Agrarian transition in the uplands of central Vietnam: Drivers of market-oriented land-use and land-cover change

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Overview of topics

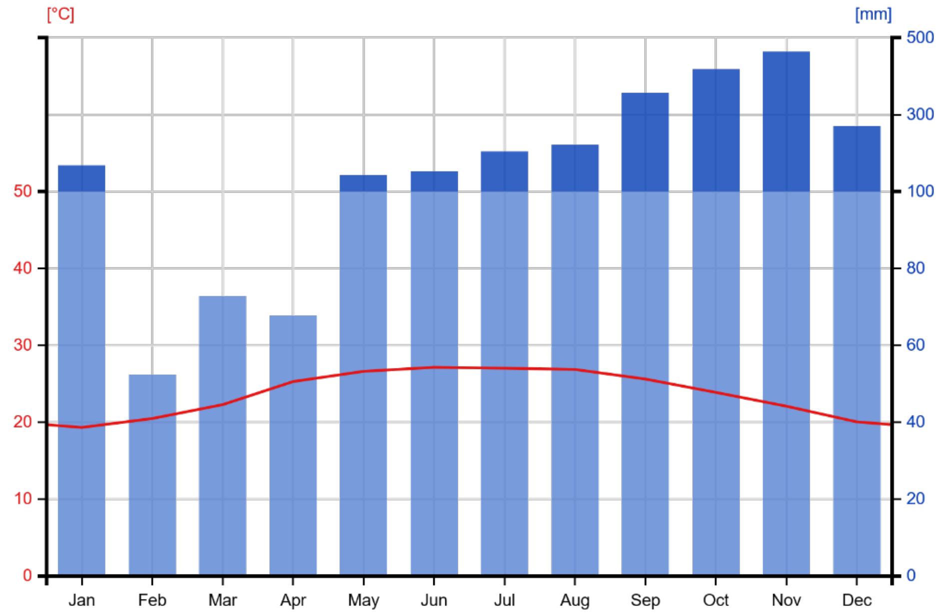
- Background on study area
  - Physical geography
  - Human geography
- Theoretical frameworks
  - Theory of land rent
  - Teleconnections / telecoupling
- Research question and hypothesis
- Land-use / land-cover (LULC) change detection analysis
- Agent-based simulation modeling of LULC change

Physical geography: Climate

- Warm humid tropical climate
- Distinct seasons:
  - “Summer” - May to October
  - “Winter” - November to January
  - “Spring” - February to April

Krông Klang, Quảng Trị, Vietnam

16.658N, 106.816E | Elevation: 54 m | Climate Class: Am | Years: 1987-2016



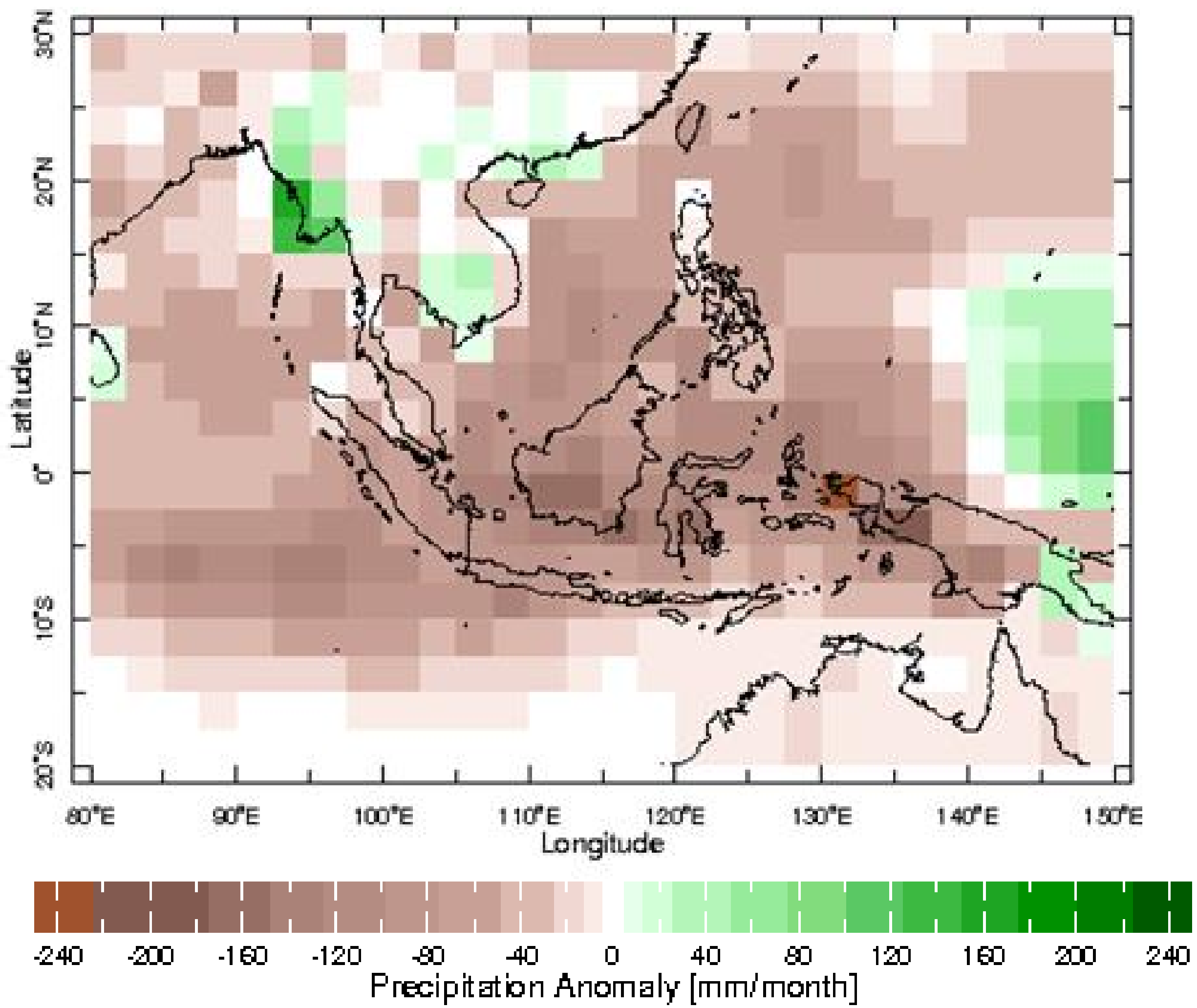
Month	Temp	Precip
Jan	19.3	167.2
Feb	20.5	52.4
Mar	22.3	72.8
Apr	25.3	67.8
May	26.6	143.1
Jun	27.1	151.9
Jul	27.0	203.8
Aug	26.9	221.2
Sep	25.6	356.6
Oct	23.9	418.3
Nov	22.1	463.2
Dec	20.0	269.7

Temperature Mean: 23.9 °C Precipitation Sum: 2588.1 mm

Data Source: http://dx.doi.org/10.5285/58a8802721c94c66ae45c3baa4d814d0

Physical geography: Climate

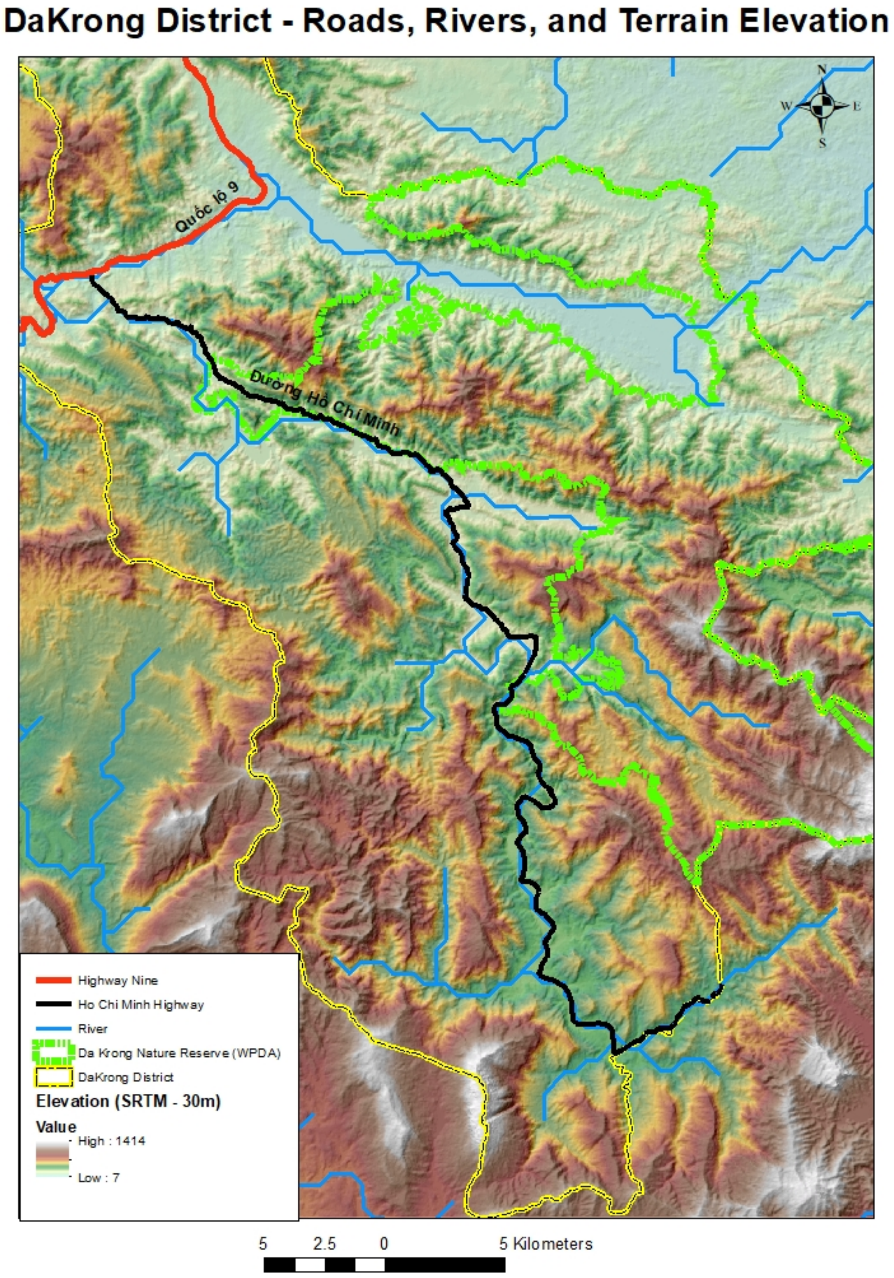
- Timing and amount of precipitation varies with El Niño Southern Oscillation (ENSO)
  - June to October (1979-2016)
    - Brown – drier conditions due to El Niño
    - Green – wetter conditions due to El Niño
  - Function of directionality and magnitude (weak, moderate, strong)



Map (right): ASEAN Specialised Meteorological Centre (ASMC), based on NOAA CPC CAMS_OPI data (1979-2016)

Physical geography: Terrain

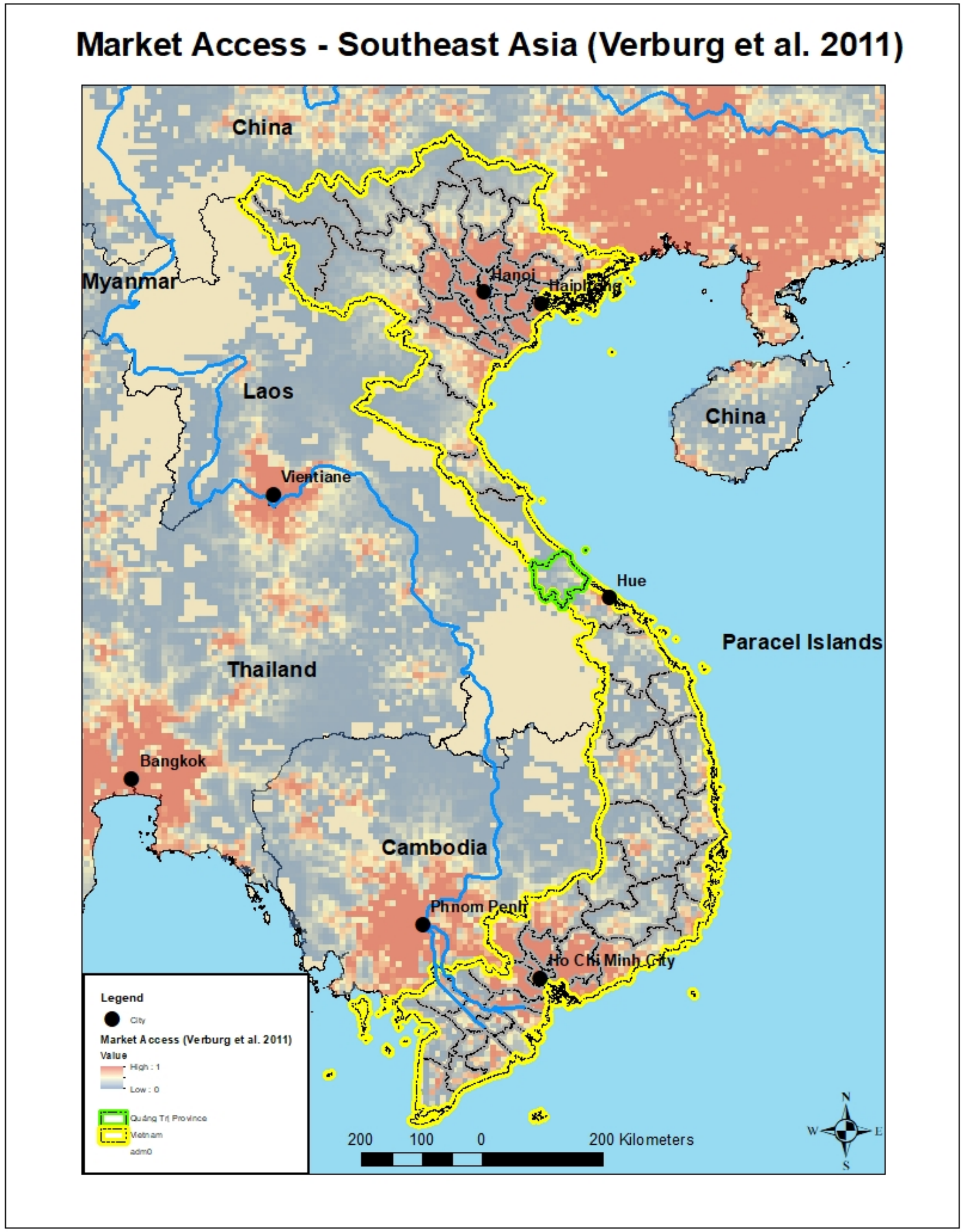
- Elevation range: 7-1400m ASL
- Slope range: 5-74 degrees
- Elevation and slope contribute to terrain dissection and roughness
- Terrain dissection and roughness constrict amount of land suitable for settled agriculture



Socio-economic indicators (Provincial level)

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

Table (above) based on the 2009 national census data (World Bank 2015).



