of extreme weather events, market price fluctuations, and pest outbreaks. Long-term resilience planning is largely absent at the household or state level, with households having to respond to ongoing disturbances mostly through short-term adaptation mechanisms such as changing crop varieties, applying increasing amounts of chemical fertilizers, and pursuing off-farm income opportunities. I conclude with context-relevant policy recommendations to increase diversity and the self-organizing capacity of the social-ecological system.

RÉSUMÉ

Au sein de la République socialiste du Vietnam, les politiques gouvernementales relatives à l'utilisation du sol, l'intégration aux marchés économiques ainsi que la réduction de la pauvreté matérielle déterminent la vision à l'égard de la résilience socio-écologique. En revanche, le changement dans le système d'occupation du sol dans ces régions a également été largement influencé par la libéralisation des marchés économiques et l'intégration des paysans de minorités ethniques au sein des pratiques et idéologies étatiques pour le développement national. Les cultures hybrides et les plantations forestières sont de plus en plus adoptées, et ce avec d'importantes retombées pour les moyens de subsistance des populations ainsi que pour les écosystèmes, malgré que les effets de ces changements d'usages demeurent encore peu connus. L'objectif de ce mémoire est d'explorer la relation entre les politiques de l'État, les changements dans l'utilisation du sol et la résilience socio-écologique, de 1999 à 2014, dans la province de Lào Cai au Vietnam. Ma recherche utilise un cadre conceptuel intégrant les systèmes socio-écologiques, la résilience, le changement du régime d'utilisation des terres et les moyens de subsistance durables. J'ai développé une méthode de classification de la couverture du sol orienté objet, ayant une résolution de 15 mètres au sol, afin d'analyser le changement dans la structure et la fonction des paysages. Employant une méthodologie mixte, j'ai également réalisé 75 entretiens semi-structurés et informels avec des officiels du gouvernement et des paysans des minorités Hmong, Yao, et Tày. Mon analyse montre qu'il y a eu une augmentation significative des plantations forestières, des cultures de rente et des zones urbaines car les paysans s'intègrent de façon grandissante dans l'économie de marché. Parallèlement, les zones cultivées et la végétation secondaire ont diminué, indiquant un changement dans le régime d'utilisation des terres. Par ailleurs, les paysans ont décrit une augmentation des occasions pour accumuler du capital financier, mais une dégradation importante du capital naturel. De plus, il existe une perte de résilience socio-écologique, causée par une augmentation de l'incidence d'événements météorologiques extrêmes, la fluctuation des marchés et les infestations d'insectes ravageurs. La planification pour la résilience à long-terme est largement absente à l'échelle du ménage et au niveau étatique. Les ménages doivent le plus souvent répondre à ces perturbations à travers des mécanismes d'adaptation à court-terme, tel qu'en variant les types de cultures, en appliquant davantage d'engrais chimiques et en cherchant des sources de revenus en dehors du secteur agricole. Pour conclure, je recommande des politiques adaptées au contexte afin d'augmenter la diversité et la capacité d'organisation du système socio-écologique.

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CHAPTER 1 INTRODUCTION

Global land system change, including deforestation, agricultural expansion, and urbanization, are occurring at an unprecedented pace and have major implications for the environment and human well-being (Foley et al. 2005; Steffen et al. 2015). While there is increasing research attention on the causes of land change, the human and ecosystem responses to land system change are not well understood. For instance, while we may acknowledge a shift from forests to intensified agriculture, we do not yet know what the long-term impact of such a change is on social, ecological, and economic systems. Evaluating social-ecological resilience provides a theoretical framework to understand changes to complex social-ecological systems (SESs).

Resilience theory differs from traditional social or ecological indicators of health as it focuses on the variables that underlie the capacity of the system to provide environmental and livelihood services, and reduce vulnerability to disturbances (Carpenter et al. 2001). There is a complex interplay between top-down (e.g. government, policy) and bottom-up (e.g. ecological change, population growth) drivers that play a fundamental role in system dynamics (Norberg and Cumming 2008). Understanding resilience in SESs is not simply a matter of social resilience plus ecological resilience, but rather requires identification and exploration of key relationships that link the two systems, such as land tenure, land use, management, and agriculture (Cumming 2011b). Anthropogenic landscapes allow for the identification of both social and ecological system variables as land systems may undergo rapid changes and shifts to new regimes governed by different economic, social, and ecological characteristics (Müller et al. 2014). Predicting the mechanisms behind land system changes - including triggers, evolution, and trade-offs - is therefore necessary to guide policy and manage increasingly scarce natural resources.

This research takes place in Lào Cai Province, an agricultural frontier located along the Sino-Vietnamese border in northern Vietnam (Figure 1.1). Agricultural frontiers, characterized by agricultural expansion, rapid land use change, growing population, and transportation infrastructure improvements, are areas undergoing transformations in land management practices (Rindfuss et al. 2007). Given these rapid changes to the SES, by examining change in frontier environments, characterizations may be made to understand system change and develop appropriate management solutions. In Lào Cai Province the elevation ranges from near sea-level to 3000m and slope varies between 0-83° (USGS). There are important differences in the biophysical conditions of this study area, which can be broadly delineated by the presence of the

Red River running through the center of the province. Regions west of the Red River have a higher elevation, are cooler, and are increasingly susceptible to heavy snowfall in the winter and heavy rain in the summer. Regions east of the Red River are composed of a predominantly karst landscape, are slightly lower in elevation and are drier in comparison (Turner and Pham 2015). The province (*tỉnh*) is comprised of nine districts (*huyện*), and smaller administrative zones known as communes (*xã*).

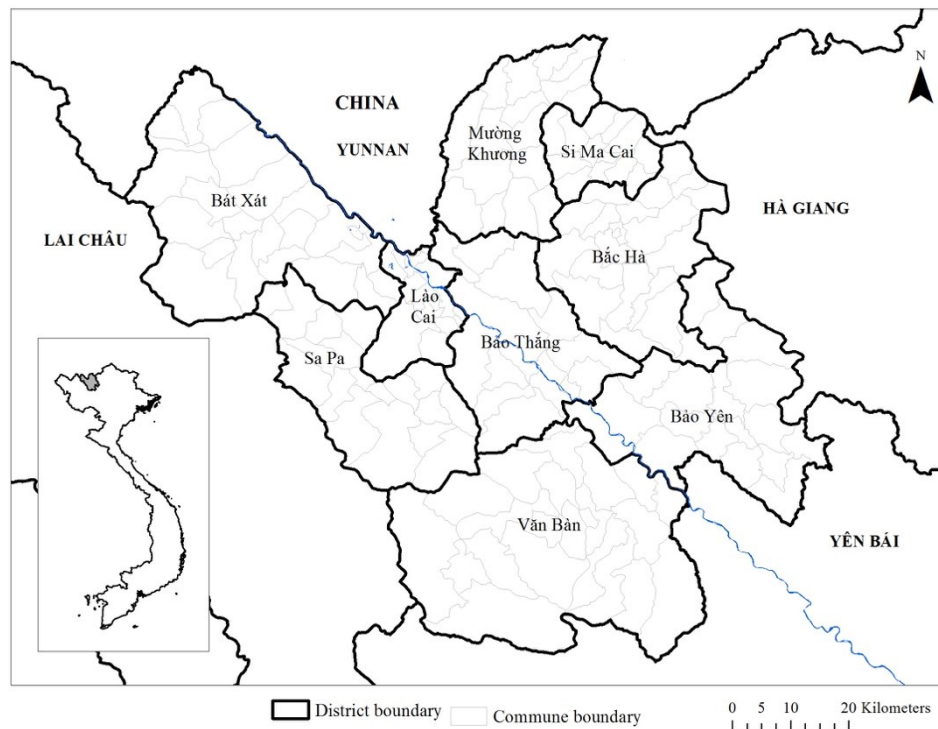


Figure 1.1 Study area (Source: Author).

Vietnam is home to 54 state recognised ethnic groups, 53 of which are ethnic minorities. Since the end of colonial rule (1954), state officials have often been unaware of or have rejected upland cultural differences, and relationships between state officials and ethnic minorities in the uplands have lacked trust (World Bank 2009). Minority groups make up 66% of Lào Cai Province's population (GSO 2009). In the mountainous regions of the province the population is overwhelmingly rural and the predominant ethnic groups are Hmong, Yao (Dao), and Tày. Traditional land use practices of these three groups revolved around a composite agricultural system. Paddy rice and maize cultivation were dominant, and were often supplemented with livestock rearing, non-timber forest product collection, home gardens, small shifting-cultivation plots, and small-scale barter and trade (Turner et al. 2015). Recently, cash-crops have been introduced to the area, including the cultivation of bananas, pineapples, tobacco, and tea.

Recent land system changes in Lào Cai Province have affected the sustainability of the land to provide natural resources and meet ethnic minority livelihood needs. The agricultural sector in Vietnam is facing key constraints, such as the lowest arable land per capital in Southeast Asia, widespread evidence of soil degradation, increasing application of chemical fertilizer and pesticides, and lack of institutional capacity (World Bank 2009; Pham and Smith 2013). However, there is no reliable picture of the regional *impacts* of land use land cover (LULC) change in northern Vietnam, or how the underlying resilience of the SES has changed, and calls have been made to understand how and why these changes are occurring (Pham et al. 2015; Turner and Pham 2015).

1.1 Thesis aim

The aim of this thesis is to **explore the relationships between state policy, LULC change, and social-ecological resilience from 1999 to 2014 in Lào Cai Province, Vietnam**. My underlying goal is to assess ecosystem and livelihood vulnerabilities so action may be taken to ensure a sustainable future for ethnic minority farmers and the ecosystems they depend on. I focus on how policies and decisions have altered the local landscape, the impact of these changes on ethnic minority livelihoods, and the cumulative effect of these changes on the state of the SES. Taking a mixed methods approach to understand complexity, my **five research questions** are:

1. What are the dominant LULC changes from 1999 to 2014 in Lào Cai Province?
2. What are the drivers of LULC change, based on interviews in selected rural sites within the province?
3. What are the implications of LULC change for social-ecological resilience?
4. Is there evidence of a LULC regime shift?
5. What strategies may be used to increase social-ecological resilience in Lào Cai Province?

Integral to understanding resilience, is a multi-scalar spatial and temporal approach, as thresholds and regime shifts operate across scales (Cassidy 2007). To answer my research questions, I analyze change from 1999 to 2014 at the meso-scale by combining two approaches: remote sensing and landscape ecology methods to examine provincial change; and interviews and observations to understand household change. I draw on the strengths of these two methodological approaches to ‘link people to pixels’ so I may better understand the extent of, and driving forces behind, land system change (Rindfuss and Stern 1998). In this highly rural area, my focus is on rural LULC, although urban changes are also noted briefly.

1.2 Thesis outline

This thesis is organized into eight chapters. To ground my research aim, in Chapter 2 I outline the conceptual framework I draw upon. I first examine the broad literature on SESs, and focus on the concepts of complexity, regime shifts, disturbances, and the adaptive cycle. I then review three bodies of literature from which I take more specific concepts to help underscore my work. First, I outline the resilience framework, for which I provide different definitions of resilience, and explain and critique the application of this framework. Second, I draw from land system science, and review key definitions and the drivers of land change. Third, I outline the sustainable livelihoods framework, including livelihood assets, vulnerabilities, strategies, and outcomes.

In Chapter 3, I present the contextual factors influencing land change in Vietnam. I examine cross scale changes in policy, land use, and the biophysical environment at the regional, national, and provincial scales. I highlight how ethnic minority land practices have shifted from traditional approaches, to those grounded in modern state-endorsed intensified land use. Then, in Chapter 4 I detail the mixed methods approach I take to answering my research questions. I outline the remote sensing approach to land cover classification, including image preprocessing and object oriented classification, and provide an overview of landscape ecology metrics and principles. I then turn to the qualitative methods used in this thesis including observation and interviewing, and highlight the importance of researcher subjectivity and critical reflexivity.

In Chapters 5, 6, and 7, I present my results and answer my first three research questions. Drawing on the results of land cover classifications and interviews with ethnic minority farmers and state officials, in Chapter 5 I uncover the dominant LULC transitions that have occurred in Lào Cai Province and analyze the direct and indirect drivers that have contributed to landscape and livelihood changes. In Chapter 6, I explore the impacts of LULC on social-ecological resilience by drawing on both landscape metrics and interview results. In Chapter 7, I provide an in-depth case-study of Bảo Yên District to demonstrate complexity in LULC change and the long-term outlook for resilience.

I conclude this thesis in Chapter 8 by answering my fourth and fifth research questions. I examine feedbacks in the SES and provide critical insights into the utility of the resilience framework. I then outline how this thesis has advanced knowledge of land change and resilience in Lào Cai Province, and summarize the thesis as a whole.

CHAPTER 2 CONCEPTUAL FRAMEWORK

To examine the impact of land change on resilience, I draw on a conceptual framework from four interrelated areas of literature: social-ecological systems, resilience, land system science, and sustainable livelihoods (Figure 2.1). In this chapter, I outline the core concepts of each body of literature, and highlight the relevant aspects of each that help inform my study.

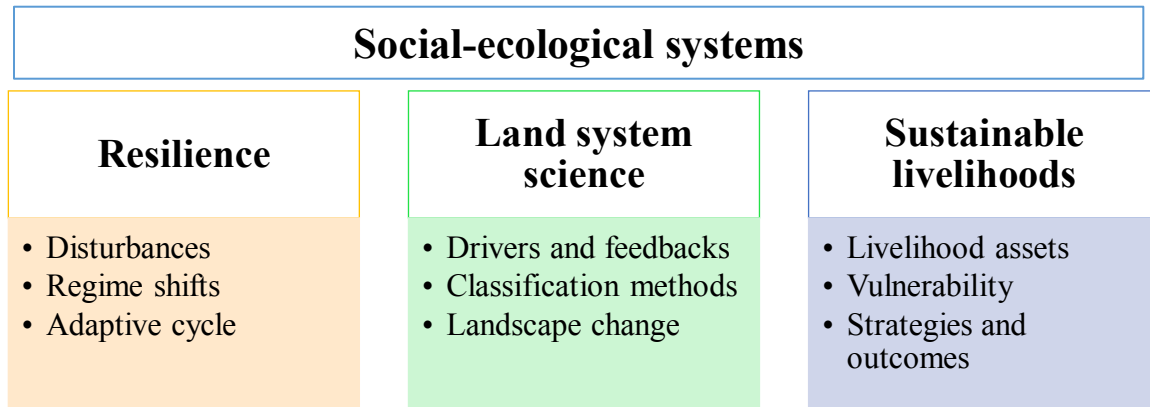


Figure 2.1 Conceptual framework guiding this thesis.

2.1 Social-ecological systems

The social-ecological systems (SESs) analytical framework emerged from a recognition that human societies do not live in isolation from the biophysical environment (Westley et al. 2002). A SES is broadly defined as an integrated system of people and nature in which feedbacks occur between human and ecological system elements (Cumming 2014). Specifically, a SES is a coherent system of biophysical and social factors that regularly interact in a resilient manner. A SES is a system that is defined at several spatial, temporal, and organizational scales, and is a dynamic complex system with continuous adaptation (Redman et al. 2004). The study of SESs involves interdisciplinary collaborations of knowledge from both the environmental and social sciences, as well as an understanding of the unique interactions and linkages that occur between systems (Redman et al. 2004; Haberl et al. 2006; Liu et al. 2007). Interactions depend on the system under study but can include elements such as land use decisions, changes in land cover, and production systems. Thus, SESs research requires a reconciliation of two epistemologies: biophysical research, grounded in empirical consistency and repeatability, must recognize that complexities of human behaviour have a subjective element that cannot easily be reinterpreted or reconstructed (Cumming 2014). This research will draw on the concept of SESs by recognizing that land change and resilience are shaped by both social systems, including state policy and ethnic minority land use decisions, and ecological systems such as biophysical and climatic

conditions. The following subsections outline key theoretical components of SESs, including the importance of recognizing SESs as complex and adaptive, as well as key terms and definitions used in this thesis.

2.1.1 Social-ecological systems as complex adaptive systems

Central to SESs literature is the recognition that interacting social and ecological systems are complex, governed by feedbacks, and subject to change (Levin 1998; Redman et al. 2004). The intellectual foundation of SESs theory is complex adaptive systems (CASs). CASs thinking emerged in the 1980s in many disciplines such as economics, institutional arrangements, political sciences, and ecosystems (Norberg and Cumming 2008). A complex system is considered adaptive based on its capacity to change in response to conditions by means of self-organization, learning, and evolving (ibid.). For instance, a farmer facing an identical situation at two points in time would make an improved decision the second time based on the outcome of the first decision.

Studying CASs involves the “study of how complicated structures and patterns of interaction can arise from disorder through simple but powerful rules that guide change” (Levin 1998, 432). CASs experience sustained diversity and individuality of components, localized interactions among components, and an autonomous selective process (ibid.). For example, Holland (1995) identified four key elements of a CAS in an ecological context: (1) aggregation or endogenous organization of species and populations within a system; (2) non-linear interactions between components of the system that change that over time as the system develops; (3) biological diversity; and (4) flows between biotic and abiotic components of the system. Norberg and Cumming (2008) further generalized these themes into three components that apply CASs thinking to SESs: (1) diversity and asymmetry in space and time; (2) networks consisting of localized nodes; and (3) information processing, such as decisions that influence the outcome of the SES. In this thesis, I examine LULC and resilience changes in the context of CASs by recognizing that changes to the SES (e.g. livelihoods, policy, or ecosystems) are governed by self-organization, learning, and evolving.

2.1.2 Adaptive renewal cycle and disturbances

A series of integrative frameworks that apply CASs theory have been developed as a means of understanding change in SESs. The framework most often applied and combined with resilience thinking is the adaptive renewal cycle (Holling 1986; Holling and Gunderson 2002) and the

related concept of panarchy (Gunderson and Holling 2002). Using the adaptive renewal cycle, the dynamic behaviour of a system can be described using four phases of development that are driven by discontinuous events and processes: growth and exploitation (r), conservation (k), release (Ω), and reorganization (α) (Figure 2.2). Major ecosystem changes occur in the release and reorganization phases while the first two phases are dominated by stable accumulation of energy and materials (Holling and Gunderson 2002). The timely progression through the phases is also unequal, whereby the exploitation and conservation phases occur slowly while transition to the release and reorganization phases occurs quickly. It has also been recognized through the concept of panarchy that adaptive cycles occur nested within, and sometimes interacting with, each other depending on the scale of analysis (Holling et al. 2002).

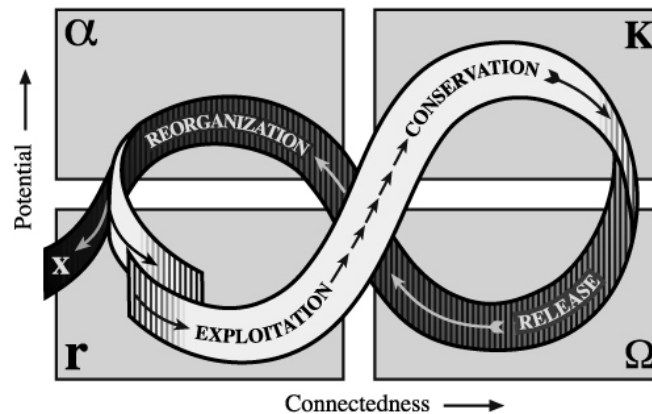


Figure 2.2 Two-dimensional representation of the adaptive renewal cycle. The y-axis represents accumulated resources in the system and the x-axis represents the degree of connectedness between independent variables (Source: Holling and Gunderson 2002, 34).

Changes to a SESs are triggered by a disturbance. There are four types of disturbances that may influence a system's trajectory: (1) the fluctuation of a flow into or out of the SES (e.g. drought, pollution, flooding); (2) change in a key parameter that affects an SES (e.g. loss of topsoil, market price fluctuation, temperature change); (3) a change in the network structure of the system (e.g. invasive species, change in population, or trade agreements); and (4) change in the social or ecological connectivity between the SES and the external environment (e.g. infrastructure change, market demand) (Schoon and Cox 2012). In stable systems, the overall structure and function of the SES will return to normal after the disturbance; however, if a system is unstable, it will undergo a change in underlying structure and function before returning to a new equilibrium. Novel disturbances, increased disturbance frequency, size or severity, and

compound disturbances may ultimately undermine resilience and make land systems vulnerable to rapid changes in ecosystem state (Johnstone et al. 2016).

2.1.3 Regime shifts in SESs

One phenomenon caused by self-reinforcing processes and non-linear dynamics in SESs is a regime shift – the ability of a system to internally switch between different self-reinforcing processes that dominate how the system functions (Gunderson et al. 2008). The source of a regime shift is driven exogenously by a disturbance or by gradual changes originating in the natural or social system (Filatova et al. 2016). Shifts can occur at different scales (e.g. patch, farm, region) and within an economic, ecological, or social/cultural domain (Kinzig et al. 2006). A regime shift occurs during the release and reorganization phase of the adaptive renewal cycle when “a threshold level of a controlling variable in a system is passed, such that the nature and extent of feedbacks change, resulting in a change in the direction (the trajectory) of the system itself” (Walker and Meyers 2004, online). Crossing a threshold in a SES often initiates crossing other thresholds at other scales, or within another domain, and can lead to cascading regime shifts into highly resilient undesirable states (Anderies et al. 2006).

Systems altered by a regime shift do not return to previous equilibrium states and thus require a new set of management practices. The concept of resilience (defined in Section 2.2) is used to describe how much change a system can undergo before a regime shift occurs. Regime shifts have been documented in several SESs such as shifts from grassland to shrub dominance (Walker et al. 1981; Ludwig et al. 1997), shifts between clear water to turbid lakes (Carpenter et al. 1999), and from coral to algae dominated reefs (Hughes et al. 2003), among others. This thesis will apply the concept of the adaptive renewal cycle to the study of land system change in Lào Cai Province from 1999 to 2014 to determine if there has been a change to the underlying structure and function of the SES, and to analyze evidence for a possible land system regime shift.

In summary, to understand the complex interactions between the human and natural systems in Lào Cai Province, I conduct my research under the overarching framework of **social-ecological systems**. I analyze land change through the lens of **complex adaptive systems**, evaluate the spatial and temporal progression through the **adaptive renewal cycle**, and evaluate the possibility of a land system **regime shift**. Next, I elaborate on the methodology developed to analyze resilience, and explore how the concept is applied to study SES change.

2.2 Resilience framework

The concept of resilience may be used to systematically think about the dynamics of SESs (Anderies et al. 2006). Resilience theory originated from ecology and co-evolved with the adaptive renewal cycle (Holling 1986) and the panarchy framework (Gunderson and Holling 2002) described in Section 2.1.2. Yet, there is a high level of conceptual confusion regarding the definition of resilience, and academic debate regarding the utility and application of the framework continues (Grimm and Wissel 1997; Schoon 2005). The original definition of resilience, now known as **engineering resilience**, concentrated on the stability of a system near steady-state equilibrium (Pimm 1984; Gunderson and Holling 2002). A second, more widely cited definition was developed by Holling (1973) based on the study of predator prey cycles and is defined as: “A measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationship between populations or state variables” (14).

Following ecological resilience, Adger (2000) applied the concept of resilience to social systems. **Social resilience** is defined as the “ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change” (Adger 2000, 347). Social resilience is strongly influenced by the role of institutions, and by community dependency on natural resources. Variability in resilience is observed when natural resource dependency is high and thus vulnerable to disturbances, such as climatic shock or market changes. Social resilience can be evaluated by understanding a communities’ resource dependency, nature of economic growth, and livelihood choices (Adger 2000). Yet, the concept of social resilience is criticized for neglecting the actions and points of view of individual actors (Obrist et al. 2010). Hence the concept of livelihood resilience emerged to consider the impacts of individuals and households on social-ecological change (see Section 2.4.2) (Speranza et al. 2014).

Adding to the increasingly complex resilience literature are the concepts of social-ecological resilience and spatial resilience. The focus of both frameworks involves the interactions between humans and the natural environment. Drawing heavily on SESs and CASs literature, **social-ecological resilience** is defined as: the amount of change the system can undertake while maintaining the same control on structure and function; the degree to which the system is capable of self-organization; and the degree to which the system can build the capacity to learn and adapt (Carpenter et al. 2001). Social-ecological resilience includes the theoretical

constructs of the adaptive renewal cycle and thus emphasizes how resilience changes as you move through the adaptive cycle. For example, social-ecological resilience is high during the conservation and exploitation phases, and low during release and reorganization. **Spatial resilience** “focuses on the importance of location, connectivity, and context for resilience, based on the idea that spatial variation in patterns and processes at different scales both impacts and is impacted by local system resilience” (Cumming 2011b, 899). Grounded in principles of landscape ecology, spatial resilience is based on a multi-scaler process-oriented approach to land system and resilience changes. Taking Wiens’ (2005, 366) conceptualization of a landscape as “a spatially defined mosaic of elements that differ in their qualitative and quantitative properties” and the template on which spatial patterns influence ecological processes regardless of scale, I examine the influence of land system change on social-ecological resilience within the political boundary of Lào Cai Province, Vietnam.

2.2.1 Vulnerability, adaptation, and sustainability

Related to social-ecological resilience are the concepts of vulnerability, adaptation, and sustainability. Taking an alternative theoretical approach to analyzing social-ecological change, **vulnerability** is concerned with susceptibility to harm from stresses and shocks in the absence of adaptive capacity (McCarthy 2001; Adger 2006). Vulnerability is often applied as a core concept in political ecology, disaster risk, livelihoods, poverty, and climate change. **Adaptation** and coping mechanisms are ways to reduce vulnerability where coping is a short-term response and adaptation is a long-term approach (Yohe and Tol 2002; Brooks et al. 2005).

Key differences between resilience and vulnerability are the unit of analysis and types of processes investigated. Resilience studies take a CASs approach to understand long-term change, system dynamics, interconnections, ecological thresholds, and feedback loops while vulnerability studies focus on well-defined units of analysis (e.g. a social group or livelihood) (Miller et al. 2010). Resilience research tends to focus on biophysical and ecological variables, while social change is evaluated in the context of management and governance of resources; and vulnerability research is interested in social, political, and economic dynamics (ibid.). Finally, **sustainability** is considered a ‘desirable’ state of resilience, where human needs are met while preserving the long-term ability of the planet to provide environmental services (Kates et al. 2001; Wu 2013).

2.2.2 Applying the resilience framework

Prior to the mid-2000s most studies used SES and the resilience framework as a theoretical construct (Carpenter et al. 2001; Liu et al. 2007). While Norberg and Cumming (2008) caution that the resilience concept is a theoretical concept able to guide thought, rather than create a scientific hypothesis that can be quantitatively evaluated; they also suggest that aspects of resilience can be measured, such as thresholds or the ability of a system to shift in response to external forces. Resilience as a measure for adaptation and learning has been successfully applied as a framework to evaluate case studies of social-ecological change, and the concept is being increasingly incorporated into global environmental policy discourse (Sellberg et al. 2015).

It is near impossible to isolate a small number of state variables that directly measure resilience. Instead, to increase conceptual clarity, resilience ‘surrogates’ can be qualitatively or quantitatively evaluated, which may be directly observable or inferred indirectly (Carpenter et al. 2005). There are four approaches that may be combined or used independently to evaluate social-ecological resilience through the use of surrogates (Allen et al. 2005; Bennett et al. 2005; Berkes and Seixas 2005; Carpenter et al. 2005): (1) stakeholder assessments (e.g. through focus group discussions to reach a common understanding of change in the SES); (2) modeling past or future system behaviour (e.g. developing maps of the system); (3) case study comparisons (e.g. evaluating how different SESs have changed and how their properties relate to resilience); and (4) historical profiling (e.g. assess the history of the SES and determine when and how resilience changed). This research draws on all four of these approaches to evaluate resilience.

To summarize, the concept of resilience is heavily embedded within SESs literature. Given highly complex and integrated human-environment land systems in the Vietnamese uplands, this research will draw on Carpenter et al.’s (2001) concept of social-ecological resilience. I also partially draw on Cumming’s (2011a) concept of spatial resilience to interpret landscape-level change, and Speranza et al.’s (2014) concept of livelihood resilience to assess change to rural ethnic minority livelihoods.

2.3 Land system science

Land system science is an interdisciplinary field concerned with monitoring and understanding changing earth surface processes and covers. Land change scientists seek to improve: observations and monitoring of global land changes; understandings of these changes as part of a complex SESs; spatial modeling of land changes; and assessment of system outcomes, such as

vulnerability, resilience, and sustainability (Lambin and Geist 2006; Turner et al. 2007). Land system science also seeks to understand the direct and indirect drivers of LULC changes and the resultant impacts on local, regional, and global environmental change (Rindfuss et al. 2004).

The field emerged in the 1970s as a result of the realization that land cover and terrestrial ecosystems directly influence global climate (e.g. through carbon sequestration and hydrological regulation) (Lambin and Geist 2006; Lambin et al. 2006). Due to rapid advancements in remote sensing technology there have been significant advancements in our understanding of global (e.g. DeFries and Townshend 1994; Ramankutty and Foley 1999; Goldewijk 2001; Bartholomé and Belward 2005; Foley et al. 2005; Gibbs et al. 2010), regional (e.g. Reid et al. 2000; Fox and Vogler 2005; Fox et al. 2012; Aide et al. 2013) and local (e.g. López et al. 2001; Sikor 2001; Poyatos et al. 2003; Boillat et al. 2015) land change.

Yet, the identification of land management dynamics, or land use changes, and the resultant impacts on socioeconomic and ecological changes remained a challenge (Rounsevell et al. 2012; Sonter et al. 2013). To account for these lesser known aspects of land system change, the ‘linking people to pixels’ approach was introduced to match spatial change with local social transformations (Rindfuss and Stern 1998). It argued that strengths of integrating social science and remote sensing research include the validation and interpretation of remote observations, quantitative measures of social phenomena and their effects, clear connections across levels of analysis, and the provision of time-series data on relevant social phenomena (ibid.).

2.3.1 Defining land use and land cover

The land change science community is increasingly recognizing the need to address land change as a complex set of coupled human and environment interactions embedded in SESs (Lambin and Geist 2006). **Land cover** is defined as the immediate attributes of the earth’s surface including biota, soil, topography, and human structures while **land use** is the purposes for which humans use land (ibid.). Central to land change science is detection of both spatial and temporal change. The complete replacement of one land cover class with another is defined as a land cover conversion, which may be associated with a SES regime shift, and may be detected using remote sensing and image classification (Lambin et al. 2003). Land cover modifications, such as changing crop varieties, are subtler changes that affect the use of the land without changing its overall land cover classification. Modifications are difficult to detect using remote sensing and are often determined on the ground through quantitative and qualitative approaches. Yet, there is

still a need for increased conceptual understandings of the decision-making processes involved in land cover transitions (Rounsevell et al. 2012). As a result of increasingly integrated natural and human landscapes, studies on landscape patterns often combine the terms land use and land cover to understand the complex relationships between land cover and human decisions governing land use (Fox and Vogler 2005; Cassidy et al. 2010; Trincsi et al. 2014).

2.3.2 Drivers of land change

One of the most challenging tasks in the land change science community is determining the causes of LULC change. Prior to the mid-1990s, land cover change was seen as a simplistic direct linear process. Researchers assumed that dominate land transitions were between forest and agricultural classes, and the dominant drivers were local population growth and changes in resource consumption (Lambin et al. 2003). However, scientific understanding of the causes of LULC change have moved from simple cause and effect hypotheses to increasingly complex representations that acknowledge the situation-specific interactions among a wide number of factors at different spatial and temporal scales (Lambin et al. 2003). For instance, summarizing many case studies, Lambin, Geist, and Leper (2003) identified five causes of land use change in tropical regions: (1) resource scarcity leading to an increase in pressure on production; (2) changing market opportunities; (3) outside policy intervention; (4) loss of adaptive capacity and increased vulnerability; and (5) changes in social organization, resource access, and attitudes. However, land use change is often driven by a combination of the above factors, rather than a single cause. Similarly, land change is influenced by teleconnections and telecoupling – distal environmental and social drivers of land change with inherent feedbacks and multidirectional flows (e.g. globalization) (Adger et al. 2009; Liu et al. 2013; Friis et al. 2016). For instance, agricultural intensification may lead to a decline in labour requirements, which in turn may encourage migration and increasing urbanization, which may then cause additional deforestation to pave way for further agricultural intensification (Barona et al. 2010).

Broadly, the causes of LULC change can understood as a combination of predisposing environmental factors, direct proximate causes, and indirect underlying causes. **Predisposing environmental factors** include biophysical conditions like elevation, slope, and soil conditions (Geist and Lambin 2002). **Proximate causes** involve a physical action on land cover, occur on the local level and are direct drivers of ecosystem change (e.g. agricultural extensification is a proximate cause of deforestation) (Geist et al. 2006). **Underlying causes** are often seen as the

root or indirect drivers of change – they are fundamental forces that are formed by complex social, political, economic, demographic, technological, cultural, and biophysical variables that originate from regional or global levels (ibid.). For instance, markets, subsidies, taxes, trade, migration, household lifecycles, access to labour, and land use history can have indirect impacts on land use decisions. Several **mediating factors**, such as ethnicity, gender, and access to land, may also intervene to affect the relationship between underlying and proximate causes.

LULC change can also be conceptualized as an integrated cycle whereby changes affect landscapes and altered landscapes affect ways in which humans monitor their environment and respond to the surroundings, which in turn influences future cycles of change (Redman et al. 2004). Thus, it is important to consider various feedback loops that influence the land cover conversion process. Drawing on forest transition data in Vietnam, Lambin and Meyfroidt (2010) categorized ongoing LULC changes as being driven by endogenous socio-ecological feedbacks and exogenous socio-economic changes. Endogenous socio-ecological feedbacks arise from the degradation of key resources within the ecosystem, which will lead to a decline in the provision of important ecosystem services. This often leads to a negative feedback loop whereby land use is modified to improve ecological stability. This process is usually guided by local LULC decisions, which are subject to an individual's perception, interpretation, or understanding of environmental change (Meyfroidt 2013). Contrarily, exogenous socio-economic change is driven by dynamics external to the land system such as urbanization, economic development, or globalization. These external factors often lead to positive or reinforcing feedbacks that facilitate homogenous land use. To answer my second research question, I examine proximate and underlying drivers of LULC change, and discuss complexity of feedbacks in Lào Cai Province.

2.3.3 Linking land change science to resilience and regime shifts

LULC change can serve as a crucial link between understanding change in both social and ecological systems (Cumming et al. 2005; Turner et al. 2007). LULC change and decisions governing those changes mediate the social-ecological resilience of the SES (Redman et al. 2004). By linking pixels and people, land cover monitoring can identify patterns in ecological diversity (Anderies and Norberg 2008) while land use monitoring can help identify patterns of social diversity (Trincsi et al. 2014). Identification of asymmetries in the landscape may also help to identify system feedbacks, thresholds, or areas of SES instability (Cumming 2011a).

Numerous relationships in SESs, including LULC change, are non-linear and experience thresholds, which makes them difficult to predict (Liu et al. 2007). LULC change can take place through slow gradual transitions, or rapid change followed by either a quick recovery of the ecosystem and return to equilibrium, or a regime shift leading to a shift to a non-equilibrium state (Lambin et al. 2003; Müller et al. 2014). Since land systems are CASs, they experience similar nonlinear and rapid changes based on their ability to absorb and adapt to underlying drivers of change (Redman et al. 2004; Müller et al. 2014). Yet, the concept of regime shifts has seen very little attention in land change science literature despite the ability of the regime shift concept to provide valuable information for land system governance decisions. Muller et al. (2014) define a **land system regime** as an equilibrium phase where a land system's overall characteristics and ecosystem functions remain stable. For instance, stable land use intensity, habitat provision, carbon dynamics, and biodiversity. A land system regime shift occurs if the feedbacks and interactions with the land system become reconstructed and reorganized.

A LULC regime shift may be triggered by proximate or underlying causes of LULC change. For instance, Nghệ An Province, Vietnam experienced a land regime shift in the 1990s from a landscape dominated by shifting cultivation to one characterized by market-oriented permanent cropping that was caused by underlying changes in government policies (Müller et al. 2014). Significant ecological transitions are often accompanied by a change in the social system, and vice versa (Haberl et al. 2006). Following regime shifts it is important to investigate the stability of alternate regimes and the self-reinforcing processes that maintain them. For instance, are new regimes leading to temporary states whereby the SES is vulnerable to collapse? Or is the direction of a land use regime towards long-term social and ecological stability?

My thesis will contribute to the current understanding of regime shifts and land use change in Vietnam (and more broadly in Southeast Asia) by analyzing in detail LULC change in an upland frontier region. I use land system science literature to develop my methodology, namely **landscape classification**, to answer my first research question: how has LULC changed from 1999 to 2014 in Lào Cai Province? I also draw on **landscape metrics**, such as diversity, to evaluate changes to spatial resilience in order answer my third and fourth research questions on resiliency and regime shifts. Finally, land change science literature on the **drivers** of change will aid in answering my second research question on the driving forces behind LULC transition.

