THESIS

AGRARIAN TRANSITION IN THE UPLANDS OF CENTRAL VIETNAM: DRIVERS OF MARKET-ORIENTED LAND-USE AND LAND-COVER CHANGE

Submitted by

Kirk Saylor

Department of Anthropology

In partial fulfillment of the requirements

For the Degree of Master of Arts

Colorado State University

Fort Collins, Colorado

Spring 2019

Master's Committee:

Advisor: Stephen Leisz

Kathleen Galvin
Randall Boone

ABSTRACT

AGRARIAN TRANSITION IN THE UPLANDS OF CENTRAL VIETNAM: DRIVERS OF MARKET-ORIENTED LAND-USE AND LAND-COVER CHANGE

This study presents an analysis of changing land-use and land-cover in the North-Central Coast region of Vietnam in recent decades, during which rural upland communities have become partially integrated into commodity markets. Market integration has resulted from the extension of transportation network infrastructure under the East-West Economic Corridor (EWEC) project completed in mid-2006. This project has improved market connectivity and accessibility between rural and urban areas, creating flows of goods, information, and money induce agrarian transition and influence land-use / land-cover change processes. Analysis of satellite imagery over the last decade shows some signs of possible agricultural intensification along the Highway 9 corridor, while elsewhere in the study area a clear and consistent trendline cannot be ascertained. Confounding factors include usability of imagery, temporal gaps in collection, and the resolution of available and usable imagery. The pattern of changing land-cover emerging along Highway 9 is hypothesized to result from changing land rents, where lower transportation costs and higher agricultural prices increase the profitability of cash cropping, incentivizing local populations to engage in market-oriented production. Such a microeconomic response would be consistent with von Thünen's extrinsic theory of land rent, as well as the multi-scalar frameworks of teleconnections and telecoupling. These dynamics are explored at the village level through a spatially explicit agent-based model that simulates household decision-making using empirically-fitted rules, to better understand the process of transition from subsistence cropping to a mixed mode of production with cash cropping.

ACKNOWLEDGEMENTS

The author wishes to acknowledge first and foremost his appreciation for two key scholars – CSU faculty advisor (Prof. S.J. Leisz) and his former graduate student (E. Rounds) - for their previous work illuminating the dynamics for the study area as relates to land-use – along with other scholars, past and present, who have built upon one another's fieldwork and research efforts (many, but not all of whom, are cited in this paper). Much gratitude is also extended to committee members - Prof. R. Boone and Prof. K. Galvin - for their kind and generous support throughout. Prof. A. Bliss also volunteered considerable assistance in various aspects of this endeavor, as did J. Norman and S. Filippelli on numerous occasions. Thanks are also owed to the Digital Globe Foundation for extending an imagery grant. Last, but not least, the author thanks his spouse and family for their material and moral support in this endeavor.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1: Background of study area and theoretical frameworks

This thesis investigates changing land-use systems and land-cover patterns associated with processes of road-enabled market integration in the rural uplands of central Vietnam occurring since approximately 2007. The first chapter presents a general background on the human and physical geography of the study area and introduces two key theoretical frameworks. The second chapter explores available satellite imagery to assess land-use / cover changes at the district level from 2001 to 2014. The third chapter presents a spatially-explicit, agent-based simulation model at the village level, which is used to explore the emergence of land-cover changes arising from household decision-making with a shift from subsistence cropping to partial market integration, built on the assumption that households exercise bounded rationality in allocating labor and land to meet food needs by cropping dry rice and income generation through cash cropping.

1.1 Introduction

Đa Krông ("Big River") District, Quảng Trị Province is situated in the uplands of north-central Vietnam. This chapter examines the physical and human geography of this area, with attention to the Van Kieu ethnic minority population. The rural populations of this area have been undergoing a process of agrarian transition involving the production of cash crops, in the context of transportation network upgrades and associated processes of market integration. Market integration appears an inevitable reality, to which local populations have been adapting their land-use systems in a more market-oriented manner. Despite the legacies of deeply rooted colonial practices and centrally-planned communist policies during the 20th century, market forces may be emerging in the early 21st century as the most important factor affecting land-use systems, patterns of land-cover change, and livelihoods.

In order to better comprehend this ongoing process of agrarian transition, the chapter presents two theoretical frameworks relevant to understanding land-use and land-cover change. The first framework considered is von Thünen's theory of land rent, a place-based microeconomic perspective that retains relevance nearly 200 years since initial publication. The second is the "teleconnections" framework and its successor "telecoupling", which provides a broader perspective on systems operating at multiple spatial scales beyond the local-scale – provincial, national, regional, and international - that influence the direction and magnitude of developments at the local-scale. These frameworks are considered mutually complementary, by acknowledging proximate and distal causes of change respectively. Their practical relevance will be considered in the analysis of the direction and magnitude of land-use and land-cover change presented in Chapter 2.

1.2 Background of study area

The land and peoples of Đa Krông District, Quảng Trị Province, Vietnam, constitute the key unit of analysis for this study. The administrative unit encompasses a rural area located in the uplands of the north-central coastal region of Vietnam (Figure 1 and Figure 2).

Figure 1: Regional-scale map showing Quảng Trị Province, Vietnam

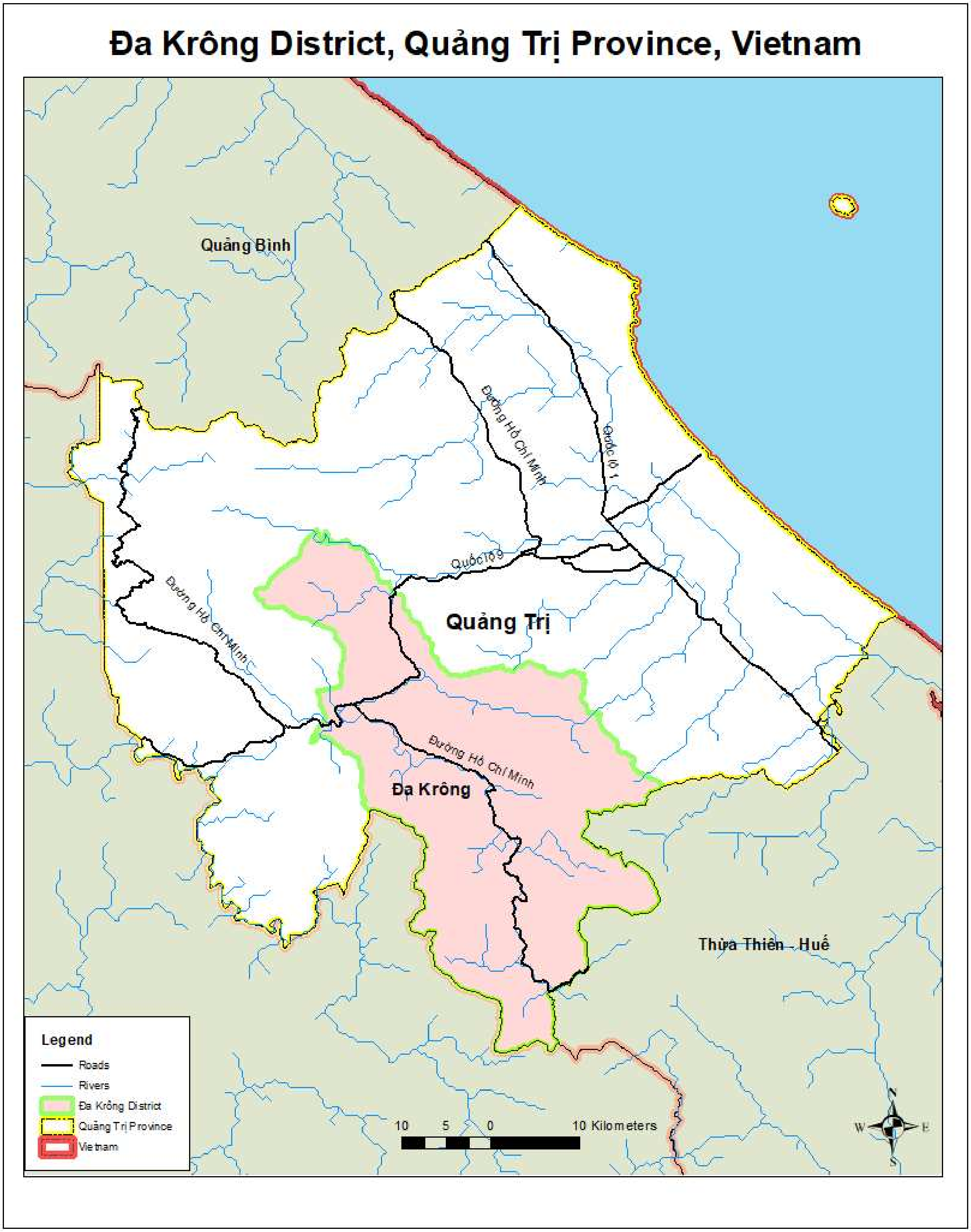


Figure 2: Provincial-scale map showing Đa Krông District, Quảng Trị Province, Vietnam

1.2.1 Human geography

The study area is inhabited primarily by the Van Kieu ethnic minority, commonly referred to as the "Bru" in ethnographic records (which translates literally as "People"), who span the uplands of Quảng Trị Province and neighboring areas of Laos (Mole 1970). The Van Kieu are one of several ethnic populations affiliated with the Mon-Khmer language family inhabiting this region, who have traditionally made their living through shifting cultivation practices, supplemented by fishing, hunting, and gathering from nearby forest areas. The Van Kieu are primarily concentrated in the Khe Sanh region west of Đa Krông District, near the border with neighboring Laos, and more importantly for the purposes of this study straddle both sides (i.e., north and south) of Highway 9 ("Quốc lộ 9") (Mole 1970).

The historical origins of the Van Kieu in the uplands of the Annamite Cordillera (Trường Sơn Mountains) before the mid-1960s remains obscure, with some speculation that they may have relocated from lowland areas under duress (McElwee 2008). This minority group, like others, was adversely affected by conflicts with French colonialists, Japanese occupiers, and later American armed forces, sustaining significant losses in terms of lives, livelihoods, and property during the First and Second Indochina Wars (McElwee 2008). Vargyas (2001) characterized these conflicts as having been disastrous for local populations due to the destruction inflicted on their agricultural systems, as well as losses of tangible items and intangible culture. Such impacts, however, forced local populations into a state of economic autarchy, which "facilitated the reconstruction of the traditional way of life and the reassertion of its values" (Vargyas 2001: 200). This post-war era thus saw a revival in traditional cultural practices amongst this marginalized ethnic minority, who maintain reverence for a pantheon of forest spirits.

Demographic estimates for the Van Kieu and other ethnic minorities inhabiting this region vary widely over time and across space at the national level (Table 1).

Table 1: Demographic distribution of ethnic minority populations (McElwee 2008: 85)

Ethnic Group(s)	**Est. population in Vietnam (1962)**	**Vietnamese Census (1999)**	**Est. population outside Vietnam (2008)**	**State(s)**
Ka Tu / Co Tu / Katu	25,000-30,000	50,458	15,000-20,000	Lao PDR
Ta Oi / Tahoi	5,000	34,960	30,000	Lao PDR
Pa Co / Pacoh	10,000	counted as "Ta Oi"	13,000	Lao PDR
Pa Hy	*Unknown*	counted as "Ta Oi"	*Unknown*	
Van Kieu / Bru	**30,000**	**55,559**	**70,000-80,000**	Lao PDR
			5,000-10,000	Thailand

To put those demographic data into context, the most recent data available gathered at the national level for Vietnam, through the census of 2009, shows that ethnic minority populations appear relatively fewer in number compared to the majority Kinh ethnicity and often reside in relatively lower density administrative units. Đa Krông District has comparatively lower levels of overall population and higher average household size relative to most other districts within the province, e.g., those in the east, which are smaller in area but more densely settled (Table 2).

Table 2: Demographic data for Đa Krông District, 2009 (World Bank 2015)

District	Population (N)	Households (N)	Average Household Size
Cam Lo	44,418	10,737	4.14
Con Co	91	28	3.25
Đa Krông	**36,413**	**7,963**	**4.57**
Dong Ha	84,063	21,759	3.86
Gio Linh	71,705	16,284	4.40
Hai Lang	85,128	21,923	3.88
Huong Hoa	74,105	14,744	5.03
Quảng Trị	22,701	6,053	3.75
Trieu Phong	94,023	27,033	3.48
Vinh Linh	85,332	23,965	3.56

The relative level of socio-economic development at the district level can be measured by various indicators pertaining to education, employment, poverty, sanitation, and water supply. By these indicators, Đa Krông District stands out for its high level of agricultural employment and ranks relatively low compared nationally by various other metrics, per 2009 data (Table 3).

Table 3: Development indicators for Đa Krông District, 2009 (World Bank 2015)

Indicator	**Đa Krông District**	**Number of districts nationwide**	**Percent districts ranking below Đa Krông**
Main employment: agriculture, Rank	91	685	86.72
Main employment: non-farm self-employment, Rank	586	685	14.45
Main employment: wage work, Rank	582	685	15.04
Main light source: electricity, Rank	616	685	10.07
Poverty: GSO-WB extreme poverty headcount, Rank	660	685	3.65
Poverty: GSO-WB poverty headcount, Rank	659	685	3.80
Poverty: Population in national bottom 40 percent, Rank	663	685	3.21
Sanitation: any flush toilet, Rank	538	685	21.46
Sanitation: indoor flush toilet, Rank	564	685	17.66
Sanitation: outdoor flush toilet, Rank	399	685	41.75
Secondary school attendance: Lower [11-15 years], Rank	600	685	12.41
Secondary school attendance: Overall [11-18 years], Rank	540	685	21.17
Secondary school attendance: Upper [16-18 years], Rank	546	685	20.29
Water: indoor tap, public tap or well, Rank	509	685	25.69

Quảng Trị Province also had relatively low overall population levels and number of households compared with most other provinces (less than half the national average) nationally, as well as relatively high levels of poverty as measured by various indices (Table 4).

Table 4: Demographic and poverty indicators for Quảng Trị Province, 2009 (World Bank 2015)

Indicator	Quảng Trị Province	National average for all provinces (mean)	Quảng Trị as % of national average
Population (N)	597,984	1,361,739	43.91
Households (N)	150,489	359,198	41.90
Working population (N)	307,838	770,091	39.97
Poverty: GSO-WB poverty headcount (%)	30	25	118.05
Poverty: GSO-WB poverty headcount (N)	179,395	267,922	66.96
Poverty: GSO-WB poverty headcount, National avg (%)	20	20	100.00
Poverty: Population in national bottom 40 percent (%)	53	46	114.90
Poverty: Population in national bottom 40 percent (N)	316,932	533,552	59.40
Poverty: Population in national bottom 40 percent, National avg (%)	39	39	100.00
Poverty: GSO-WB extreme poverty headcount (%)	11	10	112.32
Poverty: GSO-WB extreme poverty headcount (N)	65,778	87,311	75.34

With regard to the relative levels of socio-economic development of Quảng Trị province relative to national averages, Quảng Trị ranks in the bottom half compared to the other provinces (63 in total) for key indicators relating to employment and poverty levels, based on World Bank accounting of available census data for 2009 (Table 5). In other areas, such as sanitation, their ranking is more mixed. With regard to education and electrification, they rank more favorably in the upper half of the distribution.

Table 5: Socio-economic development indicators for Quảng Trị Province vs. all provinces nationally (World Bank 2015)

Indicator	**Ranking (out of 63 provinces)**
Main employment: agriculture, Rank	33
Main employment: non-farm self-employment, Rank	22
Main employment: wage work, Rank	31
Main light source: electricity, Rank	23
Poverty: GSO-WB extreme poverty headcount, Rank	47
Poverty: GSO-WB poverty headcount, Rank	47
Poverty: Population in national bottom 40 percent, Rank	47
Sanitation: any flush toilet, Rank	31
Sanitation: indoor flush toilet, Rank	18
Sanitation: outdoor flush toilet, Rank	51
Secondary school attendance: Lower [11-15 years], Rank	19
Secondary school attendance: Upper [16-18 years], Rank	9
Water: indoor tap, public tap or well, Rank	24

This situation as of 2009 as relates to rural underemployment and unemployment, and associated socio-economic issues of poverty and malnutrition, is a function of rural deficiencies in infrastructure, technology and management, despite relatively consistently high levels of economic growth following key reforms such as the Land Law of 1993, including average annual growth rates over 7 percent from 1986 to 2008 and growth of the labor force ranging from 8 to 14 percent per annum (Van Dinh et al. 2001; McCaig & Pavcnik 2013).

With regard to the population dynamics across the province for the timespan under consideration for this study, available gridded population data compiled by the European Commission (i.e., GHSL) show that there has been a gradual increase in population levels over the last few decades, primarily in the coastal regions of the province since 1975 east of Đa Krông District, with a slight increase in population along the riparian corridor traversed by Highway 9 connecting these population centers to the west. Figure 3 and Figure 4 show population levels in

2000 and 2015, as determined by the European Commission (GHSL data, 250m x 250m grid cell), and Figure 5 illustrates the net difference (gain / loss) over that timeframe. While difficult to discern at the scale of the maps presented, gaining areas occurred primarily around urban centers in more densely-settled eastern districts (e.g., Dong Ha vicinity and neighboring districts), which are undergoing rapid processes of industrialization and urbanization associated with improving international investment and trade relations (Leisz et al. 2016). While the exact magnitude of change cannot be determined with precision due to issues with the spatial and temporal resolution of available data, a general direction of change can at least be ascertained.

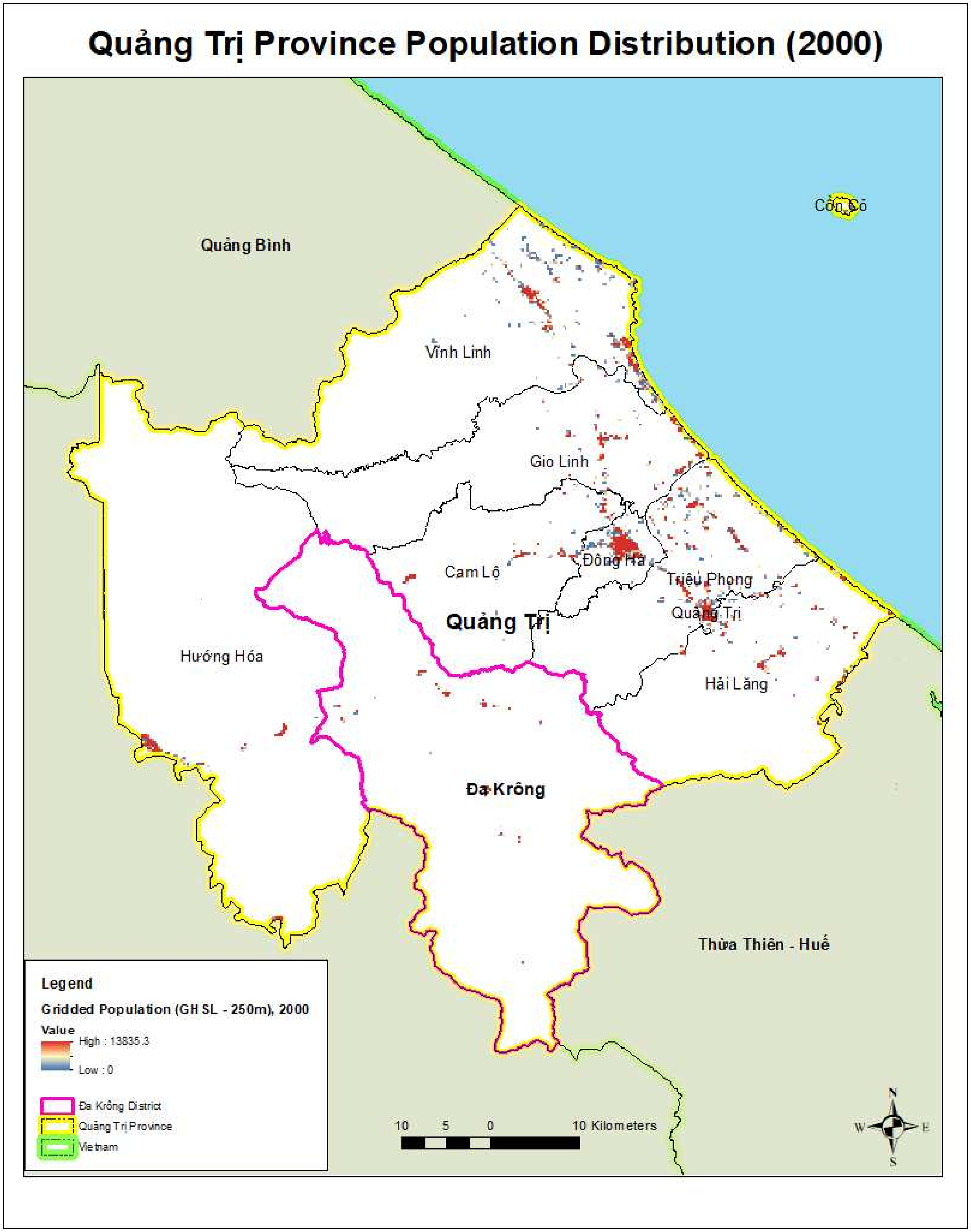


Figure 3: Estimated population distribution, 2000 (GHSL 2015)

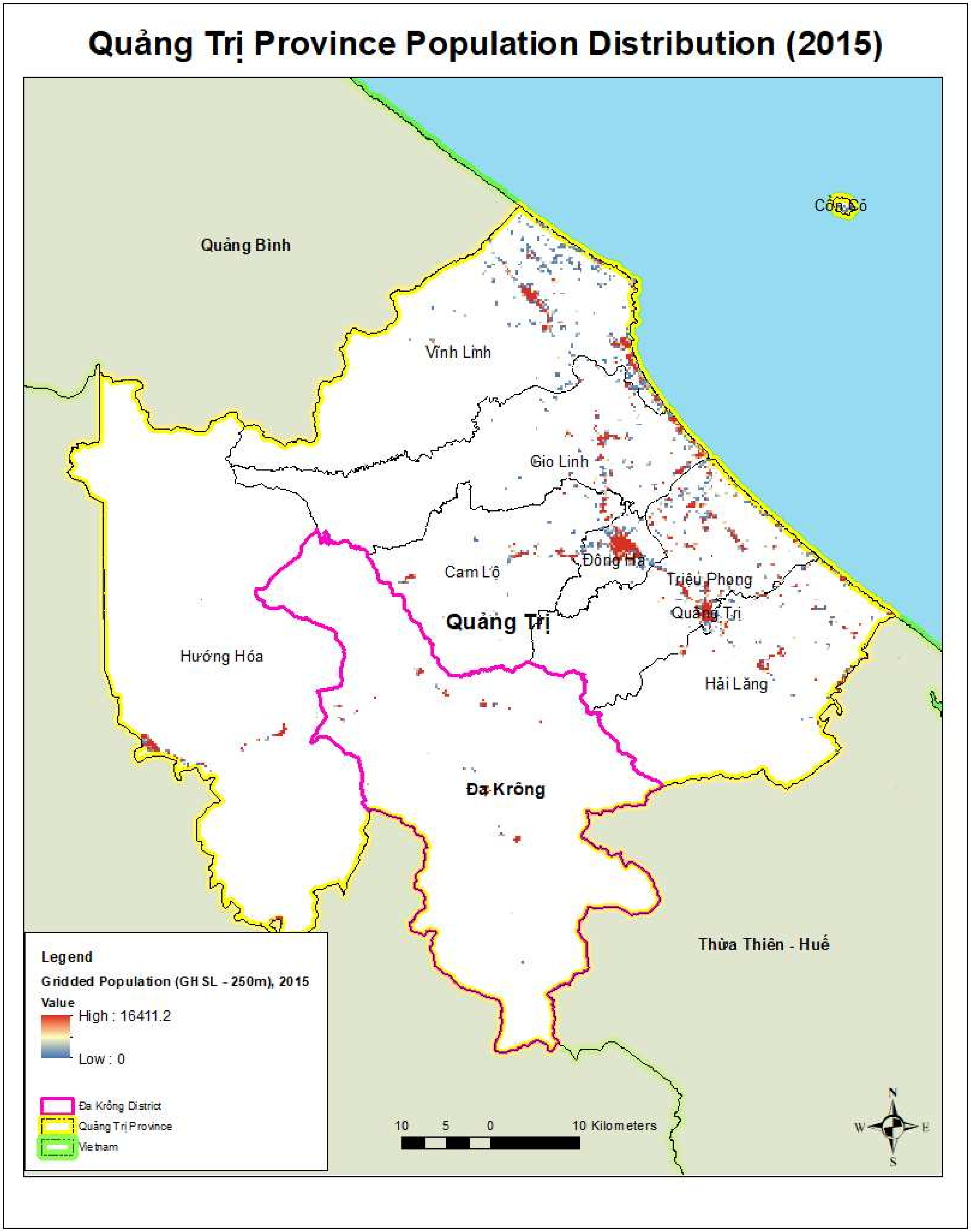


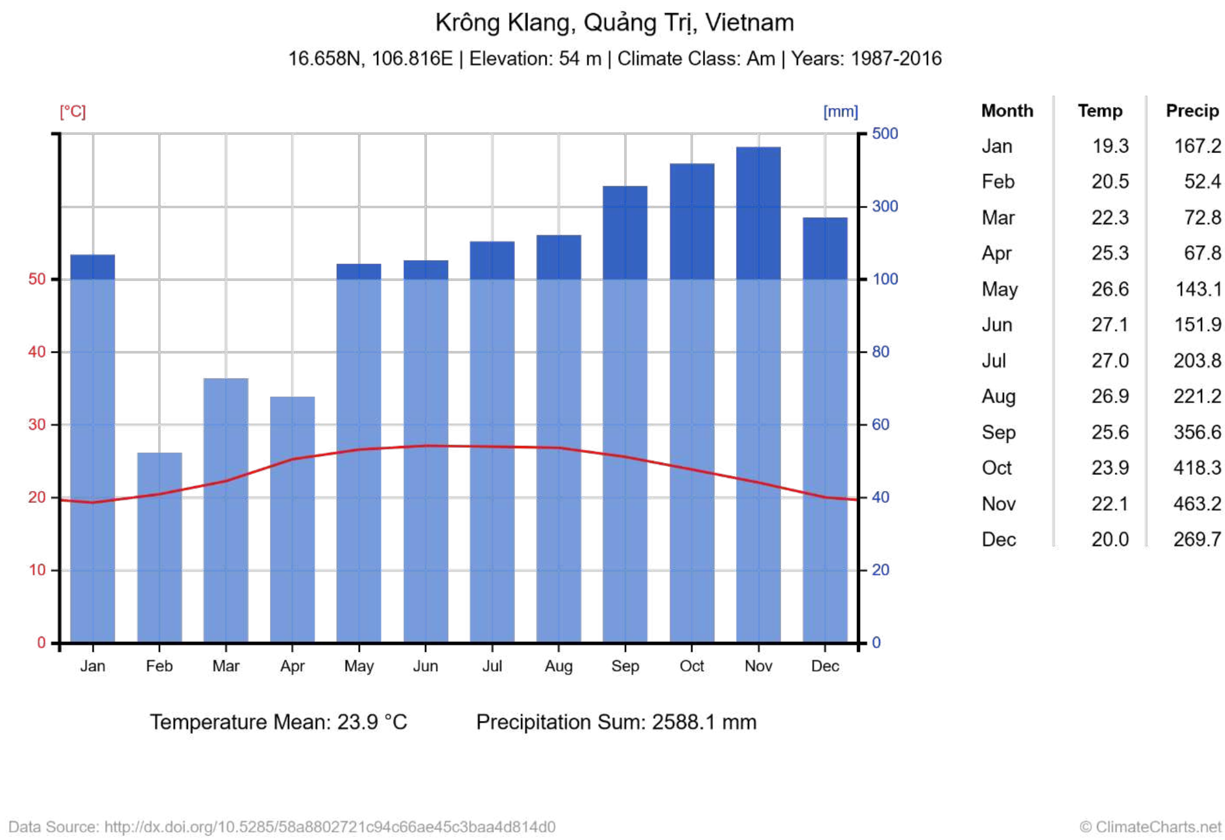
Figure 4: Estimated population distribution, 2015 (GHSL 2015)

Figure 5: Net Population Change 2000-2015 (GHSL 2015)

1.2.2 Physical geography

Đa Krông District extends approximately 60 km along its north / south axis and 25 km from east-to-west at its widest span, encompassing a total area of approximately 1100 square kilometers. Terrain elevation ranges from approximately sea level to over 1400 meters above sea level, with a high degree of variability in terms of roughness, dissection, and steepness. Average slope across the study area measures 16 degrees, ranging from a low of 5 degrees up to a maximum slope observed of 74 degrees. Three prominent mountain peaks in the surrounding area include Dong Sa Mui (1597m ASL), Dong Voi Mep (also known as "Dent du Tigre", 1774m ASL) to the north of Highway 9, and Dong Quang Ngai (2362m ASL) to the south (Mole 1970). The land-cover resulting from the management of this landscape by the local population for agriculture and agroforestry - as well as fishing, gathering, and hunting - is a highly varied patchwork, constrained by steep terrain, where slopes steeper than 40 degrees preclude cultivation due to poor soil moisture retention and high erodibility.

The study area falls in a tropical monsoon climate zone (Köppen-Geiger climate classification category "Am") with monthly mean temperatures over 18°C. Summer spans from May to October, with varying levels of monsoonal rainfall depending upon prevailing ENSO conditions, where drought or flood conditions occur from time to time. The winter seasons runs from November to April, with February, March, and April, typically seeing the least rainfall. Mole (1970) noted that rainfall in terrain at higher elevations often measures over 150 inches per year, versus ~ 60 inches per year at lower elevations. A representative climate profile for Krông Klang (106° 49' 16° 39'), a major populated place adjacent to Highway 9 in the study area, shows this general pattern of typical seasonal variation in temperature and precipitation (Figure 6).



Month	Temp	Precip
Jan	19.3	167.2
Feb	20.5	52.4
Mar	22.3	72.8
Apr	25.3	67.8
May	26.6	143.1
Jun	27.1	151.9
Jul	27.0	203.8
Aug	26.9	221.2
Sep	25.6	356.6
Oct	23.9	418.3
Nov	22.1	463.2
Dec	20.0	269.7

Figure 6: "ClimateCharts.net" climate profile for Krông Klang

Under such climate conditions, shifting cultivators traditionally clear new plots during the dry season in February, burn dried vegetation (i.e., "slash") in March, and plant crops in April (e.g., dry rice), per the customary annual cropping cycle. Taller trees with little understory are associated with primary forest cover found at higher elevations on steeper terrain. Secondary regrowth areas are characterized by shorter trees and more substantial vegetative undergrowth. The principal rivers flowing through this terrain include the Song Bo Dien flowing east to Dong Ha, the Song Quảng Trị flowing east to Quảng Trị City, and the Song Pone flowing west to the Mekong River in neighboring Laos (Mole 1970: 42-43).

The steep and highly dissected terrain of this region's physical geography has limited transportation infrastructure historically to river valley bottoms, which offer the only truly suitable corridors for transportation networks, thereby exerting influence on the region's human geography. The original Highway 9, built in 1904 under French colonial rule, extended from Dong Ha across the riparian corridor of present day Đa Krông District to Laos (McElwee 2008). An unsurfaced dirt road, it provided only dry season connectivity between the coastal regions of Quảng Trị Province and inland, upland areas of Vietnam and Laos. Within a state of relative socio-economic isolation that existed before the road upgrade project, the prevailing *modus vivendi* of villagers revolved around the shifting cultivation of staple food crops and the domestication of animals, supplemented by fishing, hunting, and gathering (Mole 1970: 55-58), with limited off-farm work opportunities. The livelihood systems during this era could be characterized as operating on the basis of the "right to subsistence" rooted in the hierarchy of human needs and associated with an agrarian ethos whereby "all members of a community have a presumptive right to a living so far as local resources will allow" and the more fortunate help those who are less well-off (Scott 1976: 176).

To provide more current context on the relative degree of market integration and isolation, Verburg et al. (2011) estimate market access globally at fairly coarse spatial resolution. Their data provide a general sense of relative levels of market integration for Vietnam. The major metropolitan areas of Hanoi and Ho Chi Minh City, which are shaded red, rate high on the spectrum, whereas the study area (north-central coastal region) bounded in green below, is shaded blue and rates low on the spectrum (Figure 7 and Figure 8).

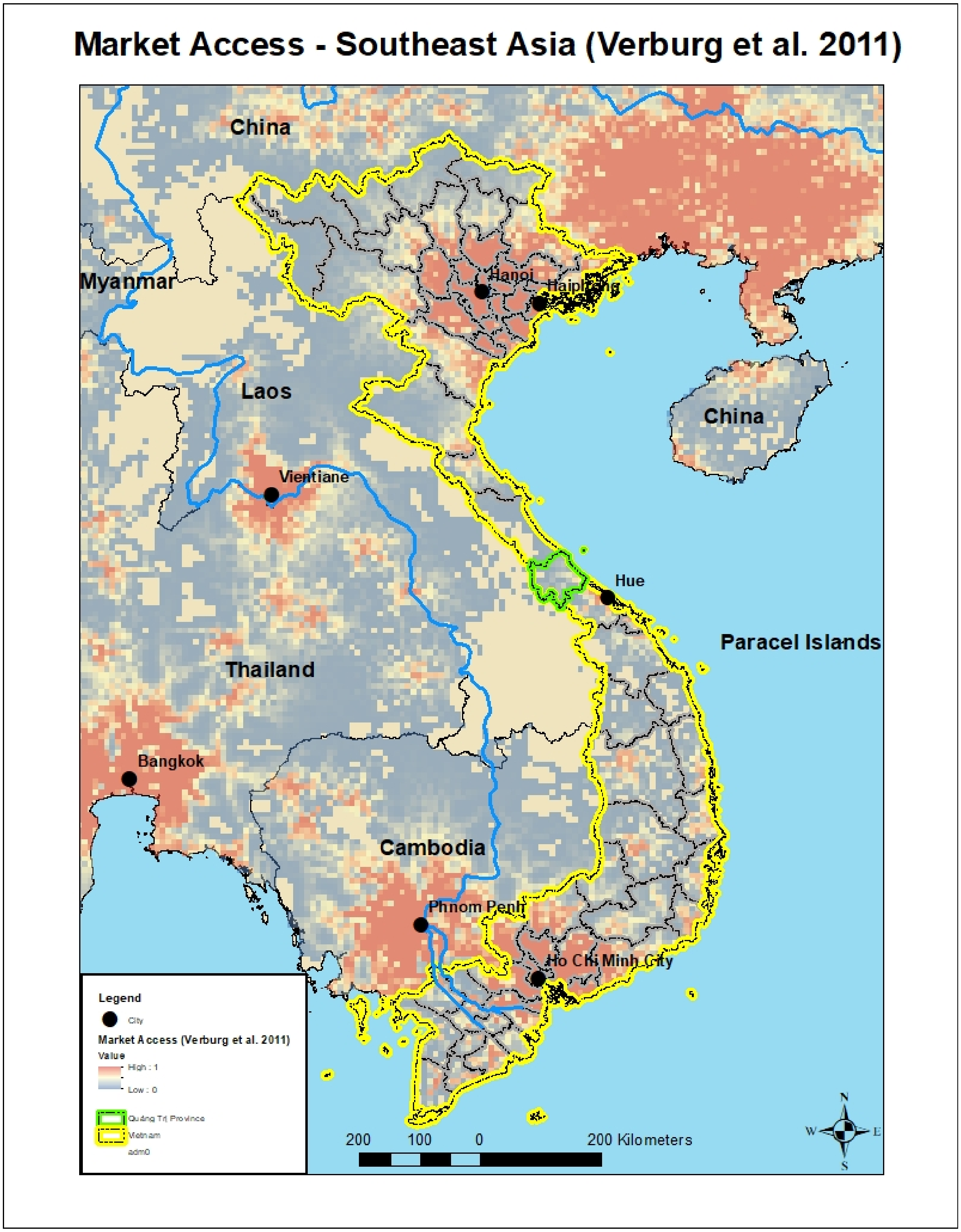


Figure 7: Regional-scale map of market access for Southeast Asia (Verburg et al. 2011)

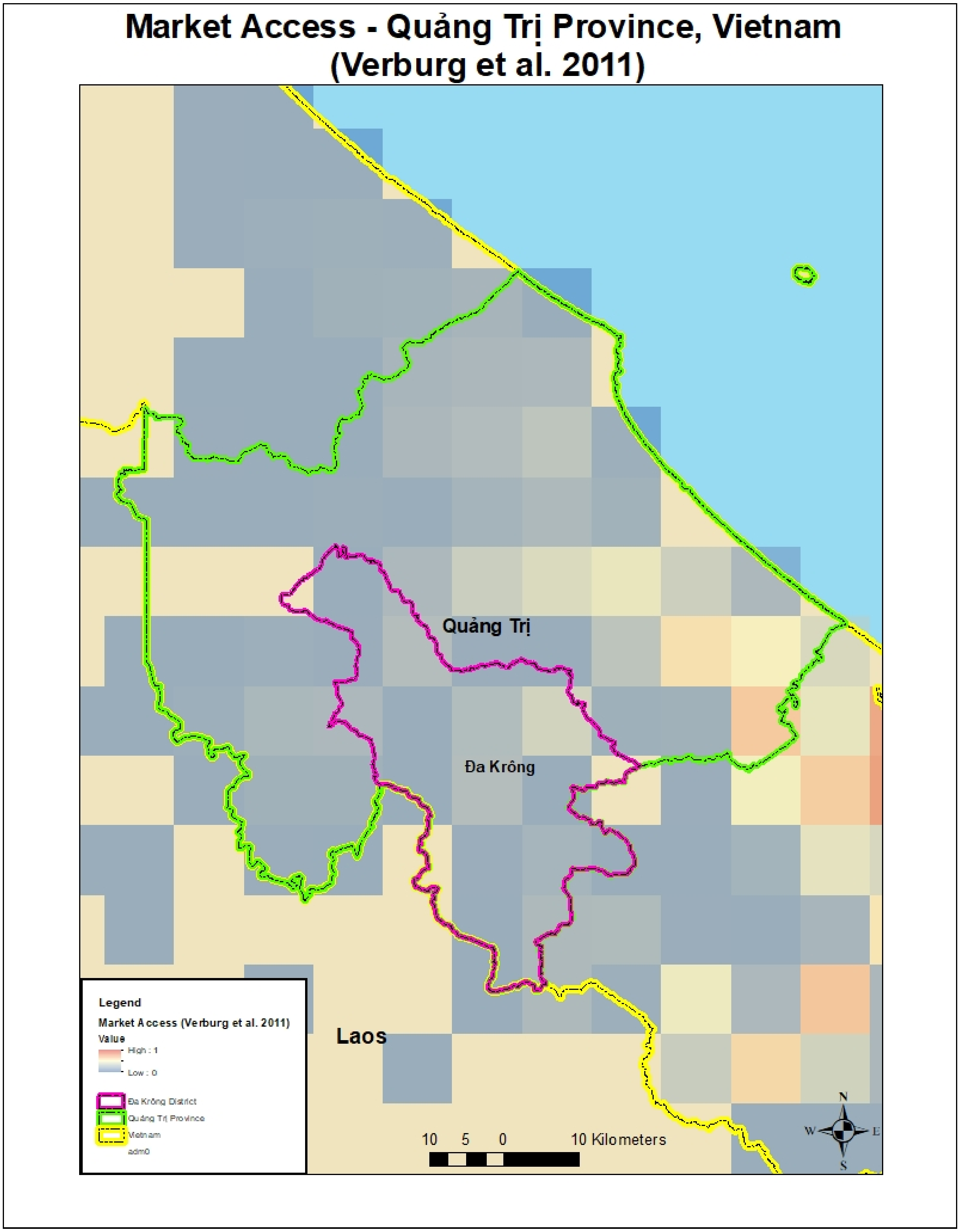


Figure 8: Provincial-scale map of market access for Quảng Trị Province, Vietnam (Verburg et al. 2011)

The improvement of Highway 9 by widening, grading, and paving with asphalt, occurred in mid-2006 as part of the East-West Economic Corridor (EWEC) project. This project aims to promote "greater cooperation by linking production and trade through infrastructure" (Ishida & Isono 2012: 11). The EWEC was given high priority by the Asia Development Bank (ADB) in 2000, as part of the Greater Mekong Subregion (GMS) program (Ishida & Isono 2012). Financial sponsors include the ADB and Japan International Cooperation Agency (JICA), with the government of Vietnam providing support and oversight (Leisz et al. 2016). The EWEC is one among several transportation corridor projects being implemented across the Southeast Asia region as part of the GSM program, which also includes the North-South Economic Corridor (NSEC) and Southern Economic Corridor (SEC) (Figure 9).

The Economic Research Institute for ASEAN (ERIA) predicts that completion of the EWEC will permit motorized travel at 80km per hour, with no delays at border crossings (Kumagai et al. 2018). ERIA projects that overall population levels of Quảng Trị Province will increase by approximately 9.8 percent from 655,000 (2005) to 719,000 by 2025 (Kumagai et al. 2018: 371). Additionally, ERIA projects economic growth to raise the overall gross domestic product (GDP) by approximately 89.6% from USD 357 million (2005) to USD 677 (by 2025) (Kumagai et al. 2018: 373). Their projections are built on a general equilibrium framework and posit the emergence of a core-periphery structure when transport costs fall sufficiently low to facilitate processes of agglomeration, overcoming tendencies toward dispersion associated with higher transportation prices (Kumagai et al. 2018). These predictions are consistent with World Bank perspectives of pro-poor rural development dating to the 1990s (Chomitz & Gray 1996).

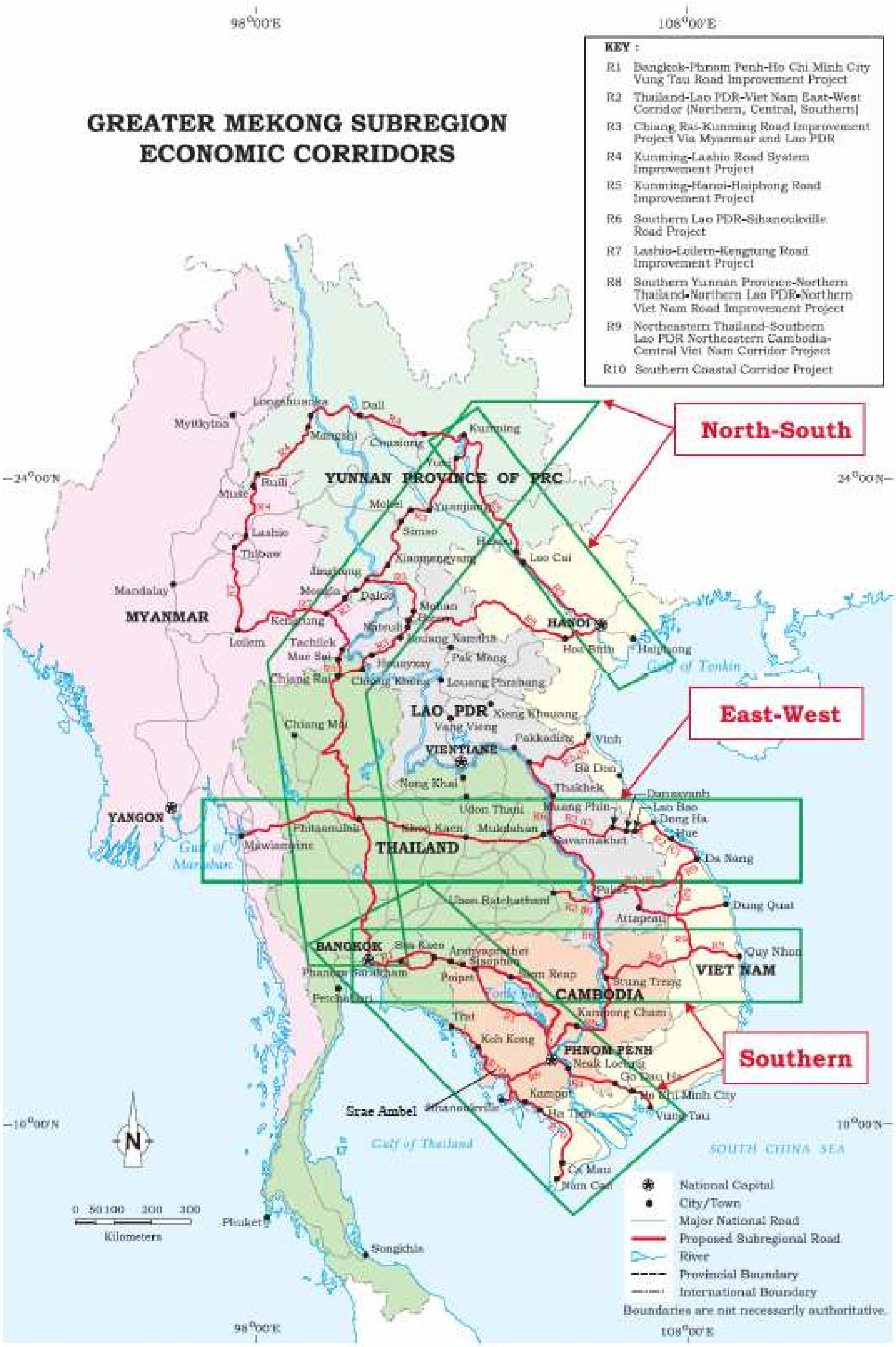


Figure 1 Three Economic Corridors in the Greater Mekong Sub-region

(Source) ADB (2002).

Figure 9: Transportation infrastructure projects between and among nations of Southeast Asia (Ishida 2009)

1.3 Literature review

1.3.1 Conceptual frameworks

The conceptual frameworks relevant to this study include J.H. von Thünen's theory of land rent, published in 1826, which concerns microeconomic dynamics on agricultural land-use on a local-scale, as well as the more recent conceptual frameworks of teleconnections and telecoupling regarding underlying drivers operating at multiple scales. Local scale land-use systems amenable to analysis in terms of microeconomic factors can be understood as rational responses by place-based actors to optimally use available factors of production (land, labor, capital), with local actors responding to the influence of exogenous forces, e.g., outside markets, on the relative value of these factors of production on their land-use systems. Local scale changes cannot be fully captured only by consideration of the local scale, however, as the system is not a closed one. The influence of outside forces must be considered in the context of meso- and macro-structures at the national, regional, and international scale, with which the rural uplands are becoming increasingly integrated. To that end, the application of a conceptual framework such as teleconnections and telecoupling is considered a necessary complement for tracing distal, underlying drivers influencing land-use systems and land-cover change.

1.3.2 Von Thünen theory of land rent

The von Thünen framework is concerned principally with agricultural decision-making concerning land-use systems based on land-rent. Land-rent is defined as the net return - or profit - of a given land-use, i.e., calculated as revenues minus costs. In this case, land rent is determined by the distance of the farm to the central marketplace. Von Thünen's theory of location-driven agriculture based of maximization of land rent was informed by detailed studies of land-use systems and land-cover in his native 19th century Germany. His theory posits that land-use at the local level, e.g., decisions related to cropping, grazing, and forestry practices, depend upon market forces and guide the optimal allocation of labor, land, and capital (von Thünen 1966). This framework predicts that concentric rings of land-use will emerge from rational economic behavior guided by agricultural land rent maximization. Land-use rings identified by von Thünen, extending outward radially from the village center, include the following:

(1) cash cropping;

(2) forestry;

(3) crop alternation system;

(4) improved system;

(5) three-field system; and

(6) stock farming.

The land-rent driven decision-making process is built on the rational agricultural actor weighing anticipated revenues against costs associated with the relevant factors of production (labor, capital, and transportation). The von Thünen framework posits that land-use patterns will be a function of rent-seeking, and the highest rents will accrue from areas in closer proximity to markets. Agricultural rent (r) equals revenues (py) minus the cost of labor, capital, and transportation ($wl - qk – vd$). Yield is y, price is p, labor is l, capital is k, wages are w, capital costs are q, transport costs are v, and distance is d (Angelsen 2010).

A review of literature illustrates the impact of upgrading infrastructure as an influence on the choice of crops a farmer will cultivate. A major reduction in distribution costs of approximately 50 percent typically results from such transportation infrastructure improvements (i.e., upgrading road surface from “dry season” to “all-season”), thereby increasing the profitability of commercial agricultural cultivation (Jacoby 2000; Angelsen 2007; Warr 2008; Brooks & Hummels 2009; Jacoby & Minten 2009; Warr 2010). This single factor – physical connectivity enabling accessibility to markets - therefore constitutes a critical driver in enabling this market-oriented development process (i.e., a necessary precondition and ongoing condition, given proper maintenance of physical infrastructure and the necessary institutional infrastructure, e.g., legal and regulatory) (Brooks & Hummels 2009: 3). In Vietnam, by facilitating connectivity to nearby demand centers, this upgrading of Highway 9 (as part of the East-West Economic Corridor Project) aligns with national goals regarding poverty reduction through income generation, while also promoting return on investment to stakeholders including those making foreign direct investments.

Land rent declines with distance, and the agricultural frontier demarcates the distance at which agricultural expansion ceases to be profitable, i.e., $r = 0$. This distance is calculated with the following equation (derived from the land rent equation): $d = (py - wl - qk) / v$.

Angelsen extends the von Thünian framework as encompassing both agricultural rent and forest rent as competing goods in a human decision-making framework, i.e., whether the use of a given plot of land is deemed more advantageous from a land-rent perspective if cleared for use in agriculture or left under tree cover and retrained as woodlands / forest, where woodlands can be used for either timber or non-timber forest products or a combination thereof. Angelsen (2007) visualized von Thünen's concentric rings in a slightly different fashion than the original publication of 1826, where each ring is defined by the relative heights (i.e., y-axis intercept) and slopes (i.e., steepness) of the associated land-rent, measured on a per hectare basis. His model differentiates between two types of agriculture (intensive and extensive) and three types of forest / woodlands (managed, open-access forests, and primary / old-growth forests). The rent curves grow relatively steeper, with higher intercepts on the rent (y) axis, as distance between the farm and central marketplace decrease (Figure 10). Angelsen acknowledges that these rings are not fixed in location, and the sequencing thereof could vary under different scenarios. Chomitz and Gray (1996: 488) posit that road impacts "will be strongly modulated by other factors affecting rent, including soil quality and distance from markets."

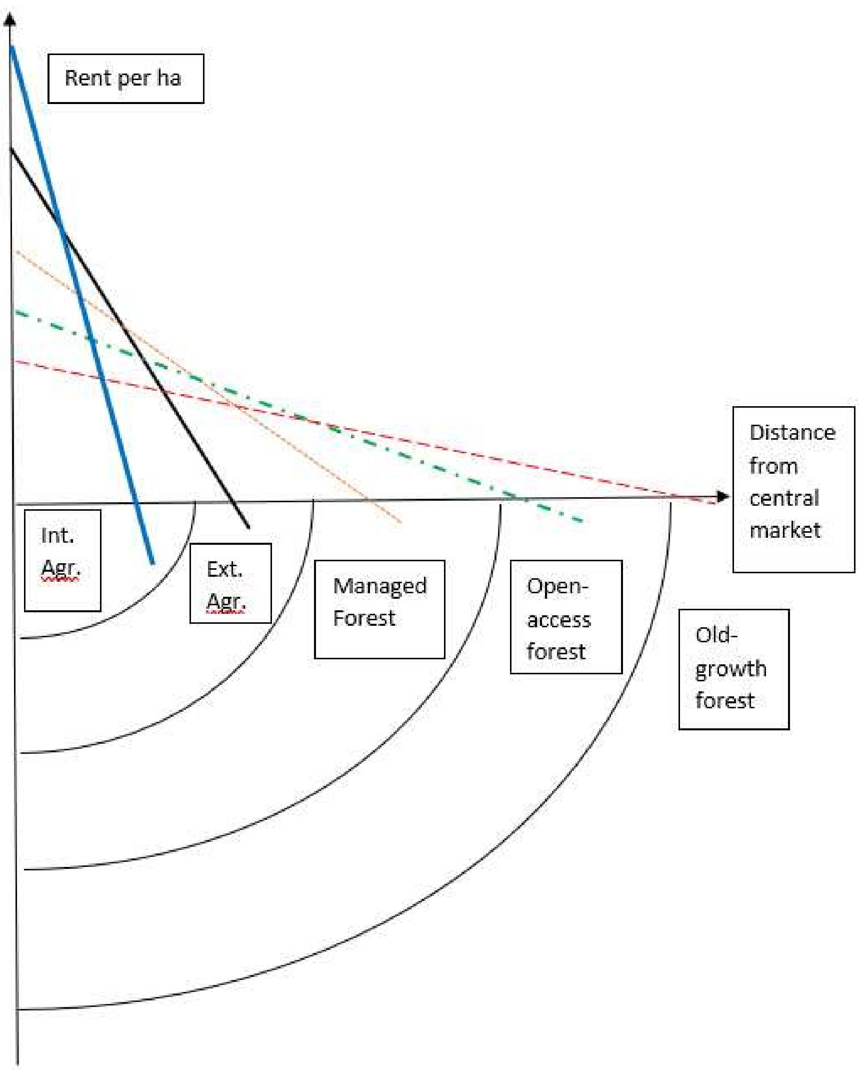


Figure 10: Concentric rings of agricultural and forest-related land-uses associated with differing land-rent per the von Thünen theory of land rent, based on Angelsen (2007)

While such economic factors are often critical, the consensus view of the land systems science community generally attributes land-cover change to one or more of following key endogenous and exogenous factors, acting alone or in combination with others (Lambin et al. 2003: 217-220):

(1) natural variability (exogenous);

(2) economic and technological factors (exogenous);

(3) demographic factors (endogenous);

(4) institutional factors (exogenous); and

(5) cultural factors (endogenous).

Lambin et al. (2003: 225-226) posit that the majority (70-90%) of observed land-use change cases are a result of the synergistic interaction of factors, while acknowledging that in a small percentage of cases that a single factor may account for the preponderance of the direction and magnitude of LULC change. Changes in land-use systems is perceived to be a function of arbitrage between the following causal elements:

(1) pressures (function of overall population, available labor, amount / type of resources available);

(2) opportunities (function of prices, production costs, transportation costs, and technology);

(3) policies (function of governance, infrastructure, property rights, subsidies, and taxes);

(4) vulnerability (function of exposure, sensitivity, coping capacity); and

(5) social organization (function of resource access, income distribution, household characteristics, and urban-rural interactions).

Given a prevailing trend in LULC change involving the conversion of forest cover or woodlands to agricultural land-use systems, Angelsen and Kaimowitz (1999) reviewed 140 economic models of deforestation and reached a consensus that the following factors are correlated discretely and more so if occurring concurrently (i.e., synergistically):

(1) higher agricultural prices;

(2) more / better roads, and

(3) low wages and shortage of off-farm employment.