Human geography

- The study area is primarily inhabited by Mon-Khmer ethnic minority populations.
- The Van Kieu, also referred to as the Bru (which literally means "People"), are thought to be the most prevalent group.

Scene of sacrificial offering ceremony, Quảng Trị Province (Salemink 2001: 53)

Demography (District level)

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

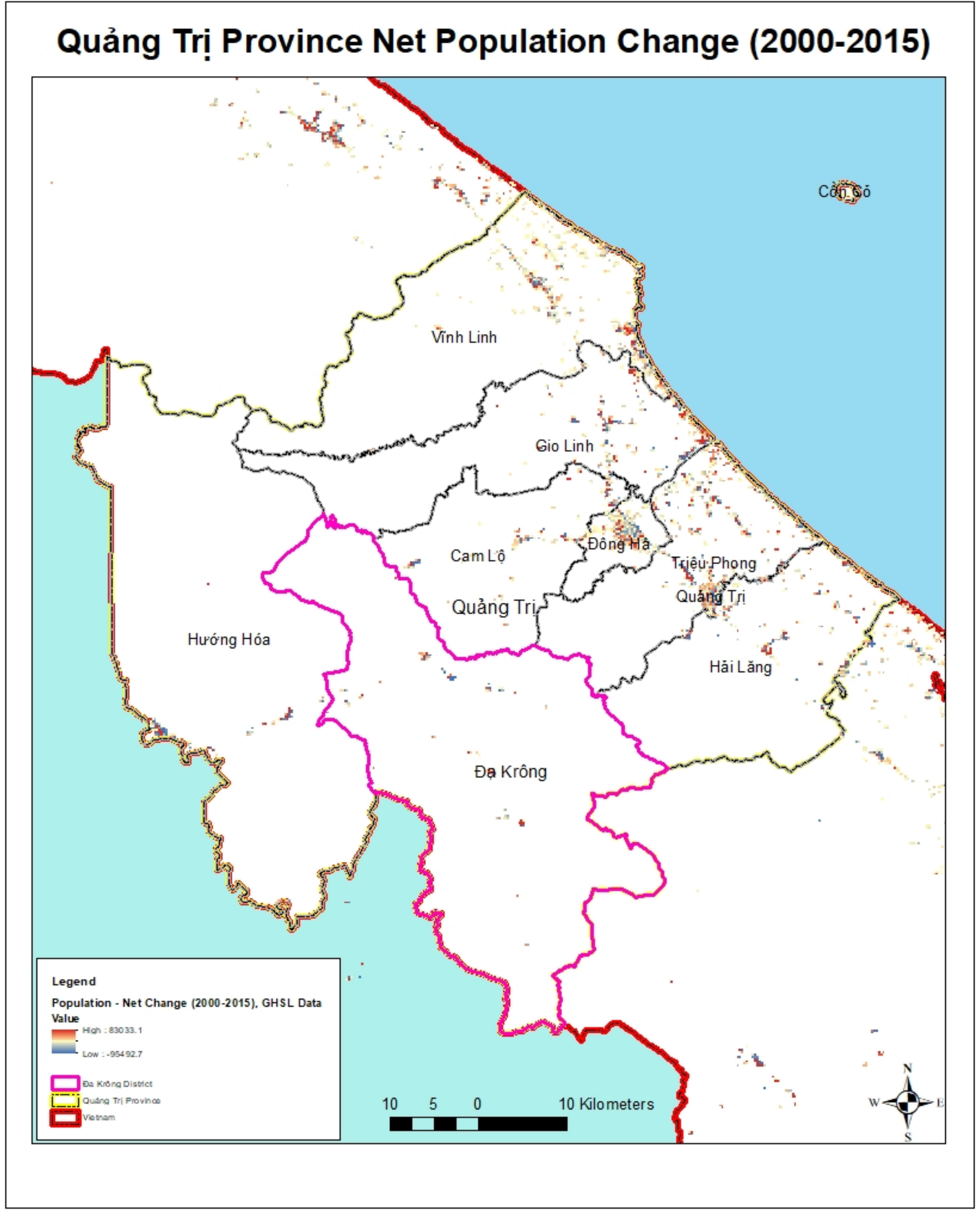


Table (above) for Đa Krông District by commune based on the 2009 national census data (World Bank 2015). Maps (right) derived from European Commission's GHSL data (2000-2015).

Regional transportation corridor projects

"Greater Mekong Subregion" (GMS) infrastructure projects touted as promoting economic cooperation by linking production and trade between nations:

- **East-West Economic Corridor (EWEC)**
- North-South Economic Corridor (NSEC)
- Southern Economic Corridor (SEC)

- Direct impacts of EWEC (Kumagai et al. 2018)
  - Expedited motorized travel (80kph)
  - Reduced delays at border crossings
- Projections for Quảng Trị Province to 2025 (Kumagai et al. 2018)
  - population increase of ~ 9.8%
  - GDP increase by ***~89.6%***

Map (right) from Ishida and Isono (2012: 2)

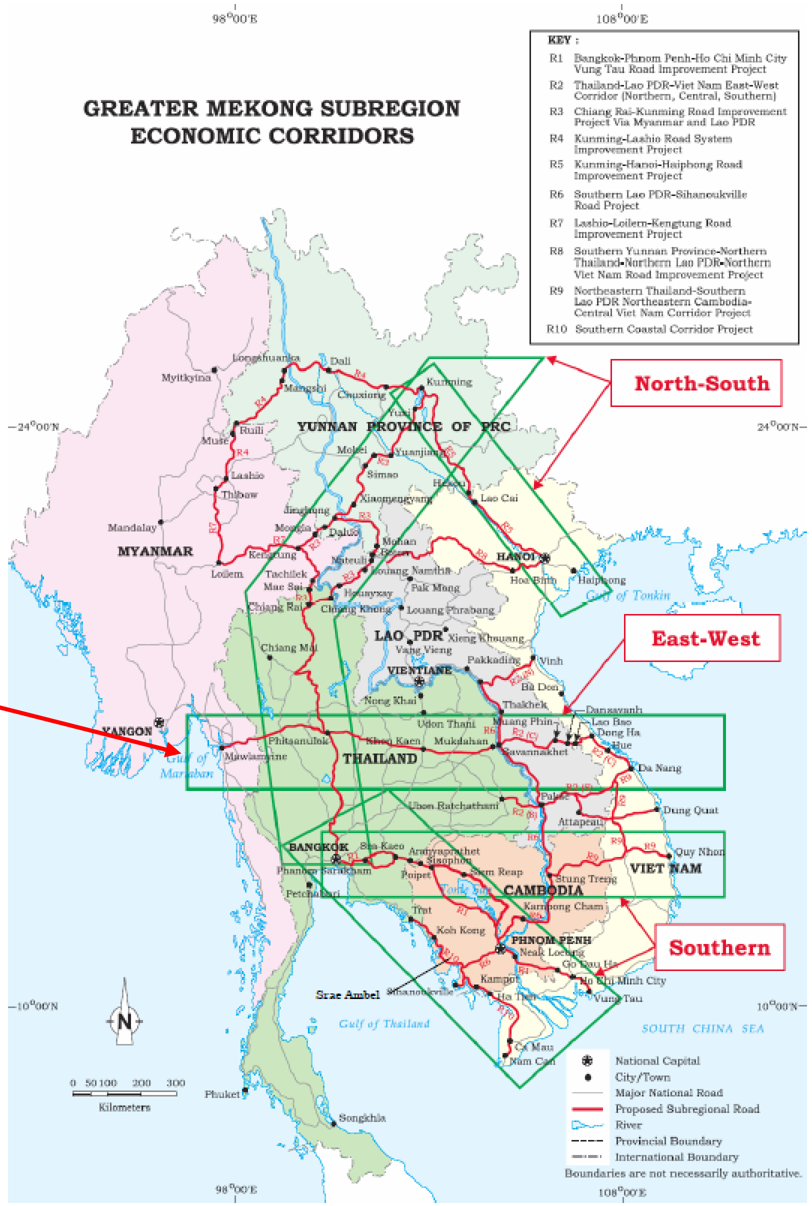


Figure 1 Three Economic Corridors in the Greater Mekong Sub-region

(Source) ADB (2002).

Research question and hypothesis

Question

- What happens when "the market comes to the forest?" (to paraphrase Jonathan Rigg)
  - to systems of land-use?
  - to patterns of land-cover?
  - to the livelihoods of local populations?
  - to nature?

Hypothesis

- Roads will influence existing systems of land-use creating newly emergent patterns of land-cover by
  - enabling market access
  - facilitating market connectivity
  - reducing transport costs
  - incentivizing market-oriented production

  This will result in net intensification of agriculture along the road corridor.

Theoretical frameworks (1 of 2): Theory of land rent

- J.H. von Thünen's theory of land rent (1826)
  - Predicts agricultural land-use based on maximizing **land rent** (r), formulated as follows:

    ***r = py - wl - qk – vd**, where*

    - *Revenues = price (p) * yield (y)*
    - *Labor costs = wage (w) * labor (l)*
    - *Capital costs = time cost of capital (q) * capital (k)*
    - *Transport costs = transport cost per distance (v) * distance to market (d)*
  - Land rent declines with distance, and the **agricultural frontier** demarcates the distance at which agricultural expansion ceases to be profitable -> **d = (** ***py - wl - qk*** **) / *v***
  - **Key assumption**: A rational actor model of behavior for allocating factors of production (land, labor, capital) to optimize land-use systems and thereby maximize profits.
  - **Land-cover pattern**: concentric rings of land-use driven by market prices, with higher value lands allocated to the cultivation of more profitable crops (graph at right)

Figure (right): Angelsen (2007: 7)

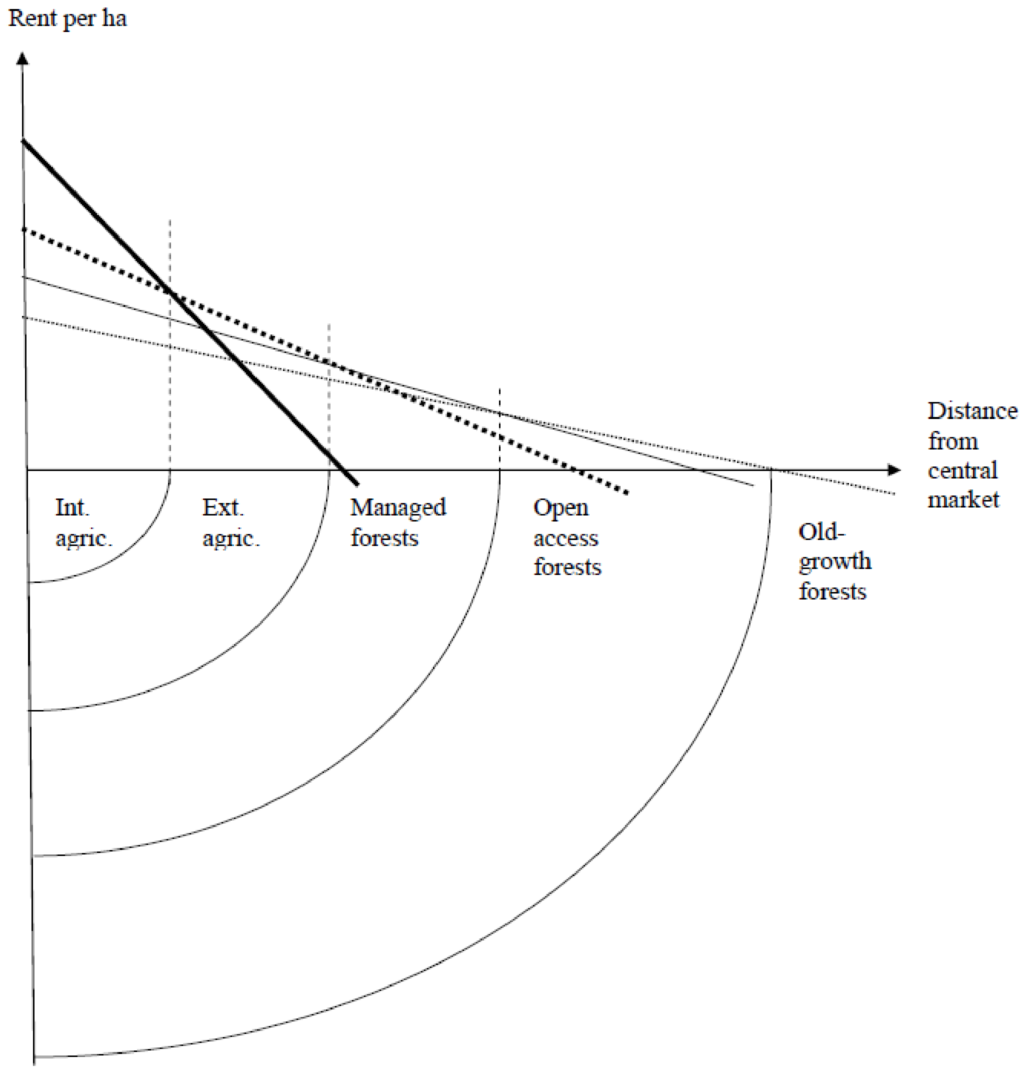


Figure 1. The von Thünen model with five alternative land uses.
Note: The four rent curves are designated by different lines: fat-solid = intensive agriculture; fat-dotted = extensive agriculture; thin-solid = managed forestry; thin-dotted = open access forestry.