2.4 Sustainable Livelihoods

The fourth body of literature I will draw upon for my thesis is **sustainable livelihoods**. Livelihoods literature examines how people make a living in complex circumstances and assesses vulnerability, assets, and livelihood strategies available to improve how one makes a living (Chambers and Conway 1992; Ellis 1998; De Haan and Zoomers 2005; Scoones 2009). The livelihoods approach emerged in the mid-1980s as an actor focused approach to development and poverty reduction (De Haan and Zoomers 2005). In comparison to highly critiqued development theories, the livelihoods approach was “argued to be more balanced, emphasizing the role of human agency in coping with vulnerability, poverty, and structural change” (Turner 2017: online). The approach also recognized that poverty interventions needed to be ‘all-embracing’, as opposed to focusing only on monetary wealth (Morse and McNamara 2013).

Put simply, a livelihood is a means of making a living (Chambers and Conway 1992). A livelihood comprises the people, capabilities, assets (including both material and social resources), and activities required for a means of living (ibid.). Expanding the basic definition of livelihoods to consider the concepts of vulnerability and sustainability, a livelihood is considered sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base (Chambers and Conway 1992; Scoones 1998; DFID 1999). Livelihoods may be examined across scales, from the individual to national level, although the most commonly used unit of analysis is the household (Ellis 1998; Scoones 1998).

2.4.1 Key livelihood concepts

Key sustainable livelihood concepts are summarized in Figure 2.3. The asset pentagon lies at the core of the livelihoods framework, and maintains that livelihoods are comprised of five **assets** (or capitals): human, natural, financial, social, and physical (Scoones 1998). Briefly, human assets are the knowledge and labour households draw upon for productive and reproductive activities; social assets are the social structures and institutional arrangements that enable people to achieve individual and community objectives, such as gaining resources; natural assets are the stock of renewable and non-renewable resources from which a livelihood can be based; physical assets are human produced capital goods that facilitate production processes and market exchanges; and financial assets are financial instruments valued for their convertibility into other types of capital or consumption goods (Scoones 1998; DFID 1999; Turner In Press). Some authors argue that

loss of one capital may be substituted by another to maintain sustainable livelihoods (Bebbington 1999), while others maintain that preservation of all capitals is necessary (DFID 1999). Assets are mediated by social and institutional processes (Ellis 2000; Scoones 2009) and access to assets is a key determinant of secure sustainable livelihoods, as increasing access often leads to the ability to escape poverty. In Chapter 6, I examine how asset portfolios of ethnic minority farmers have changed from 1999 to 2014, and uncover what these changes mean for livelihood resilience.

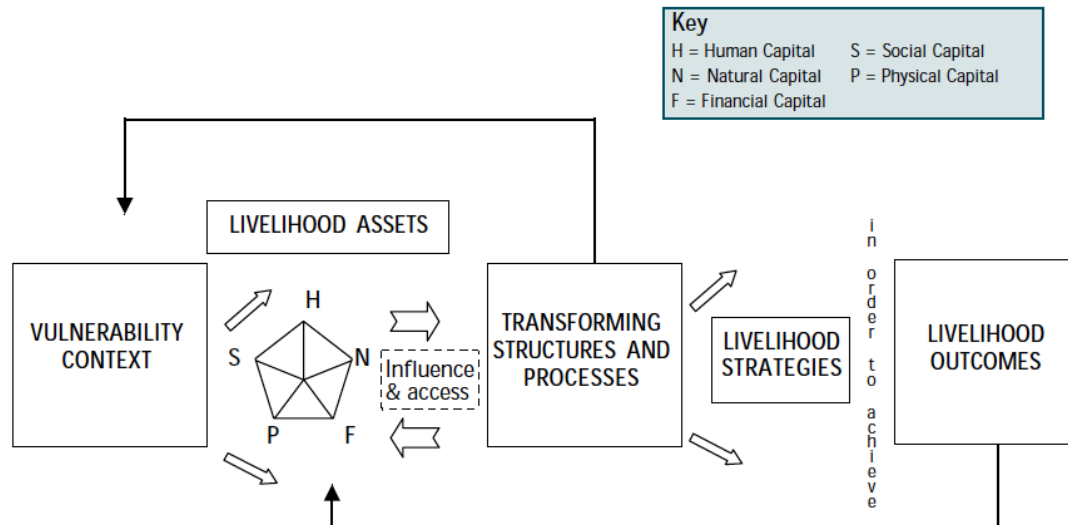


Figure 2.3 Sustainable livelihoods framework. Arrows do not imply causality, but infer influence (Source: DFID 1999: online).

Livelihoods are vulnerable to stresses, shocks, and seasonality which may directly impact livelihood assets and outcomes. Examples of vulnerabilities include: trends in governance and population; health, natural and economic shocks; conflict; change in prices, production, health, and employment opportunities; among others (DFID 1999). Parallels between the vulnerability context on the one hand, and disturbances embedded within the resilience framework on the other, can easily be drawn, as both can significantly disrupt livelihoods and cause a change in livelihood outcomes. Stresses are defined as cumulative continuous pressures, while shocks are sudden, unpredictable, often traumatic events (Chambers and Conway 1992). Livelihood vulnerability can be reduced by increasing assets, which will enhance the ability to cope with stresses and shocks.

Livelihood strategies are the choices and activities people make to achieve their desired livelihood goals. A distinction can be made between adaptive strategies to decrease vulnerability, and coping strategies – adopted during a time of crisis. Adaptive strategies involve a change in

livelihood strategy (either by sustaining the income portfolio, or by diversifying) to enhance existing security and wealth, or to reduce vulnerability and poverty (Davies and Hossain 1997). Coping strategies are short term responses to an immediate threat (Davies 1993). Households may pursue a livelihood strategy by combining, reproducing, or transforming their resource base (De Haan and Zoomers 2005; Bonnin and Turner 2014a).

Scoones (1998) identifies three clusters of livelihood strategies, which are often combined, that are available in rural contexts: agricultural intensification or agricultural extensification, diversification, and migration. Agricultural intensification involves increasing the productivity of agricultural land through investment in labour and technology, while extensification increases the amount of land under cultivation (FAO 2004; Scoones 2009). Livelihood diversification is defined as “the process by which rural families construct a diverse portfolio of activities and social support capabilities in their struggle for survival and in order to improve their standards of living” (Ellis 1998, 4). Diversified households draw on a mix of farm, non-farm, and off-farm assets to reduce vulnerability; and diversification may reduce the risk of overall income failure, reduce intra-year income variability (by diluting the effect of seasonality), and reduce inter-year income variability caused by unstable agricultural production and markets (Ellis 1998). The degree of livelihood specialization or diversification may relate to the assets available and the level of risk associated with alternative options (Scoones 1998). Finally, as a livelihood strategy, migration permits individuals to seek a livelihood elsewhere. In rural contexts, gender is often a prescriptive determinant of livelihood activities and strategies can be limited by the gender of an individual (Chambers and Conway 1992).

Livelihood outcomes are the result of livelihood strategies. Outcomes may be placed into five categories: more income, increase well-being, reduced vulnerability, improved food security, and more sustainable use of the natural resource base (DFID 1999). The combination of activities pursued, known as a livelihood portfolio, may change as external conditions change, making a temporal approach central to livelihood analyses (Scoones 1998).

Transforming structures and processes operate across scales to ultimately shape livelihoods by determining access to capitals, the terms of exchange between capitals, and returns to each given livelihood strategy (DFID 1999). Transforming structures include the public sector, private commercial sector, and civil society that implement functions that affect livelihoods, while processes include policy, legislation, institutions, and culture (ibid.). At the household

level, social institutions that shape the distribution of, access to, and use of resources are key for building resilience (Obrist et al. 2010). Bebbington (1999, 2022) also argues that livelihood assets give actors the capability to act, and form the basis of power that reproduce, challenge, or change the rules that govern the use and transformation of resources. Yet, transforming structures and processes are often downplayed in livelihood studies that tend to emphasize capitals and activities (De Haan and Zoomers 2005).

2.4.2 Linking sustainable livelihoods to SESs

Underlying the sustainable livelihoods definition are the notions of livelihood adaptation, vulnerability, resilience, and natural resource base sustainability (Scoones 1998). Livelihoods literature has been criticized as more of a development tool than an academic approach (Morse and McNamara 2013). Hence, linking livelihoods and resilience theory allows resilience research to take an actor-focused perspective to enhance understanding of long-term change, underlying structural causes of vulnerability, livelihood dynamics, and response to stresses and shocks; and permits livelihoods literature to be grounded in well-developed resilience theory (Marschke and Berkes 2006; Scott 2009; Speranza et al. 2014). Drawing on the concepts of buffer capacity, self-organization, and capacity for learning, Speranza et al. (2014, 111) argue a livelihood is resilient if it can “maintain its key functions (food, income, insurance, poverty reduction, etc.) and absorb the impacts of disturbances without causing major declines in production and wellbeing”. Marschke and Berkes (2006) also note that a key component of resilient livelihoods is the ability to diversify in a way that builds capacity to be more flexible. For instance, in the context of land change, livelihoods could become more resilient by developing the skills to manage a diversity of land uses, so in the event of stress or shock, alternative land use strategies may be drawn on.

Since both natural and social systems are CASs, it is extremely difficult to predict the outcome of human interventions in SESs (Norberg et al. 2008). Abel et al. (2006) note how a change in social, human, natural, physical, and financial capitals accompanies the release (capital loss) and reorganization (capital gain) stages of the adaptive cycle. Studies examining rural livelihood resilience generally do not measure resilience directly, but infer resilience from components of SESs conceptualized as ‘resilience building’ and used as proxies to understand capacity to respond to shocks and stresses (Pelletier et al. 2016). The applied limitations of the resilience framework must also be considered when examining livelihood resilience. Drawing on

resilience surrogates in the context of social change, such as historical profiling and case study comparisons, can be used to reduce such ambiguity (Sellberg et al. 2015).

In sum, the sustainable livelihoods approach has been criticized for not including all aspects of sustainability, such as conservation of the natural environment and long-term environmental change (Turner 2017). By embedding livelihoods analysis within the resilience framework, and more broadly within CASs and SESs literature, the full spatial and temporal consequences of land change on livelihoods may be better understood.

2.5 Chapter conclusion

As illustrated in Figure 2.1, this chapter reviewed four conceptual building blocks applied in this thesis: social-ecological systems, resilience, land system science, and sustainable livelihoods. First, **SESs** literature is used as the overarching framework to shape my study as a CAS with interacting social and ecological system components. Second, I draw on the concept of **resilience** to understand feedbacks, thresholds, and regime shifts in the SES. Third, **land system science** literature is used to analyze landscape change from 1999 to 2014, and to understand the drivers of such change. Fourth, I draw on **sustainable livelihoods** to understand how ethnic minority households adapt to, or cope with, land system and resilience changes. Given the limitations of the resilience framework outlined in this chapter, I take a cautionary approach to results regarding resilience and social-ecological change presented in Chapters 5, 6, 7, and 8. As such, I draw on the strengths of land system science and livelihoods theory to supplement my conclusions on changes to system resilience.

The concepts of diversity and regime shifts underlie all four bodies of literature on which I draw. To foster social-ecological resilience, diversity must be created within the SES to increase self-organizing capacity and reduce vulnerability to disturbance. In the context of landscapes, diversity may be fostered through a complex array of LULC that supports biodiversity and other ecological processes. Livelihood diversity can also be created through institutions, a broad base of assets, and a combination of livelihood activities. On the other hand, when there has been sufficient stress on the SES that undermines diversity and capacity of the system to resist change, a rapid shift to an alternate state may occur. Such regime shifts can occur in land systems as the feedbacks controlling LULC change, leading to land transition. Consequently, as LULC changes, rural livelihoods must adapt to ongoing changes and reorganize to maintain resilient livelihoods.

CHAPTER 3 CONTEXT

Based on previous studies in the region, I suggest that cross-scale interactions influence land change and social-ecological resilience outcomes in Lào Cai Province. An overview of LULC change across scales is therefore important, as there are many interacting linkages and feedbacks that encourage local decisions and drive ecosystem change, such as the development of national policy and international market trends. The first two sections of this chapter provide an overview of regional land management practices and broad economic, social, and ecological changes taking place in upland Southeast Asia. The following two sections put regional trends in the context of Vietnam, as I describe ethnic minority livelihoods and state policies in Vietnam that directly or indirectly impact land use. I conclude this chapter by outlining existing evidence for LULC change in northern upland Vietnam, with a specific focus on Lào Cai Province.

3.1 Regional socio-economic and land use trends in upland Southeast Asia

The upland regions of Southeast Asia are known as Montane Mainland Southeast Asia (MMSEA) (Fox et al. 2000; Xu et al. 2006), the Southeast Asian Massif (Michaud et al. 2016), and Zomia (Scott 2009). Common to these designations is the inclusion of Cambodia, Laos, Myanmar, Thailand, Vietnam, and Yunnan Province, China; and the agreement that these regions are of high elevation, exceeding 500m asl, and comprised of steep, mountainous terrain (Michaud 2010a). MMSEA represents the headwaters of major river systems in Southeast Asia including the Yangtze, Salween, Irrawaddy, Mekong, Black, Red, and Pearl Rivers.

The population of the Southeast Asian Massif is estimated at between 80-150 million, and is culturally diverse, with over 60 different ethnic groups (Xu et al. 2006; Michaud 2016). Highland ethnic groups are present in all areas of the uplands, commonly have kinship ties across borders, and often have few ties to modern-day international state delineations. Historically, the political relationship between highland and lowland societies has been complex and strained (Scott 2009). These groups live at a distance from the densely populated deltas, are geographically dispersed, and politically fragmented (Michaud et al. 2016).

Highland societies were traditionally subsistence or semi-subsistence based and practiced shifting cultivation, commonly referred to as swidden, or slash and burn cultivation (Mertz et al. 2009). There is little agreement regarding the defining characteristics of swiddening, although they generally include slash-and-burn clearing of a forest plot, followed by an annual crop cultivation phase, and a fallow phase when forest is left to regenerate (Rambo 2007). Following

slash and burn clearing, farmers typically plant upland rice in the first year of cultivation, maize or cassava in the second year, cassava in the third and fourth years, and then land is left to fallow and regenerate naturally (Tu 2007). In fields with moderate slopes (10-15°) cassava, dry rice, and maize are usually intercropped with additional crops, such as beans or peanuts, to extend the cropping cycle (ibid.). In the past, resource management under swidden relied heavily on traditional knowledge, social networks, and community organization.¹

Traditional land practices of upland ethnic groups have been blamed by national governments across MMSEA for deforestation, land degradation, and declining water quality further downstream where lowland populations reside (Forsyth and Michaud 2011). The result has been various sedentarization programs that have encouraged permanent agriculture and limited, or prohibited, shifting cultivation (Cramb et al. 2009). Settlement policies have also been entangled with broad state assumptions that ethnic groups inhabiting the uplands are ‘uncivilized’ (Sturgeon et al. 2013). Simultaneously, the countries of MMSEA are increasingly opening their economies to international markets, and have implemented policies to encourage market integration of both lowland and upland societies, such as the development of cash crops and market infrastructure. For instance, the Greater Mekong Subregion (GMS) Program involves a transportation corridor between six countries in MMSEA to facilitate international trade, with one cross-border transport link passing through Lào Cai Province (Turner 2013c).

In response to socio-economic policies, there is clear evidence across MMSEA that traditional land practices are being entirely replaced by permanent agriculture comprised of subsistence crops and cash crops including maize, cassava, coffee, cotton, peanuts, and fodder crops (Xu et al. 2005; Thongmanivong and Fujita 2006). For instance, a review of 151 case locations still engaged in swidden cultivation in MMSEA demonstrated that the average fallow length is drastically declining, and eventually being replaced with cash crop alternatives, including rubber, fruit tree cultivation, oil palm, tea, plantation timber, and logging (Schmidt-Vogt et al. 2009). Studying LULC case studies in Indonesia, China, and Vietnam, Müller (2014) also found that land use practices have moved from being dominated by shifting cultivation to dominated by cash crops or plantation forestry. Simulations of future LULC changes in MMSEA indicate these trends will continue, and between 10 and 25 percent of current land use will

¹ Estimates of the number of people still practicing swidden vary greatly from 50 million to 200 million (Mertz et al. 2009; Ziegler et al. 2009).

undergo a LULC change from 2001 to 2050 (Fox et al. 2012). Thus, the uplands of MMSEA are rapidly changing environments where ethnic minority livelihoods are increasingly being modernized and integrated into regional, and even international, markets.

3.2 Regional changes to the biophysical environment and upland livelihoods

Changes in LULC can lead to changes in the resilience of the SES (Xu et al. 2005). Here I provide an overview of the literature on the aggregate biophysical and social consequences and opportunities that have arisen out of LULC changes in MMSEA including impacts on biodiversity, hydrology, soil quality, carbon storage, and livelihoods. Attention is drawn to the conversion of swidden to other forms of land use, such as plantations and permanent agriculture.

3.2.1 Biodiversity

Southeast Asia has long been recognized as a global ‘hotspot’ of biodiversity and endemism (Le Trong 2003; Sodhi et al. 2004; Sodhi et al. 2010). For instance, Vietnam is home to 12,000 species of vascular plants, 275 species of mammals, 828 species of birds, 500 species of freshwater fish, among others (Le Trong 2003). The uplands have high biological diversity and are home to several ecosystems such as tropical premontane evergreen forest, seasonal evergreen forest, deciduous forest, sub-montane and sub-alpine forest, forest on limestone, and cloud forest (ibid.). Heterogeneous mountain and vegetation conditions create niches for the proliferation of highly diverse plant and animal species (Vogiatzakis 2006). For example, traditional agriculture practices aid in maintaining plant diversity as they can contain up to 30 species of staple crops, 30 to 40 species of vegetables, and 25 species of herbs and spices during the cropping phase (Rerkasem et al. 2009). Seed exchange networks by ethnic minority farmers are relied upon to maintain high levels of species richness and intraspecific diversity (ibid.). The biggest threats to biodiversity in MMSEA are cash crop agriculture, livestock grazing, fuel wood collection, poor management and corruption, and non-timber forest product (NTFP) collection (Melick et al. 2006). Given changing market conditions and government policies, there has been a drastic decline in biodiversity as a few hybrid crop species become preferred (or strongly encouraged by governments) over traditional upland varieties (Rerkasem et al. 2009; Turner 2012a).

3.2.2 Hydrology and soil quality

A review of hydrological dynamics under various land use practices in MMSEA revealed that under swidden cultivation, stream flow returns to normal as fallows regenerate and eventually return to forest cover (Ziegler et al. 2009). This is contrasted to annual cropping, which results in

increased surface runoff, increased sedimentation, a decrease in evapotranspiration, and a vulnerability to landslides that remains for three to 15 years after the land use conversion (ibid.). Increased sedimentation can lead to a decline in water quality both in the uplands and downstream throughout the various watersheds that make up the region. It is unclear what a transition to shortened fallow means for water quality, however it has been noted that shortened fallow leads to a decline in soil quality and eventually a loss of biodiversity (Rerkasem et al. 2009). Soil quality is also closely linked to soil resilience, or the ability of soil to restore basic function following a disturbance (Bruun et al. 2009). Thus, contrary to state assumptions that traditional land use practices lead to water degradation, more intensive agricultural practices in the uplands are causing a decline in both soil resilience and water quality.

3.2.3 Carbon storage

Complex swidden and secondary forest systems are biomass rich. The regenerating fallow phase has the potential to store 15 to 45 percent more carbon than old growth forests (Szott et al. 1999; Jepsen 2006). A review of the ability of emerging land use practices in MMSEA to store carbon revealed that traditional swidden systems store the most above ground carbon and soil organic carbon. In case studies, conversion to permanent agriculture and transition to tree plantations has led to a decline in soil organic carbon and aboveground carbon (Bruun et al. 2009). However, shortening fallows may provide opportunities for quick carbon uptake if fast-growing fallow species are used, such as bamboo and various shrub species (Hoang 2007).

3.2.4 Livelihoods

Increased access to cash income and decreased labour demands may provide rural households with a means to improve livelihood conditions. However, increased market integration comes at a price. Farmers specializing in a few tree species or annual crops for export are vulnerable to fluctuating market prices (Cramb et al. 2009). Likewise, cash crop dominated livelihoods have increasingly heightened dependences on cash inputs such as fertilizer, pesticides, and hybrid seeds (Bonnin and Turner 2012). When income needs are not met, food security declines and farmers may turn to forests and other natural resources for income and dietary deficits. In sum, biophysical and livelihood conditions in MMSEA are rapidly changing as upland land systems move from traditional swidden-fallow to permanent and cash crop agriculture and plantations.

3.3 Ethnic minority livelihoods in Vietnam

The Socialist Republic of Vietnam (SRV) has a population of over 86 million and is home to 54 ethnic groups, defined by the SRV using the criteria of language, material life, culture, and ethnic consciousness (GSO 2009). Fifty-three of these groups are considered ethnic minorities representing roughly 14 percent of the national population (ibid.). The Kinh (Vietnamese majority) typically reside in the lowlands and urban cores. Throughout history, state-upland ethnic minority relationships have been weak or fragile, characterized by factors such as lack of trust and cultural differences. Such factors in turn have led to the formation of inequalities and the generalization by lowland Kinh of upland ethnic minorities as ‘backward’ people (Turner and Michaud 2008). Yet, these assumptions have no recognition of a biased state-based development history or different livelihood aims. In 1955, Ho Chi Minh established autonomous zones for northern regions inhabited by ethnic minorities, although they were quickly dissolved during socialist rule (Corlin 2004). Following the reunification of North and South Vietnam in 1975, the state began the process of integrating highland ethnic minority groups into the socialist nation. ‘Selective cultural appropriation’ occurred whereby ethnic minority groups were given the right to maintain their traditions if they did not interfere with the socialist progress of the country (Michaud et al. 2016). As such, counterproductive and superstitious practices, like swidden cultivation, were deemed backward and targeted for eradication while ‘less-harmful’ cultural practices, such as clothing, music, and dancing, were encouraged. However, state-minority relationships are dependent on the group being discussed. Those groups who most closely identify with the Kinh, such as the Muong, are often favoured through better resource access, whereas those groups with fewer ties to the state, such as the Hmong, continue to have far less access to physical and financial assets (World Bank 2009).

Different ethnicities maintain different land systems. This research focuses on three ethnic groups that reside in Lào Cai Province (population 614,595; GSO 2009): the Hmong, Yao, and Tày. Hmong are a lineage, clan-based society that have enduring solidarity within kinship groups that cut across political and state boundaries (Corlin 2004). As such, traditional kinship and ancestral land ownership practices are considered before those determined by the state. As Corlin (2004, 305) remarks: “Land is not a commodity that can be bought and sold. Rather, the territory and its resources – water, vegetation, and game – belong to the ancestral spirits and to the spirits of the locality, and the living humans are simply stewards of the land”. Hmong

households have developed sustainable relationships with resource management which is the result of “a shared consciousness around living in peace with the forest, seen as an undividable physical and spiritual entity” (ibid., 329). Individuals outside of the clan are viewed as not having rights to infringe upon land management (Vuong 2004). This is contrasted to Kinh land tenure systems which are recognized as being privately owned and subject to direct control of the village organization. Like the Hmong, Yao households have traditionally practiced shifting cultivation (Tu 2007). Social networks are highly valued and are used to facilitate the spread of traditional knowledge and crop varieties (Sowerwine 2004). Land tenure is dually recognized as belonging to both Yao cultural land use types, and those imposed by the state (ibid.). In traditional Yao society, forest land and water resources in and around a village were protected, and communal land was managed by village law (Vuong and Hjemdahl 1997). Both the Hmong and Yao have practiced terraced wet rice cultivation in suitable areas since their arrival in Vietnam eight generations ago, often combined with swidden to ensure food security and maintain crop varieties with cultural value (Turner et al. 2015). Tày households generally reside in lower areas of the uplands where they practice sedentary agriculture, primarily based on the cultivation of wet rice. Of the ethnic groups considered, the Tày are the most numerous, and the most integrated into lowland Vietnamese (Kinh) society (Michaud et al. 2016). Yet, the relationship of local kinship groups with their land and environment is complex and varies between villages and type of subsistence (Corlin 2004).

3.4 Policies impacting LULC change outcomes in Vietnam

In a frontier environment controlled by a Socialist state, land practices are greatly influenced by state policy. For instance, drawing on a review of LULC change in northern Vietnam, Pham et al. (2015) note that the only common cause of LULC change across 17 case studies was policy. In Vietnam, complementing increasing political and economic pressures for land allocation are population growth, migration to the uplands, and the formation of national parks or protected forests, which is leading to rapidly declining land area available for upland residents. Below I highlight relevant state policies that impact natural resource outcomes in Vietnam, and underlying economic development policies that provide opportunities for households to acquire additional capital and engage in alternative land practices. A summary of policies affecting LULC change in Vietnam is presented in Table 3.1.

3.4.1 *Agricultural policies in Vietnam*

In Vietnam, laws developed at the national level are passed down through administrative levels (from province, to district, to commune) where local leaders and farmers alter them as much as possible to meet local needs (Alther et al. 2002). In the 1950s, agricultural collectivization led to the introduction of homogeneous high-impact agriculture systems. This system was fully implemented in Northern Vietnam by the 1960s and resulted in the appropriation of land by the state from wealthy landowners, and the subsequent formation of agricultural cooperatives (Kerkvliet 2006). Under the cooperative system, individual farmers were reduced to tenants and labourers on collective community land. Following reunification of North and South Vietnam in 1975, the SRV began introducing state policies to encourage state-priority agricultural programs, and to a lesser degree, to integrate ethnic groups into ‘modern’ society.

Starting in the late 1980s, the national government introduced a series of economic reforms, known as *Đổi mới*, that aimed to stimulate economic growth and push Vietnam towards a regulated market economy (Glewwe 2004). In conjunction with the *Đổi mới* reforms, a series of land laws were introduced that dismantled the cooperative system and allocated land tenure rights to individual households. Land continued to be owned by the state yet it was now managed by the people, and allocated under two major national policies: Resolution 10 (1988) and its subsequent revision Decree 5 (1993), more commonly known as the Land Law. Land was allocated using certificates – known as Red Books – for annual crops under 20-year tenure rights, and for perennial tree crops under 50 year contracts. Under these laws, land can be transferred, inherited, leased, exchanged, or rented, although in the uplands a household is limited to 3ha of annual crops and 30ha of perennial crops (Kerkvliet 2006). When tenure contracts expire, if the land user has met required land use conditions they can renew land rights. Land use planning, registration, issuing of legal documents, and settlement of land disputes is the responsibility of the province, district, and commune authorities (Corlin 2004).

In conjunction with land allocation, price controls were removed on agricultural products to allow for the sale of surpluses to markets, encourage sedentary livelihoods, and stimulate cash crop production. Hybrid rice seeds were introduced to Vietnam’s northern uplands in the late 1990s to facilitate high intensity yields to increase market sales and prevent food insecurity. Households were encouraged to entirely abandon traditional native seed varieties in favour of state-sponsored high yield varieties (Bonnin and Turner 2012). In 1998, Decree 20 called for the

subsidization of all hybrid seeds, fertilizers and pesticides for ethnic minorities to encourage a transition to mono-cropping and permanent agriculture (Turner 2012b). Concurrently, opium cultivation, introduced during the French colonial era, was banned in 1993 resulting in the loss of a historically important cash source for many upland ethnic minority groups.

3.4.2 Forest policies in Vietnam

Forest management in northern Vietnam has long been controlled by the state, starting with early French colonial forests. From the late 1950s to 1980s, nearly all accessible land in northern Vietnam with tree cover was placed under the management of State Forestry Enterprises (SFEs), primarily for timber production (McElwee 2016). In response to *Đổi mới* and cooperative dismantlement, massive deforestation (without subsequent reforestation) occurred to make room for agricultural expansion, population growth, and wood exploitation for rural and urban use (Castella et al. 2006; Meyfroidt and Lambin 2008a). Subsequently, in the 1990s several policies were introduced to protect Vietnam's rapidly declining forest cover. In 1991, the Law on Forest Protection and Development divided forested land into three categories with different regulations based on function: production forests for commercial production; protection forests for upstream watershed protection; and special use forests including national parks and nature reserves (Sam 1994). Logging bans were put in place to prevent further deforestation, although they arguably focused more on "tightening state control and instituting regulations of forest cutting, forest fire protection, and prevention of swidden practices than on seriously reconsidering the ecological costs of over-lumbering" (McElwee 2016, 102). Program 327 (1992) and the Five Million Hectare Reforestation Program (5MHRP; 1998) were subsequently implemented to encourage and enforce reforestation practices. Reforestation programs had the largest success rates far from urban cores where natural forest regeneration occurred, as well as in regions with steep slopes and low agricultural suitability (Meyfroidt and Lambin 2008a). Many argue that Vietnam has since undergone a 'forest transition' where net afforestation has exceeded net deforestation, although there has been an overall loss of biodiversity, forest density, and carbon stocks (Le Trong 2003; Meyfroidt and Lambin 2008b).

Forestland allocation to SFEs, private enterprises, and households has led to drastic changes to forest quality. Plantation forests emerged as a quick solution to declining environmental conditions, wood shortages, and market integration. There are four different systems that allow for the establishment of plantation forestry: state-owned plantations allocated to SFEs; state-

owned plantations grown on farmers' land; foreign-company owned plantations on rented land; and farmer-owned plantations (van Bueren 2004). Tree selection for plantations favours fast growing exotic species, such as Australian eucalyptus and acacia (McElwee 2016). Timber is harvested primarily for pulp and paper, furniture and special products, artificial fiber board, firewood, and other domestic uses (ibid.). Most recently (2011 onwards), individual districts in Lào Cai Province, including Bát Xát, Mường Khương, Si Ma Cai, and Bắc Hà Districts, have initiated reforestation programs that convert remaining shifting cultivation areas into plantation forests (Tráng 2011; Kim 2015).

The SRV has also engaged in international market-based programs to accelerate conservation and development objectives. At least 20 payments for environmental service (PES) projects have been implemented, backed by international organizations such as the World Bank, United Nations Development Program, and World Wildlife Fund (McElwee 2012). PES projects were originally conceptualized as a win-win situation for environmental conservation and poverty reduction (Wunder 2001). In theory, PES programs are market-based mechanisms for conservation that include a voluntary transaction where an environmental service (e.g. carbon sequestration) is purchased by a 'service buyer' from a 'service provider' (Engel et al. 2008).

The first PES program implemented was the 5MHRP (mentioned above) which offered cash incentives to farmers to plant trees and protect existing forests through forest contracts with individual households (Suhardiman et al. 2013). Under Decree 99 (2010), forest PES projects for the following payments became legal: payment for land protection; payment for watershed protection and regulation; carbon sequestration payments; landscape and biodiversity protection; payments for tourism purposes; and payments to protect aquaculture (SRV 2010). Households with Red Book certificates for qualifying forest land could claim PES funds, and provinces received money for exotic tree plantations (McElwee 2016). There is evidence that PES implementation has led to increasing wealth disparity in the uplands, which has negatively affected livelihoods and biodiversity (Dressler et al. 2013). As McElwee (2016, xii) describes:

What I saw on the ground was not an environmentalists' dream of expanding green forests, but rather a nightmare of overreliance on introduced fast-growing but low-value trees that displaced native flora and fauna. The afforestation, mainly by mono-cropped exotic Australian eucalyptus and acacias, could not hide the continuing degradation of natural forests in a nearby nature reserve. Social changes accompanied the spread of these plantations as well, and from the local point of view, the forest transition was a process that involved struggle and contestation, not a linear pathway from fewer trees to more trees. Tenure over

newly planted trees was highly contentious, and those with power and access were getting benefits from afforestation while the poor often did not. Gender relations too were unequal, with women losing rights to land as men claimed it for new forest plantations, and the promised poverty reduction benefits from the tree planting program failed to materialize for many.

Nonetheless, the Vietnamese government continues to negotiate and pilot additional PES programs to aid sustainable forest management, such as a large-scale Reducing Emissions from Deforestation and Degradation (REDD+) project (Hoang et al. 2013). In fact, McElwee (2016, 5) argues that environmental policy in Vietnam, both historically and in the present, is used as a tool to shape people, rather than the environment:

Although labeled as “environmental” many policies and actions directed at forests were in fact about the supply of wood for a war-torn nation, the movement and control of people in sensitive remote areas, or the prolonging of state employment in a declining forest sector. In other words, forest policy in Vietnam has rarely been about ecological management or conservation for nature’s sake, but about seeing and managing people, a strategy I term “environmental rule”.

McElwee (2016) also maintains that households participated in reforestation efforts primarily as a strategy to claim land for household use at a time when there was much ambiguity over land rights. This thesis draws on the concept of ‘environmental rule’ as forest and agricultural policies are examined in the context of Hmong, Yao, and Tày livelihoods in Lào Cai Province.

3.4.3 Development policies in Vietnam

Development policies relevant to land change and resilience fall into two broad categories: infrastructure upgrading and aid for rural ethnic minority farmers. To facilitate economic integration, country-wide infrastructure upgrading was undertaken, especially for roads and marketplaces. The most recent socioeconomic development plans emphasize the expansion and improvement of physical market places throughout the country, with specific emphasis on rural, remote, and mountainous regions (Bonnin and Turner 2014b). Focusing on Lào Cai Province, the *2020 Lào Cai Economic Development Plan* prioritizes investment in construction, renovation, and upgrading of facilities at the Lào Cai-Yunnan international border, as well as the construction of new border crossings to facilitate increased trade (Lao Cai People's Committee 2008). Upgraded facilities have thus increased access to regional and international markets and likely have indirect impacts on land use decisions favouring cash crops.

Table 3.1 Summary timeline of government policies that affected LULC in the northern uplands. Specific attention is drawn to their implementation in Lào Cai Province.

Year	Vietnam government decrees and interventions
1960s	• Agricultural collectivization implemented in the northern uplands.
1979	• Border war between China and Vietnam.
1981	• Individual households are assigned agricultural quotas and can retain any extra harvest.
1986	• <i>Đổi mới</i> reforms begin to encourage economic growth and market-oriented planning.
1988	• Resolution 10. Cooperative system dismantled and wet-rice land shares are allocated to households.
1991	• Law on Forest Protection and Development. Defined three types of forest and separate regulations for each: protection forest, special-use forest, production forest.
1992	• Program 327. Aimed at restoration and protection of forests as well as establishment of special use forests. Banned wood exports and reduced tree felling to 88%.
1993	• Resolution 6. Government bans opium production. • Decree 5: Land law. Inhabitants given land tenure rights (20 year renewable rights for annual crops and 50 year rights for perennial crops and forest land). • Independent international tourism permitted.
1995	• Decree 01/CP. Formalized leasing of forestland by SFEs to households (apart from Red Book system).
1997	• Permanent logging ban in special-use forests and 30-year ban in critical watersheds.
1998	• Decree 661. Five Million Hectare Reforestation Program. • Decree 20. Introduction of commodity subsidies for ethnic minority areas. • Program 135 and the Hunger Eradication and Poverty Reduction Program. Socioeconomic development of poor rural communes.
1999	• Subsidized rice seed program introduced in Lào Cai province.
2002	• Program 134. Additional land allocated to poor ethnic minority households.
2007	• Decree 18. Emphasizes move from state to social and private forestry based on market mechanisms.
2008	• Lào Cai Province economic development plan.
2010	• Decree 99. Forest PES programs become legal.
2013	• Renewing of land tenure rights for annual crops

Adapted from Sandewall (2010, 570) and Turner (2012a, 543).

In addition to infrastructure upgrades, the state has initiated several social development programs targeted at ethnic minorities since the late 1990s, specifically aimed at poor rural communes, such as the Hunger Eradication and Poverty Reduction Program (HEPR), Program 135, and Program 134. The HEPR (collectively programs 133, 120, and 143) was launched in 1998 and subsequently revised in 2001. The aims of the program were to reduce the national poverty rate, ensure poor communes have access to basic infrastructure, create jobs, and reduce unemployment in urban areas (Nguyen and Baulch 2007). Separate from the HERP but also initiated in 1998 is Program 135 – targeted at poor households living in ‘extremely difficult’ communes (ibid.). Support came in the form of infrastructure upgrades, training programs, resettlement projects, and agricultural and forestry extension. Program 134, designated in 2002, allocated additional land to ethnic minority households and improved drinking water conditions. Finally, numerous education and health care policies were implemented to further improve social conditions.

3.5 Land change and livelihoods in Lào Cai Province

The population of Lào Cai Province is estimated at 656,900 (GSO 2009). Average annual population growth is 0.9 percent whereas rural growth is 0.5 percent and urban growth is 2.5 percent.² In Lào Cai Province, 36 percent of inhabitants are Kinh and the remaining 64 percent are ethnic minorities belonging to the Tày, Nùng, Giáy, Hmong, and Yao ethnic groups (ibid.). The three largest ethnic groups are the Hmong, Yao, and Tày. Ethnic minority households are unevenly spatially distributed within the province, which has important implications for land use decisions (Figure 3.1).