These three conditions directly align with increased land rent by either raising total revenues (e.g., higher prices) or decreasing costs (e.g., lower transportation costs or holding down wages). Since agricultural commodity prices and wages tend to fluctuate, widely in some cases, transport costs may be the most critical of these variables. Whereas the friction of distance is relevant to the movement of agricultural goods from source (i.e., farm) to destination (i.e., market), improving access and connectivity through improved roads can reduce transportation costs by approximately half in many cases (Jacoby 2000; Warr 2008; Jacoby and Minten 2009). Where the inverse of any of these conditions apply, e.g., low prices, absent or deficient roads, or higher wages / better off-farm opportunities, the land-rent of agriculture will tend to diminish relative to that of forest since the profitability of agriculture declines. That is particularly true in the case where incentive structures / programs (e.g., Payments for Environment Services) are in effect.

While this land-rent oriented framework makes various simplifying assumptions relating to human agency (e.g., "absolute rationality," predicated on the availability of perfect information from an economic decision-making standpoint) and geography (e.g., a flat landscape), it did seem to characterize LULC practices in northern Europe accurately for that era (i.e., 19th century). In addition to Germany, Linnaeus describes similar patterns of land-use in southern Sweden (Dove 2015). Absolute rationality assumes "an enterprise (that) is conducted rationally (in which) the entrepreneur pursues the maximum profit and when he is possessed of all necessary knowledge to that end" (von Thünen 1966: 5). This contrasts with the notion of "bounded rationality" wherein decision-makers have imperfect information and limited time in which to evaluate. Under such conditions, satisfactory outcomes are sought as a matter of practical necessity, and this framework offers an alternative framework to absolute rationality for analysis of economic and political choice (Simon 1991; Simon 1995).

Von Thünian concepts have since found much wider application beyond the initial models pertaining to small-scale localized rural land-use systems, including but not limited to the following assortment of topics and locations: rangelands in Southwest Asia (Schaldach et al. 2013), cash crop plantations in Latin America (Furumo & Aide 2017), rural land abandonment in former Soviet states (Prishchepov et al. 2013), land-use in Amazonia (Caldas et al. 2007; Sills & Caviglia-Harris 2009; Walker 2012; Fontes & Palmer 2018), urban forests in southern Europe (Colantoni et al. 2017), urban agglomeration processes (Fujita 2012), and wetland degradation (Walker & Solecki 2004).

1.3.3 Telecoupling and teleconnections – multi-scalar drivers of LULC change trajectories

At the "macro-" and "meso-" scales, "teleconnections" and "telecoupling" provide relevant conceptual frameworks for mapping networks of socio-ecological systems (SES) and the associated flows between and among such increasingly interconnected systems on varying scales (direct and indirect, proximal and distal), often with consequential impacts on ecosystems and ecosystem services. Both frameworks seek to expand the scope of understanding beyond traditional place-based analyses conducted at the local ("micro") scale by accounting for distal forces operating at national, regional, and international ("meso" / "macro") scales and functioning as underlying drivers of change in spatially disparate locations. As a general working definition, we can consider these frameworks as explicitly accounting for "distal connections and flows" involving people, goods and services, and involving the modification of the underlying biophysical environment particularly in the context of urbanization as a system driver (e.g., land-cover as a function of land-use) (Seto et al. 2012).

Leichenko and O'Brien (2008) took a vulnerability orientation and borrowed the term "teleconnections" from climatology, but posited bidirectionality of feedbacks in terms of agent-level adaptive responses (Eakin et al. 2009; Adger et al. 2009). According to Eakin (2009: 398): "Channels that convey signals of change from the global to the local also may work in reverse, connecting the responses and choices of households in one geographic context to outcomes and choices of other households in quite distant places." Subsequent scholarship by Liu et al. (2013) adopted the term "telecoupling" and took more of a systems orientation, characterizing systems as being relationally "sending", "receiving", or "spillover" with a minimum of one-to-one connectivity between systems at a given level of the system and some minimum degree of connectivity between different levels. There is also potentially many-to-many connectivity across all levels of the system, although linkages may be asymmetrical and ephemeral / transient. This paper defines the basic components of the telecoupling framework per Liu et al., who posit that sending, receiving, and spillover systems consist of the following entities and processes:

(1) Entities (nodes and links comprising the telecoupled network):

(a) Agents (human) – functionally nodes that have definable spatial location and function

as decision-making units in the system, with varying degrees of autonomy; and

(b) Flows (material or abstract) – functional links between nodes, entailing the movements of goods, services, finances, information, or other commodity of value between agents (from sending to receiving).

(2) Processes (affecting the strength of flows between links):

(a) Causes – factors that affect supply or demand on the part of agents, or affect flows between agents, which could include developments on the one or more levels (cultural, economic, political, technological, or other);

(b) Effects – implications of reciprocal exchange agreements, including environmental and social costs previously branded as "externalities" and conveniently ignored by mainstream economists and policymakers, despite the inherent importance of such costs from a sustainability perspective. Liu et al. characterize effects as "first-order" (e.g., direct in nature / proximate in scale) as distinguished from "second-order" (e.g., indirect / diffuse or displaced).

1.3.3.1 Multi-scalar telecoupled land change: boom / bust global coffee production markets

Long-distance flows of raw materials, energy, products, people, information, and capital influence the direction and magnitude of LULC change (Friis et al. 2016). Attempts to synthesize interactions spanning oceans and interconnecting LULC change between and among the continents of the "Global South" (Africa, Asia, Latin America) and "Global North" are a logical extension of the telecoupling framework. To that end, the linkage between global markets and decisions / behaviors by local socio-ecological systems, both without formal market governance and later with informal market governance, in Southeast Asia and Latin America regarding cash cropping practices associated with coffee – and effects on socio-ecological systems resulting from such practices - receives brief consideration. With respect to the tropical forests of Latin America and Southeast Asia, there appears to have been a telecoupled systems dynamic between LULC practices in Vietnam and assorted other coffee growing nations in Latin America (Eakin et al. 2009; Eakin et al. 2017). The global coffee market, like that of many other agricultural commodities, is subject to continual flux in prices (occasionally with extreme volatility). This market has historically been dominated by producers based in Latin American – primarily Brazil, Colombia, Guatemala, and Mexico (Eakin et al. 2009). Southeast Asian nations also competing in this market have included Indonesia, the Philippines, and more recently (i.e., post-Cold War) Vietnam. The cultivation of coffee in Vietnam arose more or less spontaneously on a smallholder basis circa 1993, without the direct or active involvement of the government of Vietnam and partly in response to the collapse of the global price governance mechanism for coffee producers (the International Coffee Agreement, managed by the International Coffee Organization) that had generally constrained global coffee production, under U.S. pressure in the late 1980s (Eakin et al. 2009; Hall et al. 2011: 105; Eakin et al. 2017). Vietnamese coffee production levels rose considerably from an extent of ~ 200,000 hectares in 1999 to ~ 500,000 hectares by 2008, exceeding cultivation levels in the Southeast Asia region. In Latin America, production levels in both Colombia and Mexico fell, while Brazil maintained its status as a major producer (Eakin et al. 2009; Eakin et al. 2017).

Hall et al. (2011) posit that the availability of farmland and forestland in the Central Highlands of Vietnam was a key enabling factor for smallholders, who otherwise have very limited resources, to assume the risk of planting coffee bean plants, knowing it would take at least three - and possibly up to five - years from the time of planting to realize a harvest. The rising demand for coffee globally helped to induce intensified cultivation of this cash crop through the late 1990s. As global supplies responded to prices, an oversupply situation eventually occurred on the market due to the absence of a governance mechanism (such as the ICO had performed) amongst suppliers. Market forces triggered a price crash circa 2000, with a major drop in price to its lowest level in seventy years for a period of several years (Eakin et al. 2017). The globalization of this commodity in an unregulated market led from boom to bust with repercussions for millions of growers.

The coffee market thus appears to have been a harsh experience for all parties involved in this global agricultural commodities market (i.e., not only the Vietnamese but all other major producing nations), where growers (who were mostly smallholders) were acting on a rational basis but ultimately suffered for their efforts to diversify their livelihoods and income. The feedbacks incentivizing a cash crop boom necessarily involved LULC changes, to which Vietnamese smallholders had become committed, but the market itself (e.g., intermediaries who process the commodity and end-users consuming the product) was generally indifferent to sourcing / place of origin (i.e., a prevailing view of "food from nowhere"). Eakin et al. (2009) and Hall et al. (2011) have observed a range of impacts on social and ecological systems in the fallout from this global commodity price crash, including dispossession of lands from smallholders, influx of lowland majority populations, and environmental degradation of lands and water (Eakin et al. 2009). The end result was adverse both socio-economically and ecologically primarily for the Central Highlands of the Vietnamese landscape and its people - a region that was also a focal point of intense military conflict with outside powers during the 20th century. Late entrants to the coffee export market in Vietnam, who had taken loans before being able to realize sufficient proceeds from sale of harvested crops, suffered more than early entrants, who had in many cases already repaid their loans. What transpired involves interconnections spanning the planet, with producers operating in a vulnerable state due to the absence of a viable governance mechanism. The effects of such an unregulated marketplace on the landscapes and livelihoods of millions of smallholders cannot be understood using only a local-scale, place-based approach, given the multi-scalar feedbacks operating in this scenario. One additional feedback loop worth noting that emerged over the last decade: a grassroots movement to promote ethical product certification focused on “fair trade” and “sustainability” standards. Such certifications now extend to nearly 40% of all production of coffee crops grown globally and have thereby helped to restore / stabilize the world price of coffee to relative parity of the price preceding the major price crash circa 2001 (Eakin et al. 2017). This is non-trivial, given the objectively harmful outcomes for millions of growers caused by events in the early 2000s, which Eakin et al. characterize as a “new business culture in which socio-ecological systems are linked not merely by trade, but by a set of principles and practices embraced globally and audited by external parties” (Eakin et al. 2017).

1.3.3.2 Telecoupled LULC change at regional scale: plantation-style cropping in Southeast Asia

Two additional examples of telecoupled landscape transformation, also spurred by cash cropping, are considered at the regional level for mainland Southeast Asia. Both involve plantation-style cultivation of cash crops. The first pertains to Luang Namtha Province, Lao PDR, near the tri-border area with Myanmar and China. This area has experienced a rise in intensive cultivation of bananas as a cash crop starting in 2000, with a doubling of the area under cash crop cultivation by 2005 and a further increase of ~50% by 2010 (Friis & Nielsen 2016; Friis & Nielsen 2017). The overall yield of cash crops increased by approximately eight hundred percent (800%) over this same time period (i.e., yield rising at four times the rate of expansion in area under cultivation). This outcome reflects an intensification in cultivation practices following land acquisitions by investors based in China under the terms of six-year leases. Landscape conversions included the destruction of existing irrigation infrastructure. Land-use intensification included heavy applications of agrichemicals, such as synthetic fertilizers.

This case reflects a departure from normal pathways of transition from subsistence to market integration, and the dynamics therefore diverge from the classic von Thünen pathway. Market forces are altering land-use based on rising land rents, but the local population lacks agency in the decision-making process. The pursuit of maximum sustainable yield on behalf of exogenous stakeholders from China highlights the implications of a local population lacking clear use / access rights to land. In this case, the alienation of such use / access rights significantly impacts upon the land-use systems, landcover, and livelihoods of the local population affected by cash cropping. While telecoupling is not inherently a cause of environmental degradation and socio-economic dislocation, this is one possible outcome in the absence of effective institutions and serves as a cautionary example of market integration adversely affecting rural communities. This pathway differs markedly from what has occurred in Savannakhét province, Lao PDR – immediately west of Quảng Trị Province, Vietnam – where local populations have secure land-use / access rights and banana cultivation has not involved comparable population dislocations or environmental / ecosystem degradation (Leisz et al. 2016).

Another example of LULC change involving cash cropping driven by distal, exogenous actors, pertains to the cultivation of rubber trees in Lao PDR and Cambodia. In this case, Vietnamese investors have been actively supporting the establishment of large-scale rubber tree plantations in both neighboring states (Baird & Fox 2015). Such development can be understood within a telecoupled systems framework, where high-level flows between financiers and governments orchestrate land transfers for export-oriented production. The LULC changes associated with these commercial plantations have direct impacts on the areas where they occur and indirect, knock-on effects for socio-ecological systems elsewhere, including the displacement of local smallholders (indigenous ethnic minorities who are more rooted to their homes, and less capable of / willing to relocate than majority ethnicities in lowland areas), the in-migration of "opportunistic" laborers from outside areas to find work near such new large plantations, and ripple effects associated with lost market share by smallholders producing "jungle rubber" as a viable livelihood in other locations (Baird & Fox 2015).

As with the previous example pertaining to banana tree plantations, this case of rubber tree plantations cannot be explained or understood using only a local-scale, place-based model due to cross-scalar interactions. The sending system - comprised of investment agents in Vietnam - is physically removed from, and not organically linked with, the receiving systems - comprised of dispersed commercial plantations and industrial plants that would process the raw materials. Spillover systems include both social and ecological communities that are directly affected and / or displaced by disruptions in land access and LULC change, as well as those within a certain proximity of these plantations.

Telecoupling has a wide range of applicability beyond the foregoing examples relating to cash cropping. Other applications not addressed here include, but at not limited to, "indirect land use" (Meyfroidt et al. 2013; Yu et al 2013), "land footprints" (Bruckner et al. 2015), and nature conservation (Liu et al. 2015). Taken as a whole, this conceptual framework can be seen as a vehicle for promoting interdisciplinarity and synthesis (Kramer et al. 2017); it does so by explicitly considering reciprocal exchanges between parties in both proximity to one another and those in disparate locations, where a sending system provides a supply (of goods, services, information, etc.) to a receiving system that functions as a demand center (e.g., a rural area supplying agricultural goods to an urban center; an industrial zone supplying manufactured goods to a foreign market; a local office in the developing world performing technical support services to a multinational corporation based in Europe, Japan, or the United States).

Intermediary logistical systems enable flows by linking these supply and demand nodes, and such linkages necessarily entail both environmental and financial costs (where the former [environmental] costs are typically discounted / not acknowledged by conventional economic indicators).

The production and distribution of any good or service in the global economy, such exchanges involve spillover effects on the system vis-à-vis other relationships and their associated natural resource bases. The spillover system is therefore explicitly acknowledged by this telecoupling framework, which is an important addition to the study of these systems and one that was lacking from prior conceptual frameworks. To accurately represent dynamics operating on different scales is both complicated and difficult because it requires going beyond tangible relationships that can be observed on the scale of local place-based, bounded units of analysis.

1.3.4 Shifting cultivation in the context of extended market reach

Shifting cultivation, alternately referred to by the term *swidden*, has been defined by Mertz et al. (2009: 261) as "a land use system that employs a natural or improved fallow phase, which is longer than the cultivation phase of annual crops, sufficiently long to be dominated by woody vegetation, and cleared by means of fire." This land-use system has seen widespread adoption globally over several millennia as a means of surviving under conditions of relative geographic isolation and minimal economic integration with outside markets. And contrary to prevailing views, the practice has not been limited to the Tropics. Dove (2015) contends that the practice was integral to past societies in European and North American, and that by studying it solely as an exotic practice in tropical settings constitutes a form of "amnesia" on the part of the community of scholars. *Swidden* in sub-tropical and tropical latitudes encompasses forested regions of sub-Saharan Africa (including Madagascar), South and Southeast Asia, and the Amazonia region of Latin America.

Practitioners of shifting cultivation in Southeast Asia have generally been physically removed from commercial centers, with only limited accessibility and connectivity to markets, e.g., via "dry season" (i.e., unpaved) roads over which travel by foot or animal-drawn cart may be either very slow or altogether impractical. The provision of market accessibility through infrastructural connectivity is generally regarded as a key catalyst for market integration. With the extension of transportation network infrastructure, economic developments influencing land-use systems and associated patterns of land-cover have been observed in various locations across Asia, e.g., Bangladesh, China, Lao PDR, Myanmar, Nepal, Pakistan, and Thailand (Khandker et al. 2009; Deng et al. 2011; Gao & Liu 2012; Phompila et al. 2017; Mon et al. 2012; Bhattari et al. 2009; Ali et al. 2005; Cropper et al. 2001). Econometric analyses and general equilibrium models, e.g., LaoGEM (Warr 2007), employ differing methods but arrive at similar conclusions showing a significant reduction in transport costs estimated at ~ 50% for all-season roads vs. dry season in Africa and Asia (Jacoby 2000; Warr 2008; Jacoby & Minten 2009).

This transition should be understood within the context of Vietnam ranking as one of the "top performers" economically in the East Asia / Pacific region according to the Observatory of Economic Complexity at MIT, after China, Thailand, and the Philippines, but slightly ahead of Malaysia (Hausman et al. 2018). From 1986 to 2008, annual economic growth rates averaged over 7 percent (McCaig & Pavcnik 2013). Since 2009, observed growth rates for the national economy (as measured in terms of GDP) have exceeded projected growth rates (6.0% vs. 3.48% per year, respectively), with average per capita income projected to rise by nearly 50% by 2020 using a 2009 baseline (Hausman et al. 2018). Much of this growth is linked to and driven by trade in goods exported by Vietnam, which have been rising steadily over the study period (2001-2015) and spiking more recently (2015-2016). Trade includes exports of goods derived from cash crops including agricultural commodities (e.g., starches / tapioca derived from cassava) and tree plantations (e.g., wood fiberboard from acacia).

1.4 Conclusion

The uplands of north-central Vietnam are a relatively less developed region of the state, inhabited by predominantly ethnic minority populations. These peoples have historically practiced a shifting cultivation system of land-use, which constitutes a rational adaptation to biophysical constraints and climate factors in this environment. They have existed on the margins of Vietnamese society in a state of relative isolation, partly attributable to seasonal constraints on connectivity without markets. Census data (2009) show a condition of relative socio-economic deprivation that is projected to change under conditions of increased connectivity associated with the EWEC project upgrading Highway 9.

The chapter also presented theoretical frameworks relevant to understanding the ongoing process of agrarian transition in this area, in the context of ongoing, rapid growth of the Vietnamese economy. On one hand, microeconomic dynamics of agricultural land-use espoused by von Thünen's theory of land rent can help inform an understanding of changing patterns of land-cover explored in the next chapter. On the other, such local-scale processes cannot be understood in isolation from larger systems operating at meso-to-macro scales, for which a telecoupling perspective helps frame the growing influence of market forces. Such forces are practically mediated in an economic sense by urban centers, with cascading effects on rural areas and implications for traditional livelihoods. This multi-level process of market integration has been driving change in land-use systems and land-cover in the study area particularly since 2007. The patterns and processes associated with such changes are explored further in the next chapter.

Works Cited

Adger, W., H. Eakin and A. Winkels. (2009). Nested and teleconnected vulnerabilities to environmental change. Frontiers in Ecology and the Environment, 7 (3), 150-157.

Ali, J., Benjaminsen, T.A., Hammad, A.A., & Dick, Ø.B. (2005). The road to deforestation: An assessment of forest loss and its causes in Basho Valley, Northern Pakistan. Global Environmental Change, 15(4), 370-380.

Angelsen, A. (2007). Forest cover change in space and time: Combining the von Thünen and forest transition theories. World Bank Policy Research Working Paper 4117.

Angelsen, A. (2010). Policies for reduced deforestation and their impact on agricultural production. PNAS, 107(46), 19639-19644.

Angelsen, A., & Kaimowitz, D. (1999). Rethinking the causes of deforestation: Lessons from economic models. The World Bank Research Observer, 14(1), 73-98.

Baird, I., & Fox, J. (2015). How land concessions affect places elsewhere: telecoupling, political ecology, and large-scale plantations in southern Laos and northeastern Cambodia. Land., 4(2), 436-453.

Bhattarai, K., Conway, D., & Yousef, M. (2009). Determinants of deforestation in Nepal's Central Development Region. Journal of Environmental Management, 91(2), 471-488.

Brooks, D., & Hummels, D. (2009). Infrastructure's role in lowering Asia's trade costs: Building for trade (ADBI series on Asian Economic Integration and Cooperation). Cheltenham, Gloucestershire: Edward Elgar Publishing.

Bruckner, M., Fischer, G., Tramberend, S. & Giljum, S. (2015). Measuring telecouplings in the global land system: A review and comparative evaluation of land footprint accounting methods. Ecological Economics, 114, 11-21.

Caldas, M., Walker, R., Arima, E., Perz, S., Aldrich, S., & Simmons, C. (2007). Theorizing land cover and land use change: the peasant economy of Amazonian deforestation. Annals of the Association of American Geographers, 97(1), 86-110.

Chomitz, K.M., & Gray, D.A. (1996). Roads, Land Use, and Deforestation: A Spatial Model Applied to Belize. The World Bank Economic Review, 10(3), 487-512.

Colantoni, A., Grigoriadis, E., Sateriano, A., Sarantakou, E., & Salvati, L. (2017). Back to Von Thunen: A Southern European perspective on mono-centric urban growth, economic structure and non-urban land decline. International Planning Studies, 22(3), 173-188.

Cropper, M., Puri, J., & Griffiths, C. (2001). Predicting the Location of Deforestation: The Role of Roads and Protected Areas in North Thailand. Land Economics, 77(2), 172-186.

Deng, X., Huang, J., Uchida, E., Rozelle, S., & Gibson, J. (2011). Pressure cookers or pressure valves: Do roads lead to deforestation in China? Journal of Environmental Economics and Management, 61(1), 79-94.

Dove, M.R. (2015). Linnaeus' study of Swedish swidden cultivation: Pioneering ethnographic work on the 'economy of nature'. Ambio a Journal of the Human Environment, 44(3), 239-248.

Eakin, H., Winkels, A., & Sendzimir, J. (2009). Nested vulnerability: Exploring cross-scale linkages and vulnerability teleconnections in Mexican and Vietnamese coffee systems. Environmental Science & Policy, 12(4), 398-412.

Eakin, H., Rueda, X., & Mahanti, A. (2017). Transforming governance in telecoupled food systems. Ecology and Society, 22(4).

European Commission, Joint Research Centre (JRC); Columbia University, Center for International Earth Science Information Network - CIESIN (2015): GHS population grid, derived from GPW4, multitemporal (1975, 1990, 2000, 2015). European Commission, Joint Research Centre (JRC) [Dataset]. URL: http://data.europa.eu/89h/jrc-ghsl-ghs_pop_gpw4_globe_r2015a (accessed 19 April 2018)

Fontes, F., & Palmer, C. (2018). "Land Sparing" in a von Thünen framework: Theory and evidence from Brazil. Land Economics., 94(4), 556-576.

Friis, C., Nielsen, J.Ø., Otero, I., Haberl, H., Niewoehner, J., & Hostert, P. (2016). From teleconnection to telecoupling: Taking stock of an emerging framework in land system science. Journal of Land Use Science, 11(2), 131-153.

Friis, C., & Nielsen, J.Ø. (2017). On the system: Boundary choices, implications, and solutions in telecoupling land use change research. Sustainability, 9(6), 974.

Fujita, M. (2012). Thünen and the new economic geography. Regional science and urban economics, 42(6), 907-912.

Furumo, P.R., & Aide, T.M. (2017). Characterizing commercial oil palm expansion in Latin America: Land use change and trade. Environmental Research Letters, 12(2), 024008.

Gao, J., & Liu, Y. (2012). Deforestation in Heilongjiang Province of China, 1896–2000: Severity, spatiotemporal patterns and causes. Applied Geography, 35(1-2), 345-352.

Hall, D. (2011). Powers of exclusion: Land dilemmas in Southeast Asia. Honolulu: University of

Hawaii Press.

Hausmann, R., Hidalgo, C., Bustos, S., Coscia, M., Chung, S., Jimenez, J., Simoes, A., and Yıldırım, M.A. 2-18. The Atlas of economic complexity. Boston: MIT Press.

Ishida, M. (2009). Special economic zones and economic corridors. ERIA Discussion Paper Series, 16, 2009.

Ishida, M., & Isono, I. (2012). Old, new and potential economic corridors in the Mekong region. Emerging Corridors in the Mekong Region, BRC Research Report (8).

Jacoby, H. (2000). Access to markets and the benefits of rural roads. The Economic Journal: The Journal of the British Economic Association, 110(465), 713-737.

Jacoby, H. & Minten, B. (2009). On measuring the benefits of lower transport costs. Journal of Development Economics, 89(1), 28-38.

Khandker, S.R, Bakht, Z., & Koolwal, G. B. (2009). The poverty impact of rural roads: Evidence from Bangladesh. Economic Development and Cultural Change, 57(4), 685-722.

Kramer, D. B., Hartter, J., Boag, A. E., … and Liu, J. (2017). Top 40 questions in coupled human and natural systems (CHANS) research. Ecology and Society, 22(2).

Lambin, E.F, Geist, H.J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. Annual Review of Environment and Resources, 28(1), 205-241.

Leichenko, R., & O'Brien, K. (2008). Environmental change and globalization: Double exposures. Oxford University Press.

Leisz, S., Rounds, E., Ngo, T.A., Nguyen, T., Tran, Nguyen Bang, Douangphachanh, S. & Ninchaleune, B. (2016). Telecouplings in the East-West Economic Corridor within borders and across. Remote Sensing, 8(12), 1012.

Liu, J., Hull, V., Batistella, M., DeFries, R., Dietz, T., Fu, F., . . . Verburg, P. (2013). Framing sustainability in a telecoupled world. Ecology and Society: A Journal of Integrative Science for Resilience and Sustainability, 18(2), 26.

McCaig, B. & Pavcnik, N. (2013). Moving out of agriculture: structural change in Vietnam, Number 19616, NBER Working Papers, National Bureau of Economic Research. URL: http://www.dartmouth.edu/~npavcnik/docs/Vietnam_structural_change_October_2013.pdf (accessed 29 March 2018)

McElwee, P. (2008). "Blood relatives" or uneasy neighbors? Kinh migrant and ethnic minority interactions in the Trường Sơn mountains. Journal of Vietnamese Studies, 3(3), 81-116.

Mertz, O., Padoch, C., Fox, J., Cramb, R. A., & Leisz, S.J. (2009). Swidden change in Southeast Asia: Understanding causes and consequences. Human Ecology, 37(3), 259-264.

Meyfroidt, P., Lambin, E.F., Erb, K-H., & Hertel, T.W. (2013). Globalization of land use: Distant drivers of land change and geographic displacement of land use. Current Opinion in Environmental Sustainability, 5(5), 438-444.

Mole, R. (1970). The Montagnards of South Vietnam; a study of nine tribes (1st ed.). Rutland, Vt.: C. E. Tuttle.

Mon, M., Mizoue, N., Htun, N., Kajisa, T., & Yoshida, S. (2012). Factors affecting deforestation and forest degradation in selectively logged production forest: A case study in Myanmar. Forest Ecology and Management, 267, 190-198.

Pesaresi, Martino; Ehrlich, Daniele; Florczyk, Aneta J.; Freire, Sergio; Julea, Andreea; Kemper, Thomas; Soille, Pierre; Syrris, Vasileios (2015): GHS built-up datamask grid derived from Landsat, multitemporal (1975, 1990, 2000, 2014). European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/jrc-ghsl-ghs_built_ldsmtdm_globe_r2015b (accessed 19 April 2018)

Pesaresi, Martino; Ehrlich, Daniele; Florczyk, Aneta J.; Freire, Sergio; Julea, Andreea; Kemper, Thomas; Soille, Pierre; Syrris, Vasileios (2015): GHS built-up grid, derived from Landsat, multitemporal (1975, 1990, 2000, 2014). European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/jrc-ghsl-ghs_built_ldsmt_globe_r2015b (accessed 19 April 2018)

Pesaresi, Martino; Freire, Sergio (2016): GHS Settlement grid following the REGIO model 2014 in application to GHSL Landsat and CIESIN GPW v4-multitemporal (1975-1990-2000-2015). European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/jrc-ghsl-ghs_smod_pop_globe_r2016a (accessed 19 April 2018)

Phompila, C., Lewis, M., Ostendorf, B., & Clarke, K. (2017). Forest cover changes in Lao tropical forests: Physical and socio-economic factors are the most important drivers. Land, 6(2), 23.

Prishchepov, A.V, Müller, D., Dubinin, M., Baumann, M., & Radeloff, V.C. (2013). Determinants of agricultural land abandonment in post-Soviet European Russia. Land Use Policy, 30(1), 873-884.

Salemink, O. (2001). Viet Nam's cultural diversity: Approaches to Preservation. Paris: UNESCO Publishing.

Schaldach, R., Wimmer, F., Koch, J., Volland, J., Geissler, K., & Köchy, M. (2013). Model-based analysis of the environmental impacts of grazing management on Eastern Mediterranean ecosystems in Jordan. Journal of Environmental Management, 127, S84-S95.

Scott, J. (1976). The moral economy of the peasant: Rebellion and subsistence in Southeast Asia. New Haven: Yale University Press.

Seto, K., Reenberg, A., Boone, C.G., Fragkias, M., Haase, D., Langanke, T., …Simon, D. (2012). Urban land teleconnections and sustainability. Proceedings of the National Academy of Sciences of the United States of America, 109(20), 7687-7692.

Sills, E.O., & Caviglia-Harris, J.L. (2009). Evolution of the Amazonian frontier: Land values in Rondônia, Brazil. Land Use Policy, 26(1), 55-67.

Simon, H. (1991). Bounded Rationality and Organizational Learning. Organization Science: a Journal of the Institute of Management Sciences, 2(1), 125-134.

Simon, H. (1995). Rationality in Political Behavior. Political Psychology., 16(1), 45-61.

Van Dinh, P, Murata, T, & Van Hung, P. (2001). Key issues in the process of rural economy development in Vietnam. Journal of the Faculty of Agriculture, Kyushu University., 45(2), 643-650.

Vargyas, G. (2001) "Intangible culture of the Bru: Preservation, promotion and reassertion of values," in Viet Nam's cultural diversity: Approaches to preservation, ed. O. Salemink (Paris: UNESCO Publishing), 199-204.

Verburg, P.H. Ellis, E.C., Letourneau, A. (2011). A global assessment of market accessibility and market influence for global environmental change studies. Environmental Research Letters, 6(3), 034019.

Von Thünen, J. H., & Hall, P. (1966). Isolated state; an English edition of *Der isoliete Staat*. (1st ed.). Oxford, New York: Pergamon Press.

Walker, R. (2012). The scale of forest transition: Amazonia and the Atlantic forests of Brazil. Applied Geography, 32(1), 12-20.

Walker, R., & Solecki, W. (2004). Theorizing land-cover and land-use change: the case of the Florida Everglades and Its degradation. Annals of the Association of American Geographers, 94(2), 311-328.

Warr, P. (2007). LaoGEM: A general equilibrium model of the Lao economy.

Warr, P. (2008). How road improvement reduces poverty: The case of Laos. Agricultural

Economics, 39(3), 269-279.

Warr, P. (2010). Roads and poverty in rural Laos: An econometric analysis. Pacific Economic Review, 15(1), 152-169.

World Bank. (2018). "mapVIETNAM." URL: http://www5.worldbank.org/mapvietnam/ (accessed 14 October 2018)

Yu, Yang, K. Feng, K. Hubacek. (2013). Tele-connecting local consumption to global land use. Global Environmental Change, 23: 1178-1186.

Chapter 2: Agricultural land-use and land-cover change detection analysis (2001-2014)

Summary

Agricultural land-cover patterns in the rural upland communities of Vietnam show intermittent change over the period 2001 to 2014, but without a clear trendline across the study area (district-level) as a whole. The observed change is hypothesized to relate to ongoing processes of market integration associated with improved transportation network infrastructure and subsequent developments. Specifically, the main highway corridor traversing this area of Vietnam, Highway 9, was upgraded in mid-2006 through the East-West Economic Corridor (EWEC) project. This project has resulted in improved market connectivity and accessibility between population centers and urban industries through reduced transport costs and increased economic flows.

Within the uplands of Quảng Trị Province, agricultural clearings along roads appear to have increased and intensified as of April 2014, compared to previous near-anniversary image dates of 2006 / 2009. The pattern of land-cover change is hypothesized to result from changing land-use systems, whereby local populations are mobilizing resources toward market-oriented production of cash crops. Such change would be consistent with a von Thünian microeconomic response to rising land-rents associated with reduced transport costs, higher agricultural prices, and stagnant wages. Industrial demand for commodities originating from nearby urban market centers is also consistent with an “urban land telecoupling” and telecoupling systems frameworks.

These findings may lend credence to microeconomic theories of “transport-induced local-market development" (TILD). Local livelihoods are likely to improve due to rising incomes and improved access to goods and services. Sustainable and equitable development for communities over the longer term will depend not only economic growth through market-oriented agricultural production, but also on stakeholder involvement and institutional engagement.

2.1 Introduction

Land-use systems of local populations have been shaped historically by biophysical constraints associated with land-cover, terrain, and climate. More recently, land-use systems across the developing world, including Southeast Asia, have been influenced by proximal and distal drivers of political and socio-economic change. In Vietnam, policies promoting market liberalization since the death of Le Van Nhuan, better known as Le Duan, in 1986, have attracted foreign direct investment and fostered the development of export-oriented industries. Upgrades to transportation infrastructure network have improved connectivity and accessibility between rural uplands and urban lowlands, lowering transport costs and promoting market integration.

Market-oriented processes of agrarian transition and transformation have occurred in many parts of the developing world or "Global South" including sub-Saharan Africa (Jacoby & Minten 2009), Latin America (Caldas et al. rev2007; Sills & Caviglia-Harris 2009; Walker 2012; Furumo & Aide 2017), and Asia (Khandker et al. 2009; Deng et al. 2011; Gao & Liu 2012; Phompila et al. 2017; Mon et al. 2012; Bhattari et al. 2009; Ali et al. 2005; Cropper et al. 2001). Southeast Asia, in particular, has experienced the highest rates of agricultural land conversion for crop cultivation globally (Lambin et al. 2003), coincident with deepening and widening regional economic integration driven by growth in trade that is enabled and facilitated by transportation networks and cross-border trade agreements (Brooks & Hummels 2009; Leisz et al. 2016).

This chapter explores the question of how the landscape of a remote district in the uplands of Đa Krông ("Big River") District, located in Quảng Trị Province, Vietnam, has been changing since 2001 and attempts to characterize the direction and magnitude of this change. It then seeks to address larger questions concerning what forces are driving these changes. A key pivot point for this study area occurs in the 2006-2007 timeframe, associated with the completion of upgrades to the main east-west highway (Highway 9) that interconnects with the main north-south road (Ho Chi Minh Highway).

Roads function as conduits facilitating flows of materials, money, people, and information, both between the urban core and rural periphery - and within rural areas - are hypothesized to influence land-use systems and patterns of land-cover change at multiple scales through this connectivity (Seto et al. 2012; Güneralp et al. 2013). To the extent that this road improvement project induces intensification of agricultural land-use, it should manifest in increased clearings along the Highway 9 corridor since 2007. To the extent that no correlation exists, any changing pattern in agricultural clearings should show no preference for the road. In addition to transportation infrastructure and related market dynamics, other factors warranting consideration include demographic changes (e.g., migration flows), government policies (e.g., land allocation/use), and socio-cultural shifts (e.g., generational shifts away from traditional livelihood systems).

2.2 Literature review

Understanding the process of agrarian transition that is occurring in the study area draws primarily upon two theoretical frameworks - von Thünen's microeconomic theory of land rent and the multi-scalar conceptual framework of telecoupling (and by extension its antecedent, i.e., teleconnections). Both frameworks are discussed at greater length in the preceding chapter (Chapter 1). A brief recap of each follows here.

At a local (micro) scale, rural land managers who are given proper information can rationally weigh anticipated revenues against cost factors associated with crop production (labor, capital, and transportation) in deciding how to allocate lands to various agricultural cropping, pastoral, or forest-resource extraction related uses (von Thünen 1966). Such a calculation seeks to optimize overall return (i.e., net of revenues [price times yield] minus costs [capital, labor, and transport]) for a given land area, which has been expressed as the "land-rent" of a given land-use scenario. Where land rents are sufficiently high, producers will tend to engage in market-oriented production, e.g., the "first ring of free cash cropping" hypothesized by von Thünen (1966), wherein market-oriented crop cultivation would tend to occur closer to the market (e.g., higher-value perishable commodities) and lower value crops further away (e.g., bulky commodities).

Transport costs are considered critical to the agricultural production process due to the cost-distance of moving commodities to markets (Jacoby 2000; Angelsen 2007; Warr 2008; Brooks & Hummels 2009; Jacoby & Minten 2009; Warr 2010). The creation and improvement of road networks are thought to influence market-oriented decision-making and cropping behavior by reducing transportation costs by up to 50% (Jacoby 2000; Warr 2008; Jacoby and Minten 2009). Reductions in transport costs lower the opportunity cost of producing agricultural commodities, effectively extending the range of the "agricultural frontier", i.e., the distance at which crops can be grown profitably. This process can thereby induce rural populations to allocate more land and labor toward market-oriented production (von Thünen 1966; Angelsen 2007). In addition to the infrastructure criterion (i.e., more / better roads) and market incentive criterion (i.e., higher agricultural prices), Angelsen and Kaimowitz (1999) also find that labor criteria (e.g., low wages and shortage of off-farm employment opportunities) are key to agricultural intensification.

To provide necessary context to this place-based analysis, it is necessary to consider a broader mutli-scalar framework. Local-scale dynamics are hypothesized to occur in the context of connectivity to urban centers, which could be either relatively nearby or far away (Seto et al. 2012; Güneralp et al. 2013). These urban centers seek to extract resources (food, fiber, etc.) from the rural producers at minimal cost through economies of scale. Urban centers thus act as sending systems transmitting demand to rural areas for their own demand, while also acting as intermediaries between the rural space and larger, outside systems (national / regional / international). Local developments in rural land-use systems thus occur in a nested fashion within a broader political economy, whereby urban centers mediate flows of proximal forces of land-use/land-cover change and distal drivers.

In order to structure the analysis of systems interacting at multiple scales, Liu et al. (2013) categorize systems in relational terms as “sending”, “receiving”, or “spillover” with a minimum of one-to-one connectivity between systems at a given level of the system and some minimum degree of connectivity between different levels. These systems are comprised of human agents, who interact in cause-effect relationships with their coupled natural systems and also mediate flows between and among other outside systems with which they are interconnected.

The production and distribution of any good or service in the global economy can involve spillover effects on areas beyond the intended receiving system being targeted by the sending system. The spillover system is therefore explicitly acknowledged by the telecoupling framework, and this constitutes an important addition lacking in other conceptual frameworks. To accurately represent dynamics operating on different scales is both complicated and difficult because it requires going beyond tangible relationships that can be observed on the scale of local place-based, bounded units of analysis.

Such interconnections may extend up to the global scale and influence long-distance flows of raw materials, energy, products, people, information, and capital, which in turn influence the direction and magnitude of LULC change (Friis et al. 2016). Telecoupled systems analyses encompass the production and distribution of various agricultural commodities, e.g., bananas (Friis & Nielsen 2016; Friis & Nielsen 2017), coffee (Eakin et al. 2009; Eakin et al. 2017), and rubber (Baird & Fox 2015), all of which have entailed considerable spillover effects impacting on both human livelihoods and ecosystems (i.e., biodiversity and ecosystem services) at the local scale. Understanding the dynamics of these differing trajectories of land-use systems and resulting changes in land-cover patterns requires framing drivers at the local scale in the context of such meso- and macro-scale systems.

2.3 Methods

The study employs remote sensing and geospatial statistical methods to a chrono-series of multi-spectral Landsat imagery (30m resolution) centered on the month of April for the period 2001-2014. Agricultural clearings are derived from imagery, using remote sensing tools and methods. These clearings are then analyzed with spatial statistical methods using ArcGIS and "R" software to identify spatial patterns of land-cover change occurring over this time series.

2.3.1 Remote sensing analysis of Landsat imagery (2001-2014)

All available Landsat imagery (TM, ETM+, OLI; Level 2 Surface Reflectance) for Path 125 Row 049 and adjacent Path/Row areas were ordered from USGS "Earth Explorer" for the months of January to June for 2001 to 2019, for all scenes with less than 80% cloud cover. For the purposes of this assessment, only imagery through 2014 are considered. All imagery were processed using LandsatLinkr, available to the public via Github (Braaten et al. 2018). This "R" software package automates layer stacking and cloud masking (i.e., clouds plus cloud shadows), as well as producing Tasseled Cap (TC) transformation. The process was run for all available imagery for Path 125 Row 049.

While a tightly aligned year-on-year series of images (i.e., with anniversary dates of images within 2 weeks of each other) was not possible due to image availability / usability considerations, the following image dates (formatted as “YearJulianDate”) allow for a reasonably closely aligned spring-season change detection analysis:

2001097 (early April 2001)

2006095 (early April 2006)

2007114 (mid-April 2007)

2009087 (late-March 2009)

2014117 (mid-April 2014)

For this chrono-series, Normalized Burn Ratio (NBR) outputs were generated by the author using “Band Math” in ENVI software to identify and extract agricultural clearings. April imagery is considered well-suited for the generation of NBR, based on the customary agricultural calendar that entails cutting of vegetation in February, burning of vegetation in March, and planting of crops in April. This approach was motivated partly by Li et al. (2014), among others. A basic land-cover classification was then performed on the NBR outputs, using ENVI to generate unsupervised ISO clusters (8 classes for TM images / 20 classes for OLI images, parameterized as follows: 20 iterations, 2 percent change threshold, cloud mask applied, and no smoothing or aggregation applied, to preserve the geometric size/shape of the actual clearings as closely as possible, which tend to be relatively small and irregularly shaped).

Agricultural clearings typically exhibit a signature showing relatively high NBR levels compared to other land-cover classes earlier in the growing season, thereby allowing for relatively easy identification of areas under cultivation. This was done by visually comparing ISO outputs against the original imagery displayed using the 3-band combination SWIR-NIR-RED to identify the class or classes best aligned with clearings. Despite the noise inherent in this simplified land-cover classification, e.g., confusion between water and dark shadows on steeper forested terrain, a coarse reclassification using ArcGIS allowed for identification of basic landcover types (clouds/cloud shadow, clearings, fallowed areas, forest/woodlands, and water). The following map, drawn at scale of 1:25,000, shows an example of clearings derived from ISO clusters of the NBR image (Figure 11):

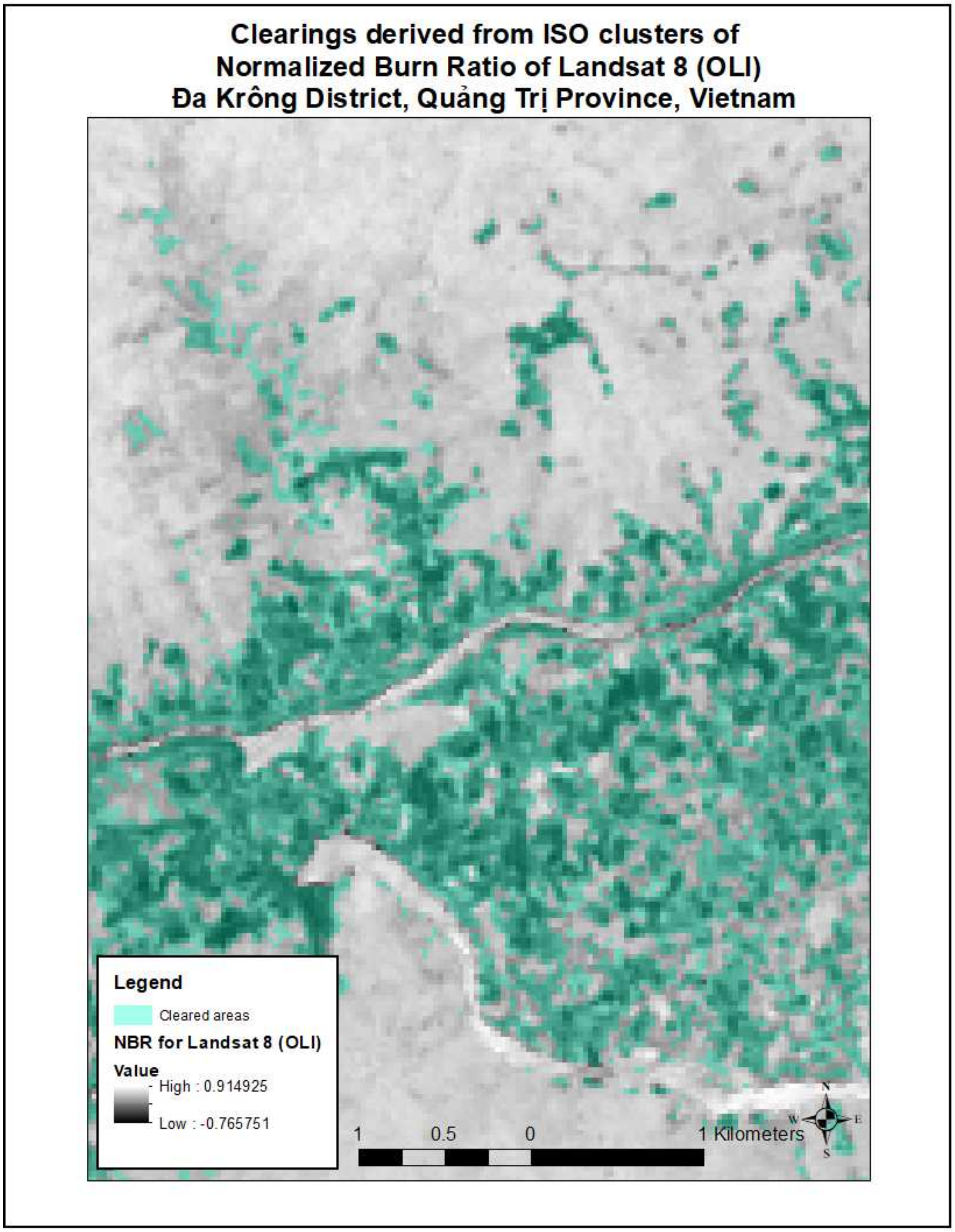


Figure 11: Exemplar of cleared areas derived from NBR

Given that unsupervised classification outputs for NBR appeared to show a nearly one-to-one correspondence with the original imagery for agricultural clearings, these outputs were considered suitable for the purposes of quantifying the number and extent of clearings. Statistical analyses of agricultural clearings assess the direction and magnitude of changing patterns of land-cover for the district both in the aggregate for the entire district as well as at the sub-district level, through zoning and sectoral segmentation of the study area based on primary roads.

2.3.2 Geospatial statistical analysis of land-cover derived from Landsat

Follow-on geoprocessing of the agricultural clearings derived from ISO-cluster outputs of NBR images included the conversion of raster grid cells to vector polygons, for performing basic summary statistical analyses (e.g., count and area), and to vector points, for additional statistical sampling and calculations (e.g., clustering, distance metrics, and terrain metrics). Both vector datasets were clipped to the district boundary and additional processing was performed to remove subsets of clearings considered suspect, based on the following criteria:

(1) very large clearings (defined here as > 3 standard deviations above the mean value), since such clearings would tend to represent areas under permanent cultivation or perhaps clear-cuts of forests or tree plantations; and

(2) very small clearings of less than one pixel in extent (i.e., < 900 square meters), as these represent "speckle" generated by ISO clustering in ENVI or from clipping to the study area in ArcGIS.

2.3.2.1 Basic spatial analyses – summary statistics and average nearest neighbor metrics

Spatial analysis of the pattern and distribution of clearings was performed using standard summary statistics to gather basic metrics regarding total number, average size (i.e., mean), variation in size relative to mean (i.e., standard deviation), and clustering of clearings (i.e., average nearest neighbor metrics, e.g., observed mean distance). Data were compiled into tabular format and plotted as graphs for basic analysis of trends.

2.3.2.2 Statistical sampling of clearings across the district

In order to look for trends in the pattern of clearings across the district as a whole, statistical samples were taken using ArcGIS for the vector point locations of all cleared areas for each time step in the chrono-series for the following metrics:

(1) distance (distance to nearest roads and distance to population centers [meters]); and

(2) terrain (elevation [meters] and slope [degrees]).

Data were used to generate an array of point data in tabular format for analysis in identifying any trends that may exist over the time series. Data were processed via the "R" software package using a basic script to produce box-plots. Box-plots characterize median values, central tendency (25-75%), standard-deviation values, and outliers for the full range of observations. This method avoids the possibility of selection bias, as all points are taken into consideration.

2.3.2.3 Zonal and sectoral segmentation of study area for mean/median center point generation

In order to discern any relative shifts in the pattern of clearings on a sub-district scale, the study area was segmented into four distinct zones for further analysis of mean/median center points as follows (Figure 12):

(1) Zone 1 encompasses Krông Klang townlet (Sector A) and Mò Ó commune (Sector B), which are adjacent to Highway 9. This zone covers an area of 46.1 square km with a total highway length of 5.7 km.

(2) Zone 2 encompasses ĐaKrông commune and is traversed by Highway 9 from east to west and Ho Chi Minh Highway from north-to-south. This zone covers a total area of 109.4 square km with an estimated road length of 25.2 km (15.3km segment of Highway 9 and

9.95km segment of Ho Chi Minh Highway). It is divided into three sectors, a north sector (sector A), southeast sector (sector B), and southwest sector (sector C).

(3) Zone 3 encompasses the area south of Zone 1 and east of Ho Chi Minh Highway, covering a total of 473.7 square km, of which 385.2 square km fall within the Đa Krông Nature Reserve and therefore under protected status. The remainder was subdivided into three distinct sectors (north, center, and south). The north sector (sector A) includes the non-protected fractions of Ba Lòng, Hải Phúc, and Triệu Nguyên communes, which have no highway adjacency and therefore are not explicitly considered in this analysis but identified for future work. The center sector (sector B) of this zone consists of the eastern parts of Tà Long commune and Húc Nghì commune and has an estimated road length of 13 km. The south sector (sector C) consists of A Ngọ and Tà Rụt communes and has an estimated road length of 27 km.

(4) Zone 4 encompasses the area south of Highway 9 and west of Ho Chi Minh Highway, covering a total area of 335.9 square km. This zone was subdivided into three distinct sectors (north, center, and south). The north sector (sector A) consists of Ba Nang commune, which lacks direct access to Ho Chi Minh Highway). The center sector (sector B) consists of western Tà Long and Húc Nghì communes, which has an estimated road length of 26 km. The south sector (sector C) consists of western Tà Rụt and A Ngọ communes, and A Bung commune, with an estimated road length of 21 km.

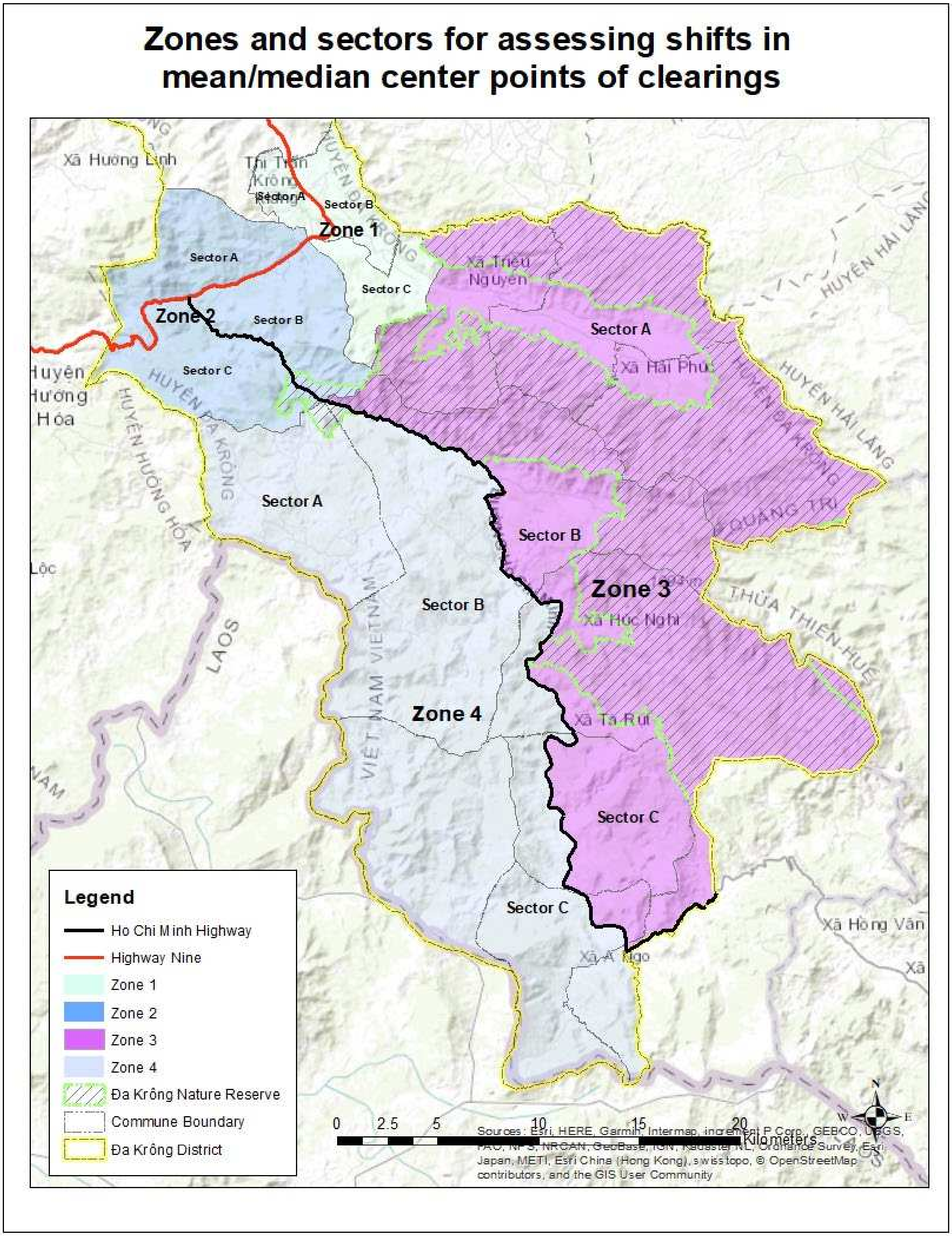


Figure 12: Segmentation of study area for assessing direction and magnitude of shifts in agricultural clearings using mean and median center points.

2.3.2.4 Kernel density surfaces as "heat map" of clearings

Kernel density surfaces were generated for each time step in the chrono-series using ArcGIS to visualize clustering on a *per hectare* basis. The outputs are then assessed visually for obvious trends and with statistical methods to characterize the direction and magnitude of change in agricultural clearings. These outputs can help to place any directional shifts in mean/median center points of clearings into better context across the landscape of the entire study area

2.4 Results

The following series of maps (Figures 13-17) depict the agricultural clearings derived from the process described in previous section (2.3.1). Two composite maps (Figure 18 and Figure 19) are also included here for visual comparison of the cumulative footprint of agricultural clearings for the period prior to the highway improvement project (2001, 2006) and the period that follows (2007, 2009, 2014).