Theoretical frameworks (1 of 2): Theory of land rent (cont.)

- Improved roads reduce transportation costs by up to 50% (Jacoby 2000; Warr 2008; Jacoby and Minten 2009)
- Conventional economic wisdom (e.g. World Bank) posits that road network infrastructure improvements result in "transport-induced local-market development (TILD)" (Mu & van de Walle 2007)

- Economic impact of roads on land rent is also "strongly modulated" by
  - Biophysical factors, e.g. soil quality
  - Distance factors, e.g. distance to markets (Chomitz and Gray 1996)
  - Other relevant factors include
    - Natural variability, e.g. climate
    - Demographic, e.g. migration
    - Institutional, e.g. government policy
    - Cultural, e.g. customary land-use practice

Theoretical frameworks (2 of 2): Teleconnections and Telecoupling

Teleconnections

- Derived from climate science (concept of "distal drivers", e.g. ENSO)
- Provides a macro-scale framework
- Link impacts of urbanization processes occurring in cities with LULC change in hinterlands (Seto et al. 2012)
- Seeks to make explicit the "linkages between processes and places" (Güneralp et al. 2013)
- Inspired the formulation of telecoupling, which seeks to extend this framework by considering bidirectionality of interactions

Telecoupling

- Views human-environment interactions in terms of coupled human and natural systems (CHANS) interacting
  - in place (locally)
  - cross-scalar (Liu et al. 2013)
- Systems
  - consist of agents
  - are categorized relationally, in terms of the directionality of their flows
    - Sending
    - Receiving
    - Spillover
- Flows include goods, people, money, and information
- Mapping is context and scale-dependent

Change detection analysis (CDA): Questions and methods

Questions

- What did the landscape look like before the EWEC road improvement project was completed in mid-2006?
- How has the landscape been changing since then (2007 to present) as a function of agricultural land-use systems?

Methods

- Remote sensing analysis of satellite imagery to identify and extract agricultural clearings over the period 2001 to 2014
- Spatial statistical analysis of agricultural clearings to identify patterns of changing land-cover

Methods (CDA): remote sensing

- Landsat imagery (TM, ETM+, OLI; Level 2 Surface Reflectance) for Path 125 Row 049
  - Obtained through USGS “Earth Explorer” portal for 2001-2018 (January to June)
  - Processed via LandsatLinkr (“R”-based tool) (Braaten et al. 2018)
  - Assessed all outputs visually for usability over study area, based on image quality and cloud-cover considerations
- Spring-based chrono-series assembled (nearest poss. “anniversary” dates):

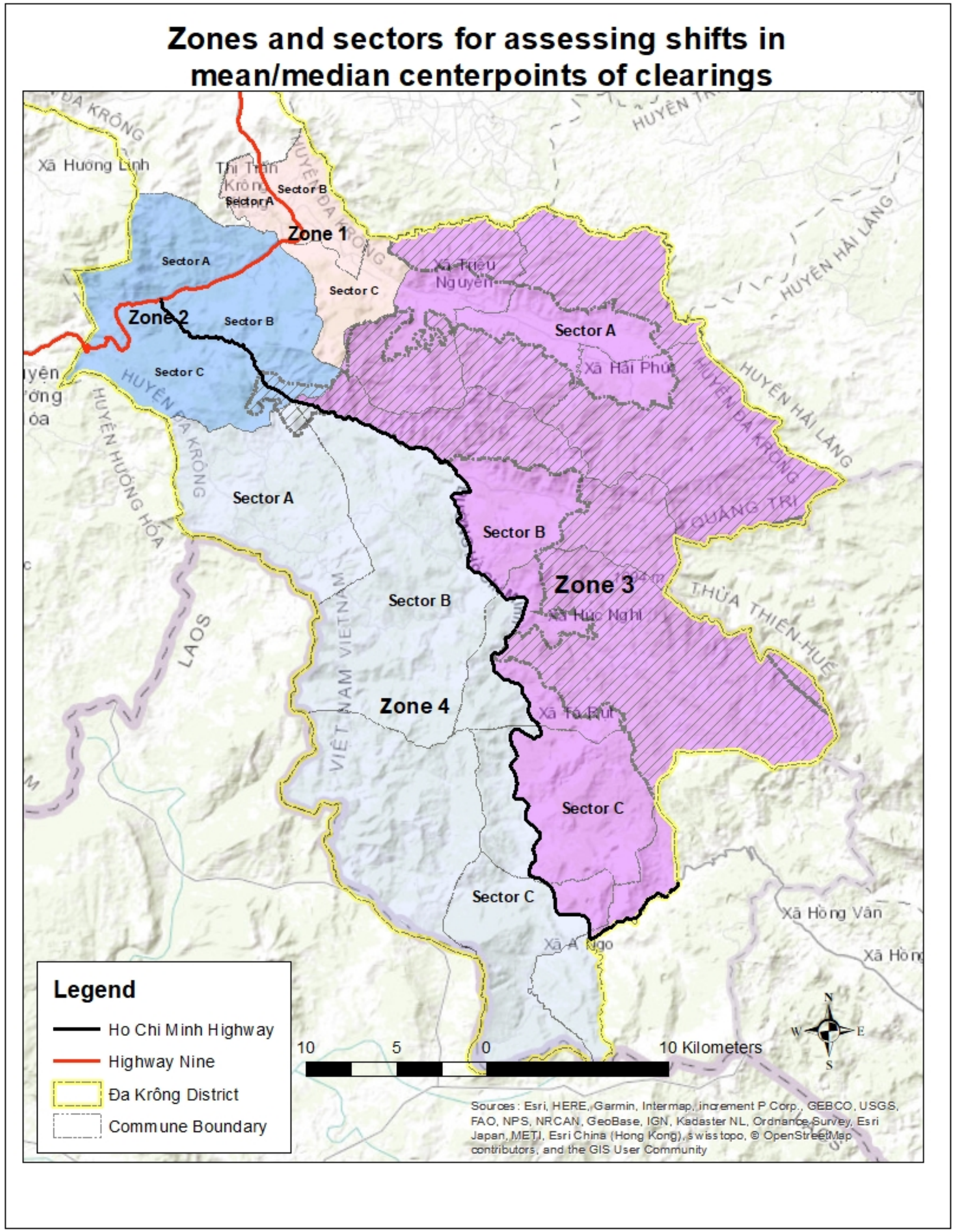
  2001097 (early April 2001)
  2006095 (early April 2006)
  2007114 (mid-April 2007)
  2009087 (late-March 2009)
  2014117 (mid-April 2014)

Methods (CDA): remote sensing / GIS

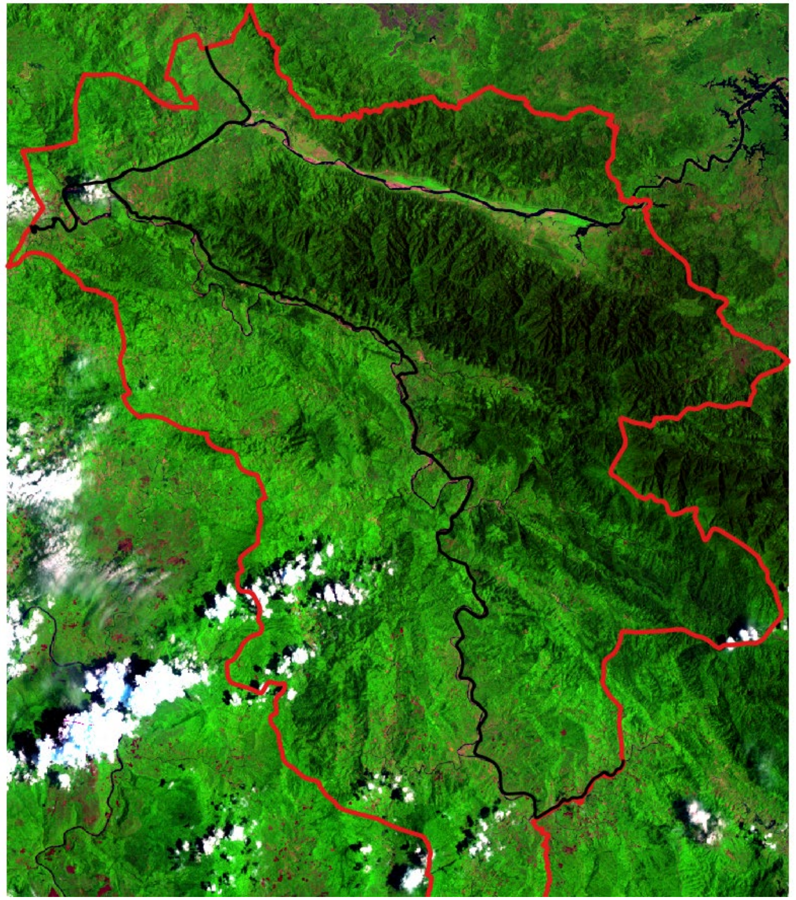
- Layer-stacked images used to generate ***normalized burn ratio*** (NBR) indices to accentuate cleared areas on the landscape (Li et al. 2014)
- NBR outputs classified using unsupervised “ISO” clustering method
- Clearings extracted using GIS for analysis with spatial statistical methods:
    - summary statistics (count / area)
    - clustering metrics (distance between clearings)
    - sampling of distance and terrain metrics
    - central tendency of clearings by zone and sector
    - heat-mapping using kernel density surfaces

Methods – median center points of clearings

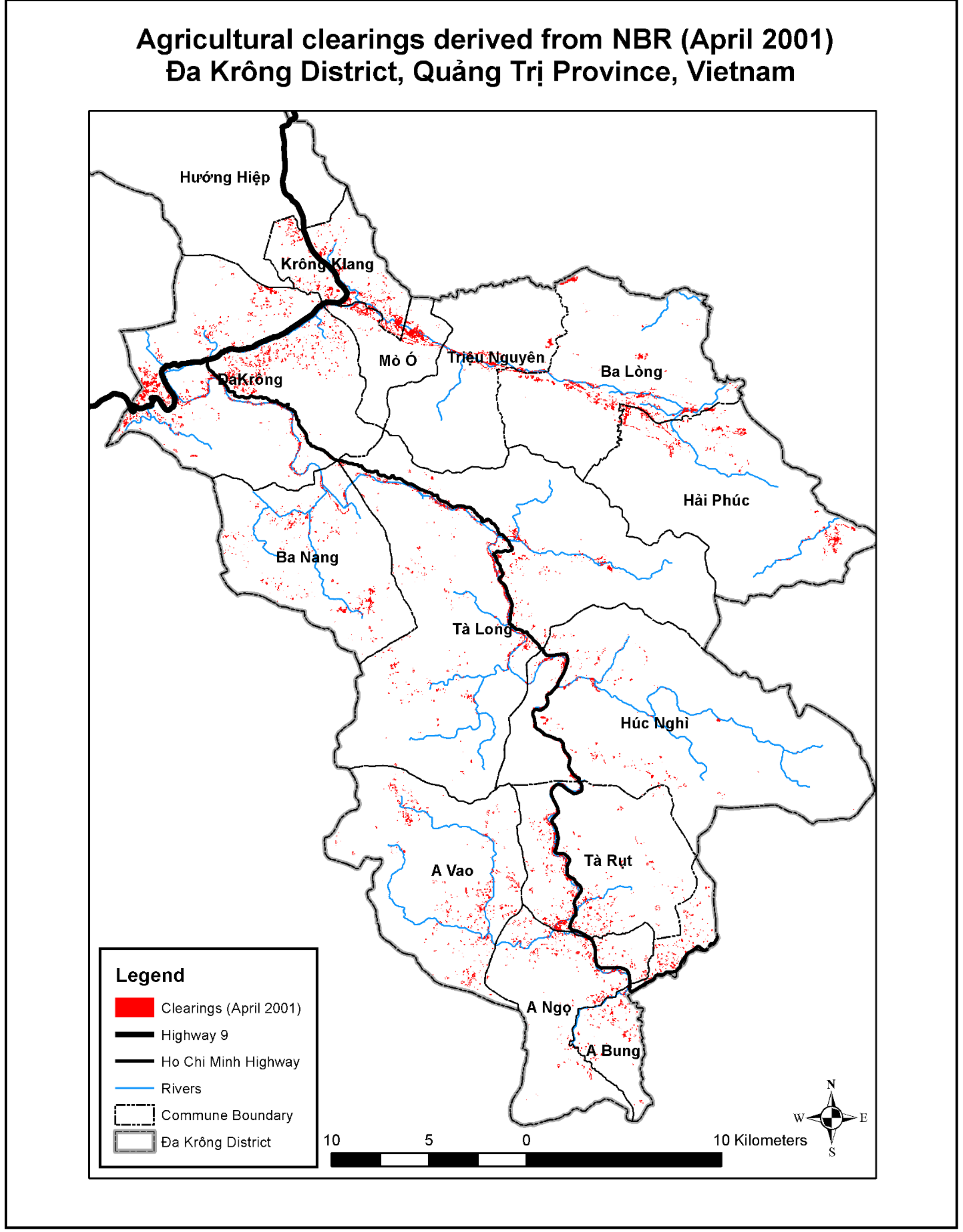
- Zone 1 (Northeast)
  - Area: 46.1 sq. km
  - Primary road length: 5.7 km
- Zone 2 (Northwest)
  - Area: 109.4 sq. km
  - Primary road length: 25.2 km
- Zone 3 (Southeast)
  - Area: 473.8 sq. km (385.2 sq. km under protected status)
  - Primary road length: 40 km (adjacent to the center and southern sectors)
- Zone 4 (Southwest)
  - Area: 335.9 sq. km
  - Primary road length: 47 km