Historically, remote regions of the northern uplands, such as Lào Cai Province, have been reasonably inaccessible to international market forces. Households were primarily concerned with subsistence food production and food-security (Vuong 2004). Trade occurred in daily or rotational markets following a barter system for lowland goods between highland ethnic minority populations (e.g. coffin wood, opium) for commodities from the lowlands via Kinh traders (e.g. salt) (Bonnin and Turner 2014b; Michaud et al. 2016). However, as government policy paves the way for infrastructure and market development, accessibility has increased, often accompanied with changes to ethnic minority land practices.

² Calculated using population data from 1995-2013.

In response to changing institutional factors, Hmong and Yao households in Lào Cai Province have increasingly transitioned from swidden to permanent agricultural systems, based on the cultivation of hybrid wet rice and/or maize (Turner 2012a; Bonnin and Turner 2014a). Unlike lowland areas, wet rice cultivation in the northern uplands is limited by the availability of mild slopes and secure land tenure (Michaud et al. 2016). However, when the right conditions are met, most dry rice cultivators are willing to switch to terraced paddy rice because it is more productive, less hazardous, and provides a more secure food source (Corlin 2004). Land use systems in northern upland Vietnam often combine at least two farming practices and most households still maintain small rotational swidden plots, although illegal, and further diversify their land use practices to include home gardens for food crops such as beans, taro, and cucumber (Leisz et al. 2005). Livestock (especially buffalo) are still important forms of insurance and are used for crop maintenance, religious ceremonies, or household consumption (Turner 2012a).

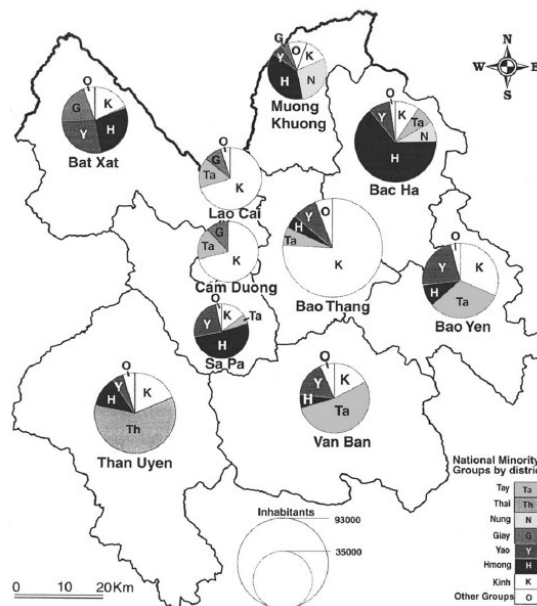


Figure 3.1 Ethnic composition of Lào Cai Province at the district level using data from 1994 (Michaud et al. 2002, 318). Note: Than Uyên District is no longer administratively part of Lào Cai Province.

In Lào Cai Province, old growth and secondary forests are used by ethnic minority households for the provision of NTFPs such as fruit, bamboo, herbs, medicinal plants, and honey (Bonnin and Turner 2012). In response to agricultural policy, villagers increasingly rely on NTFPs to contribute to the household economy during times of scarcity and food insecurity (Sowerwine 2004). Households with higher rates of female labour, those located close to markets, and those in need of cash income also rely more on NTFP collection for household

income (Quang and Anh 2006). One NTFP of particular cash value in Lào Cai Province is cardamom, cultivated primarily by Hmong and Yao farmers in high-elevation old growth forests (Tugault-Lafleur and Turner 2009). Under natural conditions, cardamom densities are relatively low, but when cultivated in diverse agroforest systems yields are high enough to ensure steady cash-income after four years of cultivation (Sowerwine 2004; Tugault-Lafleur and Turner 2009). Other contemporary market activities of Hmong and Yao households include textile and alcohol production, as well as tourism activities.

Most LULC change studies in northern Vietnam have been conducted outside of Lào Cai Province (Pham et al. 2015). However, a few generalizations can be made for the northern uplands: (1) soil degradation is driving LULC change decisions; (2) farmers with the ability to sell agricultural surplus are more inclined to intensify or extensify their agricultural production; and (3) policy implementation underlies most LULC changes. The relationships between the state and highland land use practices are further complicated by local institutions, such as community relationships that may predate national reforms and international borders (Sikor 2001). In some cases, land changes have resulted in increased crop yields and provided alternative livelihood strategies, yet the results have not been uniform and upland residents have met economic expansion with careful negotiation and at times resistance (Turner and Michaud 2008). However, given socialist rule, any sign of ethnic discontent is rapidly quelled (Turner 2013b). As Turner et al. (2015, 58) describe: “To date, farmers appear to have decided that the best, most resilient tactic... is a composite approach to their livelihoods, adopting new practices and maintaining other practices that are firmly rooted in local cultural knowledge”. Thus, Hmong, Yao, and Tày households in Lào Cai Province are faced with multiple decisions and opportunities to diversify their livelihoods in response to economic opportunities emerging around them (Turner 2012b).

3.6 Chapter conclusion

In this chapter I explored the rapid LULC changes that are taking place across in MMSEA. While trends can be observed at regional scales, the complex interactions that occur at the provincial and household scales remain ill-understood. National agricultural and forestry policies appear to have a major influence, although their degree of effectiveness varies from location to location. Having described the broad contextual factors influencing LULC, I now turn to the methods I use to gain a better understanding of the specific LULC and resilience changes that have occurred in Lào Cai Province since 1999.

CHAPTER 4 METHODS

A thorough assessment of land change and social-ecological resilience requires a mixed methods approach, combining both quantitative and qualitative methods. Quantitative and qualitative research differ in their basic philosophical assumptions, types of research strategies, and specific methods employed (Creswell 2014). Quantitative research is based on a postpositivist philosophy and calls for objective procedures that eliminate bias, detachment from the object of study, and empirically justified cause and effect hypotheses, while qualitative research takes a constructivist approach aimed at understanding the subjective lived experiences of human participants (Johnson and Onwuegbuzie 2004; Creswell 2014). Thus, a mixed method research approach is defined as:

A research design with philosophical assumptions as well as methods of inquiry. As a methodology, it involves philosophical assumptions that guide the direction of the collection and analysis of data and the mixture of qualitative and quantitative approaches in many phases of the research process. As a method, it focuses on collecting, analyzing, and mixing both quantitative and qualitative data in a single study or series of studies. Its central premise is that the use of quantitative and qualitative approaches in combination provides a better understanding of research problems than either approach alone (Creswell and Clark 2007, 5).

To fully understand the complexity of land change and link people to pixels, mixed methods research is common in LULC change studies (c.f. Brannstrom and Vadjunec 2013; Rindfuss and Stern 1998; Turner and Pham 2015). For instance, in northern Vietnam, Turner and Pham (2015) demonstrated qualitative work can greatly improve interpretations of land cover change, while LULC maps aid qualitative work through a better understanding of the ‘bigger picture’. Drawing on an explanatory mixed-method research design, I divide this chapter into two sections that outline the quantitative and qualitative methods used in this thesis.

4.1 Quantitative methods

This thesis builds off 30m resolution LULC classifications initially calculated in 2012 for my Honours project that focused on the five border districts of Lào Cai Province: Bát Xát, Lào Cai, Bảo Thắng, Mường Khương, and Si Ma Cai for 1999 and 2009 (Trincsi 2013; Trincsi et al. 2014). During the first year of my Master’s research I expanded upon these classifications by creating an additional land cover map for 2014 of the five border districts, to support field case study site selection. Due to several setbacks while in the field (see Section 4.2.1), my study area was expanded to include the remaining four districts of Lào Cai Province: Bắc Hà, Sa Pa, Bảo

Yên, and Văn Bàn. Hence, land cover mapping was recalculated for the entire province upon returning to Canada. I used this opportunity to refine land cover mapping methods using image fusion to create classifications with higher accuracy and spatial resolution. This section describes the quantitative methods used to create land cover maps for all nine districts of Lào Cai Province at 15m resolution for 1999 and 2014, including data sources, image preprocessing, image fusion, object-oriented classification, and image validation. I conclude by outlining the basics of landscape metrics, which were used to evaluate resilience for the province as a whole.

4.1.1 Land use land cover classification

Determining the rate and extent of LULC change in mountainous environments is difficult given challenging topography and remote road access (Lambin and Geist 2006). Remote sensing techniques rely on the unique spectral signature that objects on the earth's surface emit, in response to solar radiation, and may be used to monitor land cover change in lieu of extensive field access. This thesis used five images to complete LULC classifications (Table A.1 in Appendix). These include four Landsat scenes downloaded from the United States Geological Survey (USGS) for Lào Cai province (path 128, rows 44 and 45) for 1999 and 2014, as well as an STRM digital elevation model (DEM), also obtained from USGS, at the 30m resolution. Several STRM DEM tiles were stitched together using a seamless mosaic function. The Landsat scenes were acquired during the winter months when agricultural fields were bare, allowing for identification and separation of vegetation classes.

4.1.1.1 Atmospheric and topographic corrections

Image preprocessing, including atmospheric corrections, topographic corrections, and image fusion improve land cover classification accuracy, especially when comparing images from different dates (Song et al. 2001; Gitas and Viegas 2002; Mitri and Gitas 2004; Vanonckelen et al. 2013; Lin et al. 2015). For instance, Vanonckelen (2013) tested 15 combinations of atmospheric and topographic corrections on a LULC classification of a mountainous area in Romania and found that in all cases of combined corrections, classification was improved. Thus, four atmospheric and topographic corrections were undertaken for this thesis.

First, the acquired Landsat images were pre-processed to remove sensor irregularities and correct for atmospheric and topographic conditions using both ENVI (v. 5.1) and PCI Geomatica (v. 2015). Image digital numbers were converted to top of atmospheric reflectance and processed to obtain ground-level reflectance (Equation 1).

$$L_{\lambda sensor} = Gain_{\lambda} * DN_{\lambda} + Bias_{\lambda} (1)$$

where L_{λ} is at satellite radiance; $Gain_{\lambda}$ is the calibration gain coefficient; DN_{λ} is the Landsat TM digital number; and $Bias_{\lambda}$ is the radiometric bias (Lu et al. 2002).

Second, to remove the effect of the earth's atmosphere, including scattering, absorption, and refraction of light, on spectral signatures, three absolute radiometric atmospheric corrections were tested: Fast Light-of-Sight Atmospheric Analysis of Spectral Hypercubes (FLAASH), dark-object subtraction, and ATCOR. FLAASH is an atmospheric correction algorithm that incorporates the MODTRAN radiation transfer code to remove atmospheric effects caused by molecular and particle scattering (Chavez 1996; Felde et al. 2003). Dark-object subtraction is a relatively simple method that assumes the darkest pixels of each band do not reflect light and atmospheric effect is uniform across an image while ATCOR incorporates MODTRAN 4 code and haze correction (Richter 2004). In lieu of ground spectra data, the atmospheric corrections were compared on the basis of band surface reflectance statistics, consistency in class reflectance between years, and a visual examination of haze removal (Lu et al. 2002). The FLAASH correction was chosen as the best atmospheric correction method.

Third, an improved-cosine topographic correction (Equations 2 and 3) was applied to correct for topographic shadowing (Riaño et al. 2003). This method was chosen following LULC mapping of Lào Cai Province that compared cosine, improved cosine, Sun-Canopy-Sensor, and Minnaert topographic corrections (Trincsi et al. 2014). Fourth, cloud and shadow masking was conducted on the 2014 image following methods outlined by Martinuzzi et al. (2007).

$$\rho H = \rho T + (\rho T \left(\frac{\bar{IL} - IL}{\bar{IL}} \right)) (2)$$

Where ρH is the reflectance of a horizontal surface; ρT is the reflectance of an inclined surface; IL is the illumination conditions calculated using equation 3; $\bar{IL}$ is the average IL of the scene.

$$IL = \cos \theta_p \cos \theta_z + \sin \theta_p \sin \theta_z \cos(\phi_a - \phi_b) (3)$$

Where θ_p is the slope angle; θ_z is the solar zenith angle; ϕ_a is the solar azimuth angle; and ϕ_b is the aspect angle.

4.1.1.2 Image fusion and validation

Image fusion is a process whereby low-resolution multispectral bands are combined with high-resolution panchromatic imagery to obtain an image with higher resolution (Zhang and Mishra 2012; Lin et al. 2015). After testing 11 available fusion methods for a wide variety of image sensors, Zhang and Mishra (2012) concluded that the Pansharp model performed the best – based

on qualitative image evaluation by industry professionals. Following a literature review of fusion methods (Zhang 2008; Zhang and Mishra 2012), I tested four fusions on the 1999 Landsat image to determine best performance: ENVI Gram-Schmidt, ENVI Principle Component Analysis, and PCI Pansharp algorithms 1 and 2.

The image fusions were validated using metrics chosen through a review of existing literature including: bandwise statistics (mean, standard deviation, correlation coefficient of each band), image differencing (mean, standard deviation, root mean square error), and global measures (mean root mean square error, erreur relative globale adimensionnelle et synthese) (Wald 2000; Colditz et al. 2006; Du et al. 2007). These quantitative evaluations were carried out in R Studio Statistical package (v. 1.0.44) and supplemented with visual examination (Zhang 2008; Zhang and Mishra 2012). PCI's Pansharp 1 was chosen as the best, and both the 1999 and 2014 images were fused to their respective panchromatic bands to create 15m resolution imagery.

4.1.1.3 Land cover classification and accuracy assessment

Traditional land cover classification relies on the classification of individual pixels using user-defined algorithms. Object-oriented (OO) classification emerged out of a need for a user-controlled approach to class segregation (Whiteside and Ahmad 2005). OO classification segments pixels into objects and classifies segments based on criteria such as shape, spectral signature, texture, or density. For this study, OO classification was chosen over traditional unsupervised approaches following a review of literature which demonstrated that object-oriented classification can produce high-accuracy land cover maps in steep mountainous terrain (Willhauck et al. 2000; Dorren et al. 2003; Yan et al. 2006).

The images were segmented at two levels using eCognition (v.8) (Figure 4.1). Level 2 objects were segmented at 40, shape 0.8, and compactness 0.3; and Level 1 objects were segmented at 10, shape 0.8, and compactness 0.3. The classifications were supported by vegetation and soil indices including the Normalized Difference Vegetation Index (NDVI), Simple Ratio (SR), and Enhanced Vegetation Index (EVI). Land cover was classified based on Level I land cover types on a mosaic of the 1999 and 2014 pre-processed image tiles (Anderson 1976). Class delineation was based on knowledge of land cover types in the region, previous classifications of Lào Cai Province (Turner and Pham 2015), and field experience. Forest cover was segregated into two land cover classes: open canopy forest, comprised of less than 10% canopy cover and vegetation over 5m; and closed canopy forest comprised of greater than 10%

canopy cover and vegetation over 5m (FAO 2000). While there is little grassland in this mountainous region, shrubs comprise small patches of grass mixed with regenerating vegetation, or some cash crops (e.g. bananas). These designations are in line with local classifications of forest cover in northern Vietnam. As McElwee (2016) explains: locals never call land without trees forest land; open forest are areas with tree stems generally taller than people but without a dense canopy; and high forest (here closed forest) are defined as tall trees closing off the view of the sky with shade-loving undergrowth. Cropped land, comprised of subsistence crops (e.g. maize, rice) and cash crops (e.g. cassava, tea) are classified under the bare soil class since the images were acquired during the winter. Crops planted under young agroforestry systems (e.g. cassava planted with cinnamon seedlings) are likely to appear as shrubs. Finally, built-up areas were separated from bare soil as their spectral signature is brighter and indicative of urban areas.

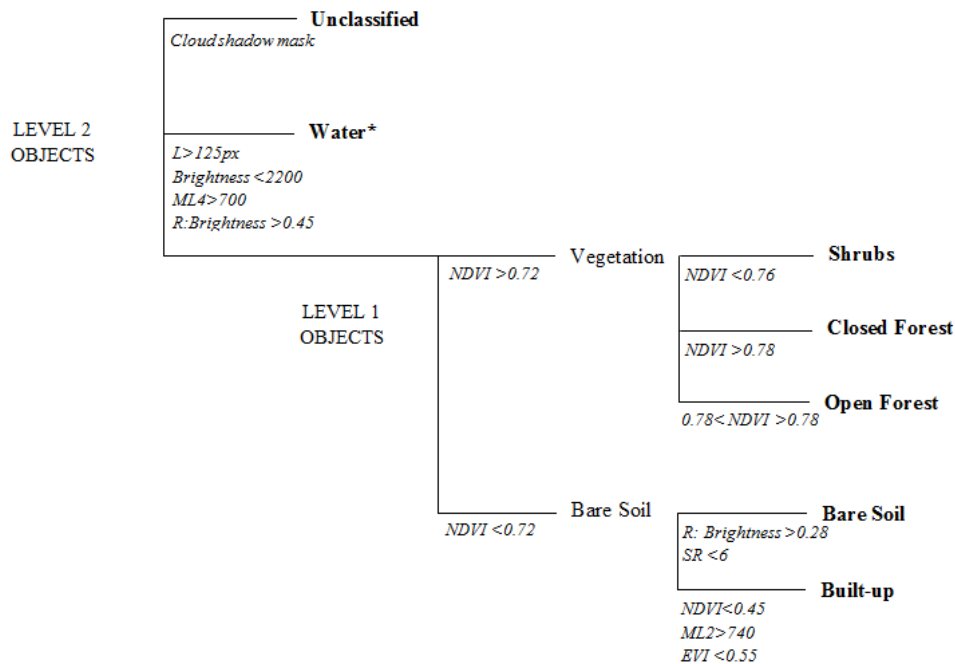


Figure 4.1 Classification tree including levels and rules where L =length, R =red band, ML =mean layer, $NDVI$ =normalized difference vegetation index, SR =simple ratio, and EVI =enhanced vegetation index.

An accuracy assessment was performed on the 2014 classification using 270 points derived from a combination of field survey plots and visual interpretation of high resolution IKONOS/Quickbird images from Google Earth (Congalton and Green 2009). Field access in Vietnam is difficult given restricted government permissions and harsh terrain. From June to July 2015 I collected 50 field samples from 30mx30m plots of all land cover types chosen randomly

based on permitted road access.³ Locations were chosen using opportunistic sampling while traveling between interviews in areas with large continuous land cover. Field samples were supplemented using 220 points acquired from Google Earth using knowledge of areas visited, land use planning, and elevation. Validation was conducted using a confusion error matrix (Congalton 1991); however, an accuracy assessment was not carried out on the 1999 imagery due to unavailable reference data. Yet, the classification methods followed were the same and I infer their accuracy is similar.

4.2.2 Assessing landscape resilience

A central idea of landscape ecology is landscape pattern strongly influences ecological characteristics and processes. Changes to landscape structure causes changes in function and vice-versa (Forman and Godron 1986). Analyzing resilience using land cover classifications infers that pixels may be viewed as ‘populations of species’ that interact by mechanisms similar to ecological communities (Cumming 2011a). Resilience can be assessed at the landscape level using land cover class metrics and landscape metrics, such as heterogeneity, functional connectivity, and area of natural habitat (Cumming 2011a; McGarigal 2015; Oliver et al. 2015). This approach seeks to establish correlations between groups of species to infer potential ecological casualties; however, the aggregated approach may lead to an under-appreciation of complexity of ecological processes and differences between individual species (Fischer and Lindenmayer 2007). To aid in answering my third research question, I calculated landscape metrics in 1999 and 2014 using Fragstats (v. 4.2) to provide a comparison of landscape structure over time, and to make inferences on the state of the ecological system in Lào Cai Province. I now turn to key concepts in landscape ecology relevant to resilience including fragmentation, heterogeneity, diversity, connectivity, and natural habitat. For a full description of landscape metrics see McGarigal (2015).

Fragmentation is a combination of four unified processes: reduction in habitat amount, increase in number of patches, decrease in patch size, and increase in patch isolation (Fahrig 2003; Mitchell et al. 2013). Fragmentation is widely acknowledged as contributing to global species loss (Fischer and Lindenmayer 2007). Environmental heterogeneity promotes diversity of resources, species richness, and thus beta diversity to increase the stability of ecosystem function.

³ For both field and remotely required groundtruth points a minimum of ten points was collected for each land cover types. For vegetation classes with high spectral confusion (especially open canopy forest, shrubs) a greater number of points were collected.

Of the available diversity indices, the Shannon Diversity Index is most frequently used in LULC studies (e.g. Acharya and Bennett 2001; Jiang et al. 2003; Fédoroff et al. 2005; Rescia et al. 2010). Using this index, the greater the number of land cover types and the more similar they are in proportion, the higher the diversity. Connectivity is also important when assessing or planning for biodiversity in landscapes (Leitão and Ahern 2002). In well-connected landscapes, populations can recolonize rapidly following an environmental disturbance. Hence, landscapes with greater connectivity are considered more resilient. Landscapes with high fragmentation have low connectivity and the functional linkages between habitat patches decrease, often with consequences to species dispersal and biologic diversity (Mander 2008). Finally, the total area of natural habitat can contribute to ecological resilience by providing a greater amount of resources, which promotes higher species richness and population size (Oliver et al. 2015). This is likely to promote genetic diversity and functional redundancy – both of which promote resistance of ecosystem functions. A loss of native vegetation and landscape connectivity can provide a sufficient shift in the relationship between key ecosystem variables to cause a land system regime shift (Fischer and Lindenmayer 2007).

To summarize, to understand land cover change, and what such changes mean for social-ecological resilience, I used primarily quantitative methods. First, I created land cover classifications for 1999 and 2014 by performing preprocessing, image fusion, and OO classification on Landsat scenes. Second, the output of the classifications was analyzed for basic land cover change statistics. Third, class-level and landscape-level metrics were calculated to compare changes to landscape structure and function over the time-frame of this study.

4.2 Qualitative field methods

Qualitative field research took place over ten weeks in Vietnam from May to July 2015. Two weeks were initially spent in Hanoi making professional connections, followed by four weeks conducting interviews with Hmong and Yao farmers at marketplaces across the northern districts of Lào Cai Province. My field season concluded with a two-week in-depth case study of Bảo Yên District, interviewing local officials and Tày, Hmong, and Yao farmers, followed by a final two weeks in Hanoi. The qualitative methods described in this section were used to gather information to support all five of my research question. First, I demonstrate the importance of back up plans and the role of both gate keepers and research assistants (RAs) in facilitating access to field sites. I then present an overview of my interviewing strategies and I conclude this

chapter with a discussion on my position as a researcher conducting social science research in Vietnam. All fieldwork aspects of my research were approved by McGill University's Research Ethics Board.

4.2.1 Accessing the field

Taking an official approach to research in Vietnam requires a research visa and a series of official permissions, or 'red stamps'. This process was facilitated by my supervisor's connections with the Department of Geography at Vietnam National University (VNU). It required an in-depth field plan to be submitted to the Department of Immigration, prior to receiving official researcher status. I arrived in Vietnam anticipating a short adjustment period in Hanoi before leaving for the northern borderlands with a RA from VNU. The initial plan was for the assistant to accompany me to the five border districts of Lào Cai Province to facilitate access to the field by introducing me to local officials and by organizing commune level permissions in three previously chosen case study locations. Shortly after arriving in Vietnam however, unforeseen circumstances related to provincial and district level preparations for an important National Congress meant I was prohibited access to the five border districts I had conducted land cover mapping and initial fieldwork preparations for. This area was deemed too sensitive for foreign researchers at the time, especially those conducting research with ethnic minority groups. I was however permitted access to the two southernmost districts (Văn Bàn and Bảo Yên) of Lào Cai Province, which I did not have land cover mapping completed for. Given that Vietnam is a socialist country, and overseas researchers have little bargaining power regarding gaining official permissions, my home and host supervisors advised to me to accept this new direction.

To access the approved southern districts, paperwork was required at various levels of government. After submitting the requested paperwork, the new permissions were delayed several times due to hesitations regarding the details of my project, and were finally obtained four weeks later. During this time, I traveled from Hanoi to Sapa town in Lào Cai Province to find a local RA. I was also able to travel to marketplaces in Bắc Hà, Si Ma Cai, Bát Xát, Mường Khương, and Sa Pa Districts to start informal observations regarding Hmong and Yao livelihoods. Even at this stage, plans and locales were constantly being renegotiated and finally, I decided to focus my research efforts on an in-depth case study of Bảo Yên District, and specifically, three communes within it. Following my case study in Bảo Yên I became seriously

ill and had to return to Canada at the advice of a doctor, shortening my intended field season by three weeks.

4.2.1.1 Field sites

With the granting of official permissions, I completed two weeks of fieldwork in Bảo Yên District. In Bảo Yên I interviewed high-level district officials, commune-level officials, and Hmong, Yao, and Tày farmers. There are 17 communes in Bảo Yên and I was permitted to access seven of these: Bảo Hà, Nghĩa Đô, Điện Quan, Vĩnh Yên, Long Khánh, Việt Tiến, and Long Phúc. In reality, I was not able to visit Bảo Hà due to road conditions and difficult access, but I travelled to the remaining six communes. Điện Quan, Vĩnh Yên, and Việt Tiến communes were chosen for in-depth case studies based on LULC characteristics, ethnic composition, and willingness of commune officials to help my research team. I travelled to and from these villages by motorbike and I stayed in the case-study villages with host families, giving me the opportunity to have many informal discussions on land change.

To complement this case study, I also completed participant observation and informal interviews in other districts of Lào Cai Province. These were conducted in weekly marketplaces - places of social interaction and trade amongst ethnic minority groups. To a foreign researcher, they provide access to a diverse number of participants without having to travel from village to village. These interviews allowed me to interact with participants from villages that spanned the initial five border districts, and the districts of Sa Pa and Bắc Hà (not initially considered in land cover mapping) for a broad overview of changes occurring across the province. Over one month I completed repeat visits to five marketplaces to interview Hmong and Yao farmers: Mường Hum market (in Bát Xát District), Sapa (in Sa Pa District), Mường Khương (in Mường Khương District), Can Cau (in Si Ma Cai District), and Bắc Hà (in Bắc Hà District). When posing questions regarding land change, marketplace interviews provided surprisingly rich and diverse responses on change in villages across the district, and in some cases across the province. For instance, in Mường Hum market, one participant with whom I spoke with came from Mường Khương, nearly 130km away, and another from Y Ty, 30km away.

4.2.1.2 Gatekeepers

Although my research topic was not highly politically sensitive, the location and timing of my project required gatekeepers to help access my field sites. Gatekeepers are individuals who “control and facilitate access to respondents, resources and knowledge, such as interpreters,

social contracts and research participants themselves, who hold the ultimate power to allow or deny our work” (Heller et al. 2011, 73). I developed relationships with several gatekeepers through my supervisor, and in return, I could navigate the official red stamp process, conduct interviews with high-level government employees, and obtain access to official state land use data. There were also instances of gatekeepers inhibiting access, such as commune level officials interfering with participant interviews. During my time in Bảo Yên, I was assigned a police escort to monitor my movement and activities throughout the district, as well as local commune-level ‘hosts’ that ensured compliance with the state and that my interview questions did not touch on any politically sensitive topics. In many cases, interviewees were uncomfortable by the presence of such gate keepers and were initially hesitant to provide in-depth answers to my interview questions. To get around this, I often tried to gauge participants’ willingness and level of comfort, and adjust my interview questioning and style to make them more at ease. This included various tactics such as taking the time to develop a rapport with the participant, eliminating or rephrasing several questions, and asking more sensitive questions when the officials were occupied with something else (e.g. talking on the phone, outside for a cigarette).

4.2.1.3 Research assistants

When conducting my fieldwork, I had the opportunity to work with four RAs, each with their own personality, positionality, and perspectives. Interviews were conducted in four languages (Hmong, Tày, Yao, and Vietnamese) and I relied on these assistants for constant interpretation and translation to English, as well as being key informants in their own right. Given their unique positionalities, language abilities, and skillsets they could each contribute differently to my research. My first RA was a young, recently married, Hmong woman who works as a trekking guide in Sa Pa District, and who was referred to me by another researcher. My second research assistant, also referred, was a middle-aged Yao woman from Sa Pa, involved in a plethora of income generating activities such as trekking and textile sales. Both women spoke excellent English and could navigate the complex social norms and interactions involved when speaking with Hmong and Yao informants. My third and fourth RAs were university-educated and were referred to me by my host organization. One was Kinh and holds a Master’s degree in remote sensing and land cover change, with previous field experience in Lào Cai Province. The other was Tày and an undergraduate student in anthropology, who had never travelled to Lào Cai

Province. I compensated all four of my RAs financially for their time and paid for their meals and accommodation. I further discuss their role in accessing field locales in Section 4.2.3.

4.2.2 Qualitative methods

The primary methods I used in the field were interviews and participant observation. Interviews are a commonly used method for learning about the experiences, attitudes, and demographic characteristics of individuals, households, or groups (Gregory 2009), while observation involves counting, complementing, and contextualizing activities observed (Kearns 2010). Below I detail the process of conducting interviews, including participant sampling, interview techniques, challenges, and data analysis.

4.2.2.1 Participant sampling

Qualitative research is often criticized for a lack of transparency when it comes to the sampling process, since non-probability sampling techniques are often used to ensure researcher access and willingness to participate (Bryman 2008). I used three strategies for selecting participants: purposeful (selected by pre-defined criteria), opportunistic (willingness to participate), and snowball (gatekeeper introductions choose participants) sampling (Burgess 1984). When interviewing in markets, a combination of purposeful and opportunistic sampling was used. My judgement was based on participants' dress (indicative of ethnicity), how busy they were, and (at times) what they were vending (e.g. spices, livestock, products from China, among others). This approach was combined with randomly approaching ethnic minority farmers and asking whether they would be willing to answer my questions. Snowball sampling was used in Sa Pa District with both my Hmong and Yao RAs, since these women knew of several people in their communities who were knowledgeable about land change. Likewise, when working in Bảo Yên District, I would discuss with my case-study hosts the types of questions I was interested in asking and they would suggest households to visit. Table 4.1 summarizes the number interviews that took place in the different field locales.

4.2.2.2 Interview techniques

There are three methods for conducting interviews to account for differences in structure, dynamics, responses, and discourse. A structured interview follows a predesigned set of questions that cannot be modified during the interview (Burgess 1984). A semi-structured interview is organized around an ordered but flexible questioning style, while an unstructured interview is much more conversational in nature and the questions asked are determined entirely

by the participant's earlier responses (Dunn 2010). Unstructured interviews are often the most useful when the perceptions, histories, and experiences of individuals lie at the core of research questions (Zhang and Wildemuth 2009; Dunn 2010). I employed semi-structured interviews for state officials in Bảo Yên District, and unstructured interviews with ethnic minority farmers both in Bảo Yên District and in marketplaces. Interviews took place in marketplaces, government offices, and farmer's homes. Interviews for both groups revolved around several core themes including current and past land use, environmental well-being, and social well-being. Additionally, state official interviews included questions regarding the implementation and effectiveness of land use policies. In marketplace interviews I took brief notes on my smartphone and then de-briefed with my RA at the end of the day to ensure all information was included in written notes. In Bảo Yên District, I could record interviews after asking participant's permission, which I then transcribed. All participants were compensated for their time with small gifts such as a meal, fruit, salt, sugar, and candies or stickers for their children.

Table 4.1 Number of interviews conducted from May to July 2015, not including many informal discussions that took place with my research assistants and other gatekeepers.

Location	Livelihood of interviewee	Number of Participants	Number of Interviews
Mường Hum market	Farmers and part-time traders	13	10
Sapa market and nearby villages	“	29	11
Mường Khương market	“	7	5
Can Cau market	“	6	4
Bắc Hà market	“	10	8
<i>Sub-total</i>		<i>65</i>	<i>38</i>
Bảo Yên	State officials	19	10
	Việt Tiến farmers	13	9
	Vĩnh Yên farmers	15	10
	Điện Quan farmers	7	6
	<i>Sub-total</i>	<i>54</i>	<i>35</i>
Total		119	73

4.2.2.3 Interview challenges

Since my interviews were conducted in four languages (Hmong, Yao, Tày, and Vietnamese) it was unrealistic for me to learn all four given thesis time constraints, I therefore relied heavily on the translation abilities of my research assistants/interpreters. Working with interpreters in a cross-cultural context often means that the assistant's role is both that of a translator and cultural consultant (Turner 2010). Assistants conduct fieldwork with their own preconceptions, values,

and belief systems, based on their own knowledge and world views (Temple and Edwards 2002; 2008; Turner 2010). Temple and Young (2004, 171) remark: “The translator always makes her mark on the research, whether this is acknowledged or not, and in effect some kind of ‘hybrid role’ emerges in that, at the very least, the translator makes assumptions about meaning equivalence that make her an analyst and cultural broker as much as translator”. When working across languages, the translator is faced with an array of word combinations that could convey similar meaning, while the researcher often has to word questions in simplified terms, to ensure information is not lost on the translator or the participant (Temple and Edwards 2002). There were several instances where I was unsure about the ‘correctness’ of participant responses. To deal with this, when I began working with my RAs, I had in-depth discussions on the type of information I was looking for. For example, after working with one RA for a while, I began to sense information provided was based off what she anticipated I wanted to hear, and not verbatim what the participant had said. Additionally, it was difficult to determine exactly how interviewee’s perceptions of certain land use types vary from my own which I had used to develop classifications. This required constant triangulation methods, such as asking the same question in a different format later in the interview, and consistently discussing with my RAs the importance of translating verbatim.

4.2.2.4 Interview analysis

Coding data is an approach used to create connections in the data and add rigour to qualitative analysis (Cope 2010). A code is a “word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data” (Saldana 2013, 3). Through the process of coding the researcher can take raw data and raise it to a conceptual level (Corbin and Strauss 2008). To code my field notes, I attempted to take on the role of the ‘other’, in order to understand land use from the participant’s perspective (ibid.). All interview data was transcribed upon returning from the field and transcripts were coded at two levels: first level descriptive codes were assigned to capture the essence of the data while second level analytic (or thematic) codes were assigned to identify emergent patterns and themes. Thus, coding was the final step in collecting and analyzing data from semi-structured interviews, unstructured interviews, and observations in the field.

4.2.3 Reflections on the field

All knowledge production is situated (Haraway 1988). An examination of situated knowledge comes into the research process by looking ‘inward’ through self-reflexivity to understand one’s positionality, and by looking ‘outward’ to analyze relations with others (Rose 1997). Temple and Edwards (2002) suggest that in a cross-cultural setting knowledge is bound by ‘triple subjectivity’ – that of the researcher, the assistant, and the researched. To minimize the role of subjectivity in the data collection process, the researcher must constantly engage in critical reflection, examine their positionality, and consider power dynamics.

Being reflexive is a constant process of scrutiny towards the self and the research, often supported by diary writing (Dowling 2010). Through this process, the researcher can reflect upon power dynamics, their positionality, ethical dilemmas, and their emotional state during the field experience. This was my first field research experience in Asia, and more so in a Socialist state, and I kept a constant diary to help reflect on the process. I had discussed the practicalities and difficulties of doing fieldwork in Vietnam, especially the need to be flexible, with my supervisor and members of my research lab, however, only after living the experience was I truly able to understand the art of flexibility. As Caretta (2015, 502) remarks: “True reflectivity can also mean letting go of control and letting yourself be guided and protected by your assistants”. Likewise, by consistently examining my field notes, I could reflect and improve upon my methods and my relationship with myself and those around me. Reviewing my journal, there are several mentions of the psychological and physical exhaustion myself and my RAs felt. I often felt that my work ethic and desire to accomplish a lot in the limited time allocated in my research permissions was more intense than my RAs were used to, and I constantly had to remind myself to give them breaks throughout the day. Likewise, I attempted to find ways to involve my RAs in the research process, rather than only paying them to ask questions they may not have been interested in. For instance, with one RA I frequently discussed Hmong livelihoods and the results of the day’s interviews with her so she could develop ideas for her own undergraduate research project. By incorporating this process into our work routine, I found she became more interested in the questions and took greater initiative as time progressed.

Researcher positionality is defined as the recognition that “all knowledge is produced in specific contexts or circumstances and that these situated knowledges are marked by their origins” (Valentine 2002, 116). As a white, female, unmarried foreigner working closely with an

ethnic minority guide, I drew attention to myself during my fieldwork. When traveling to upland marketplaces, my Hmong RA suggested I borrow her local dress to conduct interviews in. The few times I tried this, I found participants were much more open to speaking with me compared to when I wore western style clothing. This small change broke down cultural barriers and allowed me to be perceived as more of an insider into Hmong customs and practices compared to other researchers and tourists. On the other hand, in Bảo Yên District I was told I was the first foreign researcher to conduct fieldwork there and I was simultaneously regarded with respect and suspicion. For instance, male local officials often invited my research team to meals where we were encouraged to drink maize wine, a sign of welcoming. On the other hand, I was not allowed out of sight when staying in the case study communes. If I wanted to go outside of the house for any reason, an official had to accompany me. While this was non-threatening, it served as a constant reminder that I was ‘under the state’s gaze’ (Turner 2013a).