Analysis of clearings over this time series using GIS-based and R-based spatial statistical methods described in the previous section shows the following for period following the highway improvement project (further elaborated in subsections that follow):

(1) Increasing total area cleared;

(2) Increasing number of clearings;

(3) Decreasing average distance between clearings; and

(4) Decreasing distance to roads of more intensively cultivated areas

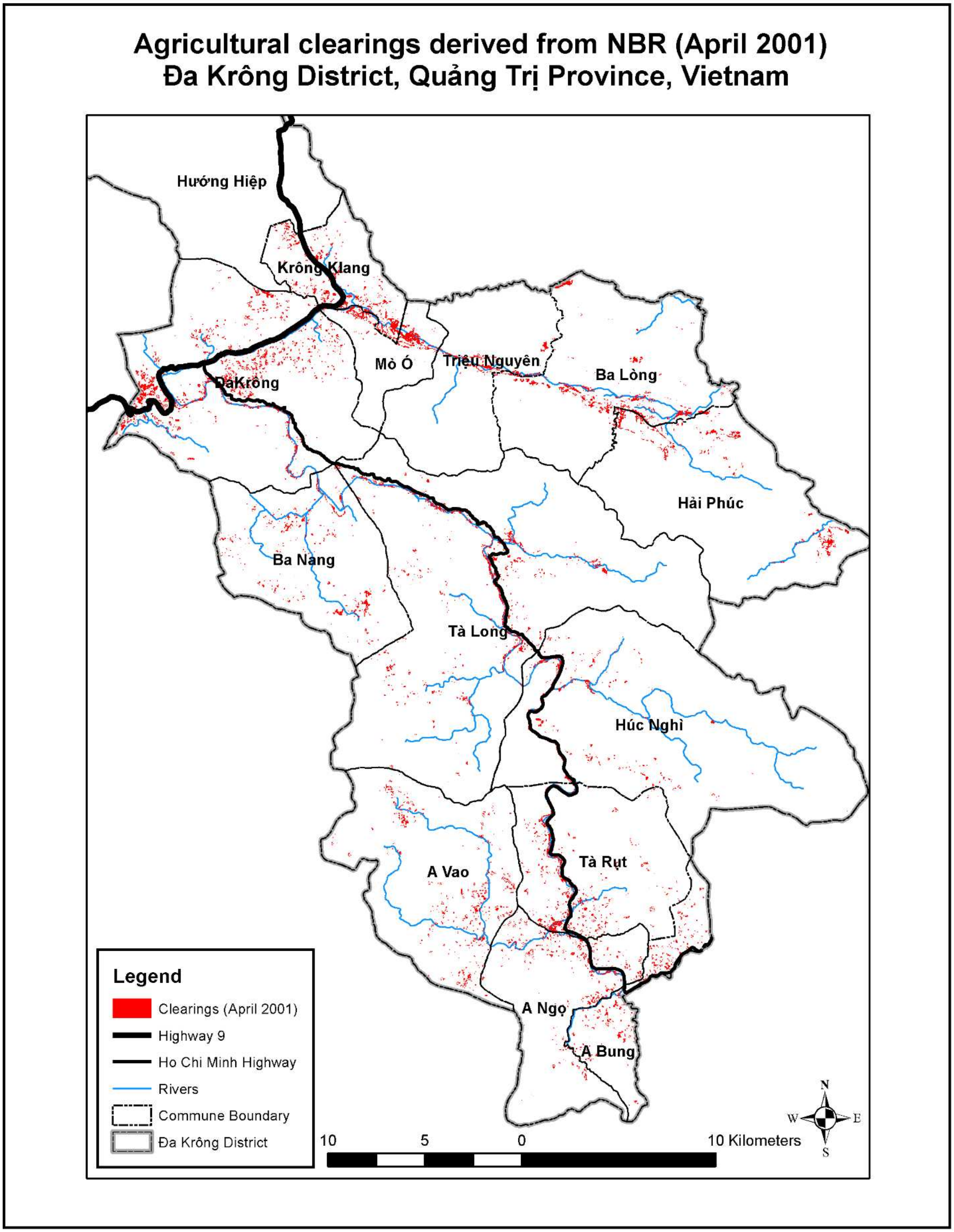


Figure 13: Map of agricultural clearings for study area (7 April 2001)

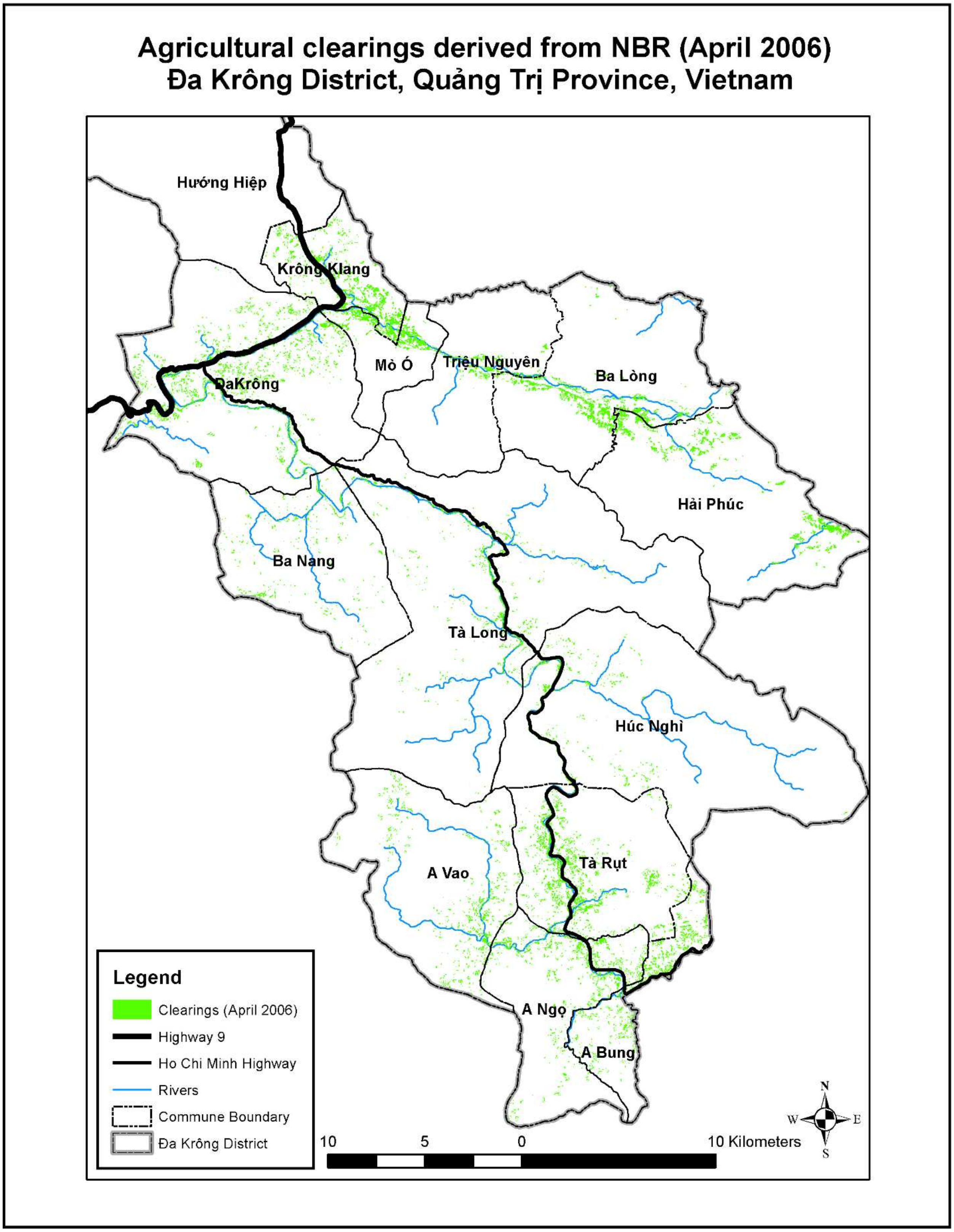


Figure 14: Map of agricultural clearings for study area (5 April 2006)

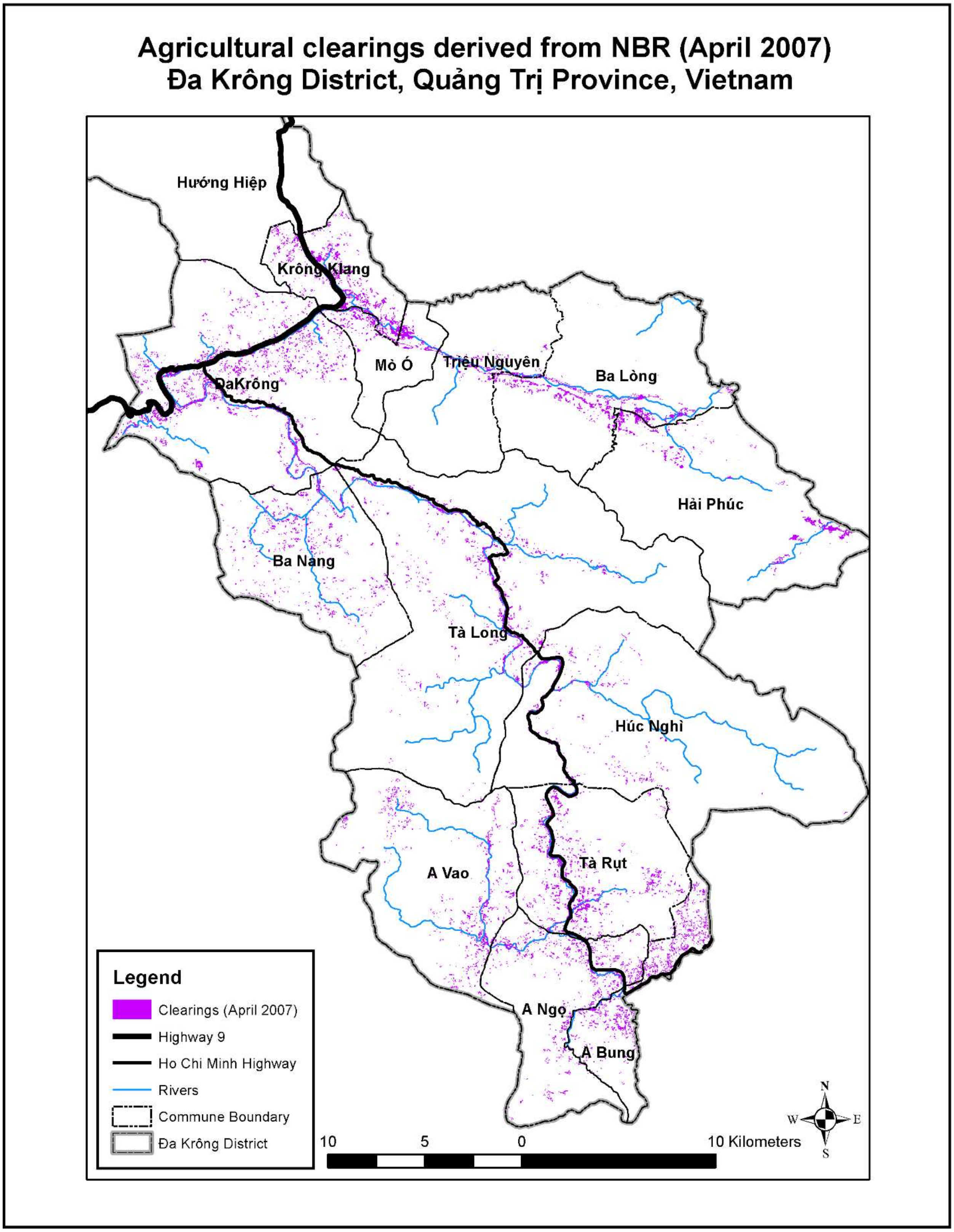


Figure 15: Map of agricultural clearings for study area (24 April 2007)

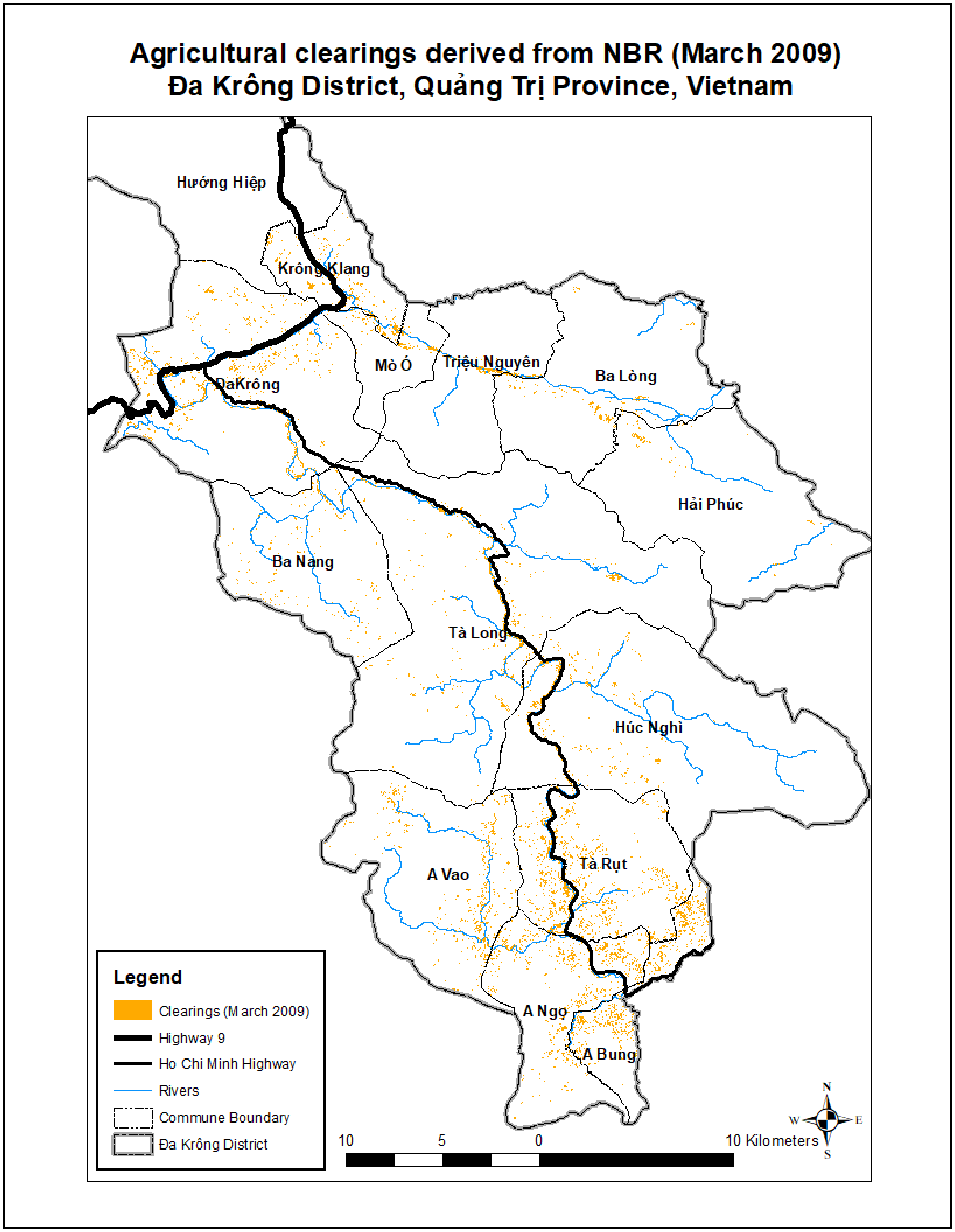


Figure 16: Map of agricultural clearings for study area (28 March 2009)

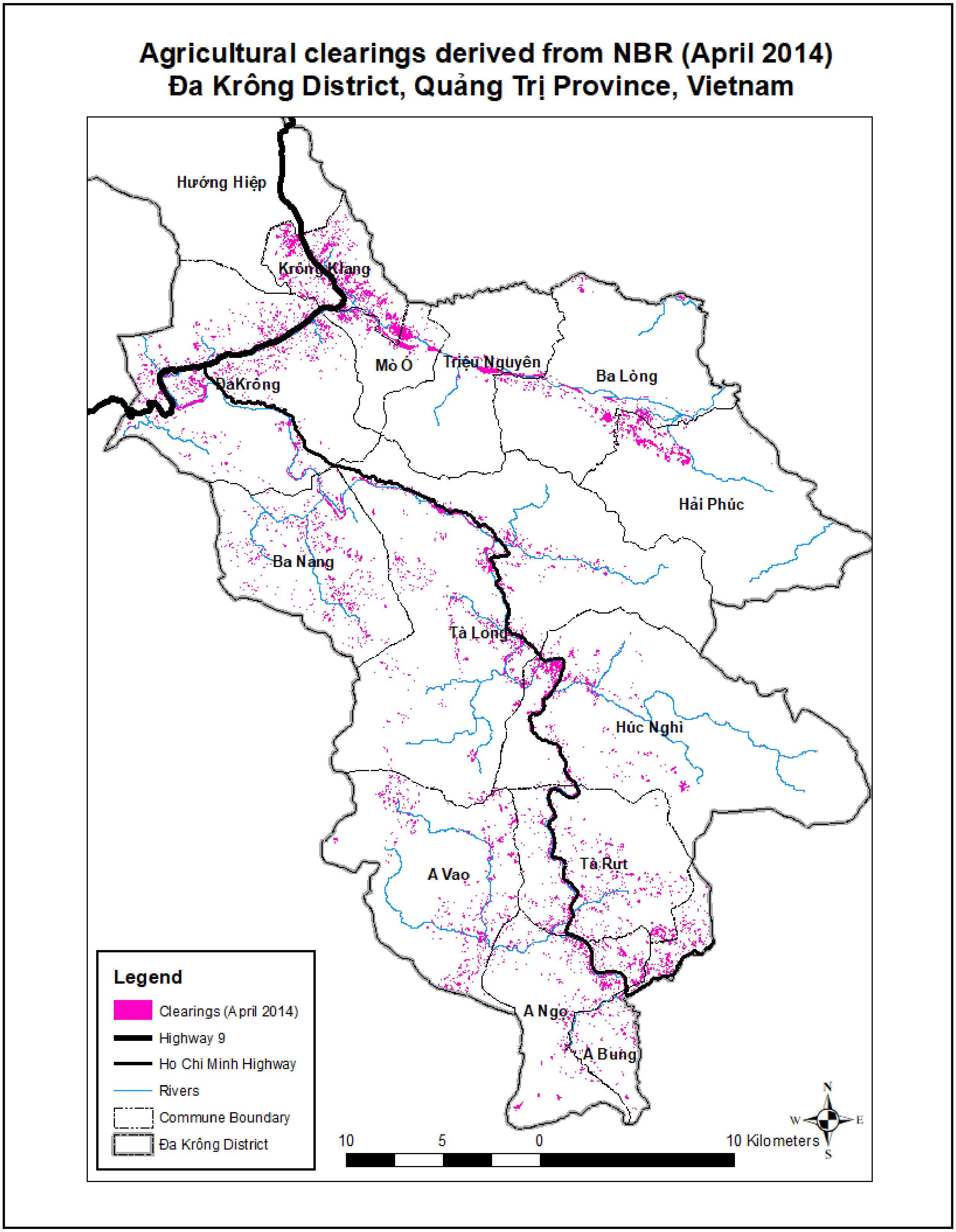


Figure 17: Map of agricultural clearings for study area (27 April 2014)

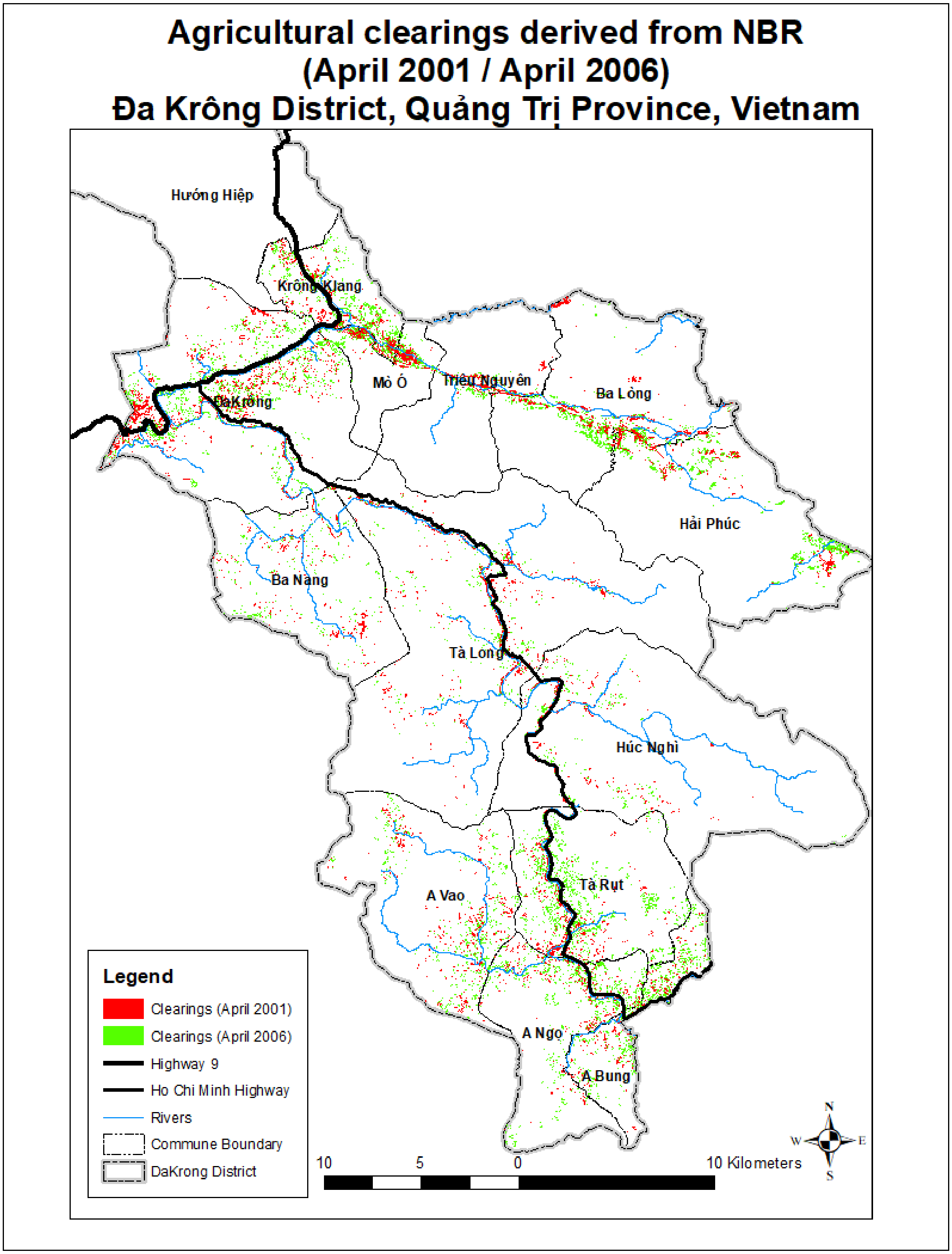


Figure 18: Composite map of agricultural clearings derived from NBR of Landsat TM (2001, 2006)

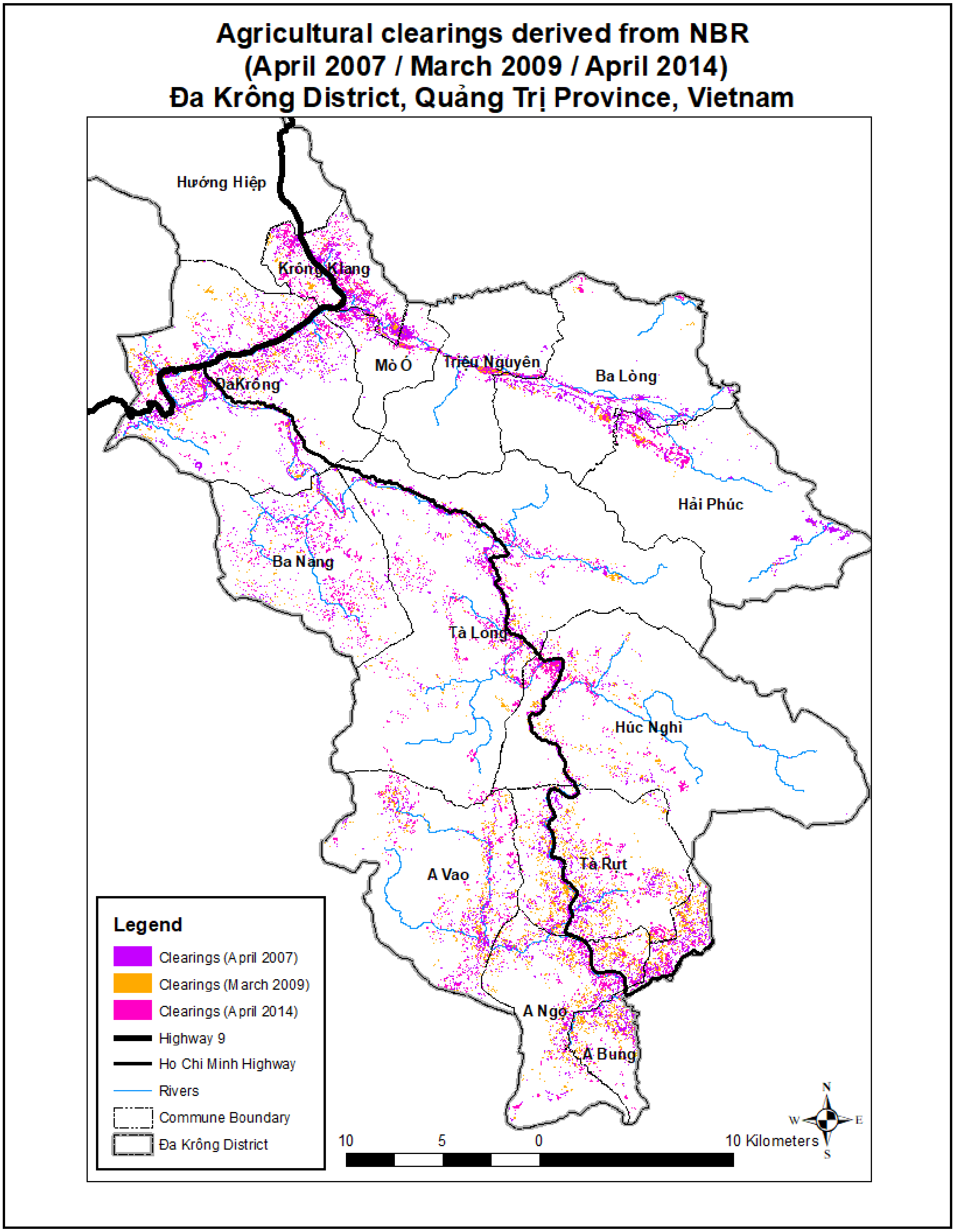


Figure 19: Composite map of agricultural clearings derived from NBR of Landsat TM (2007, 2009) and Landsat OLI (2014)

2.4.1 Summary statistics results – total area, count, and clustering

An analysis of all clearings across the study area as a whole for this time series finds fluctuation in the total area cleared and number of clearings over the period 2001 to 2014, peaking in 2014 (Figure 20 and Figure 21). The total extent of clearings as of 2014 measured approximately 14.9% greater than 2006 and 39.9% greater than 2007 (Figure 21). The data for 2009 constitute something of an anomaly or outlier, due to the occurrence of severe flooding across most of the study area as reported by the local population (Leisz et al. 2014).

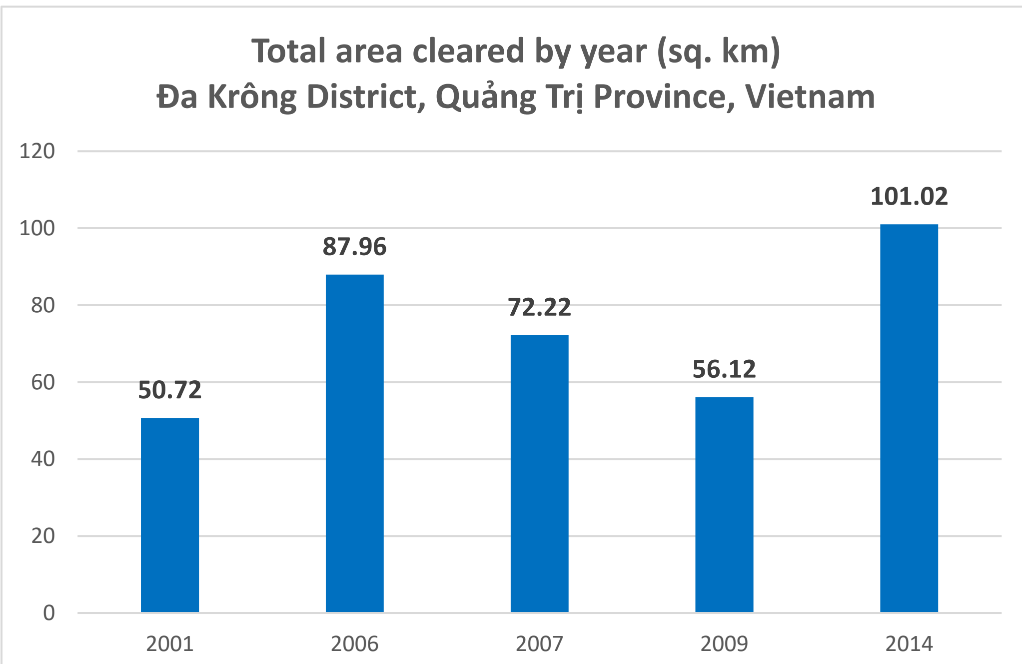


Figure 20: Total area cleared by year (April-centered chrono-series), 2001-2014

With regard to the number of clearings (i.e., count), counts showed a general trend of increase except for 2009, with the total count for 2014 measuring approximately 25.0% greater than 2006 and 18.6% greater than 2007 (Figure 21).

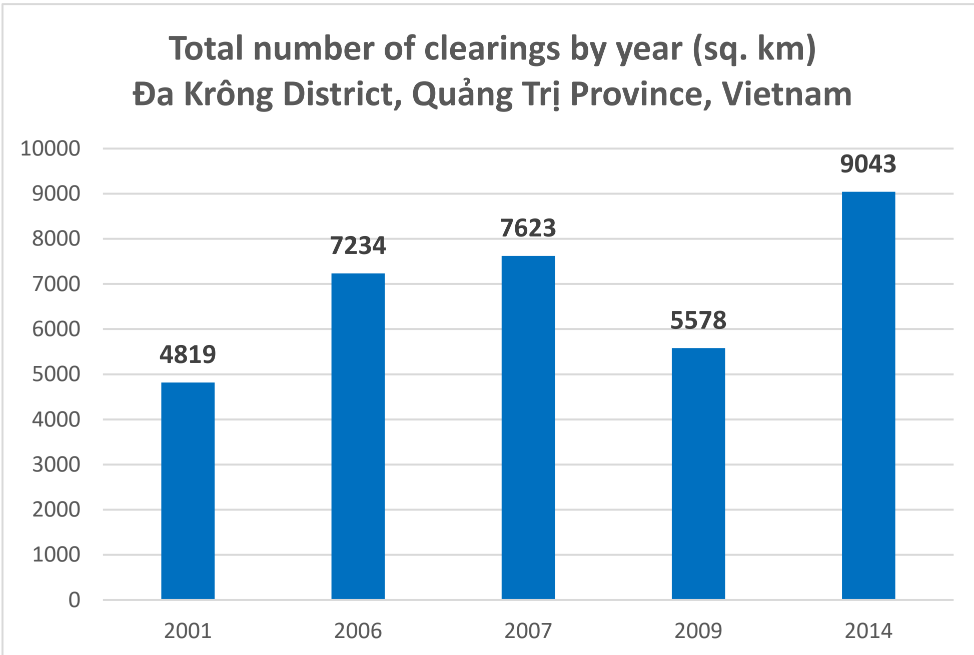


Figure 21: Total count of clearings by year (April-centered chrono-series), 2001-2014

In addition to the increases in the total area and number of clearings, the average distance between clearings (i.e., observed mean distance), fell by approximately 40.1% over the period 2001-2014, trending downward with the exception of a bump in values in 2009 (Figure 22).

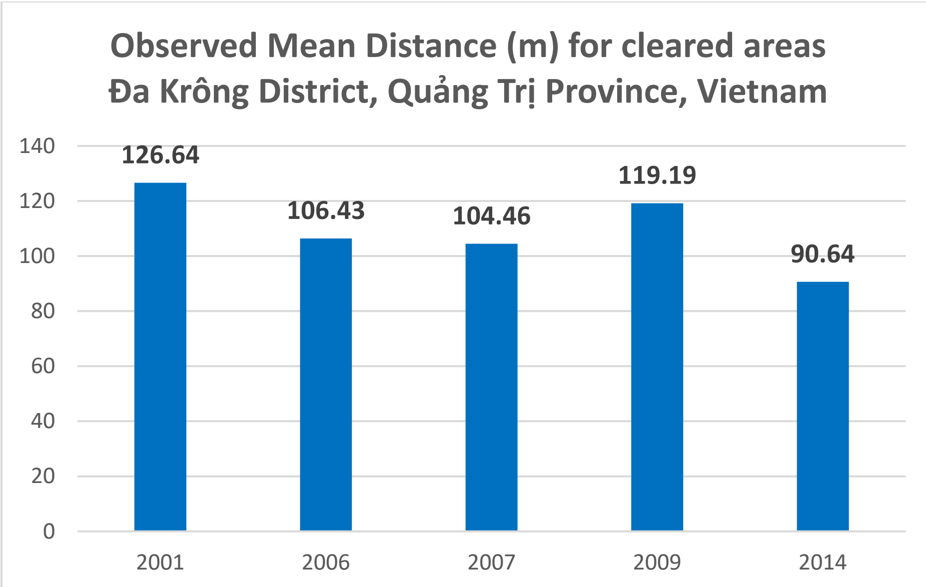


Figure 22: Average distance between cleared areas (April-centered chrono-series), 2001-2014

2.4.2 Statistical sampling of clearings across district finds no clear trendline

Statistical samples taken for distance metrics (distance to population centers / distance to roads) and terrain metrics (elevation and slope) of *all clearings* for each image date (2001-2014) show oscillations in the values of those metrics, and do not appear to reveal trendlines showing a clear and consistent direction of change over the chrono-series, suggesting that data aggregated for the district as a whole does not show have a consistent directionality of change (Figure 23, Figure 24, Figure 25, and Figure 26). For each time step, the box encompasses the central tendency (25-75% range of values), with the line inside that box representing the median; the whiskers represent 1.5 standard deviations in either direction of the central (median) value.

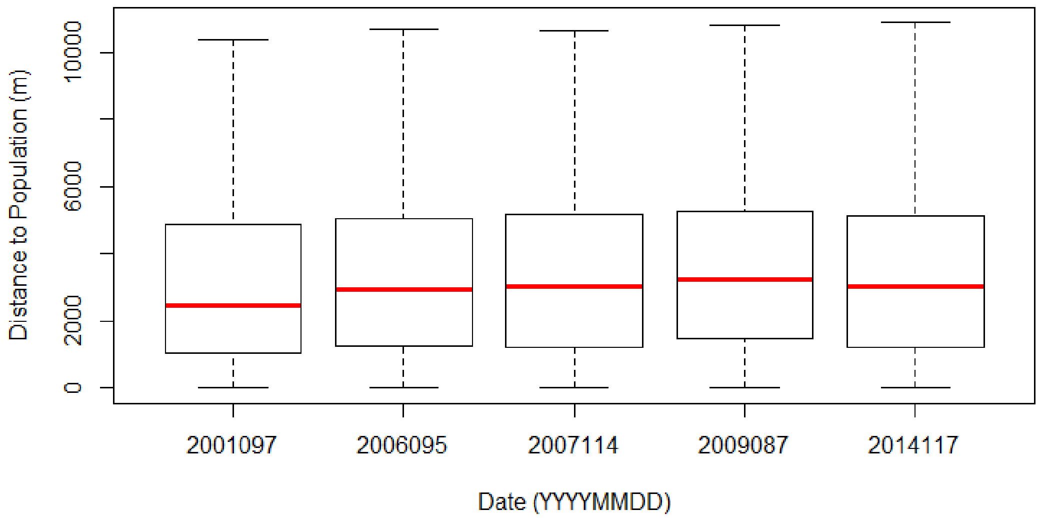


Figure 23: Boxplot showing range of values in Distance to Population for all clearings across district for each image date (2001-2014)

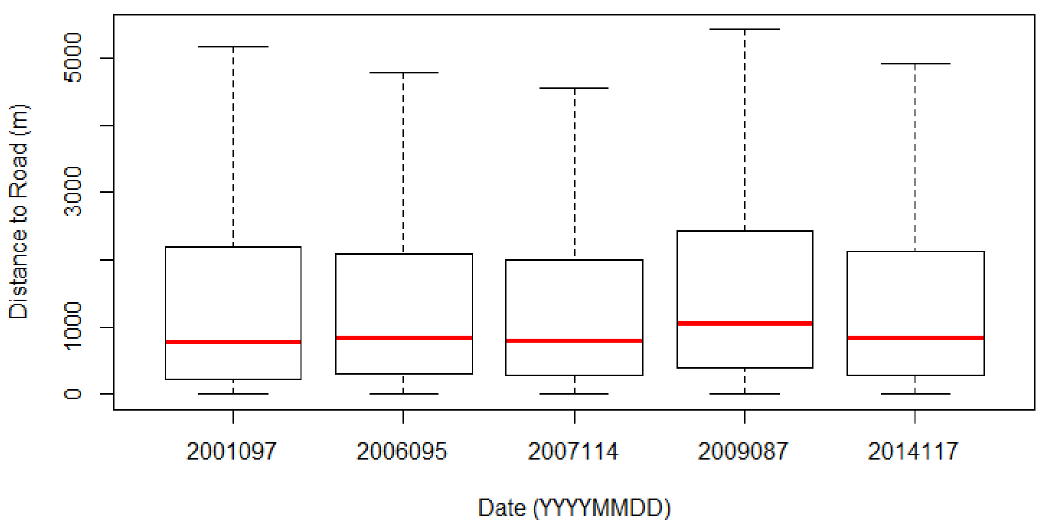


Figure 24: Boxplot showing range of values in Distance to Road for all clearings across district for each image date (2001-2014)

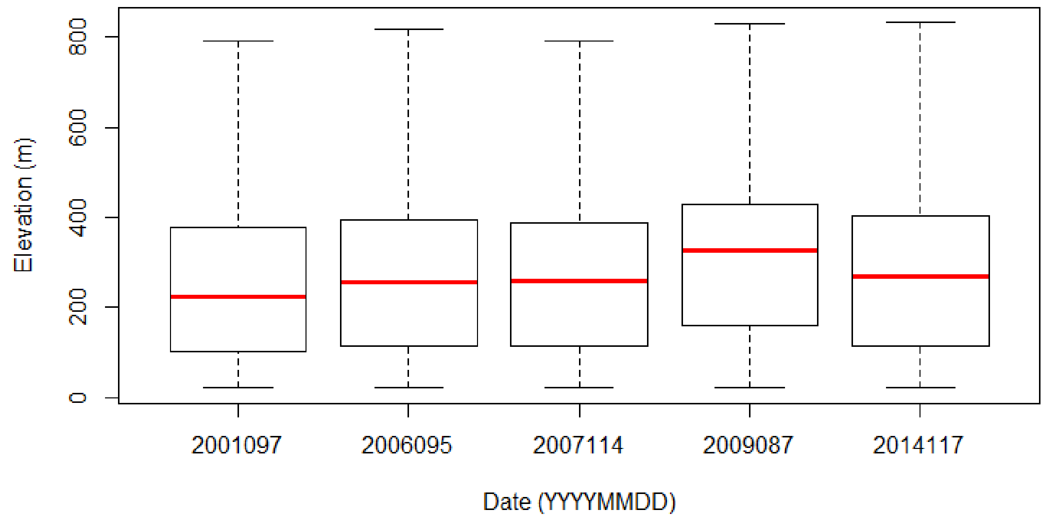


Figure 25: Boxplot showing range of values in Elevation for all clearings across district for each image date (2001-2014)

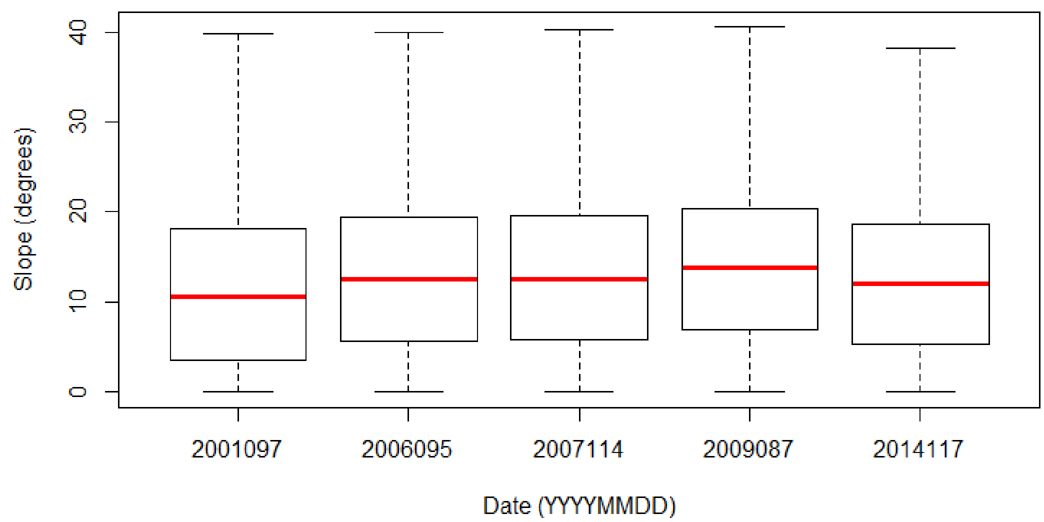


Figure 26: Boxplot showing range of values in Slope for all clearings across district for each image date (2001-2014)

Selecting only clearings that occurred within 1500m of the two main highways - Highway 9 (east-west) and Ho Chi Minh Highway (north-south) - for the period 2001 to 2014, again shows an oscillation in values without a clear directional trendline over the time series (Figure 27, Figure 28, Figure 29, and Figure 30):

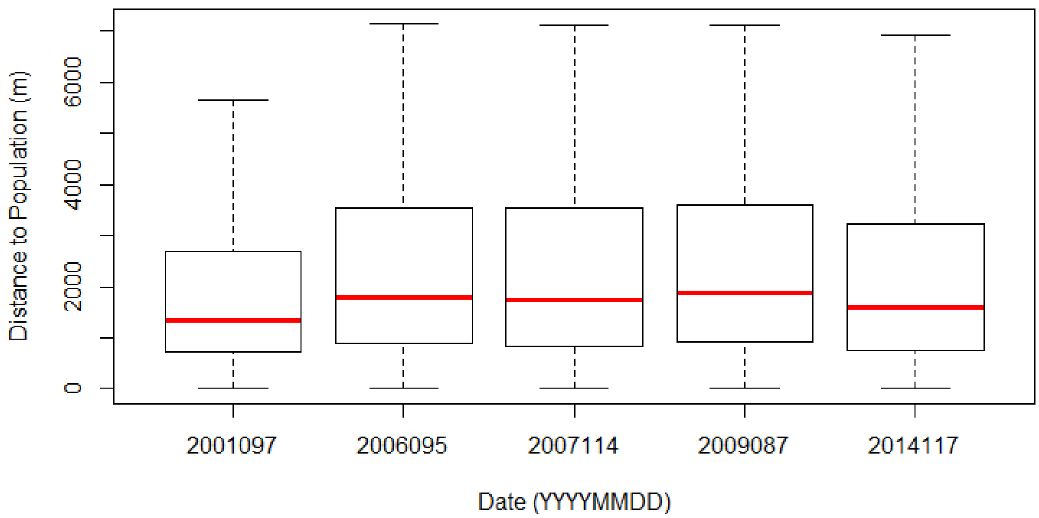


Figure 27: Boxplot showing range of values in Distance to Population of clearings within 1500m of Highway 9 / Ho Chi Minh Highway for each image date (2001-2014)

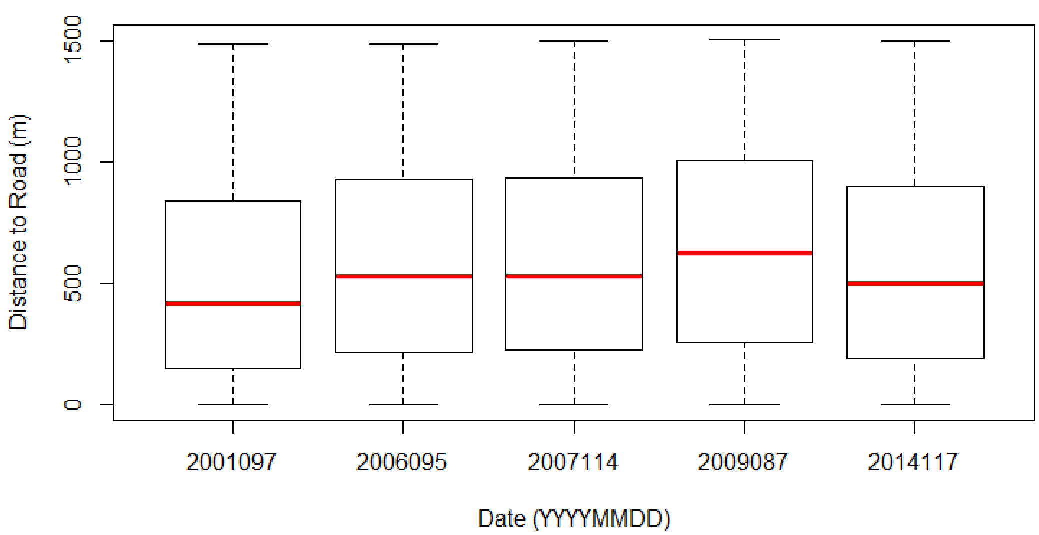


Figure 28: Boxplot showing range of values in Distance to Road for clearings within 1500m of Highway 9 / Ho Chi Minh Highway for each image date (2001-2014)

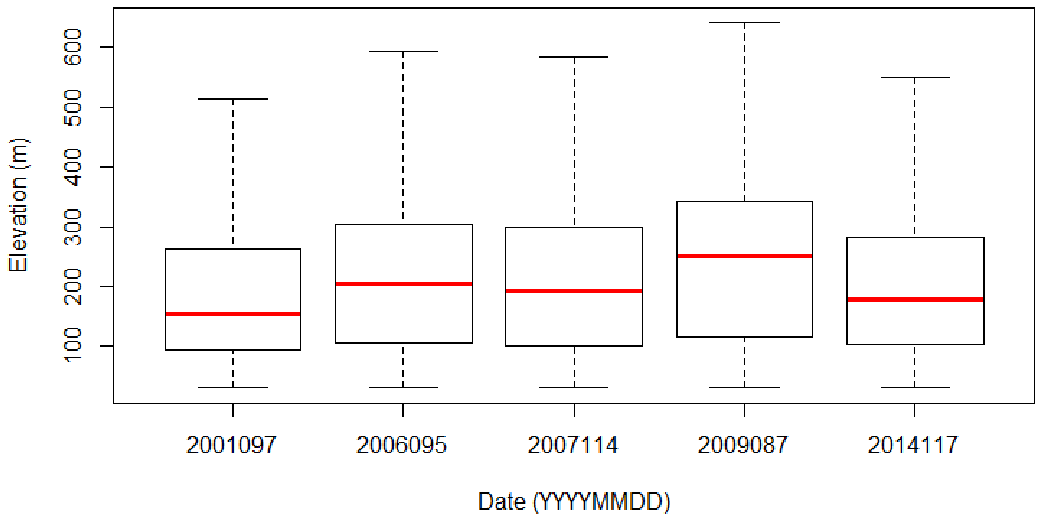


Figure 29: Boxplot showing range of values in Elevation of clearings within 1500m of Highway 9 / Ho Chi Minh Highway for each image date (2001-2014)

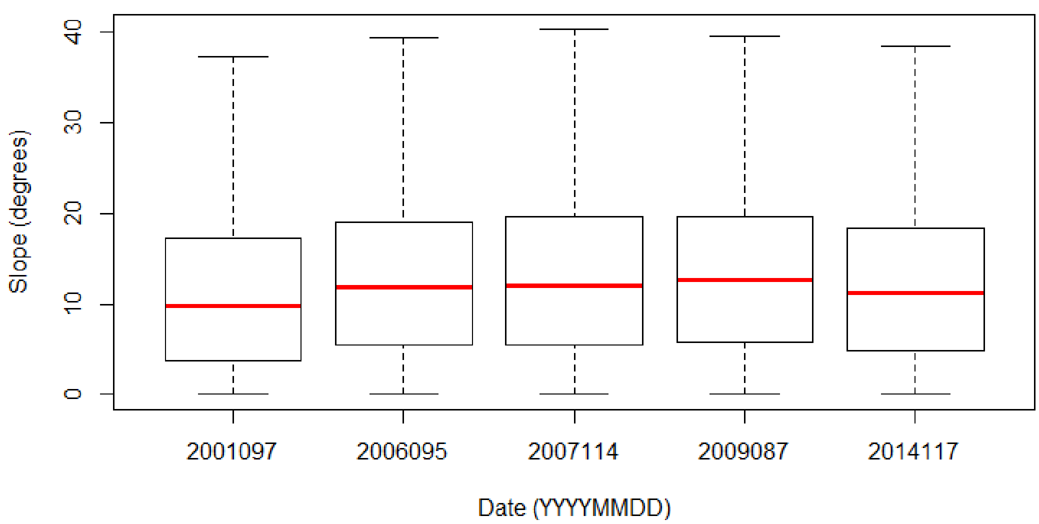


Figure 30: Boxplot showing range of values in Slope of clearings within 1500m of Highway 9 / Ho Chi Minh Highway for each image date (2001-2014)

2.4.3 Direction of change relative to highways based on median center points

Comparing median center points, which measure central tendency robust to outliers vs. mean center points, for defined areas of interest (i.e., zones and sectors) allows for the identification of shifts in the concentration of clearings for sectors straddling the primary roads (Highway 9 and Ho Chi Minh Highway) for the study area over time. The shifts identified here are based only on median center points of clearings by date, and as such do not incorporate other distance metrics.

2.4.3.1 Direction of change in Highway 9 corridor (Zones 1 and 2)

Analysis of median center points of clearings in Zone 1 (Krông Klang district town and Mò Ó commune) shows substantial movement toward Highway 9 in two sectors and relative stasis in one sector (Table 6 and Figure 31):

(1) Sector A: the median center points of clearings in the western half of Krông Klang townlet showed net movement toward Highway 9 by 191m (24.3%);

(2) Sector B: the median center points of clearings in the eastern half of Krông Klang townlet showed net movement toward Highway 9 by 224m (23%); and

(3) Sector C: the median center points of clearings in Mò Ó commune did not show net movement toward or away from Highway 9.

Analysis of median center points of clearings in Zone 2 (ĐaKrông commune) shows relatively moderate movement toward Highway 9 in one sector, slight movement away from the Highway 9 in another sector, and a substantial shift toward Ho Chi Minh Highway in one sector (Table 6 and Figure 32):

(1) Sector A: the median center points of clearings in the northern sector of ĐaKrông commune showed net movement toward Highway 9 by 180m (19.3%);

(2) Sector B: the median center points of clearings in the southeastern sector of ĐaKrông commune showed net movement away from Highway 9 by 12m (1.3%); and

(3) Sector C: the median center points of clearings in the southwestern sector of ĐaKrông commune showed net movement toward Ho Chi Minh Highway by 695m (35%).

2.4.3.2 Direction of change in Highway 9 corridor (Zones 3 and 4)

Analysis of mean and median center points for clearings in Zone 3 shows shifts away from Ho Chi Minh highway for both sectors evaluated. Sector A was excluded from this analysis due to a lack of connection to / adjacency with the primary road network. Findings were as follows (Table 6, Figure 33, and Figure 34):

(1) Sector B: the median center points of clearings in the center sector of this zone showed net movement away from Ho Chi Minh Highway by 283m (18.8%); and

(2) Sector C: the median center points of clearings in the center sector of this zone showed net movement away from Ho Chi Minh Highway by Highway 9 by 811m (39.3%).

Analysis of mean and median center points for clearings in Zone 4 shows shifts away from Ho Chi Minh highway in the north sector and south sectors and a shift toward the road in the center sector (Table 6, Figure 33, Figure 34, and Figure 35):

(1) Sector A: the median center points of clearings in the north sector showed net movement away from Ho Chi Minh Highway by 304m (6.9%);

(2) Sector B: the median center points of clearings in the center sector showed net movement toward Ho Chi Minh Highway by 361m (20.7%); and

(3) Sector C: the median center points of clearings in the south sector showed net movement away from toward Ho Chi Minh Highway by 348m (56.3%).