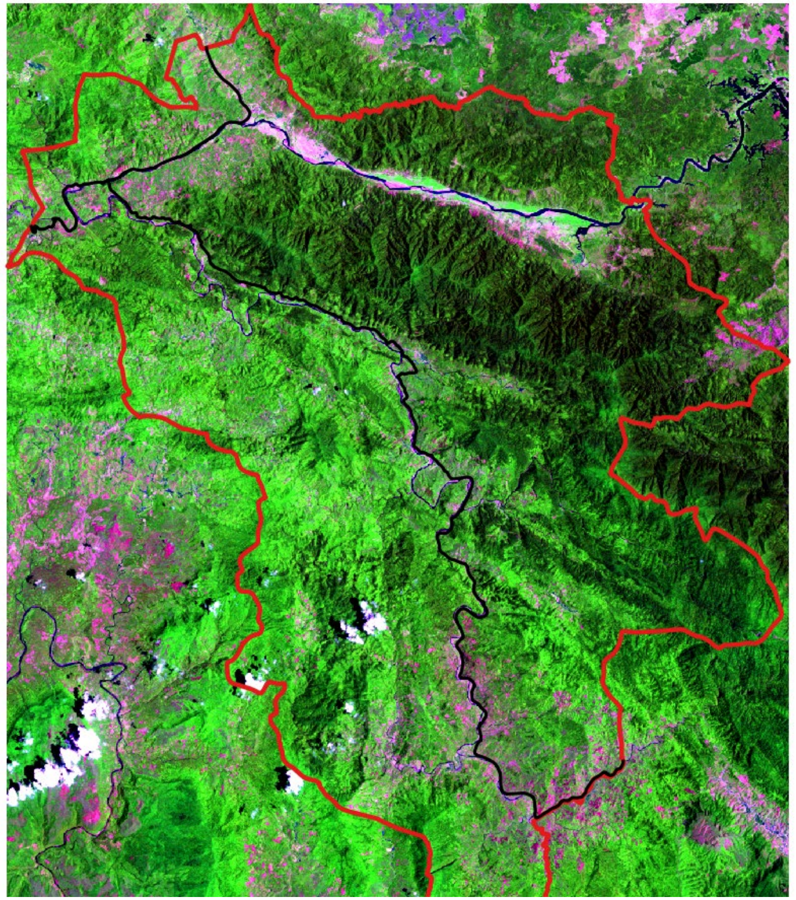
Results – extraction of cleared areas (2001)



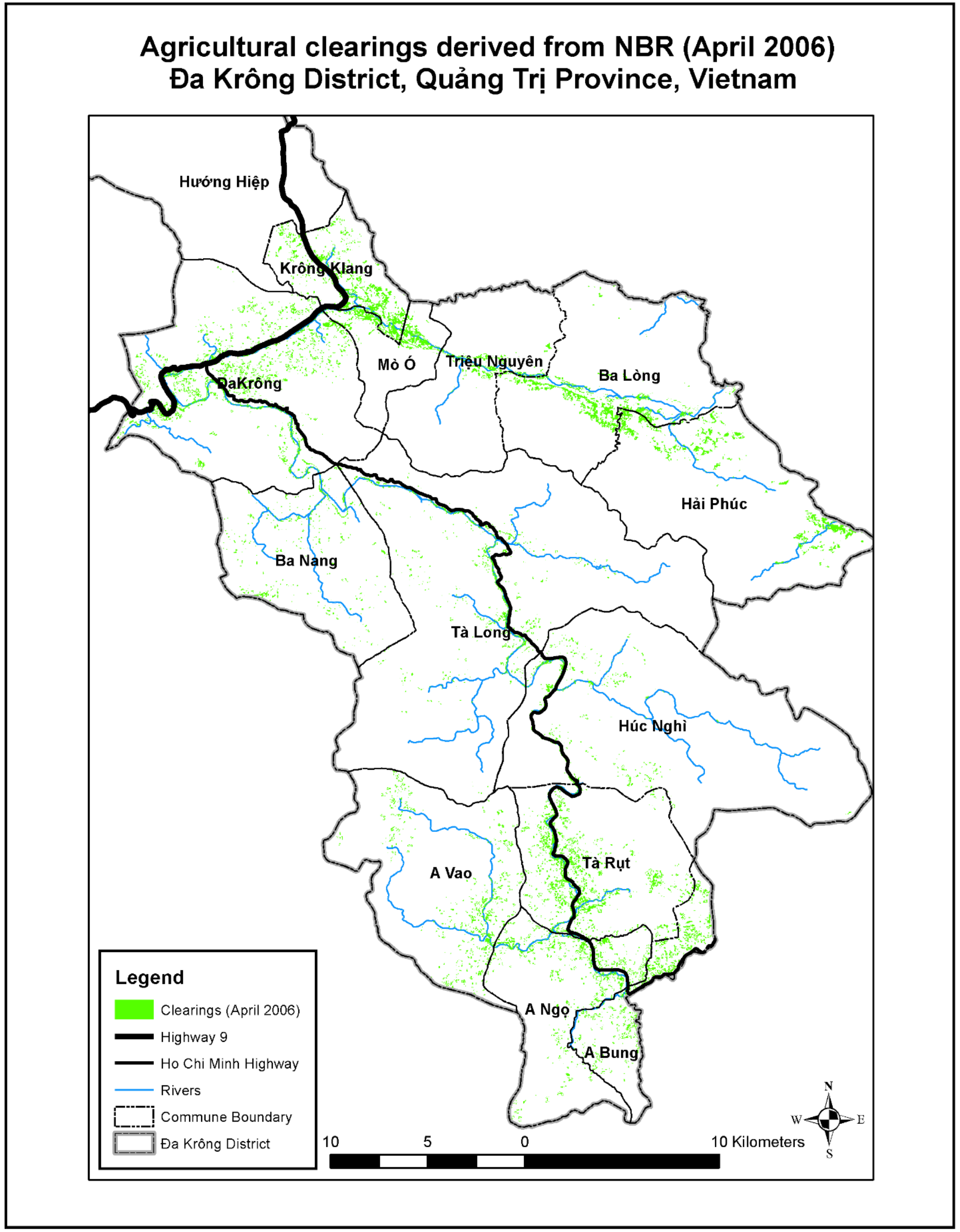
Original Landsat 5 (TM) for April 2001
(Path/Row 125/049, Band combination 6-4-3)



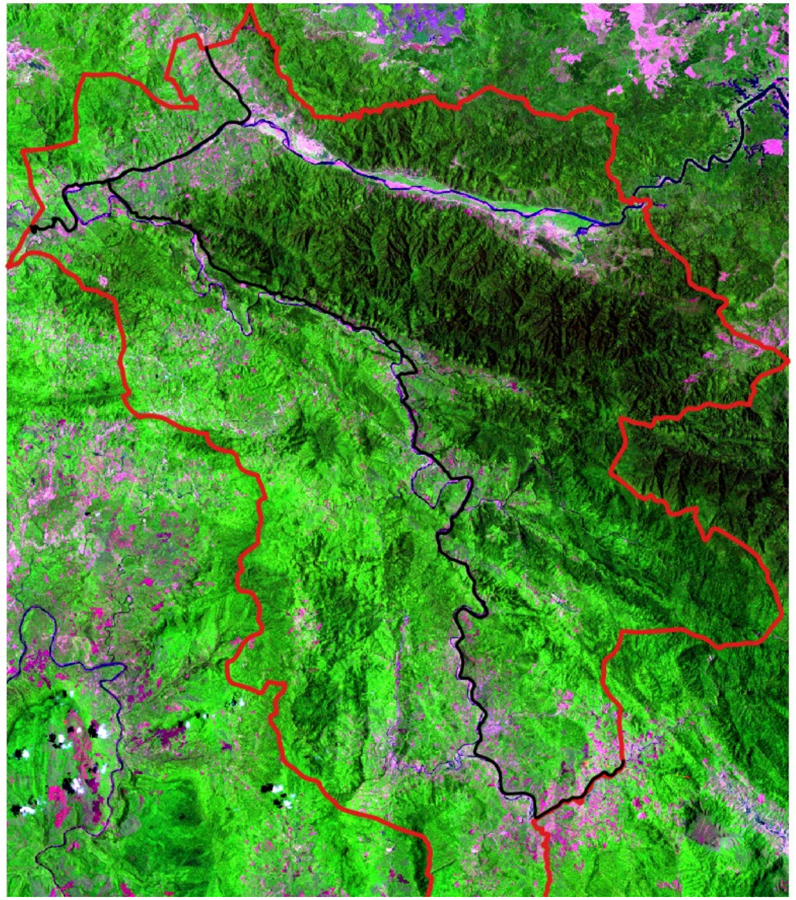
Results – extraction of cleared areas (2006)



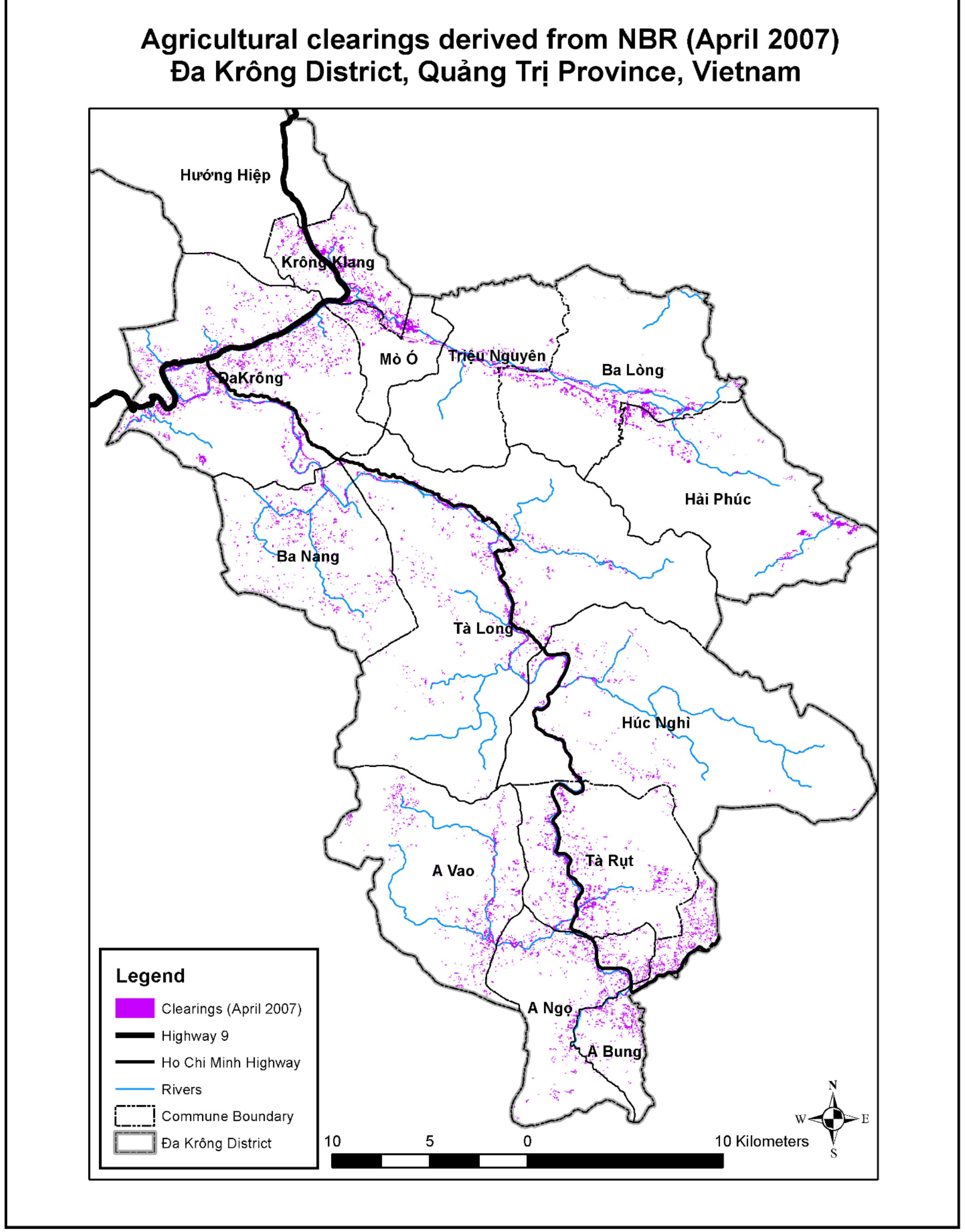
Original Landsat 5 (TM) for April 2006
(Path/Row 125/049, Band combination 6-4-3)