As part of the reflexivity process, I was constantly aware of power dynamics. By following the official research pathway, I was responsible to fulfil the wishes of my host organization, even though they often conflicted with my research interests. This often meant changing my plans, accepting less than ideal conditions, and learning when to “give up, move on and hope things might get better later” (Michaud 2010b, 222). There are also ethical concerns that arise when ‘speaking for’ others, especially those less privileged than myself (Alcoff 1991). As a western researcher, I can never fully understand the livelihood choices and outcomes experienced by my participants; however, by being reflexive I aimed to reduce my researcher bias and positionality, and as much as possible convey the experience of my participants. I found myself consistently reflecting on this during my fieldwork, a process that continued into writing the results chapters. Thus, by critically reflecting on my subjectivity, positionality, and power from the initial conceptualization of this thesis to the final manuscript, I could improve the rigour of my work.

4.3 Chapter conclusion

In this chapter, I introduced a diverse set of methods including qualitative interviews, remote sensing of land use change, and quantitative landscape analysis. By supplementing land cover mapping with local in-depth understanding of land use and environmental changes, a mixed methods approach enabled a holistic understanding of social-ecologic dynamics in Lào Cai Province. In the subsequent three results chapters, I draw on the methods outlined in this chapter to answer my research questions.

CHAPTER 5 DRIVERS AND OUTCOMES OF LAND CHANGE IN LÀO CAI PROVINCE

In this chapter, I examine the drivers and outcomes of land change at the provincial and household scales. I begin with my first research question: ‘*What are the primary LULC changes from 1999 to 2014 in Lào Cai Province?*’ in Section 5.1 by presenting a quantitative analysis of the land cover changes in Lào Cai Province. In Section 5.2, I compare the results of land cover classifications with interview data on LULC change in selected field sites. In Section 5.3, I answer my second research question: ‘*What are the drivers of LULC changes?*’ and analyze how land change outcomes varied across districts. This chapter reveals the largest LULC transitions that occurred in Lào Cai Province from 1999 to 2014 were an increase of plantation forestry and urban areas, driven by state reforestation and modernization policies.

5.1 Land use land cover changes from 1999 to 2014

Drawing on knowledge of important land cover types, the OO classification process resulted in 15m resolution classifications of seven distinct land cover classes: water, built-up, bare soil, shrubs, closed canopy forest, open canopy forest, and unclassified, presented in Figure 5.1. The overall accuracy of the 2014 classification was 85% (Table 5.1). The highest accuracies were in the built-up (96%) and closed canopy (92%) classes. The shrubs (79%) and open canopy forest (73%) classes yielded the lowest accuracies – likely due to confusion between the vegetation-based classes. Open canopy forest and shrubs are both sparse vegetation classes which are difficult to segregate using low-resolution remote pixel-based methods (Li and Fox 2012; Turner and Pham 2015); however, the accuracies of both classes are acceptable, given the high accuracy of the remaining land cover classes (Foody 2002).

A second source of class confusion may be attributed to the date of image acquisition. The 1999 images were acquired during the winter (December 27th) when there was little agricultural foliage given winter conditions, allowing for easy recognition of the bare soil (or agricultural) class. The 2014 images were acquired during the fall (October 9th) when some agricultural foliage (in particular, wet rice) may have been present, near the end of the harvest. The difference in image acquisition dates was taken into consideration when developing the classification ruleset by decreasing the simple ratio (SR) value, an index to evaluate green vegetation, for bare soil delineation from 6.0 (2014) to 4.5 (1999).

Table 5.1 Land cover classification accuracy assessment

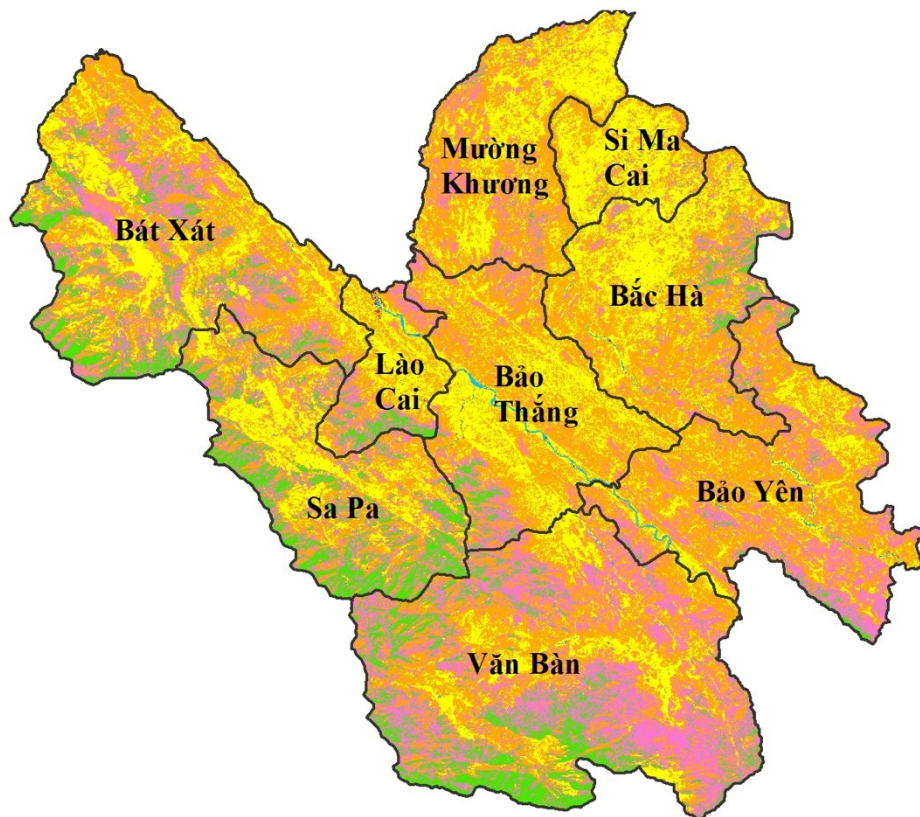
Class	Water	Built-up	Bare soil	Shrubs	Open forest	Closed forest	Row total	User's accuracy
Water	10	0	0	0	0	0	10	0
Built-up	1	48	3	0	0	0	52	0.08
Bare soil	1	2	47	2	2	2	56	0.16
Shrubs	0	0	5	38	0	3	46	0.17
Open canopy forest	0	0	1	5	56	6	68	0.18
Closed canopy forest	0	0	2	3	3	30	38	0.21
Column total	12	50	58	48	61	41	270	
Producer's accuracy	0.83	0.96	0.81	0.79	0.92	0.73		
Overall accuracy	0.85							

The classifications revealed significant change in built-up and closed canopy forestry classes. Transition statistics are presented in Tables 5.2 and 5.3.⁴ Built-up, or urban, areas increased at an annual rate of 20.36 percent and most of this growth occurred in Lào Cai city (*Thành Phố Lào Cai*) and Bảo Thắng District. Transition to the built-up class originated primarily from land classified as bare soil (72.1km²) and shrubs (28.7km²) in 1999. On the other hand, closed canopy forest increased annually by 12.44 percent with the three largest land cover transitions overall being from shrubs (1572.7km²), open canopy forest (1000.8km²), and bare soil (376.3km²).

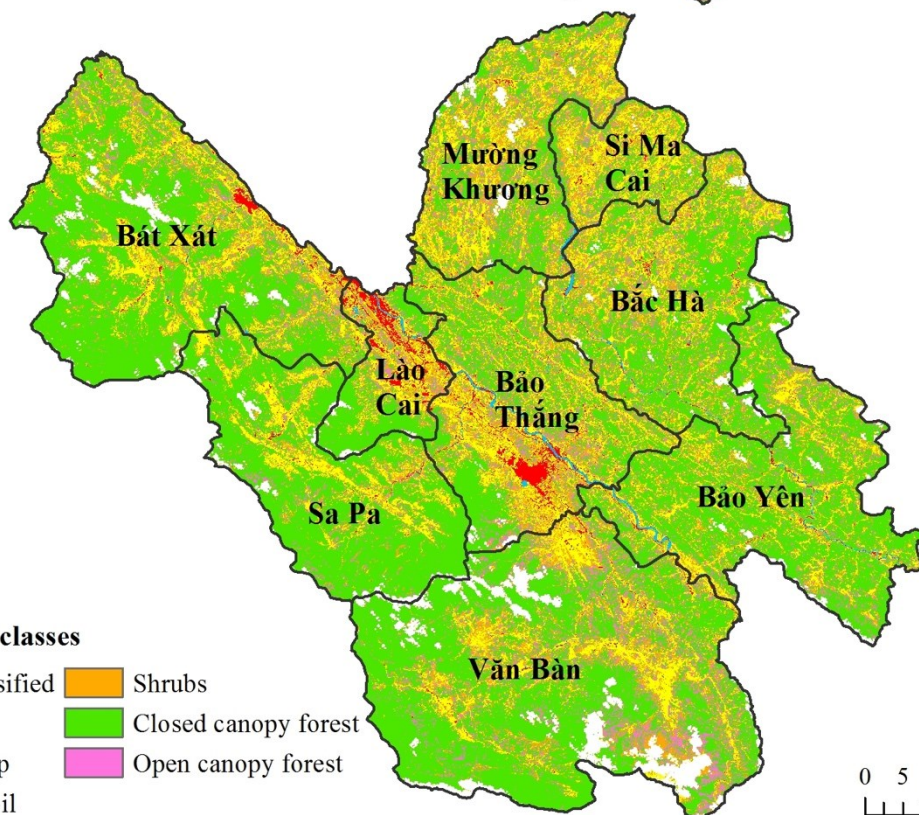
With the exception of water, the remaining land cover classes declined in area from 1999 to 2014. Bare soil, closely representative of agriculture, declined by 3 percent annually, as it transitioned to other land covers including urban and closed canopy forest. Similarly, there was an annual 7.21 percent decline in shrubs and a 5.11 percent decline in open canopy forest as this area transitioned to mostly closed canopy forest. Water increased over this timeframe, suggesting either an error in the classification, an increase in river dam reservoirs, or increased flooding of paddy land. Overall, these findings are consistent with previous land cover mapping in the province (Trincsi et al. 2014; Turner and Pham 2015).

⁴ Pixels under cloud cover in 2014 were masked from the 1999 image to improve class change calculations.

1999



2014



Land cover classes

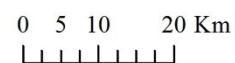
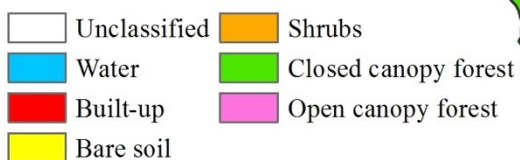


Figure 5.1 Land cover classification for Lào Cai Province for 1999 and 2014.

Table 5.2 Area in km² and percent change of each land cover class.

Class	1999	2014	Percent change over 15yrs	Annual rate of change ⁵
Unclassified	255	255	0	0.00
Water	26	35	34	1.95
Built-up	5	109	2020	20.36
Bare soil	1582	1009	-36	-3.00
Shrubs	2710	919	-66	-7.21
Closed canopy forest	533	3446	546	12.44
Open canopy forest	1237	575	-54	-5.11

Table 5.3 Transition between classes (in km²) from 1999 to 2014. Shaded areas indicate no change between years and bolded values indicate five largest transitions.

2014	1999							
	VALUE	Unclassified	Water	Built-up	Bare soil	Shrubs	Closed canopy	Open canopy
	Unclassified	255.1	0.0	0.0	0.0	0.0	0.0	0.0
	Water	0.0	20.2	1.0	10.2	3.5	0.0	0.1
	Built-up	0.0	3.7	2.8	72.1	28.7	0.2	1.7
	Bare soil	0.0	2.0	1.2	653.1	311.2	4.8	37.2
	Shrubs	0.0	0.2	0.1	340.7	474.9	12.7	89.9
	Closed canopy	0.0	0.1	0.0	376.3	1572.7	496.1	1000.8
	Open canopy	0.0	0.0	0.0	129.7	318.7	19.6	107.2

5.1.1 Land cover change by district

At the district level, land cover transitions reflected those occurring in the province (Table 5.4). Of the thirteen largest transitions, all of them occurred in the built-up and closed canopy forest classes (8/13 and 5/13 respectively). Interestingly, districts that had the greatest closed canopy growth were all east of the Red River (Bắc Hà, Bảo Thắng, Bảo Yên, Mường Khương, and Si Ma Cai), potentially pointing to the role of Hoàng Liên National Park in preserving forest cover in Sa Pa and Văn Bàn Districts. However, districts west of the Red River still experienced significant annual closed canopy forest increase (8.1% to 11.2%). With respect to bare soil, all districts experienced a loss in total area, with Bắc Hà having the largest reduction (48%) and Văn Bàn the smallest (11%). In all districts, shrubs declined annually by between 2.6 to 9.9 percent. Contrary to calculations at the provincial scale, which showed an overall decrease in open canopy forest, open canopy area both increased (Bảo Thắng, Mường Khương, Si Ma Cai) and decreased (Bắc

⁵ Calculated using standardized annual rate of change (Puyravaud 2003).

Hà, Bảo Yên, Bát Xát, Lào Cai, Sa Pa and Văn Bàn). Finally, water increased in all districts but Văn Bàn, with the largest growth occurring in Mường Khương (7.5%) and Sa Pa (7.6%).

Table 5.4. Land cover change by district.

	Land cover class					
	Water	Built-up	Bare soil	Shrubs	Closed canopy	Open canopy
Bắc Hà						
1999	2.3	0.3	225.4	336.7	23.4	76.3
2014	4.0	6.0	116.3	119.7	349.9	68.7
Total change	74.5	1641.5	-48.4	-64.5	1396.4	-10.0
Annual change	3.7	19.0	-4.4	-6.9	18.0	-0.7
Bảo Thắng						
1999	7.9	0.9	229.7	353.9	16.5	68.6
2014	9.2	35.4	151.9	127.9	282.9	70.4
Total change	16.3	3726.7	-33.9	-63.9	1609.7	2.6
Annual change	1.0	24.3	-2.8	-6.8	18.9	0.2
Bảo Yên						
1999	7.7	0.8	143.2	452.3	14.9	178.6
2014	9.3	6.8	109.2	102.8	503.4	66.0
Total change	20.6	743.8	-23.8	-77.3	3270.6	-63.1
Annual change	1.2	14.2	-1.8	-9.9	23.5	-6.6
Bát Xát						
1999	1.5	0.3	249.2	420.6	120.5	222.0
2014	2.3	16.6	153.9	122.2	650.4	68.6
Total change	60.5	5004.9	-38.2	-70.9	439.7	-69.1
Annual change	3.2	26.2	-3.2	-8.2	11.2	-7.8
Lào Cai						
1999	3.0	2.2	76.8	85.9	18.6	34.7
2014	3.3	25.5	47.7	34.0	92.9	17.9
Total change	9.8	1079.3	-38.0	-60.4	398.9	-48.4
Annual change	0.6	16.5	-3.2	-6.2	10.7	-4.4
Mường Khương						
1999	1.0	0.2	193.1	282.3	5.0	63.3
2014	3.0	4.9	126.5	130.5	211.3	68.8
Total change	209.1	2077.3	-34.5	-53.8	4088.6	8.7
Annual change	7.5	20.5	-2.8	-5.1	24.9	0.6
Sa Pa						
1999	0.1	0.1	157.5	214.4	138.0	140.1
2014	0.2	3.9	87.9	56.6	467.2	34.4
Total change	210.8	2535.2	-44.2	-73.6	238.7	-75.5
Annual change	7.6	21.8	-3.9	-8.9	8.1	-9.4
Sì Ma Cai						

1999	0.7	0.1	135.1	82.6	2.5	10.8
2014	1.8	3.2	63.3	56.0	81.2	26.3
Total change	168.9	4680.8	-53.2	-32.2	3204.6	143.2
Annual change	6.6	25.8	-5.1	-2.6	23.3	5.9
Văn Bàn						
1999	2.1	0.2	172.0	481.1	193.9	442.5
2014	2.0	7.1	152.9	169.0	806.8	154.0
Total change	-5.3	4455.7	-11.1	-64.9	316.0	-65.2
Annual change	-0.4	25.5	-0.8	-7.0	9.5	-7.0

To summarize, I uncovered the primary land cover changes in Lào Cai Province at a 15m resolution using OO image classification to an accuracy of 85 percent. The largest land cover changes that occurred over a fifteen-year period from 1999 to 2014 were an increase in urban areas and an increase in closed canopy forest, which occurred uniformly across the province's nine districts. In the next section, I compare the above quantitative results with in-depth interviews and field observations to better understand corresponding land use changes.

5.2 Results of interviews on land use and land cover change

I now turn to the primary LULC changes from 1999 to 2014 that were described by farmers and key informants, namely an increase in forest cover, urbanization, a transition to hybrid crop varieties, and intensified forest use. When possible, I compare these changes to the land cover classifications in Figure 5.1 to account for similarities and discrepancies. The aim of this section is to provide a composite overview of trends in LULC change in the province, drawing on discussions about household, commune, and district changes in the seven districts visited.⁶

5.2.1 Land cover change: reforestation and urban expansion

Similar to the results of the classifications, the dominant land cover change noted by interviewees was an increase in forest cover. Prior to the implementation of state reforestation projects, interviewees explained that much of Lào Cai Province was dominated by 'barren' land composed of shrubs and open canopy forest. Where there were mature forest stands, they were managed by SFEs for watershed protection and timber production (McElwee 2016). Primary and secondary forests were heavily harvested for firewood, timber, swidden plots, and in the mid-1990s there

⁶ Following quotations is an abbreviation for the district about which the individual was discussing land change: BX is Bát Xát District, SP is Sa Pa District, LC is Lào Cai city, MK is Mường Khương, BH is Bắc Hà, SMC is Si Ma Cai and BY is Bảo Yên. Similarly, individuals are noted by ethnicity: H is Hmong, Y is Yao, T is Tày, K is Kinh. KI is a key informant. When three or more respondents confirmed a statement, I place these in a footnote to avoid long lists of sources in the main text.

were several large forest fires (confirmed in the western districts) in Lào Cai Province that also greatly reduced forest cover [SP, H10, 13.06.2015].

With the onset of national reforestation programs (in 1992 and 1998) tree planting efforts were initiated in Lào Cai Province, although the timing varied throughout the province. In the lowland districts (e.g. Bảo Thắng and Bảo Yên Districts), officials noted that reforestation efforts focused on ‘production’ forests, which began to be planted in 1994 with the introduction of cinnamon trees (used for both timber and spice cultivation) [BY, KI14, 02.07.2015; BY, KI19, 04.06.2015]. However, key informants from Bảo Yên District noted that the bulk of reforestation occurred due to Program 661 from 2000 to 2005, and focused on fast-growing tree species, specifically benzoin and acacia.⁷ Farmers explained that reforestation efforts in the high elevation regions of the province (e.g. Sa Pa and Bát Xát Districts) began in 1998 with ‘protection’ and ‘special use’ forests being created as a state-run effort to reduce landslides, protect biodiversity, and increase water availability.⁸

The transition to forest cover took place mostly from what interviewees considered shrub, unused land, or unsuccessful agricultural land. With respect to the land cover classifications, trees in early stages of growth are still likely to appear as shrubs or open canopy forest. Indeed, in all districts the amount of land classified as shrubs in 1999 was larger than in 2014 (e.g. in Bảo Thắng 55% of total land was classified as shrubs in 1999 and only 12% in 2014). Yet, the classifications suggest different rates of forest growth, as district-wide open canopy forest both increased (Bảo Thắng, Mường Khương, Si Ma Cai) and decreased (Bắc Hà, Bảo Yên, Bát Xát, Lào Cai, Sa Pa and Văn Bàn). At the provincial scale, over 1000km² of open canopy forest became closed canopy forest, and 1570km² of shrubs transitioned to closed forest, suggesting early reforestation land cover may have been captured by the 1999 classification.

The types of trees that were planted were selected by state officials and were predominantly introduced species chosen for provisional properties, such as fast-growing timber, resin, oil, or spice. As McElwee (2016, 137) notes: “Trees of any kind were better than no trees [which] led to incentives to plant cheap, fast growing species over more slowly growing indigenous ones”. Every farmer I spoke with who was involved in household forestry activities

⁷ [BY, KI16, 02.07.2015; BY, KI17, 03.07.2015; BY, KI18, 03.07.2015]

⁸ [KI1, 08.06.2015; BX, H8, 21.06.2015; SP, H10, 13.06.2015]

(n=42) explained that they planted one to three varieties of state-introduced trees, including benzoin, various fruit trees, acacia, cinnamon, cypress, and/or pine, among others (Table 5.5).

The distribution of tree species was linked to biophysical and market constraints including access, elevation, and intended use for the area. For instance, a Yao key informant explained how “in Sa Pa District the elevation is too high to grow cinnamon, but they grow it in Văn Bàn and Bảo Yên” [SP, KI2, 20.06.2015]. Similarly, a farmer from a high elevation region of Mường Khương District explained how “the government only supplied fir trees in my village because it is easy to grow in the highlands” [MK, H15, 14.06.2015]. On the other hand, a group interview with six commune officials in Bảo Yên revealed that since 2000, the government had supplied households with bamboo, acacia, and benzoin seedlings, and since 2013 cinnamon [BY, KI8, 03.07.2015]. A Hmong key informant in Sa Pa District also explained how fast-growing timber for markets was not planted in mountainous regions because it is difficult to extract and export, whereas Bảo Yên and Bảo Thắng are low elevation districts with easy access to international timber markets [SP, KI1, 07.06.2015].

Table 5.5 Common tree species planted from 1999 to 2015.

Vietnamese name	English name	Scientific name
Pơ mu	Fujian cypress	<i>Fokienia hodginsii</i>
Bồ đề	Siam benzoin	<i>Styrax tonkinensis</i>
Keo	Acacia	<i>Acacia</i> spp.
Cây thông	Pine	<i>Pinus</i> spp., suspect <i>Pinus kesiya</i>
Cây thông gay	Fir	Uncertain, suspect <i>Abies A. delavayi</i>
Cây tùng quốc sủi	Alder	Uncertain, suspect <i>Alnus nepalensis</i>
Mỡ	N/A	<i>Manglietia conifera</i>
Tre	Bamboo	<i>Bambusoideae</i> spp.

Another land cover change noted by interviewees was an increase in built-up areas. Most urban growth occurred in Lào Cai city, corresponding to the 16.5% annual increase in urban areas revealed in the classifications. Several construction projects were underway from 1999 to 2014 including an international highway to connect China with Hanoi (and beyond) which cut across Lào Cai Province, expansion of a 10km long highway strip to house all provincial administrative buildings in Lào Cai city, and several luxury housing projects also in the city [KI13, 12.06.2015; KI15, 01.07.2015]. While some densification occurred within the centre of Lào Cai city, most urban change was large-scale expansion south of the city on the western side of the Red River (Lao Cai People's Committee 2015). To account for the increase in built-up area, many farmers lost agricultural lands without being reassigned land rights. One key

informant, a foreign graduate student researching Lào Cai city's development, noted how the expansion of the city caters towards the elite, rather than rural residents who once resided in the peri-urban areas:

These buildings are on the main highway – behind these buildings is land for the relocated families. You have to see the difference between these kinds of buildings, the prestigious buildings, and the very small houses built by the people themselves. The people don't have enough money so you can see the contrast between them [KI14, 16.04.2016].

Haphazard expansion of Lào Cai city is expected to continue, which this key informant calls 'irrational' (ibid.). Construction projects are in the hands of private companies and planning has not catered to household or community needs, but rather private interests. For instance, planning does not consider the creation of green spaces for residents, who instead use areas in front of state-buildings as public space (ibid.).

In rural regions of the province, such as Sa Pa District, and the more remote Mường Khương District, urban growth (21.8% and 20.5% respectively) took place mostly in the form of infrastructure expansion and construction of markets, roads, schools, tourism facilities, and medical centres [observations]. Expansion in rural districts took place at the expense of agricultural fields, although not to the same magnitude as surrounding Lào Cai city. However, parallels can be drawn between urban and rural 'irrational' planning. For instance, in Sapa town, the marketplace – long used by ethnic minority traders – was relocated to a new building located one kilometer away from the town center in 2014, causing an expansion of urban activity into the periphery. During an unstructured group interview with six Hmong women vending at the new market, one woman explained: "The new market makes me cry every day. No tourists come to the new market and we make no money" [SP, H10, 10.06.2015]. Another vendor explained: "When tourists come to the town they only have a few hours. In the old [centrally-located traditional] market they could shop while walking through the town, now they must go out of their way, and most don't know where the new market is" [SP, H9, 10.06.2015]. Hence, irrational urban planning has led to loss of livelihood activities for many rural households.

In sum, the two largest land cover changes noted by interviewees were an increase in closed forest and an increase in urban areas. These commentaries are consistent with the results disclosed by the land cover classifications, although interviewees placed greater importance on forest changes. This highlights the importance of concentrated land changes (e.g. forest change in

rural areas) and the role of natural resources in ethnic minority livelihood strategies. A decline in shrubs, bare soil, and open canopy forest was not frequently mentioned. Rather, interviewees across the province focused on land use changes, which I analyze in the following section.

5.2.2 Land use changes: agricultural intensification and forest product extraction

There were several land use changes that emerged from interviews with farmers that were not evident on the classifications, such as agricultural intensification and forest product use. With land *use* changes, the land *cover* class is likely to remain the same, showing little or no change on the classifications, but the primary use of the land has been drastically altered, with implications for social-ecological resilience. Following restrictions on swidden cultivation and the introduction of hybrid seed subsidies in 1999, the largest land use change that occurred in the province, according to all the farmers I interviewed (n=60), was a transition from traditional crop varieties of maize, wet rice, and cassava to hybrid varieties.

The timing of land use transitions and proportion of fields under hybrid cultivation varied greatly by crop, ethnicity, household capital, and location. Householders explained how hybrid wet rice seeds were planted first (for the majority around 1999), followed by maize (majority around 2003), and finally cassava (2008 onwards). However, many factors influenced individual household decisions regarding when to switch to hybrid seeds, such as seed availability and financial capital. Farmers either maintained areas of traditional varieties, transitioning sections of their fields cautiously, or implemented the change all at once. For instance, a group of 12 Yao farmers in Sa Pa District explained how they began planting only hybrid maize around 2003 [SP, Y4, 24.06.2015], whereas a Hmong household living in a remote region of Bảo Yên District transitioned a small portion of their field in 2009, and only planted their entire field with hybrid maize in 2011 [BY, H32, 10.07.2015]. While hybrid seed varieties cannot be distinguished on 15m resolution image classifications, there was a 36% total decline in bare soil which may suggest a reduction in field size as yields increased, or the presence of a greater proportion of fields under fallow. Indeed, a sixth of interviewees, including Hmong and Yao farmers from Bát Xát, Mường Khương, Sa Pa, and Bảo Yên Districts (n=11) noted that they no longer cultivate traditional dry rice for subsistence needs, because hybrid rice provides enough food.

Mimicking changes seen across Montane Mainland Southeast Asia, another emerging agricultural land use trend was a transition from fallow or subsistence agricultural land, to cultivated cash crops. I observed several cash crops while travelling throughout the province

including tobacco, bananas, tea, cassava, maize, pineapples, roses, and soy, although the magnitude of cultivation once again varied among districts. For instance, I spoke with three households who grew tea to sell to Kinh traders until around 2010 in Bát Xát and Sa Pa Districts,⁹ yet most tea cultivation occurred in Mường Khương District in large-scale tea plantations [observations; KI1, 14.06.2015]. In Mường Khương District, pineapples were also grown in large plantations by Kinh farmers who hired local Hmong to tend to their fields [MK, H7, 21.06.2015; KI1, 21.06.2015]. Tobacco was grown by small-scale farmers in the border districts of Bát Xát and Mường Khương in the past, although production stopped around 2012 due to a drop in price.¹⁰ Most farmers I spoke to in Bảo Yên District of Yao, Hmong, and Tày ethnicities (n=11), cultivated hybrid cassava for sale to wholesalers; however, I did not find evidence that cassava was grown as a cash crop in other districts. Finally, throughout the province, households who could meet food needs were able to sell surplus maize (n=9) and rice (n=10) in markets or to agricultural intermediaries.

Based on my interviews, cultivation and extraction of NTFPs intensified in secondary and primary forests in Lào Cai Province from 1999 to 2014. Strict regulations regarding forest removal in special-use forests were put in place in 1997 and farmers were no longer able to rely on forests for firewood and construction material. As a Yao key informant explained: “[Since 2005] if you take wood out of the old growth forest from anywhere the government will catch you and you will have to pay” [SP, KI2, 20.06.2015]. However, regulations regarding NTFP removal were haphazardly enforced, and many households could draw on these resources to aid in livelihood security. As the need for cash to purchase seeds, pesticides, and fertilizers increased, households turned to NTFPs such as honey, bamboo, fruit, birds, medicinal herbs, orchids, cinnamon, and cardamom. Cardamom is a spice crop, cultivated primarily by Hmong and Yao farmers, and grown at high elevation in the shade of non-plantation forests. It was traditionally grown for medicinal purposes, and more recently has become a primary source of income for households who sell it as a cash crop to traders, with the crop destined for China (Tugault-Lafleur and Turner 2009). I interviewed Hmong farmers actively involved in cardamom cultivation (n=16) in Bát Xát, Sa Pa, and Si Ma Cai Districts, although cultivation yields have drastically declined since 2011 due to changing weather conditions (see Chapter 6). Nearly every

⁹ [BX, D1, 21.06.2015; BX, H8, 21.06.2015; SP, Y4, 24.06.2015]

¹⁰ [BX, D1, 21.06.2015; MK, H13, 14.06.2015; MK, H14, 14.06.2015]

farmer I interviewed in Bảo Yên District (Hmong, Tày, and Yao, n=25) was involved in cinnamon bark collection and wholesale, with some beginning as early as 1994, and others around 2013 (see Chapter 7). On a smaller scale, many Yao households in Sa Pa District were actively involved in orchid collection (and propagation), as well as medicinal herb collection to sell to tourists and Kinh traders.

In Bảo Yên District I found evidence that natural forest was replaced by plantation forest to facilitate a transition to production forest and a timber-based economy. Large native trees were cut down in the mid-to-late 1990s as markets emerged for timber. One 35-year-old Tày interviewee noted: “When I was young all the trees were big, they were so big I could not wrap my arms around them. Now all you see is acacia and benzoin” [BY, T5, 07.07.2015]. Likewise, a Tày farmer explained that “before 2000 there was grass and many kinds of big trees in the forest. I cut down all the trees [on my land] to sell the wood and after planted acacia and benzoin” [BY, T7, 08.07.2015]. In 1999, Bảo Yên had only 15km² of closed canopy forest, suggesting that much of this land use transition occurred earlier. Likewise, natural forests in Mường Khương District were gradually felled and often replaced by rubber (Pham 2016, pers. comm.). Thus, forest use intensified as farmers turned to NTFPs and timber for income.

In sum, LULC changes noted by interviewees largely corresponded to changes noted on the classifications and broad regional LULC changes highlighted in Chapter 3. Beginning in 1999, households described transitioning to hybrid rice, while the state began reforestation programs in Lào Cai Province. Following hybrid rice, many households experimented with other cash crops, like maize, cardamom, cinnamon, orchids, tobacco, and most recently cassava and soy. Individuals from most households where I conducted interviews (70%) described engaging in some form of plantation forestry, beginning as early as 1994, although most households started to plant trees closer to 2010.

5.3 Drivers of change and differences in place

The drivers of LULC change in Lào Cai Province were identified by coding interview transcripts for factors that led a household or state official to implement a land change. Drivers were sorted into direct or indirect based on the magnitude of impact on the SES and ability to influence land use decisions at the household, district, or provincial scales.

5.3.1 Direct drivers

Proximate drivers involve a physical action on land cover, occur on the local level, and are direct drivers of ecosystem change (Geist et al. 2006). First, linked to an underlying need for cash, at the local level farmers altered the use of natural resources including forestry and agricultural activities. Proximate drivers of land change thus included agricultural expansion and intensification, NTFP collection, and wood cultivation and extraction. LULC changes implemented ranged given ethnicity, knowledge of modern land use practices, and access to markets. For instance, between 1999 and 2014, households altered LULC by cultivating cardamom in closed canopy forests (Hmong and Yao in Bát Xát, Sa Pa, and Si Ma Cai), livestock rearing (across ethnicities and districts), collecting orchids (Yao in Sa Pa), cultivating cash crops like pineapple, tea, and bananas (Hmong and Yao in Mường Khương District), planting and harvesting forest plantations (across ethnicities and districts), and several small scale cash-crop ventures such as roses (Hmong in Sa Pa), traditional medicines (Hmong and Yao across districts), and fruit trees (across ethnicities and districts).

Second, given finite land availability, change in one land cover caused a direct loss of another land cover. For instance, urbanization was a proximate cause of agricultural loss in Lào Cai city. As state officials displaced households to make room for urban growth, agricultural land was lost or expanded into nearby vegetation [KI14, 16.04.2016; Pham 2016, pers. comm.]. Infrastructure extension, such as construction of roads, schools, hospital, and markets, throughout the more rural regions of the province also contributed to LULC change, although at a much smaller scale than in Lào Cai city. Operating on a smaller scale, land allocation through Program 134 (Section 3.4.3) also led to land cover change, as households allocated additional land could convert secondary vegetation to either forest plantations or agricultural fields.

5.3.2 Indirect drivers

Underlying causes are the root or indirect drivers of land change – they are fundamental forces that are formed by complex social, political, economic, demographic, technological, cultural, and biophysical variables that originate from regional or global levels (Geist et al. 2006). I uncovered four indirect drivers of land change: government policy, tied to reforestation programs and market access; market prices; extreme weather events; and social networks. Government policy indirectly drove rural and urban land change through the provision of agricultural subsidies, reforestation programs, and infrastructure expansion. My interviews revealed that much of the

546% total increase in closed canopy forest from 1999 to 2014 may be attributed to state-wide reforestation policies. Through the creation of special uses forests, like Hoàng Liên National Park, forest was protected and farmers were prohibited from harvesting timber, while logging bans worked to prevent deforestation in special use and protection forests. SFEs also planted and managed large tracts of forest dedicated to production forest and timber supply in the lowland districts beginning in the early 2000s. For instance, in Bảo Yên District, Department of Agriculture and Rural Development (DARD) officials explained how the state owned 425km² of production forest [KI11, 06.07.2015]. PES programs also influenced household decisions to plant or protect existing trees although the terms of payment greatly varied from commune to commune. For example, since 2010 in the Muong Hoa valley near Hoàng Liên National Park in Sa Pa District, some households were given 225-360USD/year to protect their forestland from deforestation [KI1, 08.06.2015], while a household living inside the Park was only given 10USD/year to protect their own forests starting in 2015 [SP, H10, 13.06.2015]. In Mường Khương and Bắc Hà Districts, households were given a combination of benzoin, pine, and mandarin trees to plant in their forest plots in exchange for fertilizer packages, although the exact number of trees varied from village to village.¹¹ Finally, several households in all districts I visited were given up to 3000 tree seedlings for free as part of anti-poverty schemes. While PES programs have been successful in encouraging forest cover increase in central Vietnam (McElwee 2011), some Hmong farmers I interviewed mentioned how trust in these programs has declined as many households have not been paid or permitted to harvest trees as promised by local officials [SMC, H20, 27.06.2015].

Government officials influenced household decisions to plant trees through policy information, meetings, and propaganda, with concurrent goals of poverty reduction and environmental restoration. Officials explained that by planting trees households would have enough wood to build homes for their children, and similarly, although to a much lesser extent, explained that planting trees would help protect the local environment. One Hmong woman trader in Bát Xát market explained:

I bought seedlings from the government to plant because my land is very steep and there is not enough water for crops. I can now sell the trees to people who want to build houses [for 10-15USD per tree] and use the money for my family and I can

¹¹ [MK, H16, 14.06.2015; MK H17, 14.06.2015; BH, H23, 27.06.2015; SMC, H20, 27.06.2015]

give wood to my children. This area now has a little more water and is colder so I am very happy I planted trees [BX, H8, 21.06.2015].

Similarly, an informant from Si Ma Cai District commented: “If you do not plant you do not get in trouble, but everyone in the village has to help so the natural environment comes back” [SMC, H24, 28.06.2015]. Overall, reforestation strategies appear to be working, as nearly every household I spoke with in Lào Cai Province had engaged in some form of tree planting since 1999, ranging from a few trees to large plantations.

My interviews also revealed that government policy, linked to *Đổi mới*, the GMS Program, and the Lào Cai Economic Expansion Plan, drove urban growth. An interview with a graduate student conducting research in Lào Cai city uncovered several reasons for urban expansion in Lào Cai: first, Lào Cai city is aiming to become a grade-I city whereby Lào Cai would be seen as an economic, cultural, administrative, and exchange hub to facilitate socio-economic development in the northern uplands; second, migration rose as urbanization continued and job creation increased; third, to help facilitate trade between China and Vietnam; and fourth, as part of larger state plans whereby Vietnam is concentrating on urbanizing small cities to slow urbanization in larger cities [KI14, 14.04.2016; see also SRV 2009].