Table 6: Median centerpoints summary table by zone and sector (2001 vs. 2014)

Zone	Sector	Distance to road - 2001 (m)	Distance to road - 2014 (m)	Difference 2001-2014 (m)	Change (%)	Direction of movement	Nearest highway
1	A	785	594	191	24.33	toward road	Highway 9
	B	976	752	224	22.95	toward road	Highway 9
	C	2143	2142	1	0.05	no net movement	Highway 9
2	A	932	752	180	19.31	toward road	Highway 9
	B	914	926	-12	-1.31	away from road	Highway 9
	C	1984	1289	695	35.03	toward road	HCM Highway
3	B	1507	1790	-283	-18.78	away from road	HCM Highway
	C	2065	2876	-811	-39.27	away from road	HCM Highway
4	A	4407	4711	-304	-6.90	away from road	HCM Highway
	B	1744	1383	361	20.70	toward road	HCM Highway
	C	618	966	-348	-56.31	away from road	HCM Highway

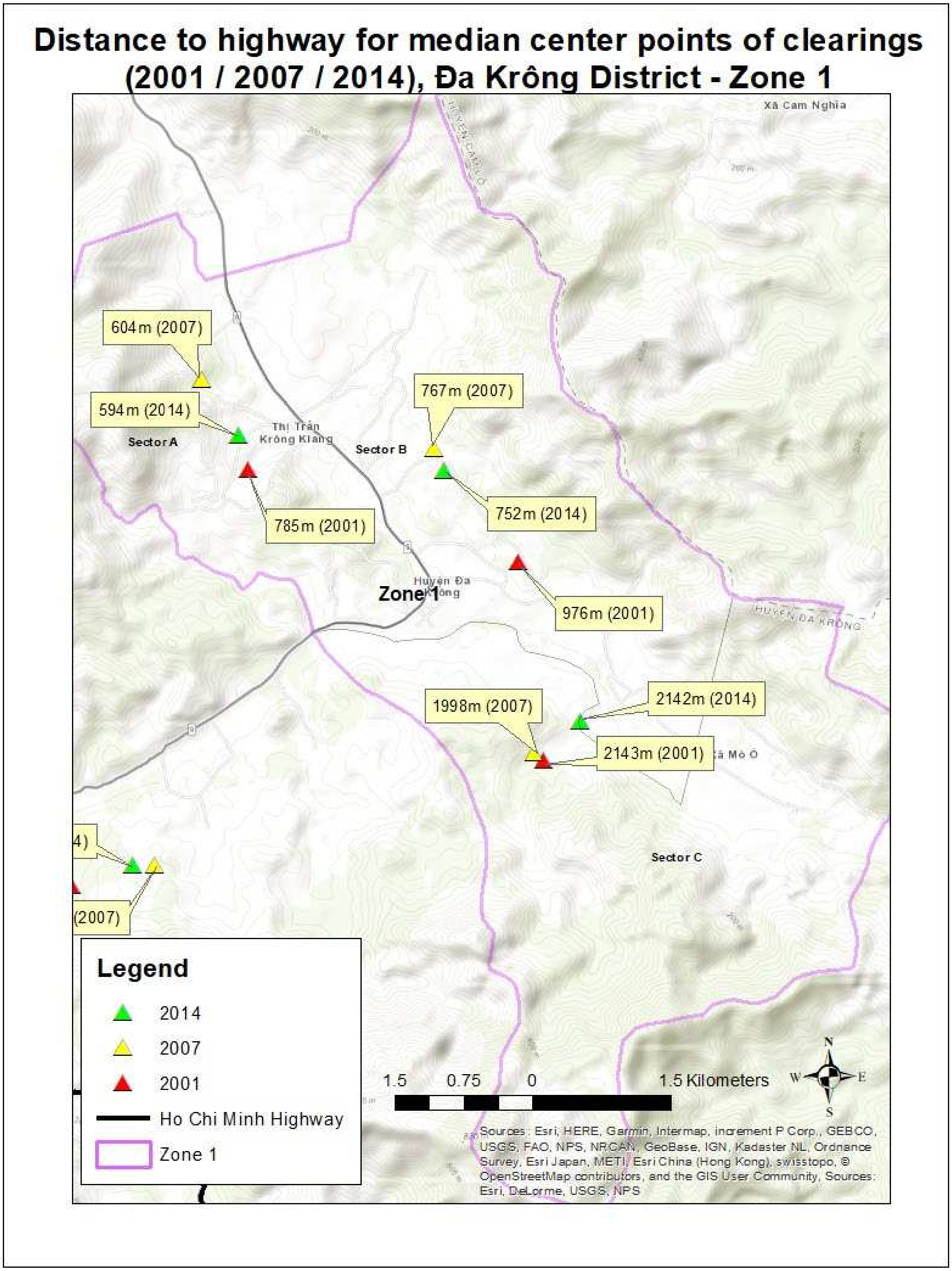


Figure 31: Distance to nearest highway for median center points of clearings (2001 / 2007 / 2014) in Zone 1 (Krông Klang townlet and Mò Ó commune)

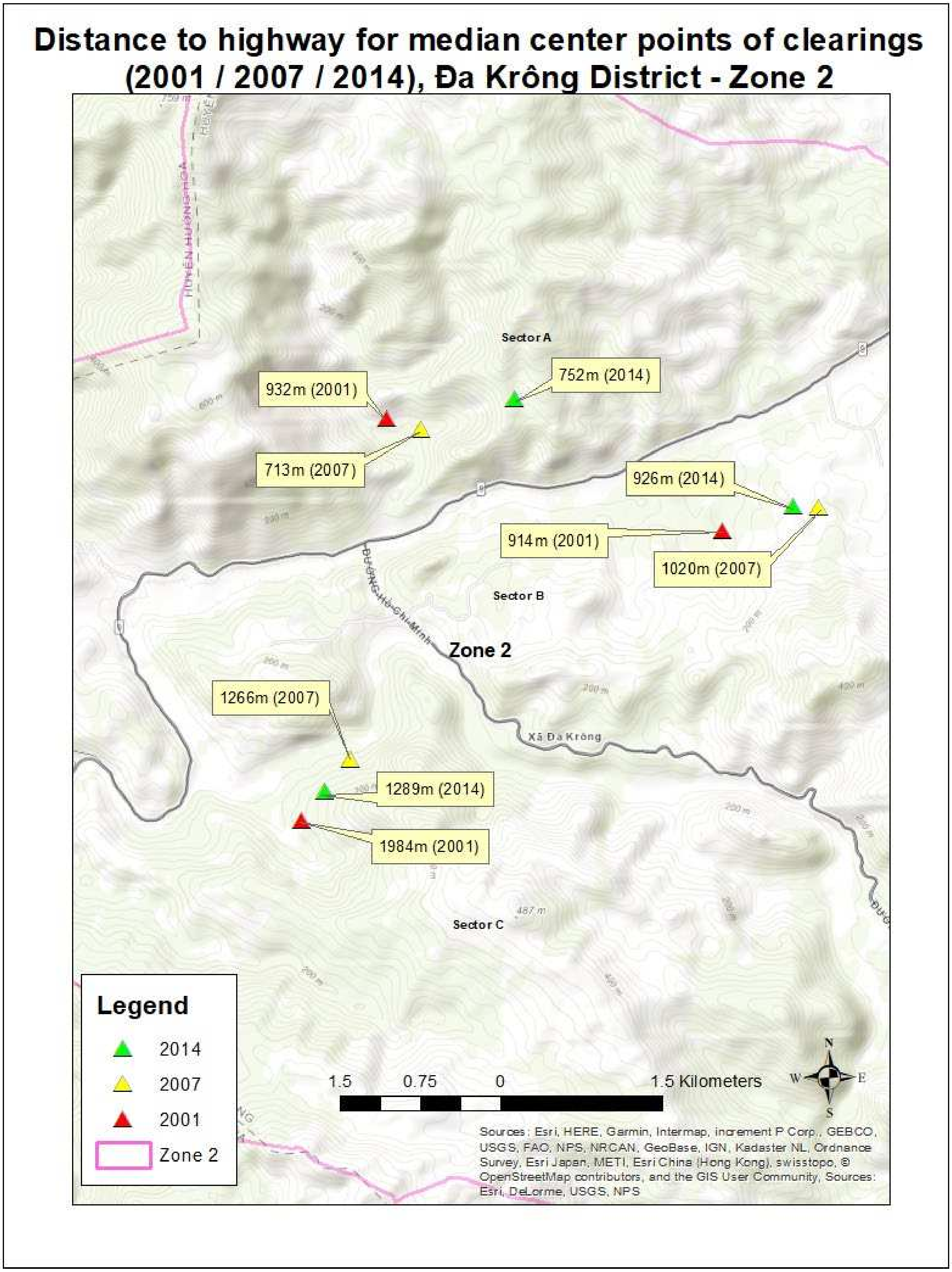


Figure 32: Distance to nearest highway for median center points of clearings (2001 / 2007 / 2014) in Zone 2 (ĐaKrông commune)

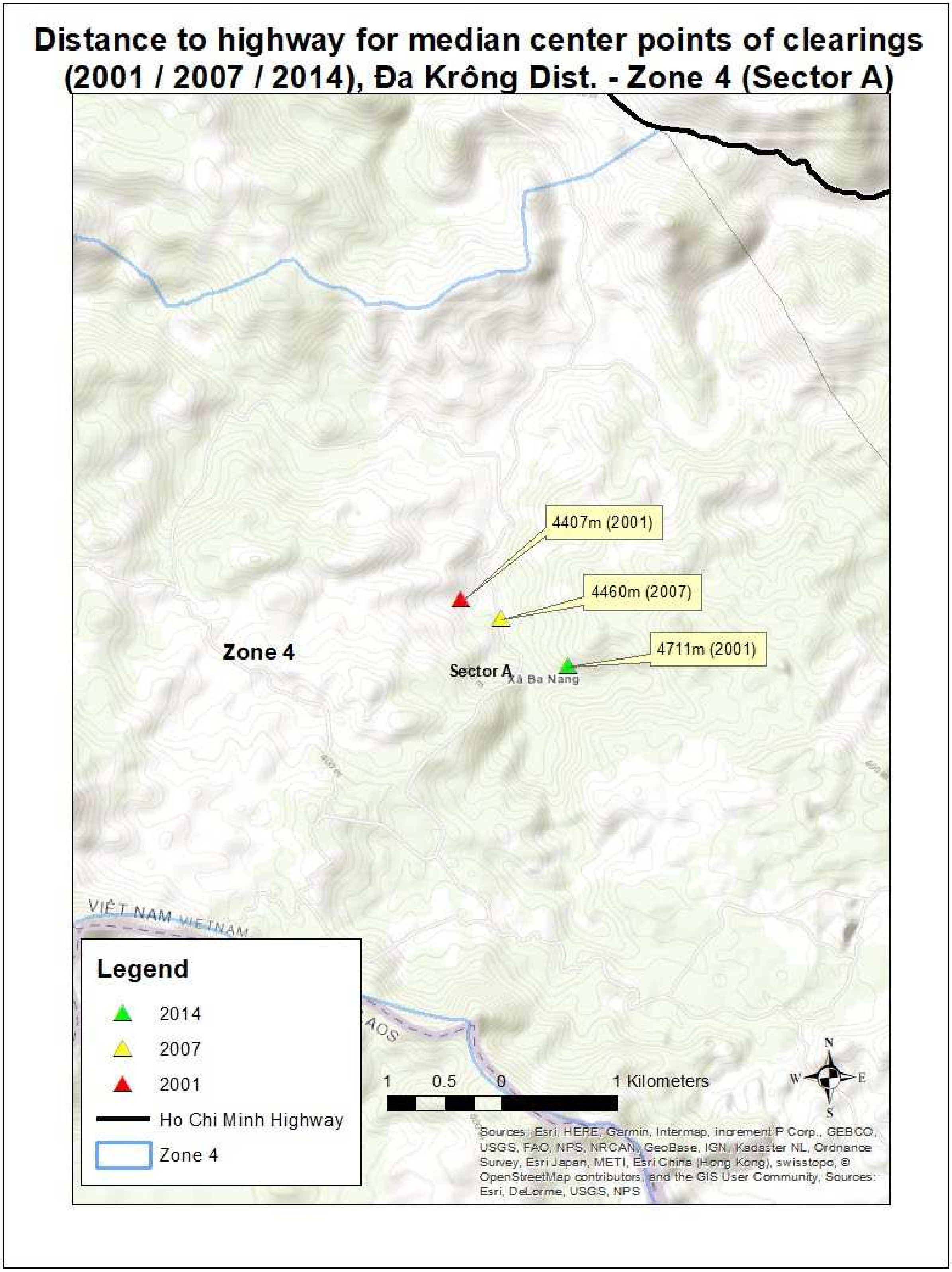


Figure 33: Distance to nearest highway for median center points of clearings (2001 / 2007 / 2014) in Zone 4 (Ba Nang Commune)

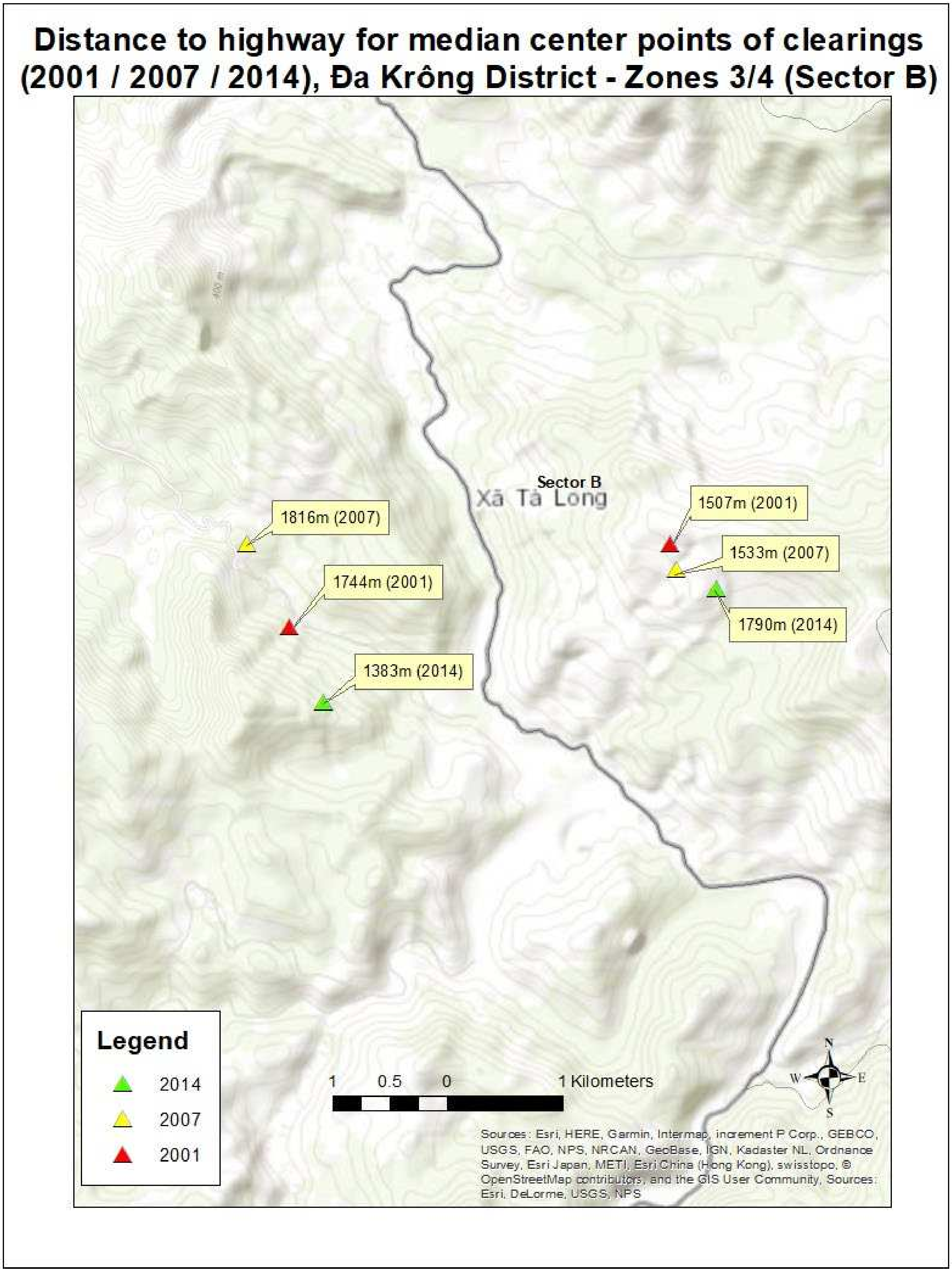


Figure 34: Distance to nearest highway for median center points of clearings (2001 / 2007 / 2014) in Zone 3 and Zone 4 (center sectors)

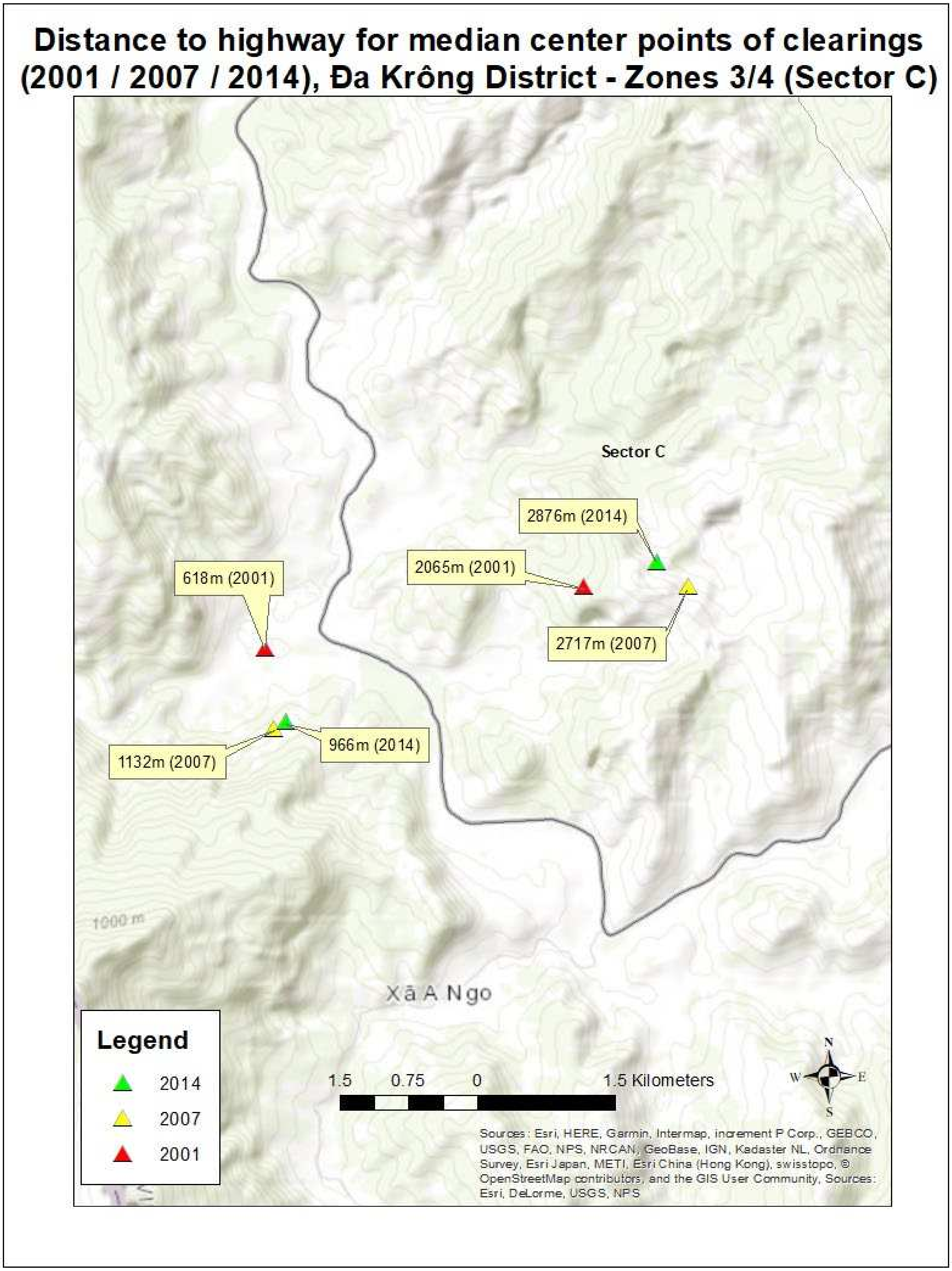


Figure 35: Distance to nearest highway, median center points of clearings (2001 / 2007 / 2014) in Zone 3 and Zone 4 (south sectors)

2.4.4 Direction and magnitude of change based on shifts in density of clearings

Kernel density surfaces of clearings per hectare show an increase in clearings across the east-west corridor traversed by Highway 9 and toward the southern end of the Ho Chi Minh Highway corridor. Summary statistics of clearings per hectare show a net *decrease* in the total amount of lower density cultivation (0-10% per hectare cleared) and increase in the total amount of higher density cultivation (10-30% per hectare cleared) (Figure 36 and Table 7). Clearings with higher densities over 40% per hectare, which were not observed prior in 2009 or prior, first appear in 2014 (Table 7). Areas with lower density clearings tend to be found further from roads, whereas higher density cultivated zones tend to be located closer to roads (Figure 37 and Table 8).

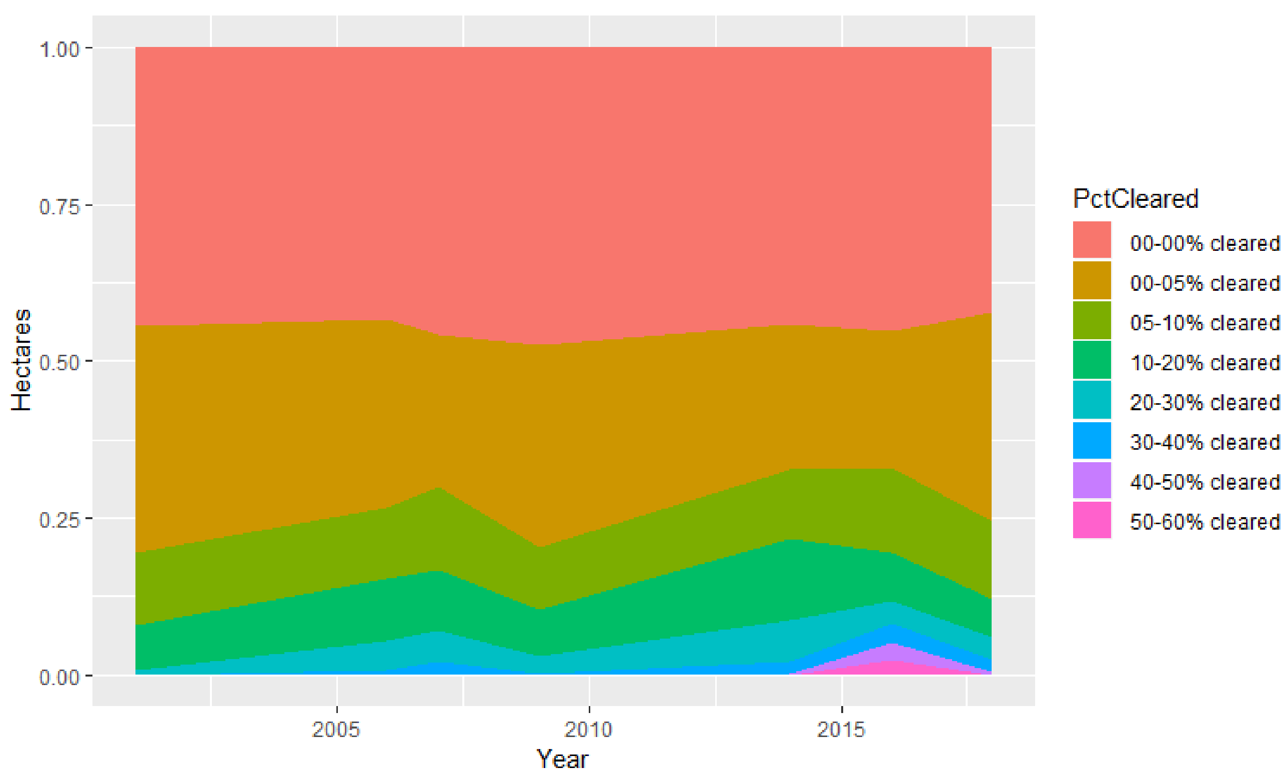


Figure 36: Changing distribution of clearings by intensity class (kernel density)

Table 7: Changing distribution of clearings by intensity class (kernel density), 2001-2014

Year	Hectares with 0% cleared	Hectares with > 0% / < 5% cleared	Hectares with 5-10% cleared	Hectares with 10-20% cleared	Hectares with 20-30% cleared	Hectares with 30-40% cleared	Hectares with 40-50% cleared
2001	79917	65130	20715	12942	1476	0	0
2006	83924	52156	19492	16971	8183	1326	0
2007	82576	43692	23971	17109	9027	4018	0
2009	84849	58175	17666	13259	4667	628	0
2014	71987	38181	17812	21382	10710	3119	490
% change (2001-2014)	-9.92	-41.38	-14.01	65.21	625.61		
% change (2007-2014)	-12.82	-12.61	-25.69	24.98	18.64	-22.37	

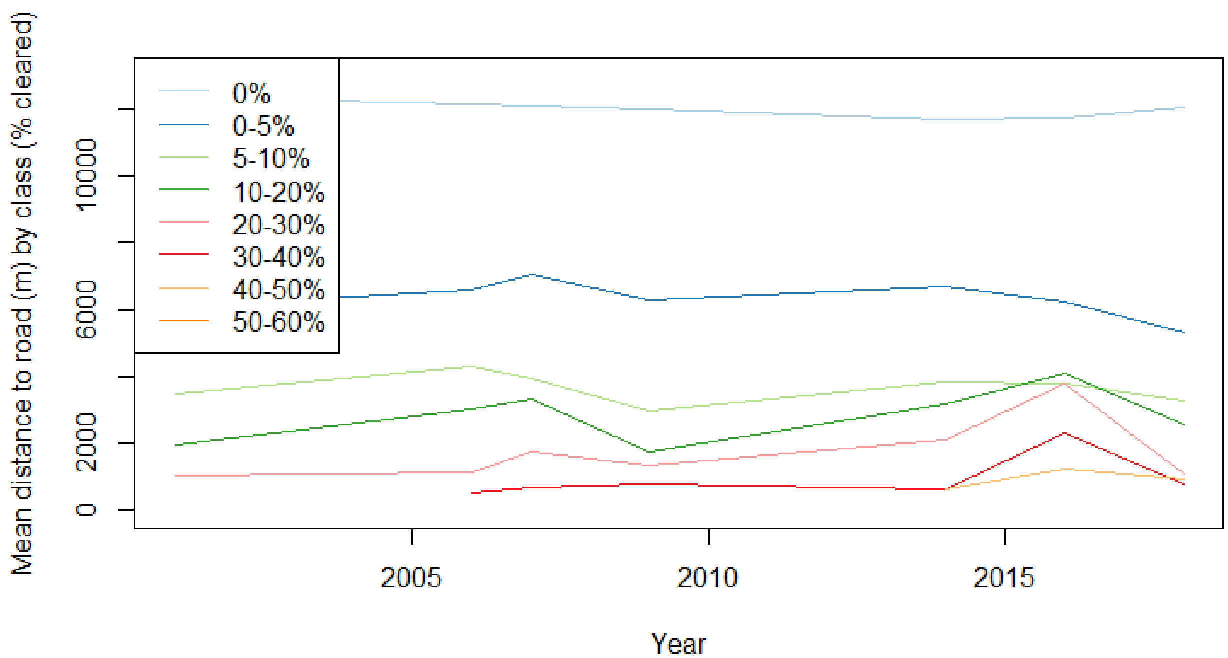


Figure 37: Mean distance to road of cleared areas by intensity class (kernel density)

Table 8: Mean distance to road of cleared areas by intensity class (kernel density), 2001-2014

Mean distance to road of clearings by intensity class	Hectares with 0% cleared	Hectares > 0% and < 5% cleared	Hectares with 5-10% cleared	Hectares with 10-20% cleared	Hectares with 20-30% cleared	Hectares with 30-40% cleared	Hectares with 40-50% cleared
2001	12351.46	6076.75	3481.98	1969.26	1024.44	0.00	0.00
2006	12130.50	6574.55	4314.80	3021.67	1164.30	527.47	0.00
2007	12109.51	7037.99	3962.78	3310.98	1776.95	695.22	0.00
2009	12004.05	6291.80	2956.04	1765.72	1334.89	794.06	0.00
2014	11684.31	6712.80	3834.05	3205.38	2100.06	617.12	656.26
Overall % change (2001-2014)	-5.40	10.47	10.11	62.77	105.00		
Overall % change (2007-2014)	-3.51	-4.62	-3.25	-3.19	18.18	-11.23	

A series of maps depicts the density of clearings per hectare across the study area for each time step in this chrono-series (Figures 38-42). These maps show more concentrated cultivation along the Highway 9 corridor in the north of the study area, peaking in 2014. The relatively lower level of clearings for late March 2009 are considered an anomaly from this trendline due to a severe flooding event impeding normal crop planting according to local villagers (Leisz et al. 2014). With regard to the apparent increase in agricultural clearings in the southern end of the study area suggesting intensification of cultivation, there are no data currently available regarding household decision-making and cropping behavior. Further research and analysis would be needed to contextualize land-use systems vis-à-vis land-cover change in that area.

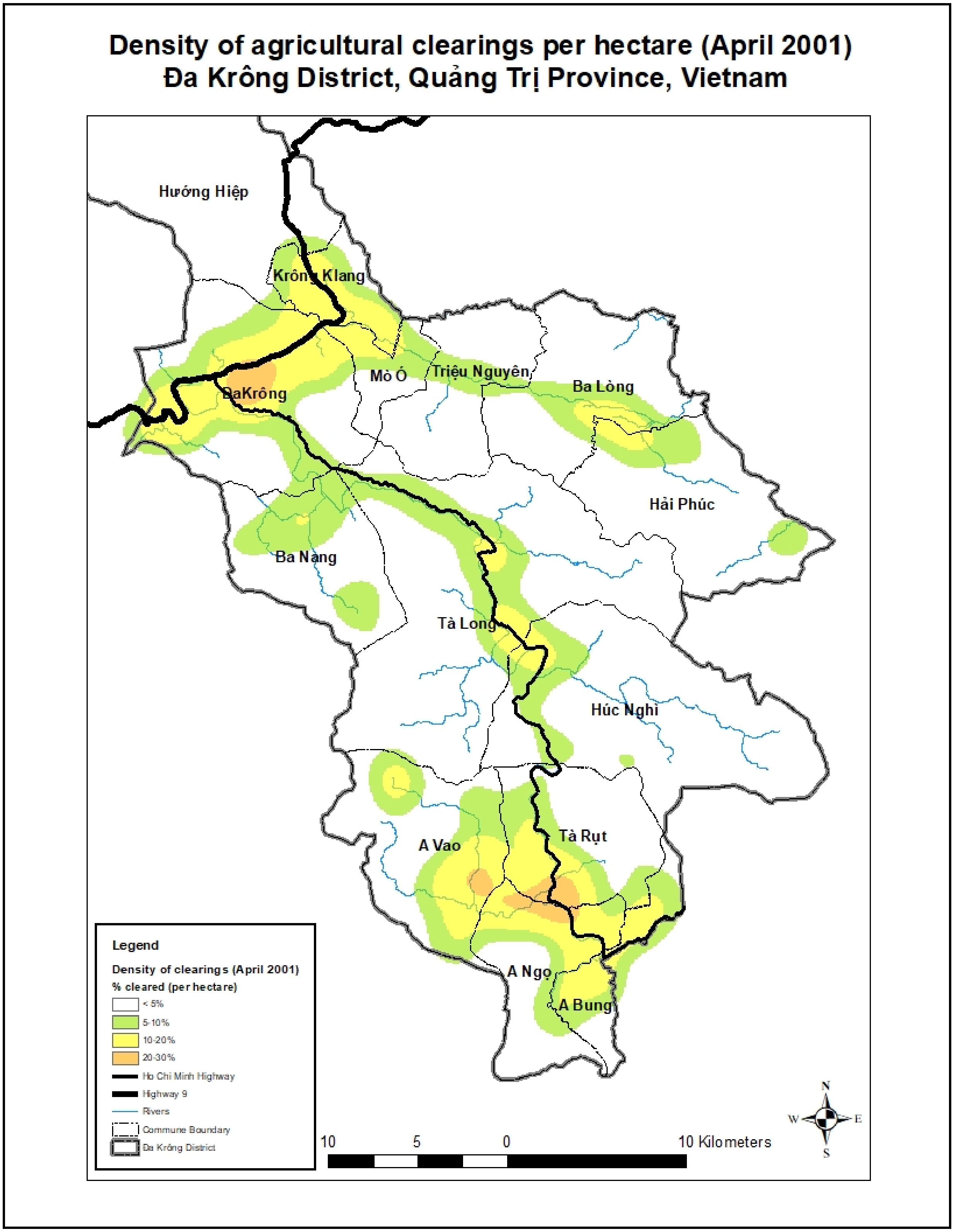


Figure 38: Density of agricultural clearings per hectare, Đa Krông District, Quảng Trị Province, Vietnam (April 2001)

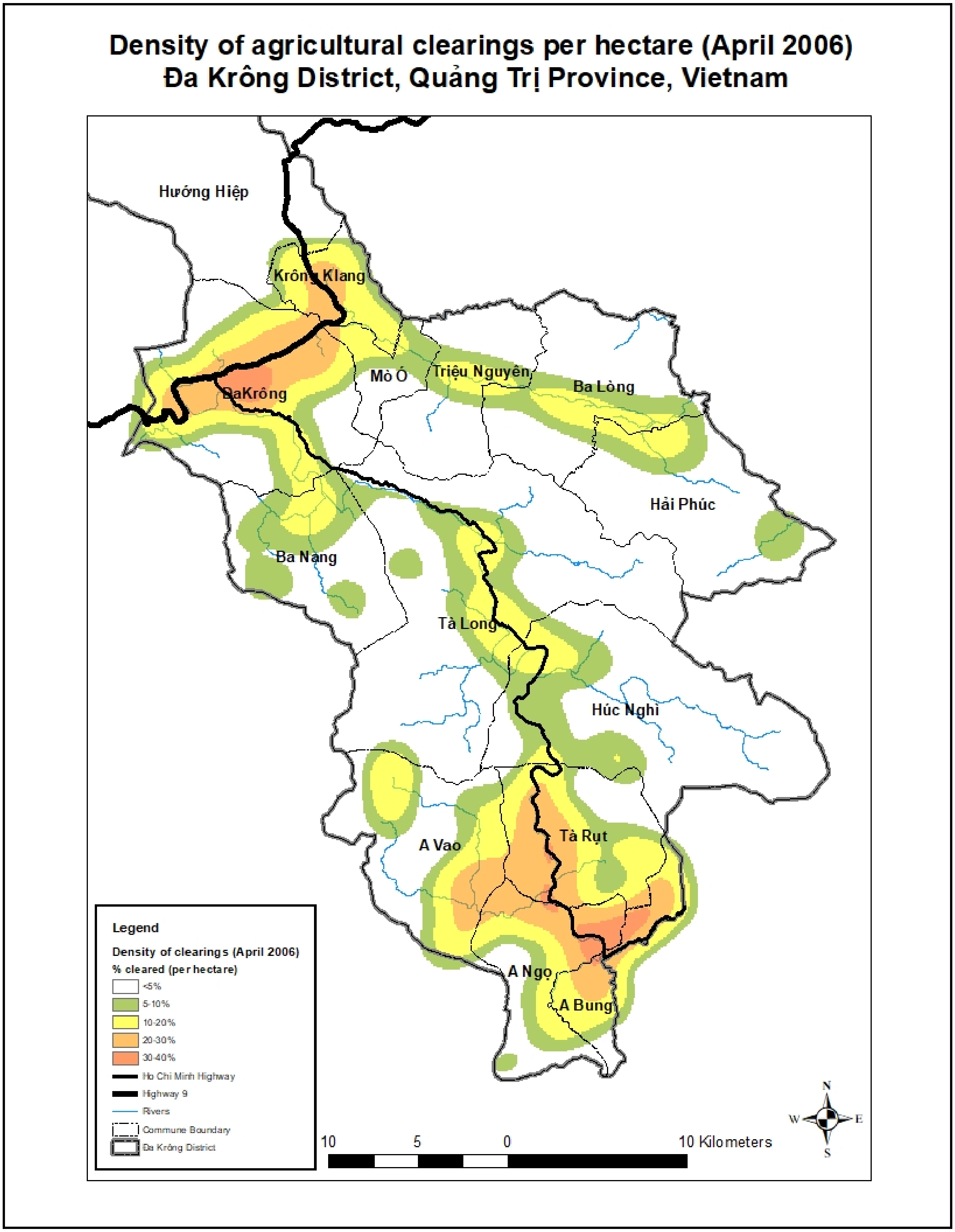


Figure 39: Density of agricultural clearings per hectare, Đa Krông District, Quảng Trị Province, Vietnam (April 2006)

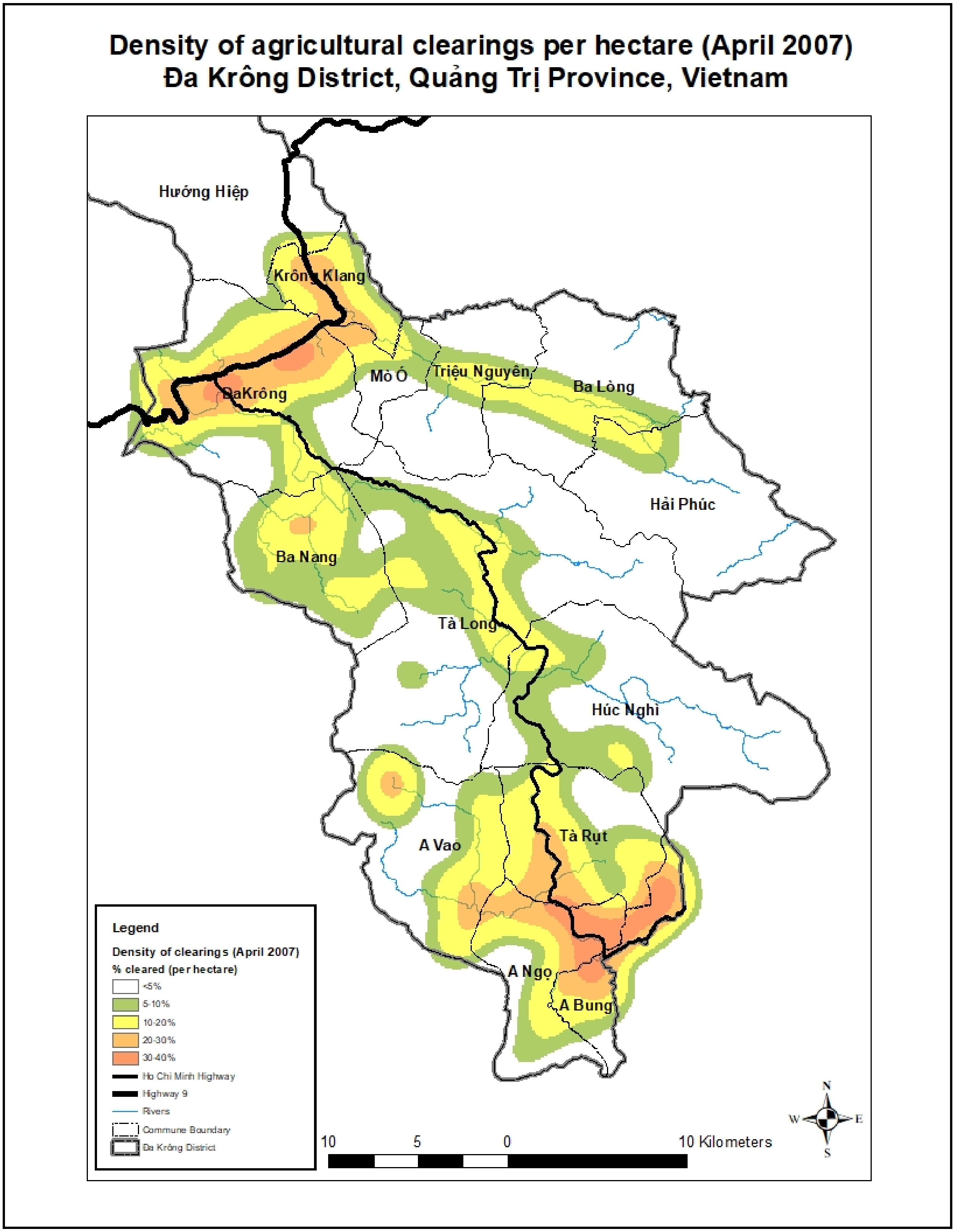


Figure 40: Density of agricultural clearings per hectare, Đa Krông District, Quảng Trị Province, Vietnam (April 2007)

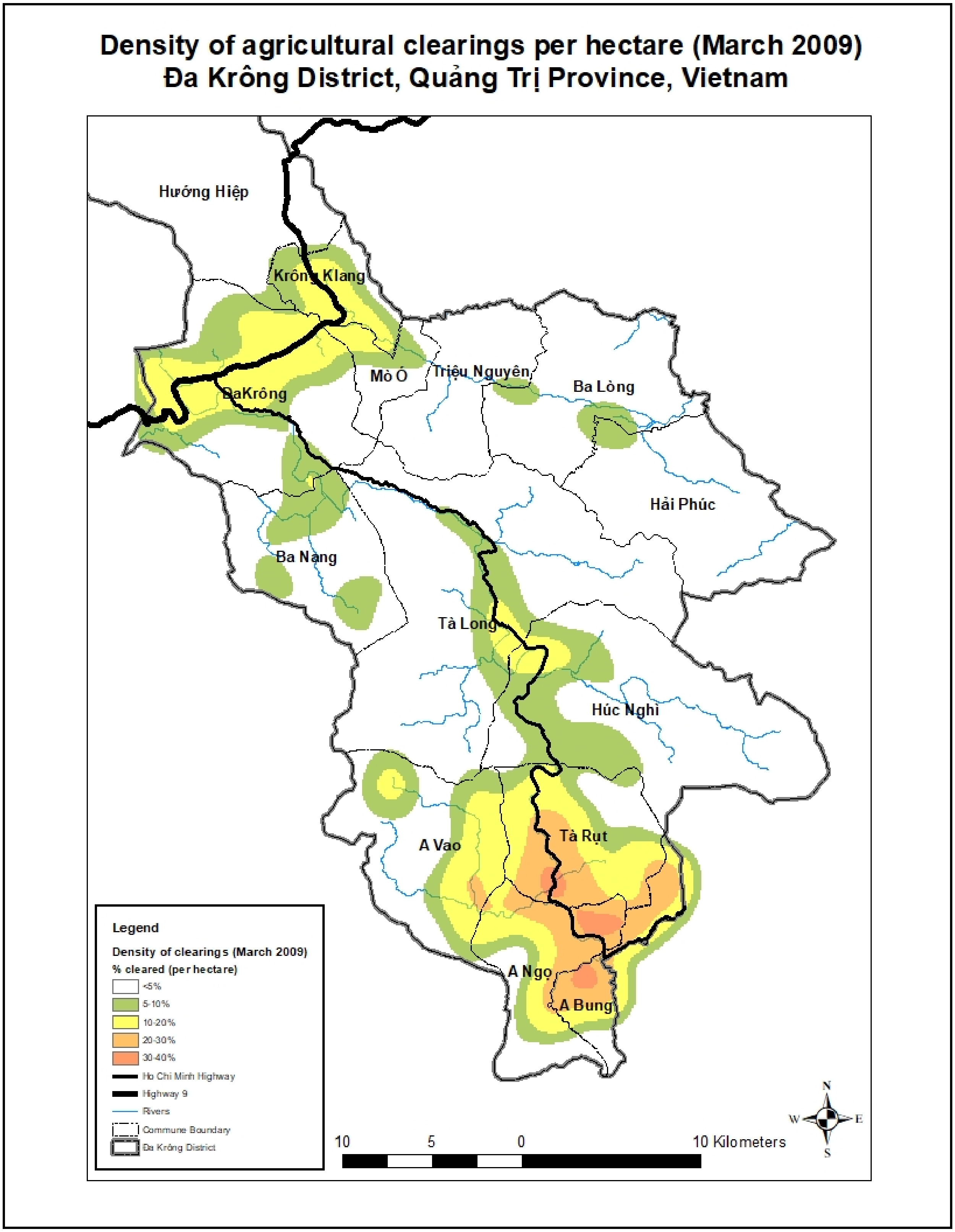


Figure 41: Density of agricultural clearings per hectare, Đa Krông District, Quảng Trị Province, Vietnam (March 2009)

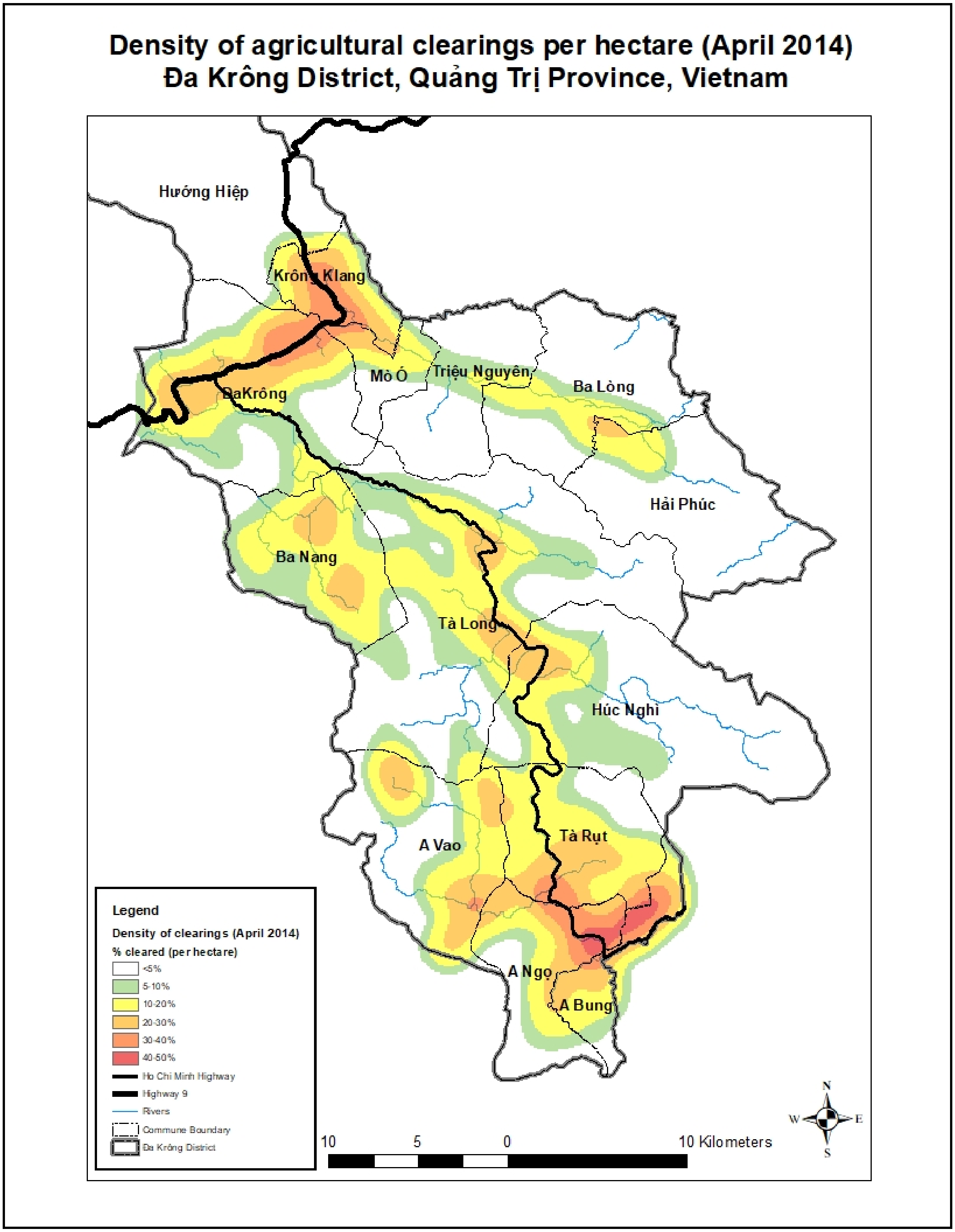


Figure 42: Density of agricultural clearings per hectare, Đa Krông District, Quảng Trị Province, Vietnam (April 2014)

2.4.5 Caveats on results as relate to data availability / quality, tools and methods

Before proceeding to a substantive discussion concerning the assessed direction and magnitude of land-cover change, a few important disclaimers on the results of the methods employed and the data available are warranted. Efforts to date have been constrained in important ways, including but not limited to the following:

(1) spatial and temporal resolution of available data;

(2) usability of available data; and

(3) limitations in tools and methods for change detection analysis.

The USGS Landsat program undoubtedly provides regular and reliable revisit to areas of interest, maintaining continuous coverage of the planet's surface and often providing imagery of tremendous value to the land change science community. However, it bears noting that the resolution of the available imagery – spatially at 30m by 30m pixel size and temporally at 16-day intervals – does present challenges for the detection and identification of change in the landscape. With regard to spatial resolution, a pixel size of 900 square meters generally works well for most areas, but fieldwork has found that agricultural plots cleared by individual households in many cases may cover an area of only ~ 500 square meters (Leisz et al. 2014). This results in an agricultural footprint that may appear to be merely noise, and therefore get lost in satellite imagery, due to the mixed pixel problem, where spectral mixing arises from complex mosaics of land-use. With regard to temporal resolution, the cropping cycle engaged in the spring season for the study area (i.e., February / March / April) may commence at slightly different times from one year to the next, and it may proceed at a faster or slower rate depending upon prevailing climate conditions, than can be captured by the 16-day revisit cycle interval.

With regard to the usability of imagery, environmental and operational issues bear noting. Regarding environmental issues, Landsat imagery collection obtained under normal conditions (Landsat 5 “TM” / Landsat 8 “OLI”) for this area of interest often show persistent, dense cloud-cover throughout most of the year, severely limiting the ability to discern landscape conditions on the ground. Additionally, technical difficulties affecting two platforms - Landsat 5 “TM” over the period from 2010 to 2013 and Landsat 7 (ETM+) for most of its operational lifetime – substantially reduce the imagery available for analysis. This four-year gap limits the ability to correlate patterns of land-cover change with land-use systems during a key window.

A final challenge in identifying patterns of change (direction and magnitude) from these limited and correlating such patterns with events on the ground arises from the inherent limitations of available tools and methods to render a one-to-one map of conditions on the ground. Even high-quality satellite imagery with moderate spatial resolution and rich spectral content only informs a certain level of accuracy, especially in the absence of ground truth across the study area as a whole, for those dates being evaluated, for cross-referencing and validation.

2.5 Discussion of observed change in land-cover patterns and drivers thereof

Lambin et al. (2003: 228) define transition as “a process of societal change in which the structural character of society (or a complex subsystem of society) transforms.” They posit that LULC change exhibits indeterminacy and instability, thus trajectories of transitions vary highly (Lambin 2003: 228). Such transitions are not foreordained in nature or deterministic in sequence, but rather trajectories can be influenced by external factors, e.g., markets and policy (Lambin et al. 2003).

An *agrarian transition* has been underway in the uplands of rural areas of north-central Vietnam, as across much of the Vietnam post-Đổi Mới and neighboring areas of the Greater

Mekong Subregion. The agrarian transition taking place in the study area over the last decade has involved a shift in agricultural land-use toward market-oriented production. This change has manifested partially in changing patterns of land-cover, and most land-use changes have mixed implications for rural livelihoods and ecosystem sustainability.

This section considers fundamental causes that are associated with this process of agrarian transition. These include exogenous factors (economic and political) that operate from a distance and influence endogenous factors (social and cultural) at the local level. Endogenous factors in turn influence land-use systems decision-making at the local level in rural, upland communities. While the improved road network cannot be conclusively shown to be a causal factor, it is considered a key factor correlated with this process, by facilitating connectivity that drives interactions between urban centers and rural communities.

2.5.1 Discussion of changing land-cover patterns

Insofar as a pattern of LULC change can be ascertained, given practical constraints with data and methods and the general indeterminacy of land-use transition per Lambin et al. (2003), the change detection analysis performed for 2001 to 2014 appears to show a net increase in the total areal extent of agricultural clearings and increasing clustering of clearings across the study area as a whole. Along the Highway 9 corridor traversing from east to west in north of the study area, the distance of clearings to roads decreased for multiple sectors, based on shifts in median center points representing the central tendency of clearings (Zone 1, two out of three sectors and Zone 2, two out of three sectors). Additionally, kernel density surfaces show higher density of clearings per hectare near Highway 9, while the maximum distance of lower density bands to roads declines slightly. This shift suggests more cultivation along the intensive margin and a slight a reduction in cultivation at the extensive margin. Developments elsewhere in the study area do not show clear directionality of change with respect to primary roads.

The identified changes in agricultural clearings, at least along the Highway 9 corridor, are at least partly associated with a rise in cash cropping, based on the findings of fieldwork (Leisz et al. 2016) for several communities located within the EWEC sphere of influence. Villages worth noting specifically in this regard are Klu, located at the crossroads of Highway 9 and Ho Chi Minh Highway in Đa Krông Commune, and Ta Rec, located ~10km to the south in Ba Nang commune. Citing these examples does not constitute proof by anecdote, i.e., is not meant to imply that what is true to two villages can be extrapolated across the study area as a whole. Rather, it highlights a need for follow-up and further research to broadly assess more recent developments in land-use by households at the village level elsewhere.

Shifts by such agrarian communities in their cropping practices away from subsistence cultivation and toward market-oriented production often reflect a response to demand originating from urban-based industries, enabled by exogenous actors and facilitated by the improved road network. Initial findings appear to reflect this is occurring in at least those sub-areas with greater proximity to market (i.e., along the Highway 9 corridor), where distance costs and time costs associated with moving agricultural commodities are relatively lower than areas farther from markets (e.g., along Ho Chi Minh Highway in this study area, particularly for those communities lacking all-season access to the main roads).

This trend of changing land-cover observed for Highway 9 does not hold across the study area *as a whole* for each timestep over the time period 2001 to 2014. It is therefore not possible to assert a clear and consistent trendline that supports the claim of a compelling link between the road improvement project and changing patterns of LULC change. The hypothesized von

Thünen effect, the core microeconomic hypothesis, is thus not particularly well-supported at this time for the full spatial and temporal scope of the study. However, it would also appear premature to assert that the null hypothesis, i.e., that the road exerts no causal influence on the pattern of cultivation, applies.

The reality lies somewhere in between. As an interim statement, for further evaluation in subsequent chapters, this author opines that even if causation cannot be established, at least a probable spatio-temporal *correlation* exists between more recent LULC change and road improvements completed under the EWEC project. This is attributed to the role that improved market access and connectivity play in extending the reach of the “commodity web” into rural communities, incentivizing market-oriented production (Sikor and Tuong Vi 2005).

2.5.2 Linking land-cover change with land-use systems vis-à-vis five fundamental causes

This hypothesized road influence occurs in the context of multiple factor interactions. Five fundamental causes of land-use change include the following (Lambin et al. 2013):

(1) changing market-related opportunities;

(2) outside policy interventions;

(3) resource scarcity;

(4) loss of adaptive capacity/increased vulnerability; and

(5) changes in social organization.

The first and second factors are considered exogenous to communities, and the third, fourth, and fifth as endogenous. The interplay of these factors occurs at multiple scales, from the micro- (local) to the macro-, with meso-scale systems functioning as intermediaries. Both endogenous and exogenous factors bear on the dynamics of land rent, i.e., the von Thünen framework, and both sets of factors are amenable to analysis using a telecoupling framework perspective, due to the multi-scalar nature of the dynamics associated with land-use systems change.

2.5.2.1 Changing market-related opportunities and constraints (exogenous)

It is axiomatic that markets constitute complex adaptive systems involving a multitude of interacting components and fluctuating supply and demand dynamics. Such markets create business opportunities that can bring benefits to households and communities. These general concepts did not apply to the Vietnamese economy as a whole for several decades, when the economy was largely insulated from market forces under a socialist system of central planning run by the Vietnamese Communist Party. That command economy has given way since the 1990s to a more decentralized system driven by capital markets, giving rise to increasing investment and trade (Brooks and Hummels 2009). Since 2007, the market has been extending its reach from densely populated lowland regions into the rural hinterlands of Vietnam, e.g., the EWEC, with the financial support of outside investors, e.g., ADB and JICA (Leisz et al. 2016).

Fieldwork has found that several communities of the Đa Krông District, in the uplands of north-central Vietnam, have diversified their livelihood strategies by modifying land-use systems to incorporate cash cropping practices into their agricultural production (Leisz et al. 2016). These practices were enabled by the introduction of new crops, e.g., acacia and hybrid cassava, to local communities by outside actors. Cultivation was subsequently incentivized by brokers offering deposits to households to plant such crops for purchase at harvest at agreed-upon prices. The improved road network in this scenario constitutes a necessary condition, by facilitating the movement of essential people, materials, and funds. Hence the road can be viewed as a critical enabling factor, if not a direct causal trigger – and also, importantly, one framed in the context of government policies, e.g., the relative success of program 327 (1995), promoting acacia plantations, as contrasted with program 30A (2010), promoting rubber tree plantations, and program 135 (date unknown) to promote paddy rice cultivation (Kull et al. 2011; Vu et al. 2015).