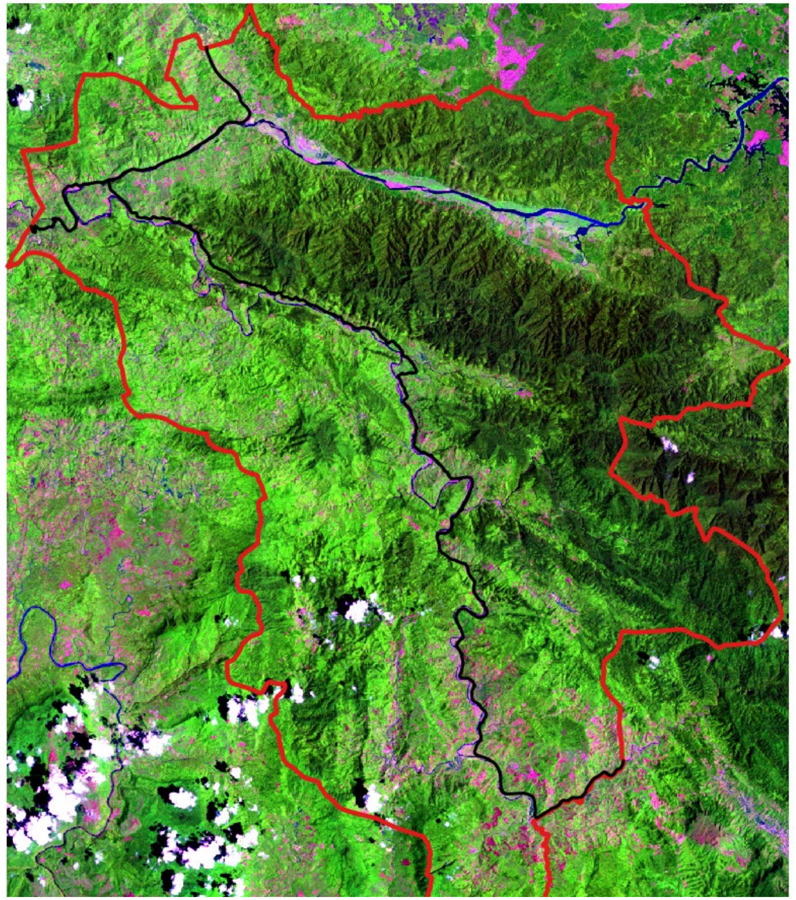
Results – extraction of cleared areas (2007)



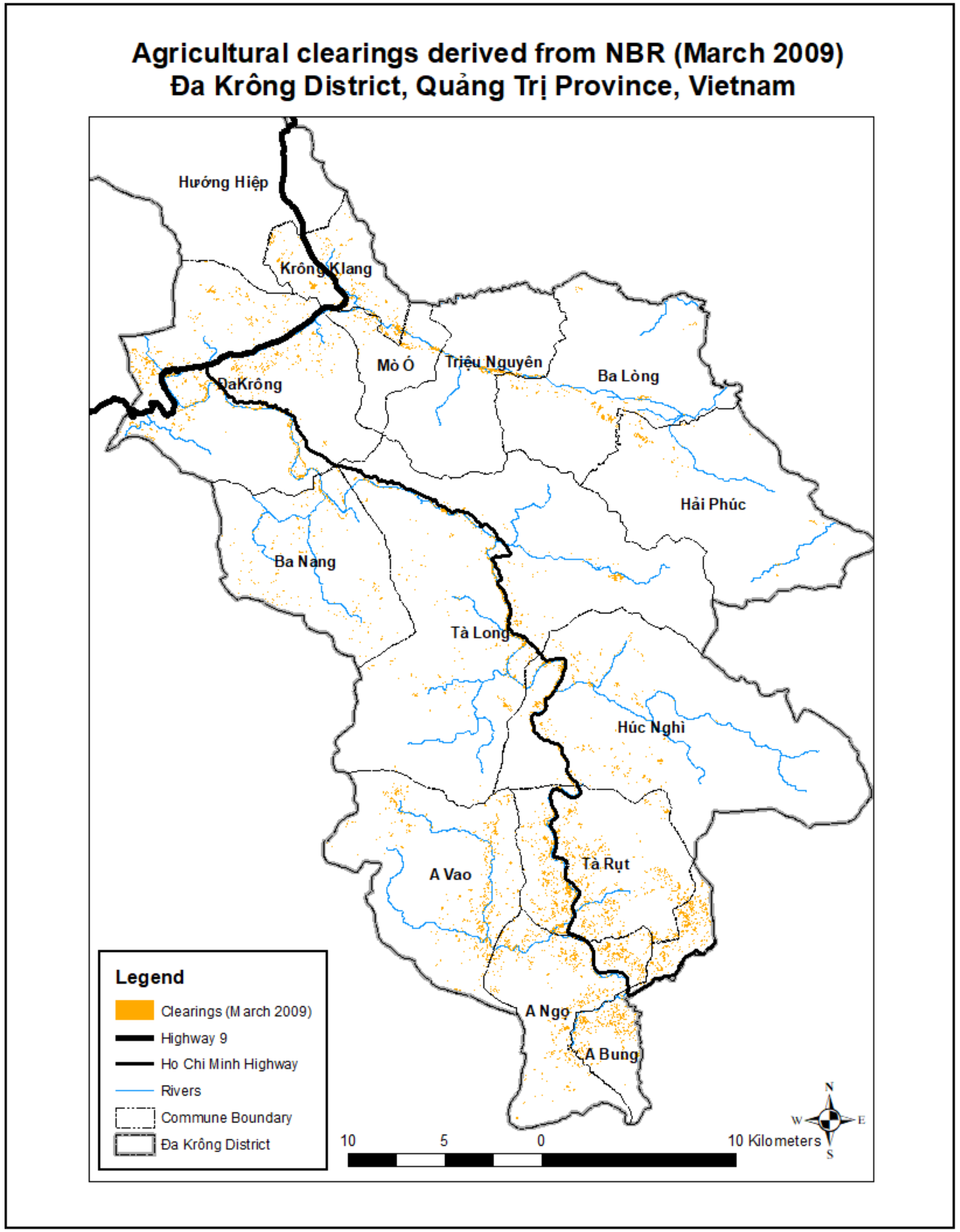
Original Landsat 5 (TM) for April 2007
(Path/Row 125/049, Band combination 6-4-3)



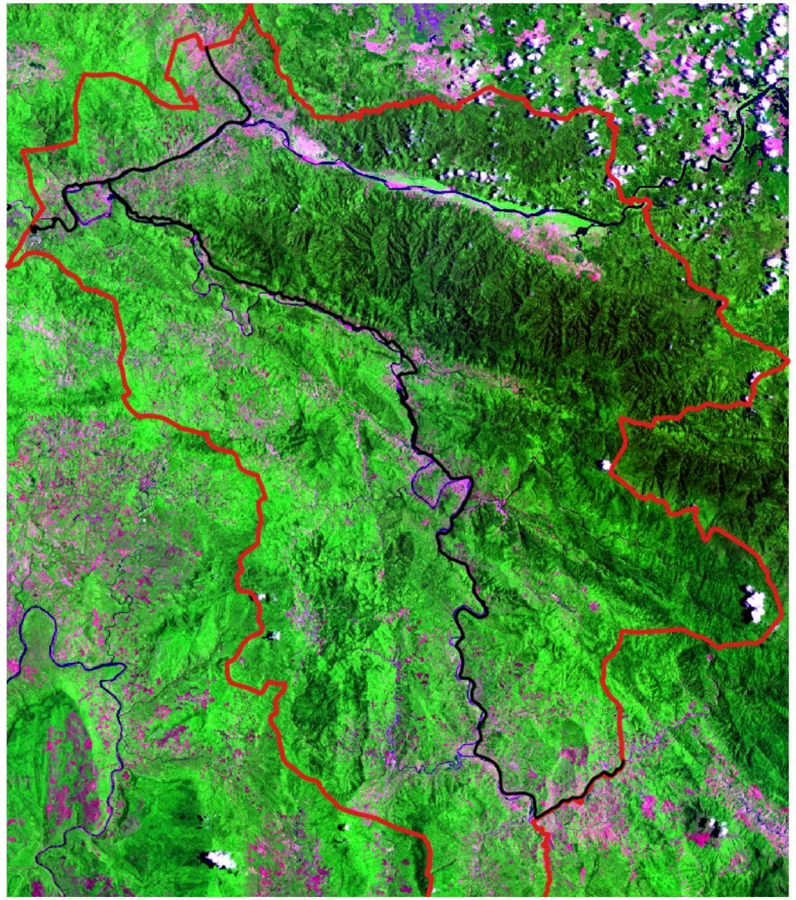
Results – extraction of cleared areas (2009)



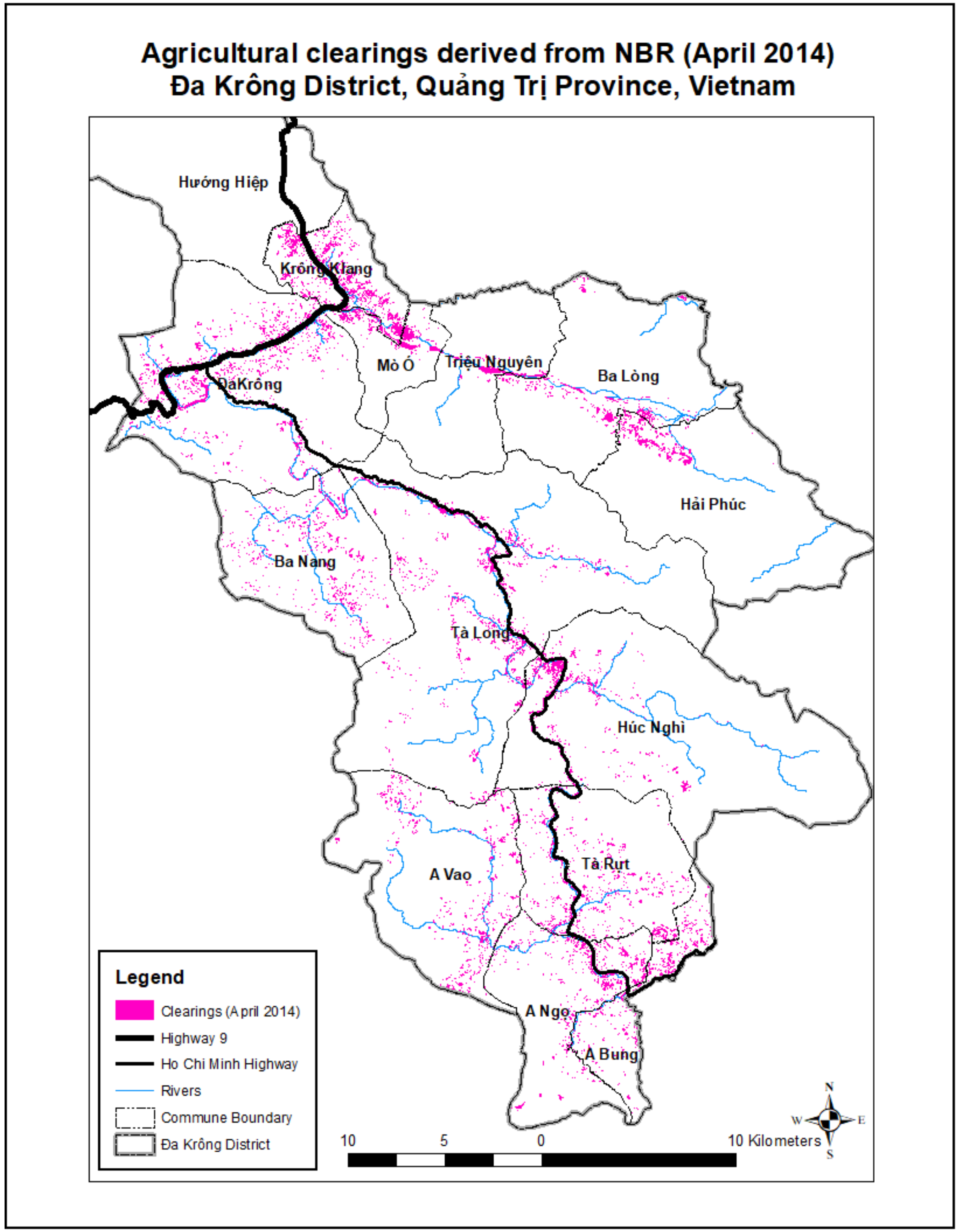
Original Landsat 5 (TM) for March 2009
(Path/Row 125/049, Band combination 6-4-3)