Similarly, market accessibility, through the expansion of roads and markets, indirectly influenced cash crop development. Officials in Bảo Yên District commented on how upgraded roads helped farmers to access marketplaces, and facilitated wholesalers and intermediaries to access remote communes to purchase timber and agricultural surpluses. For instance, a senior district official explained how since rural development programs expanded infrastructure in Bảo Yên, there have been significantly more agricultural sales compared to before, specifically of buffalo, rice, maize, tea, cinnamon, and fruit [BY, KI3, 01.07.2015]. Roads also facilitated access to non-agricultural market opportunities, such as tourism in Sa Pa and seasonal labour opportunities in China for those who lived close to the border. For example, a key informant explained how a paved road through the Muong Hoa valley facilitated tourism by reducing the amount of time it took for residents to access Sapa town [SP, KI1, 08.06. 2015]. Similar to Champalle’s (2012) findings just across the border in southern Yunnan, I found that households in remote areas without extensive infrastructure did not experiment with cash crops and relied to a far greater degree on traditional rice and maize seed varieties. Not surprisingly, remaining large tracts of old growth forest and natural land cover were also located far from main roads and were

therefore less accessible to illegal loggers and NTFP markets, such as remote regions of Si Ma Cai District [SMC, H28, 28.06.2015].

Market prices also indirectly affected land use decisions by determining whether cash crop commodities would provide sufficient income to meet household needs. When prices for cash crops, such as tobacco or tea, were high, interviewees noted that they were more likely to experiment with the necessary land change to grow or expand their crops. For instance, Hmong informants in Mường Khương District began cultivating tobacco in the mid-2000s. However, since the price of tobacco had dropped drastically since then, their fields were abandoned or transitioned to other crops. As one Hmong woman noted: “People in my village used to grow tobacco but now they don’t because the price is not good. Instead they grow soybeans to eat, or some rice and maize to eat or sell” [MK, H14, 14.06.2015]. Prices for plantation timber also fluctuated significantly from year to year. For example, the price of 1kg of cinnamon bark changed by 0.09-1.61USD between years. As a Tày farmer noted: “I’m not afraid to grow fast trees like acacia because the wood is exported, but I am afraid the price of cinnamon wood will drop by the time it is ready to harvest it [20 years to maturity]” [BY, T2, 07.07.2015].

Extreme weather events, such as drought, extreme heat, heavy rain, floods, landslides, cold winters, and snow affected all the farmers I interviewed (n=60). Every farmer mentioned how extreme weather events increased in duration, magnitude, and frequency, and significantly affected their crops, both agricultural and NTFPs (also noted by Delisle and Turner 2016). For example, drought and heavy snowfall have affected cardamom yields since 2011, and 15 of the 16 households I interviewed who were engaged in cardamom cultivation reported drastic declines to 2014 yields, such as 300kg (2011) to 0kg (2014) [BX, H8, 21.06.2015], 100kg to 5kg [BX, H2, 07.06.2015], and 300kg to 30kg [SP, Y1, 10.06.2015]. Likewise, rising temperatures led to losses in wet rice and maize productivity. Farmers explained that the more frequently these events occurred, the more likely they were to experiment with a different hybrid seed variety or different crop entirely. One Yao interviewee noted: “I think it is very hot now compared to ten years ago. I cannot grow rice in some spots so I have to grow more maize, but my maize is not growing as well as before” [SP, Y5, 24.06.2015]. Similarly, two Hmong women from Bắc Hà explained: “In our village it is too hot and there is not enough water to grow wet rice now. Instead we grow dry rice because it can grow, but there is not enough food for the family this way” [BH, H26, 28.06.2015]. Acute events like hail storms, landslides, and floods also wiped out

entire fields and led to property damage, such as a hail storm in 2010 in Mường Khương [MK, H15, 14.06.2015] and severe flooding in 2008 in Bảo Yên [BY, K1, 08.08.2015].

Finally, kinship ties and close social networks motivated many ethnic minority household land decisions in Lào Cai Province. Nearly all my informants (of all ethnicities) discussed with their kin, both inside and outside their household, whether to implement a land change. For instance, one Hmong woman from an isolated village in Si Ma Cai noted that she now travels to Bắc Hà market to sell medicinal NTFPs because everyone in her village did and they were able to generate income [SMC, H28, 28.06.2015]. Likewise, in Bảo Yên District, a Tày couple purchased several additional hectares of forestland to plant cinnamon trees because their parents had had success with harvesting and selling cinnamon bark [BY, T9, 09.07.2015]. This finding is consistent with another study in the northern uplands, which found that most farmers relied on informal social networks such as family, neighbours, and friendships, for advice on farming decisions (Lan et al. 2006). Thus, political, economic, biophysical, and social factors worked to shape LULC change in Lào Cai Province.

5.3.3 Predisposing environmental factors

Predisposing environmental factors include biophysical conditions like elevation, slope, and soil conditions (Geist and Lambin 2002). Biophysical conditions affected available LULC options and can reveal the importance of place when implementing land change decisions. Wet, cool, and high altitude districts west of the Red River, including Bát Xát, Sa Pa, and Văn Bàn Districts, benefited from conditions favourable to NTFP cash crop growth, especially cardamom. On the other hand, districts east of the Red River were generally dry and hot and provided excellent growing conditions for other cash crops, like pineapples, bananas, and tea. Land use is also constrained by the impact of weather conditions, tied to biophysical conditions. For instance, cardamom cultivation in Bát Xát drastically declined due to extreme high temperatures in summer and snow in winter, while in Si Ma Cai District there was little or no change to yields in cool dry areas of high elevation, with one Hmong interviewee I spoke with harvesting as much as 1000kg in 2014 [SMC, H18, 27.06.2015]. Elevation and precipitation also restricted the productivity of crops. Lowland regions, such as Lào Cai city, Bảo Thắng, and Bảo Yên Districts, were able to plant two rice crops per year (reducing the need livelihood diversification) and thus required less land to meet household needs, whereas regions of high elevation were only able to cultivate one rice crop. Additionally, one Hmong woman described how the fields around her

village were too steep for wet rice and there was too much water for hybrid maize, so she was only able to grow local maize and dry rice [SMC, H28, 28.06.2015].

To summarize, multiple factors operated across scales and influenced land transition in Lào Cai province. The proximate direct drivers included agricultural expansion and intensification, NTFP collection, wood cultivation and extraction, and land displacement. Indirect drivers included government policy, market prices, extreme weather events, and support from social networks. These findings show that there is a statistically significant effect of distance to roads, distance to markets, elevation, and slope on land change (see also Trincsi 2013).

5.4 Chapter conclusion

In this chapter, I have analyzed the drivers and outcomes of LULC change in Lào Cai Province from 1999 to 2014. My results were based on a combination of remote sensing, observations, and interview data, and demonstrate the benefits of combining methods. Namely, provincial level changes observed in the classifications did not illustrate nuanced details or subtleties of land *use* change that occurred at the household level. However, the classifications provided a broad understanding of the extent of land cover changes throughout the province while interviews were essential in determining household land use strategies and the drivers of landscape change.

The primary LULC changes included an increase in closed canopy forest cover, which informants revealed was linked to cardamom cultivation and plantation forestry; urbanization to facilitate economic growth; and an intensification of cash crops, hybrid rice, and maize tied to market integration policies and household food security. The drivers of land change were proximate and distal and included household change in agricultural and forestry LULC, land displacement, policy, extreme weather, market prices, and social networks, which were influenced by predisposing environmental factors. In the next chapter, I uncover what these LULC changes mean for resilience.

CHAPTER 6 SOCIAL-ECOLOGICAL RESILIENCE IN LÀO CAI PROVINCE

In this chapter, I assess changes in social-ecological resilience to answer my third research question: ‘*What are the implications of LULC change for social-ecological resilience in Lào Cai Province?*’ I reference the resilience framework (Figure 6.1) (part of my conceptual framework, see Section 2.2) to examine changes to, and outlooks for, social-ecological resilience. I begin with an analysis of the primary threats to resilience, namely extreme weather events, market price fluctuations, and pest outbreaks. I then present the results of a landscape metrics analysis to assess landscape changes that may affect ecological resilience, followed by field observations and interview analyses and interpretations regarding ecological health. Next, I compare ecological changes with changes to livelihood resilience from 1999 to 2014 at the household scale, and examine what the current and expected future impacts on ethnic societies, local economies, and the environment are. I conclude this chapter with findings on how households are adapting to land system change and embracing intensification and diversification strategies to build and maintain resilient livelihoods.¹²

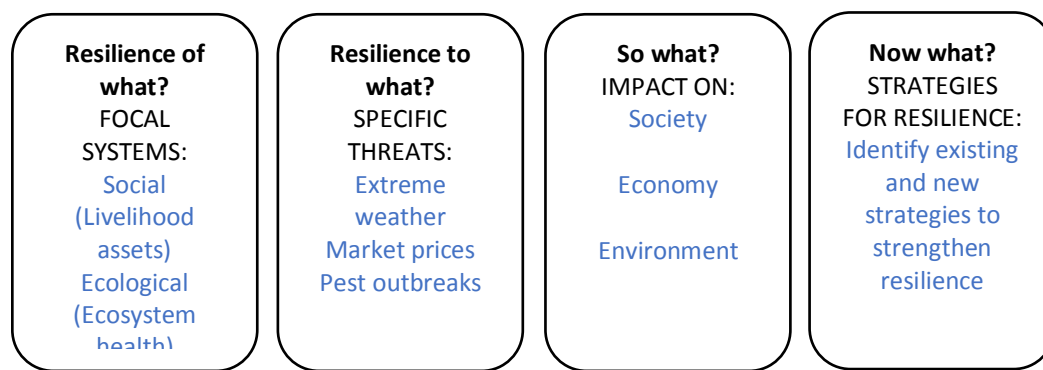


Figure 6.1 Resilience framework applied to land change in Lào Cai Province. Adapted from Sellberg et al. (2015).

6.1 Threats to resilience in Lao Càì Province

The driving forces of land system change are intrinsic attributes of CASs that may hinder or promote social-ecological resilience. Hence, land systems may undergo rapid change based on their ability to absorb underlying indirect drivers of change (Liu et al. 2013; Müller et al. 2014). In Section 5.3 I uncovered the underlying indirect drivers of LULC change in Lào Cai Province. While the direct proximate drivers influence land change outcomes, an accumulation of indirect drivers may gradually increase until a threshold is crossed and a small disturbance may trigger a

¹² I define the system as all social and ecological components, such as human and non-human species, abiotic environmental elements, and institutions, operating in, or living within, the political boundary of Lào Cai Province.

large-scale change and push the SES to a new state (Müller et al. 2014). For example, if every rural household in Lào Cai Province transitioned their entire land to pineapple cultivation and a pesticide-resistant strain of pineapple disease broke out (system disturbance), there would likely be important implications for livelihood security. Based on interviews with key informants and rural farmers in all seven districts I visited, there are three primary shocks or stressors that have acted as system disturbances and have the potential to drastically alter the state of the SES: extreme weather events, market price fluctuations, and pest outbreaks.

6.1.1 Extreme weather events

Within resilience literature, changes to local climate and weather can lead to systems crossing a threshold and entering alternate regimes (Allen et al. 2016). Every farmer I spoke with in Lào Cai Province (n=60) commented on how extreme weather events, including cold and hot weather spells, fire, drought, flooding, and intense storms, were increasing in both duration and frequency. Crop yields thus became vulnerable to uncontrollable climatic conditions that left farmers feeling vulnerable and uncertain about future livelihood practices. As a Hmong woman explained: “Ten years ago it was not this hot and when it rained there wasn’t as much as now” [MK, H8, 21.06.2015] and a male Tày farmer remarked:

The weather is a major problem. We have had problems with water starting three years ago. There is no rain for a long time and all of the villages have no water. It is so dry wherever I decide to plant [wet] rice the plants die and I am worried my family will not have enough food to eat [BY, T4, 07.07.2015].

During a group interview with six Hmong vendors in Sa Pa District, they also commented on how recent dry weather has led to an increase in forest fires, and a loss in cardamom yields [SP, H10, 13.06.2015]. These findings are consistent with forecasts that predicted both increasing excessive rainfall and drought from climate change (Chaudhry and Ruyschaert 2007). Local news outlets also reported an increasing number of extreme weather events for Lào Cai Province. Between 2005 and 2013 there were 33 events reported in the northern upland region, including cold weather, floods, landslides, rainfall, and snow (Delisle 2014). Thus, land has become increasingly vulnerable to erosion and crops yields have declined as temperatures rise.

6.1.2 Market price fluctuations

Low landscape diversity, characterized by homogenous LULC, is not economically resilient to global price fluctuations for market commodities (Swinnen 2007; Eakin et al. 2009). Examples

include: the case of the decline in the price for cocoa and the corresponding large-scale socio-economic crisis in Brazil in the 1990s (Andreoni and Duriavig 2013), a decrease in coffee prices in Latin America as Vietnam became a major global producer (Ha and Shively 2008), among others. As explored in Chapter 5, since 1999 many farmers in Lào Cai Province increasingly experimented with cash crops as part of their livelihood portfolios. However, rapid fluctuations in market prices, such as prices for tobacco and tea, left numerous farmers uncertain as to the success of their land decisions and significant price changes drastically affected livelihood security. As a Tày farmer explained: “I am afraid to grow cinnamon because other trees like acacia grow faster. If I grow cinnamon, the price will go down and I will have no money” [BY, T2, 02.07.2015]. Ethnographic fieldwork carried out in Sa Pa District also uncovered that cardamom prices can vary daily by as much as 1.20-1.75USD per wet kilogram or 4.50-7.50USD per dry kilogram (Delisle 2014). Noted commodity price fluctuations are consistent with global crop volatility which accelerated in 2008 and is expected to increase into the future (FAO 2011).

6.1.3 Pest outbreaks

A key component of resilience involves the degree to which ecosystem functions can resist or recover rapidly from environmental disturbance (Oliver et al. 2015). Pest outbreaks, otherwise inhibited by natural plant and animal functions, were noted by most interviewees in both their agricultural fields containing paddy rice, maize, and other cash crops, and plantation forests. As rural households became more engaged in the market economy, experimentation and the proliferation of cash crops have resulted in a significant loss in genetic plant diversity inherent in naturally occurring upland vegetation (see Section 6.3.3). Six officials in Bảo Yên District commented on how pest outbreaks in forests and fields were increasingly common since 2005 [BY, KI14, 02.07.2015 – KI19.04.07.2015]. Likewise, a Hmong farmer in Si Ma Cai noted: “I have had a lot of problems with pesticides. There are a lot of insects in my fields. Ten years ago, when I started growing hybrid rice, I did not have a problem with pests and I did not spend money on pesticides” [SMC, H29, 28.06.2015]. Indeed, comparisons can be made to existing literature on the link between intensified irrigated rice production, insecticide use, and pest outbreaks in Southeast Asia (e.g. Way and Heong 1994). Interestingly, of the three disturbances, pest outbreaks have yet to significantly affect LULC decisions among the farmers I interviewed.

To summarize, LULC changes in Lào Cai Province from 1999 to 2014 left the land system, and hence local environments and households, vulnerable to specific threats that included

extreme weather events, market price fluctuations, and pest outbreaks. In the following sections I consider the ‘so what’ box of Figure 6.1, namely focusing on the aggregate impacts of land changes on environmental quality and ethnic minority farmer livelihoods. I begin with an overview of ecological changes inherent with land cover class change (Section 6.2), followed by the results from interviews on environmental change (Section 6.3). I then present results on how LULC change affected household livelihood capitals (Section 6.4).

6.2 Assessing resilience at the provincial scale using landscape metrics

To evaluate changes in resilience from 1999 to 2014 at the provincial scale, I examined the land cover classifications for overall trends in landscape and class metrics. The full results of the analysis are included in Appendix B. Given the vast quantity of metrics, below I present a summary of the overall patterns of landscape change. For easy interpretation, all land cover classes except water are grouped into two groups with similar results: Group 1 including bare soil, shrubs, and open canopy forest, and Group 2 including built-up and closed canopy forest.

Class area and edge metrics revealed an increase in total class area of Group 2 and a decrease in Group 1 (Table B.1). In 1999 shrubs occupied the largest percent of the landscape (46%) and built-up the smallest (0.08%), while in 2014 closed canopy forest (56%) and water (0.6%) were the largest and smallest. In 1999 the largest continuous patch of land cover belonged to the shrubs class which occupied 18% of the landscape and declined to only 0.04% in 2014. The largest patch in 2014 belonged to closed canopy (13%), up from 0.3% in 1999. Likewise, the number of patches and patch density for all classes increased, possibly indicating greater subdivision of patches. The core area index showed Group 1 maintained larger core areas in 1999 than in 2014, while Group 2 and water had larger core areas in 2014. This highlights how the dominant land cover classes, and hence landscape composition, shifted over time as LULC changes were implemented.

Fragmentation, assessed through edge metrics (Table B.1), increases as class edges increase and will lead to changes in microclimate, species competition, and population densities (McGarigal 2015). The ultimate consequence of habitat loss and fragmentation is insufficient habitat quantity, quality, and connectivity to support individuals and viable populations (ibid.). Edge density decreased for Group 1 (bare soil, shrubs, and open canopy forest) meaning that this group became less fragmented. Yet, the largest reduction in mean patch size (also an indication of fragmentation) occurred in shrubs, with decreases in water and the remainder of Group 1

classes. Thus, even though habitat became more uniform in Group 1, the possible benefits of decreased fragmentation may have been offset by a large decline in habitat area. Edge density increased for Group 2 as these classes became more fragmented (built-up and closed canopy forest), with the largest change occurring in closed canopy – likely due to the rapid expansion of forestry in the province. Thus, even though forestry area expanded, habitat quality is likely to have been affected given fragmentation of closed canopy forest cover.

Similarly, the shape, contrast, and core area metrics analyzed highlight patch complexity and aid in the assessment of landscape fragmentation (Table B.2) (McGarigal 2015). The shape and fractal indices indicated that patches became less complex in all classes except built-up and closed canopy forest. The largest change to all five shape indices was a decline in patch complexity of shrubs, which points to the loss of shrubs as a complex secondary land cover. While not quantified directly in this analysis, contrast increased between built-up and other vegetation classes. Fragmentation and core area metrics also have important implications for humans in social-ecological landscapes as greater access to the interior of a patch allows for more rapid land use transformation (Leitão and Ahern 2002).

When considering resilience at the landscape scale, land cover homogeneity undermines resistance to ecological disturbance (Oliver et al. 2015). The radius of gyration was largest for Group 1 in 1999 and Group 2 in 2014 which suggests landscape continuity increased for Group 2. These results are consistent with the contiguity index (measuring degree of patch connectedness, Table B.2) which was highest for Group 1 classes in 1999 and for Group 2 in 2014, with the highest contiguity in bare soil in 1999 (0.89) and closed canopy in 2014 (0.91). Thus, heterogeneity increased in Group 1, with possible benefits to ecological resilience. Yet, of the three Group 1 classes, the bare soil class experienced the largest land use transition as farmers engaged in hybrid rice, maize, and cassava cultivation. Thus, monoculture agriculture is likely to undermine emerging heterogeneity of Group 1 classes. Closed canopy forest, dominated by plantation forestry, became the most homogenous land cover class in 2014, further undermining ecological resilience at the landscape level.

The final group of class metrics analyzed were aggregation metrics which describe ecological properties of dispersion, interspersions, subdivisions, and isolation (Table B.3). Aggregation metrics may be used to understand how ecological disturbances, like pest outbreaks, may move through a landscape (Leitão and Ahern 2002), as classes with greater dispersion and

interspersions facilitate spread. The metric for percentage of like adjacencies isolates class dispersion and indicated higher dispersion in Group 1 and water in 1999 and higher dispersion in Group 2 and water in 2014, with the most significant change to shrubs. Yet, the Interspersion and Juxtaposition Index shows higher interspersions in all classes except water and open canopy forest in 2014, although the coefficient of variation for Euclidean distance revealed that Group 2 is more irregularly distributed in 2014. Greater isolation means greater functional isolation and biodiversity loss. The Proximity Index quantifies isolation and distance between patches of the same class, and indicated greater isolation in Group 1 classes in 2014, with the largest changes in shrubs and bare soil. Similarly, following the Cohesion Index, Group 2 classes were more connected in 2014 and Group 1 classes more connected in 1999.

At the landscape scale, I looked at change in landscape diversity since a key component of maintaining landscape resilience is diversity. The results revealed a decline in the Shannon Diversity Index (1.28 in 1999 to 1.23 in 2014) indicating a moderate loss in landscape diversity. Interestingly, similar work carried in Lào Cai Province showed higher diversity in 2009 (compared to 1999) possibly pointing to a land cover regime shift (Trincsi et al. 2014).

In sum, the patterns of land cover change directly impact ecological function through fragmentation, aggregation, and changes to landscape diversity (Forman and Godron 1986). If landscape resilience can be understood through a combination of heterogeneity, fragmentation, and diversity, the overall effect of land cover changes has been a loss in resilience in all vegetation classes. From 1999 to 2014, closed canopy forest became more homogenous, more connected, highly fragmented, and the dominant land cover class in Lào Cai Province. On the other hand, bare soil, shrubs, and open canopy forest became less fragmented as their overall proportion of area and habitat declined. Yet, land use within these land cover classes, especially bare soil, decreased in diversity. When combining all classes, and observing the landscape as a whole, there was a reduction in overall diversity and leading to a loss of landscape resilience.

6.3 Results of interviews: impacts of land change on the biophysical environment

LULC changes from 1999 to 2014 explored in Chapter 5 have affected the biophysical environment, namely changes to soil conditions, water quality, and biodiversity. Turning to the results of interviews with ethnic minority farmers and government officials, I now examine the impacts of landscape change on biophysical conditions.

6.3.1 Soil

Northern upland Vietnam is no exception to the decline in soil fertility noted in Montane Mainland Southeast Asia from intensified agricultural production (Rerkasem et al. 2009; Ziegler et al. 2009; Saint-Macary et al. 2010). The most cited change by farmer interviewees (n=52) regarding environmental conditions was a drastic decline in soil quality in both plantation forests and agricultural fields. To put it simply: “Every day the soil gets worse and worse” [MK, H16, 14.06.2015]. In agricultural fields, interviewees on both sides of the Red River valley described how a decline in soil fertility began with sedentary agricultural practices, a decline in traditional shifting cultivation following the 1993 Land Law, and the introduction of hybrid seeds.¹³ The aggregate effect of changes to soil fertility, coupled with extreme weather events, has led to a loss in crop yields and an increase in chemical fertilizer application. Farmers noted that when they first planted hybrid seeds they could rely solely on natural fertilizers (such as animal manure) but in subsequent years, manure had to be mixed with increasing amounts of chemical fertilizers. Fertilizers are manufactured in Vietnam or China and are purchased at agricultural centers and markets. In some cases, yields of hybrid maize and paddy rice fell so drastically that farmers I interviewed were concerned about food security. As a young Hmong couple in Si Mai Cai District noted: “We have had problems with hybrid rice not producing enough, or sometimes any, rice. When the plants grow very fast from too much fertilizer they do not produce any rice” [SMC, H29, 28.06.2015]. Likewise, a Hmong farmer in neighbouring Bắc Hà District explained how she no longer grows hybrid rice because the soil is not good enough and instead has reverted to growing local rice [BH, H23, 27.06.2015].

Interviewees also explained that soil quality was declining in plantation forests, although compared to agricultural fields the problem was not considered as severe. In forests with a history of two cycles of clear-cutting (a minimum of 12 years since planting) farmers noted how they must apply fertilizer to young trees, or experiment with intercropping in the first few years of growth to aid soil fertility [BY, T5, 07.07.2015; BY, T8, 09.07.2015]. Interestingly, household and state narratives regarding soil quality differed greatly. In Bảo Yên District I asked every farmer I interviewed (n=25) if they thought soil quality had improved after logging and re-planting a different tree species but not a single interviewee said ‘yes’. For instance, one middle-aged Tày woman explained how she tried planting acacia, cinnamon, and bamboo to improve her

¹³ [SP, H11, 13.06.2015; MK, H13, 14.06.2015; MK, H16, 14.06.2015]

soil conditions but her soil had only become worse [BY, T10, 09.07.2015]. Likewise, a Hmong farmer described how he cut down his natural forest because village officials told him planting cinnamon and acacia would improve the quality of his soil. Now, after transitioning to plantation species, he noted how the forest soil quality was worse, albeit not nearly as bad as in his agricultural fields [BY, H32, 10.07.2015]. In contrast, four Bảo Yên officials commented that there has been an increase in soil quality, possibly pointing to a disconnect between understandings of local growing conditions between farmers and officials. A senior official working for the DARD explained he thought soil conditions improved because locals were continuously changing how they used the land (e.g. planting different species) [BY, KI11, 06.07.2015]. Nonetheless, one former district level official did admit soil quality had worsened, although he concluded it was “because people do not use the land for the right reasons” [BY, T6, 07.07.2015].

6.3.2 Water

Similar to soil quality, farmer interviewees in the districts I visited overwhelmingly noted a decline in water availability and water quality. Drought-like conditions since 2010 have led to dramatic declines of water availability (and therefore crop yields) in streams, for non-irrigated sloping fields, and for irrigated rice fields. While traveling throughout the province – during the usual wet season – I observed many paddy terraces that had been planted with rice in the spring completely dry from a lack of water (Figure 6.2). As an elderly Hmong woman explained:

This year there is not enough rain and many people cannot plant rice. My family has many fields where they did not plant rice. We did not plant anything else because it is too late for the corn. If we wait for the rain, there is no rain. In some places near the river we try to bring the water up to plant rice but I am afraid this year we will have nothing to eat [BH, H22, 27.06.2015].

Similarly, a Yao key informant explained how people in her village increasingly had problems with hybrid seed yields due to a lack of water: “When there is not enough water, the next year the house will grow corn instead” [SP, Y4, 24.06.2015]. Others noted that groundwater levels were low, leading to an insufficient supply of drinking water [SP, Y1, 10.06.2015].

Since 1999, water quality has also been affected by the introduction of hybrid seeds (and hence fertilizers) and timber harvests, with direct implications for human and livestock health. Numerous informants recalled how water was now dirtier and full of runoff chemicals from

agricultural fields.¹⁴ A commune official in Bảo Yên District noted how “the water in the river is really bad because of pesticides from paddy rice” [BY, KI14, 02.07.2015] and another official commented “because people use a lot of chemicals and pesticides the water quality is getting polluted but the buffalo are eating plants with pesticides and growing very fast” [KI5, 02.07.2015]. Likewise, a Hmong woman explained “the water is getting worse because of the pesticides people use for the farm” [BY, H35, 12.07.2015] and another explained, “the water is bad, we have more disease, we must dig wells to get clean water” [BY, H34, 12.07.2015]. In Bảo Yên District, where timber plantations were most developed, farmers also commented on how the water appeared dirtier – an indication of soil erosion and sediment influx.



Figure 6.2 Dried hybrid paddy rice fields in Việt Tiến Commune, Bảo Yên District (Source: Author).

6.3.3 Biodiversity

I found that biological diversity had changed across all land cover types researched. Globally, there are over 100,000 rice (*Oryza sativa*) cultivars with significant potential for within plant diversity, and therefore pest management and insect resistance (Way and Heong 1994). However, with the introduction of hybrid seeds in 1999, rice seed diversity in Lào Cai Province has transitioned from hundreds of locally adapted seed varieties to less than a dozen hybrid seeds, leading to a loss in genetic agro-biodiversity. For instance, a Hmong farmer from Bát Xát District commented on how she had ‘lost’ her traditional wet seed varieties and could no longer cultivate them [BX, H5, 21.06.2015], while a Yao farmer from Bảo Yên District explained: “I stopped using the traditional seed because I lost [the traditional seed]” [BY, Y11, 12.07.2015]. Similar

¹⁴ [KI1, 05.06.2015; BY, T8; 09.07.2015; BY, T10; 09.07.2015; BY, H32, 10.07.2015; BY, H33, 12.07.2015]

declines in biodiversity were observed for hybrid maize and cassava, introduced to Lào Cai Province in the mid to late 2000s. Urbanization further contributed to a decline in agrobiodiversity as former paddy fields became paved surfaces (72km² throughout the province).

These fieldwork results are consistent with landscape metrics which showed a decline in total area and patch size for agriculture. The long-term resilience consequences of the loss of endemic and locally adapted maize and rice varieties remains poorly understood. However, it is clear from interviews that many of these varieties have disappeared and cannot be brought back should hybrid seed varieties no longer provide sufficient genetic diversity. Yet, despite numerous concerns, there were some benefits noted by farmers of hybrid varieties including resilience to strong winds and most importantly, increased yields (under appropriate agro-ecological conditions). As a group of Hmong vendors explained: “We have had success with hybrid rice and our families do not go hungry compared to before when the wind would blow [traditional] rice down” [SP, H10, 13.06.2015].

A decline in diversity arose for other woody vegetation land cover classes. There was a large reduction in habitat area in open canopy forest and shrubs (54% and 66% respectively), which indicates a loss in ecologically complex secondary forests and shrubs. The landscape metrics also revealed that shrubs became significantly more isolated in 2014 with direct consequences for biologic diversity and household security. For instance, a plot-level analysis in the Central Highlands revealed that a 50mx2m plot of shrubs contained 22 species and 168 plants, all with important local livelihood uses such as fuel wood, income, medicine, construction material, or food and fodder (McElwee 2009; 2016). My interviews uncovered that many households would rather plant plantation tree species on their land than have ‘barren land’, raising concerns for long-term genetic diversity of non-woody species.¹⁵ However, enthusiasm for plantation forestry was limited to households who have had success in generating income from timber already, as those who have not yet experimented with this cash crop remain distrustful of state reforestation schemes [SMC, H20, 27.06.2015; MK, H16, 14.06.2015].

Similarly, forests have transitioned from a network of old-growth and highly diverse secondary forest prior to 1999 to primarily plantation forests, dominated by only a few tree species (Table 5.5). As detailed in Chapter 5, the species of tree planted varied depending on classified forest type (e.g. production or special use forest), the program the tree was planted

¹⁵ [BX, H8, 21.06.2015; BY, T9, 09.07.2015; BY, Y9, 10.07.2015, BY, Y10, 10.07.2015]

under (e.g. a PES project or Program 661), and local officials. While the habitat area for closed canopy forest expanded, the majority of tree varieties selected – such as acacia – are not native to Vietnam and are not adapted to local biophysical conditions, which affects the ability of these trees to withstand disease (McElwee 2016). Closed canopy forest also became more connected which facilitated spread of pests. Low diversity was actively maintained as farmers described applying chemical fertilizers and pesticides to naturally regenerated vegetation or removing it.¹⁶ However, the proliferation of plantation forests on relatively short (six to ten year) harvest cycles did lead to rapid carbon sequestration, which contributed to global carbon budgets and Vietnam's emerging PES program.

On the other hand, interviews revealed that in forested areas that remain dominated by native species, forest quality was affected by the overharvesting of NTFPs, such as orchids and medicinal herbs, for cash income. As one Hmong farmer explained:

People in my village take a lot of things out of the old forest, especially medicine and orchids. They bring them to sell in Sa Pa: the orchids starting four or five years ago, and the medicine starting two or three years ago. The government allows them to take these things out. They do not protect it because it is inside the cardamom fields or other grassy products. The government only cares about the wood [MH, H8, 21.06.2015].

A group of Hmong women also noted that around 2000, Hmong farmers over-harvested a range of NTFPs and the quality of forest in Hoàng Liên National Park declined so drastically they became concerned about how they would continue to sell NTFPs. Yet, despite their increased awareness, since 2000 the quality of the forest has not improved [SP, H10, 13.06.2015]. The women also described that there “are only a few animals in the forest now, mostly monkeys, but it does not matter because the government will not let us have guns” (ibid.). Two Yao vendors also explained how forest quality decreased because “trucks from Hanoi come to Sa Pa District, fill up with forest products and drive back to Hanoi” [SP, Y1, 10.06.2015]. Thus, the demand for NTFPs in the lowlands had a considerable impact on species diversity in the uplands.

To summarize, LULC changes in Lào Cai Province had direct implications for the biophysical environment. At the provincial level, 12 percent annual reforestation and increased connectivity between land cover classes facilitated rapid carbon sequestration and the appearance of biological corridors in closed canopy forests. While imperceptible on land cover maps, at the

¹⁶ [BY, T5; 07.07.2015; BY, T8; 09.07.2015; BY, Y10, 10.07.2015]

household scale, ecological changes were deemed by interviewees to be primarily negative. Farmer interviewees experienced declines in soil quality, water quality, water quantity, biodiversity, and became increasingly vulnerable to disturbances (outlined in Section 6.1). Either due to or despite such declining environmental conditions, land changes have resulted in a change in livelihood strategies. In turn, these new livelihood strategies helped to foster livelihood resilience for some farmer households as explained in the following section.

6.4 Results of interviews: impacts of land change on livelihood resilience

To understand changes to the social aspects of the SES researched in Lào Cai Province, I draw on Speranza et al.'s (2014) conceptualization of livelihood resilience. Similar to the sustainable livelihoods definition, a livelihood is considered resilient if it “can maintain its key functions (food, income, insurance, poverty reduction, etc.) and absorb the impacts of *disturbances* without causing major declines in production and well-being” (Speranza et al. 2014, 111). I focus here on the interactions between LULC changes and changes to household assets in Lào Cai Province. I draw on interviews with state officials and Hmong, Yao, and Tày farmers to describe changes in human, social, natural, physical, and financial capitals, and highlight households’ abilities to respond to disturbances, such as extreme weather events, market price fluctuation, and pest outbreaks.

6.4.1 Changes to livelihood capitals

Here I focus on four of the five capitals of the livelihood capital pentagon, human, financial, physical and social capitals, since changes to natural capital have been discussed in depth in Section 6.3. In short, I found that soil quality declined, carbon sequestration increased with large scale reforestation projects, runoff and erosion increased from tree plantation harvests, pest outbreaks were on the rise, and biodiversity declined.

6.4.1.1. Human capital

The land use changes I have analyzed involved changes to human capital, including knowledge, experience, skills, and health conditions among Hmong, Tày, and Yao farmers. Rapid environmental changes, such as increasing extreme weather events, and the introduction of the hybrid seed programs, mean farmers have had to adapt to and learn how to cultivate new crops in constantly changing agro-ecological conditions. Many farmers explained that as they transitioned to new agricultural and forestry opportunities they were still experimenting with what worked and what did not [BX, H6, 21.06.2015]. In general, Hmong and Yao households did not feel

equipped nor prepared to manage their new environment. As one 60-year-old Hmong woman bluntly explained: “We are Hmong and do not know how to do anything” [BX, H3, 07.06.2015]. Farmers felt particularly vulnerable to changing weather conditions as two Hmong women from Sa Pa District commented that they were unable to do anything to prepare for/reduce future weather-related vulnerability because they did not have the knowledge or financial capital [SP, H11, 13.06.2015]. A Yao interviewee likewise exclaimed: “We have not done anything to prepare for future water loss and we are worried” [SP, Y1, 10.06.2015]. Yet at the same time, three district and commune level officials in Bảo Yên District stated the biggest overall change in local livelihoods since 1999 was an increase in modern agricultural knowledge of the locals.¹⁷

Nonetheless, agricultural modernization has resulted in lost cultural knowledge associated with traditional crop cultivation, such as knowledge of seasonal crop calendars and seed saving practices. As hybrid seeds and plantation forest became the norm, knowledge of seed saving techniques and traditional medicinal practices were lost as the youngest generation learns new livelihood strategies for this frontier environment. For instance, a few interviewees explained that a member of the eldest generation was responsible for seed saving practices since the youngest generation had come to rely on hybrid seeds [KI1, 08.06.2015; BY, T1, 07.07.2015].

As land cover became increasingly urbanized with urban expansion and new transportation routes, access to local primary and secondary level education and even university education drastically increased. Seven ethnic minority households that I interviewed had children attending university. However, for the most part, graduates were unable to find ‘modern’ jobs upon returning home as one retired district official explained: “There are five people in university in this village alone. When they come back it is very hard for them to find jobs” [BY, T7, 08.07.2015]. More immediately, households relocated away from paddy lands because of urban expansion were unable to cope with their loss of agricultural livelihoods. As a key informant explained: “Once relocated the ethnic minority farmers do not have anything else to do for work. Farming is their knowledge, their experience, they are not educated” [KI14, 16.04.2016]. Hence, while state-sponsored development projects improved access to knowledge and skills for some, many informants were not confident in new knowledge, and were concerned about a loss in traditional agricultural and cultural practices.