The recent development trajectory of Đa Krông District has not been foreordained by government or other outside parties, and its future progress is not locked into a predetermined path. What has occurred can be seen as having emerged from household decision-making and behavior at the village level in assessing and responding to market incentives, where households allocated land resources and labor in response to specific opportunities that are reevaluated each year. Such autonomy at the local level would necessarily be constrained by the relative availability of endogenous factors of production, i.e., land and labor, per household, and influenced by capital costs, transport costs, and wages, which are exogenously determined.

Additional factors meriting consideration are market prices of inputs and outputs, which are also exogenously determined and bear directly on household decision-making processes. To the extent that households weigh anticipated revenues and costs as rational actors (whether in an absolute or bounded sense of the word), an increase in output prices relative to inputs would tend to incentivize market-oriented production, whereas the converse would apply to the obverse scenario. With regard to transportation costs, agrarian communities sited nearer to centers of demand benefit from the reduced distance and time costs from source to sink, and thus tend to benefit where adequate physical connectivity exists. This is particularly true in the production of bulky and heavy commodities, as with agroforestry / tree plantations (Clement et al. 2009).

While these factors cannot be detailed with a precise accounting of data at the local level (district / commune / village) to precisely reconstruct revenues, costs, and land rents associated with agricultural commodities, observations from field work in 2014 reflect the increasing adoption of acacia and cassava as cash crops by households in several villages (Leisz et al.

2016). Where market, policy, or other barriers do not preclude households from cash cropping, households can act autonomously in deciding whether or not to plant a given crop on lands available. The direction and magnitude of change in land-cover would be an emergent phenomenon proportional to the collective adoption of certain crops over time, within constraints associated with biophysical factors (e.g., soil quality, terrain suitability, water availability) and human-defined practices (e.g., agronomic practices relating to patch re-use and fallow length).

Several other market-related factors identified by Lambin et al. (2003) include capital flows, investments, and credit access. Comprehensive data down to the district, commune, and village level are not available to this author, but anecdotal findings at the village level note the local shopkeepers have engaged in the practice of extending credit to local households early in the year, allowing them to defray start-up costs associated with the agricultural cropping cycle (Leisz et al. 2014). Whether or not such loans are interest-bearing and, if so, at what rate, is not known.

Finally, with regard to technology, Lambin et al. (2003: 218) note that "improving agricultural technology…can potentially encourage more deforestation" rather than relieving pressure on the forests." However, in the case of Đa Krông District, it appears that the level of technology being applied to shifting cultivation practices farther from roads and cash cropping nearer to roads do not involve felling large stands of trees. Rather, land-cover modifications appear to alter the composition and distribution of trees on the landscape, due partly to the introduction of fast-growing exotic tree species, primarily acacia and to a lesser degree rubber (Leisz et al. 2014).

To circle back to transportation costs and roads more generally, in the broader economic context, the EWEC project directly enabled the establishment of a physical link facilitating the transmission of demand from urban centers (e.g., industries) and supply from rural areas (e.g., production of food and fiber commodities in bulk needed by these industries). By reducing per unit transportation costs, it has helped to achieve economies of scale.

The extension of the agricultural frontier along Highway 9 appears uneven, but a spatial bias toward areas closer to market centers (e.g., peri-urban industries in the Dong Ha vicinity) is consistent with interpretations of a von Thünen effect articulated by World Bank economists (Chomitz and Gray 1996; Angelsen and Kaimowitz 1999). Given that these villages no longer exist in a state of relative isolation, and that the households constituting them interface directly with market actors, a systems-level perspective afforded by the urban teleconnections perspective seems fitting. To the extent that such teleconnections give rise to feedback effects at the provincial scale and beyond (national or international), a telecoupling perspective also seems appropriate, wherein urban businesses with rural farmers through intermediary commodities brokers, construed of as sending and receiving systems.

2.5.2.2 Outside policy interventions (exogenous)

Markets operate within the scope of government policy and encompasses a wide range of factors, including land tenure policies, subsidies, taxes, and trade agreements. Land tenure is considered a very significant issue in the pre- and post-Đổi Mới context, but less directly pertinent to more recent LULC change-related developments. The process of decollectivization associated with the 1993 Land Law has extended land access and use rights gradually over the last 25 years (Kirk and Nguyen 2009). While the law is not pervasive nationwide, and issues of landlessness have resulted from implementation of this law, it is considered largely a background factor for the study area, where land access and use rights are generally stable. Kirk and Nguyen (2009: 25) posit that "land-tenure reforms have triggered a sustaining process that will relieve the country from food insecurity, combat hunger, and improve the nutritional status of the rural and urban population." More practically, the government has issued "Red Books" to some, but not all, households at the village level in the study area since 2009 (Leisz et al. 2014).

Subsidies have profoundly changed in the post-Đổi Mới context. The removal of household-level subsidies on essential food commodities, e.g., staples such as rice, have been replaced with subsidies to corporate land-users, including plantation owners / operators (Barr & Sayer 2012). Thus, while subsidies had benefited households in the past, they now benefit powerful interests, while exposing households to greater price volatility including major price shocks in 2007 / 2008 (Fulton & Reynolds 2015). This combination of factors is unfavorable to poor, rural households reliant on agricultural production and would logically reinforce a household preference for continuing to cultivate rice, even when cash cropping is profitable. This practice is consistent with imagery analysis corroborated by fieldwork observations (Leisz et al. 2016).

Other policy measures pertaining to market functioning – taxes and trade agreements – also bear directly upon recent and current local land-use systems, land-cover patterns, and livelihoods. With regard to taxes in the pre-reform era (i.e., before the Đổi Mới and subsequent market liberalizing policy measures), the government took on average 10 percent of annual agricultural output per household (Kirk and Nguyen 2009). The actual rates levied by the government on households with respect to income, property, sales, and other applicable taxes, are not known for this study area for the time period (2001 to 2014) being evaluated. However, it is assumed that taxes comprise a non-trivial percentage of household resources, due to the extension of government services, e.g., education and health care, to rural areas. Such costs would tend to reinforce processes of market integration, including market-oriented production.

With regard to trade agreements, the cross-border trade agreement (CBTA) between Vietnam and Laos, as part of the broader regional economic development strategy for the GMS, should increase interaction including trade with neighboring countries (Ishida 2009). This is expected to correlate with a general trend toward intensification of market-oriented land-use systems favoring cash crops that maximize land rent, consistent with a von Thünian microeconomic framework, although feedback effects will certainly emerge that amplify or dampen prices consistent with the teleconnections and telecoupling systems perspectives. Assessing the full range of potential market-driven price dynamics and resulting feedbacks on LULC change exceeds the scope of this chapter.

Finally, one last topic worth noting pertains to the overlap between government policy and markets with respect to infrastructure projects. According to Lambin et al. (2003: 218), "Market access is largely conditioned by state investments in transportation infrastructure." While that statement generally holds true, the case of the EWEC project appears to constitute an important exception, insofar as outside parties – i.e., ADB and JICA - provided the necessary financing (Leisz et al. 2016). Upkeep and maintenance of this road may require government involvement in the future, entailing the assessment of taxes on populations benefiting from this infrastructure.

2.5.2.3 Resource scarcity, changing adaptive capacity / social organization (endogenous factors)

Compared with market forces and government policies, less is known about the set of endogenous factors – resource scarcity, adaptive capacity, and social organization – that pertain to processes of LULC change at the local level. With regard to resource availability, this issue is broadly construed to encompass biodiversity, ecosystems, and ecosystem services. Insofar as households perceive land tenure as secure, the relevant constraints to agriculture from a natural resource perspective would include soil quality and water availability, which along with labor intensity and other inputs (e.g., technology) affect potential yields of cash crops and revenues derived from the sale thereof. Systems of land-use, e.g., agronomic practices relating to plot reuse and fallow length, entail feedback effects on the level of soil fertility. Additional effects relate to direct impacts on habitat and indirect impacts on biodiversity. The dynamics of resource management at the local scale involve coupled processes and require the rationally acting household to consider sustainability in land-use modification decision-making processes.

Land-use decisions entailing land-cover modification similarly involve climate-related feedbacks – e.g., albedo, transpiration, carbon sequestration. There also exists the potential for sudden and rapid climate-driven change. The risk of natural hazards is illustrated by severe flooding events in the spring of 2009, dampening agricultural activity across most of the study area other than the southernmost areas located upstream relative to the overall watershed. The flooding events directly impacted upon households in downstream locations, disrupting the normal cycle of planting (and thus harvesting) of crops. The land-cover impacts along the Highway 9 corridor appear substantial comparing the map for 2009 (Figure 41) to previous and subsequent time steps from 2007 and 2014 respectively (Figure 40 and Figure 42).

With regard to changing levels of adaptive capacity and vulnerability, the communities in this study are considered to have similar levels of vulnerability to climate events, price shocks, and other adverse developments, given their relatively high reliance upon agricultural practice for meeting both household food requirements and annual household income requirements. Households practicing shifting cultivation in the region confront challenges meeting rice requirements (Rigg 2006a). Interviews with local populations have confirmed vulnerability of agricultural crops to numerous factors, including but not limited to normal seasonal weather variability, domesticated animals, wild animals and birds (Leisz et al. 2014).

Such vulnerability-related considerations would tend to reinforce adaptive capacity diversity livelihoods through alternative land-use systems including cash cropping. Market-oriented production thus represents a rational response to uncertainty in meeting basic household needs for food through subsistence agriculture supplemented by foraging nearby forested areas (Rigg 2006a). There exists evidence of such diversified land-use even in relatively smaller communities with indirect connections to road networks and more attenuated access to markets (e.g., Ta Rec village, Ba Nang Commune). Practices include the adoption of various cash crops by households including annual food crops (e.g., cassava, coffee, maize), perennial tree crops (e.g., acacia and banana), and an assortment of non-timber forest products (NTFPs, e.g., broom grass and honey) (Leisz et al. 2014; Leisz et al. 2016).

Lastly, with regard to change in social organization, fieldwork appears to confirm that the village functions effectively as a communal manager of land resources (Castella et al. 2007; Ngo et al. 2009; Leisz et al. 2016). The viability of the village appears to rest on equitable access to resources and equitable distribution of income and risk (Sikor and Tuong 2005). The existence of a "subsistence floor" for households (Sikor and Tuong 2005) seems important to lessening disparities within communities. To the extent that the government refrains from interfering with such subsistence-oriented practice, villages would tend to benefit in terms of socio-cultural continuity. While this may not necessarily accord with optimizing land-use through profit maximization, per an absolute rationality interpretation of land rent-drive behavior, it does appear a rational way to reconcile household needs for both self-reliant production of staple foods and income generation through market-oriented production of commodities.

In attempting to synthesize these fundamental forces associated with LULC change, one could broadly group the exogenous factors - markets and policy – as distal drivers, and the endogenous factors – resources, adaptive capacity/vulnerability, and social organization – as proximate causes. Local populations reliant on agriculture for meeting basic household needs must continually reconsider land-use systems based on external influences. The changing land-cover of the community that results thus constitutes a response variable. To the extent that households have secure access and use of their resources and autonomy in their decision-making, they will evaluate market incentives in land-use decision-making processes, using land rent as a basis for allocating land and labor resources to market-oriented vs. subsistence practices. An array of market forces - e.g., prices, wages, transport costs – and policy measures – e.g., subsidies and taxes – will alter the profitability of cash cropping by raising and lowering revenues and costs. Insofar as market dynamics are complex, the household act within a bounded rationality framework to meet its needs and improve its overall livelihood trajectory. Understanding this process of interactions and feedbacks between sending and receiving systems also requires a systems-level perspective, for which teleconnections and telecoupling provide relevant frameworks.

2.6 Conclusion and future work

The two most prominent agricultural land-use trends for the study area over the last decade involve the cultivation of fast-growing exotic tree crops, principally *acacia*, for processing into wood products, and high-yielding annual food crops such as hybrid varietals of cassava (“K94”) (Leisz et al. 2016). Cassava is used as an input for various products - animal feed, starch, tapioca - a well-established cropping practice in recent decades in Vietnam (Hershey 2000; Nambiar 2015). Cash cropping has not completely displaced subsistence cultivation practices, but it has reduced the area under cultivation for local production of staples crops (Leisz et al. 2016). While the emergent pattern of land-cover does not show a clear and compelling directional trend over the time series at the district level, there has been a shift in land-use systems from a state of relative autarky to one of partial market integration, consistent with von Thünen's concept of a land-rent driven transition.

This market-oriented agrarian transition for this study area mirrors national and regional trends toward more cultivation of roots and tubers, the output of which tripled over the period 2000 to 2014. During this same period, estimated forest cover increased from 38% to 45%. Exogenous factors – better transportation infrastructure, higher agricultural prices, and lower wage levels – have contributed to this process of agricultural intensification. Endogenous factors – e.g., cultural and demographic – are also seen as important but as exerting lesser influence over the more recent trajectory of LULC change. One cultural example worth noting pertains to the persistence of dry rice cultivation among those engaged in a shifting cultivation system of land-use.

While no single factor can fully account for and explain the full direction and magnitude of observed change in LULC, the study finds that economic factors identified by Angelsen and Kaimowitz (1999) - higher agricultural prices, more and/or better roads, and a general shortage of off-farm employment – are probably the most pertinent for this study area over the timeframe considered. Of these three factors, the improved road transport network has provided a tangible link to nearby centers of demand and functioned as an enabling mechanism for conveyance of supply. By lowering transport costs for brokers seeking agricultural commodities demanded by urban-based industries, rural regions become an accessible source of supply. Farmers are thus incentivized by favorable land rents to cultivate cash crops (e.g., cassava and acacia), minus the costs of transport borne by third parties and built into gray market prices.

On a relatively local-scale, and from an urban land teleconnections perspective, the rural system can be seen as a rational response to emerging economies of scale in nearby urban-based, industrial processing centers (Angelsen 2007; Güneralp et al. 2013). Road networks can therefore be regarded as a necessary precondition for economic development by providing market accessibility and connectivity. However, enhanced transportation network infrastructure does not appear a sufficient condition for sustainable development. In this case, the coincidence of higher prices and lower wages were also critical factors by providing a comparative advantage to the cultivation of cash crops *in situ* versus relocating out of the village on either a temporary or more permanent basis for off-farm work.

The trajectory of the agrarian transition within Đa Krông District, Quảng Trị Province, bears some similarities to market-oriented cash cropping elsewhere in Vietnam. Cash cropping of coffee in the central highlands region of Vietnam has shown vulnerability to adverse price shocks linked with global boom and bust cycles (Eakin et al. 2009). Although acacia and cassava are generally hauled relatively short distances from production to consumption – around 50km from farms to factories in and around Dong Ha - producers remain exposed to market volatility due to the major degree of influence exerted by large buyers (e.g., China) on the global market.

The overall trajectory of change in north-central Vietnam also differs from that in neighboring Cambodia and Laos. The cultivation of cash crops (e.g., bananas and rubber) has adversely impacted local communities and the environment (Baird & Fox 2015). In various locations of Laos in particular - Luang Namtha, Luang Prabang, and Oudomxai in the north, and Salavan in the south – the benefits of resource extraction have overwhelmingly accrued to outside interests, (Friis et al. 2016; Friis and Nielsen 2017; Sikor 2012). Local communities, by contrast, have experienced ecosystems degradation and little livelihood improvement (Rigg 2006a). One exception to this general trend may be Savannakhet Province, in central Laos, which straddles the Highway 9 corridor and where local communities have seen general improvement over the last decade (Leisz et al. 2016).

With regard to future work, the relatively large spatial footprint and slow repeat cycle of Landsat could be enhanced through incorporation of additional imagery from other platforms with smaller footprints but higher resolution and more regular repeat cycles (e.g., European sources such as Sentinel-2 and SPOT) and commercial platforms (e.g., DigitalGlobe). Such imagery combined with more recent and widespread ground-based observations could better illuminate analysis of LULC change. In order to better understand processes of market integration occurring under the influence of exogenous factors in this study area, more research is needed. Additional analysis of remotely sensed satellite imagery and *in situ* fieldwork, employing mixed methods engaging stakeholders across multiple sites per Leisz et al. (2016), can help better ascertain patterns of land-cover change and associated land-use systems, which involve complex mosaics of agricultural and agroforestry cropping. Additional market data on prices over time at local scales would add values. Combining such primary and secondary sources could substantively enhance the understanding of the interplay of factors, above and beyond the limited scope of the current inquiry, to inform analysis and policy.

Works Cited

Ali, J., Benjaminsen, T.A., Hammad, A.A., & Dick, Ø.B. (2005). The road to deforestation: An assessment of forest loss and its causes in Basho Valley, Northern Pakistan. Global Environmental Change, 15(4), 370-380.

Angelsen, A. (2007). Forest cover change in space and time: Combining the von Thünen and forest transition theories. World Bank Policy Research Working Paper 4117.

Angelsen, A., & Kaimowitz, D. (1999). Rethinking the causes of deforestation: Lessons from economic models. The World Bank Research Observer, 14(1), 73-98.

Baird, I., & Fox, J. (2015). How land concessions affect places elsewhere: telecoupling, political ecology, and large-scale plantations in southern Laos and northeastern Cambodia. Land., 4(2), 436-453.

Bhattarai, K., Conway, D., & Yousef, M. (2009). Determinants of deforestation in Nepal's Central Development Region. Journal of Environmental Management, 91(2), 471-488.

Braaten, J., Cohen, W., and Yang, Z. (2018). LandsatLinkr: Tools to spectrally link Landsat data. R package version 0.5.0, URL: http://landsatlinkr.jdbcode.com/

Brooks, D., & Hummels, D. (2009). Infrastructure's role in lowering Asia's trade costs: Building for trade (ADBI series on Asian Economic Integration and Cooperation). Cheltenham, Gloucestershire: Edward Elgar Publishing.

Caldas, M., Walker, R., Arima, E., Perz, S., Aldrich, S., & Simmons, C. (2007). Theorizing land cover and land use change: the peasant economy of Amazonian deforestation. Annals of the Association of American Geographers, 97(1), 86-110.

Cropper, M., Puri, J., & Griffiths, C. (2001). Predicting the Location of Deforestation: The Role of Roads and Protected Areas in North Thailand. Land Economics, 77(2), 172-186.

Deng, X., Huang, J., Uchida, E., Rozelle, S., & Gibson, J. (2011). Pressure cookers or pressure valves: Do roads lead to deforestation in China? Journal of Environmental Economics and Management, 61(1), 79-94.

Eakin, H., Winkels, A., & Sendzimir, J. (2009). Nested vulnerability: Exploring cross-scale linkages and vulnerability teleconnections in Mexican and Vietnamese coffee systems. Environmental Science & Policy, 12(4), 398-412.

Eakin, H., Rueda, X., & Mahanti, A. (2017). Transforming governance in telecoupled food systems. Ecology and Society, 22(4).

Friis, C., Nielsen, J.Ø., Otero, I., Haberl, H., Niewoehner, J.,& Hostert, P. (2016). From teleconnection to telecoupling: Taking stock of an emerging framework in land system science. Journal of Land Use Science, 11(2), 131-153.

Friis, C., & Nielsen, J.Ø. (2017). On the system: Boundary choices, implications, and solutions in telecoupling land use change research. Sustainability, 9(6), 974.

Fulton, M., & Reynolds, T. (2015). The Political Economy of Food Price Volatility: The Case of Vietnam and Rice. American Journal of Agricultural Economics, 97(4), 1206-1226.

Furumo, P.R., & Aide, T.M. (2017). Characterizing commercial oil palm expansion in Latin America: Land use change and trade. Environmental Research Letters, 12(2), 024008.

Gao, J., & Liu, Y. (2012). Deforestation in Heilongjiang Province of China, 1896–2000: Severity, spatiotemporal patterns and causes. Applied Geography, 35(1-2), 345-352.

Güneralp, B., Seto, K.C., & Ramachandran, M. (2013). Evidence of urban land teleconnections and impacts on hinterlands. Current Opinion in Environmental Sustainability, 5(5), 445-451.

Hershey, C., Guy, H., Best, R., Kazuo, K., Reinhardt, H., Iglesias, C. (2000). Cassava in Asia: Expanding the Competitive Edge in Diversified Markets. FAO. Web. URL: http://www.fao.org/docrep/009/y1177e/Y1177E02.htm (accessed 6 March 2018)

Ishida, M., & Isono, I. (2012). Old, new and potential economic corridors in the Mekong region. Emerging Corridors in the Mekong Region, BRC Research Report (8).

Jacoby, H. (2000). Access to markets and the benefits of rural roads. The Economic Journal: The Journal of the British Economic Association, 110(465), 713-737.

Jacoby, H. & Minten, B. (2009). On measuring the benefits of lower transport costs. Journal of Development Economics, 89(1), 28-38.

Khandker, S.R, Bakht, Z., & Koolwal, G. B. (2009). The poverty impact of rural roads: Evidence from Bangladesh. Economic Development and Cultural Change, 57(4), 685-722.

Kirk, M., & Tuan, N. D. A. (2009). Land-tenure policy reforms: Decollectivization and the Đổi Mới system in Vietnam. Intl Food Policy Res Inst. (927),

Kumagai, S., Gokan, T., Isono, I., & Keola, S. (2008). Geographical Simulation Model for ERIA: Predicting the Long-run Effects of Infrastructure Development Projects in East Asia. *International Infrastructure Development in East Asia: Towards Balanced Regional Development and Integration. ERIA Research Project Report*, (2).

Lambin, E.F, Geist, H.J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. Annual Review of Environment and Resources, 28(1), 205-241.

Leisz, S., & Rounds, E. (2014). Project on "Increased accessibility, landscape changes, rural transformations, and urbanization: Impacts of the east-west economic corridor from Da Nang, Vietnam, to Khon Kaen, Thailand," Field notes.

Leisz, S., Rounds, E., Ngo, T.A., Nguyen, T., Tran, Nguyen Bang, Douangphachanh, S. & Ninchaleune, B. (2016). Telecouplings in the East-West Economic Corridor within borders and across. Remote Sensing, 8(12), 1012.

Li, P., Feng, ZM, Jiang, LG, Liao, CH, Zhang, JH. (2014). A review of swidden agriculture in Southeast Asia. Remote Sensing, 6(2), 1654-1683.

Liu, J., Hull, V., Batistella, M., DeFries, R., Dietz, T., Fu, F., . . . Verburg, P. (2013). Framing sustainability in a telecoupled world. Ecology and Society: A Journal of Integrative Science for Resilience and Sustainability, 18(2), 26.

Mon, M., Mizoue, N., Htun, N., Kajisa, T., & Yoshida, S. (2012). Factors affecting deforestation and forest degradation in selectively logged production forest: A case study in Myanmar. Forest Ecology and Management, 267, 190-198.

Mu, R., & van de Walle, D. (2007). Rural roads and poor area development in Vietnam. Policy Research Working Paper, no. 4340. The World Bank, Washington, DC.

Nambiar, E. (2015). Acacia plantations in Vietnam: Research and knowledge application to secure a sustainable future. Southern Forests, 77(1), 1-10.

Ngo, T. A., See, L. M., & Drake, F. (2009). An agent-based approach to simulating the dynamics of shifting cultivation in an upland village in Vietnam. European Journal of GIS and Spatial Analysis, 19 (4), 493–522.

Phompila, C., Lewis, M., Ostendorf, B., & Clarke, K. (2017). Forest cover changes in Lao tropical forests: Physical and socio-economic factors are the most important drivers. Land, 6(2), 23.

Quang, D.V., Schreinemacher, P., & Berger, T. (2014). Ex-ante assessment of soil conservation methods in the uplands of Vietnam: An agent-based modeling approach. Agricultural Systems, 123, 108-119.

Rigg, J. (2006). Land, farming, livelihoods, and poverty: Rethinking the links in the Rural South. World Development., 34(1), 180-202.

Seto, K., Reenberg, A., Boone, C.G., Fragkias, M., Haase, D., Langanke, T., …Simon, D.

(2012). Urban land teleconnections and sustainability. Proceedings of the National Academy of Sciences of the United States of America, 109(20), 7687-7692.

Sikor, T. (2012). Tree plantations, politics of possession and the absence of land grabs in Vietnam. The Journal of Peasant Studies, 39(3-4), 1077-1101.

Sikor, T., & Tuong Vi, P. T. (2005). The dynamics of commoditization in a Vietnamese uplands village, 1980–2000. Journal of Agrarian Change, 5(3), 405-428.

Sills, E.O., & Caviglia-Harris, J.L. (2009). Evolution of the Amazonian frontier: Land values in Rondônia, Brazil. Land Use Policy, 26(1), 55-67.

Van De, N. (2008). Erosion and nutrient loss on sloping land under intense cultivation in southern Vietnam. Geographical Research, 46(1), 4-16.

von Thünen, J. H., & Hall, P. (1966). Isolated state; an English edition of Der isoliete Staat. (1st ed.). Oxford, New York: Pergamon Press.

Walker, R., & Solecki, W. (2004). Theorizing land-cover and land-use change: the case of the Florida Everglades and Its degradation. Annals of the Association of American Geographers, 94(2), 311-328.

Warr, P. (2008). How road improvement reduces poverty: The case of Laos. Agricultural Economics, 39(3), 269-279.

Warr, P. (2010). Roads and Poverty in Rural Laos: An Econometric Analysis. Pacific Economic Review, 15(1), 152-169.

Chapter 3: Simulating agrarian transition from subsistence to cash cropping at the village level using an agent-based modeling approach

Summary

The land change science community has modeled land-use and land-cover change processes associated with shifting cultivation practices using agent-based models, cellular automata, statistical regression, and various other modeling methods at multiple spatial and temporal scales over the last several decades. Such models are relevant for understanding the impacts of land-use systems on land-cover, livelihoods, and ecosystems. This paper presents a spatially-explicit, agent-based model that builds on efforts by other scholars to simulate shifting cultivation and cash cropping and provides a proof-of-concept of agrarian transition from subsistence to partial market integration. The model presented here is built using NetLogo, a free open-source software package, to simulate agricultural land-use for two villages in the rural uplands of north-central Vietnam. It simulates subsistence agriculture, then transitions to a hybrid system involving both subsistence and cash cropping. The primary goal of modeling such a transition is to explore the influence of market forces and other fundamental forces on land-use systems and resulting patterns of land-cover. Road networks reduce transportation costs and facilitate market interactions, thereby incentivizing cash cropping and inducing intensification, consistent with von Thünen's theory of land rent. In addition to market prices, other model parameters modified to test the influence of endogenous and exogenous variables on household decision-making as relates to land-use include agronomy, climate, demography, and terrain-related constraints. Modeled responses are generally consistent with expectations in terms of directionality, while the magnitude of modeled responses appear discrepant with the discrete set of observations

available. Further work will be needed to fully and properly calibrate and validate this model to more realistically simulate this complex process. Various enhancements are also proposed.

3.1 Introduction

Southeast Asia has experienced significant economic development over the last two decades. Capital markets have expanded rapidly since inception of the Đổi Mới reforms starting in the late 1980s, with investment-driven improvements in infrastructure facilitating the production and distribution of goods between and among neighboring states within the region and beyond (Brooks & Hummels 2009). Road infrastructure networks have interconnected lowland coastal areas with upland regions, creating year-round connectivity between urban and rural populations, where formerly there existed only intermittent access due to monsoon conditions rendering roads impassable (McElwee 2008; Leisz et al. 2016). This connectivity has contributed to changing livelihoods in rural, upland areas through increased movement of goods, information, and migration (Leisz et al. 2016). Rural, uplands areas are primarily inhabited by ethnic minority populations characterized by lower educational, health, and socio-economic status (McElwee 2008). Despite the national government's efforts to eradicate traditional shifting cultivation through policy measures over several decades, such practices have remained prevalent into the early 2000s (Schmidt-Vogt et al. 2009). Such livelihood systems were integral to the survival of these populations during the First and Second Indochina Wars and remain central to the culture of these peoples (Vargyas 2001). However, with the increasing reach of market forces, land-use systems have begun to integrate with markets through the cultivation of cash crops and agroforestry products for urban industries (Leisz et al. 2016). This chapter considers local level interactions associated with the process of agrarian transition in land-use through development and testing of an agent-based model simulating a shift from pure subsistence cultivation to a hybrid system of cash and subsistence crop cultivation under conditions of partial market integration. In so doing, it allows for testing the influence of different variables on the dynamics of land-use / land-cover (LULC) change in upland, rural Vietnam.

3.2 Literature review: Land-use / land-cover change modeling

The literature on land-use and landcover change modeling spans several decades since its inception in the 1980s, with peer-reviewed publications numbering in the thousands of articles. The Land-Use/Cover Change (LUCC) project in the mid-1990s and Global Land Project, since renamed the Global Land Programme, have increased awareness and interest in these issues (Verburg et al. 2006). An analysis of the scholarly publications in the ISI "Web of Science" finds that most studies focus on the consequences of anthropogenic modification and conversion of landscapes on ecosystems (e.g., on biodiversity, hydrology, soils, etc.), while a small number of other studies focus on impacts to human communities, e.g., socio-economic impacts (Van Vliet et al. 2016). There remains a need to better understand both the causes and consequences of land-use and land-cover (LULC) change, and modeling can provide a vehicle for simulating the agricultural land-use decision-making at the most basic level of organizations (i.e., household) to see patterns of emergence at the higher levels of organization (e.g., village, district, province, region, etc.). This section reviews LULC change modeling efforts at two scales: relatively coarse scale for large areas (global, regional, and national) and relatively finer scales (i.e., local-scale, for place-based case studies). Although the literature regarding spatially-explicit, agent-based modeling of the processes underlying LULC change has been characterized as sparse, various relevant studies conducted for Africa, Latin America, and Asia will be considered here.

3.2.1 Large area, coarse-resolution models: Global, regional, national-scale modeling

The scholarly community has undertaken efforts over the last few decades to model the Earth as a holistic system using approaches such as Integrated Assessment Models (IAMs) (Verburg et al. 2006). Such efforts have focused on critical topics such as climate, in support of the Intergovernmental Panel on Climate Change (IPCC), as well as agriculture, on behalf of the International Food Policy Research Institute (IFPRI) (Steffen et al. 2006; Rosegrant et al. 2001; Verburg et al. 2006). Early efforts included but were not limited to IMAGE and its successor IMAGE-2, IMPACT, and GTAP (Rosegrant et al. 2002; Eikhout et al. 2004; Verburg et al. 2006). Such models are generally predicated on a general equilibrium theoretical framework and do not allow for individual decision-making as such.

More recent efforts, led by European scholars, have sought to improve upon IAMs through the development of sophisticated Earth system models (ESMs) (Müller-Hansen et al. 2017). Models such as LandSHIFT have been used to explore land-use dynamics, projecting the direction and magnitude of LULC change and identifying "hot spots" of change for vast areas, e.g., expansion in cultivated areas and corresponding losses in other cover types such as forest across the entire continent of Africa (Alcamo et al. 2011). More recently, scholars have made efforts to promote interdisciplinary modeling of LULC change more widely by publishing open-source software platforms allowing multiple simulation models ("World-Earth models") to be run by researchers in parallel, as well as allowing for the building of customized models from pre-built components (Donges et al. 2018).

Given the myriad challenges with modeling socio-ecological systems and LULC change at the global scale, efforts have also been made to model at "meso-scale" for regions and nations. Efforts to model at the regional scale thus far in the 21st century include the Sudano-sahelian region of Africa (Stéphenne & Lambin 2001), European rural landscape change (Klijn et al. 2005), and Amazonian fire regimes (Morello et al. 2017). Modeling at the national level has been done for Chinese land-use systems under the IIASA-LUC project (Fischer & Sun 2001), Brazilian plantation agriculture and rangeland use (Lapola et al. 2010), Indian forest cover (Reddy et al. 2017), and Jordanian pastoralism, urbanization, and hydrology (Schaldach et al. 2013; Koch et al. 2018).

Such efforts may prove valuable for improving human understanding of cross-scalar dynamics associated with human-environment interactions (HEI) involving processes of LULC change. Yet, it bears noting that relatively high levels of uncertainty exist for models attempting to simulate LULC change at such spatial scales, especially over longer timespans (Van Asselen & Verburg 2013; Arneth et al. 2017; Bayer et al. 2017; Heinimann et al. 2017; Stocker et al. 2017; Fuchs et al. 2018; Yue et al. 2018). Such efforts are commendable and necessary toward realizing the goal of an all-encompassing theory of land-use change. More data and research will be needed to better design, parameterize, and run simulation models of such complex socio-ecological systems. The multitude of approaches taken by scholars at varying scales underscores the fact that there is no single approach to modeling LULC change that can address the full range of research questions regarding causes and consequences (Verburg et al. 2006).

3.2.2 Small-area, fine-resolution models: Local-scale modeling

At the other end of the modeling spectrum are models of relatively small areas, which allow for much finer spatial resolution than macro- and meso-scale models. Given the complexity inherent in large-area models, with nested feedback loops operating across multiple spatial and temporal scales, there remains a need for local-scale models grounded in place-based understanding to simulate anthropogenic processes of LULC change and related issues of concern, such as Ecosystem Services (ESS), greenhouse gas emissions, and hydrology (Hiratsuka et al. 2018; Thellmann et al. 2018). Critics may dismiss local-scale models as lacking broader relevance (e.g., for cross-comparison or transferability to other locations), but such models are relevant for understanding LULC changes arising from communities engaged in land management practices such as shifting cultivation and for developing policy recommendations, as well as testing the impacts of policy. By modeling coupled human-environment systems *in silico*, scholars may replicate processes of LULC changes backwards or forwards in time to better understand factors of interest to researchers and policymakers, such as the relative influence of market forces and policy measures (e.g., conservation incentive programs, land-use restrictions, etc.) (Jourdain 2014). And they may do so ethically, by avoiding the dilemmas inherent in interfering with real world land-use practices of a given community of interest.

Modeling at the local scale is often centered on bounded communities, e.g., a given built-up area and its surrounding land holdings, as this constitutes a basic spatially cohesive unit of socio-economic organization for analysis of LULC change. Temporal scales may span from several years to several decades or longer. In this context for agricultural communities, households act as discrete decision-making units that may act autonomously and independently, or in coordination with others in decision-making and actions relating to agricultural land-use, which may be done for meeting subsistence needs, market demand, or a combination thereof. Decision-making may be influenced by preferences to clear certain areas for cultivation based on perceived suitability factors relating to patch characteristics (e.g., fertility), relative location (e.g., distance to village, water sources, etc.), or other factors (e.g., avoidance of shared plots or preference for clustering). Land-use practices are also constrained by labor availability, biophysical factors (e.g., landcover type), terrain (e.g., slope), and policy constraints (e.g., protected areas off-limits to agriculture.

A number of noteworthy model-based approaches to simulating shifting cultivation practice have been conducted for tropical forest regions of Africa, Latin America, and Southeast Asia. Studies on Africa include Cameroon (Brown 2008), Guinea (Gilruth et al. 1995), Democratic Republic of Congo (Wilkie & Finn 1988), and West Africa more broadly (Dvorak 1992). Studies published on Latin America, which appear fewer in number and extent, include Mexico (Manson & Evans 2007) and Venezuela (Riris 2018). Studies on Asia include Indonesia (Sulistyawati et al 2005), Laos (Wada et al. 2007), the Philippines (Overmars & Verburg 2014), and Vietnam (Castella et al. 2007; Castella et al. 2007; Jepsen et al. 2006; Ngo et al. 2009). These modeling efforts build on the largely descriptive work of earlier scholars, e.g., Condominas (2009), Conklin (1961), Dove (1985), Izikowitz (1951), Pelzer (1945), and Spencer (1958), who have documented subsistence-oriented agricultural practices across the region over much of the 20th century.

Brown (2008) contributes substantively to this literature by providing a human-environment framework based on research in the tropical forest region of Cameroon that underpins a model of shifting cultivation. His model concerns shifting cultivation as a subsistence strategy for meeting basic food requirements undertaken by households which view production and consumption as non-separable activities, i.e., this form of agriculture is undertaken first and foremost of necessity for survival of the household, with any remaining surplus available for sale or trade (i.e., market-based transactions being a by-product rather than the organizing principle). From an ecological standpoint, Brown (2008) posits that the sustainability of shifting cultivation requires that shifting cultivators rest cultivated lands for sufficiently long periods (i.e., fallows of up to 25 years) in order to restore optimal fertility to the landscape. Despite stated preferences from the local population for managing lands on a timeline consistent with this sustainability threshold, Brown finds disparities in actual land-use practices by households. His empirically-fitted and spatially-explicit model incorporates a rule-based decision-making process predicated on household preference for cultivating a landscape patch with the “greatest marginal net benefit” (Brown 2008: 653). Patch suitability is viewed as a composite of factors including fallow age (i.e., years in fallowed status), fertility, proximity to the village, and proximity to other cultivated fields (Brown 2008). Brown (2008) further posits the following factors as being relevant to household land-use decision-making and practice: available labor; migration flows; land holdings; availability of other village lands (i.e., above and beyond holdings specific to a given household); per capita subsistence requirement; rate of population change; general health; relative value of labor vs. leisure; residual rights to fallow lands; market access; market prices; and transport costs. His principal finding was that nearly all households place a very high level of importance on soil fertility and fallow age, which informs the model he operationalizes to simulate LULC change under shifting cultivation. The model was built and tested on a platform - “Simile” - that has not been referenced by other scholars in published peer-reviewed journals, and the model code was not included with the published paper. Nevertheless, the framework represents an important contribution to local-scale modeling of household decision-making at the scale of the village, providing a coherent structure for model development by others studying this phenomenon.

Castella produced models of LULC change associated with shifting cultivation in the uplands of northern Vietnam using bottom-up and top-down processes (Castella et al. 2007; Castella & Verburg 2007). Local populations engaged in participatory exercises through SAMBA, a multi-agent role-playing game that includes a geographic information systems component. This data was complemented by top-down modeling using spatially-explicit cellular automata modeling software (CLUE-S) to simulate changing landcover patterns. Both approaches showed relatively favorable alignment with the reference data, and comparison of model outputs did not show one approach to be clearly superior to the other. More importantly, the research promoted partnership among researchers and between researchers and stakeholders. Land-use planning processes may also improve across the study area (district) due to improved communication between local populations and decision-makers.

Jepsen et al. (2006), also focused on shifting cultivation in the uplands of northern Vietnam. It applied a rigorous analysis of household behavior to define rules for optimizing labor allocation in clearing village lands to meet basic subsistence needs, operationalized through a spatially-explicit agent-based model implemented using NetLogo software (Wilensky 1999). With regard to household agents, the model considered the simulated space a "closed system" and held the village population constant over time, but the model did reflect customary practice of cultivating in groups to minimize labor expended on fence-building. Regarding landscape (patch) agents, it applied an ecologically grounded function to simulate the regeneration of fertility on fallowed patches to realistically model varying harvest yields. Model outputs showed a fairly strong correspondence to patterns of clustering observed in the reference data but discrepancies in the total area of land being cleared, highlighting a need for further model calibration and validation.

A third model, produced by Ngo et al. (2009), also simulates LULC change associated with shifting cultivation practices in northern Vietnam for a village adjacent to protected forest areas. The model parameterizes household agents based on data gathered through fieldwork and landscape agents (i.e., cover type) based on satellite imagery. Households are grouped into three cohorts, based on relative levels of land holdings and other resources available to them, where the most disadvantaged group (i.e., those with least resources and greatest reliance on shifting cultivation) indicated a higher willingness to clear forested areas deemed off-limits. Harvest yields vary based on soil conditions similarly to Jepsen et al. (2006). Fallow patches regenerate through the process of vegetative succession - in this case per VN-LUDAS (Le et al. 2008). Unlike Jepsen et al. (2006), additional household factors are also incorporated into the yield calculation, such as the relative level of household agricultural education, which serves as a proxy for agronomic management and productivity. The model operationalizes rules whereby households chose a patch regarded as best suited to maximize yield subject to cost-benefit analysis, whereby households weigh the yield from clearing protected forested lands against the perceived social costs that could be incurred from authority figures (e.g., the village chief and / or Vietnamese Communist Party officials). Model outputs represent landcover as of the year 2006, which show a relatively close correspondence to the reference data (2000), whereas the "null" model shows significant divergence from the reference data. However, it should be noted that the duration of the model being tested spanned a period of only six years (i.e., a relatively brief span of time). Ngo et al. found fairly large, unexplained variance in outputs (~35%) and posit a need for additional validation and calibration to identify additional factors that may be relevant to policymakers. Later work extended the simulation timeline to 14 years (2006 to 2020) to explore possible future states of the landscape (Ngo et al. 2012).

Sulistyawati et al. (2005) offer a model of agrarian land-use transition in West Kalimantan, Indonesia, under conditions of partial market integration associated with improved road networks. Partial market integration refers to the practice of adopting market-oriented practices while maintaining self-sufficiency practices that prevailed under conditions of absent markets, per de Janvry (1991). Their model, which was implemented using the Borland DELPHI software package, incorporates population growth over time and tested for the influence of market prices on subsistence-oriented vs. market-oriented land-use. It found that while market connectivity and accessibility promoted cash crop production, the continuity of shifting cultivation was still important and necessary due to market volatility, i.e., the tendency for major fluctuations in the price of agricultural commodities. As such, the continuation of shifting cultivation practice provides an important backstop against adverse market price shocks.

Finally, Wada et al. (2007) provide a slightly larger area analysis at the provincial scale for Lao PDR, to examine the influence of market-based supply/demand dynamics on patterns of LULC change for the 1990s. Given the moderate spatial extent, the spatial resolution was coarsened from 0.5-2.5km to 5-10km grid cells. The model outputs appeared generally valid for that time and place under consideration, per the authors of this study. It should be noted, however, that pixels at this resolution may equal or exceed the footprint of small- to medium-sized villages engaging in shifting cultivation as their primary agricultural land-use system.

3.2.3 Generalized models

The widespread application of local-scale case studies implemented using agent-based modeling approaches does not lessen their relevance but has given rise to what could be characterized as “model fatigue”, termed the “YAAWN” syndrome meaning “yet another agent-based…whatever nevermind” (O’Sullivan et al. 2014). Adherents to this perspective tend to consider such models as being “overfitted” and aspire to achieving more broadly relevant models. To that end, scholars have undertaken efforts in more recent years to develop and build generalized models to simulate the relative effect of market influence on LULC change in Asia and North America, although with mixed results based on comparing initial results of testing against “null” models (Magliocca & Ellis 2014). More work in this area could help bridge the gap between local-scale and larger spatial contexts.

The model presented in this chapter concerns agrarian transition from a subsistence mode to one of partial market integration involving a hybrid mode of cash cropping and subsistence cultivation. It incorporates elements of Brown (2008), Jepsen et al. (2006), Ngo et al. (2009), and Sulistyawati et al. (2005), in operationalizing a ruleset specified by expert knowledge (Leisz et al. 2014). The current model establishes a baseline for LULC change under conditions of partial market integration, providing a local-scale window into the process of agrarian transition, for which the existing literature is relatively scarce. While the model functions micro-economically, it allows for outside influence by incorporating the influence of exogenous variables (climate, market forces, and policy) and thus takes a small step in the direction of modeling micro-to-meso level interactions relating to land-use systems and land-cover change.

The underlying hypothesis of the model presented in this chapter is that it can be used to identify trends in LULC change related to external forcing factors including climate, markets, and terrain constraints, as well as endogenous factors including agronomy and population. The relative level of agreement or disparity between the direction and magnitude of modeled change and observed change will inform further validation and calibration of the model. It could thereby serve as a prototype for a decision-support tool, pending further calibration and validation. This model could perhaps eventually be used as a building block to scale up modeling of agricultural land-use under conditions of partial market integration from the village to the commune level, and perhaps subsequently to the district level. Scaling upwardly would require sufficient empirical data to more accurately characterize and parameterize human agents, landscape agents, and socio-ecological systems governing the interactions of the former with the latter, a matter given further consideration in the future work section at the end of the chapter. Such data would help to define relevant human factors related to disposition, mobility, decision-making processes, and behavioral rules vis-à-vis land-use systems, in the context of absent markets and under varying degrees of market integration.

3.3 Study area

The agent-based model presented in this chapter has been designed, built, and tested for two villages in Đa Krông ("Big River") District, Quảng Trị Province, in the north-central region of Vietnam: Klu, in Đa Krông Commune, and Ta Rec, in Ba Nang Commune (Figure 43). The villages constituting the spatial units of analysis for simulating changing land-use systems are considered for the period 1991 to present, with the upgrading of Highway 9 under the East-West Economic Corridor occurring in mid-2006. Upgrading the road created reliable, all-season market connectivity between the rural uplands and industries based in lowland urban centers. This project roughly coincides with the start of an agrarian transition toward market-oriented agricultural production in some locations within the study area, as observed in satellite imagery and reported by the local population (see Chapter 2).

The first village, Klu, is located in Đa Krông commune in the vicinity of 16°40' N 106°50'E and traversed by Highway 9. The village encompasses an area of approximately 15 square kilometers with terrain elevations ranging from 33-572 meters above sea level, with an average (mean) slope of 18 degrees and maximum slope over 50 degrees. The village was comprised of 134 households, with the Van Kieu minority ethnic group constituting approximately 97% of this population and only three households identified as majority Kinh ethnicity (Leisz et al. 2016). The primary modes of food production before the highway upgrade project, with market-oriented production occurring in the period since 2007, involved the shifting cultivation of upland rice along with various other crops and animal husbandry (Leisz et al. 2016).

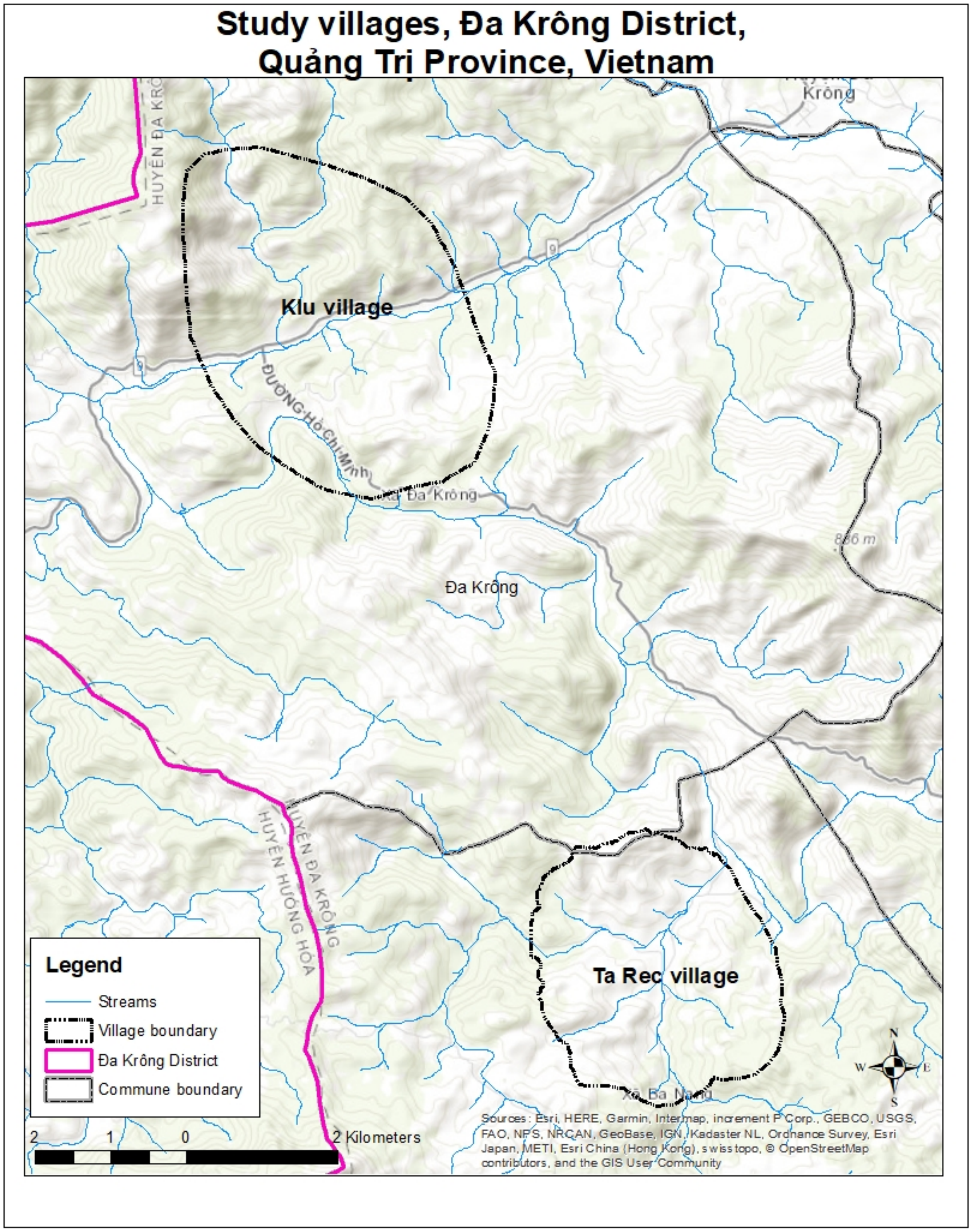


Figure 43: Villages of Klu and Ta Rec, Đa Krông District, Quảng Trị Province

The following imagery depicts the landscape of the village of Klu in 2001, prior to the highway improvement project (Figure 44):

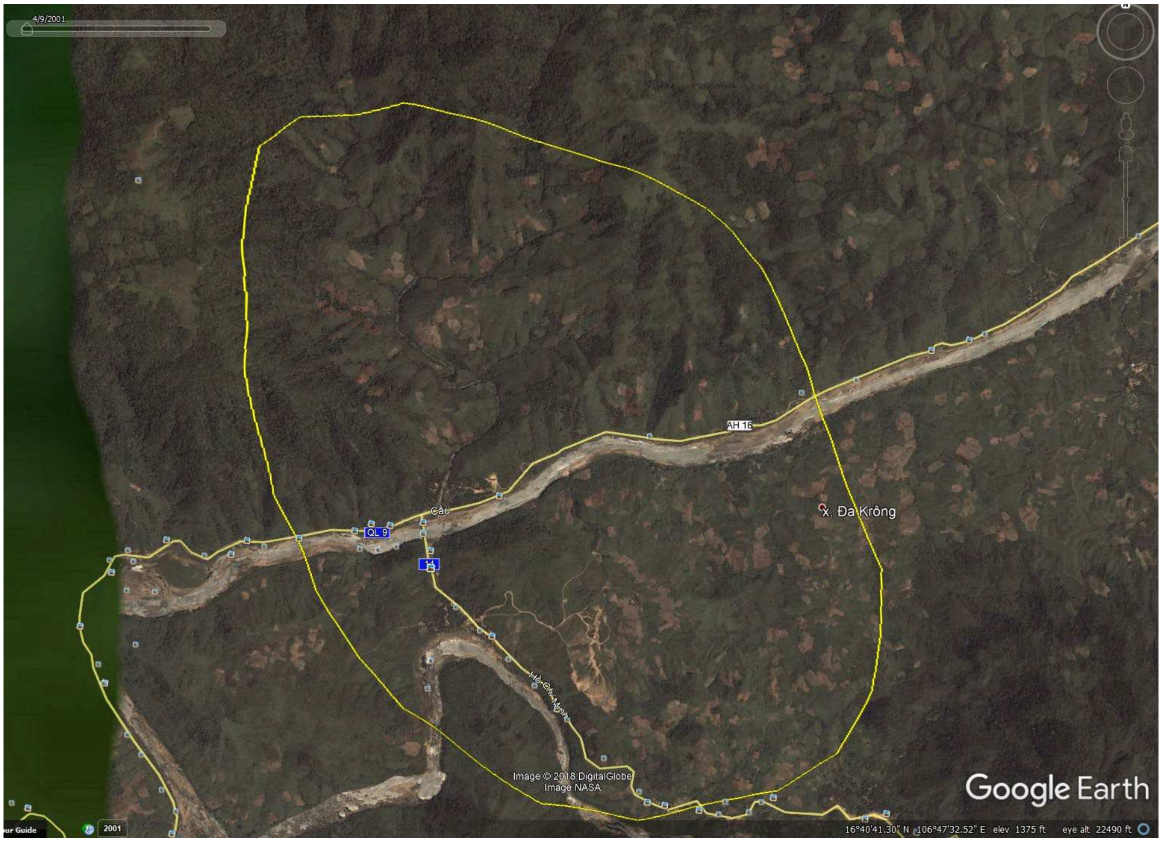


Figure 44: Klu Village, April 2001, as seen in high-resolution commercial satellite imagery (Google Earth)

The second village, Ta Rec, is located in Ba Nang commune in the vicinity of 16°35' N 106°51 E, approximately 10km south of Klu and several kilometers southwest of Ho Chi Minh Highway. The village encompasses an area of approximately 9 square kilometers with terrain elevation ranging from 114-363 meters above sea level, with an average (mean) slope of 14 degrees and maximum slope of over 40 degrees. The population consisted of 80 households of Van Kieu ethnicity, engaged in subsistence-oriented livelihoods (Leisz et al. 2016). Like the village of Klu, Ta Rec existed in a state of relative isolation, with little connection to outside markets prior to the EWEC upgrade.

The following depicts the landscape of the village in 2001, prior to the highway improvement project (Figure 45):

Figure 45: Ta Rec Village, April 2001 - as seen in high-resolution commercial satellite imagery (Google Earth)

3.4 Methods – overview, design, and details of model development process

The methods used in designing this spatially-explicit agent-based model are built on a general conceptual framework similar to Sulistyawati et al. (2005) and Brown (2008), centered on the household as the principal decision-making unit. The platform used in building and testing this model is the free, open-source software package NetLogo (v. 6.0.2), which has seen limited adoption by the land change science community (Jepsen et al. 2006; Ngo et al. 2009; Barton et al. 2013).

The simulation models applied to the village-scale case studies in this paper simulate the cumulative effects of households, as the decision-making agent, on the landscape. Household agents are modeled based on data gathered through fieldwork and socio-economic data and operationalized based on rules presented below (section 3.4.2). Landcover, terrain, and other relevant variables for the patch environment are derived from satellite imagery and other ancillary datasets (see chapter 2).

3.4.1 Purpose of model

Agricultural production at the local scale for the two villages is baselined. The magnitude and direction of landcover change under these land-use systems can be altered by the modification of various model parameters pertaining to initial conditions related to agricultural land-use practices (i.e., agronomy), climate (i.e. extreme weather events, e.g., drought / flood), demographics (i.e. number of households), markets prices, and terrain-related constraints. The model assumes bounded rationality, where households engage in cash cropping efforts for income, while also maintaining some level of self-sufficiency through rice cultivation. This behavioral mode accords with the "moral economy of the peasant" espoused by Scott (1976).