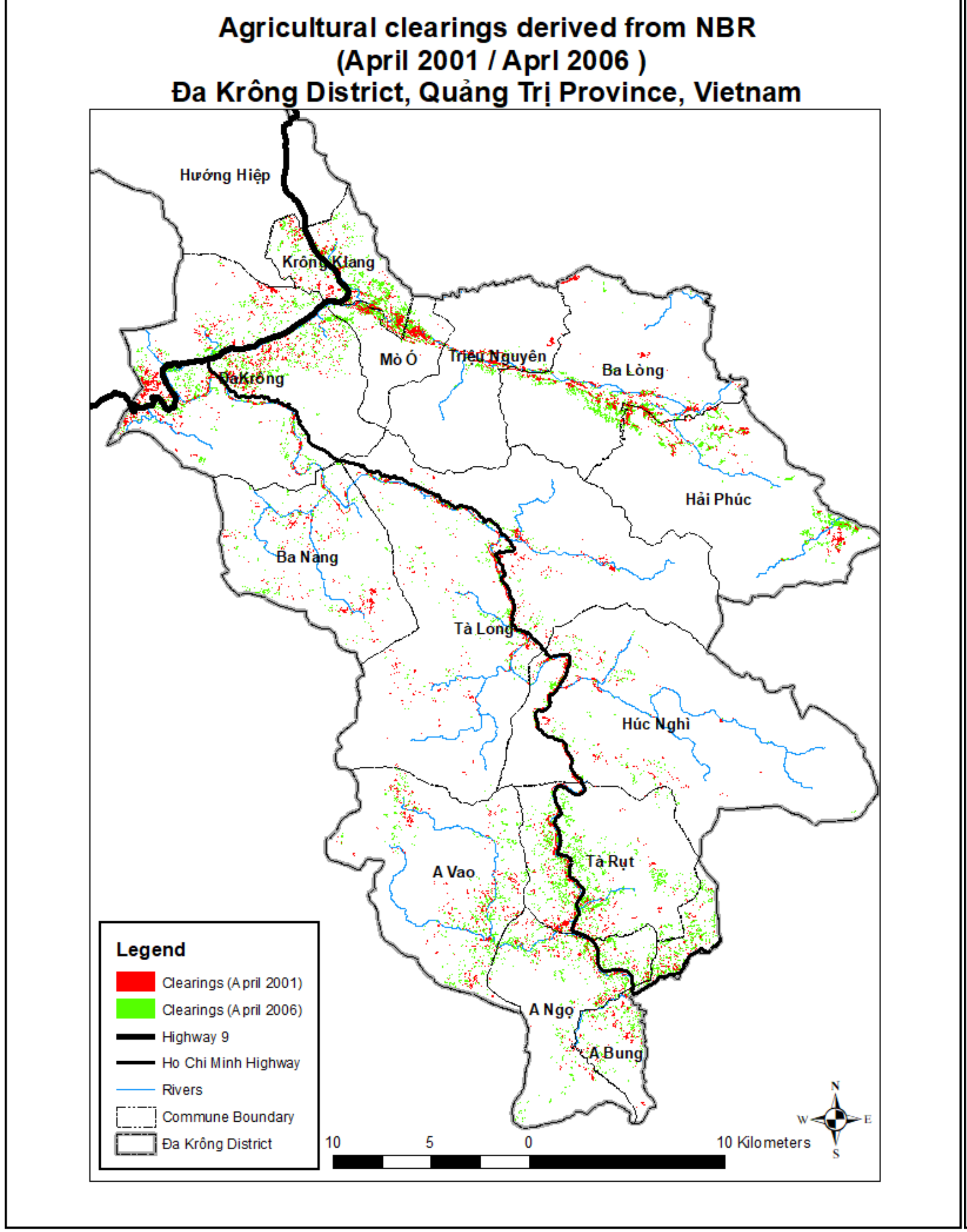


Results – extraction of cleared areas (2014)

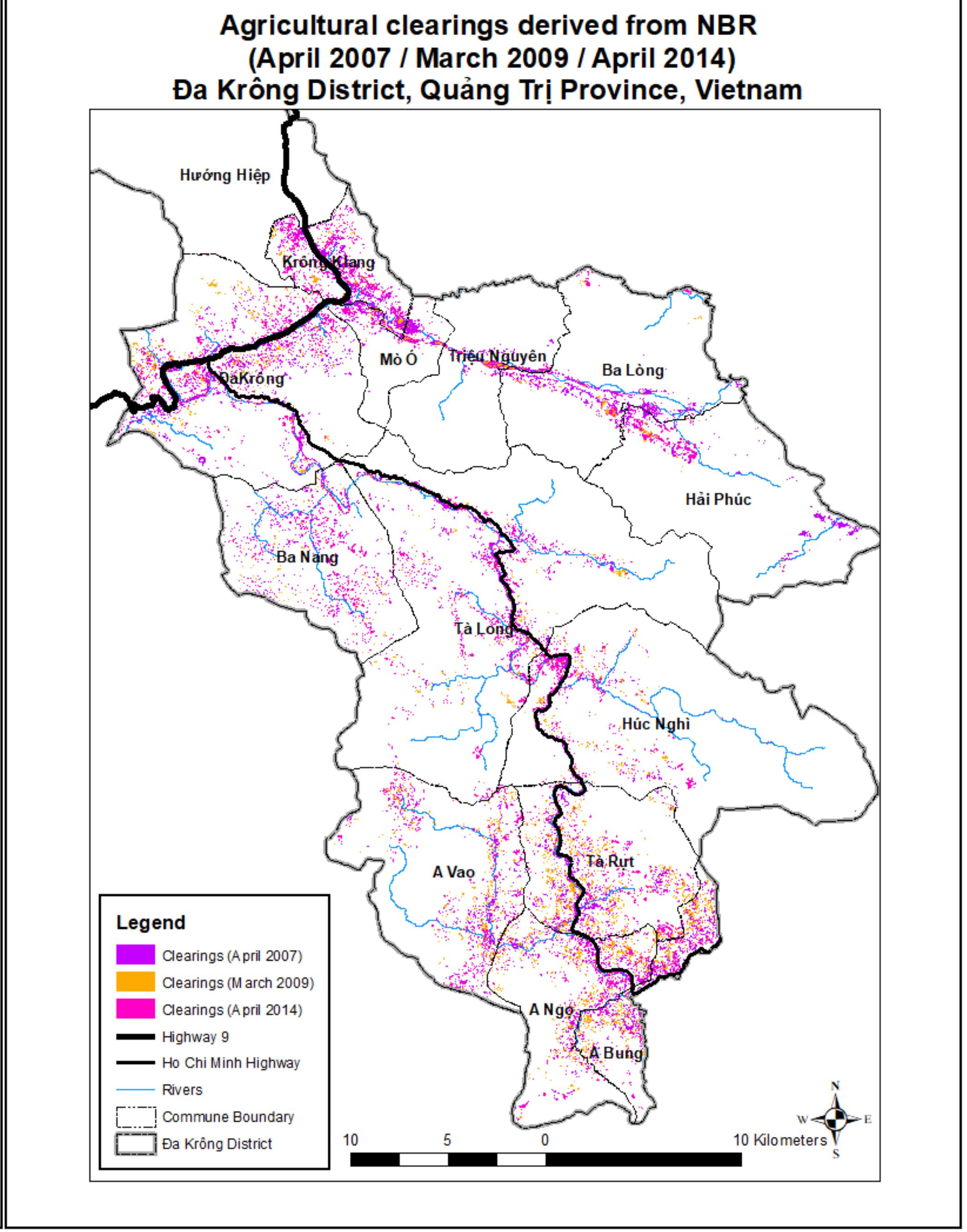


Original Landsat 8 (OLI) for April 2014
(Path/Row 125/049, Band combination 7-5-4)





Agricultural clearings derived from NBR
(April 2001 / April 2006)
Đa Krông District, Quảng Trị Province, Vietnam
Hướng Hiệp
Krông Klang
Mò Ó
Triệu Nguyên
Ba Lòng
ĐaKrông
Hải Phúc
Ba Nang
Tà Long
Húc Nghì
Tà Rụt
A Vao
A Ngo
A Bung
Legend
Clearings (April 2001)
Clearings (April 2006)
Highway 9
Ho Chi Minh Highway
Rivers
Commune Boundary
Đa Krông District
10 5 0 10 Kilometers



Agricultural clearings derived from NBR
(April 2007 / March 2009 / April 2014)
Đa Krông District, Quảng Trị Province, Vietnam
Hướng Hiệp
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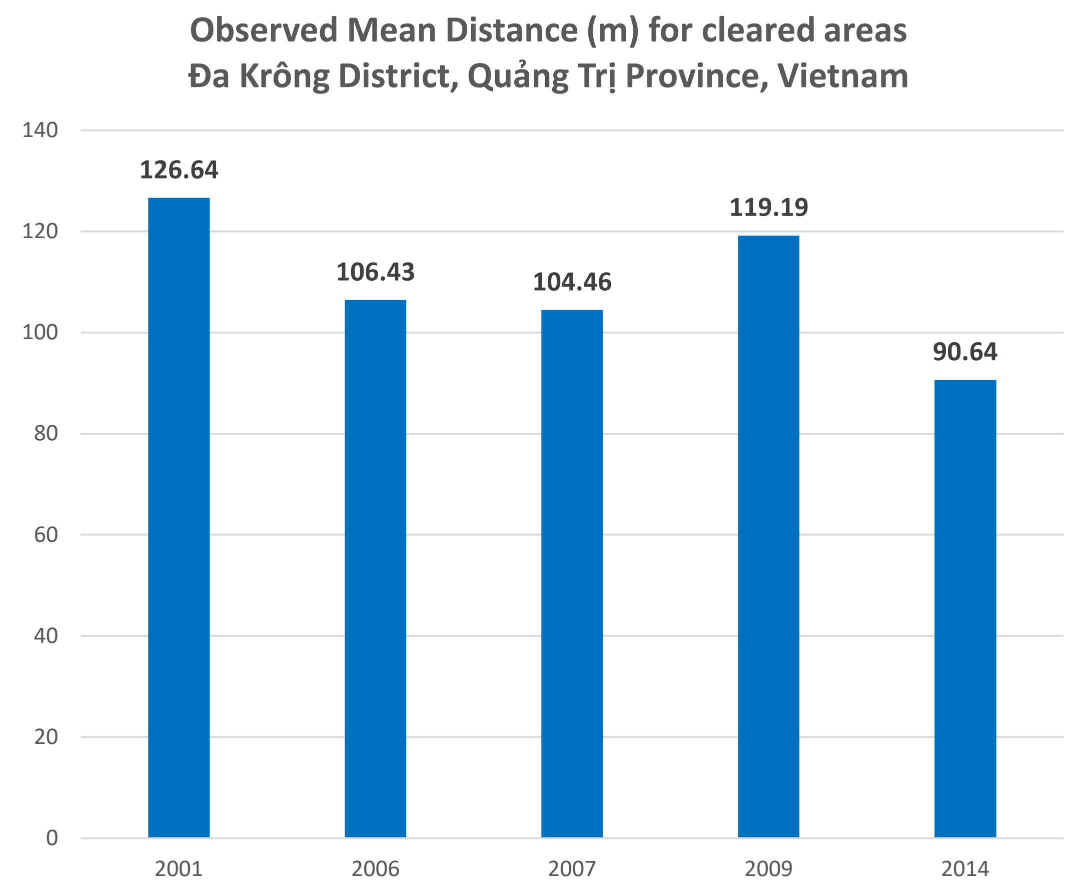
Hải Phúc
Ba Nang
Tà Long
Húc Nghì
Tà Rụt
A Vao
A Ngo
A Bung
Legend
Clearings (April 2007)
Clearings (March 2009)
Clearings (April 2014)
Highway 9
Ho Chi Minh Highway
Rivers
Commune Boundary
Đa Krông District
10 5 0 10 Kilometers

Results – summary statistics

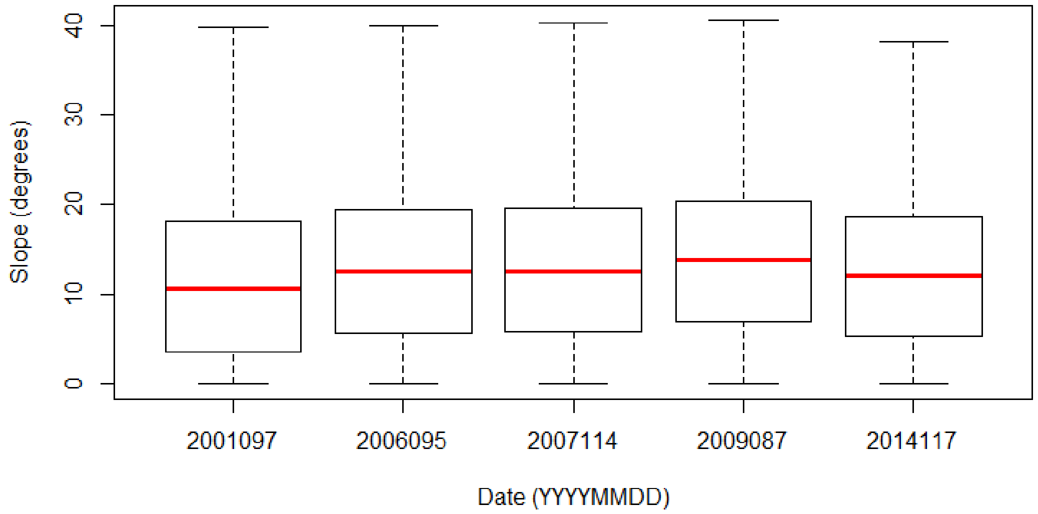
- Total Area
  - 14.9% increase (2014 vs. 2006)
- Total count of clearings
  - 25% increase (2014 vs. 2006)
- Observed mean distance
  - 15% decrease (2014 vs. 2006)