¹⁷ [KI2, 01.07.2015; KI4, 02.07.2015; KI9, 04.07.2015]

6.4.1.2. Financial capital

The rise of cash crops and increased market access has led to intensified agricultural outputs, new commodity opportunities, and increased labour demand, securing additional financial capital for many households. For instance, Yao households I interviewed who propagated orchids for Kinh traders made nearly 5000USD/year and a business-savvy Tày woman explained how she could make 1350USD/year from a general store, in addition to income from cassava sales and plantation trees. Selling in markets also yielded high incomes, and a Hmong interviewee noted he could earn 225-403USD/day vending agricultural chemicals from China in Bắc Hà market [SMC, H27, 28.06.2015], while a Hmong woman vending Chinese household products could make 90USD/day [MK, H16, 14.06.2015]. Households in border districts also took advantage of cross-border opportunities during the winter months such as working in banana plantations in China, or purchasing Chinese textiles for Hmong New Year [H5; H6; D1; H23; H29; H13; Y4]. Similarly, tourism created opportunities for cash generation such as becoming a tour guide, running a homestay, selling embroidered textiles, and operating medicinal baths. For instance, Yao medicinal bath houses in Sa Pa District made 1350USD/month by providing hot-tub-like baths to tourists [SP, Y5, 24.06.2015]. Yet, ethnic minority women were unable to work legally as tourist guides without a license, which is costly and difficult to acquire [KI1, 08.06.2015; SP, Y4, 24.06.2015]. Thus, many tour guides were forced to work illegally, or for a tourism company for a fraction of the possible profits (ibid.).

Not all households benefited from hybrid seeds, cash crops, and other cash-generating opportunities from 1999 to 2014. As one Hmong farmer remarked: “I have some maize fields but I no longer use them because I do not have enough money to buy fertilizer” [BX, H5, 21.06.2015]. Likewise, livestock diseases in the districts where I completed fieldwork resulted in a loss of important household savings, with 12 households explaining that they had lost numerous livestock since 1999. While diversifying assets made households more resilient, those who emphasized cash-generating activities were still vulnerable to market prices fluxes and extreme weather conditions. As a Hmong woman explained:

I used to harvest 100 to 300kg of cardamom but lately the snow killed the plants and it is not as good as before. Lately I can only get ten or 20kg. Before when I had big harvests I could buy clothes, fertilizer, seeds, and motorbikes. Now I must work in the market to buy those things” [BX, H8, 21.06.2015].

Likewise, a Yao informant described how many Yao households were involved in cardamom

production, but when yields declined due to poor weather conditions three to five years ago, most households diversified their livelihoods and started growing orchids instead [KI2, 20.06.2015; SP Y2, 13.06.2015]. Hence while opportunities to gain financial capital were on the rise, they were not evenly distributed over space or available to all farmers.

6.4.1.3. Physical capital

As some ethnic minority household incomes rose from 1999 to 2014, these households could increase their physical capital, such as machinery, buildings, and equipment. Nearly every household I interviewed had at least one motorbike, purchased between 1995 to 2010. Near universal access to motorbikes, coupled with upgraded road networks, created a positive feedback loop whereby households could travel further distances to increase other livelihood assets, namely financial capital. Several Hmong traders I spoke with travelled to three or four markets each week to sell agricultural and household supplies purchased once a week in China - a livelihood practice that would not have been possible without road infrastructure and transport improvements. In Bảo Yên, two Tày and Yao households used extra income to purchase trucks to use for small agricultural export businesses [BY, Y7, 07.07.2015; BY, T9, 09.07.2015] and a Yao farmer described how people in her village were using income from orchids to purchase machines to aid with plowing fields [SP, Y2, 13.06.2015]. Monetarily wealthy households had access to many modern items including cell phones, televisions, and farm machinery [observations], while poorer households relied on resources (e.g. bags of rice and warm blankets) distributed by village officials, although distribution was often unfair and based on social connections [SP, Y5, 24.06.2015; SMC, H28, 28.06.2015].

Of note, increasing extreme weather events since 1999 have led to damage of physical capital, such as a hail storm that damaged many buildings in Mường Khương [MK, H14, 14.06.2015; MK, H16, 14.06.2015] and landslides that destroyed crop fields in most districts I visited [KI1, 07.06.2015; SP, H11, 13.06.2015]. Interviewees were also concerned about population growth and declining land availability [SP, Y4, 24.06.2015; SP, Y1, 10.06.2015]. Shrinking farm sizes prevent fallow and soil restoration, and can ultimately threaten the productivity and insurance capacity of the agro-ecosystem (Tiftonell 2014). Nonetheless, three Tày and Yao interviewees in Bảo Yên District with financial capital from forestry and cash crops were able to purchase additional land to generate more income. Overall, most households

experienced a gain in physical assets from 1999 to 2014, which may be linked to improving market access and opportunities.

6.4.1.4. Social capital

Shared knowledge and experience can improve coping strategies and increase resilience for rural farmers (Cumming 2011b). As noted in Section 5.3.2, households that I interviewed are increasingly drawing on social capital to make land use decisions. For example, one Tày couple decided to experiment with a small cinnamon plot because their friends had success selling the bark [BY, T9, 09.07.2015]. Another young Hmong woman from an isolated village in Si Ma Cai District explained how she began selling NTFPs, primarily medicinal herbs, at the Bắc Hà market because her neighbours were successful in selling similar products [SMC, H28, 28.06.2015]. Likewise, a Tày farmer actively encouraged her neighbours to switch to plantation trees so they could earn more money [T1, 07.07.2015]. Farmers also drew on social networks in times of need to improve livelihood conditions. For instance, a Tày farmer from Bảo Yên District described how kin relied on each other to illegally harvest wood from the small remaining areas of natural forest [BY, T2, 02.07.2015]. Hmong vendors commented on social security networks as they explained: “Our income from selling to tourists is not good because we are in the new market. We must ask family for help to buy food and fertilizer” [SP, H10, 13.06.2015]. While the availability of social capital has not changed much from 1999 to 2014, farmers were increasingly drawing on this resource as they coped with disturbances and adapted to land use opportunities.

6.4.1.5. Summing up changes to livelihood capitals

Overall, there were several important changes to upland household livelihood assets as land use practices in Lào Cai Province changed from 1999 to 2014 (Figure 6.3). Ultimately, livelihood resilience in this region depends on household-specific factors, including ethnicity, size of household, land access and size of land holdings, access to assets and infrastructure such as roads and marketplaces, and willingness to experiment with new opportunities. The vast majority of households I interviewed expanded their livelihood portfolios. The most noticeable change I uncovered has been by a cash-generating pathway, through cash crops and collection and sale of NTFPs, which led to an increase in financial capital and permitted an expansion of other capitals, such as knowledge through education, and physical assets. Since 1999, forestry activities have become an increasingly important livelihood activity in Lào Cai Province, with financial benefits to the rural poor, but with long-term implications for natural capital that may undermine

resilience in the future. Importantly, not every household engaged in these opportunities equally and many were still struggling to meet basic income and food security needs.

6.4.2 Emerging livelihood strategies

Returning to the definition of a resilient livelihood outlined at the beginning of Section 6.4, from 1999 to 2014 many informants experienced a significant change in ‘livelihood function’ due to frequent disturbances. As extreme weather shocks increased in frequency and led to irreversible changes to household assets, including damage to physical capital and loss of natural capital, households faced declines in livelihood resilience. While households remained vulnerable to market prices, I did not interview any who experienced a loss in key livelihood function because of price fluctuations. Likewise, pest outbreaks have affected most households, either through farm or forestry activities, although they have not yet drastically altered livelihoods.

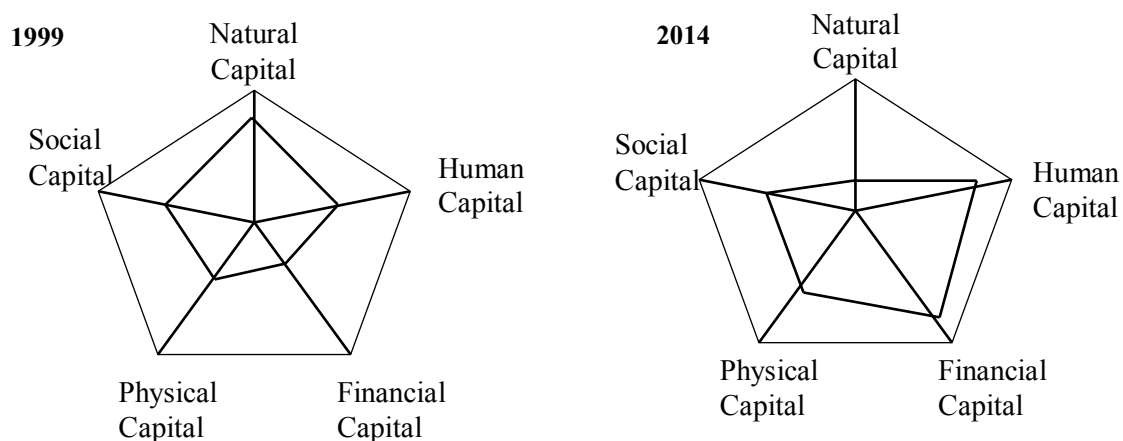


Figure 6.3 Asset pentagons representing changes in typical Hmong and Yao livelihoods drawing on interviews.

Yet, the line between stress and shock, and between disturbance and threshold are not always clear, as a stress for one household may be a shock for another (Marschke and Berkes 2006). My interviews revealed that households either specialized or diversified LULC to support livelihood resilience, with the strategy pursued varying amongst households (Table 6.1). Those who engaged in resource specialization were more vulnerable to price and ecological disturbances, while those who diversified maintained greater household resilience to all three disturbances. In the future, as greater stress is placed on the ecological system, namely a loss in genetic plant diversity, soil quality, and water quality, the sustainability of specialized livelihood activities will come further into question.

Overall, there were numerous changes to rural minority livelihoods in the province from 1999 to 2014. While change in assets was household specific, my research uncovered patterns that included an increase in access to formal or ‘modern’ knowledges (formal education and agricultural techniques), countered by a loss in traditional ecological knowledge. There was also an increase in financial and physical capitals as profits from cash crops rose, a decline in natural capital, and a strong reliance on social networks when making land use transitions. Most households engaged in intensification or diversification of their resource base to promote resilience, with many turning to plantation forestry as a livelihood strategy.

Table 6.1 Livelihood strategies by resource sector.

Resource activity	Activities	Impact on household resilience
Agriculture	• Diversification with cash crops including rice, corn, cassava, cardamom, pineapples, bananas • Some specialization in hybrid varieties and other crops depending on biophysical conditions and ethnicity • Partial return to dry rice and traditional rice varieties to maintain food security	• Specialization increases vulnerability to all three disturbances (extreme weather, market prices, pests) • Diversification increases household resilience
Forestry	• Planting small number of seedlings, often given freely by officials • Large-scale planting as dominant livelihood strategy	• Small-scale planting decreases ecological vulnerability • Large-scale planting increases vulnerability to timber price flux and ecological disturbance
Non-farm	• Engaging in tourism activities, market vending, acting as agricultural intermediaries, working as hired labourers	• Increases household income diversity, hence resilience

6.5 Livelihood strategies to foster land system resilience

Focusing on the ‘now what’ aspect of resilience (Figure 6.1), I turn to: (1) how transforming structures and processes inhibited or promoted social-ecological resilience, and (2) the various strategies households used to foster livelihood resilience. My evidence suggests that state resilience planning is, in most cases, short-sighted. Since the introduction of hybrid seeds, the state altered seed varieties available in agriculture distribution centres to adapt to pest outbreaks and improve yields [KI1, 07.06.2015]. Likewise, as tree species varieties proved unsuccessful in improving soil fertility, the primary initiative laid out by the DARD was the introduction of

alternative species, often with the same results. For example, when reforestation initiatives began in Bảo Yên around 2000, primarily benzoin was planted, however, by the mid-2000s households planted almost entirely acacia to aid in soil fertility [KI8, 03.07.2015]. As fertility declined under acacia forests, the state endorsed cinnamon and cassava around 2013 to help farmers improve fertility. Yet, as previously noted, not a single farmer interviewed in that district (n=25) observed improved soil conditions. These outcomes highlight how state narratives were often short sighted, did not foster long-term resilience, arguably increased vulnerability to disturbances, and were used as a tool for ‘environmental rule’ (McElwee 2016).

To increase livelihood resilience, the state placed a focus on rural development programs, including infrastructure upgrading (e.g. roads, schools, electricity), provision of tree seedlings, irrigation projects, and primary education. Two programs that interviewees cited (n=9) as having important impacts on livelihoods since 1999 were Program 134 (support for production land) and Program 135 (the Program for Socio-Economic Development of Extremely Difficult Communes in Ethnic, Mountainous, Boundary and Remote Areas), introduced in Section 3.4. According to officials, social programs were highly successful in “making the lives of the locals better” [KI4, 02.07.2015], and were “very effective for locals” [KI7, 03.07.2015]. District and commune level officials maintained that the best way to improve livelihood conditions further was additional support in the form of pesticides, seeds, and increased agricultural specialization.

To maintain forest diversity and combat pest outbreaks, there were several provincial plans to protect remaining natural areas through the designation of ‘special use’ forests, such as Hoàng Liên National Park, spanning Sa Pa and Văn Bàn Districts. However, how effective special use forests were at maintaining endemic diversity may be debated, since timber in the mountainous regions of Sa Pa District was heavily harvested by SFEs prior to the 1990s (McElwee 2016). Efforts also included engaging ethnic minority farmers in biodiversity protection projects. One key informant, working at the provincial level in the Department of Culture and Tourism, explained how forest was better protected in locales where ethnic minorities had spiritual beliefs related to forests. Hence, the province was working with these villages (specifically in Bát Xát District) and UNESCO to understand the relationship between humans and ecology, and the role of traditional knowledge in forest management, to further encourage conservation and protection in Lào Cai Province [KI10, 04.07.2015] (Tran 2014). At the district and commune levels, there was less long-term planning with regards to diversity and

more emphasis on the short-term management of pest outbreaks. For instance, in Việt Tiến commune of Bảo Yên District, local officials decided to cut a physical barrier around plantation forests to prevent disease spread from neighbouring communes [KI4, 02.07.2015].

Many households I interviewed coped as disturbances occurred (e.g. applied pesticides to one species of rice), rather than adapted to ongoing disturbances (e.g. planted many species of rice to promote genetic diversity and prevent outbreaks), although adaption responses appeared to be increasing in frequency. To combat the impact of disturbances, many households engaged in land use diversification or intensification. Interviewees noted instances where state-sponsored hybrid seeds were ill-adapted to their field conditions and their household experimented with alternative crops, like corn or beans, as an adaptation strategy. Alternatively, a handful of farmers returned to traditional seeds to maintain livelihood security and offset the risks to extreme weather. For instance, some Hmong households I spoke with, particularly in Bắc Hà and Si Ma Cai, increased the number of landrace rice varieties they planted in the last three years, with the intention of continuing if dry weather conditions continue to make hybrid paddy rice cultivation difficult.¹⁸ The added benefit of dry rice is that it does not require chemical inputs and is relatively low maintenance compared to hybrid paddy rice varieties, and unlike hybrid seeds, costs do not increase each year (Turner et al. 2015). Dry rice may also provide a possible income opportunity. A Hmong woman from Bắc Hà explained that she continued to cultivate local dry rice despite lower yields because it tasted better and she could sell it to many households in her village who had abandoned this practice [BH, H24, 28.06.2015].

Forest diversification was another strategy used by Hmong, Yao, and Tày farmers to foster long-term resilience. In communes with little natural forest, some households invested time into creating more diverse forest plots. A Hmong woman explained how “the government told me to save forest so I started to go to the old forest to get plants to bring to my forestland” [MK, H8, 21.06.2015]. Likewise, a 68-year-old Tày farmer I spoke with explained how “when a lot of trees are cut down in the old forest I will go there to get seedlings and bring them to my garden to protect them” [BY, T1, 07.07.2015]. Yao farmers who collected significant quantities of medicinal herbs also ensured that they gave plants sufficient time to regenerate to protect the quality of their forests [KI2, 24.06.2015]. Likewise, a Yao interviewee described how the

¹⁸ [BH, H23, 27.06.2015; BH, H24, 28.06.2015; BH, H26, 28.06.2015; SMC, H28, 28.06.2015; SMC, H29, 28.06.2015]

cinnamon tree seedlings available in Bảo Yên District were only one variety. However, the seeds available in neighbouring Yên Bái Province have a higher oil content which she prefers, so she traveled to Yên Bái to purchase a handful of seedlings [BY, Y7, 07.07.2016].

Other adaptation strategies used by households I interviewed included increasing fallow length, experimenting with new crop locations, and migration-based strategies. To adapt to declining soil quality, households across ethnicities with sufficient land allowed their fields to go fallow with naturally regenerating plants for one or two years to aid in soil fertility – a strategy that works well in current upland conditions [SP, H11, 13.06.2015]. By experimenting with new crop locations, households could maintain or expand crop varieties. For instance, a Hmong couple I spoke with commented on how households in their village moved cardamom plants within old forest areas to protect them against snow [SMC, H29, 28.06.2015]. By moving plants into gullies, cardamom cultivators were able to buffer against extreme weather by preventing significant snow build up in the winter, and ensure sufficient water availability in the summer.

Although, in many cases, extreme weather events decreased the resilience of households, they also created opportunities. Warm temperatures and dry conditions expanded the range of crops traditionally grown at lower elevations and lower latitudes. In high elevation regions of Mường Khương increasing warm temperatures have expanded the range of area suitable for pineapple and banana cultivation [KI1, 14.06.2015; MK, H7, 21.06.2015]. In other highland communes, some farmers considered planting two rice crops per year instead of one, provided there is sufficient water– although this strategy has not yet been put in place [KI1, 27.06.2015]. As noted in Section 6.4.1, households also engaged in migration strategies, namely working as hired labourers in construction projects, working on plantations in China, and traveling to several upland markets a week, or sometimes even a day, to maximize financial returns.

Resistance-based strategies were also used to cope with land changes and government restrictions. Although highly discouraged by local officials, households in remote regions of the province engaged in shifting cultivation, primarily for root vegetable production [SMC, H28, 28.06.2015; BY, H30, 10.07.2015]. Illegal wood harvesting for construction timber and for sale on the black market occurred regularly, as a young male Tày farmer from Bảo Yên described how kin illegally harvested wood from the remaining areas of natural forest [BY, T2, 07.07.2015]. In Sa Pa town where ethnic minorities were banned from engaging in stationary trading to tourists along the main streets (except for two evenings a week in specific locales),

some were overtly resisting by engaging in mobile tourism activities (Turner and Oswin 2015). In Bắc Hà market, officials patrolled for vendors selling Chinese pesticides and fertilizer as these items are banned [KI1, 28.06.2015]. To avoid being fined, vendors sold packages from concealed bags [observations; SMC, H27, 28.06.2015]. Finally, around Lào Cai city, households displaced from urban expansion relied on illegal urban gardening. As a key informant explained:

When farmers were relocated to vacant land that was under construction – they borrowed this land and tried to cultivate it. They take advantage of any vacant land because they don't have anything else to do. This is their only livelihood and they are counting on that. It is urban agriculture. Even if there are sidewalks, even if it is just a small tree, they plant it. [KI14, 16.04.2016].

Despite the above ad-hoc strategies, households were still uncertain and wary about the future. Apart from a Lào Cai city climate action resilience plan (M-BRACE 2014), I did not find evidence that there was long-term resilience planning, either by households or the state.

6.5 Chapter conclusion

Land changes in this frontier environment have impacted social-ecological resilience. I have shown through landscape metrics and interview analyses how LULC changes have greatly undermined ecological resilience. At the landscape level, there was a loss in land cover diversity from 1999 to 2014. Landscape metrics also pointed to an increase in connectivity in closed canopy forest and built-up areas, while the remaining vegetation classes experienced a reduction in habitat size and edge effects. An accumulation of biophysical changes has resulted in declines in crop yields, water quality, and genetic diversity. Land changes were connected to changes in household livelihood portfolios, which both diversified and specialized with respect to land use decisions. Livelihood resilience has been impacted negatively predominantly by extreme weather events, although there were noted vulnerabilities to market price fluctuations and ecological disturbances. State departments largely responded to household resilience changes through limited actions, such as sometimes providing different hybrid seed varieties; while households responded to changes in land system resilience mostly through short-term adaptation mechanisms which focused on specialization. I argue that the aggregate effect of such adaptation strategies is short sighted and has ultimately led to an overall decline in the ability of the system to cope with ongoing disturbances. Next, I analyze these changes in detail in the case of Bảo Yên District, and highlight how space and ethnicity greatly influenced land change and resilience outcomes.

CHAPTER 7 CASE STUDY ON LAND CHANGE AND RESILIENCE IN BẢO YÊN

Drawing on the results of Chapters 5 and 6, in this chapter I present a case study of Bảo Yên District. I demonstrate how there were several marked differences in the drivers and outcomes of land change across small regions of space and consequently, how the outlook for social-ecological resilience varies. I begin with an overview of Bảo Yên District, including biophysical and social-economic conditions. I then examine the primary LULC changes, drawing on land cover maps, interviews, and rural land use survey (RLUS) data, before turning to an in-depth look at three case-study communes. Overall, I found that plantation forestry emerged as the dominant industry in Bảo Yên and the case study communes demonstrate how land use planning, market access, and ethnicity were primary forces shaping household and state decisions. I conclude with a discussion on the outlook for the SES in Bảo Yên, and closely examine the role of land use intensification in promoting and/or hindering resilience.

7.1 Overview of Bảo Yên District

Bảo Yên District is in south-eastern Lào Cai Province. The average slope is 19.4° and the average elevation is 333m (STRM DEM). The dominant ethnic group is Tày (35%), followed by Kinh (25%), Yao (25%), and Hmong (24%) (GSO 2011). I interviewed ten district and commune officials and twenty-five ethnic minority farmers in Bảo Yên. There are 17 communes, of which I visited seven (due to permissions and access restraints): Điện Quan, Long Khánh, Long Phúc, Nghĩa Đô, Phố Ràng, Vĩnh Yên, and Việt Tiến (Figure 7.1).¹⁹ While traveling between communes I could observe land use near roads, and discuss observations with key informants, RAs, and police escorts traveling as part of my field team.

7.2 Primary land use, land cover, and livelihood changes in Bảo Yên District

Land cover changes in Bảo Yên District mimicked trends seen across Lào Cai Province in Chapter 5, such as a decline in shrubs, open canopy forest, and bare soil, as well as an increase in closed canopy forest and built-up areas (Figure 7.2). The main differences in land cover change and livelihood change between Bảo Yên and other districts where I completed fieldwork was the rapid proliferation of plantation forestry since 2000, planted by both SFEs and households. Of the nine districts in Lào Cai Province, my calculations revealed that Bảo Yên had the second largest increase in forestry from 1999 to 2014 (3270%) following Mường Khương District (4088%), which also maintains an active plantation forestry industry (Sandewall et al. 2010). My

¹⁹ All interviewee IDs in this chapter are from Bảo Yên District unless otherwise noted.

interviews revealed that there was little forest planted for protection and management, rather most plantations were designated as production forests. In the early 2000s, Programs 661 and 327 were widely implemented in the district whereby initially benzoin was planted, followed by acacia [KI4, 02.07.2015; T5, 07.07.2015; T6, 07.07.2015]. An official from Long Phúc commune noted that in 2014 forest area was 8:1ha of state owned versus locally owned [KI6, 02.07.2015].



Figure 7.1. Location of communes visited and case studies in Bảo Yên District.

Cinnamon cultivation in Bảo Yên far exceeded other districts I visited, due to favourable biophysical conditions and the agenda of District officials to make Bảo Yên the primary cinnamon exporter for Vietnam [KI11, 06.07.2015]. DARD calculations reported that in 2014, 42km² of the district were dedicated to cinnamon plantations, representing ten percent of closed canopy forest cover. One senior-level official from the DARD remarked: “Before 2005 we grew many trees – acacia, benzoin – and from 2005 we started growing cinnamon to take the oil” (ibid.). There were two species of cinnamon cultivated: *Cinnamomum Aromaticum* (Saigon cinnamon) cultivated primarily for essential oil, and *Cinnamomum Loureiroi* (Chinese cinnamon) cultivated for spice (ibid.). While some households planted cinnamon as early as 1994 [T9, 09.07.2015], most cultivation began in 2013 when a PES program was implemented at the

district level whereby households were given free seedlings and cash if they allocated 85 percent of their forestland to cinnamon trees. Cinnamon oil is exported to Korea, China, and Japan where it is refined and exported at a higher price to the international community [KI11, 06.07.2015].

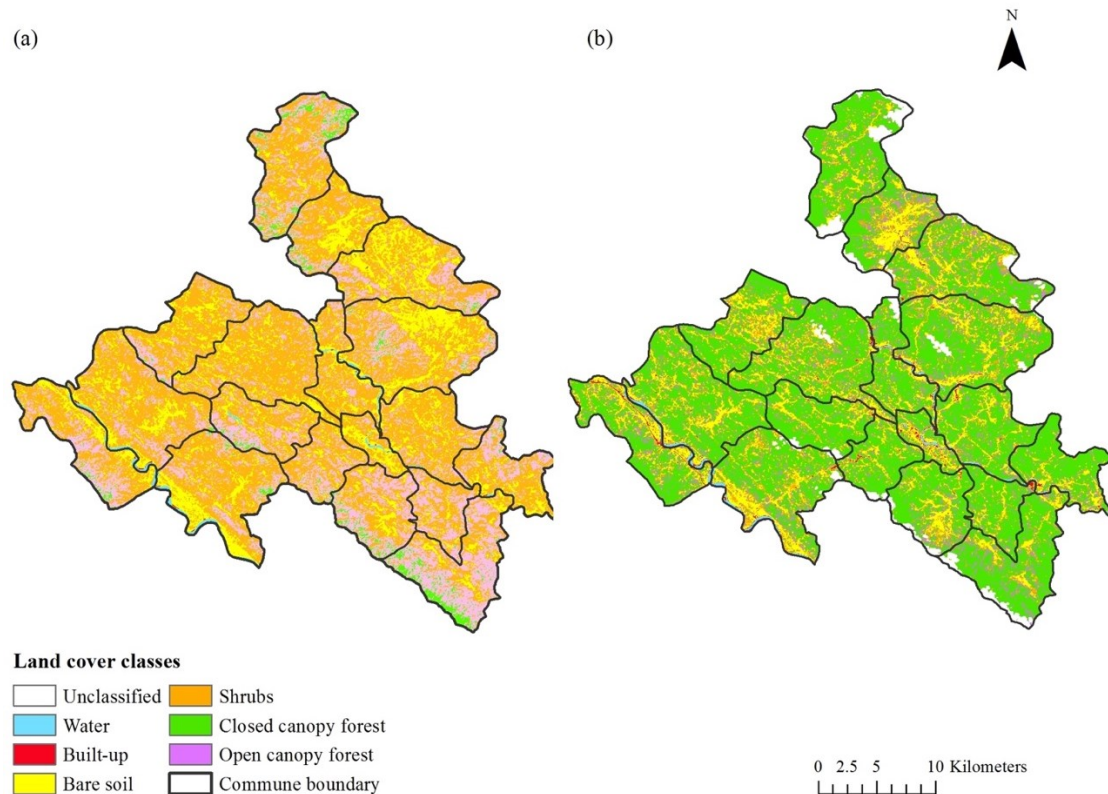


Figure 7.2 Land cover in Bảo Yên District in (a) 1999 and (b) 2014.

Provided a household had sufficient forestland leases, cinnamon made a lucrative livelihood investment. Since it is a slow-growing tree, the first few years of growth can be intercropped with cassava, grown as a cash crop [T5, 07.07.2015]. As a Tày farmer explained: “Before we had to depend on the farm for food. Now we depend on the farm for cinnamon and cassava” [T10, 09.07.2015], while another commented: “Plantation trees are much better than farmland because food and clothes money is provided. We depend on the wood for life” [K1, 07.07.2015]. Beyond seedlings distributed for free, to purchase additional cinnamon seedling from state nurseries cost only 0.04USD/seedling, while household income from cinnamon bark reached up to 5000USD/year [T9, 09.07.2015].

To facilitate commercial forestry interests, there are two large and 44 small-scale timber and oil processing plants in the district (RLUS 2011) (Figure 7.3). In Long Phúc commune a state-owned wood processing facility was used to regularly process wood from 25km² plots from

each commune owned by the district SFE: The Bảo Yên Forest Company (425km² from the district, representing 85% of closed canopy forest); and some acacia, benzoin, bamboo purchased from locals [KI11, 06.07.2015]. There is also one large state-run cinnamon factory that opened in Tan Duong commune in 2012, while the state plans to construct two additional cinnamon facilities in the future (ibid.).



Figure 7.3 Small scale wood processing and drying facilities (Source: Author).

The second largest land cover change in Bảo Yên District from 1999 to 2014 was a 744% increase in built-up areas. Compared to other districts in Lào Cai Province there were few large-scale infrastructure projects, and Bảo Yên had the lowest urbanization rate. By examining Figure 7.2, it is evident that urban growth was fragmented, predominantly along transportation corridors. This was likely due to highly active development programs including Programs 134 and 135 [KI4, 02.07.2015; KI11, 06.07.2015]. However, tourism may also be accountable for urban growth. Increased tourism infrastructure in Bảo Hà commune and the recent completion of the highway linking Hanoi to Lào Cai, permitted Kinh tourists to travel to the commune to visit a well-known Buddhist temple [KI10, 04.07.2015]. In the future, there are also plans from the People's Committee of Lào Cai to implement a homestay based tourism hotspot in Nghĩa Đô commune, a picturesque region of paddy-rice and steep mountains, because it is on the way to Hà Giang, another province becoming increasingly popular for tourism (ibid.).

Agricultural intensification and cash-crop production was wide-spread in the district, likely due to favourable slope and transportation conditions. When asked “what is the biggest change in Bảo Yên since 1999?”, three out of ten officials identified that knowledge of the locals

had improved.²⁰ Specifically, farmers appropriated and learned how to use upland technology to improve market-oriented agricultural processes. As a result, there were significantly more agricultural sales than before, especially for buffalo, rice, corn, tea, cinnamon, and fruit. Two representatives from the DARD noted that the most frequently adopted agricultural change since 2000 was the introduction of ‘high-quality’ seeds and the specialization of agricultural production in the communes [KI11, 06.07.2015]. The majority of household rice fields were able to produce two crops of paddy rice each year, due to favourable biophysical conditions, with notable exceptions in high slope regions of Vĩnh Yên commune. According to locally-produced calculations, in 2014 there were 3000ha of maize and 5700ha of paddy rice cultivated in Bảo Yên District (ibid.). Officials noted that there was no longer dry rice cultivation since it was greatly reduced in 2000 and eventually eliminated in 2009 because “dry rice is very slow to cultivate so the government made plans to change to seeds with higher yield production” (ibid.). Officials noted that dry rice was replaced with paddy rice cultivation (for household food needs) or plantation forestry (for income to buy food) [KI9, 04.07.2015]. Starting in 2000, households who were unable to successfully implement a transition from shifting cultivation were given 675USD/household to develop new areas for paddy cultivation [KI11, 06.07.2015]. However, Hmong farmers I spoke with mentioned that there were still small areas under cultivation [H30, 10.07.2015; H32, 10.07.2015].

Compared to other districts I visited, Bảo Yên had substantially more cassava. Hybrid varieties of cassava were introduced in 2011 and most cassava cultivated was exported to China for around 0.22USD/kg through agricultural intermediaries. In China, the cassava is dried and made into biofuel, animal feed, and candies [T4, 07.07.2015; H34, 12.07.2015]. Farmers described how cassava became profitable with hybrid varieties and upgraded roads, and some have purchased additional agricultural land to increase production.²¹ Cassava as a cash crop could be surprisingly profitable for ethnic minority households, especially since it was combined with alternative land use systems using agroforestry practices. For instance, one entrepreneurial Yao woman with 22ha of plantation forest in various stages of cultivation could 800USD per year from cassava sales by intercropping cassava with cinnamon [Y10, 10.07.2015].

²⁰ [KI3, 01.07.2015; KI4, 02.07.2015; KI8, 03.07.2015]

²¹ [T4, 07.07.2015; T8, 09.07.2015; Y10, 10.07.2015]

Even though there was a 77 percent decrease in shrubs from 1999 to 2014, there was more livestock produced in the district, especially near Bảo Hà commune. DARD officials noted how buffalo from Bảo Yên are ‘famous’ and exported to other Vietnamese provinces [KI11, 06.07.2015]. Buffalo were raised by a state-run farm and local household producers, with more than 5000 buffalo bred each year [KI4, 02.07.2015]. Officials estimated 400ha of state-owned grass was grown and stored for winter buffalo feed annually, in addition to household production.

In sum, the predominant LULC changes that took place in Bảo Yên District from 1999 to 2014 were an increase in forestry, linked to the emergence of a plantation forestry industry, and an intensification of cassava cultivation, for export to China. Urbanization occurred in fragmented areas, mostly along transportation corridors, due to rural development programs.

7.3 Commune case studies

I now highlight how the outcomes of land and livelihood change varied greatly across space by focusing on three case study communes: Việt Tiến, Vĩnh Yên, and Điện Quan. The communes were chosen while I was in the field to maximize diversity of LULC, ethnic composition, and willingness of local officials to help my research team. A summary of land cover changes for each commune is presented in Table 7.1.

Table 7.1 Land cover by case-study commune (in m²).

	Việt Tiến			Vĩnh Yên			Điện Quan		
	1999	2014	Annual change (%)	1999	2014	Annual change (%)	1999	2014	Annual change (%)
Water	359,550	980,775	6.69	0	38,700	85.77	-	-	0
Built up	156,375	323,100	4.84	28,800	206,325	13.13	900	76,725	29.64
Bare soil	4,710,600	3,281,850	-2.41	16,816,950	8,337,150	-4.68	7,782,525	6,646,275	-1.05
Shrubs	17,823,825	2,853,225	-12.21	30,599,325	9,936,900	-7.50	28,977,300	6,758,775	-9.70
Closed canopy	495,225	23,338,125	25.69	565,875	34,216,650	27.35	287,550	27,281,700	30.35
Open canopy	9,079,650	1,848,150	-10.61	11,346,975	6,622,200	-3.59	6,538,050	2,822,850	-5.60

7.3.1 Việt Tiến Commune

Việt Tiến commune is 16km from the district centre, along the highway connecting Yên Bái Province to Lào Cai Province and China to the northwest; and to Hanoi and the port of Hai Phong to the southeast. The mean elevation is 236m and mean slope is 19.4° (STRM). It has a population of 758 households, comprised almost entirely of Kinh (48%) and Tày (41%) (GSO 2011; Appendix A.2). In comparison to the other case study communes, Việt Tiến had the highest percentage of households granted loans under credit programs and the highest rate of Red

Book land certificates (72%). The percentage of households with modern possessions was the highest for all categories evaluated in the RLUS (cell phones, agricultural machinery, television, and access to electricity), except for motorbikes. Việt Tiến was also the only commune to have a primary income source for households (2%) from ‘construction and industry’, and it had the highest percentage of households engaged in ‘trade, transportation and other services’ (6%) (GSO 2011). Việt Tiến was one of three communes selected as a pilot commune for rural development beginning in 2010, which upgraded roads and built a bridge to cross the Chay river, to link the commune to the district centre and beyond [KI4, 02.07.2015]. Officials commented that the locals benefited greatly from the program, and it was a highly influential change in the commune [KI4, 02.07.2015]. Roads were upgraded from 1m wide dirt roads to 2.5m wide paved roads, suitable for large trucks and motorcycles [T4, 07.07.2015]. Finally, there are three small-scale wood processing facilities (for all types of timber) along the main highway.

The largest change to LULC and livelihoods in Việt Tiến commune was the rapid proliferation of production forests. Timber production has nearly doubled each year since 2000, with the highest rates of harvest occurring since 2013 [KI4, 02.07.2015]. State-led reforestation projects, namely Program 661, were widely implemented and reforestation efforts began in 1997, although the bulk of household planting began around 2008.²² Prior to reforestation, LULC was comprised mostly of shrubs and mixed trees.²³ Some households started experimenting with plantation forestry in small areas around 2000, and have produced two timber harvests since [T1, 07.07.2015; T6, 07.07.2015]. Tree seedlings were not subsidized, apart from citrus trees (including oranges, pomelo, grapefruit, and limes) since the commune was designated by DARD to specialize in fruit production [KI4, 02.07.2015; KI11, 06.07.2015].

Of the ten households I interviewed in Việt Tiến, nine had plantation forest as their primary income source, with a large proportion of residents cultivating a combination of acacia, bamboo, and fruit trees. The primary income earner of the remaining interviewee’s household worked for the district SFE processing wood, although her household also planted some trees in 2003 with plans to grow more in the future [Y7, 07.07.2015]. In fact, forestry was so successful that the price of sloping land leases in the highlands appreciated. As an informant explained: “Now buying sloping land [in the highlands] is getting more expensive because it is easy to make

²² [KI4, 02.07.2015; T2, 07.07.2015; T6, 07.07.2015]

²³ [KI4, 02.07.2015; T4, 07.07.2015; T7, 08.07.2015]

money now in forest plantations” [T1, 07.07.2015]. For example, timber from a 3ha plot of mature forest mixed with acacia and cinnamon could be sold for 3600USD with minimal effort required to maintain tree stands [T1, 07.07.2015; T4, 07.07.2015]. In 2013, cinnamon trees were introduced in large state-sponsored seed programs to the commune, and as households harvested their acacia stands they began to plant cinnamon as the replacement [KI4, 02.07.2015].