3.4.2 Agents

3.4.2.1 Household agents

The agents in this simulation represent "households" which are defined by a nuclear family of two parents and their children (the number of whom is based on average household size minus two, currently set at five). Ages of children are staggered with variability within households. Houses have endowments in the form of capital and labor. Capital is represented by a cashbox and food-stock, with both set at initial values approximately equal to one year of rice cost and rice supply respectively. The labor endowment is simply the household's ability to engage in agricultural cropping activity, where children over the age of 10 have a labor capacity set at half that of their adult parents and children under the age of 10 are considered non-laborers.

The primary functions of the household on a recurring annual basis relate to agricultural cropping decision-making and behavior that alter the land-cover of the village landscape. Crop yields accrue to the household in the form of energy under subsistence and monetary returns under cash-cropping. The patches within the village that are not under active use by households, as well as the surrounding landscape outside the village boundary, regenerates through a process of vegetative succession.

With regard to land holdings, households in this model do not hold exclusive claim over particular plots within the village. A customary tenure system with the following rules applies instead:

(1) households can clear patches within the village landscape that are not infeasible or otherwise off-limits due to explicit policies set by the government or village norms. Patches deemed non-arable and thus unsuitable for cultivation include the following:

(a) built-up areas (i.e., slope less than 5 degrees);

(b) prohibitively steep slopes (i.e., slope greater than 40 degrees);

(c) roads;

(d) sacred forests;

(e) stream-beds; and

(f) lands beyond the recognized village boundary.

(2) patch selection and clearing of lands for agriculture would be based on the aforementioned land-cover preference hierarchy, subject to patch re-use and fallow periods constraints;

(3) households will tend to cluster in groups of up to four, per empirical observations gathered from fieldwork (Leisz et al. 2014); and

(4) upon completion of the agricultural cycle, households do not retain residual claims to particular plots of land for the next cultivation cycle in contradistinction to individual titling (i.e., where household assert exclusive claim to a particular plot of land).

On this last point, it bears noting that this tenure system differs from an unmanaged open-access regime, as described by Hardin (1968) in his depiction of a "tragedy of the commons." Instead, this system of land access / use rights would be better characterized as a "common-property regime" with *sharing* rights rather than exclusive rights (Ostrom & Nagendra 2006).

The plot selection function employed by household agents gives preference to patch(es) within its sensing cone (i.e., radius and distance) that maximize return on labor in terms of crop yield while minimizing clearing and weeding efforts. Rules governing this process are as follows:

(1) If patch with cover type of "cleared" has consecutive years of re-use less than maximum allowed, then the patch can be reused;

(2) If patch with cover type of "cleared" has consecutive years of re-use equal to or greater than maximum allowed, then the plot is allowed to revert to fallow; and

(3) Additional patches are surveyed to identify suitable candidate plots, applying the following hierarchy of land-cover preference:

(a) first preference - mix of bush and small trees ("regrowth")

(b) second preference - mix of bush and grass ("fallow")

(c) third preference - tree cover ("woodlands" or "forest")

Additional criteria that apply to patch selection include terrain factors (e.g., slope) and relative distance factors (e.g., proximity to other households) that can be varied by the user on the model interface. The default minimum slope threshold is specified as 5 degrees and the maximum slope threshold is set at 40 degrees, due to the sheer practical difficulty of physically clearing steeper slopes. A proximity threshold is specified that groups of farmers not exceed a cluster size of four households with a random offset distance between groups to prevent conflicting patch use.

3.4.2.2 Landscape Agents

Patches represent the landscape within the village and surrounding areas, where each village boundary has been buffered by approximately two (2) kilometers. The peripheral region is included to allow for comparison of landcover dynamics inside the village associated with agriculture against those outside the village under forest succession (i.e., in the absence of ongoing human alteration of the landscape as currently configured for this model). It also allows for future modification / variation of the model to allow for land-use beyond the recognized boundary perimeter of the village, which is considered a plausible scenario under sufficiently high levels of market-oriented production.

The patch environment draws on a range of grid ASCII rasters (discrete and continuous) generated using ArcGIS. Spatial-explicit model layers include the following:

(1) direction and distance to roads (roads taken from Open StreetMap extracts);

(2) elevation (SRTM 30-meter resolution, with pits filled using TauDEM);

(3) slope (derived from pit-filled SRTM elevation data); and

(4) landcover (derived from satellite imagery).

The base land-cover was derived from Landsat 5 TM imagery from January 1991, with a coarse classification produced using unsupervised ISO clusters to identify areas of water, forest, intermediate regrowth, fallow, and clearings. There are additional binary layers made available under the “Spatial_Layer” dropdown on the NetLogo “Interface” tab, e.g., binary surfaces representing inclusion vs. exclusion zones (e.g., within road buffer and within village boundary).

The process of vegetative succession for all patches not in current use by households is based on the following transition rules for dominant cover types by fallow age range:

(1) Grass and grass-bush (years 1-4);

(2) Bush and small trees (years 5-7); and

(3) Trees (year 8 and beyond).

3.4.3 Model process: stepwise execution of the model

The model process consists of a “Setup” procedure, whereby households and the patch environment (i.e., landscape) are created with initial values set based on the baseline, business-as-usual scenario. The default values are specified in the model code under the “restore parameters” procedure. Many model parameters relating to households - initial number and conditions of household agents (e.g., annual rice requirement, cashbox, cost of living) and household behavior (e.g., agronomy, household fissioning, sensing / movement related to patch selection) - are alterable by the user post-Setup. Landscape agent values relating to yield can be adjusted by the user as well (e.g., clearing costs and typical yields). Exogenous variables relating to agricultural prices (i.e., rice and cassava) can also be modified. Finally, there are a number of sliders pertaining to background environmental conditions, i.e., probability of extreme weather (e.g., drought / flood), and socio-economic conditions (i.e., time step value when the road improvement project would occur) that can be modified by the user if wanted.

Once the model has been initialized by running “Setup” and modifications (if any) made to any default sliders or switches, the “Go” procedure is launched to initiate a single run of the model. Households agents engage in an annual cycle of cultivation of crops on selected patches.

Patch selection is based on identifying suitable patch-sets and grouping in clusters of up to four households, with a random offset between groups. The hierarchy of preference for patch selection are as follows:

(1) first preference: previously cleared patches below maximum years in use threshold due to adequate fertility relative to minimal clearing requirement (i.e., yield generally sufficient to meet basic household subsistence requirements);

(2) second preference: secondary regrowth, due to high fertility return relative to effort required for clearing, where cut and burned vegetation returns a nutrients to the soil in a temporally concentrated pulse per Jepsen et al. (2006);

(3) third preference: fallow regrowth, due to moderate fertility return relative to effort required for clearing; and

(4) fourth preference: forest (i.e., dominant tree cover), due to high level of effort required for clearing (Leisz et al. 2014).

Households must abide by the dual constraints regarding the maximum number of years for consecutive patch re-use and the minimum number of years for selecting their "most preferred" (or "least objectionable") patch-set. Clearing, planting, and cultivation of patches then occur, with labor costs assigned based on relative levels of energy expenditures per cover type and activity. All values are defined on the user interface and can be adjusted by the user. Harvest yields are then computed by the model, where rice yield is based on the following (Equation 1):

Equation 1: Dry rice yield equation (Jepsen et al. 2006: 1071)

$$y = \frac{a}{1 + b \cdot \exp(-cx)}$$

where y=yield; x=fallow age; a=1,866; b=8.07; and c=0.52. R^2 is 0.99.

This equation is implemented with the numerator (“a”) set to 1866, except in cases where the model makes a random probabilistic determination that an extreme flood / drought event has occurred, in which case the value of the numerator (“a”) is reduced by half to 933 – representing a “bad year” but not a total crop failure. The following graph, based on the above equation, visualizes diminishing crop yields per hectare with reduced length of fallow (Figure 46):

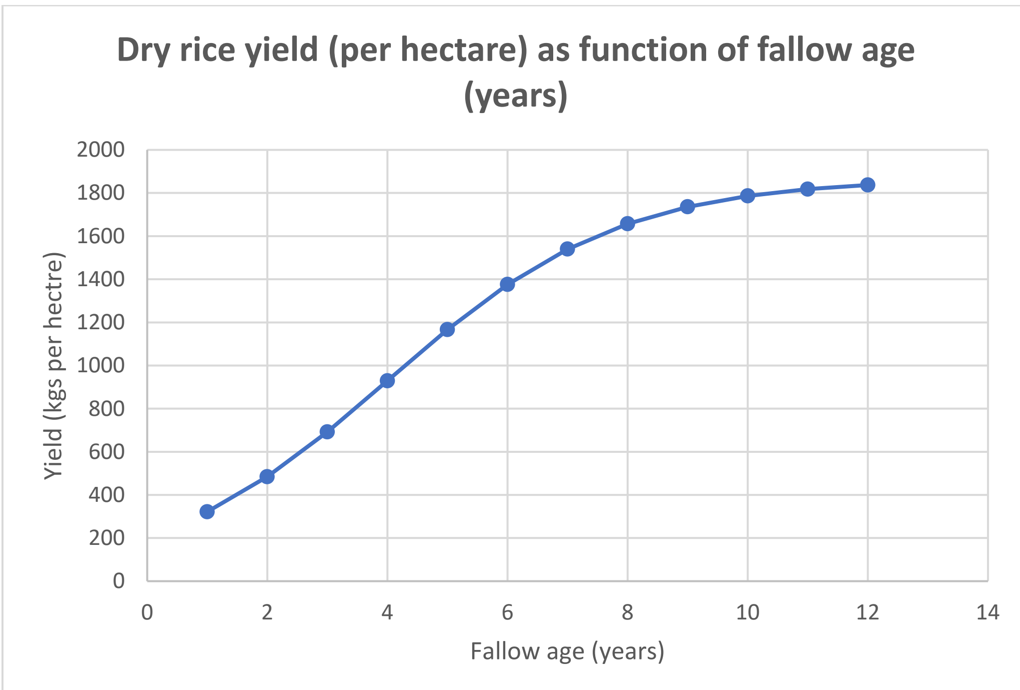


Figure 46: Dry rice yields (kgs per hectare) based on fallow age, based on Jepsen (2006: 1071)

With regard to cassava yields, the model does not have a sophisticated equation weighing multiple agronomic or ecological factors. As a proxy, a simple three-year crop yield rule is applied, based on observations reported by local populations (Leisz et al. 2014), as follows:

(1) 10,000 kgs per hectare in the first year of cultivation;

(2) 6,000 kgs per hectare in the second year of cultivation; and

(3) 4,000 kgs per hectare in the third year of cultivation.

This is a fairly conservative baseline, since typical yields of cassava in Vietnam have tended to average around 15,000kgs per hectare (Howeler 2006). However, the K94 varietal is being grown by most households without additional inputs of water and fertilizer. A significant fact with regard to this form of cash cropping, per Van De (2008: 4), is that "poor farmers…see crop yields drop dramatically after two or three years of cultivation due to the fertility decline."

With regard to meeting basic subsistence need for rice as the main staple grain, households simulated in this scenario typically clear areas of approximately 6-9 patches (5400-8100 square meters or 0.54-0.81 hectares) to grow a sufficient quantity of rice to provide a supply for at least nine months of the year (based on the official standard set by the government of 300 kgs per person per year for self-sufficiency). The simulated area being cleared per household for cassava is set at approximately a half hectare and varies upwardly for households with relatively higher capital (i.e., cashbox), who are more secure to assume risks associated with cash cropping than households with relatively lower capital.

Patches not under cultivation during a given cycle of the model undergo a process of vegetative regrowth, transitioning to new landcover based on reaching certain vegetative succession thresholds. With the disclaimer that vegetative succession spans a continuum of growth, the model applies the following thresholds for simulating discrete land-cover types (Table 9):

Table 9: Fallow vegetation regeneration land-cover thresholds

Fallow age range	**Landcover category**
1-7 years	Early fallow (grass/bush)
8-12 years	Late fallow (small trees)
13-20 years	Secondary regrowth (open canopy)
> 20 years	Mature forest (closing / closed canopy)

3.4.4 Full run of the model (30 timesteps) and model outputs

The model continues to run until reaching a specified number of time steps designating the stopping point, unless the household agent population were to collapse to a count of zero before that time step is reached, in which case the model ends prematurely. The model as currently configured runs for 30 years under normal, "business-as-usual" conditions without exhibiting population collapse, but such an outcome can be induced by changing various parameters to extreme values. Upon completion of a run, the user interface displays the following, which can be exported:

(1) end-state land-cover pattern ("world" frame);

(2) end-state values of households and patches (monitors), including number of households mean age, mean cashbox, land-cover type by area / percentage of landscape ; and

(3) changing values of households and patches over the model run, including household counts by cropping type, crop yields, clustering of clearings (average distance between households), household distance to roads, and land-cover by class and sector (inside vs. outside the road buffer).

In addition to the aforementioned outputs on the user interface ("world", monitors, and plots) that can be exported from a given run of the model, BehaviorSpace also generates outputs in tabular (CSV and Excel) and raster (ASCII) format. These can be generated for each time step of the model, or simply the end-state.

3.4.5 Model testing – Baseline scenario and BehaviorSpace experiments

NetLogo's BehaviorSpace interface provides a vehicle for testing alternative scenarios differing from the norm tested under the baseline scenario. In addition to the Baseline (30 runs), which test for the "business-as-usual" scenario, five additional tests were performed for each village. Two of these tests pertain to endogenous factors - agronomy and demography. Three tests pertain to exogenous factors - climate variability, market prices, and terrain-related constraints. The user can modify parameters for the relevant controlling variables in the BehaviorSpace interface before running the model for either village (i.e., Klu or Ta Rec).

To explore the influence of various variables on LULC change in the study village, a series of experiments were performed, whereby certain variables regarding as controlling variables were tested to observe what effect, if any, these had on agricultural land clearings (response variable). The five basic experiments conducted on these variables using the BehaviorSpace function in NetLogo were as follows:

(1) agronomy – for this test, patch use variables for consecutive years in cultivation and minimum fallow length were varied low and high of the normal baseline values (specified per sliders on the user interface per field notes by Leisz et al. 2014; see also Ziegler et al. 2009) ;

(2) climate – for this test, the likelihood of extreme weather (flood or drought) was raised to higher levels (doubling, triping, quadrupling) over the baseline value (10%), where ten percent is considered a default value for “bad years”; in the event of an extreme climate event, the projected loss in harvest yield is estimated at ~ 50%;

(3) demography – for this test, the initial number of households is varied above and below the estimated baseline population of the village to simulate effects on agricultural land clearings; household size is held constant due to limitations with simulating the expansion of land clearings beyond nine patches per household in the code for this model as currently constituted (version 21);

(4) market prices – for this test, the prices of the two key agricultural commodities (cassava and rice) are varied low and high of the prevailing market prices that were

determined by fieldwork (Leisz et al. 2014); households that grow cassava will always sell, whereas households will only buy rice as needed (i.e., do not sell rice);

(5) terrain constraints (allowable slope range) – for this test, the range of allowable slope varied below and above the normal values (where normal values are based on lands below a grade of five degrees are typically reserved for other uses, e.g., built-up areas or paddy rice, and lands with grade > 40 degrees are generally considered impractical to cultivate due to the steepness of the terrain.

3.5 Results of model testing - Baseline scenario and BehaviorSpace testing

3.5.1 Results for Klu village

3.5.1.1 Baseline scenario

The baseline scenario for the village of Klu was parameterized based on a "business-as-usual" (BAU) scenario for shifting cultivation practices during the period prior to the Highway 9 upgrade (1991-2006), whereby households disperse randomly across the village landscape and clear suitable patches for a maximum of three-to-four years consecutively followed by moderately long fallow periods of ten years. As the model enters its sixteenth year, a road improvement project starts to trigger a shift in land-use, whereby households can now consider cash cropping based on the "grey market" or farm-gate price for hybrid cassava (K94) offered by brokers who visit the village. Farm-gate prices reflect the difference between the market price and costs borne by the middle man (i.e., transport and marketing).

Before commencing the cultivation cycle, households apply a decision-rule whereby the projected proceeds (i.e., revenue) from the sale of the anticipated cassava harvest (based on average yield) is compared against the household's annual rice cost (based on prevailing market prices for rice). If the former is greater than the latter, and the household has savings sufficient to cover one year of annual rice costs, as a minimum buffer to cover their survival in the event of a catastrophic harvest failure, the household deems cash cropping a worthwhile risk to assume for the given cultivation cycle and clears land inside the road buffer. If the projected proceed of cassava exceed by a larger margin (based on user-specified threshold on the model interface) and the household has a sufficiently large cashbox (based on user-specified threshold on the model interface), the household can cultivate cassava only. As currently parameterized for BAU, nearly all household agents exhibit similar cropping behavior whereby they clear village lands to grow cassava within the road buffer zone and rice beyond the road buffer zone. Only in rare instances under BAU would households choose to exclusively engage in either cassava or dry rice only.

The overall change in simulated land-cover for the village landscape by cover-type, where only four basic cover types are represented, was as follows (Figure 47):

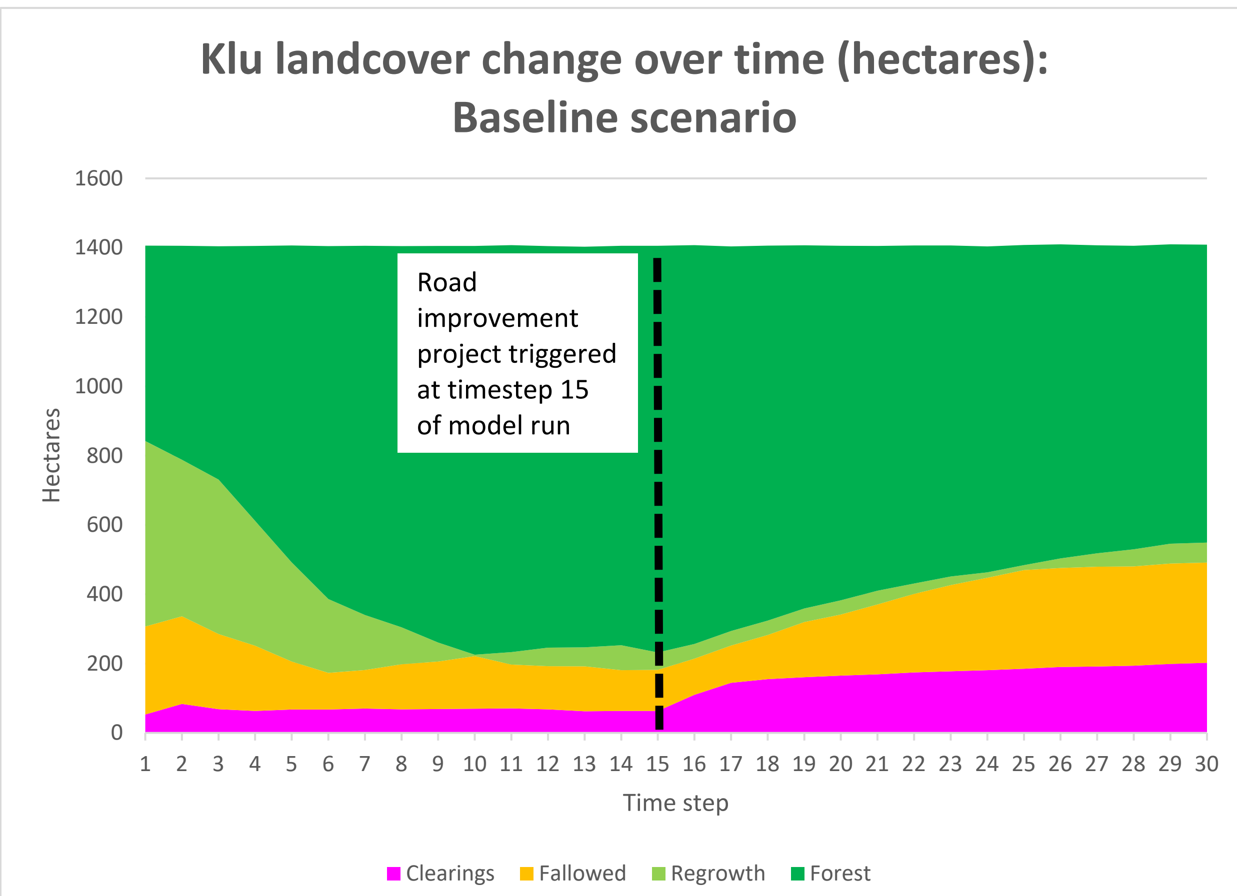


Figure 47: Overall change in land-cover over time by cover type (median values) for Klu, Baseline scenario (30 runs)

There is a fairly steep decline in the extent of the intermediate regrowth cover class in the first six years of the model run, which continues to decline at a slower rate through year ten. In the second half of the model run, the total extent of both agricultural clearings and fallowed areas increases, while the overall area under forest cover shrinks in extent. The intermediate regrowth cover class accounts for the smallest proportion of the landscape through the second half of the model run, while cleared, fallowed, and forest cover classes all increase.

Additional graphs allow for differentiating between land-cover changes occurring inside the road buffer vs. those occurring outside the road buffer, where relatively intensity of land-use shifts halfway through the model run. The following graph shows the total area cleared (hectares) per year over the 30-year period inside the road buffer (<350 meters), where dry rice cropping occurs in the first half of the model run and cash cropping occurs in the second half of the model run (Figure 48):

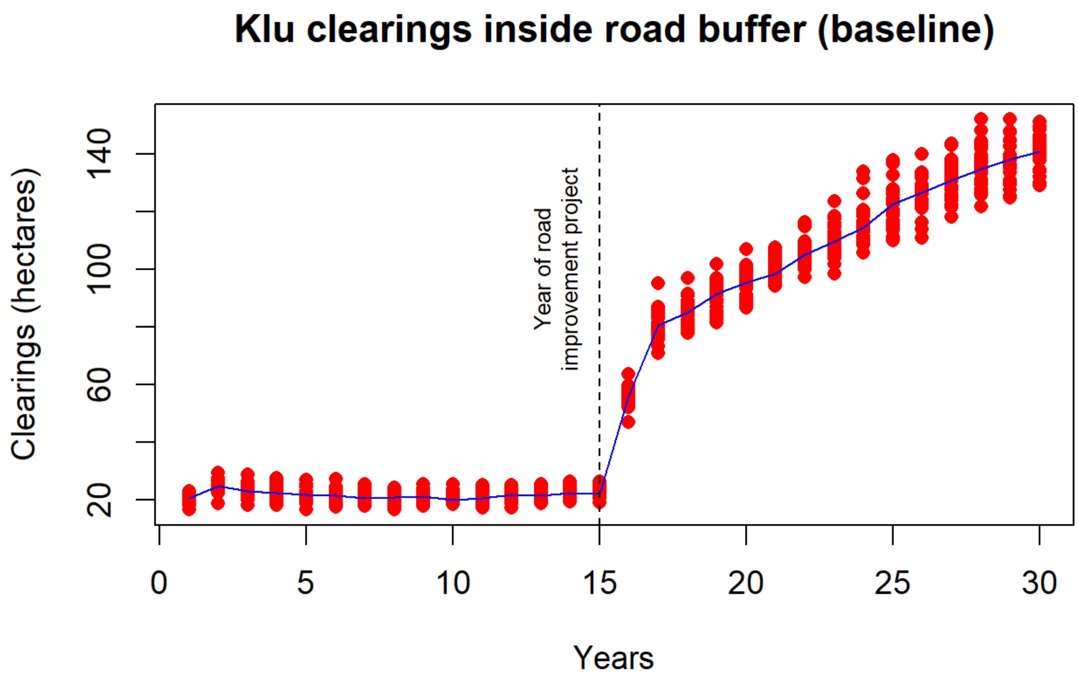


Figure 48: Agricultural clearings simulated via ABM inside the road buffer zone (600m) for Klu village; generated in NetLogo v. 6.0.2, BehaviorSpace "Baseline" experiment (30 runs at 30 steps/run)

Agricultural clearings inside the road buffer (<350m from roads) during the period preceding the road improvement project (years 1-15), shows relatively lower median values and a narrower range of values, as compared to the period following the road improvement project (years 16-30), when households have incentive to crop in this zone. The overall change in simulated land-cover within the road buffer zone associated with this modeled land-use was as follows (Figure 49):

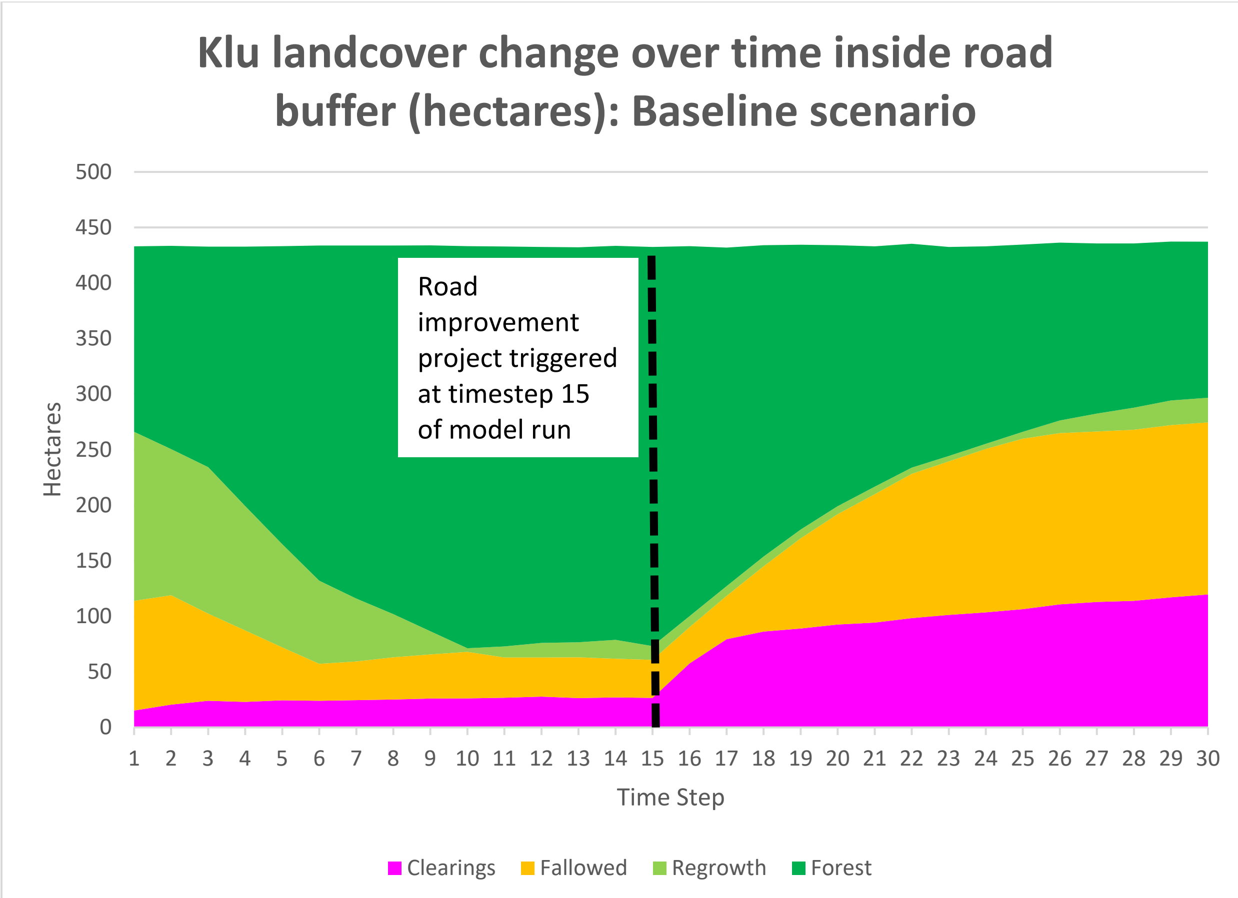


Figure 49: Change in land-cover inside road buffer zone over time by cover type (median values) for Klu, Baseline scenario (30 runs)

The cumulative effects of household land-use on village land-cover inside the road buffer involve a rapid reduction in the area of intermediate regrowth during the first half of the model run, followed by a substantial increase in cleared and fallowed areas during the second half of the model run with a corresponding reduction in the area of woodlands / forest.

The following graph shows the total area cleared (hectares) per year over the 30-year period for the area outside the road buffer zone (>350m), where only subsistence rice growing takes place in the simulation model (Figure 50):

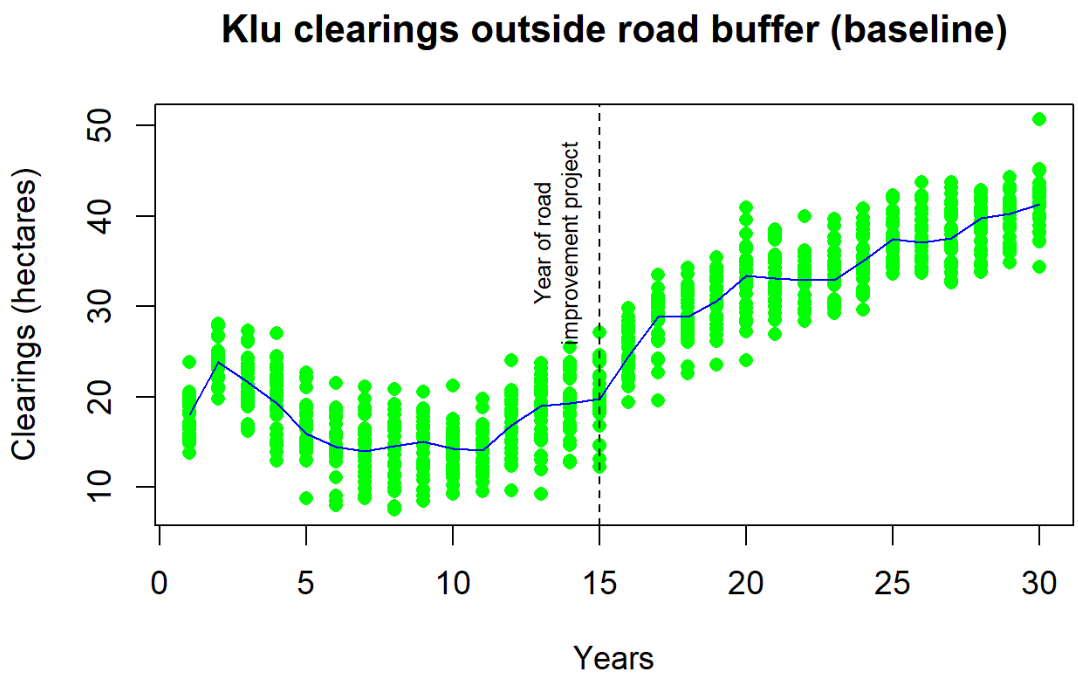


Figure 50: Agricultural clearings simulated via ABM outside the road buffer zone (600m) for Klu village; generated in NetLogo v. 6.0.2, BehaviorSpace "Baseline" experiment (30 runs at 30 steps/run)

Agricultural clearings outside the road buffer during the period preceding the road improvement project (years 1-15), shows relatively lower median values and more interannual variability than the period following the road improvement project (years 16-30). The overall change in simulated land-cover outside the road buffer zone associated with this modeled land-use was as follows (Figure 51):

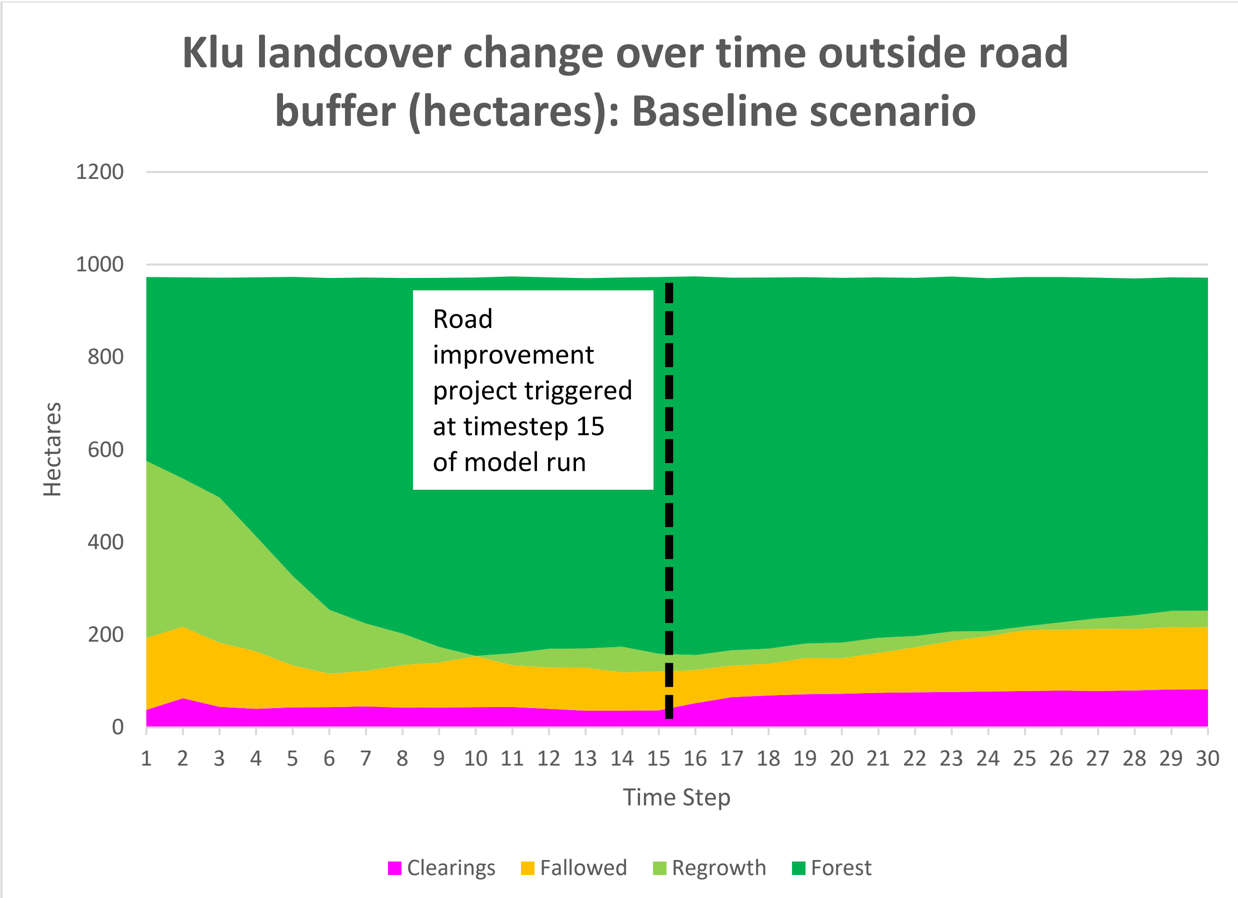


Figure 51: Change in land-cover outside road buffer zone over time by cover type (median values) for Ta Rec, Baseline scenario (30 runs)

The cumulative effects of household land-use on village land-cover inside the road buffer involve a rapid reduction in the area of intermediate regrowth during the first half of the model run, followed by moderate increase in cleared and fallowed areas during the second half of the model run. The net area of woodlands / forest cover increases corresponding to the reduction in areas under intermediate regrowth.

3.5.1.2 Results of BehaviorSpace experiments testing alternate scenarios

The following series of graphs depicts the differing effects of the different variables tested in the experiments that were performed with respect to agricultural LULC outcomes, where each

BehaviorSpace test is run 30 times per combination of variables with the random seeds set to the same numeric value as the BehaviorSpace run number to make all model results fully replicable.

3.5.1.2.1 Agronomy

This experiment tests for varying years in consecutive use of patches under cultivation and minimum fallow lengths for patches taken out of cultivation. Results for nine scenarios tested (30 runs per scenario) were as follows (Figure 52):

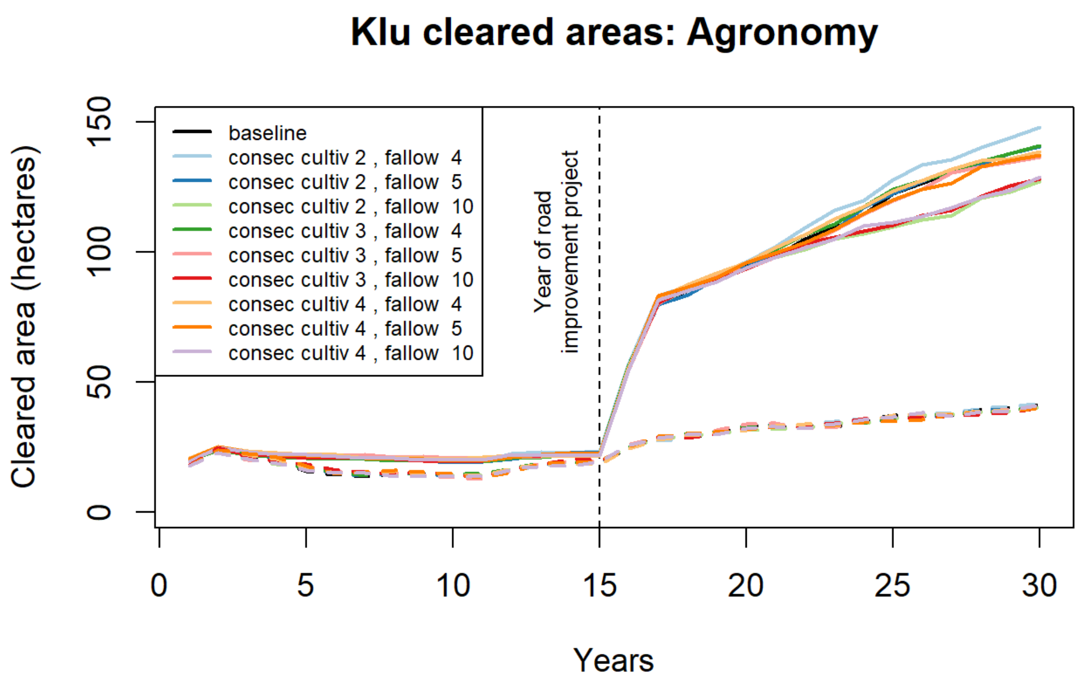


Figure 52: Agricultural clearings simulated via ABM inside and outside the road buffer zone (600m) for Klu village; generated in NetLogo v. 6.0.2, BehaviorSpace "Agronomy" experiment.

Varying the duration of patch re-use and fallow length variables for cash cropping from those tested under the Baseline scenario results in differing impacts on the total area cleared inside the road buffer zone (600m). The combination of the shortest cropping cycles (2 years) and shortest fallow period (4 years), rendered as a light blue line, results in more land being cleared inside the road buffer. Scenarios testing long fallow lengths (10 years) show less land being cleared inside the road buffer. Intermediate scenarios where fallow length is held constant (5 years) appear fairly closely aligned with the Baseline scenario. For all scenarios tested, it appears that land-use and land-cover outside the road buffer hold constant to the Baseline scenario.

3.5.1.2.2 Climate variability

This experiment tests for increasing likelihood of extreme weather - conceived of here as either major flood or drought event causing lost crop yield - over and above the Baseline value of 10 percent. Such events may cause a loss of up to 50% in crop yield. Results for the three scenarios tested (30 runs per scenario) were as follows (Figure 53):

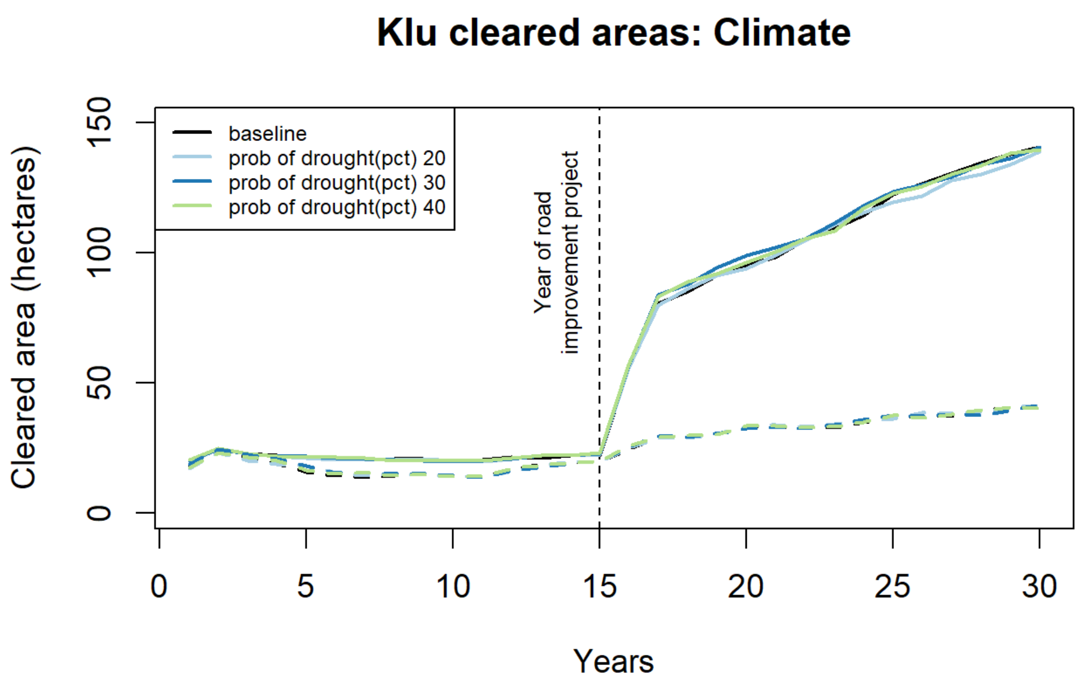


Figure 53: Agricultural clearings simulated via ABM inside and outside the road buffer zone (600m) for Klu village; generated in NetLogo v. 6.0.2, BehaviorSpace "Climate Change" experiment.

Raising the likelihood of an extreme drought or flood event over those tested under the Baseline scenario results in land-cover outcomes that show little variation from the Baseline in this instance. This result appears inconclusive for this village, and it differs from the results observed for Ta Rec village that are presented in the next section.

3.5.1.2.3 Demography

This experiment tests for decreasing and increasing the initial number of households below and above the Baseline value (60 households). Results for the five scenarios tested (30 runs per scenario) were as follows (Figure 54):

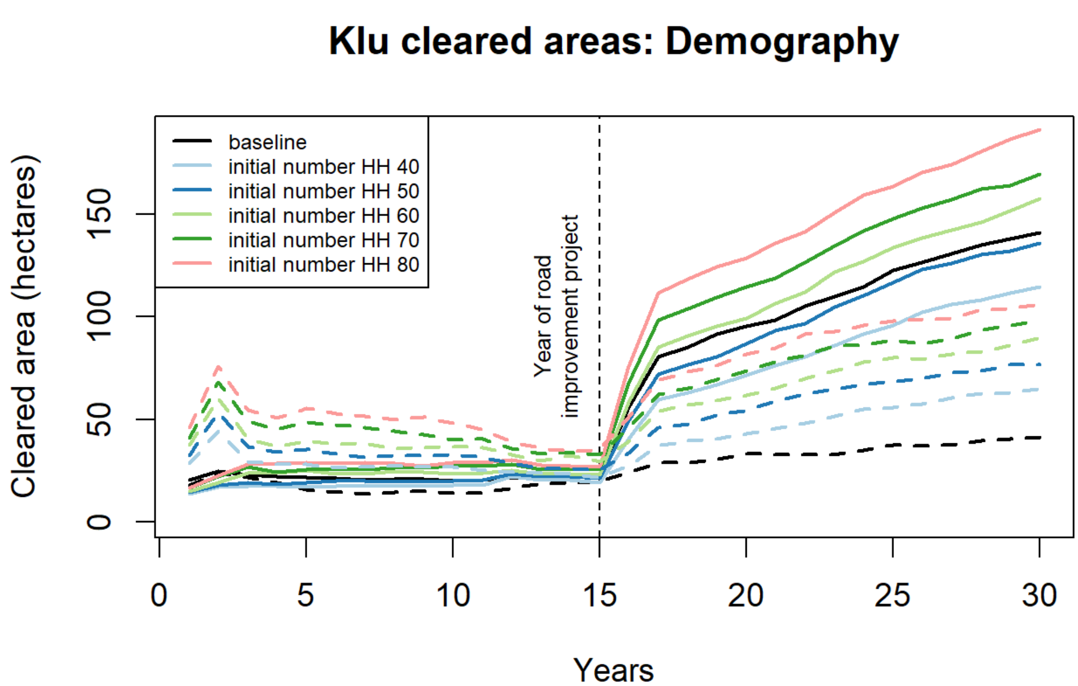


Figure 54: Agricultural clearings simulated via ABM inside and outside the road buffer zone (600m) for Klu village; generated in NetLogo v. 6.0.2, BehaviorSpace "Demographics" experiment.

Varying the initial population values low or high of the Baseline value (60 households) results in a proportional decrease or increase in the amount of land cleared vis-à-vis the Baseline scenario both inside and outside the road buffer zone (600m). The effect on total area cleared inside the road buffer is substantially larger than the impact upon the total area cleared outside the road buffer, which is a function of the default plot sizes being parameterized at 8100 square meters vs. 6400 square meters respectively, as tested.

3.5.1.2.4 Market Prices

This experiment tests for lowering and raising the market price for rice and the grey market price for cassava below and above the Baseline values (5000 VND and 1200 VND respectively). Results for the nine scenarios tested (30 runs per scenario) were as follows (Figure 55):

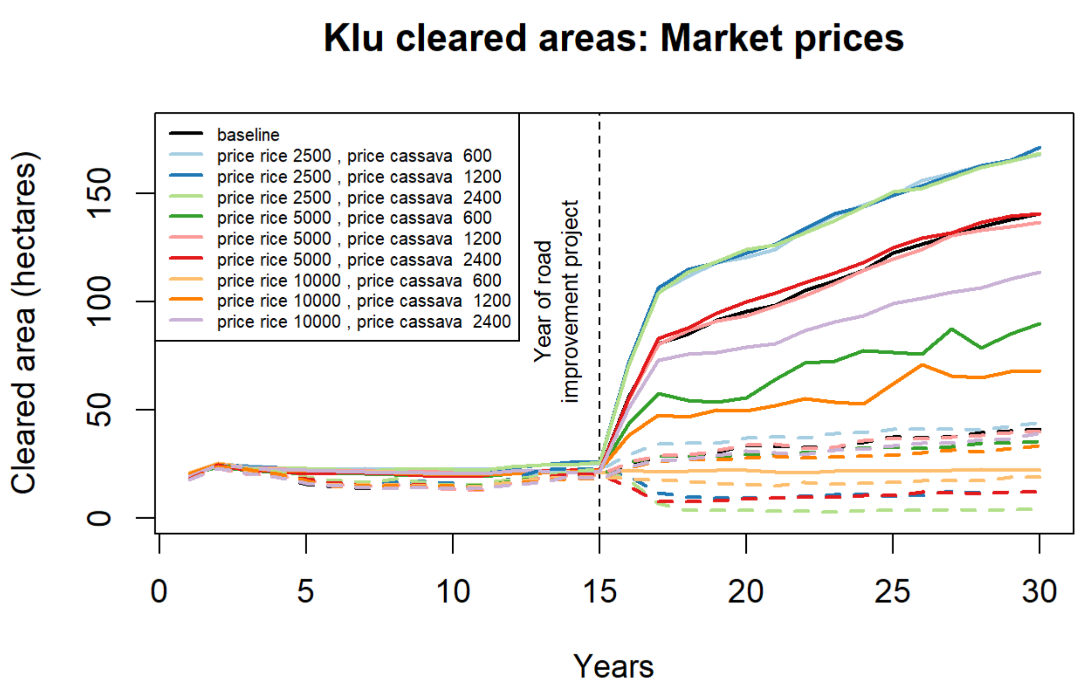


Figure 55: Agricultural clearings simulated via ABM inside and outside the road buffer zone (600m) for Klu village; generated in NetLogo v. 6.0.2, BehaviorSpace "Market Prices" experiment.

Varying the prices of rice and cassava from the values tested under the Baseline scenario result in widely divergent outcomes in the extent of land area cleared both inside and outside the road buffer zone (600m). The most dramatic increase on land clearing inside the road buffer results from a 50% reduction in the cost of rice, which leads to an increase of approximately one-third increase in the intensity of cash cropping (light green and blue lines [solid]). Conversely, a reduction in land-use inside the road buffer of approximately one-third results from a 50% reduction in the price of cassava (dark green and orange lines [solid]). An intermediate case between this scenario and the Baseline results from the doubling of the price of rice (purple line [solid]). Noteworthy results on clearings outside the road buffer include the following:

(1) a pronounced decrease in area cleared where rice prices are halved and cassava prices are doubled (light green line [dashed]);

(2) a moderate decrease in area cleared where price of cassava is doubled while holding the price of constant (red line [dashed]) and where the price of rice is halved while holding the price of cassava constant (blue line [dashed]); and

(3) a slight increase in area cleared where the price of cassava is halved while holding the price of rice constant.

3.5.1.2.5 Terrain (Slope constraint)

This experiment tests variation in the minimum and maximum allowable slope thresholds for agricultural clearing and cultivation below and above normal values used in the Baseline scenario. The lower slope threshold is varied from 3-5 degrees and the upper slope threshold is varied from 30-60 degrees in increments of 10. Results for the 12 scenarios tested (30 runs per scenario) were as follows (Figure 56):

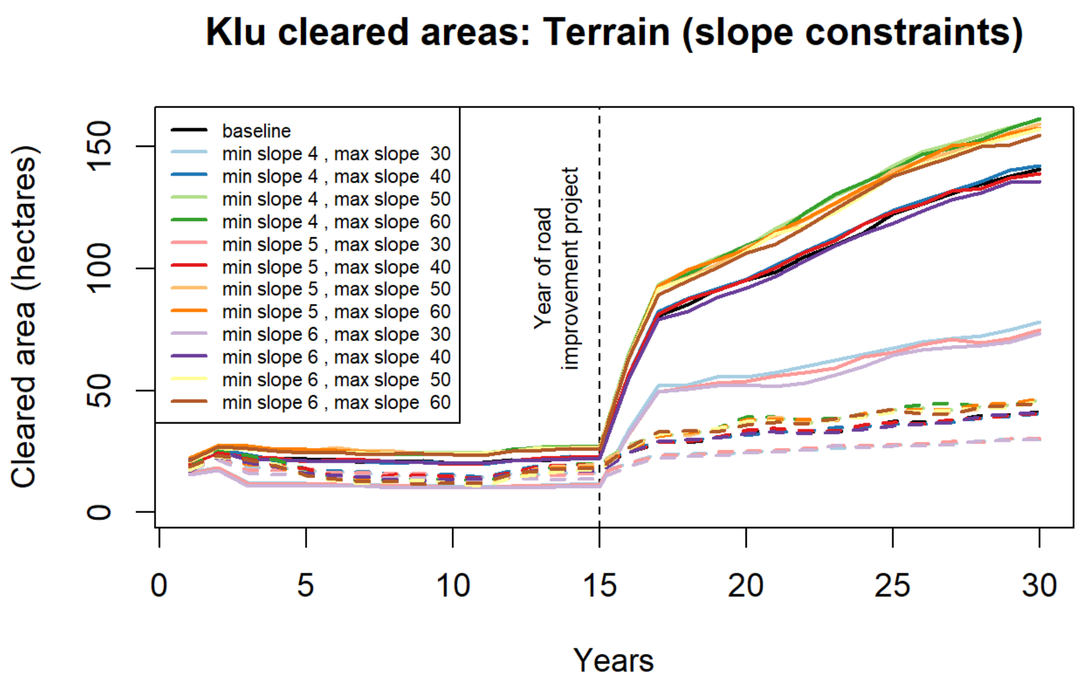


Figure 56: Agricultural clearings simulated via ABM inside and outside the road buffer zone (600m) for Klu village; generated in NetLogo v. 6.0.2, BehaviorSpace "Terrain Constraint (Slope)" experiment.

Varying the minimum and maximum allowable slope values from the normal constraints specific in the Baseline scenario (5 degrees and 40 degrees respectively) can exert a drastic effect on the land under cultivation. Predictably, higher maximum slope thresholds allow for the cultivation of more land area both inside and outside the road buffer zone. Similarly, lowering the minimum slope value allows for the cultivation of more land area. The most pronounced effect of the combinations tested appears to occur under the scenario with minimum slope values of 4-6 degrees and maximum slope value of 60 degrees (dark green line, dark orange, and yellow lines). Slight variations in minimum slope values appear to have limited effect as compared to the larger variation in maximum slope value. Conversely, lowering the maximum slope threshold and raising the minimum slope threshold both reduce the extent of lands available for cultivation. The most pronounced effect appears to result from enforcing a maximum slope value of 30 degrees (light blue, pink, and light purple lines), which results more than half of the land cultivated under the Baseline scenario being taken out of production.

3.5.2 Results for Ta Rec village

3.5.2.1 Baseline scenario

The baseline scenario for the village of Ta Rec was parameterized based on the business-as-usual scenario for shifting cultivation practices during the period prior to the Highway 9 upgrade (1991-2006), whereby households disperse randomly across the village landscape and clear suitable patches for a maximum of three-to-four years consecutively followed by moderately long fallow periods of ten years. As the model enters the sixteenth year, the road improvement project starts to trigger a shift in land-use, whereby households can now consider cash cropping based on the grey market price for hybrid cassava (K94) offered by brokers who visit the village. Households apply a decision-rule whereby the projected proceeds (i.e., revenue) from the sale of the anticipated cassava harvest (based on average yield) is compared against the household's annual rice cost (based on prevailing market prices for rice). If the former is greater than the latter, and the household has savings sufficient to cover one year of annual rice costs, as a minimum buffer to cover their survival in the event of a catastrophic harvest failure, the household deems cash cropping a worthwhile risk to assume for the given cultivation cycle and clears land inside the road buffer. In most cases, the household will also clear land and grow rice within the village boundary beyond the road buffer zone at a slightly reduced areal extent.