Results – statistical sampling (All clearings district-wide)

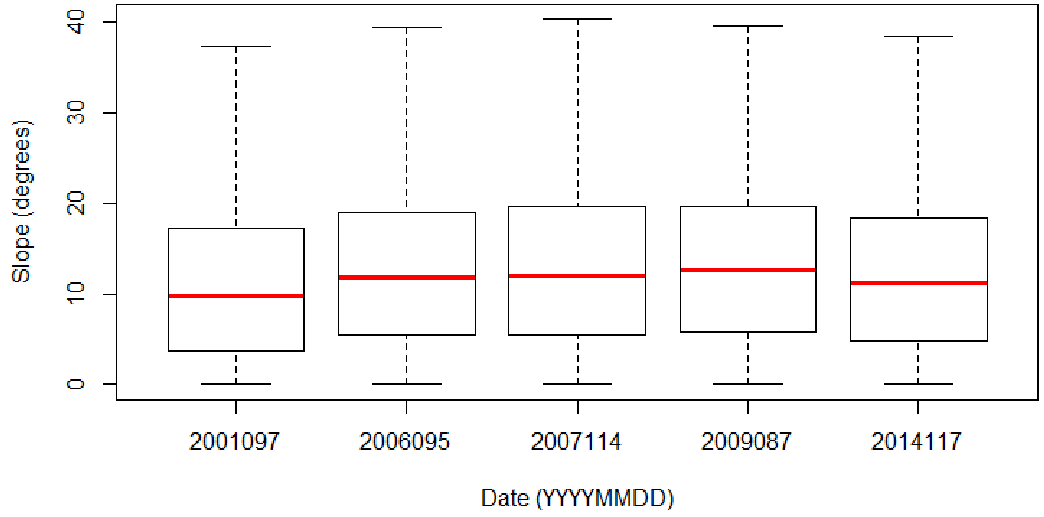
Statistics sampled for all clearings district-wide, extracting values for

- Distance metrics
  - Distance to population
  - Distance to roads
- Terrain metrics
  - Elevation
  - Slope

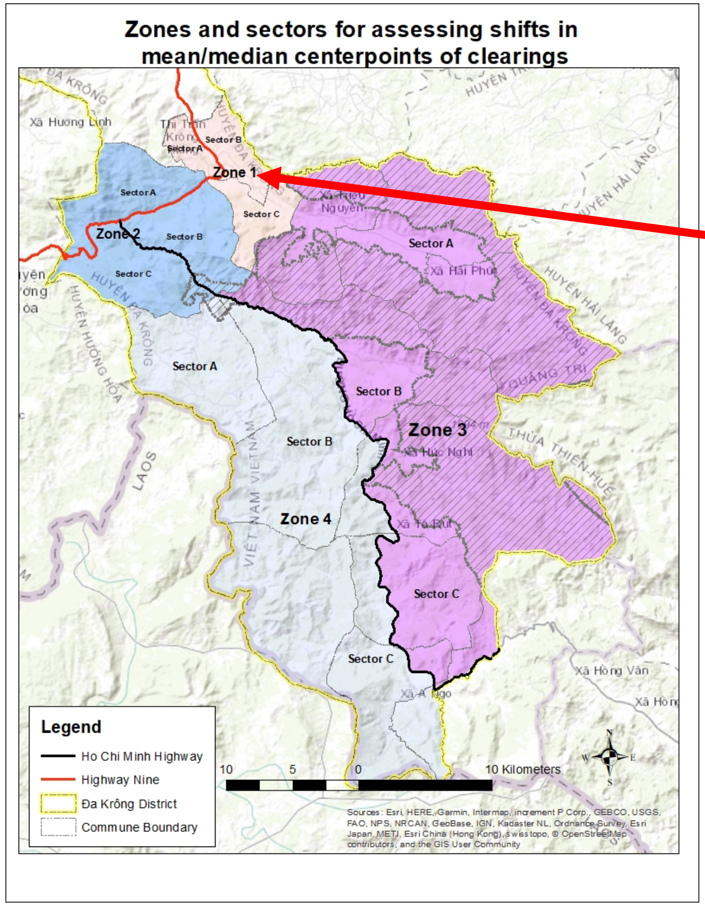


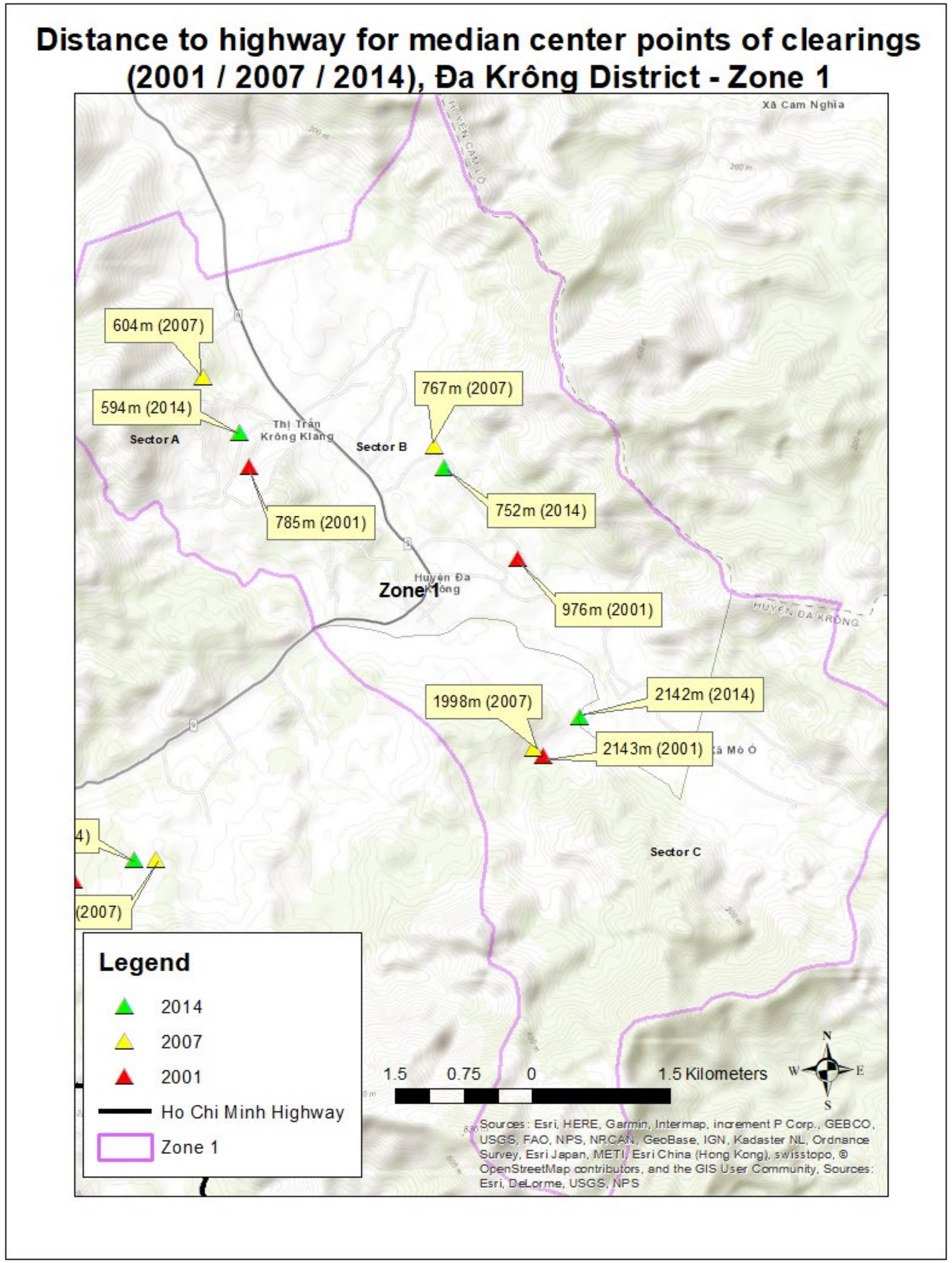
Results – statistical sampling (Subset of clearings – 1500m road buffer)

- Samples taken for subset of clearings (1500m road buffer)
- Distance metrics
  - Distance to population
  - Distance to roads
- Terrain metrics
  - Elevation
  - Slope
- Reason for subsetting: “variation…is obscured in aggregate data (for example, district-level means)” (Chomitz and Gray 1996)

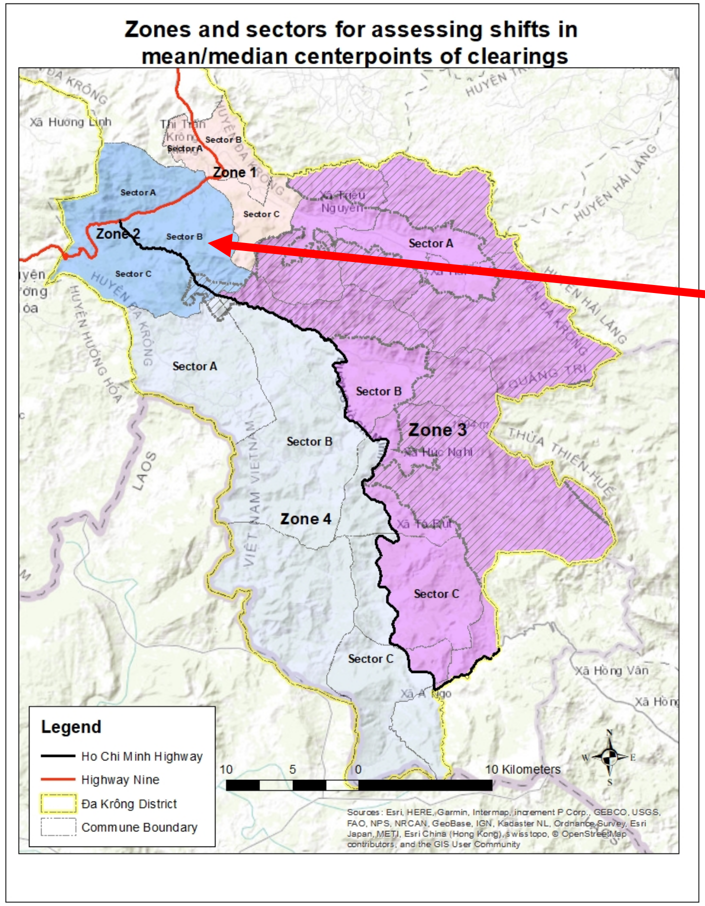


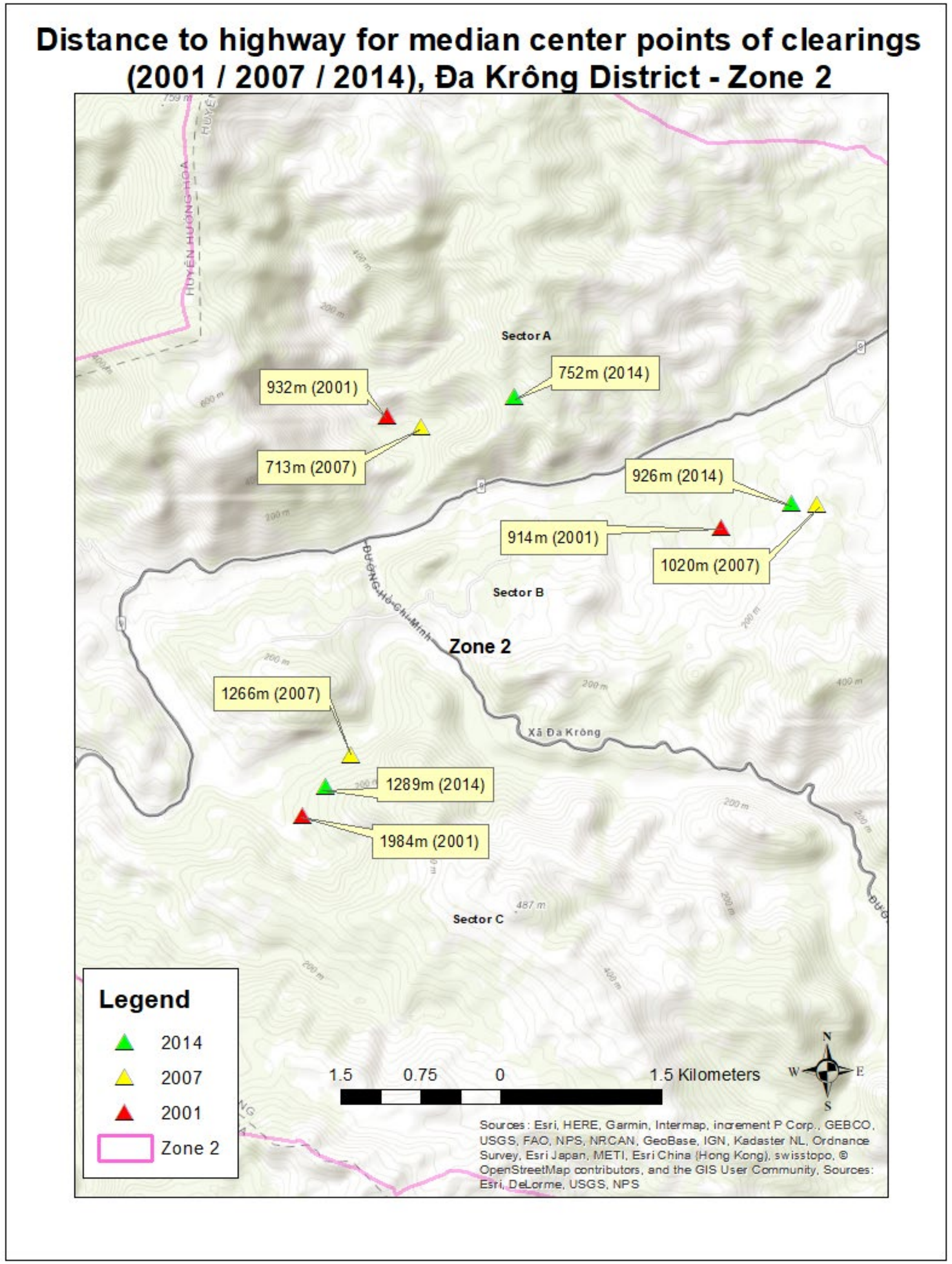
Results – median center points (Zone 1 – Northeast)