The proportion of land dedicated to agriculture was smaller in Việt Tiến compared with the other two communes as all households could produce two rice crops per year, in addition to small home gardens, and maize fields for animal feed. In July 2015, purchasing paddy land was still more expensive than forestland, although one farmer I interviewed suspected in the future this will be reversed [T1, 07.07.2015].

7.3.2 Vĩnh Yên Commune

Vĩnh Yên commune is in north-eastern Bảo Yên along the highway that leads to Hà Giang Province, 20km from the district centre. The mean elevation is 404m and mean slope is 20.3° (STRM). With 587 households, the population is mostly Tày (68%) followed by Hmong (28%) (GSO 2011). Vĩnh Yên was not the focus of infrastructure development initiatives and road access is limited to mostly dirt roads in poor condition [observations]. The commune official identified Vĩnh Yên as ‘very poor’ and explained how households received substantial food and development aid, such as free tree seedlings and access to primary education [KI7, 03.07.2015]. According to the RLUS, in comparison to the other case study communes, Vĩnh Yên was the only commune that had villages without full access to electricity in 2011. Only 52 percent of households were granted loans under programs in 2010, yet Vĩnh Yên had the largest total dollar value allocated to loans. The commune had the lowest percentage of households with motorbikes, cell phones, electricity, and televisions, and had the highest percentage of households engaged in ‘agriculture, forestry and fisheries’ as the primary source of income (96%) (GSO 2011). There are two small-scale timber processing facilities on the main road, bordering Nghĩa Đô commune, which has a booming forestry industry, as well as a cinnamon oil distilling facility in a Tày home [KI11, 06.07.2015; KI15, 09.07.2015].

Compared to Việt Tiến, forestry was not as widely adopted in Vĩnh Yên. Commune officials explained that there were few state-owned forest plantations developed, since the commune was very isolated and Program 661 did not operate there (yet Program 321 was successfully implemented) [KI7, 03.07.2015]. At the household level, the degree of

experimentation with forestry greatly varied. Of the nine households interviewed, spokespeople from three Tày households described how forestry was their primary source of income, whereas only one of three Yao households interviewed was involved in forestry as the primary livelihood activity. The three Hmong households I interviewed planted some trees but depended on agriculture for their livelihoods. An interview with a local wood processing facility owner also confirmed that most trees he processed were from “the local people not from the government forests” and many of the trees were from Tày households [K2, 11.07.2015].

All nine interviewees explained that the majority of trees that their households had planted since 1999 were cinnamon. Cinnamon cultivation began in 1994, yet with these slow growing trees the first wood harvests did not occur until 2014 [T9, 09.07.2015]. The primary uses for cinnamon were to harvest the bark for spice and essential oil production [T9, 09.07.2015; T10, 09.07.2015]. To facilitate the further expansion of existing cinnamon plantations, in 2013 commune officials provided each household with 2000 cinnamon seedlings, and did not sell other tree varieties. As a Hmong household with less than 1ha of plantation explained: “We did not plant acacia, benzoin, or any other tree, because the government did not support those seeds – they only supported cinnamon” [H32, 10.07.2015]. The local tree processing facility also explained that most timber processed in 2014 was cinnamon wood [K2, 11.07.2015]. Hmong and Yao households described planting more bamboo than Tày households, since these trees propagate naturally and grow quickly and thus provide steady income [H30, 10.07.2015; H32, 10.07.2015]. Some Hmong households have recently planted cardamom plants brought from Bắc Hà District in their plantation forest, yet there is much uncertainty if they will grow successfully since climatic conditions are likely to be too hot and dry [KI7, 03.07.2015].

Interestingly, land cover statistics show an increase in plantation forestry comparable to other communes in the district, raising the question of whether household driven reforestation was the primary driver in this commune. Two of the households I interviewed were the first to experiment with plantations in their villages [T9, 09.07.2015; Y10, 10.07.2015]. Both described how they were able to use income from their first round of acacia harvests, in conjunction with livestock sales and cinnamon bark, to purchase additional land which they used to plant more trees, mostly cinnamon. This led to observable income gaps between these households and others, as their homes were the most renovated (e.g. concrete, fences, two to four motorbikes). For instance, most households had between 1 to 5ha of forestry, but the two well-off households,

one Tày and one Yao, had 10ha and 22ha respectively. Interestingly, these households acted as asset providers for others. The Yao interviewee described how she acted as a village safety net by providing households with livestock, allowing them to cultivate her farmland for their own food supply, and paying a small wage to work in her forests. The Tày household used their timber income to purchase a truck in 2010, which the eldest son used to purchase cinnamon bark from households to sell to a company in Yên Bái Province, or Hải Phòng port.

I observed that there was substantially more cassava grown in Vĩnh Yên commune, possibly due to the proliferation of cinnamon, compared to the other six communes I visited. Households of all ethnicities were engaged in cassava cultivation although Hmong farmers reported difficulties selling it because of access to markets. As a Hmong interviewee commented: “To sell the cassava it’s hard to reach the market because the road is bad. When the business comes to pick up cassava it is hard to reach here, especially when it rains” [H30, 10.07.2015]. My interviews and observations also revealed that agricultural production was strongly correlated with elevation and water availability in Vĩnh Yên. Maize did not grow well in the lowland areas of the commune due to soil conditions, where Tày households focused on wet rice and forest production [T10, 09.07.2015, observations]. On the contrary, Hmong and Yao households at higher elevations were unable to produce sufficient (if any) wet rice and instead relied on hill rice, maize, root vegetables, and food aid to meet basic household needs.²⁴

7.3.3 Điện Quan Commune

Điện Quan commune is along the major highway connecting Bảo Yên District to Lào Cai city and China. The mean elevation is 285m and mean slope is 20.3° (STRM). Of the 833 households in the commune, ethnicity is distributed amongst Yao (45%), Hmong (23%), and Tày (19%) households (GSO 2011). Roads in Điện Quan are mostly paved, although remote regions of the commune have dirt-road access only. Of the three case study communes, Điện Quan had the smallest number of loans allocated, and the lowest percentage of households with land use rights (GSO 2011). The commune lies between Việt Tiến and Vĩnh Yên with regards to most socio-economic indicators evaluated in the RLUS (Table A.2). There is one wood processing facility in the commune that opened in 2013.

Contrasting with Vĩnh Yên and Việt Tiến, households in Điện Quan specialized in maize production rather than plantation forestry from 1999 to 2014, providing another example of cash

²⁴ [10.07.2015 - H31; H32; Y8; Y9]

crop specialization among communes. Officials calculated that the commune had the largest area dedicated to maize production [KI11, 06.07.2015], however land cover statistics did not show a greater proportion of land classified as bare soil (indicative of agriculture). Intensified maize production began in 2003, shortly after hybrid maize was introduced in 2002, when a trade company convinced the commune officials and locals to plant more maize [KI9, 04.07.2015]. Maize was purchased by a handful of regional Kinh traders who lived outside of Bảo Yên who passed through the district when travelling from Yên Bái to China, and was ultimately sold in China where the price was higher [KI11, 06.07.2015]. Selling maize to agricultural intermediaries, households made upwards of 1350-1800USD/year [H33, 12.07.2015; Y11, 12.07.2015]. Interviewees explained that cultivation was not for personal consumption – it was grown to generate income to purchase rice, which cannot be easily grown in the dry climatic conditions of the commune [KI9, 04.07.2015; H33, 12.07.2015; H34, 12.07.2015].

All seven households interviewed also cultivated cassava for animal feed and to sell to Kinh traders. Cassava intensification began in 2010 in fields where soil conditions were no longer suitable for maize or dry rice cultivation [H35, 12.07.2015; Y11, 12.07.2015]. As an interviewee explained: “I stopped growing corn in 1999 because the productivity was low so I started to plant cassava” [Y12, 12.07.2015]. However, most households I interviewed explained how cassava was grown mainly for household animal feed until 2010-2013, when Kinh traders began arriving at their homes to purchase it. Similar to the other case study communes, cassava provided substantial financial capital which in turn aided food security [Y11, 12.07.2015].

Interviewees reported that plantation forestry was not very successful in Điện Quan because of pest outbreaks and poor soil conditions. For instance, acacia, which was widely grown elsewhere in the district cannot be planted [KI9, 04.07.2015]. Rather, most households planted cinnamon and bamboo, with the majority of cinnamon cultivation beginning from 2010 to 2013 with the aid of an NGO project, although interviewees explained that only Yao and Tày villages, not Hmong, received seedlings in 2013 [KI9, 04.07.2015; H33-H26, 12.07.2015]. Interviewees concurred that they mostly planted bamboo, but 57 percent of households had some area under cinnamon cultivation. None of the interviewees enthusiastically embraced forestry compared to the other communes visited. For instance, a Hmong farmer described how he had four hectares of naturally regenerated secondary forest, with no plans to transition to plantations in the future [H33, 12.07.2015]. However, as conditions for maize cultivation worsened, some households

unenthusiastically turned to plantation forestry to make up for lost maize income. One Hmong man explained: “I planted cinnamon and bamboo in 2014 because of the bad soil. I could not grow any food so I decided to plant trees” [H36, 12.07.2015]. Finally, a commune official noted that Hmong households still practiced shifting cultivation, although they transitioned to plantations as soil quality declined [KI9, 04.07.2015].

To summarize, I found that from 1999 to 2014 each commune experimented with natural resource intensification and specialization. In Việt Tiến commune, plantation forestry was the dominant livelihood strategy and there were several tree varieties including acacia, cinnamon, benzoin, and bamboo, with many households also specializing in fruit production. Vĩnh Yên commune was highly focused on the cultivation of cinnamon while Điện Quan farmers based their livelihoods on maize cultivation, although households have begun to transition to plantation forests (albeit somewhat reluctantly). Households in all three communes intensified cassava production for sale to agricultural intermediaries. Overall, land cover trends were consistent with those seen in the district and province, which highlights how subtle differences and trajectories of household land use change and livelihood strategies are not be evident on 15m resolution land cover maps. Next, I demonstrate how the drivers LULC change acted differently in each commune to influence land transitions, and how the degree of agricultural specialization was related to ethnicity, with Hmong households most likely to remain diversified.

7.3.4 Market access as a driver of land change

Within the three case study communes I found market access to be the strongest predictor of whether a certain land use was implemented. Road access facilitates access to the interior of land cover patches and hence can increase the rate of expansion of cash crops in frontier environments (Leitão and Ahern 2002). Most officials I interviewed cited the upgrading and extension of the road network as a primary catalyst for change in both well-connected (Việt Tiến) and remote communes (Vĩnh Yên), as households could access markets with lower barriers to entry. A land use planning official from Nghĩa Đô commune noted that “tree plantations are very effective... some households sell wood and can make a lot of money but how much wood they sell depends on how far they are from the road” [KI8, 03.07.2015]. Neighbouring Nghĩa Đô commune, in Vĩnh Yên commune where roads are poorly developed, farmers still relied on intermediaries to sell cash crops, but the quantity cultivated was limited by poor road access, as noted in Section

7.3.3. Likewise, Điện Quan was chosen by Kinh traders to specialize in maize due its location on the highway connecting Bảo Yên with China.

In Việt Tiến commune the upgraded road from the rural development program facilitated entry into the forestry industry. As a benzoin cultivator commented: “The new road makes it convenient to go to the forest and to work” [T4, 07.07.2015]. A Tày farmer explained that when using the former road, small businesses and entrepreneurs could not easily transport cash crops because trucks would get physically stuck, however since the road was upgraded it is much easier to move people and for small-scale businesses to travel to all commune villages to buy cassava, wood, and other products [T5, 07.07.2015]. Because of easier access, the price for agricultural and forestry products such as fruit, cassava, and timber, increased, as they could be bought and sold in bulk (ibid.). Households preferred to sell to intermediaries because crops like cassava are very heavy and difficult to transport. As an interviewee explained: “The small business goes to everyone’s home with a truck to buy cassava because it is very heavy. The price is much cheaper in the market so it’s better to sell to the small business” [T4, 07.07.2015]. Prior to road upgrading, timber was moved out of the commune using buffalo and a shallow river which took 75 percent longer than using the paved road [T5, 07.07.2015]. A vendor concluded that “the road makes my life more comfortable, because of the bridge it is more easy to move things for my store across the river” [T2, 07.07.2015]. Thus, land use intensification is linked to road and market access, as communes with greater access are more likely to intensify cash crops.

7.3.5 Role of ethnicity and biophysical factors

Mediating factors, such as institutions, gender, and ethnicity, govern the interplay between drivers of LULC change (Geist et al. 2006). My interviews uncovered that household ethnicity played a large role in land use decisions and resilience. In general, the Tày and Kinh in Bảo Yên District developed more specialized land use from 1999 to 2014, while Hmong households remained the most diversified. In Việt Tiến, Tày and Kinh households were highly specialized in tree plantations and fruit production, whereas in Vĩnh Yên predominantly Tày households relied on forestry for their primary source of income, while Hmong and Yao households had small areas of plantations (Hmong and Yao households had on average 0.5-2ha of plantation forestry compared to 5ha or more for Tày households). When visiting a Yao village there was a clear line dividing the village from the neighbouring land – on the village side completely bare, on the other side completely forested. According to a Yao farmer, the forested land belonged to Tày

households and is planted with cinnamon, benzoin, and bamboo [Y9, 10.07.2015]. Another Yao householder in the village explained: “To increase my quality of life if I had money I would buy seeds to grow cinnamon” [Y8, 10.07.2015]. I also uncovered that Hmong interviewees were most likely to have shifting cultivation plots and a diversity of crops to maintain livelihood security.

Previous work in the Vietnamese uplands established that many ethnic groups are segregated by elevation (Michaud et al. 2002). Hence predisposing biophysical factors indirectly work to constrain or promote specific land use decisions. In Bảo Yên District, Hmong and Yao villages are located at high elevations where access is only possible using dirt roads. For example, in extremely mountainous Long Phúc commune, 78 percent of the population is Yao and lives entirely in areas with steep slopes [KI6, 02.07.2015]. Hmong villages are often remote, at high elevation, and in areas of low water availability [KI7, 03.07.2015]. Given the role of roads in accessing financial capital (via access to markets), Hmong and Yao households were thus inopportunately located to take advantage of cash crop opportunities. Tày who occupy low slope lowland areas could rely on two wet rice crops, which provided more of a food security safety net, compared to Hmong and most Yao informants who were only able to produce one crop, further heightening the need for LULC diversity. All ten Tày households I interviewed also relied on aquaculture for food security and were more likely to experiment in the service industry. For example, Việt Tiến commune had the most number of households engaged in services and the highest number of timber processing centres. Of my interviewees, the two households who owned small stores were Tày [T2, 07.07.2015; T8, 09.07.2015], and Tày households generally had more expensive homes and more physical and financial capital [observations]. Likewise, the commune I visited with the most plantations, experimentation with cash crops, and plans for tourism was Nghĩa Đô commune, which has a population of 97 percent Tày [KI8, 03.07.2015].

7.4 Implications for resilience

I now turn to how LULC changes in the case study communes, and more broadly in Bảo Yên District, have led to heightened vulnerability to extreme weather, market prices, and pest outbreaks. I also discuss adaptation and coping mechanisms (or lack thereof) employed by farmers and the state to deal with ongoing social-ecological transformation.

As uncovered by examining the commune case studies, there is a high degree of natural resource specialization in Bảo Yên, which consequently means livelihood resilience is vulnerable

to disturbances and market prices (Chapter 6). My interviews uncovered that from 1999 to 2014 extreme weather events impacted livelihoods more than market price fluctuations or pest outbreaks. As a forty-year old Tày store owner explained: “Over the last 15 years our lives and the land has not changed much, but the weather changed a lot” [T2, 07.07.2015]. Interviewees identified 2008 and 2014 as the two worst years with regards to extreme weather events. For instance, in 2008, most citrus trees in Việt Tiến commune died during a cold-spell [KI4, 02.07.2015] and intense flooding, with corresponding landslides and erosion, in one lowland village led to rice being reduced from two crops to one crop per year since [T5, 08.07.2015]. The DARD commented that in 2014, 60km² of forestry were severely affected by extreme heat with plantation yields reduced by 50 percent [KI11, 06.07.2015]. Meanwhile, a Điện Quan commune official explained that more than 200ha of corn and 8ha of rice died due to drought in 2014 [KI9, 04.07.2015]. Interviewees in Điện Quan also described severe water shortages that began in 2012 which drastically reduced maize yields [H33, H34, H35 – 12.07.2015].

Linked to extreme weather events were generally declining environmental conditions, as seen in Lào Cai Province. In Điện Quan commune where households specialized in maize and cassava cultivation, four Hmong households reported that the soil quality had declined since intensifying maize production in 2003. In response, seeds were rotated every crop as old seeds no longer suited agro-ecological conditions. In addition, hybrid maize seeds advertised as drought-resistant planted in 2014 did not withstand weather conditions, and yields were as low, or lower, than previous years. Even in Việt Tiến commune, Tày farmers described turning to hybrid seeds as a solution for yield and climate changes, putting faith in hybrid seeds as an adaptation strategy [T3, 07.07.2015]. For instance, one interviewee mentioned how “every two years the seeds need to be changed; if you grow the old [hybrid] seeds they will not produce enough” [T1, 07.07.2015]. This short-term planning has temporarily allowed households to continue to plant maize every year, although the long-term outlook is grim.

In Việt Tiến and low elevation villages of Vĩnh Yên, specialization in forestry by Tày and Yao households was the main strategy to restore environmental conditions and reduce vulnerability to extreme weather. Importantly, the decision to transition land use in these locales was made following the arrival of state narratives that plantations would improve soil quality. For instance, a Tày householder in Vĩnh Yên commune explained that many people in the village stopped growing maize in 2008 when it no longer produced high yields due to dry soil with poor

quality, and instead transitioned to cinnamon, which successfully improved soil conditions, albeit only for a few years [T10, 09.07.2015]. Once already involved in tree production, households continued to experiment with tree varieties in response to environmental concerns. As a retired official explained: “Before it was natural forest but I changed to plantation forest because it changes the soil, acacia makes the soil better but benzoin makes it worse” [T7, 08.07.2015]. A neighbouring farmer who alternated acacia and benzoin harvests since 1997 to counteract declining soil quality noted: “Acacia makes the soil better but after seven or ten years if you still grow acacia the soil will be bad, it is better to cut acacia all at once and grow benzoin” [T2, 07.07.2015]. In Việt Tiến, two households first planted fruit trees with the support of state fruit tree programs such as oranges and pomelo, followed by bamboo and benzoin in the early 2000s, and eventually transitioned to acacia, following concerns regarding soil fertility [T1, 07.07.2015; K1, 08.07.2015]. Another Tày household described how orange trees were not suitable to soil conditions so they experimented with planting grapefruit to see if soil conditions would improve. As a commune official explained: “The acacia trees are better than the orange trees because the leaves fall and make the soil better” [KI4, 02.07.2015]. Overall, narratives regarding which tree species would be better for the soil were highly inconsistent, yet all interviewees who grew trees explained that tree plantations at first improved soil fertility which later became worse.

If households and SFEs continue to specialize in plantations, cumulatively there is a risk of undermining forest diversity and spatial resilience. Pest outbreaks in plantations were common in Bảo Yên District. In Long Khánh commune there was a severe outbreak in 2013 that killed most benzoin trees [KI5, 02.07.2015]. Neighbouring Long Phúc commune also experienced severe pest damage since 2012 while officials in Nghĩa Đô commune 37km away explained many insects destroyed acacia and benzoin trees [KI6, 02.07.2015; KI8, 03.07.2015]. As a result, the Bảo Yên Forest Company and households decided to plant cinnamon and bamboo instead. However, in 2014 there were already small localized cases of cinnamon fungus that attacked young cinnamon trees [T10, 09.07.2015] and an official noted cinnamon cannot grow without frequently applying pesticides [KI9, 04.07.2015]. The district-level response to pest management was that “there are small outbreaks but there are pesticides to protect the trees and locals also know how to protect them” (ibid.). Yet a commune official commented that “there is substantial increase in the knowledge required to grow trees, but knowledge for pest management is low”

[KI8, 03.07.2015] and another noted that it is very difficult to apply pesticides since the pests live in the top of the canopy and trees can easily reach 8m in height [KI5, 02.07.2015].

As mentioned in Chapter 6, there were several places where natural forests were cut down to develop plantations. Old growth trees were harvested because “acacia and benzoin get a better price and grow fast” [T5, 07.07.2015]. One retired official explained: “Before there was grass and many kinds of old trees, the trees were very big and three to four people could hug one tree. They cut down all the trees – the big ones they were able to sell the wood; after they planted acacia and benzoin” [T7, 08.07.2015]. He also explained how “before there were squirrels, wild boar, deer; now there is only wild chickens and snakes. Hunting and deforestation removed all the animals” (ibid.). In Vĩnh Yên, a farmer explained that deforestation was driven by forestland allocation:

People started to destroy the natural forest a lot since 1997. They destroyed it because the government divided the land for the people and the people cut down the old trees to grow other trees like benzoin. After they cut these down and grew cinnamon [Y9, 10.07.2015].

In production forests, there were an alarmingly low number of tree species selected, yet the DARD has plans to reduce this further. In 2015, the total area under cinnamon cultivation was 42km² yet the state has plans to double this to 85km² by 2020 [KI9, 04.07.2015]. More alarming is that expansion plans intend on focusing only on Saigon cinnamon (*Cinnamomum Loureiroi*) since it has a higher oil content [KI11, 06.07.2015]. Furthermore, trees – especially those in early stages of growth – are vulnerable to drought and by basing Bảo Yên’s forest economy on one species of tree, households and SFEs remain vulnerable to market price fluctuations.

However, most farmers I interviewed described tree plantations as a significantly more stable source of income, hence improving livelihood security, when compared to rice and maize cultivation, and are likely to plant more trees in the future. While forest plantations provided a source of income, they also required little labour and were less vulnerable to extreme weather compared to other cash crops. Households described visiting their forest plots once or twice a month to cut down short succession trees and grasses, and in some cases, apply fertilizer [T5, 07.07.2015; T8, 09.07.2015]. One Tày woman explained: “I will continue to grow more forest in the future because there is not much work involved” [T8, 09.07.2015]. An official also commented that “the two biggest benefits of forest plantations is people have more income and they can protect the environment” [KI9, 04.07.2015]. In Điện Quan, an official noted that “in the future there will be no more area for forest to be planted, and agricultural land will have such bad

soil that it will have to be planted with tree plantations” [KI9, 04.07.2015]. Hence, land availability is likely to constrain future land use decisions.

7.4.1 Strategies for resilience

Compared to other districts in Lào Cai Province, household opportunities for diversification to foster livelihood resilience, namely relying on tourism and NTFP collection, were not as accessible in Bảo Yên District. Tourism was limited to two communes and without significant old growth forest, NTFP collection (e.g. cardamom, orchids) was not available as a diversification strategy [KI8, 03.07.2015; KI11, 06.07.2015]. I also found little evidence of households turning to migration as a strategy. Thus, intensification was the most accessible pathway for households of all ethnicities, especially given state programs that actively encourage it. However, while intensification is the pathway to improving financial capital, with current land use practices, it is ultimately undermining ecological resilience.

With increasing frequency and intensity of disturbances, households had to employed adaptation mechanisms. For instance, an interviewee explained how he chose to grow only bamboo over other state sponsored tree varieties because it could grow with less water in emerging climate conditions [T4, 07.07.2015]. Likewise, buffalo feed was harvested in advance and stored in case the weather became too hot or cold to grow feed [KI11, 06.07.2015]. Interviewees also described weighing expected ecological benefits with price changes when making tree variety transitions. For instance, a middle-aged Tày woman mentioned that in 2000 she grew 1ha of orange trees and in 2010 switched to 0.5ha of grapefruit and 0.5ha of cinnamon to improve soil quality [T1, 07.07.2015]. She also considered the switch because the price of grapefruit was higher than oranges, and the two types of trees used equal amounts of water.

I found evidence of two state-sponsored programs that promoted ecological resilience. First, the district had plans to reduce cassava from 30km² to 10km² to improve soil fertility, despite the success cassava cultivation had in raising household financial capital [KI11, 06.07.2015]. In Điện Quan, there was a pilot program to rotate cassava and soy to aid in soil fertility, and if proven successful it will be implemented throughout the district [KI9, 04.07.2015; KI11, 06.07.2015]. Furthermore, since 2010, there was an active strategy to reduce insects in Việt Tiến by clearing a 10m wide boundary around the commune to keep insects out [KI4, 02.07.2015]. Both officials and farmers noted this strategy had worked as all farmers in Việt Tiến

reported no pests, while officials in neighbouring Long Phúc and Long Khánh communes described severe infestations [02.07.2015 – KI5, KI6; 07.07.2015 – T2, T3, T4].

In sum, the outlook for social-ecological resilience in Bảo Yên District is highly dependent on land use intensification and cash crop substitution. Long term resilience planning was widely absent amongst households and institutions working in the district, with households turning to short-term adaptation mechanisms to manage disturbances. In the future, vulnerability to declining soil fertility, market prices, and tree infestations is likely to increase, since land use planning will further encourage low diversity tree plantations.

7.5 Chapter conclusion

In this chapter I analyzed the drivers and outcomes of land change, and the resultant changes to the SES in Bảo Yên District. The results suggest that land cover trends were consistent to those seen in Lào Cai Province, namely an increase in plantation forestry and cash crop intensification. Land use planning by officials in Bảo Yên directly encouraged livelihood specialization in timber, cinnamon (for oil), maize, and fruit trees. The commune case studies revealed that land use decisions (and planning) varied across space, and were mediated by ethnicity and biophysical conditions. Access to roads also strongly affected the degree of intensification, as households with greater access to agricultural intermediaries were more likely to specialize. Households who specialized, such as those engaged in plantation forestry, were more vulnerable to disease and market price fluctuations. However, many households described how intensification led to greater financial, thus food, security and were unlikely to diversify LULC to improve resilience. Rather, households described turning to land cover modifications, such as changing tree varieties, to adapt to ongoing disturbances. In the following chapter, I uncover feedbacks in the above land and resilience changes, and discuss evidence for a land cover regime shift in Lào Cai Province.

CHAPTER 8 DISCUSSION, POLICY RECOMMENDATIONS AND CONCLUSIONS

In this final chapter, I build on my three results chapters to answer my fourth and fifth research questions: *‘is there evidence for a LULC regime shift?’* and *‘what strategies may be used to increase resilience?’*. I begin by highlighting complexity in understanding LULC, livelihood, and resilience changes to SESs. I then analyze evidence for a LULC regime shift, and outline the utility of the resilience framework for understanding environmental and livelihood change by examining subjectivity, methods, and issues of scale. In Section 8.3, I present policy recommendations to increase social-ecological resilience in Lào Cai Province, namely fostering diversity and promoting learning within institutions. I end this chapter by outlining my main thesis findings and insights on land system resilience in Lào Cai Province.

8.1 Complexity in land change and livelihood transitions in Lào Cai Province

The drivers of land change, and corresponding changes in resilience in Lào Cai Province do not follow an isolated linear trajectory. Rather, they take place in a complex SES with inherent feedback loops. Drawing on my conceptual framework (Chapter 2), a resilience approach recognizes the inherent capacity of the SES to self-organize, observable through feedback loops that emerge in response to change (Berkes et al. 2003; Marschke and Berkes 2006). Land system science literature also recognizes this complexity as Lambin and Meyfroidt (2010) identify two feedback loops largely responsible for land transitions: negative social-ecological feedback caused by a decline in key ecosystem goods and services, and positive feedback caused by socioeconomic change arising exogenously from urbanization, economic development, and globalization. Drawing on a systems modeling approach and processes governing feedback loops in land system science and resilience literature, in Figure 8.1 I show a causal loop diagram of feedbacks I found to be inherent in LULC change in Lào Cai Province. Causal loop diagrams can offer a narrative basis on which to describe and (qualitatively) analyze the system’s response to disturbances and shifts between regimes (Filatova et al. 2016).

Drawing on my field work and land cover classifications, the LULC change from 1999 to 2014 that had the most noticeable impact on the SES was reforestation. However, it is difficult to isolate if reforestation was characterized by solely endogenous or exogenous feedbacks. Exogenous socio-economic change largely drove reforestation efforts by SFEs, as timber was harvested and used in domestic and international markets to stimulate growth. For instance, the estimated value of acacia hybrids (accountable for 40% of Vietnam’s plantation timber) from

1988 to 2018 was 115 million USD (van Bueren 2004). The state also facilitated the development of forest plantations through the construction of roads and other support measures (e.g. low interest loans, tax exemptions for foreign investors, tariffs and restrictions on paper imports, and exemption from land rent) that promoted commercial plantations (ibid.). At the household level, most households I interviewed engaged in reforestation to improve their livelihoods. Plantation forestry as a livelihood strategy was widely adopted by Tày farmers, and to a lesser extent Hmong and Yao farmers throughout Lào Cai Province. Similarly, Thulstrup et al. (2013) found that wealthier households were more likely to engage in acacia plantations in Vietnam's Central Highlands as their primary income source, while poorer households relied on rice cultivation and working as hired labourers on plantations. Thus, the state provided the necessary socio-economic conditions for reforestation, yet the degree of household engagement in forestry was mediated by ethnicity, and access to roads, and capital.

Yet, an argument may also be made for reforestation driven by a negative social-ecological feedback. As numerous informants explained, officials encouraged reforestation to protect watersheds, improve soil fertility, and ensure firewood provision. For instance, in Bảo Yên District, reforestation was presented as a solution to improve declining soil fertility (Section 7.4). Yet, farmers I interviewed who engaged in plantations (1ha or more) as a source of financial capital described how soil conditions did not improve, biodiversity had declined, and water sources became polluted. Thus, the feedbacks governing forestry changes in this frontier environment are complex and may be described by either exogenous or endogenous processes.

Agricultural change in Lào Cai Province can also be described in the context of social-ecological and socio-economic feedbacks. State policies encouraging modernization and cash crop development operated consistently from 1999 to 2014 as additional land policies further incentivized land use change (e.g. subsidies for hybrid seeds, programs to eliminate swidden cultivation, upgraded market facilities). Yet, negative social-ecological feedback also led to agricultural adaptation by Hmong, Yao, and Tày farmers. For instance, as hybrid seeds became unsuitable to agro-ecological conditions, most farmers adapted by experimenting with alternative hybrid seed varieties, crop substitution, intercropping, and/or returning to traditional seeds.

There are additional ongoing processes and feedbacks not captured in Figure 8.1, which focuses on LULC change based on 15m resolution land cover maps. For instance, alterations to land *use* may occur (1) on a small enough scale that they cannot be captured by meso-scale land

cover maps, such as the case of changing benzoin to cinnamon trees to aid soil fertility in Bảo Yên District, or (2) feedback may not have been substantial enough to cause land transformation. For example, I showed that remaining natural forests have undergone an overharvesting of NTFPs, such as orchids and medicinal plants. Yet I did not find substantial evidence that a decline of NTFPs led to significant forest use or forest cover change. Overall, the drivers and outcomes of land change in Lào Cai Province are complex and can be best understood by examining the drivers of land change and the feedbacks inherent in the SES. By examining land change across scales, I showed that land transitions were driven both exogenously and endogenously depending on the unit of analysis, further highlighting complexity.

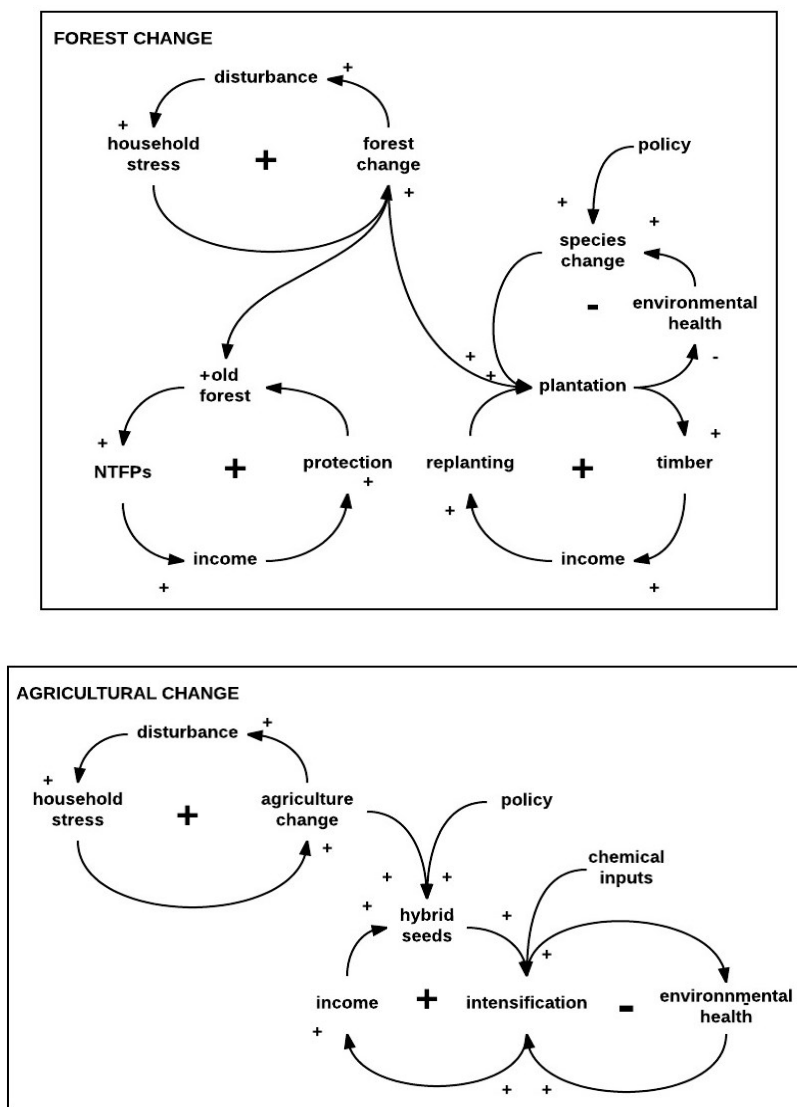


Figure 8.1 Causal loop diagrams summarizing complexity in LULC change.

8.2 On systems and resilience

In this section, I look closely at the resilience framework in the context of LULC change. I begin with a summary of the evidence from my thesis that supports a LULC regime shift from 1999 to 2014. I then examine the resilience framework, with critical insight into how it may be used to understand environmental and livelihood change. I conclude this section with a discussion on scale and tradeoffs between social and ecological system components.

8.2.1 Evidence for a land use land cover regime shift

Drawing on a literature review of landscape change and fragmentation, Fischer and Lindenmayer (2007, 273) note that regime shifts are “likely to arise when native vegetation cover is severely reduced, when vegetation structure throughout the landscape is greatly simplified, and when entire functional groups or keystone species are lost”. Similar to Müller (2014), my results suggest that the state of the SES where I completed fieldwork in Lào Cai Province has moved from a resilient regime of semi-subsistence livelihoods dependent on highly diverse, complex secondary vegetation and swidden fallows, to an alternate state dominated by low-diversity cash crop agriculture and plantation forestry. In 1999 the land cover was characterized by a complex array of bare soil (indicative of agriculture), open canopy forest, and shrubs; however, by 2014 the land cover transitioned to mostly closed canopy forest. Likewise, in 1999 ethnic minority livelihoods were mostly semi-subsistent yet by 2014 livelihoods depended on cash, generated through cash crops, especially for those with road access.²⁵ Furthermore, of the 6129km² of the province classified, only 1754km² (29%) of *land cover* remained stable between 1999 to 2014, with the most stability in bare soil – the class that experienced the largest *land use* modification.