The overall change in simulated land-cover for the village landscape by cover-type, where only four basic cover types are represented, was as follows (Figure 57):

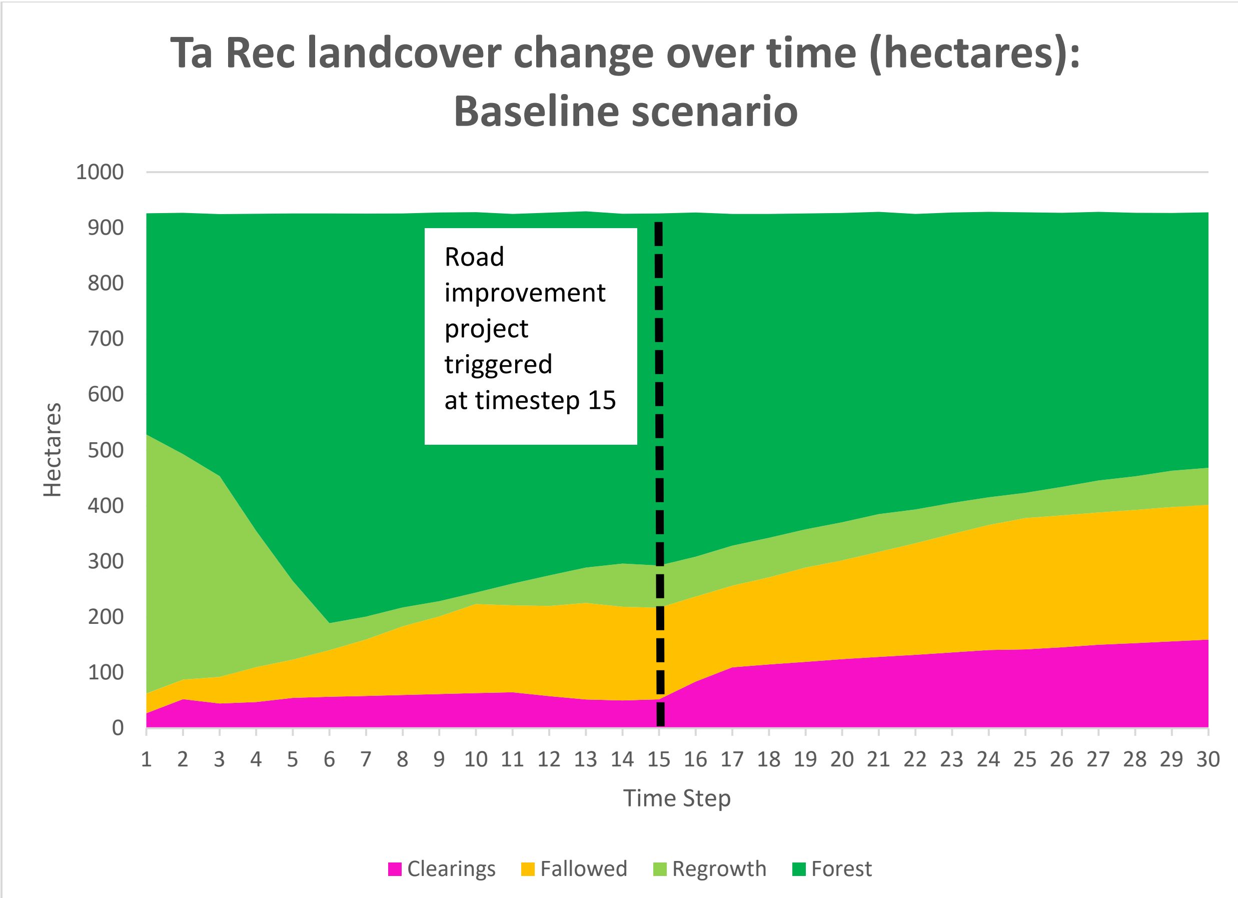


Figure 57: Overall change in land-cover over time by cover type (median values) for Ta Rec, Baseline scenario (30 runs)

There is a fairly steep decline in the extent of intermediate regrowth in the first six years of the model, concurrent with an increase fallowed area and forest. Through the remainder of the model run, the total extent of both agricultural clearings and fallowed areas increases, while forest area shrinks in extent and intermediate regrowth holds relatively steady.

Additional graphs allow for differentiating between land-cover changes occurring inside the road buffer vs. those occurring outside the road buffer, where relatively intensity of land-use shifts halfway through the model run. The following graph shows the total area cleared (hectares) per year over the 30-year period inside the road buffer (<350 meters), where dry rice cropping occurs in the first half of the model run and cash cropping occurs in the second half of the model run (Figure 58):

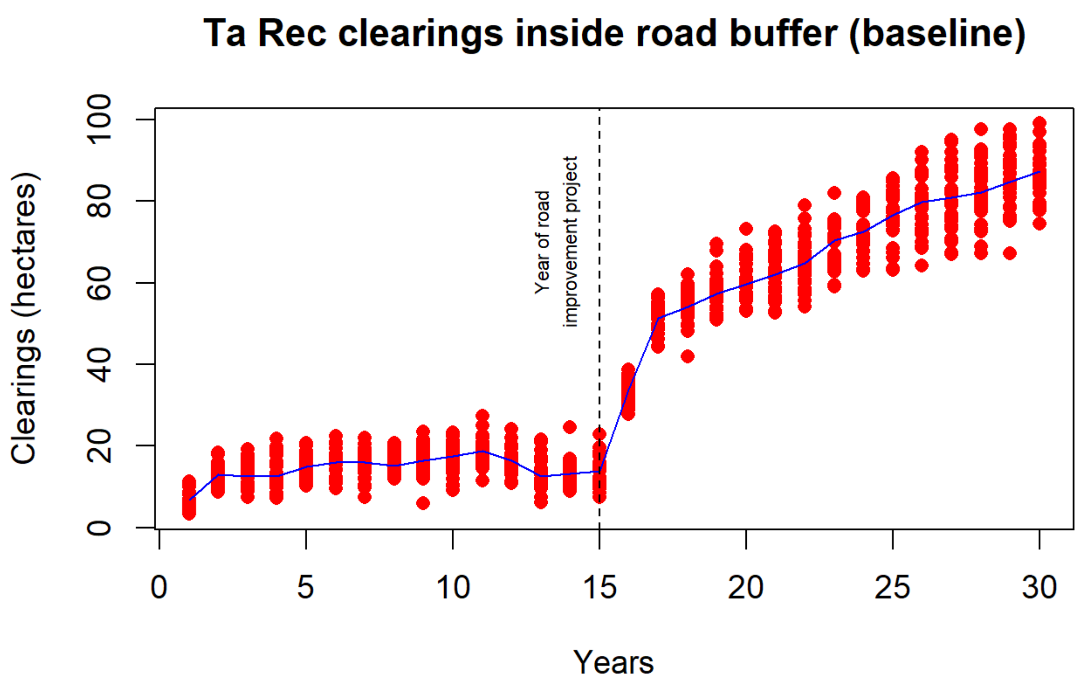


Figure 58: Agricultural clearings simulated via ABM inside the road buffer zone (350m) for Ta Rec village; generated in NetLogo v. 6.0.2, BehaviorSpace "Baseline" experiment (30 runs at 30 steps/run)

Agricultural clearings inside the road buffer (<350m from roads) during the period preceding the road improvement project (years 1-15), shows a relatively lower median values and a narrower range of values, as compared to the period following the road improvement project (years 16-30). There is a latency effect of at least one year, and possibly 2-3 years, due to model "spin-up" as households shift from subsistence to mixed mode of production (i.e., subsistence plus cash cropping). The overall change in simulated land-cover within the road buffer zone associated with this modeled land-use was as follows (Figure 59):

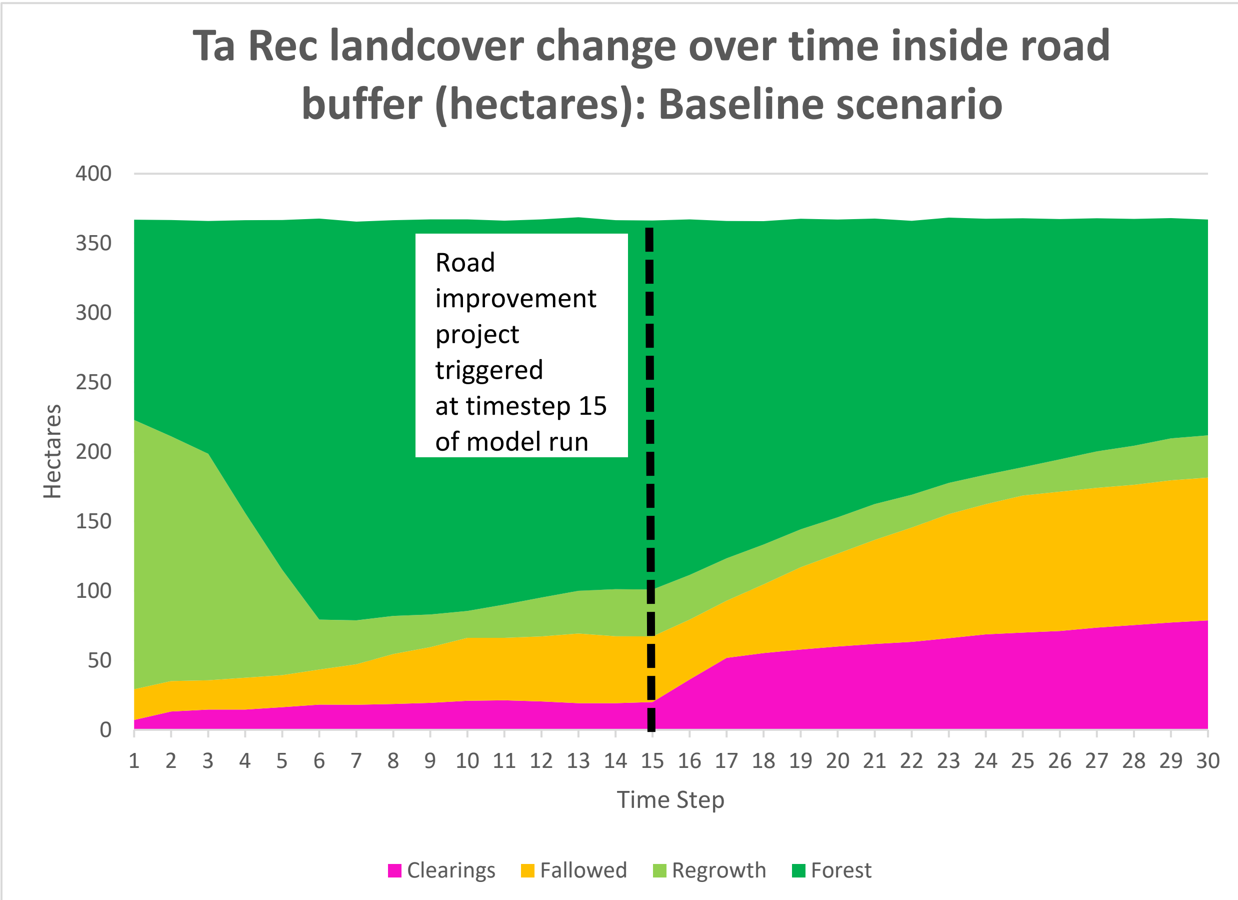


Figure 59: Change in land-cover inside road buffer zone over time by cover type (median values) for Ta Rec, Baseline scenario (30 runs)

There is a decline in the extent of intermediate regrowth in the first six years of the model, concurrent with a rise in forest and fallowed area. In the second half of the model run, increased agricultural clearings lead to further increases in fallowed areas and reductions in forest area, while the extent of intermediate regrowth holds relatively more stable. The following graph shows the total area cleared (hectares) per year over the 30-year period outside the road buffer zone, where only subsistence rice growing takes place (Figure 60):

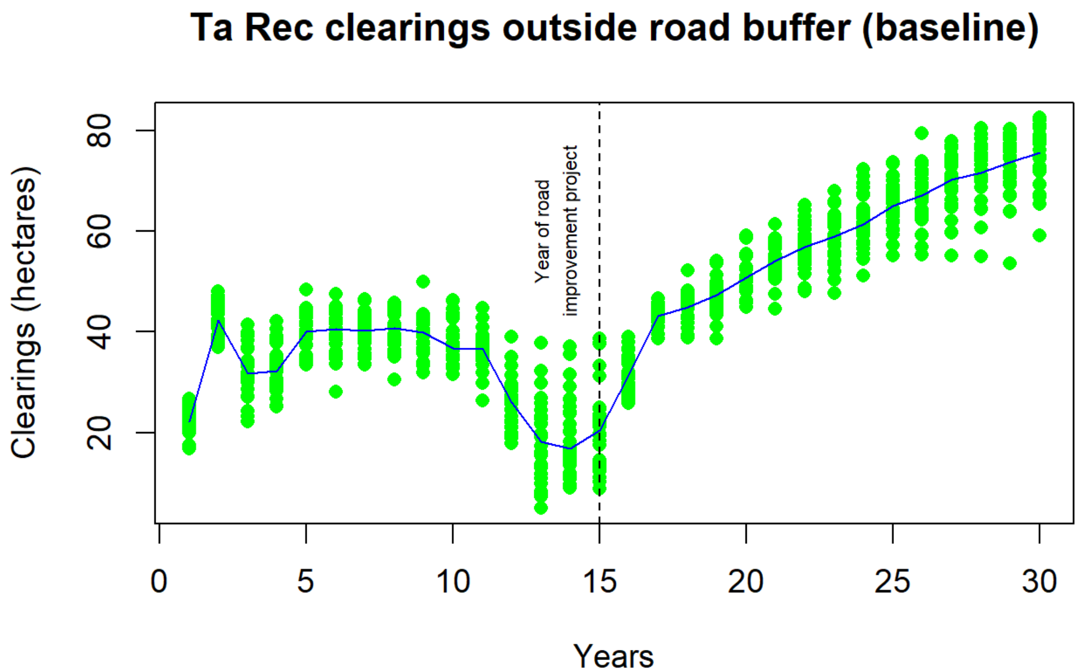


Figure 60: Agricultural clearings simulated via ABM outside the road buffer zone (350m) for Ta Rec village; generated in NetLogo v. 6.0.2, BehaviorSpace "Baseline" experiment (30 runs at 30 steps/run)

Agricultural clearings outside the road buffer during the period preceding the road improvement project (years 1-15), shows relatively lower median values and more interannual variability than the period following the road improvement project (years 16-30). The overall change in simulated land-cover outside the road buffer zone associated with this modeled land-use was as follows (Figure 61):

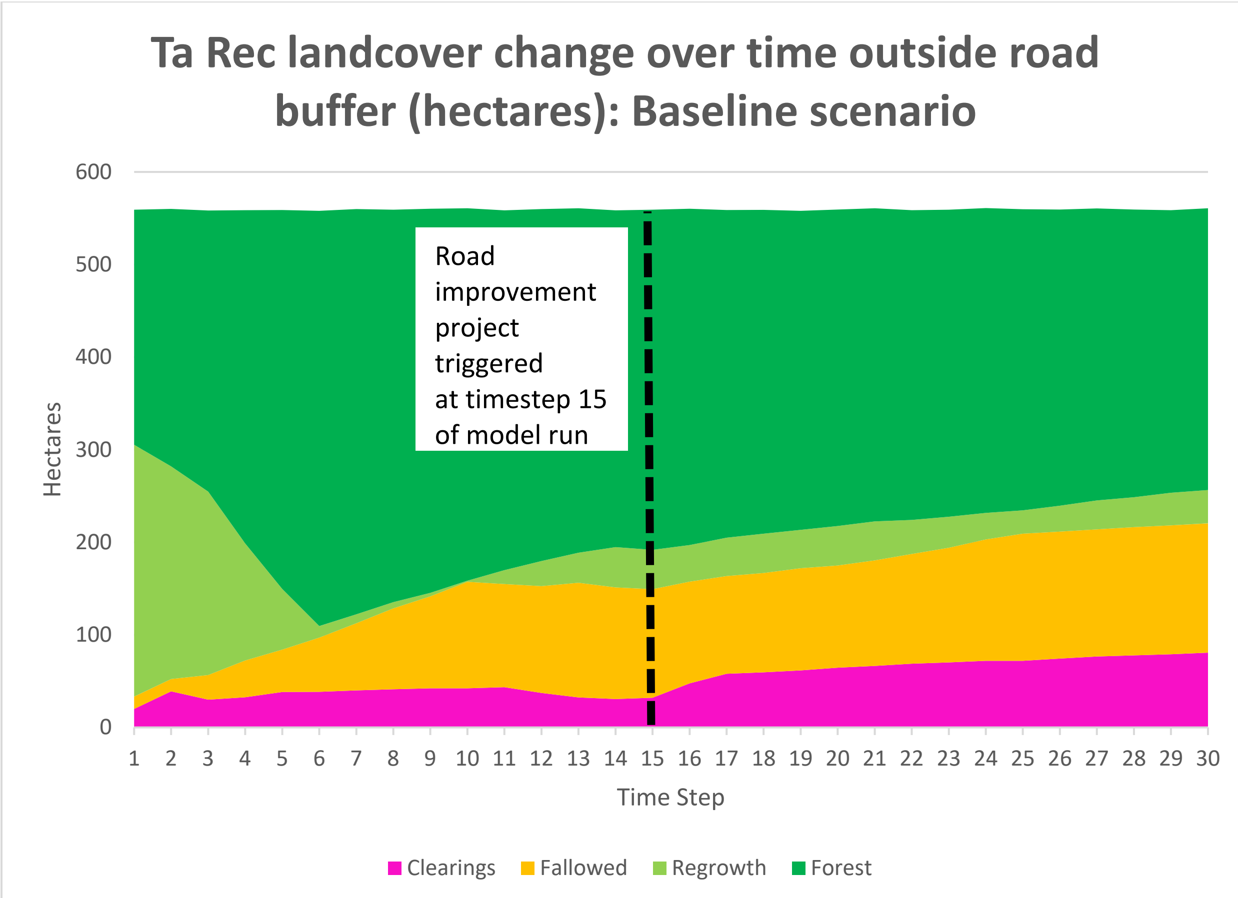


Figure 61: Change in land-cover outside road buffer zone over time by cover type (median values) for Ta Rec, Baseline scenario (30 runs)

There is a steep decline in the extent of intermediate regrowth during the first six years of the model run concurrent with rise in fallowed area and forest. In the second half of the model run, agricultural clearings and fallowed areas gradually increase and forest area gradually decreases, while intermediate regrowth holds relatively stable.

3.5.2.1 Results of BehaviorSpace experiments testing alternate scenarios

The following series of graphs depicts the differing effects regarding agricultural LULC, where each BehaviorSpace test is run 30 times per combination of variables with the random seeds set to the same value as the BehaviorSpace run number to make all model results fully replicable.

3.5.2.1.1 Agronomy

This experiment tests for varying years in consecutive use of patches under cultivation and minimum fallow lengths for patches taken out of cultivation. Results for nine scenarios tested (30 runs per scenario) were as follows (Figure 62):

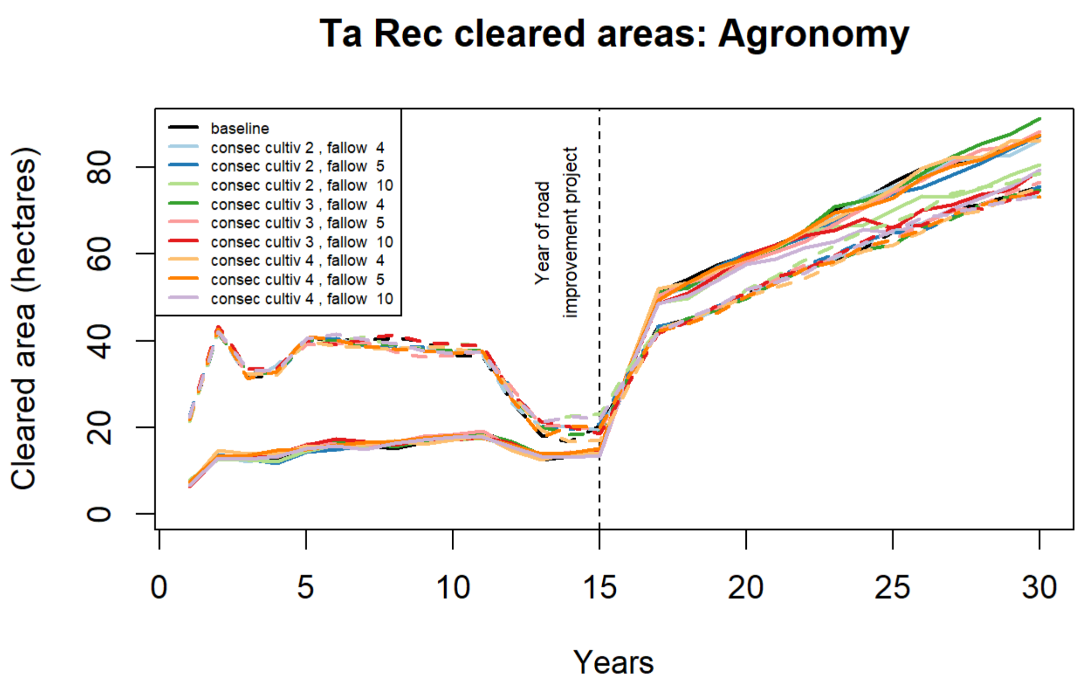


Figure 62: Agricultural clearings simulated via ABM inside and outside the road buffer zone (350m) for Ta Rec village; generated in NetLogo v. 6.0.2, BehaviorSpace "Agronomy" experiment.

Varying the duration of patch re-use and fallow length variables for cash cropping from those tested under the Baseline scenario results in land-cover outcomes result in differing impacts of cultivation on land-cover inside the road buffer zone (600m). The combination of the shortest cropping cycles (2 years) and shortest fallow period (4 years), rendered as a light blue line, results in more land being cleared inside the road buffer, whereas all scenarios testing long fallow lengths (10 years) show less land being cleared inside the road buffer. Intermediate scenarios where fallow length is held constant (5 years) show appear fairly closely aligned with the Baseline. Land-use outside the road buffer is not altered in this scenario and therefore land-cover outcomes hold constant to the Baseline scenario.

3.5.2.2.2 Climate variability

This experiment tests for increasing likelihood of extreme weather event (flood or drought). Results for the three scenarios tested (30 runs per scenario) were as follows (Figure 63):

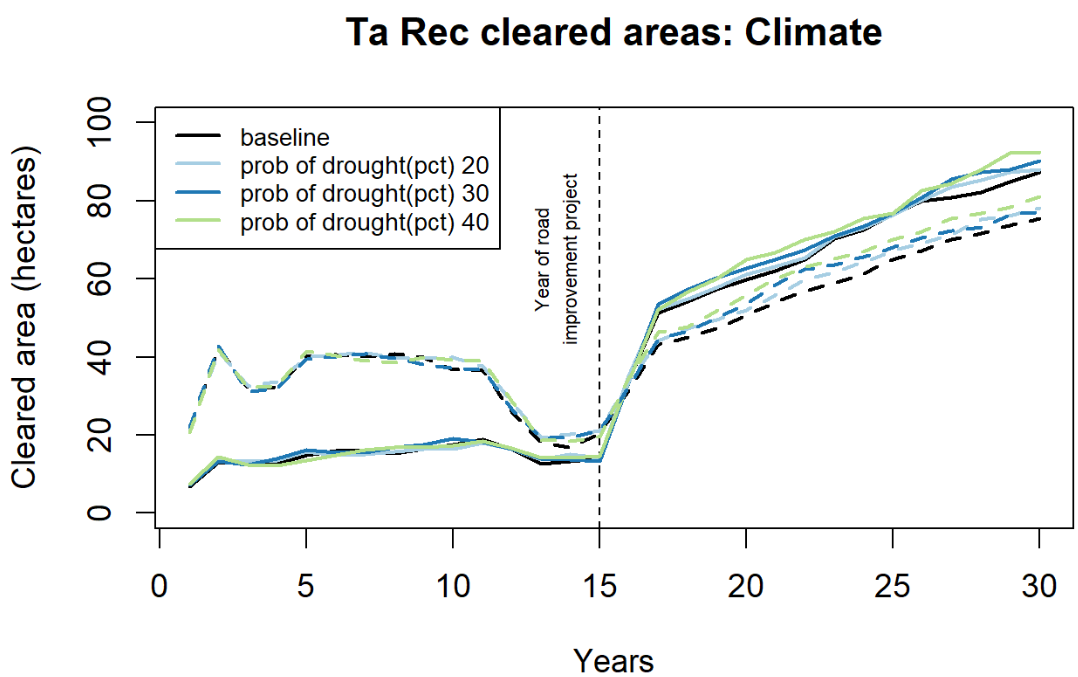


Figure 63: Agricultural clearings simulated via ABM inside and outside the road buffer zone (350m) for Ta Rec village; generated in NetLogo v. 6.0.2, BehaviorSpace "Climate Change" experiment.

Raising the likelihood of an extreme drought or flood event over those tested under the Baseline scenario results in land-cover outcomes that show slight increases over the Baseline values both inside and outside the road buffer. This result differs from the results observed for Klu village presented in the previous subsection.

3.5.2.2.3 Demography

This experiment tests for decreasing and increasing the initial number of households below and above the baseline value. Results for the five scenarios tested (30 runs per scenario) were as follows (Figure 64):

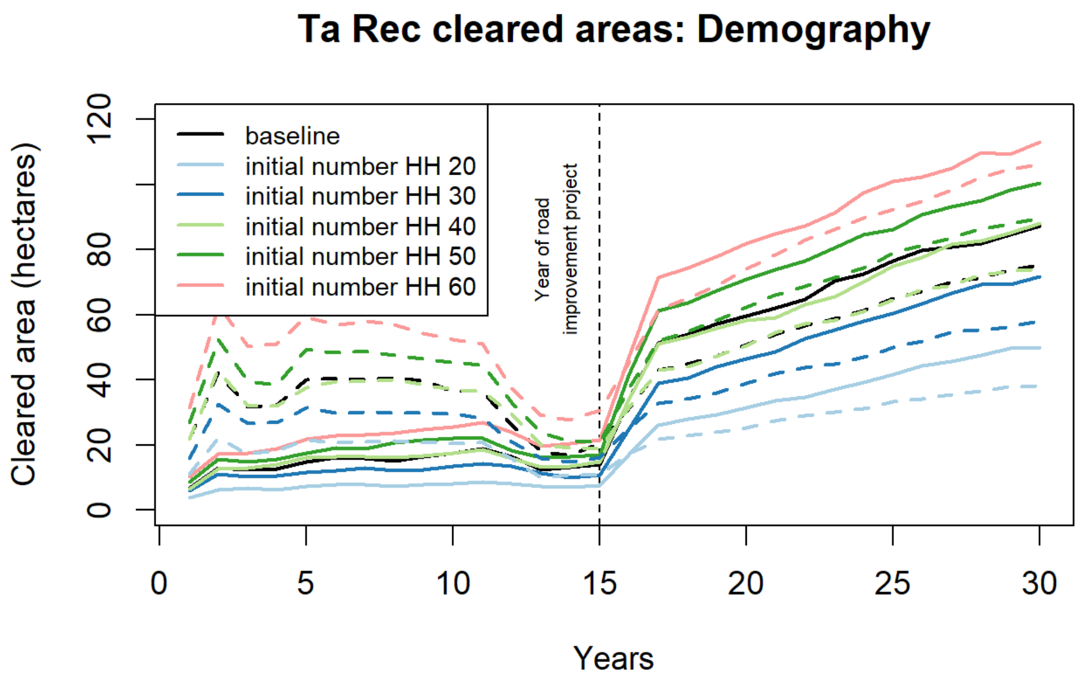


Figure 64: Agricultural clearings simulated via ABM inside and outside the road buffer zone (350m) for Ta Rec village; generated in NetLogo v. 6.0.2, BehaviorSpace "Demographics" experiment

Varying the initial population values low or high of the Baseline value (60 households) results in a proportional decrease or increase in the amount of land cleared vis-à-vis the Baseline scenario both inside and outside the road buffer zone (600m). The effect on total area cleared inside the road buffer is substantially larger than the impact upon the total area cleared outside the road buffer, which is a function of the default plot sizes being set at 8100 square meters vs. 6400 square meters respectively.

3.5.2.2.4 Market prices

This experiment tests for lowering and raising the market price for rice and the grey market price for cassava below and above the baseline value. Results for the nine scenarios tested (30 runs per scenario) were as follows (Figure 65):

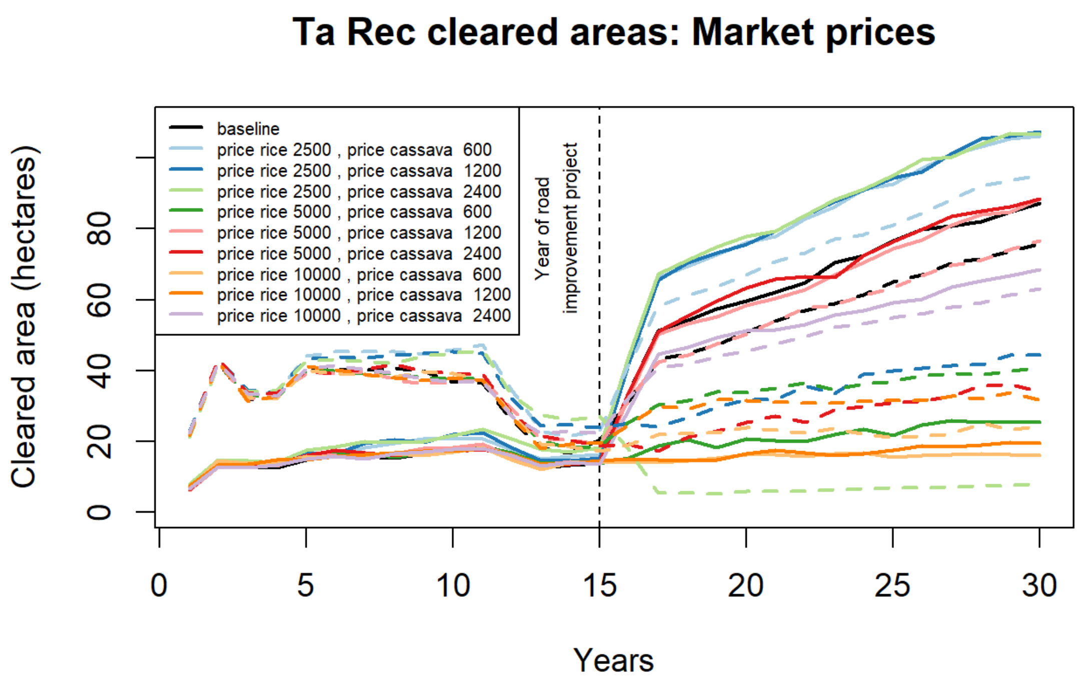


Figure 65: Agricultural clearings simulated via ABM inside and outside the road buffer zone (350m) for Ta Rec village; generated in NetLogo v. 6.0.2, BehaviorSpace "Market Prices" experiment.

Varying the prices of rice and cassava from the values tested under the Baseline scenario results in widely divergent outcomes in the extent of land area cleared both inside and outside the road buffer zone (i.e., < 600m / > 600m from roads). The most dramatic increase in area cleared inside the road buffer results from a 50% reduction in the cost of rice, which leads to an increase of approximately one-third increase in the intensity of cash cropping (light green and blue lines [solid]). Conversely, a reduction in land-use inside the road buffer of approximately one-third results from a 50% reduction in the price of cassava (dark green and orange lines [solid]). An intermediate case between this scenario and the Baseline results from the doubling of the price of rice (purple line [solid]). Noteworthy results on clearings outside the road buffer include the following:

(1) a pronounced decrease in area cleared where rice prices are halved and cassava prices are doubled (light green line [dashed]);

(2) a moderate decrease in area cleared where price of cassava is doubled while holding the price of constant (red line [dashed]) and where the price of rice is halved while holding the price of cassava constant (blue line [dashed]); and

(3) a slight increase in area cleared where the price of cassava is halved while holding the price of rice constant.

3.5.2.2.5 Terrain (Slope constraint)

This experiment tests for lowering and raising the allowable slope range of village lands for agricultural clearing / cultivation. Results for the 12 scenarios tested (30 runs per scenario) were as follows (Figure 66):

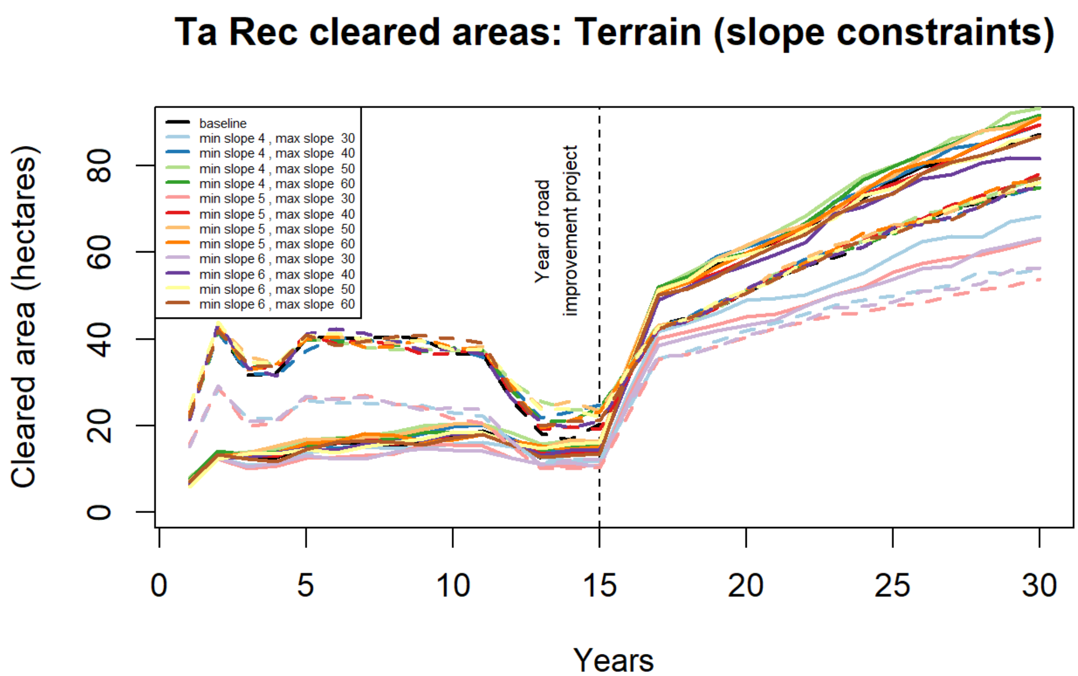


Figure 66: Agricultural clearings simulated via ABM inside and outside the road buffer zone (350m) for Ta Rec village; generated in NetLogo v. 6.0.2, BehaviorSpace "Terrain Constraint (Slope)" experiment.

Varying the minimum and maximum allowable slope values from the normal constraints specific in the Baseline scenario (5 degrees and 40 degrees respectively) can exert a drastic effect on the land under cultivation. Predictably, higher maximum slope thresholds allow for the cultivation of more land area both inside and outside the road buffer zone. Similarly, lowering the minimum slope value allows for the cultivation of more land area. The most pronounced effect of the combinations tested appears to occur under the scenario with minimum slope values of 4-6 degrees and maximum slope value of 60 degrees (dark green line, dark orange, and yellow lines). Slight variations in minimum slope values appear to have limited effect as compared to the larger variation in maximum slope value. Conversely, lowering the maximum slope threshold and raising the minimum slope threshold both reduce the extent of lands available for cultivation. The most pronounced effect appears to result from enforcing a maximum slope value of 30 degrees (light blue, pink, and light purple lines), which results more than half of the land cultivated under the Baseline scenario being taken out of production.

3.6 Discussion – Baseline scenario and BehaviorSpace experiments

3.6.1 Baseline results assessment

The main findings of testing performed to date using this spatially-explicit, agent-based simulation model under the Baseline (i.e., "business-as-usual") scenario fall into two general categories – expected and emergent behaviors.

3.6.1.1 Expected behaviors

With regard to expected behaviors, the Baseline scenario for this model exhibits the following general trends:

(1) a relatively consistent pattern of dispersed land-use for the first half of the model run (years 1-15, representing the years 1991-2006);

(2) a steady increase in cultivation inside the road buffer zone in the second half of the model run (years 16-30), which is associated with the cash cropping of cassava; and

(3) a persistence of rice cropping (years 16-30) at a slightly reduced level per household outside the road buffer zone.

This result is consistent with the more extensive footprint of subsistence-oriented production for the period before the road upgrade, during which households show no preference based on patch distance to roads, as proximity confers no advantage to the household (i.e., is not a rational behavior). Conversely, under the mixed mode of production associated with partial market integration in the period following the road upgrade, households tend to concentrate clearings closer to roads for cultivating cash crops, due to the extremely bulky nature of cassava that must be transported by third parties (i.e., preference for proximity to roads is now a rational response to markets). This results in a more intensive pattern of cultivation inside the road buffer zone (<350m for Ta Rec / <600m for Klu). Concurrent with this cash cropping nearer to roads, subsistence-oriented production is displaced outwardly toward the periphery of the village.

The overall area under cultivation increases for both zones in the second half of the model run, despite slightly smaller patch sizes for both crops (where households are typically cropping both cassava and dry rice). This is attributable primarily to a relatively steady but varying increase in the total number of households. The growth in the overall village population is an inherent property of household fissioning, whereby the number of households approximately doubles over a period of 25-30 years, which is a doubling timeframe consistent with an average household size of 5 persons (i.e., 3 children). However, population does not operate in isolation from other factors, several of which contribute to emergent properties in land-use and land-cover change.

3.6.1.2 Emergent behaviors

In addition to population, the magnitude of the collective impact of the village on the overall landscape is also a function of interactions occurring at the village and household level with the following stochastic processes:

(1) varying household cropping behavior preferences, based on relative advantage of cash cropping as compared to a household's annual rice cost, under conditions of continual fluctuations in the prices of cassava and rice simulated at each time step;

(2) varying patch counts by household by cropping type based on household cashbox level relative to annual household cost of rice (a break-even decision factor);

(3) varying fertility levels of landscape patches under cultivation; and

(3) the random occurrence, however infrequent, of a severe climate event (i.e. drought / flood).

With regard to prices, the prices of cassava and rice both apply uniformly to all households per step of the model, but the price of both crops varies from one timestep to the next within a window based on random-normal distributions. These variations in price alter the relative profitability of growing cassava. The relative profitability of growing cassava influences the choice of cropping behaviors, where it can induce a household to change from mixed mode (i.e., cassava and rice) to a single model (i.e., cassava-only or rice-only).

With regard to crop yields, these are also set to vary within a window based on random-normal distributions under both normal climate and severe climate conditions. Additionally, yields also vary based on the fertility of the patches under cultivation, and the fertility of the landscape is continually changing as a function of cultivation and fallowing. Furthermore, the number of patches being cultivated varies by household, with lower cashbox levels inducing a preference for allocating more land and labor toward rice cropping and higher cashbox levels inducing a preference for allocating more land and labor toward cassava cropping. Finally, the occurrence of a severe climate event (i.e., flood or drought) is also a random occurrence that impacts upon households by causing a reduction in yields of 50%.

The interaction of these variables continually alters both prices and yields, which in turn alter the profitability of cash cropping and cashbox levels, on a per timestep basis. Prices, yields, and cashbox levels in turn factor into decision-making in the subsequent timestep of the model. The intensity of cropping of both cassava and rice in the second half of the model run are thus emergent properties of fluctuating prices, yields, and cashbox levels and influence their cropping behavior (i.e., bidirectional feedback loop).

To the extent that prices and yields remain constrained within a random-normal distribution, cashbox levels tend to rise over time throughout the second half of the model run to levels much higher than the annual cost of rice, which holds relatively constant over time. This upward trajectory in household cashbox levels occurs even with a percentage of the household cashbox being deducted per model step for basic cost of living, with a default value set at 25%.

3.6.2 BehaviorSpace results assessment

The testing of various alternative scenarios to the Baseline – agronomy, climate, demography, market prices, and policy constraints on sloping terrain - appear to suggest that several variables influence the collective response of the community in terms of its land-use practice and the resulting pattern of land-cover relative to the typical trajectory of the Baseline scenario. All other things being equal, i.e., holding other variables in the model constant, the following three variables appear to exert moderate to high levels of influence on landcover change by altering agricultural land-use decision-making / behavior at the household level:

(1) market prices (i.e., farmgate price for selling cassava and market price for buying rice);

(2) policy constraints on sloping terrain (i.e., allowable slope range); and

(3) population (i.e., number of households, holding average household size constant).

3.6.2.1 Assessing the influence of changing Market Prices on modeled LULC change

Market prices appear to strongly influence landcover relative to the Baseline scenario. When the price of cassava increases and the price of rice is held constant or decreases, there is an increase in cash cropping, manifested by increase land clearing inside the road buffer zone, relative to the Baseline scenario. This is a predictable, rational response by the household to focus its efforts on growing the crop that is in relatively higher demand based on market pricing, e.g., when cassava prices spike and the price of rice is held constant or reduced, it behooves the household to reallocate labor toward cash cropping and the cultivation of rice drops well below the baseline level. In the opposite scenario, i.e., where rice prices increase while the price of cassava is held constant or decreases, households reallocate labor toward subsistence cropping. This behavior comports with a von Thünian logic of agricultural resource management. where higher prices for cash crops and lower transportation costs contribute to increased land-rent, thereby making land-use in the "first ring" a rational location for the "free cash cropping" land-use scenario, as first postulated by von Thünen nearly 200 years ago. It also bears noting that the scenario wherein the prices of both cassava and rice are doubled show the dampening effect of higher rice prices overriding the higher price of cassava.

These various outcomes of this BehaviorSpace experiment are summarized below (Table 10):

Table 10: Simulated LULC impacts of changing market prices

Rice		**Cassava**			
Direction of change in price	**Magnitude of change in price (%)**	**Direction of change in price**	**Magnitude of change in price (%)**	**Direction of LULC change (inside road buffer)**	**Direction of LULC change (outside road buffer)**
Reduced	50	Reduced	50	Increased area cleared	Increased area cleared
Reduced	50	Held constant	0	Increased area cleared	Decreased area cleared
Reduced	50	Increased	100	Increased area cleared	Decreased area cleared
Held constant	0	Reduced	50	Decreased area cleared	Comparable to baseline
Held constant	0	Held constant	0	NA (Baseline scenario)	NA (Baseline scenario)
Held constant	0	Increased	100	Increased area cleared	Decreased area cleared
Increased	100	Reduced	50	Decreased area cleared	Decreased area cleared
Increased	100	Held constant	0	Decreased area cleared	Comparable to baseline
Increased	100	Increased	100	Decreased area cleared	Comparable to baseline

If correlations can be established between market prices for staple grains (i.e., primarily rice and secondarily maize) and cash crops (i.e., primarily cassava and secondarily acacia) and land under production for a given cropping cycle, this would better inform modeling efforts. Rice prices are particularly important to the relative socio-economic well-being of households. As noted by Hoang et al. (2016: 132): "A notable proportion of agricultural households in emerging markets rely on rice as consumers and/or as producers. It is also well documented that changes in rice prices, output, and productivity play critical roles in rural household welfare." Much of the rural upland population have existed historically at or below the poverty line, which was set by the Vietnamese GSO at 2,559,000 VND (approximately US$160) as of January 2006, prior to the highway improvement project (Hoang et al. 2016).

Applying the land rent equation ($r = py - wl - qk – vd$) per Angelsen (2010) to a highly simplified scenario, where land has two possible cropping uses (dry rice or hybrid cassava, i.e., K94), to estimate revenues, costs, and net profit can inform a basic assessment of the comparative value of land, as a proxy for agricultural land rent. With the caveat that the numbers used here are not authoritative, but rather are taken from fieldwork in a small subset of villages along the EWEC adjacent to or near Highway 9, the following is a very approximate breakdown of the relative bottom line for cropping rice vs. cassava, where the household weights the costs of having to buy its annual rice supply against net revenue of cassava (Table 11).

Table 11: Simplified comparison of dry rice vs. hybrid cassava market values, based on fieldnotes (Leisz et al. 2014)

	Crop	Dry rice	Cassava
	Area planted (ha)	0.5	0.5
Revenue	Mean Price (VND per KG)	5000	1200
	Average yield (KG)	1200	10000
	Max. yield (KG)	1875	12500
	Ave. revenue (VND)	6000000	12000000
	Max. revenue (VND)	9375000	15000000
	Ave. revenue / annualized (VND)	6000000	12000000
	Max. revenue / annualized (VND)	9375000	15000000
Costs	Wage (VND)	0	0
	Labor	0	0
	Capital required per hectare	0	1225000
	Annual cost of capital	0	1
	Cost/KM	0	0
	Distance to market	0	0
	Net Costs	0	1225000
Profit/rent	"Average" (VND)	6000000	10775000
	Max (VND)	9375000	13775000

Under this scenario, the anticipated profit on an average yield of cassava sold by a household at the prevailing farmgate price would substantially exceed that of rice, if a household had to purchase that rather than growing. In reality, villagers would not abandon rice cropping for socio-cultural reasons, but assuming sufficient labor were available at the household level, for which wages need not apply, cultivating cassava is a viable option with considerable revenue potential and minimal cost outlays (i.e., other than the direct costs of purchasing stems to plant and any optional inputs, e.g. fertilizer, since irrigation is not necessary).

In reality households do have other cash cropping choices, e.g., agroforestry options such as acacia, which entails some startup capital costs in the form of seedlings but can also yield substantial profits comparable to cassava and unlike cassava entails a fairly large delay of five years from planting to harvest, even under fast growing conditions (Leisz et al. 2014). The nitrogen fixation of acacia when intercropped with rice can provide for an improved fallow, however, as compared with monocropping (Leisz et al. 2014).

3.6.2.2 Assessing the influence of Terrain Constraints on modeled LULC change

With regard to constraints on sloping terrain, that could be imposed by policymakers under the guise of forest conservation (e.g., the VCP setting an upper limit on maximum allowable slope below that customarily used by the local population), the imposition of such constraints reduces the overall area accessible to households by taking land out of production. The effect can be seen in figures in the previous section for the villages of Klu and Ta Rec (Figure 42 and Figure 66), which show the drastic effect of decreasing maximum allowable slope to 30 degrees, where the upper limit on slopes under cultivation is normally ~ 40 degrees. The amount of land that can be cleared under this 30-degree slope scenario is markedly reduced, highlighting the potential adverse impacts of government policies on the socio-economic condition of these communities.

Conversely, completely relaxing this constraint to allow cultivation on any slope in the village boundary shows the opposite outcome, where lands formerly off-limits to cultivation would be cleared. This simulated outcome is perhaps contrary to real world conditions, where such clearings would be unlikely due to the extreme difficulty of clearing slopes greater than 50 degrees. Even if this were physically possible, such practice could undermine long-term sustainable land-use practice, a consideration beyond the scope of the current version of the village models).

3.6.2.3 Assessing the influence of Population on modeled LULC change

With regard to population levels, there is a clear directional trendline under this scenario for the villages of Klu and Ta Rec, as can be seen in figures in the previous section (Figure 54 and Figure 64). As initial population levels are lowered or raised relative to the Baseline values for both villages, the amount of land area cleared both inside and outside the road buffer zone decreases or increases in direct proportion. This scenario has little real-world relevance, as the villages under consideration have not experienced any significant fluctuations in overall population due to net in-migration or out-migration flows during the time period under consideration, contrary to other places and time periods where the national government engaged in resettlement under their efforts to encourage fixed settlement of upland ethnic minority populations in the post-war period and/or efforts to encourage ethnic Kinh to leave lowland areas and settle among upland minority communities under a policy to ostensibly promote solidarity and brotherhood (McElwee 2008). On a more practical note, the model as currently built and tested applies uniform size to the initial state of households across the village as a whole, when in reality initial household size would vary within some range of the mean.

3.6.2.4 Assessing the influence of agronomy on modeled LULC change

Regarding other scenarios tested, the influence of slightly modified agronomic practices (i.e., patch re-use and fallow length) appeared to show relatively minor impacts on landcover outcomes for the villages of Klu and Ta Rec (Figure 52 and 62), where medium-long fallows (defined here as 10 years) reduce the total area under cultivation and shorter fallows (3-4 years) slightly increase the area of land under cultivation relative to the baseline value. In order to explore the relative influence of these variables, additional testing across a wider range of values should be explored, including for testing over longer temporal durations (i.e., beyond 30 timesteps). Much of the literature on shifting cultivation has established the importance of adequate fallow length for maintaining and restoring soil fertility essential to the sustainability of shifting cultivation land-use systems (Brown 2008). The shortening of fallow length associated with increasing patch re-use has been a well-studied phenomenon for over 40 years (Coppock & Ruthenberg 1973).

3.6.2.5 Assessing the influence of Climate Variability on modeled LULC change

With regard to climate, the results of BehaviorSpace testing show inconclusive results for the village of Klu (Figure 53) and modest effects for the village of Ta Rec (Figure 63). With regard to Ta Rec, the increase in the likelihood of extreme weather (i.e., drought or flood) causing lost agricultural yields due to crop damage and lost harvest predictably causes an increase in the amount of land cleared for agriculture.

As the occurrence of such events is random under the simulation modeling scenario, additional testing over longer timeframes might help to better discern impacts for the villages being simulated. Such simulation testing could incorporate temperature and precipitation as discrete variables, rather than using one catchall variable for climate, since changing seasonal patterns of rainfall and temperature could have large implications for human and landscape agents, affecting both agricultural practices and the regeneration rates for different land-cover types.

3.7 Discussion of model quality and reliability

Assessing the quality and reliability of an agent-based model typically involves three general processes: validation, verification, and replication. Validation is defined as "the process of determining whether the implemented model corresponds to, and explains, some phenomenon in the real world" (Wilensky & Rand 2015: 311). Verification is defined as "the process of determining whether an implemented model corresponds to the target conceptual model" (Wilensky & Rand 2015: 311). Replication is defined as "the implementation by one researcher or group of researchers of a conceptual model previously implemented by someone else" (Wilensky & Rand 2015: 312)

This section is concerned with validation. As averred by Wilensky and Rand: “Validation, by its nature, is complex, multilevel, and relative” (2015: 321). Various approaches have been taken for validating models. According to Latombe et al. (2011: 1557), there is a “lack of a standard framework for developing, communicating and testing” agent-based / individual-based models. Many approaches to validation apply statistical methods to assessing locational accuracy (van Vliet et al. 2016). Examples include fractal analysis (Mandelbrot 1982), Kappa test for “image similarity” (Gilruth et al. 1995), Multiple Resolution Goodness of Fit (Costanza 1989), nearest neighbor indices (NNI) (Campbell 1995), and relative operating characteristic (ROC) (Pontius and Schneider 2001). More recent efforts to assess model quality and reliability take a more holistic approach focused on the entire modeling process including conceptual development, data development, implementation, output verification, and sensitivity analysis. Examples include “pattern-oriented modeling” (Magliocca & Ellis 2013) and the “evaludation” framework (Augusiak et al. 2014). The latter includes a structured documentation process called “TRACE” (Grimm et al. 2014).

The analysis presented here focuses on “macrovalidation” as opposed to “microvalidation.” The former is “the process of ensuring that the aggregate, emergent properties of the model correspond to aggregate properties in the real world” (Wilensky & Rand 2015: 326). The latter entails “making sure the behaviors and mechanisms encoded in the agents in the model match up with their real-world analogs” (Wilensky & Rand 2015: 326). Both “microvalidation” and “macrovalidation” can be performed at two levels of detail: “face validation” and “empirical validation”. The former is a subjective process to show general agreement. The latter compares model outputs against real world observations and is therefore considered more objective. Modeled outputs of agricultural clearings are compared against those derived from satellite imagery to gauge relative level of (dis)agreement between these two sets of data. The discussion taken here focuses on “macrovalidation” which is provided at two levels: face and empirical.

3.7.1 Face level “macrovalidation”

“Face” level validation “helps ensure that someone who looks…without detailed analysis can easily be convinced that the model contains elements and components the correspond to agents and mechanisms that exist in the real world.” Face level validation typically involves an assessment of the model animation with attention to agent behaviors in the aggregate, an immersive assessment focused on an individual agent in the model, and an assessment of outputs in terms of acceptability of the range of values resulting from the model (Ngo & See 2012).

Due to space constraints and for expedience, the section presents a visual assessment of modeled land-cover outputs against land-cover outputs derived from satellite imagery. It suggests that while disparities exist, the simulation model approximates land-use systems of shifting cultivation of dry rice and cash cropping of cassava *reasonably well* and produces a pattern of landcover bearing a *general level of resemblance* to that found in satellite imagery. Disparities are attributable partly to constraints inherent in NetLogo, e.g. compromises and simplifications required to implement this simulation model in this software platform, as well as limits in ability to make decision-making and behavior fully explicit due to gaps in knowledge of social dynamics (e.g., kinship and the dynamics of collective interaction at the village level).

3.7.1.1 Face level “macrovalidation” for Klu village

Under the Baseline scenario, simulation results for the modeled landscape of Klu village consistently show a preponderance of cultivation along both sides of the road buffer (< 600m) for cassava, with clearings for dry rice concentrated in the northern half of the village (Figure 67).

Distributional disparities between simulated outputs and observed pattern may be partly attributable to the fact that NetLogo code execution appears to be consistently orienting household agents in a northerly direction due to the pseudo-random nature of “random” number generation. The may cause households to survey the landscape preferentially in one zone of the village when selecting patches to clear for cultivation. Additionally, NetLogo performs household execution serially, meaning that patch selection recurs in a similar order from one timestep to the next, with the first household establishing where group members will cluster. The combination of directional bias and serial execution tends to create recurring patterns on the landscape with emergence in land-cover arising from the introduction of new households to the model.

When the model is run with all parameters specified the same as the Baseline except for the road improvement project being disabled, the model functions in subsistence-only mode yielding a more dispersed pattern of land-cover emerges at the end of the model run (30 time steps) (Figure 68). With regard to households, the end-state population counts are similar to the Baseline, i.e., no issues emerge regarding household fissioning under conditions of subsistence-only production. With regard to the landscape, the end-state land-cover map shows no preference for cropping near the road and a much lower overall level of clearing.