Ramankutty and Coomes (2016) argue land use regime shifts may be understood by (1) characterizing the preconditions and triggers for land change, and (2) the self-reinforcing processes that maintain the new state. While preconditions and triggers are similar concepts, “preconditions provide the incentives and/or pressures that make the general environment favourable for a land use regime to shift, whereas triggers provide the immediate impulse for the shift” (Ramankutty and Coomes 2016, online). As highlighted in Chapter 3, state discourse and

²⁵ Increased LULC variance may also be used as an indicator signaling a land use regime shift, occurring before a shift, or once the process has started (Scheffer et al. 2012; Ramankutty and Coomes 2016). Land cover diversity statistics presented in Chapter 6 indicated that diversity in Lào Cai Province decreased from 1999 to 2014, yet, previous work conducted on the five border districts (albeit at 30m resolution) suggested that LULC diversity increased from 1999 to 2009 (Trinci et al 2014; Pham and Turner 2015). Thus, LULC captured in 2009 may signal the *release and organization* stage of the adaptive renewal cycle (Figure 2.2), further supporting evidence for a LULC regime shift. However, given differences in study scale, this cannot be inferred indeterminately.

policy programs in northern upland Vietnam, such as the 5MHRP and Program 327, have long highlighted the importance of maintaining and improving forest cover and provided preconditions necessary for a land system regime shift. Modernization strategies have also strongly encouraged rural ethnic minority integration into Vietnamese society. As such, development programs that supported infrastructure, sedentarization, and integration into the cash economy have made conditions ripe for a transition to sedentary ethnic minority livelihood practices, that in turn are dependent on cash-generating highly vulnerable land use decisions. This research suggests that the trigger for a land use regime shift was road upgrading, specifically the expansion and paving of existing roads, and the construction of the highway linking Lào Cai to China, which increased demand for agricultural and forestry exports. For example, road development in Bảo Yên District facilitated large-scale trade of cash crops, like cassava, cinnamon, and timber, through agricultural intermediaries.

Self-reinforcing processes will maintain an emerging land regime in Lào Cai Province, dominated by forest plantations, and make it difficult to shift back to previous conditions, in this case ‘bare-land’. These processes include state and private investment in the land use (cash crop plantations) that sustains production and encourage expansion, intensification, technological change, and further investment in infrastructure (Ramankutty and Coomes 2016). Household financial returns from forest plantations not only maintain subsequent harvest cycles, they also encourage the expansion of plantations as farmers share knowledge about financial gains through social networks. Likewise, farmers noted that forest intensification and resulting soil degradation make it near-impossible to transition back to other forms of LULC (especially without drastic intervention to soil management). Households have also come to depend on emerging LULC for income and livelihood security, such as the farmer who noted: “We depend on the wood for life” [K1, 08.07.2015]. Infrastructure expansion, such as pulp and paper processing facilities, have further encouraged forest conversion as households in once inaccessible regions are now able to reach markets. Finally, ongoing policy discourse has created conditions that favour forest maintenance, such as PES programs that provide international donor aid, and state classification of cash crops (such as rubber and coffee) as trees (McElwee 2016). Global demand will also maintain a forest regime through international conservation frameworks like REDD+, and demand for ‘forest’ products including coffee, rubber, timber, and plywood.

8.2.2 *A state of 'undesirable' resilience*

Stedman (2016) notes that individual and collective scholar interpretations of SESs are biased by human subjectivity. Subjectivity is shown in descriptive attributes such as what defines a system and its key features, as well as in normative attributes like the intended state of the system. Within my study, I followed the resilience framework of 'to what, so what, and now what' to add structure and rigidity, yet this could not fully account for subjectivity. My position as a western researcher interested in global sustainability influenced which attributes of the system I considered desirable and undesirable (Walker et al. 2004), such as support for traditional knowledge and biodiversity conservation. Thus, future resilience research would benefit from clear theoretical frameworks that work to eliminate researcher and disciplinary biases.

The state of the SES may be considered desirable for different stakeholders, which ultimately raises the question of resilience '*for whom*'? From the perspective of the Vietnamese state a land system dominated by increased international trade of cash crops, greater forest cover, and ethnic minority sedentarization are desirable attributes, yet from a global sustainability perspective, the emergent land regime in Lào Cai is not sustainable. Rural livelihoods have improved by some objective measures since 1999, such as food quantity and income, but the altered land use regime does not consider long term ecological and social consequences like pest outbreaks, a decline in soil fertility, and loss of traditional knowledge and land use practices.

It is also unclear if the emerging land regime is stable. A focus on cash crops places farmers at risk for extreme weather events and market price fluctuations. Programs that foster agro-ecological resilience and stability are widely absent, and state officials ignore farmer requests to supply hybrid seed varieties farmers consider more suited to local ecology or to plant native tree species for timber production, or outright dissuade households from engaging in resilient land use practices (e.g. shifting cultivation) (Turner et al. 2015; McElwee 2016). While success can be claimed for moving from net deforestation to net reforestation in the timeframe of this study, the method chosen to do so does not promote diversity nor sustainability. For instance, acacias are strongly critiqued for being invasive, reducing stream flow near plantations, causing extensive soil erosion, providing poor quality fuelwood, and being vulnerable to blowing over in tropical storms (Kull et al. 2011; Nambiar et al. 2015; McElwee 2016).

Given the influence of state policy in driving LULC decisions in Lào Cai Province, and the fact that Vietnam is politically a socialist state with little room for overt dissent, the state is

largely responsible for resilience outcomes. Since adaptive cycles can occur nested within, and sometimes interacting with each other depending on the scale of analysis (Holling et al. 2002), Hmong and Yao households are arguably in an interacting cycle with state policies, and Kinh and Tày household land use decisions. At the household scale, Hmong and Yao household inequities are often reinforced by powerful local official institutions, described as endogenously reinforced poverty traps (Tittonell 2014). My research showed that, in general, Tày households have largely embraced cash crops and the market economy, while Hmong and Yao households, especially those in remote regions with poor market access, are maintaining some traditional livelihood practices, are less likely to engage in the market economy, and thus more likely to have poor access to financial capital. In such cases, a transition to an alternative household regime may not be possible as no other regime is available (ibid.). Since resources are necessary preconditions for regime shifts to happen, but are not triggers themselves (Ramankutty and Coomes, 2016), increasing resource access to Hmong and Yao households may provide sufficient diversity to stimulate systems shifts in a more desirable direction. While the state has engaged in physical resource allocation (albeit inconsistently across spatial and temporal scales), like subsidizing hybrid seeds and providing tree seedlings, accepting that traditional practices, including traditional seed networks and swidden, foster diversity may also be appropriate. In sum, there is evidence that the land system of Lào Cai Province moved from a regime dominated by traditional land practices to an alternate regime dominated by cash crops, which is maintained by a different set of self-reinforcing processes.

8.2.3 Resilience trade-offs and issues of scale

Linked to subjectivity in deciding resilience ‘for whom’, are the questions of trade-offs and assessing trade-offs across scales. The notion of tradeoffs is inherent in resilience, land change, and livelihoods frameworks (cf. DFID 1999; Holling and Gunderson 2002; DeFries et al. 2004; Illukpitiya and Yanagida 2010; Persha et al. 2011). For instance, development strategies for improved livelihood outcomes may involve tradeoffs, such as greater food security at the cost of a less sustainable use of the natural resource base (McShane et al. 2011).

Importantly, what may be considered resilient at one scale, might not be considered resilient at another, or may even reduce resilience. This thesis has looked at land and resilience changes at the meso-scale, with resilience at the global (macro) and ecosystem (micro) outside of the scope of this study. For instance, resilience at the micro-scale may not be resilient at the

meso-scale (e.g. diversity of within-plot tree selection may not support local vertebrae or invertebrate species). On the other hand, at the commune or district level, low tree diversity may be considered not resilient; however, at the national scale, resilience may be fostered by selecting individual communes for tree specialization, like cinnamon cultivation in Vĩnh Yên commune, which would aggregate to high LULC diversity in Vietnam. Global trade-offs should also be considered, as the import and export of natural resources may hinder or promote resilience through teleconnections (Friis et al. 2016). For instance, maize cultivation in Lào Cai Province that is exported to China benefits Chinese consumers, while degrading resources and providing financial capital to rural farmers in Vietnam. Consequently, the more integrated Vietnam becomes in the global market, the greater the indirect impacts on land system resilience. Resilience is also affected by the timeframe under consideration, as the difference between what is considered sustainable and resilient could be related to a time-lag in how long it takes for a change to impact the SES. This highlights the importance of having multi-functional landscapes and governance that can promote a variety of processes.

In sum, the emergent land regime, while stable for the time being, may not be sustainable nor resilient when considering long-term land change and livelihood outcomes. Inherent in these changes are questions of scale and trade-offs, and understanding which attributes of the system are desirable for various stakeholders. Additionally, given criticism of the resilience framework as a useful applied approach to evaluate system change (c.f. Norberg and Cumming 2008), interpretations presented in this thesis must be taken cautiously. The allocated two-years for a master's thesis is insufficient to provide an in-depth resilience assessment, as these projects may take several years, require substantial funding, and integrate multidisciplinary teams. Rather, this thesis provides a composite overview of social-ecological change, and raises questions relevant to short-term policy making and land use decisions regarding the resilience of natural resources and farmer livelihoods in the uplands.

8.3 Policy recommendations

Land systems altered by a regime shift will not return to a previous equilibrium state and thus require a new set of management practices, especially if an undesirable state of resilience is to be avoided. Policy responses to land systems undergoing environmental change in Vietnam are criticized by academics for embodying linear thinking, and not taking into consideration complexity and shifting temporal dimensions (McElwee 2016). In Chapter 5 I showed LULC

change between 1999 and 2014 was largely driven by underlying state policy. In Lào Cai Province, a land system characterized by traditional knowledge, swidden cultivation, secondary forests, and diverse native vegetation is unlikely to return. Thus, policy makers must find effective ways to reduce negative consequences of plantation forestry and cash crops (Filatova et al. 2016). The challenges of maintaining resilient landscapes are outlined by Cumming:

Growing a resilient landscape depends heavily on finding an appropriate match between the scales of demands on ecosystems by human societies and the scales at which ecosystems are capable of meeting these demands. While the dynamics of environmental change and ecosystem service provision form the basis of many landscape ecology studies, enhancing landscape resilience is, in many ways, a problem of establishing relevant institutions that act at appropriate scales to modify and moderate demand for ecosystem services and the resulting exploitation of ecosystems. It is also of central importance for landscape sustainability that institutions are flexible enough to adapt to changes in the external environment (Cumming et al. 2013, 1139).

Two possible pathways to promote social-ecological resilience in Lào Cai Province are to: (1) build a landscape that is resilient to future vulnerabilities, particularly those identified by my interviewees as the most pressing (i.e. extreme weather events, market price fluctuation, and pest outbreaks) by promoting LULC diversity in the SES; and (2) foster education and training within institutions, ideally by combining modern knowledge with traditional ecological knowledge.

To reduce vulnerability to disturbances, diversity must be fostered in landscapes, and institutions. Fischer et al. (2006) maintain that there are four key components of resilient production landscapes (i.e. those encompassing forestry and agriculture), namely: large patches of native vegetation, structural complexity throughout the landscape, buffers around sensitive areas, and landscape heterogeneity. Diversity may be practically implemented by maintaining key species interactions and functional diversity, applying appropriate disturbance regimes (e.g. fire), controlling excessive or over-abundant invasive species (e.g. acacias), minimizing threatening ecosystem processes (e.g. hunting or pollution), and maintaining species of particular concern (ibid.). These principles could potentially be applied in Lào Cai Province by policies that (1) favour structurally complex vegetation, like swidden plots, or naturally regenerated forest which declined from 1999 to 2014; (2) control for invasive pests and other species by increasing functional diversity in production forests and maize, rice, and cassava seeds; (3) support some traditional seed varieties, despite lower yields; (4) continue strict monitoring of illegal timber harvesting and work closer with local farmers to identify illegal harvesters; (5) implement

regulations that protect NTFPs from overharvesting, especially of species identified as endemic; and (6) prevent and restore environmental degradation in order to reduce vulnerability to disturbances, and prevent constraints on land use because of poor conditions (e.g. in Bảo Yên District farmers may only engage in plantations in some regions because conditions are too poor for other land uses). Environmental conditions may be improved by reducing pesticide and fertilizer application, planting cover crops to promote nitrogen fixation, allocating additional land use rights to households so fields may go fallow without compromising household food security, and establishing riparian vegetation (e.g. bamboo) along contours to prevent erosion.

Regarding combining modern and traditional knowledge of land use practices: while short-term management strategies are a concrete place to begin to work with resilience in complex SESs, researchers have called for increasing attention to the political dimension of SES governance (Olsson et al. 2014; Orach and Schlüter 2016). Resilience theory is criticized as being depoliticized and inadequate in accounting for questions of power. Indeed, redistribution and sharing of power is a key condition for flexible, collaborative management (Olsson et al. 2014). Since traditional knowledge largely encompasses resilience thinking (Berkes et al. 2000), policies that value the role of traditional knowledge in resource management will ultimately increase resilience and sustainability of land systems. For instance, in Yunnan Province, China, Champalle (2012) showed traditional resilience thinking was a core feature in determining if rural ethnic minority farmers could sustain livelihoods when faced with climate shocks. Further, Tittone (2014, 13) researching African agroecosystems noted “a key step to understanding adaptation strategy is the study of local perceptions and knowledge sustaining mechanisms of indigenous resilience, particularly at the scale of the landscape and its functionality”.

Ultimately, policy makers must to draw on complementary methods and an integrated conceptual framework to implement sustainable land use practices in Lào Cai Province (Turner and Pham 2015). In the context of upland Vietnam, officials and departments must acknowledge and value ethnic minority land use practices that may contribute to a resilient landscape, and recognize that diversity fosters resilience, rather than promote single land use systems. Resource management approaches should also stimulate social learning across scales and actors, support the translation of new knowledge and practices, and offer safety nets to communities more willing to engage in experimentation (Cumming et al. 2013). Yet this Socialist state has been critiqued for not considering long-term LULC sustainability, well-being of ethnic minorities, and

the benefits of traditional land practices, among others (McElwee 2016). Thus, the international aid and research communities may work to foster learning at highest levels of governance (e.g. through strict controls on aid, responsible investing, and global commodities demand).

8.4 Thesis conclusion

In this thesis, I **explored the relationships between policy, LULC change, and social-ecological resilience in Lào Cai Province from 1999 to 2014**. In Chapter 2, I reviewed relevant literature in SESs, resilience theory, land change science, and sustainable livelihoods. I placed my research in the context of CASs, governed by both social and ecological processes. I pulled out key concepts that could act as surrogates to evaluate social-ecological resilience and help direct my research methods, including system disturbances, land cover classification, the drivers of land change, as well as sustainable livelihood assets, strategies, and vulnerability. In Chapter 3, I provided an overview of the political and ecological context for land change in northern upland Vietnam, and more broadly MMSEA, noting relevant policies that drove land use decisions. In Chapter 4, I presented the mixed methods approach used to answer my research questions, drawing on quantitative methods grounded in remote sensing and landscape ecology to develop land cover classifications and analyze provincial trends in land cover change. I also described interview techniques I used in the field, while also addressing questions of access, sampling, positionality, and power.

In Chapter 5, I answered my first and second research questions: ‘*what were the dominant land use and land cover changes from 1999 to 2014?*’ and ‘*what were the drivers of land cover change?*’. My results showed that the primary land cover changes were a rapid rise in forestry, through special-use and state production forests of acacia, benzoin, pine, cypress, and cinnamon trees; as well as rapid urbanization along the Red River valley and throughout rural communes in the form of roads and basic infrastructure upgrades (e.g. markets). My interviewees explained that the primary land use changes were an increase in plantation forestry and agricultural intensification through a transition to cash crops, especially maize, rice, and cassava. NTFP collection intensified as ethnic minority farmers turned to cardamom, bamboo, and medicinal herbs (among others), to increase household income necessary for dependence on hybrid agricultural inputs. Both interview and classification results revealed a decline in shrubs and complex secondary forests. Interviews with Hmong, Tày, and Yao farmers, as well as key informants, revealed that the drivers of LULC change are complex, vary across space, and

operate both directly and indirectly. I uncovered that the direct drivers of LULC change from 1999 to 2014 were the need for cash and land displacement effects, while the indirect drivers were government policies (especially reforestation and urbanization policies), extreme weather events, market prices, market access, and support from social networks.

Building on the results of Chapter 5, in Chapter 6 I investigated what were the *impacts of LULC changes on social-ecological resilience* to answer my third research question. I first identified relevant disturbances to the SES in Lào Cai Province, namely extreme weather events, market price fluctuations, and pest outbreaks. By applying landscape ecology principles, I evaluated ecological resilience using land cover metrics at the class and landscape levels. I showed that from 1999 to 2014 there was a decline in landscape diversity and a loss in resilience in all vegetation classes due to loss of habitat, and increasing fragmentation and homogeneity. I combined landscape metrics results with interviews on soil fertility, water quality, and biological diversity to show that there was an overall decline in resilience from 1999 to 2014 in many areas of the province. Using the lens of livelihood resilience, I explored how LULC changes affected ethnic minority livelihoods, and I uncovered how there was an increase in human, financial, and physical capitals, and a decrease in natural capital. Ethnic minority farmers have embraced forestry activities as a livelihood activity, either through intensification or diversification, and adapted to ongoing disturbances through crop substitution. In many cases, farmers changed their livelihood strategies in response to forestry opportunities, deciding that there was a beneficial trade-off between inputs and financial capital.

In Chapter 7, I presented a case study of land change and resilience in Bảo Yên District to demonstrate the role of ethnicity, the DARD, and market access in influencing land change and resilience outcomes. Drawing on three case study communes, I uncovered that each commune engaged in agricultural and forestry resource specialization, such as mixed timber in Việt Tiến commune, cinnamon essential oil and timber in Vĩnh Yên commune, and maize cultivation in Điện Quan commune. The degree of specialization was linked to market access as communes located along major transport corridors were more likely to engage in cash crops. I also showed how Tày households engaged in plantation forestry as a form of resource intensification, while Hmong and Yao households experimented with plantations as a diversification strategy. This highlighted the role of ethnicity in land change outcomes. I also uncovered that the outlook for resilience for plantations is grim, as all interviewees in Bảo Yên reported a loss in soil fertility,

and many noted declines in biodiversity, water quality, and water quantity. Moreover, households explained that with plantations they were increasingly vulnerable to market prices and pests.

In this final chapter, I used SESs literature and my results presented in Chapters 5, 6, and 7 to answer my fourth and fifth research questions on *evidence for a land cover regime shift* and *policy recommendations to promote social-ecological resilience*. I first highlighted the complexity in land systems by showing that feedback for land decisions was governed by complex exogenous socio-economic change and endogenous social-ecological feedback. I then showed how the cumulative effects of socio-economic and political conditions in Lào Cai Province suggest a LULC regime shift, from a semi-subsistent agricultural landscape to one dominated by cash crops. I also highlighted the utility and limitations of the resilience framework in understanding change to SESs, and recognized the importance of asking, ‘resilience for whom?’ Finally, policy recommendations to promote a *sustainable* SES in Lào Cai Province were put forward, namely the importance of fostering diversity across scales within the landscape, and promoting flexibility and education within governance and institutions.

The results presented in this thesis contribute to broader SESs literature in several important ways. First, I contributed to LULC change research in Vietnam by mapping land cover change at the provincial scale at a 15m resolution. Second, I uncovered a meso-scale land cover transition to forestry from 1999 to 2014, which points to a LULC regime shift. Third, my work on social-ecological resilience took an intricate look at both social and ecological system components, by integrating land change, resilience, and livelihood frameworks. At the time of writing, I am the first to take a land systems approach to evaluate social-ecological resilience in Lào Cai Province. I showed how household and state decisions aggregated at the provincial level to indicate a loss of diversity, and how there are many inherent trade-offs when considering long-term outlooks and policy prescriptions for resilience. Most importantly, I raised the questions of ‘*resilience for whom, and at what scale?*’ as outcomes for resilience are largely influenced by researcher subjectivity, temporal scale, and intended anthropogenic use for the SES. Finally, I contributed to broad theoretical discussions on resilience and land cover change by showing that a multi-scale mixed methods approach is important for understanding complexity.

To conclude, this thesis showed that policy changes implemented in Lào Cai Province have been integral in promoting land change and resilience outcomes between 1999 and 2014. In the complex agro-ecological SES, there have been rapid rises in plantation forestry and urban

areas, leading to a loss of ecological resilience as key biophysical resources have experienced a decline in quality. Ethnic minority farmers have experimented with market opportunities and many – but not all – have, in turn, improved their livelihoods. I argue that the land system has undergone a regime shift from semi-subsistence to one dominated by cash crops. Moving forward, Vietnamese policy makers must acknowledge that land change must foster diversity, and social-ecological resilience may degrade rapidly when thresholds are crossed. Actions should be taken to improve long-term resilience planning by fostering learning in institutions.

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APPENDIX A

Table A.1 Sensor characteristics of images used for land cover mapping.

Date	Path/Row	Sensor/Image type	Bands	λ (μm)	Resolution (m)
1999-12-27	128/44 128/45	Landsat ETM+	1 Blue	0.45-0.52	30
			2 Green	0.52-0.60	30
			3 Red	0.63-0.69	30
			4 NIR	0.77-0.90	30
			5 SWIR 1	1.55-1.75	30
			6 TIRS	10.40-12.50	60
			7 SWIR 2	2.09-2.35	30
			8 PAN	0.52-0.90	15
2014-10-09	128/44 128/45	Landsat 8 OLI	1 Aerosol	0.43-0.45	30
			2 Blue	0.45-0.51	30
			3 Green	0.53-0.59	30
			4 Red	0.64-0.67	30
			5 NIR	0.85-0.88	30
			6 SWIR 1	1.57-1.65	30
			7 SWIR 2	2.11-2.29	30
			8 PAN	0.50-0.68	15
			9 Cirrus	1.36-1.38	30
			10 TIRS 1	10.60-11.19	100
			11 TIRS 2	11.50-12.51	100
2000-02-11	n20_e102 to n20_e105 n21_e102 to n21_105 n22_e102 to n22_105 n23_e102 to n23_105 n24_e102 to n24_105	STRM DEM	-	-	30

Table A.2 Household characteristics of three case study communes in Bảo Yên District (GSO 2011).

	Điện Quan	Việt Tiến	Vĩnh Yên
Number of households	758	587	833
Number of villages	14	11	17
Average household size	4.95	4.20	5.25
Percent villages with electricity	100	100	35
Distance from commune center to District center	23	16	20
Number of schools	4	3	5
Number of villages with culture houses	4	1	17
Number of villages with radio system	2	0	5
Percent of households with water supply	42	25	35
Presence of market in commune	Yes	No	Yes
Number agricultural processing stations	13	16	30
Number of forestry processing stations	0	3	2
Percent of households granted loans under programs in 2010	49	72	52
Total loan amount under programs (million dong)	5536	7542	7775
Percent of households with land use rights	80	100	93
<i>Household assets:</i>			
Percent households with cell phone	80	82	63
Percent households with agricultural machinery	3	10	6
Percent households with electricity	97	100	82
Percent households with motorbike	80	77	61
Percent households with TV	81	89	61
<i>Main source of household income (% of households):</i>			
Agriculture, Forestry, Fishery	94	92	96
Industry, Construction	0	2	0
Trade, transportation, other services	5	6	4
<i>Household Ethnicity:</i>			
Kinh	85	282	27
Tày	147	243	569
Hmong	176	0	230
Yao	341	2	7
Other	9	60	0

APPENDIX B LANDSCAPE METRICS

Where MN=mean, AM=area weighted mean, RA=range, SD=standard deviation and CV=coefficient of variation. Unless otherwise indicated, AM is used for metric interpretation to provide a landscape-centric perspective of landscape structure.

Table B.1 Area and edge metrics

CLASS	CA	PLAND	NP	PD	LPI	TE	ED	AREA_MN	AREA_AM	AREA_MD	AREA_RA	AREA_SD	AREA_CV
1999													
W	2617.25	0.22	58.00	0.00	0.13	661605.00	0.55	45.12	955.54	8.37	1565.12	202.69	449.17
BU	515.54	0.04	921.00	0.08	0.01	361815.00	0.30	0.56	17.18	0.20	88.63	3.05	544.88
BS	158207.51	13.13	26585.00	2.21	2.04	38686590.00	32.11	5.95	7691.07	0.56	24558.93	213.86	3593.60
S	270980.17	22.49	25852.00	2.15	9.14	69502935.00	57.69	10.48	50115.53	0.45	110107.35	724.71	6913.84
CC	53340.84	4.43	21820.00	1.81	0.29	18669945.00	15.50	2.44	503.58	0.27	3524.29	35.00	1431.77
OC	123697.55	10.27	36901.00	3.06	1.00	48660330.00	40.39	3.35	1658.11	0.38	12060.54	74.48	2221.81
2014													
W	3506.49	0.29	249.00	0.02	0.13	810960.00	0.67	14.08	810.04	1.46	1591.65	105.87	751.81
BU	10928.99	0.91	8660.00	0.72	0.17	5271705.00	4.38	1.26	595.37	0.23	2007.54	27.38	2169.71
BS	100940.27	8.38	33000.00	2.74	0.55	35491875.00	29.46	3.06	1183.02	0.41	6679.76	60.08	1964.08
S	91861.49	7.63	84560.00	7.02	0.04	67166190.00	55.75	1.09	23.10	0.18	511.00	4.89	450.11
CC	344604.92	28.60	41585.00	3.45	12.77	72445215.00	60.14	8.29	72346.46	0.07	153824.54	774.24	9343.11
OC	57516.71	4.77	65881.00	5.47	0.02	35791875.00	29.71	0.87	6.91	0.43	279.09	2.30	262.90

Table B.1 (continued) Area and edge metrics

CLASS	GYRATE_MN	GYRATE_AM	GYRATE_MD	GYRATE_RA	GYRATE_SD	GYRATE_CV
1999						
W	855.02	9590.59	327.41	15015.96	2022.92	236.59
BU	28.32	218.36	19.13	920.60	38.69	136.61
BS	54.32	4211.02	32.39	11737.45	144.98	266.91
S	55.50	11027.39	30.66	20707.04	193.99	349.55
CC	41.69	906.33	24.00	3612.71	79.68	191.13
OC	50.02	1591.86	28.86	7326.97	98.88	197.65
2014						
W	246.50	8148.51	68.84	14887.98	1083.87	439.70
BU	38.17	1441.80	20.29	4150.95	105.50	276.41
BS	48.87	2401.09	27.81	11288.23	142.79	292.21
S	41.85	250.43	21.98	1508.93	61.08	145.93
CC	34.10	15556.03	12.65	30036.87	191.59	561.83
OC	39.62	104.39	31.40	930.81	32.77	82.73

Table B.2 Shape and core metrics

CLASS	SHAPE_MN	SHAPE_AM	SHAPE_MD	SHAPE_RA	SHAPE_SD	SHAPE_CV	FRAC_MN	FRAC_AM	FRAC_MD	FRAC_RA	FRAC_SD	FRAC_CV
1999												
W	4.30	11.88	3.73	14.64	2.63	61.23	1.22	1.31	1.23	0.36	0.08	6.53
BU	1.31	3.49	1.20	10.52	0.50	38.08	1.07	1.16	1.06	0.36	0.05	4.62
BS	1.53	25.59	1.33	57.74	0.95	62.54	1.09	1.30	1.08	0.43	0.05	4.58
S	1.65	89.05	1.38	165.45	1.67	101.71	1.10	1.40	1.09	0.49	0.06	5.40
CC	1.51	7.55	1.33	19.58	0.78	51.25	1.09	1.24	1.08	0.37	0.06	5.31
OC	1.64	17.29	1.39	69.32	1.16	70.38	1.10	1.29	1.09	0.46	0.06	5.62
2014												
W	2.18	9.91	1.77	12.86	1.60	73.42	1.13	1.28	1.12	0.33	0.08	6.93
BU	1.40	9.90	1.17	21.93	0.97	69.20	1.07	1.24	1.05	0.44	0.07	6.56
BS	1.44	15.43	1.22	56.07	0.99	68.56	1.07	1.27	1.06	0.45	0.06	5.34
S	1.75	4.91	1.33	16.25	1.16	65.96	1.11	1.24	1.10	0.44	0.09	8.54
CC	1.67	62.90	1.25	97.70	1.55	92.48	1.10	1.40	1.08	0.45	0.10	9.06
OC	1.49	2.15	1.38	9.18	0.46	30.84	1.09	1.14	1.09	0.32	0.05	4.89

Table B.2 (continued) Shape and core metrics

CLASS	PARA_MN	PARA_AM	PARA_MD	PARA_RA	PARA_SD	PARA_CV	CIRCLE_MN	CIRCLE_AM	CIRCLE_MD	CIRCLE_RA	CIRCLE_SD	CIRCLE_CV
1999												
W	501.37	263.23	484.56	952.87	177.58	35.42	0.89	0.98	0.95	0.66	0.15	16.47
BU	1209.46	707.37	1142.86	2375.99	476.55	39.40	0.58	0.74	0.58	0.93	0.17	28.66
BS	831.02	246.68	740.74	2578.07	413.35	49.74	0.59	0.77	0.59	0.97	0.13	22.58
S	997.74	259.37	888.89	2537.75	518.96	52.01	0.60	0.79	0.62	0.94	0.15	25.68
CC	1182.69	360.48	1111.11	2566.70	556.85	47.08	0.60	0.75	0.62	0.94	0.17	29.21
OC	1069.06	399.89	969.70	2522.64	533.53	49.91	0.61	0.76	0.62	0.97	0.16	26.74
2014												
W	846.34	242.93	606.06	2576.37	635.02	75.03	0.72	0.95	0.76	1.00	0.22	30.43
BU	1314.27	484.91	1066.67	2524.62	715.31	54.43	0.52	0.81	0.53	1.00	0.24	46.77
BS	972.36	355.12	800.00	2533.65	578.61	59.51	0.57	0.81	0.58	0.98	0.18	32.72
S	1656.96	736.62	1666.67	2480.69	787.14	47.51	0.54	0.78	0.66	0.99	0.32	58.84
CC	2006.14	213.88	2000.00	2566.00	701.69	34.98	0.46	0.80	0.62	0.97	0.35	75.18
OC	1055.97	628.10	888.89	2485.28	549.99	52.08	0.62	0.69	0.65	0.96	0.18	28.87

Table B.2 (continued) Shape and core metrics

CLASS	CONTIG_MN	CONTIG_AM	CONTIG_MD	CONTIG_RA	CONTIG_SD	CONTIG_CV	PAFRAC	TCA	CPLAND	NDCA	DCAD
1999											
W	0.78	0.89	0.79	0.42	0.08	10.04	1.79	177.03	0.01	105.00	0.01
BU	0.49	0.70	0.50	0.88	0.19	38.54	1.38	0.29	0.00	1.00	0.00
BS	0.65	0.89	0.68	0.96	0.17	26.05	1.40	25593.71	2.12	4448.00	0.37
S	0.58	0.89	0.62	0.94	0.21	35.51	1.42	24635.27	2.04	9737.00	0.81
CC	0.50	0.85	0.53	0.96	0.22	42.97	1.40	4513.05	0.37	1369.00	0.11
OC	0.55	0.83	0.59	0.94	0.21	38.21	1.44	2500.65	0.21	2606.00	0.22
2014											
W	0.65	0.90	0.74	0.96	0.23	35.99	1.48	314.10	0.03	139.00	0.01
BU	0.47	0.79	0.54	0.94	0.26	54.60	1.42	1246.43	0.10	143.00	0.01
BS	0.59	0.85	0.65	0.94	0.22	36.51	1.39	4936.77	0.41	2244.00	0.19
S	0.35	0.69	0.29	0.92	0.28	79.10	1.50	200.05	0.02	352.00	0.03
CC	0.23	0.91	0.17	0.96	0.24	106.21	1.54	123163.85	10.22	6561.00	0.54
OC	0.56	0.73	0.61	0.92	0.21	37.51	1.36	83.27	0.01	158.00	0.01

Table B.2 (continued) Shape and core metrics

CLASS	TCA	CPLAND	NDCA	DCAD	CORE_MN	CORE_AM	CORE_RA	CORE_SD	CORE_CV	CAI_MN	CAI_AM	CAI_RA	CAI_SD	CAI_CV
1999														
W	177.03	0.01	105.00	0.01	3.05	105.01	175.46	22.84	748.16	0.24	6.76	11.21	1.47	621.08
BU	0.29	0.00	1.00	0.00	0.00	0.01	0.29	0.01	3033.15	0.00	0.06	3.08	0.10	3033.15
BS	25593.71	2.12	4448.00	0.37	0.96	1864.31	6407.64	52.72	5475.91	0.15	16.18	46.98	1.49	1006.25
S	24635.27	2.04	9737.00	0.81	0.95	5833.53	12794.31	84.41	8857.83	0.10	9.09	30.50	1.01	957.87
CC	4513.05	0.37	1369.00	0.11	0.21	110.99	1018.82	8.33	4025.46	0.08	8.46	45.28	1.07	1408.68
OC	2500.65	0.21	2606.00	0.22	0.07	72.71	560.97	3.46	5106.93	0.03	2.02	24.42	0.44	1403.93
2014														
W	314.10	0.03	139.00	0.01	1.26	97.62	199.96	13.17	1043.90	0.51	8.96	46.32	3.70	722.72
BU	1246.43	0.10	143.00	0.01	0.14	167.39	739.26	8.40	5836.00	0.04	11.40	41.83	0.86	2318.86
BS	4936.77	0.41	2244.00	0.19	0.15	111.36	803.09	6.70	4481.35	0.05	4.89	42.58	0.71	1433.88
S	200.05	0.02	352.00	0.03	0.00	0.48	68.24	0.24	10281.59	0.00	0.22	16.51	0.15	3457.14
CC	123163.85	10.22	6561.00	0.54	2.96	38484.02	83931.41	414.98	14011.28	0.05	35.74	54.56	0.95	1881.93
OC	83.27	0.01	158.00	0.01	0.00	0.18	18.81	0.11	8416.33	0.00	0.14	11.66	0.12	3931.27

Table B.3 Aggregation metrics

CLASS	PROX_MN	PROX_AM	PROX_MD	PROX_RA	PROX_SD	PROX_CV	ENN_MN	ENN_AM	ENN_MD	ENN_RA	ENN_SD	ENN_CV
1999												
W	306.50	438.94	0.00	13916.40	1813.82	591.78	2125.61	498.81	821.60	14098.26	2932.75	137.97
BU	13.95	22.99	0.00	999.13	94.04	673.99	421.84	210.88	138.29	8335.27	803.40	190.45
BS	8412.02	39897.17	6.73	289055.73	33715.38	400.80	81.94	38.33	60.00	2088.61	81.92	99.97
S	101019.22	100352.93	63.44	1225670.05	268355.03	265.65	60.34	32.57	45.00	916.07	49.38	81.84
CC	386.50	909.87	3.27	39170.28	2299.84	595.04	97.72	41.89	47.43	4995.56	154.82	158.44
OC	2635.58	8277.29	12.33	143270.25	13671.06	518.71	71.96	38.62	45.00	2078.18	75.89	105.46
2014												
W	183.22	89.06	0.00	14152.58	1128.78	616.09	868.98	253.73	150.00	14406.74	1841.67	211.94
BU	344.32	799.29	0.40	22351.00	2034.46	590.87	176.03	74.19	76.49	4667.71	280.04	159.09
BS	1268.07	6160.46	3.28	74907.57	5542.15	437.05	89.34	43.77	63.64	1888.24	86.78	97.14
S	72.19	185.31	17.13	4544.64	180.40	249.89	49.60	40.96	33.54	2070.86	46.77	94.29
CC	177489.13	111331.13	794.33	1733571.56	439418.23	247.57	39.74	30.57	33.54	676.12	24.60	61.90
OC	7.94	28.45	1.94	2516.11	38.73	487.60	77.02	65.48	61.85	1608.02	57.51	74.67

Table B.3 (continued) Aggregation metrics

CLASS	CLUMPY	PLADJ	IJI	CONNECT	COHESION	DIVISION	MESH	SPLIT	AI	NLSI	LSI
1999											
W	0.90	90.13	45.08	0.42	99.19	1.00	2.08	580323.80	90.39	0.10	33.62
BU	0.74	73.47	25.12	0.07	92.52	1.00	0.01	163869045.02	73.96	0.26	40.12
BS	0.89	90.75	14.92	0.01	99.66	1.00	1010.03	1192.75	90.78	0.09	245.27
S	0.87	90.27	49.63	0.01	99.91	0.99	11272.72	106.87	90.30	0.10	337.54
CC	0.86	86.48	20.14	0.01	98.24	1.00	22.30	54030.38	86.54	0.13	208.10
OC	0.83	85.00	45.59	0.01	99.15	1.00	170.25	7075.98	85.04	0.15	351.57
2014											
W	0.91	90.89	16.37	0.28	99.10	1.00	2.36	510956.56	91.12	0.09	35.94
BU	0.82	81.82	33.75	0.01	98.19	1.00	5.40	223047.20	81.93	0.18	126.72
BS	0.86	86.68	39.60	0.00	99.16	1.00	99.12	12153.62	86.72	0.13	282.00
S	0.70	72.38	51.16	0.00	94.47	1.00	1.76	684073.20	72.41	0.28	558.03
CC	0.89	91.98	51.15	0.01	99.89	0.98	20694.63	58.21	92.00	0.08	313.85
OC	0.75	76.45	14.73	0.00	89.33	1.00	0.33	3653044.80	76.49	0.24	376.55

Table B.4 Diversity metrics

YEAR	PR	PRD	RPR	SHDI	SIDI
1999	6	0.0005	100	1.23	0.6208
2014	6	0.0005	100	1.2768	0.6859