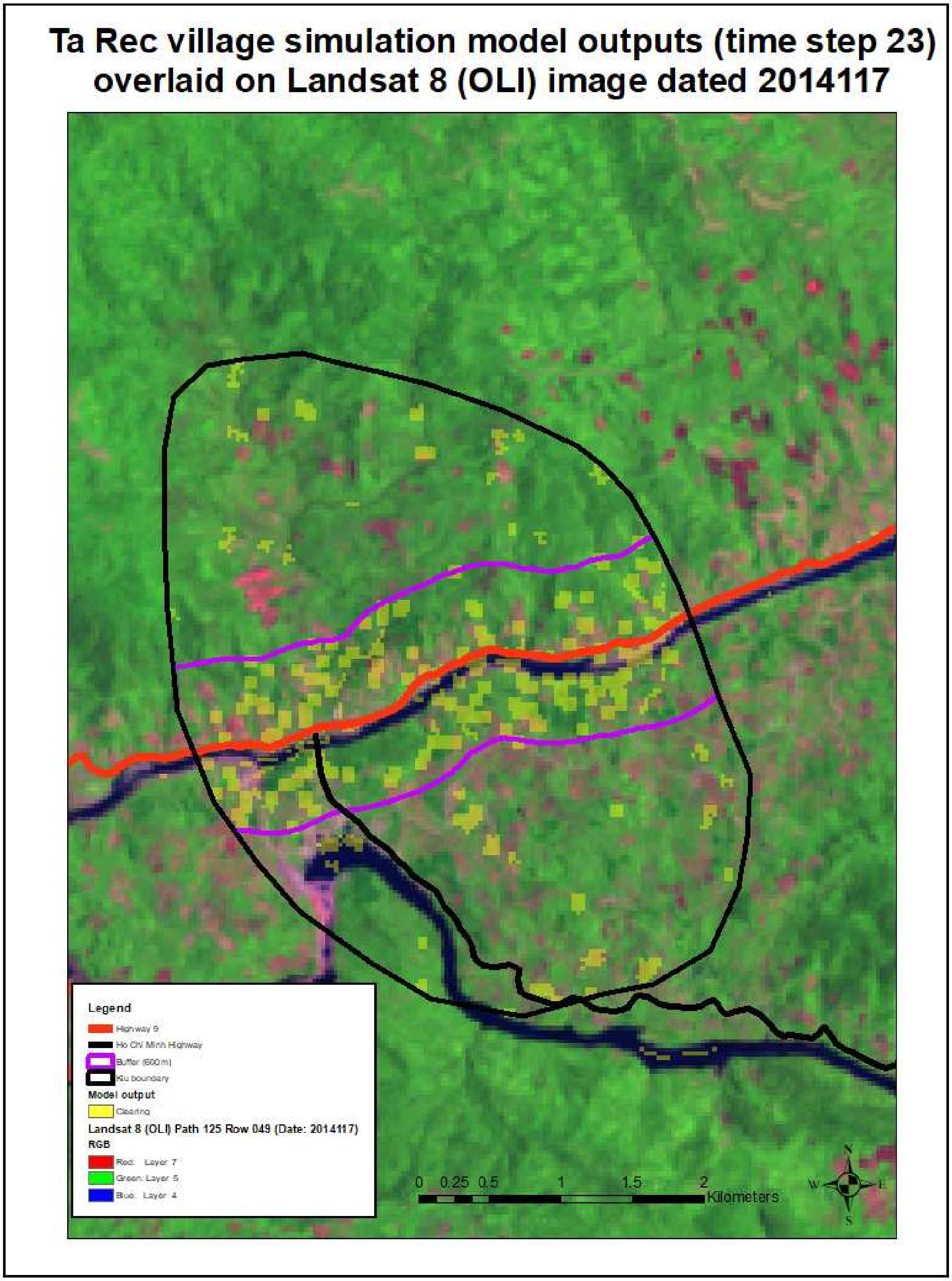


Figure 67: Simulated agricultural land-use in Klu village at time step 23 of model run (Baseline scenario with road improvement enabled) overlaid on April 2014 Landsat 8 (OLI) imagery. Yellow represents cleared areas generated by model output. Reddish and pinkish hues on landscape represent actual clearings.

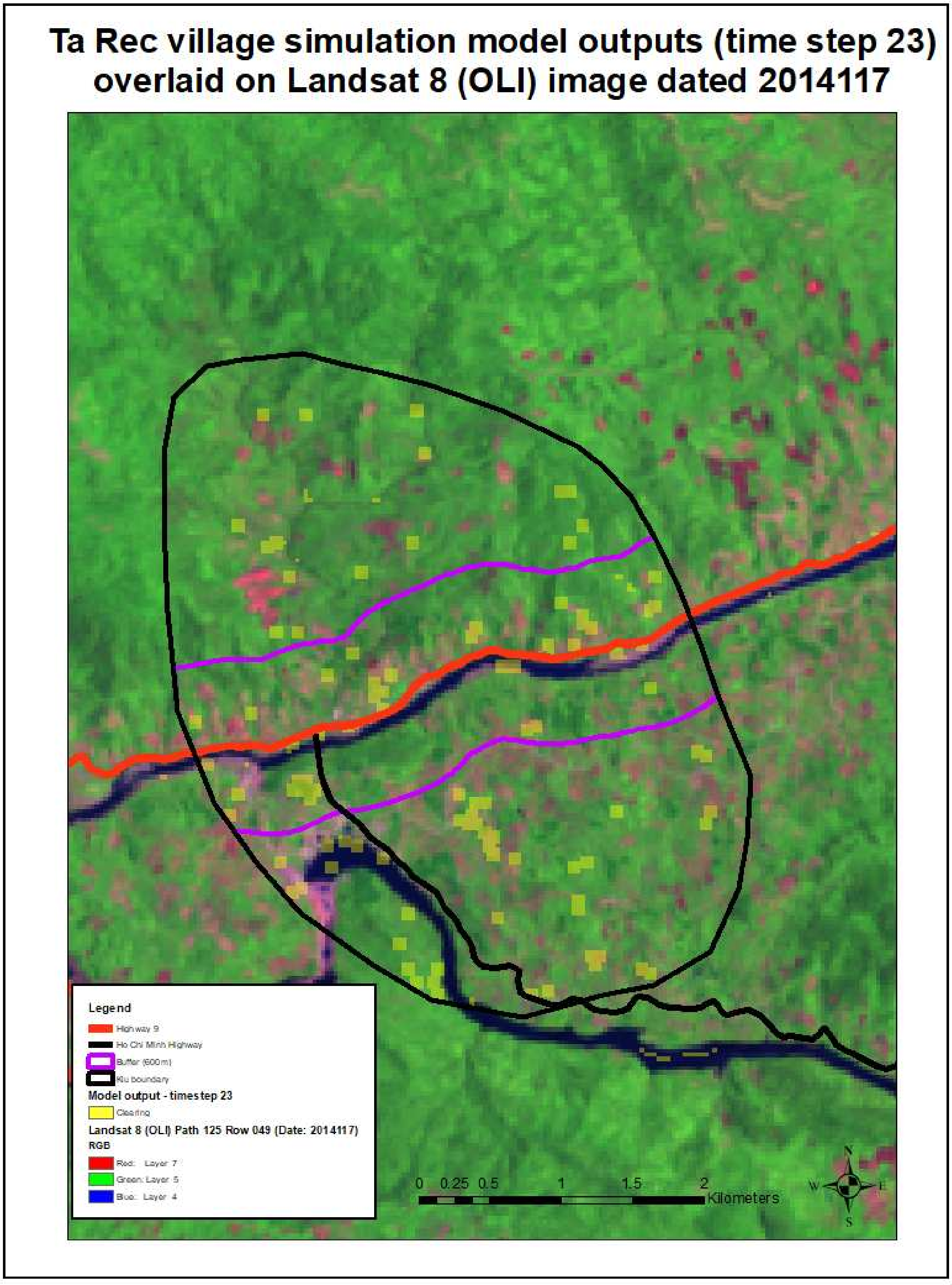


Figure 68: Simulated agricultural land-use in Klu village at time step 23 of model run under subsistence-only (Baseline scenario with road improvement disabled) overlaid on April 2014 Landsat 8 (OLI) imagery. Yellow represents cleared areas generated by model output. Reddish and pinkish hues on landscape represent actual clearings.

3.7.1.2 Face level "macrovalidation" for Ta Rec village

Under the Baseline scenario, simulation results for the modeled landscape of Ta Rec village consistently show a generally symmetrical distribution of clearings for both cassava (< 350m to road) and dry rice (>350m to roads) (Figure 69). While these distributions are somewhat discrepant, this is attributed partly to the household agents in NetLogo giving equal weight to the road segments, whereas in reality the villagers appear to show preference for roads closer to the primary north-south Ho Chi Minh highway. The possible influence of other biophysical and socio-economic factors warrants further exploration.

When the model is run with all parameters specified the same as the Baseline *except for* the road improvement project being disabled, the model functions in subsistence-only mode yielding a more dispersed pattern of land-cover emerges at the end of the model run (30 time steps) (Figure 70). With regard to households, the end-state population counts are similar to the Baseline, i.e., no issues emerge regarding household fissioning under conditions of subsistence-only production. With regard to the landscape, the end-state land-cover map shows a much lower level of clearing and no indication of household preference for cropping near the road.

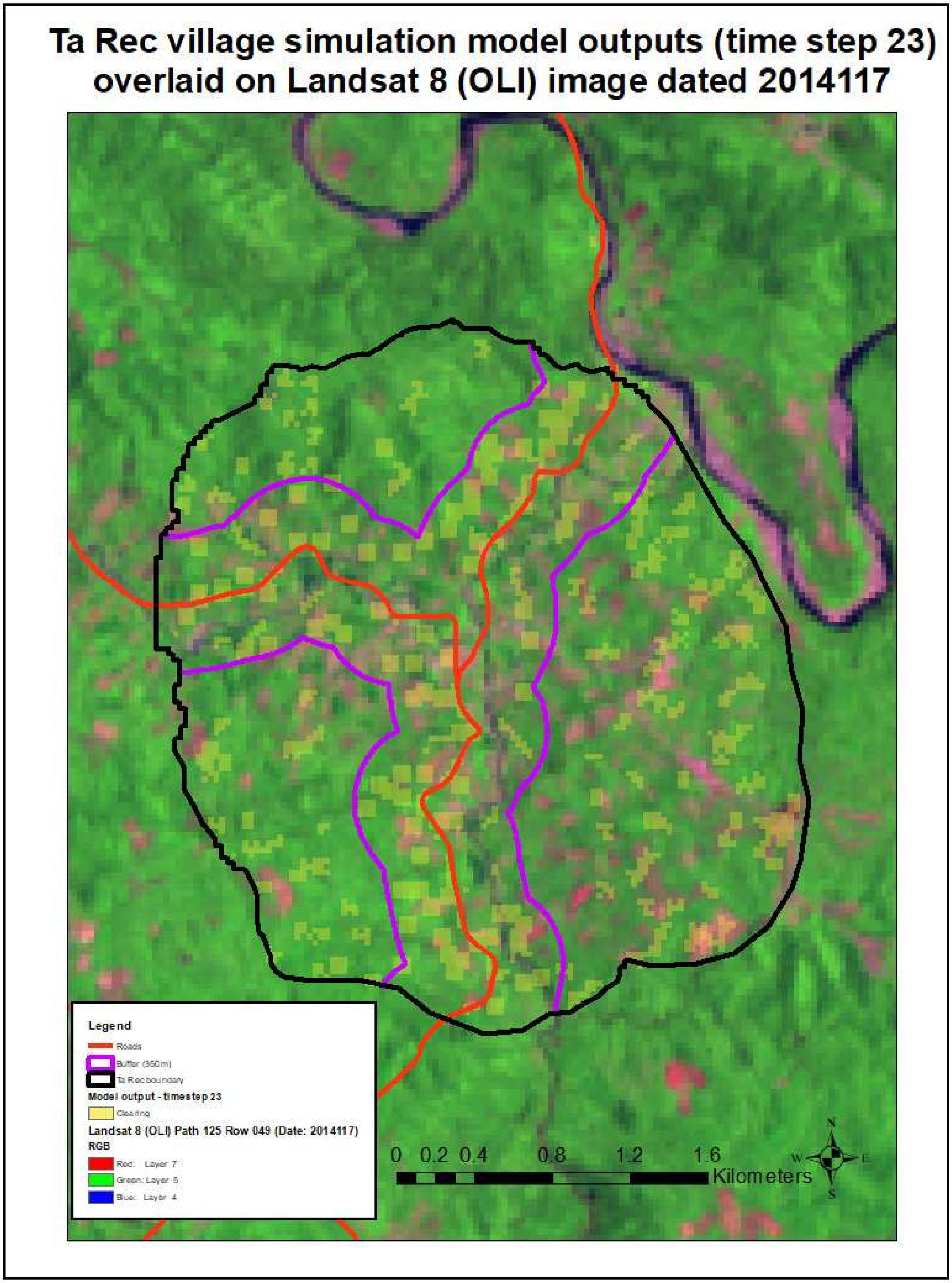


Figure 69: Simulated agricultural land-use in Ta Rec village at time step 23 of model run (Baseline scenario with road improvement enabled) overlaid on April 2014 Landsat 8 (OLI) imagery. Yellow represents cleared areas generated by model output. Reddish and pinkish hues on landscape represent actual clearings.

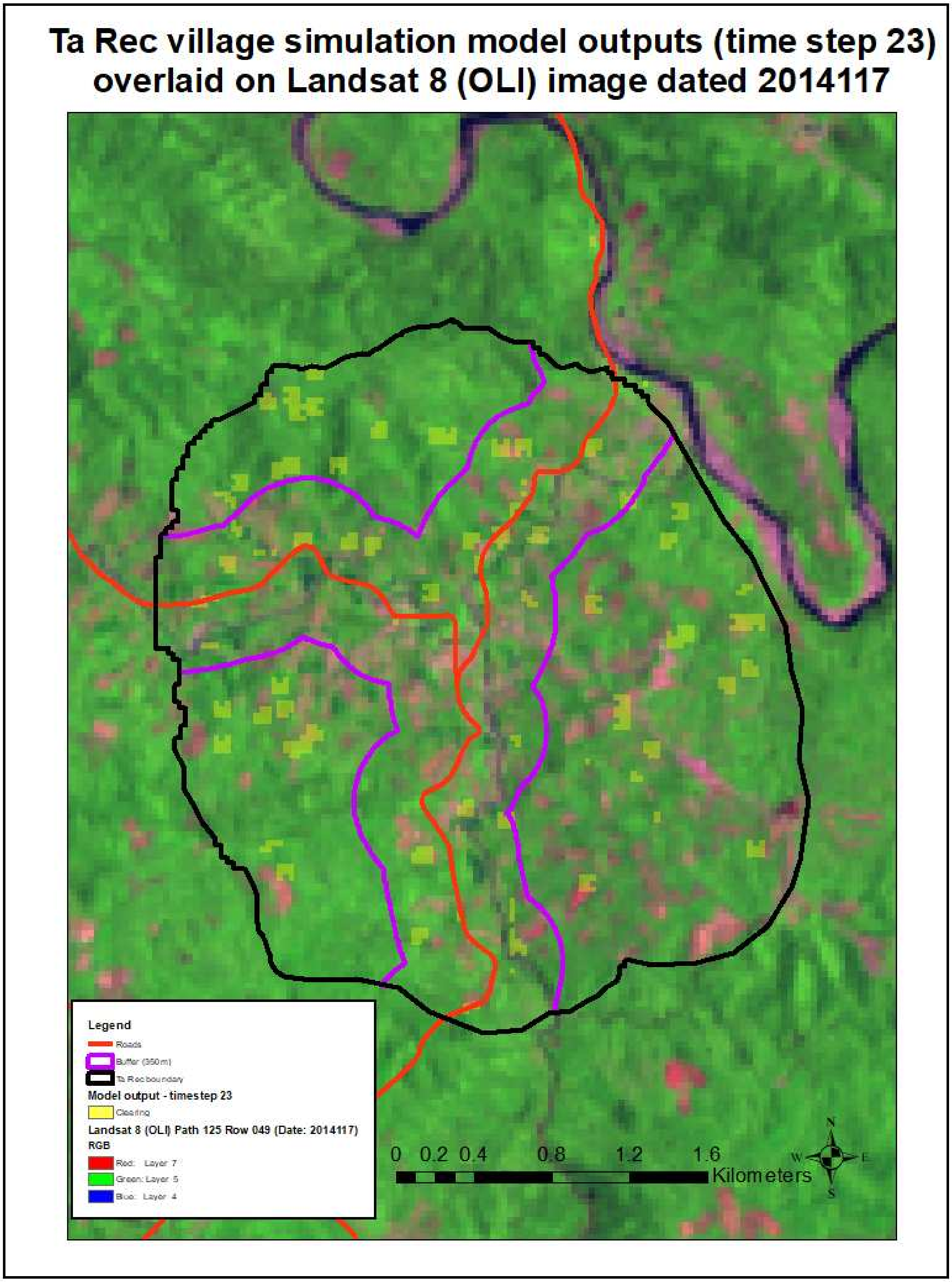


Figure 70: Simulated agricultural land-use in Ta Rec village at time step 23 of model run under subsistence-only (Baseline scenario with road improvement disabled) overlaid on April 2014 Landsat 8 (OLI) imagery. Yellow represents cleared areas generated by model output. Reddish and pinkish hues on landscape represent actual clearings.

3.7.2 Empirical level "macrovalidation"

Empirical validation of model outputs vs. observed patterns of change requires quantifying simulated land-cover against findings derived from satellite imagery to compare the following metrics:

(1) total area cleared

(2) sectoral distribution of clearings (inside vs. outside the road buffer);

(3) relative degree of clustering (observed mean distance values between clearings); and

(4) relative proximity to roads (observed mean distance values of clearings to roads).

With regard to the extent of areas being cleared under both models, an analysis of satellite imagery shows that the mean size of plots ranges fairly widely (6700-8200 square meters for Klu / 3300-7300 square meters for Ta Rec). More importantly, standard deviation values exceed mean values for both villages. Thus, the noise that is inherent in the data makes it difficult to characterize what actually constitutes a "typical" clearing size for either of these study areas. Additionally, with regard to NetLogo, the model code as currently configured does not allow for households to clear areas larger than nine patches (i.e., 8100 square meters). This constraint precludes patch selection across a more widely varying range as observed in available imagery.

On a more general note: in making such comparisons, it should be noted this is a "complex model yielding rich behavior" and so the focus should be not strictly on data agreement per se but rather on "the range and plausibility of the trend in model output" per Sulistyawati et al.(2005: 280). This disclaimer is corroborated by Augusiak et al. (2014) and van Vliet et al. (2016), who caution against the problem of equifinality, where model outputs could show close agreement or wide disparity, but this does not necessarily indicate the relative degree of the validity of the underlying model process generating these outputs.

3.7.2.1 Empirical level macrovalidation for Klu village

With regard to the village of Klu, the following data constitute a general baseline (Table 12), which has been supplemented by analysis of additional imagery for 2016 and 2018 using the same methods at the village scale as were applied in the preceding chapter (chapter 2):

Table 12: Klu village clearings (Leisz et al. 2016: 12)

Table 1. Area of upland cleared for agriculture by year in Klu Village (hectares).

Year	All Cleared Land for Upland Agriculture	Cleared Land for Upland Agriculture within 600 m of Highway	Cleared Land for Upland Agriculture >600 m from Highway
1996	85.77	24.03	61.74
2002	122.58	19.53	103.05
2004	169.56	22.14	147.42
2006	139.86	52.29	87.57
2007	139.86	51.21	88.65
2010	263.52	50.40	213.12
2014	229.05	92.07	136.98

Comparing metrics for the village of Klu shows that the observed values (Table 13) are greater on average than the modeled values under the Baseline scenario (Table 14) for total area cleared, area cleared inside, and area outside the road buffer:

Table 13: Observed extent of cleared areas for Klu village derived from satellite imagery, 2014 / 2016 / 2018

Year	Total area (ha)	Inside 600m (ha)	Outside 600m (ha)
2010	263.52	50.40	213.12
2014	229.05	92.07	136.90
2016	294.75	212.04	82.71
2018	164.25	115.83	48.42
Mean	237.89	117.58	120.29

Table 14: Modeled extent of cleared area for Klu village (median values), timesteps corresponding to years in Table 13

Model Timestep	Total area (ha)	Inside 600m (ha)	Outside 600m (ha)
19	160.70	89.10	71.60
23	177.84	101.25	76.59
25	185.00	106.52	78.48
27	191.61	112.91	78.71
Mean	178.79	102.44	76.34

A comparison of mean values shows that the model underpredicts the cleared area for the village as a whole by approximately 25%. The underprediction for the zone inside the road buffer (<600m) is approximately 13%, whereas the underprediction for the area outside the road buffer (>600m) is substantially greater at ~ 36%.

However, in looking at the observed data values, the disparity for the zone inside the road buffer appears to be mostly a result of the extreme spike in clearings that occurred in 2016, so the level of agreement is actually closer than a comparison of mean values would suggest. With regard to the zone outside the road buffer, the spike in observed values in 2010 creates a similar skew in the data. Observed levels of clearings seem to vary much more widely than the model could predict, insofar as the model is predicated on households seeking to meet their annual rice requirement, which requires a fairly consistent level of land-use for rice cropping from one year to the next, other things being equal.

With regard to the relative degree of clustering in clearings and distance of clearings to roads, there appears to be a fairly close correspondence between observed values (Table 15) and the outputs of the simulation model for this village under the Baseline scenario (Table 16):

Table 15: Observed mean distances between clearings and mean distances of clearings to roads (derived from satellite imagery), 2010-2018

Year	Observed Mean Distance (m)	Mean distance to road (m)
2010	47.52	1032.01
2014	55.39	819.39
2016	64.17	828.40
2018	75.81	776.76
Mean	65.12	864.14

Table 16: Observed mean distances between clearings and mean distances of clearings to roads, timesteps corresponding to years in Table 15

Model Timestep	Observed Mean Distance (m)	Mean distance to road (m)
19	71.71	1263.94
23	64.56	770.46
25	41.70	1062.49
27	73.76	754.36
Mean	62.93	962.81

A comparison of mean values shows that the model underpredicts clustering of clearings across the village as a whole by approximately 3.4% and overpredicts road distance by approximately 11%. This suggests a reasonable level of agreement between the imagery and the model, at least for the subset of dates available for comparison in the period since the road improvement project.

3.7.2.2 Empirical level macrovalidation for Ta Rec village

With regard to the village of Ta Rec, the following data constitute a general baseline (Table 17), which has been supplemented by analysis of additional imagery for 2016 and 2018 using the same methods at the village scale as were applied in the preceding chapter (Chapter 2):

Table 17: Ta Rec village clearings (Leisz et al. 2016: 13)

Table 2. Cleared upland agriculture land by year in Ta Rec (hectares).

Year	All Cleared Land for Upland Agriculture	Cleared Land for Upland Agriculture within 350 m of Secondary Roads	Cleared Land for Upland Agriculture >350 m from Secondary Roads
1996	27.90	0	27.90
2002	44.28	0	44.28
2004	60.93	0	60.93
2006	62.46	26.46	36.00
2007	52.11	10.26	41.85
2010	105.48	57.69	47.79
2014	89.28	42.75	46.53

Comparing metrics for the village of Ta Rec shows that the observed values (Table 18) are lower on average than the modeled values under the Baseline scenario (Table 19) for total area cleared and area cleared outside the road buffer but higher on average than modeled values area for the area cleared inside the road buffer:

Table 18: Observed clearings for Ta Rec village derived from satellite imagery, 2014 / 2016 / 2018

Year	Total area (ha)	Inside 600m (ha)	Outside 600m (ha)
2010	105.48	57.69	47.79
2014	89.28	42.75	46.53
2016	233.37	167.22	66.15
2018	58.59	37.44	21.15
Mean	121.68	76.28	45.41

Table 19: Modeled clearings for Ta Rec village (median values), timesteps corresponding to years in Table 18

Model Timestep	Total area (ha)	Inside 600m (ha)	Outside 600m (ha)
19	119.34	57.74	61.61
23	128.21	61.74	66.47
25	141.93	69.93	72.00
27	150.12	73.49	76.64
Mean	134.90	65.72	69.18

Comparison of mean values show that the model overpredicts the cleared area for the village as a whole by approximately 11% and overpredicts for the zone further from the road (>600m) by 52%, while underpredicting for the zone nearer the road (<600m) by 14%. As with the village of Klu, there appears to be a much wider fluctuation from one timestep to the next in the imagery than in the range of values generated by model which may operate in a more steady-state fashion than do actual households in the real-world village content.

With regard to the relative degree of clustering in clearings and distance of clearings to roads, there appears to be some disparity between observed values (Table 20) and the outputs of the simulation model for this village under the Baseline scenario (Table 21):

Table 20: Observed clustering of clearings and distance to roads derived from satellite imagery, 2010 / 2014 / 2016 / 2018

Year	Observed mean distance between clearings (m)	Mean distance to road (m)
2010	43.25	577.16
2014	59.48	541.20
2016	73.38	430.12
2018	138.49	370.72
Mean	78.65	479.80

Table 21: Modeled clustering and distance to roads, timesteps corresponding to years in Table 20

Model Timestep	Observed mean distance between clearings (m)	Mean distance to road (m)
19	44.88	955.55
23	52.39	880.94
25	45.65	554.41
27	42.84	380.65
Mean	46.44	692.89

The same default values for used for the village of Klu produced highly divergent outcomes for the village of Ta Rec with respect to both clustering and distance to road values. However, it should be noted that observed mean distances derived from satellite imagery appear to vary by a fairly large amount from one timestep to the next in this period, skewing the mean value, whereas the model is more consistent. This suggest a need to introduce more stochasticity into the model for clustering, which would require a better understanding of factors that encourage or discourage households to cluster clearings (e.g., kinship or other factors). Conversely, the imagery show a more consistent range of values for distance to roads which suggests that the dispersion of households in the simulation model needs to be constrained within a narrower window than the range of random values currently generated in the NetLogo code.

Further tests could be performed to assess the relative level of agreement or disagreement between the patterns observed in satellite imagery and the patterns derived from the simulation models, including the aforementioned tests (MRG, ROC, etc.) as well as statistical "similarity validation" processes using regression techniques (Bradley et al. 2016). Such tests would benefit from more granular land-cover classification than provided for by the current landscape input, defined by coarse classification of imagery, and landscape outputs generated by the model.

3.8 Future work to improve model process and outputs

A multitude of pathways could potentially enhance the design and functioning of the model presented in this chapter. This section offers a few ideas for achieving better simulation of LULC change for the agricultural land-use scenarios being modeled.

3.8.1 Household agents

Better modeling of household agents could entail the following:

(1) giving households "memory" whereby they factor the past (up to a certain number of years) into their present decision-making process;

(2) making grouping behavior of households differ by cropping type, where the "rule of four" currently in force might apply to subsistence-oriented cropping, but a different rule might apply to cash cropping behavior;

(3) varying agronomic practices to allow households to intercrop, rather than simply engage in monocropping behavior on a given patch of the landscape; and

(4) simulating a "social component" to site selection.

With regard to memory, an ability to recall the occurrence of a recent extreme weather event (drought or flood) could inform cropping strategies, e.g., avoiding higher elevation terrain in the year immediately following a drought or avoiding low-lying valley bottoms in the year immediately following a flood (although the latter scenario could work the other way depending on the severity of the flood event and resulting erosion). Another example of memory-enabled adaptive response might involve altering agronomic practices to lessen patch re-use or increase fallow length in event of recent drought.

With regard to agronomy, intercropping is a widespread practice amongst households at the village level, as confirmed by field-based research (Leisz et al. 2014), e.g., the improved fallowing process involving intercropping of rice with acacia saplings. Such processes could benefit from modeling interactions between households to allow for sharing and transfer of inputs and knowledge relevant to such cropping behaviors. Such interactions are not built into the current model.

With regard to site selection, ethnographic research indicates that additional factors, including a social component, are involved in site selection (Mole 1970; McElwee 2008). As currently constituted, this dynamic is not captured in the NetLogo code being used to model land-use decision-making and behavior. Even though villagers have traditionally tended to make similar land-use decisions per the scholarship on shifting cultivation, incorporating variation between individuals, which generally applies to economic decision-making including land use systems, could be an important attribute to confer on households in this context (Boone & Galvin 2014).

3.8.2 Landscape agents – vegetative succession and soil degradation / loss

While better modeling of landscape agents might ultimately be better accomplished through other approaches (e.g., cellular automata), potential improvements over the current implementation in NetLogo could include the following:

(1) improving the process of vegetative succession to more accurately increment and decrement fertility values based on patch use and fallowed status;

(2) improving the process for updating soil conditions to reflect the differing impacts of subsistence vs. cash cropping on degradation, erosion, and loss of soil; and

(3) linking yields of crops to the improved modeling of fertility and soil conditions.

Improved modeling of soil conditions and vegetative succession have considerable importance given that declining crop yields are closely coupled with fertility decline (Van De 2008). The ecological sustainability of cash cropping may ultimately hinge on checking such declines in fertility associated with relatively high rates of soil loss, measured up to 27 tons for cassava per hectare per annum (Quang et al. 2014). Quang et al. (2014) estimate that soil losses at these rates cost households a substantial share of income over a 25-year period, and notes that such losses could be mitigated. Such conservation-oriented practices are beyond the scope of the current model but could provide a valuable enhancement in future versions.

3.8.3 Socio-economic realism

Finally, the model could take some steps toward greater socio-economic realism. Possible ideas toward achieving that goal might include the following:

(1) incorporating outside actors (e.g., commercial agriculturalists and timber companies);

(2) permitting mobility, whereby village-based households agents can leave the model and return at a later date (e.g., off-farm seasonal labor); and

(3) adding market dynamics, e.g., inflation and/or volatility in commodity prices.

With regard to outside actors, any implementation of the model at a broader spatial scale would probably need to incorporate other actors modifying and converting the landscape for agricultural production, agroforestry, and timber extraction. More research would be needed to properly design and operationalize such agents.

With regard to market dynamics, the model could be modified to incorporate actual agricultural commodity prices, which affect household production and consumption decision-making and behaviors. Short term fluctuations in crop prices can have profound effects on household allocation of land and labor assets. Long-term effects of inflation can diminish household purchasing power, with the export orientation of Vietnam contributing to the gradual devaluation of the national currency against the US Dollar over the last decade.

3.9 Conclusion

The spatially-explicit, agent-based models of agricultural land-use presented for two villages in the rural uplands of north-central Vietnam's region have sought to build upon the work of other scholars and extend it by simulating a process of agrarian transition under conditions of partial market integration. As noted by Boone and Galvin (2014: 20), "Agent-based modeling has been useful in representing human decision making. The method is highly flexible, and able to incorporate individual variation and path dependencies. If-then structures and the parameters used in them become hypotheses that may be tested, in direct analogy to field experiments." Despite simplifying assumptions necessary in the design and building of this model, it has sought to capture decision-making processes underlying LULC change at the local scale predicated on rational market-based decision-making criteria, while not assuming perfect knowledge and allowing for variation in the values of thresholds that apply to decision-making criteria.

Results of the Baseline scenario appear to show a pattern of increasing concentration of agricultural activity in the zone close to the road for both villages, which indicates that the model captures the primary land-use decision-making and behavior expected of the model. The patterns of overall land-cover change associated with this transition reflect the influence of not only gradual increasing population but also the interaction of market factors influencing cropping behavior and household incomes through a feedback loop. This rational actor dynamic is predicated on von Thünen's theory of location, whereby falling transportation costs and rising land rents along the road corridor induce market-oriented production of cash crops in the "first ring" of free cash cropping, displacing other agricultural activity further from the road (von Thünen 1966; Angelsen 2007).

With regard to BehaviorSpace experiments, it appears that the household agent decision-making and behavior with respect to agricultural land-use and land-cover can be influenced to a large degree by both market forces altering prices (e.g., cash crops and staple grains) and policy constraints on land-use (e.g., sloping land). Lesser but notable effects also arise from modifying agronomic practices (e.g., patch re-use and fallow length) and raising the probability of extreme climate-related events (e.g., drought and flood). Finally, any major changes in the population level of the village relative to the baseline value appear to exert a proportional effect on overall levels of land-use, assuming households pursue similar cropping behaviors.

The models presented here require further validation, calibration, and testing, based on moderate to large discrepancies between observed patterns of land-use derived from satellite imagery and modeled outputs. However, it should be noted that available satellite imagery shows large variation at the village scale from one image date to the next, and therefore real-world stochasticity may be larger than this model can accommodate. With that caveat, it is hoped this model may have future relevance and applicability for informing decision support systems in the when fully validated, since the simulated responses generally exhibits correct directionality in response to variations in key variables. Various enhancements could be made to these models in the future to achieve greater realism with respect to households, the landscape, socio-economics, and ecosystems. Pending such additional work, it is possible that these models could also be scaled up from the village level to the commune, and perhaps subsequently to the district level, to provide a wider window on recent and future trajectories of LULC change.

Works Cited

Alcamo, J., Schaldach, R,, . . . Priess, J. (2011). Evaluation of an integrated land use change model including a scenario analysis of land use change for continental Africa. Environmental Modelling & Software with Environment Data News, 26(8), 1017-1027.

Angelsen, A. (2007). Forest Cover Change in Space and Time: Combining the von Thünen and Forest Transition Theories. World Bank Policy Research Working Paper 4117.

Angelsen, A. (2010). Policies for reduced deforestation and their impact on agricultural production. PNAS, 107(46), 19639-19644.

Arneth, A, Sitch, S, . . . Lindeskog, M. (2017). Historical carbon dioxide emissions caused by land-use changes are possibly larger than assumed. Nature Geoscience, 10(2), 79-84.

Augusiak, J., Van den Brink, P.J., & Grimm, V. (2014). Merging validation and evaluation of ecological models to 'evaludation': A review of terminology and a practical approach. Ecological Modelling, 280, 117-128.

Bayer, A. Lindeskog, M., Pugh, T.A. M., Anthoni, P.M., Fuchs, R., Arneth, A. (2017). Uncertainties in the land-use flux resulting from land-use change reconstructions and gross land transitions. Earth System Dynamics, 8(1), 91-111.

Boone, R. B., & Galvin, K. A. (2014). Simulation as an approach to social-ecological integration, with an emphasis on agent-based modeling. In Understanding Society and Natural Resources (pp. 179-202). Springer, Dordrecht.

Brooks, D., & Hummels, D. (2009). Infrastructure's role in lowering Asia's trade costs: Building for trade (ADBI series on Asian Economic Integration and Cooperation). Cheltenham, Gloucestershire: Edward Elgar Publishing.

Brown, D.R. (2008). A spatiotemporal model of shifting cultivation and forest cover dynamics. Environment and Development Economics, 13, 643-671.

Campbell, D. J. (1996). Aggregation and regularity: an inclusive one-tailed nearest-neighbour analysis of small spatially patchy populations. *Oecologia*, *106*(2), 206-211.

Castella, J-C., & Verburg, P.H. (2007a). Combination of process-oriented and pattern-oriented models of land-use change in a mountain area of Vietnam. Ecological Modelling, 202(3-4), 410-420.

Castella, J-C., Kam, S.P., Quang, D., . . . Thai Hoanh, C. (2007b). Combining top-down and bottom-up modelling approaches of land use/cover change to support public policies:

Application to sustainable management of natural resources in northern Vietnam. Land Use Policy, 24(3), 531-545.

Condominas, G. (2009). Anthropological reflections on swidden change in Southeast Asia. Human Ecology, 37(3), 265-267.

Conklin, H. (1961). The Study of Shifting Cultivation. Current Anthropology, 2(1), 27-61.

Coppock, J., & Ruthenberg, H. (1973). Farming Systems in the Tropics. The Geographical Journal, 139(1), 149-149.

Costanza, R. (1989). Model goodness of fit: a multiple resolution procedure. Ecological modelling, 47(3-4), 199-215.

Donges, J. F., Heitzig, J., … Lucht, W. (2018 / in review) Earth system modelling with complex dynamic human societies: CORE World-Earth modeling framework, Earth Sys. Dynam. Discuss.

Dove, M. R. (1985). Swidden agriculture in Indonesia: the subsistence strategies of the Kalimantan Kantu'. New Babylon Studies in Social Sciences 43. Mouton Publishers, Berlin.

Dove, M.R. (2015). Linnaeus' study of Swedish swidden cultivation: Pioneering ethnographic work on the 'economy of nature'. Ambio a Journal of the Human Environment, 44(3), 239-248.

Dvorak, K. (1992). Resource Management by West African Farmers and the Economics of Shifting Cultivation. American Journal of Agricultural Economics, 74(3), 809-815.

Eickhout, B., van Meijl, H., Tabeau, A., & van Zeijts, H. (2004, June). Between liberalization and protection: four long-term scenarios for trade, poverty and the environment. In GTAP Conference Paper, presented at the 7th Annual Conference on Global Economic Analysis, Washington, DC.

Fischer, G., & Sun, L. (2001). Model based analysis of future land-use development in China. Agriculture, Ecosystems & Environment., 85(1-3), 163-176.

Fuchs, R., Prestele, R., & Verburg. P.H. (2018). A global assessment of gross and net land change dynamics for current conditions and future scenarios. Earth System Dynamics, 9(2), 441-458.

Gilruth, P.T, Marsh, S.E, & Itami, Robert. (1995). A dynamic spatial model of shifting cultivation in the highlands of Guinea, West Africa. Ecological Modelling, 79(1-3), 179-197.

Grimm, V., Augusiak, J., Focks, A., & Railsback, S.F. (2014). Towards better modelling and decision support: Documenting model development, testing, and analysis using TRACE.

Ecological Modelling, 280, 129-139.

Heinimann, A., Mertz, O., Frolking, S., Christensen, A.E., & Hurni, K. (2017). A global view of shifting cultivation: Recent, current, and future extent. PloS One, 12(9): 1-21.

Hiratsuka, M., Tsuzuki, H.,. . . Amano, M. (2018). Living biomass of fallow areas under a REDD project in mountainous terrain of Northern Laos. Journal of Forest Research, 23(1), 56-63.

Hoang, T.X., Pham, C.S., & Ulubaşoğlu, M.A. (2016). The role of rice in poverty dynamics in rural Vietnam: 2002–2008. Journal of the Asia Pacific Economy, 21(1), 132-150.

Howeler, R. (2006). Cassava in Asia: Trends in Cassava Production, Processing and Marketing. Presented at "Partnership in Modern Science to Develop a Strong Cassava Commercial Sector in Africa and Appropriate Varieties by 2020", Bellagio, Italy, May 2-6, 2006.

Izikowitz, K. G. (2018). Lamet hill peasants in French Indochina. Goteborg (1951).

Jepsen, M.R, Leisz, S.J., . . . Christiansen, L. (2006). Agent-based modelling of shifting cultivation field patterns, Vietnam. International Journal of Geographical Information Science, 20(9), 1067-1085.

Jourdain, D., Boere, E., , . . . Pandey, S. (2014). Water for forests to restore environmental services and alleviate poverty in Vietnam: A farm modeling approach to analyze alternative PES programs. Land Use Policy, 41, 423-437.

Klijn, J. A., Vullings, L. A. E., van de Berg, M., Van Meijl, H., Van Lammeren, R., Van Rheenen, T., ... & Westhoek, H. (2005). EURURALIS 1.0: A scenario study on Europe's Rural Areas to support policy discussion. *Background document. Alterra report*, *1196*.

Koch, J., Wimmer, F., & Schaldach, R. (2018). Analyzing the relationship between urbanization, food supply and demand, and irrigation requirements in Jordan. The Science of the Total Environment., 636, 1500-1509.

Lapola, D., Schaldach, R., Alcamo, J., Bondeau, A., Koch, J., Koelking, C., & Priess, J. (2010). Indirect land-use changes can overcome carbon savings from biofuels in Brazil. Proceedings of the National Academy of Sciences of the United States of America., 107(8), 3388-3393.

Latombe, G., Parrott, L., & Fortin, D. (2011). Levels of emergence in individual based models: Coping with scarcity of data and pattern redundancy. Ecological Modelling, 222(9), 1557-1568.

Leisz, S., Rounds, E., & Bang, T.N. (2014). Project on "Increased accessibility, landscape changes, rural transformations, and urbanization: Impacts of the east-west economic corridor from Da Nang, Vietnam, to Khon Kaen, Thailand," Field notes.

Leisz, S., Rounds, E., Ngo, T.A., Nguyen, T., Tran, Nguyen Bang, Douangphachanh, S. & Ninchaleune, B. (2016). Telecouplings in the East-West Economic Corridor within borders and across. Remote Sensing, 8(12), 1012.

Macmillan, & Huang. (2008). An agent-based simulation model of a primitive agricultural society. *Geoforum, 39*(2), 643-658.

Magliocca, N.R. & Ellis, E.C. (2013). Using Pattern-oriented Modeling (POM) to Cope with Uncertainty in Multi-scale Agent-based Models of Land Change, Transactions in GIS, 17(6), 883-900.

Mandelbrot, B. (1982). The fractal geometry of nature (Updated and augmented). New York: W.H. Freeman.

Manson, S.M., & Evans, T. (2007). Agent-based modeling of deforestation in southern Yucatan, Mexico, and reforestation in the Midwest United States. Proceedings of the National Academy of Sciences of the United States of America, 104(52), 20678-20683.

McElwee, P. (2008). "Blood Relatives" or Uneasy Neighbors? Kinh Migrant and Ethnic Minority Interactions in the Trường Sơn Mountains. Journal of Vietnamese Studies, 3(3), 81-116.

Morello, T., Parry, L., Markusson, N., & Barlow, J. (2017). Policy instruments to control Amazon fires: A simulation approach. Ecological Economics, 138, 199-222.

Müller-Hansen, F., Schlüter, M., . . . Heitzig, J. (2017). Towards representing human behavior and decision making in Earth system models – an overview of techniques and approaches. Earth System Dynamics, 8(4), 977-1007.

Ngo, T. A., See, L. M., & Drake, F. (2009). An agent-based approach to simulating the dynamics of shifting cultivation in an upland village in Vietnam. European Journal of GIS and Spatial Analysis, 19 (4), 493–522.

Ngo, T.N. & See, L. (2012). "Calibration and validation of agent-based models of land cover change," in Agent-Based Models of Geographical Systems (eds. Heppenstall, A.J.et al.) Dordrecht: Springer Netherlands.

Ostrom, E. & Nagendra, H. (2006). Insights on linking forests, trees, and people from the air, on the ground, and in the laboratory. Proceedings of the National Academy of Sciences, 103(51), 19224-19231.

O'Sullivan, D., Evans, T., Manson, S., Metcalf, S., Ligmann-Zielinska, A., & Bone, C. (2016).

Strategic directions for agent based modeling: Avoiding the YAAWN syndrome. Journal of Land Use Science, 11(2), 177-187.

Overmars, K.P., & Verburg, P.H. (2006). Multilevel modelling of land use from field to village level in the Philippines. Agricultural Systems, 89(2-3), 435-456.

Pelzer, K. (1945). Pioneer settlement in the Asiatic tropics; studies in land utilization and agricultural colonization in southeastern Asia (Special publication (American Geographical Society of New York) ; no. 29). New York, N.Y.: American geographical society.

Pontius Jr, R. G., & Schneider, L. C. (2001). Land-cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA. Agriculture, Ecosystems & Environment, 85(1-3), 239-248.

Quang, D.V., Schreinemacher, P., & Berger, T. (2014). Ex-ante assessment of soil conservation methods in the uplands of Vietnam: An agent-based modeling approach. Agricultural Systems, 123, 108-119.

Reddy, C.S., Singh, S.; Dadhwal, V. K. (2017). Predictive modelling of the spatial pattern of past and future forest cover changes in India, Journal of Earth System Science, 126(1), 8.

Riris, P. (2018). Assessing the impact and legacy of swidden farming in neotropical interfluvial environments through exploratory modelling of post-contact Piaroa land use (Upper Orinoco, Venezuela). The Holocene, 28(6), 945-954.

Rosegrant, M.W., & Cai, X. (2002). Water Constraints and Environmental Impacts of Agricultural Growth. American Journal of Agricultural Economics., 84(3), 832-838.

Rosegrant, M. (2001). The economics of world wheat markets. Journal of Agricultural Economics, 52(2), 125-129.

Schaldach, R., Wimmer, F., Koch, J., Volland, J., Geissler, K., & Köchy, M. (2013). Model-based analysis of the environmental impacts of grazing management on Eastern Mediterranean ecosystems in Jordan. Journal of Environmental Management, 127, S84-S95.

Schmidt-Vogt, D., Leisz, S.J., Mertz, O., Heinimann, A., Thiha, T., Messerli, P., Epprecht, M. (2009). An assessment of trends in the extent of swidden in Southeast Asia. Human Ecology, 37(3), 269-280.

Spencer, J.E. (1958). Preliminary Notes on Shifting Cultivation in Southeastern Asia. Yearbook of the Association of Pacific Coast Geographers, Vol. 20, 49-51.

Steffen, W. (2006). The Arctic in an Earth System Context: From Brake to Accelerator of

Change. Ambio: a Journal of the Human Environment, 35(4), 153-159.

Stéphenne, N., & Lambin, E. (2001). A dynamic simulation model of land-use changes in Sudano-sahelian countries of Africa (SALU). Agriculture, Ecosystems & Environment., 85(1-3), 145-161.

Stocker, B., Yu, Z., Massa, C., & Joos, F. (2017). Holocene peatland and ice-core data constraints on the timing and magnitude of CO 2 emissions from past land use. Proceedings of the National Academy of Sciences of the United States of America., 114(7), 1492-1497.

Sulistyawati, E., Noble, I.R., Roderick, M.L. (2005). A simulation model to study land use strategies in swidden agriculture systems. Agricultural Systems, 85(3), 271-288.

Thellmann, K., Cotter, M., … & Asch, F. (2018). Tipping Points in the Supply of Ecosystem Services of a Mountainous Watershed in Southeast Asia. Sustainability, 10(7), 2418.

Van Asselen, S., & Verburg, P.H. (2013). Land cover change or land-use intensification: Simulating land system change with a global-scale land change model. Global Change Biology, 19(12), 3648-3667.

Van De, N. (2008). Erosion and nutrient loss on sloping land under intense cultivation in southern Vietnam. Geographical Research, 46(1), 4-16.

Van Vliet, J., Bregt, A.K, . . . Verburg, Peter H. (2016). A review of current calibration and validation practices in land-change modeling. Environmental Modelling & Software with Environment Data News., 82, 174-182.

Vargyas, G. (2001) "Intangible Culture of the Bru: Preservation, Promotion and Reassertion of Values," in Viet Nam's Cultural Diversity: Approaches to Preservation, ed. O. Salemink (Paris: UNESCO Publishing), 199-204.

Verburg, P. (2006). Simulating feedbacks in land use and land cover change models. Landscape Ecology, 21(8), 1171-1183.

Von Thünen, J. H., & Hall, P. (1966). Isolated state; an English edition of *Der isoliete Staat*. (1st ed.). Oxford, New York: Pergamon Press.

Wada, Y., Rajan, K.S., & Shibasaki, R. (2007). Modelling the spatial distribution of shifting cultivation in Luangprabang, Lao PDR. Environment and Planning., 34(2), 261-278.

Wilensky, U. (1999). NetLogo. https://ccl.northwestern.edu/netlogo/ . Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

Wilensky, U., & Rand, W. (2015). An introduction to agent-based modeling: Modeling natural, social, and engineered complex systems with NetLogo (YBP Print DDA). Cambridge, Massachusetts: The MIT Press.

Wilkie, D.S, & Finn, J.T. (1988). A spatial model of land use and forest regeneration in the Ituri forest of northeastern Zaire. Ecological Modelling, 41(3-4), 307-323.

Yue, C., Ciais, P., . . .Peng, S. (2018). Representing anthropogenic gross land use change, wood harvest, and forest age dynamics in a global vegetation model ORCHIDEE-MICT v8.4.2. Geoscientific Model Development, 11(1), 409-428.

Chapter 4: Overall conclusion

This thesis has sought to explore the ongoing process of agrarian transition taking place in the rural uplands of Vietnam's North-Central Coast region, particularly as relates to discerning road influence in the period since the completion of the EWEC in mid-2006 under the aegis of the ADB-led effort to increase transportation network interconnectivity across the GMS subregion. The overarching question of development concerns what happens when the market comes to the forest (Rigg 2006a). The attempt taken here to answer Rigg's question has involved two main approaches:

(1) an assessment of observed change through the application of remote sensing and GIS tools and methods to satellite imagery at the district level (Đa Krông District, Quảng Trị Province); and

(2) the building and testing of a spatially explicit simulation model at the village level (Klu and Ta Rec villages, Đa Krông District).

Both observed and modeled changes in land-cover have been considered from two conceptual vantage points - the microeconomic theory of land rent, espoused by von Thünen in 1826 at the local level (i.e., from farm to nearby market), and the more recent frameworks of teleconnections and telecoupling at multiple scales (i.e., from micro- to meso-, meso- to macro-, and vice versa).

The agrarian transition process underway in the study area has involved the partial integration of ethnic minority populations traditionally engaged in shifting cultivation as smallholders, particularly the Van Kieu, into larger outside markets. Integrating ethnic minority smallholders into larger, outside markets can follow several pathways associated with the reallocation of factors of production - land, labor, and capital - toward fulfilling market demands, ranging from changes in local land-use systems at one end of the spectrum to global labor mobility and remittances at the other. One relevant pathway in this scenario involves incentivizing local populations to mobilize labor and land resources toward producing agricultural commodities, such as acacia for fiberboard and cassava for various industrial products, as alternative or supplementary practices to subsistence cultivation of dry rice. Field-based research has found evidence of both practices in several villages (Leisz et al. 2016). In keeping with conventional economic wisdom (e.g., World Bank), such market-oriented production is a manifestation of "transport induced local development", which arises from road-enabled market access and connectivity. To the extent that reduced transport costs and higher agricultural prices obtain, the theory of land rent holds validity at the microeconomic level. To the extent that rural change is linked with urban growth and urban-based industrialization dynamics, the teleconnections framework applies. And to the extent that the more attenuated influence of national policies extending back over 30 years to 1986 can be linked with increases in greater autonomy at the local level and increased capital flows from abroad driving industrialization, a telecoupling perspective seems to hold water.

Analysis of the April-centered chrono-series of Landsat imagery for the period 2001-2014 at the district level finds possible indications of agricultural intensification along the Highway 9 corridor traversing the study area. While circumstantial, movement of median center points of clearings for multiple sectors in Zones 1 and 2 (Figure 12, Figure 31 and Figure 32) and changes in the areal extent and spatial distribution of lower- and higher-density clearings (Table 7 and Table 8) suggest road influence. To the extent that a pattern of clearings correlate with agricultural intensification involving cash crop cultivation, this would be consistent with von Thünen's theory of land rent, whereby rationally acting agriculturalists are shifting production within the "first ring of free cash cropping" toward meeting market demand.

However, this assessment did not find a clear pattern across the study area as a whole, thus it is not possible to conclusively show road influence at the district level. This underscores a need for further collection and evaluation of both remotely-sensed and ground-based data for the period since 2014 across the entire study area to ascertain factors other than the EWEC that pertain to changing LULC in Zone 3 and Zone 4 (Figure 12, Figure 33 and Figure 34). Additional imagery for the entire timeframe from other sources, such as Sentinel, SPOT, DigitalGlobe, etc., could also help to offset limitations inherent in the Landsat archive (e.g., cloud contamination of available imagery and gaps in collection).

The application of a spatially explicit, agent-based approach to modeling land-use systems at the village level for the period from 1991 to “2021” (i.e., projected end-date) provides for a controlled, virtual laboratory capability for exploring household decision-making, land-use behavior, and emergent land-cover responses. Simulating a business-as-usual scenario of subsistence cultivation (1991-2006) with a market-oriented shift in 2007, results in intensification of cultivation along the road corridor. This shift hinges on households determining, under bounded rationality, that a mixed mode of production (i.e., subsistence plus cash cropping) is a better system of land-use than a strictly subsistence-only approach. Emergent land-cover changes with a simulated road improvement show a consistent trend of increased clearings of land for cassava within the road buffer zone. Experimental scenarios testing the relative influence of agronomy, climate, demography, market prices, and terrain constraints show that both exogenous and endogenous factors exert influence trajectories of LULC change. Model validation shows a need for further tuning and testing of these village-based models, with various pathways possible for enhancing both household and landscape agents to achieve a greater level of realism.

Taking stock of the overall results of the change detection analysis and simulation modeling efforts made, it appears that neither approach can fully capture the complexity of human-environment interactions associated with this agrarian transition. Baselining observed LULC change suggests at least a possible correlation between roads and LULC change, while highlighting the influence, however intermittent, of other factors (e.g., climate as seen in 2009). Simulating LULC change via modeling shows the ability to capture expected behaviors in terms of directionality, but with moderate to large disparities in magnitude. It is hoped that future work, including but not limited to various ideas mentioned in the preceding chapter (Chapter 3), will result in improvements needed to properly connect people and pixels. Pending the success of such efforts, it may be possible to better ascertain the relative influence of various fundamental factors on land-use systems and resulting patterns of land-cover change.

For now, differentiating the relative influence of fundamental factors, whether exogenous or endogenous, remains challenging. However, there appears to be a consensus among scholars that market-oriented measures promoting greater trade and investment since 1986 have facilitated industrial development, with ADB-led road corridor projects of the 2000s including the EWEC likely to extend this development into the hinterlands. Road corridors enable greater flows and interactions, influencing changes in land-use and land-cover. Although the results of available imagery analysis and modeling efforts cannot prove road connectivity, findings to date appears to at least refute the null hypothesis, while also indicating a need for further research to examine issues of conjoint causation, confounding factors, and synergistic interaction between variables.

Understanding LULC change for this study area may require a hybrid approach, wherein political-economic forces operating at national and international scales can be understood as structuring the direction and influencing the magnitude of microeconomic responses. The direction and magnitude of such responses at the local level will vary depending upon the relative degree of local autonomy and the relative influence of endogenous and exogenous factors. In the final analysis, land-use systems, land-cover patterns, and livelihoods at the level of even relatively remote villages in the rural uplands have become increasingly interconnected to and influenced by outside systems and their agents. Thus, analysis of LULC change increasingly requires considering the influence, however seemingly attenuated, of exogenous factors. This is not to discount the importance of endogenous factors, but rather to emphasize the need to frame microeconomic theories (e.g. land rent) in the broader context of macro-structural influences on micro-agency as posited by Lambin et al. (2003). While the change detection analysis and simulation modeling approaches employed capture LULC change to some extent at their respective scales, further work will be needed in the future for bridging across scales.

This need may become more pronounced in the event that the agricultural sector begins to diminish relative to the rapidly emerging service sector (McCaig & Pavcnik 2013). It also bears noting that the smallholder livelihood practice of shifting cultivation itself has experienced marked decline in recent decades, with continuation of this trend projected over the coming decades (Schmidt-Vogt et al. 2009; Heinimann et al. 2017). To the extent that smallholders remain engaged in agricultural production in these rural upland settings, contrary to such trends, issues of commercial viability, cultural acceptability, and ecological sustainability will remain important for such populations (Ngo et al. 2009). Whether local populations maintain traditional livelihoods on the margins, while also continuing to cultivate cash crops to sustain a basic level of cash income, remains to be determined, and will require additional research and analysis of observables as well as simulation modeling of both business-as-usual and alternative pathways.

Works Cited

Heinimann, A., Mertz, O., Frolking, S., Christensen, A.E., & Hurni, K. (2017). A global view of shifting cultivation: Recent, current, and future extent. PloS One, 12(9): 1-21.

Lambin, E.F, Geist, H.J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. Annual Review of Environment and Resources, 28(1), 205-241.

Leisz, S., Rounds, E., Ngo, T.A., Nguyen, T., Tran, Nguyen Bang, Douangphachanh, S. & Ninchaleune, B. (2016). Telecouplings in the East-West Economic Corridor within borders and across. Remote Sensing, 8(12), 1012.

McCaig, B. & Pavcnik, N. (2013). Moving out of agriculture: structural change in Vietnam, No. 19616, NBER Working Papers, National Bureau of Economic Research. URL: http://www.dartmouth.edu/~npavcnik/docs/Vietnam_structural_change_October_2013.pdf (accessed 15 April 2018).

Ngo, T. A., See, L. M., & Drake, F. (2009). An agent-based approach to simulating the dynamics of shifting cultivation in an upland village in Vietnam. European Journal of GIS and Spatial Analysis, 19 (4), 493–522.

Rigg, J. (2006a). Forests, marketization, livelihoods and the poor in the Lao PDR. Land Degradation & Development, 17(2), 123-133.

Schmidt-Vogt, D., Leisz, S.J., Mertz, O., Heinimann, A., Thiha, T., Messerli, P., Epprecht, M. (2009). An assessment of trends in the extent of swidden in Southeast Asia. Human Ecology, 37(3), 269-280.