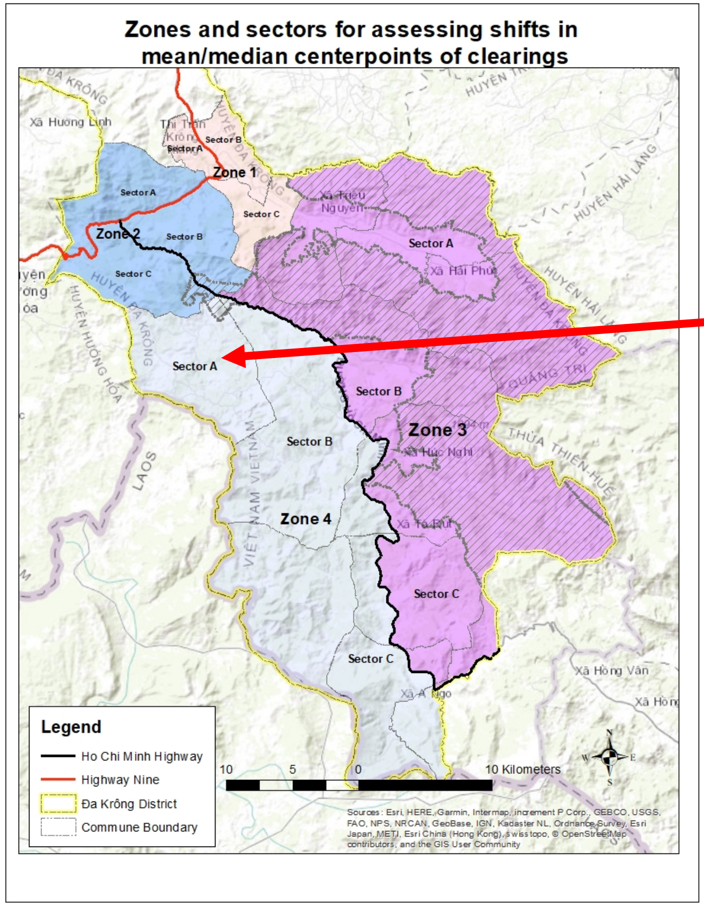


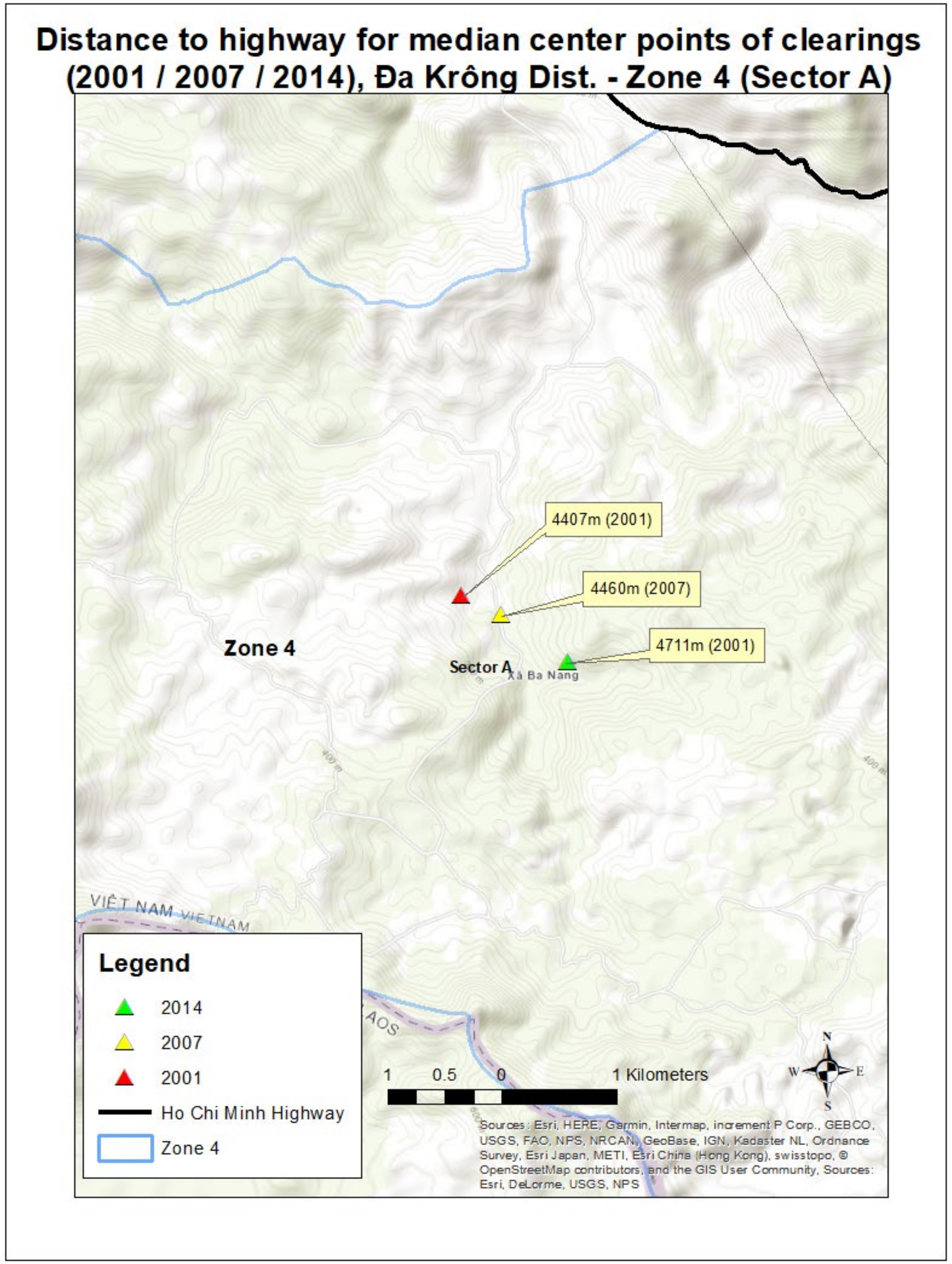
Results – median center points (Zone 2 – Northwest)



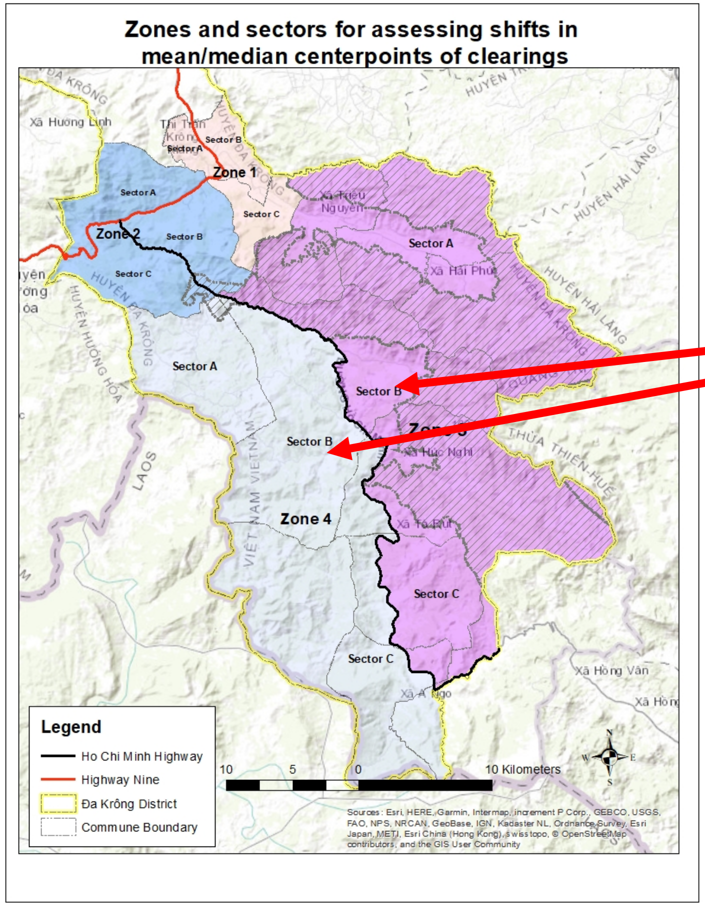


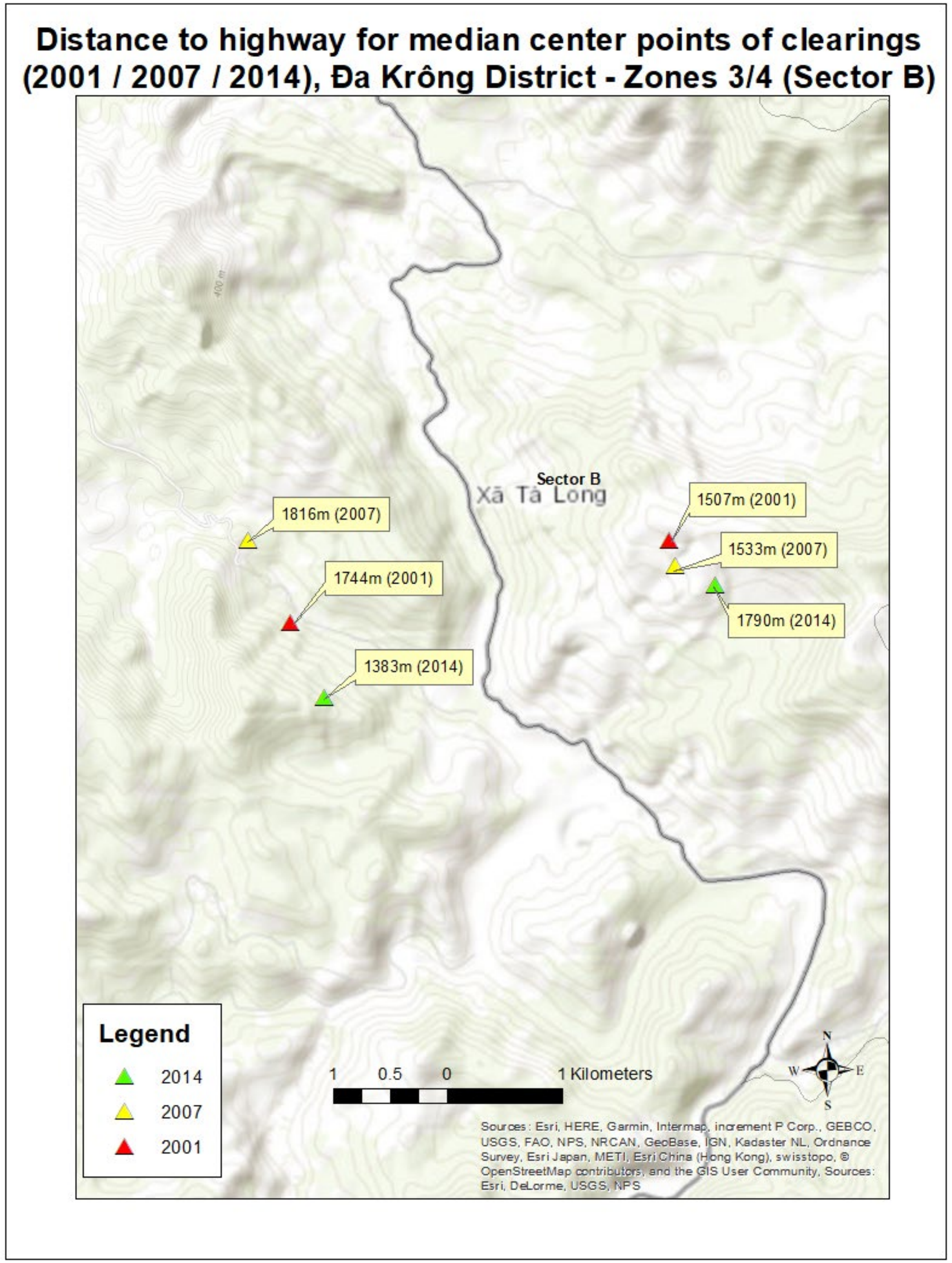
Results – median center points (Zone 4 – Sector A)



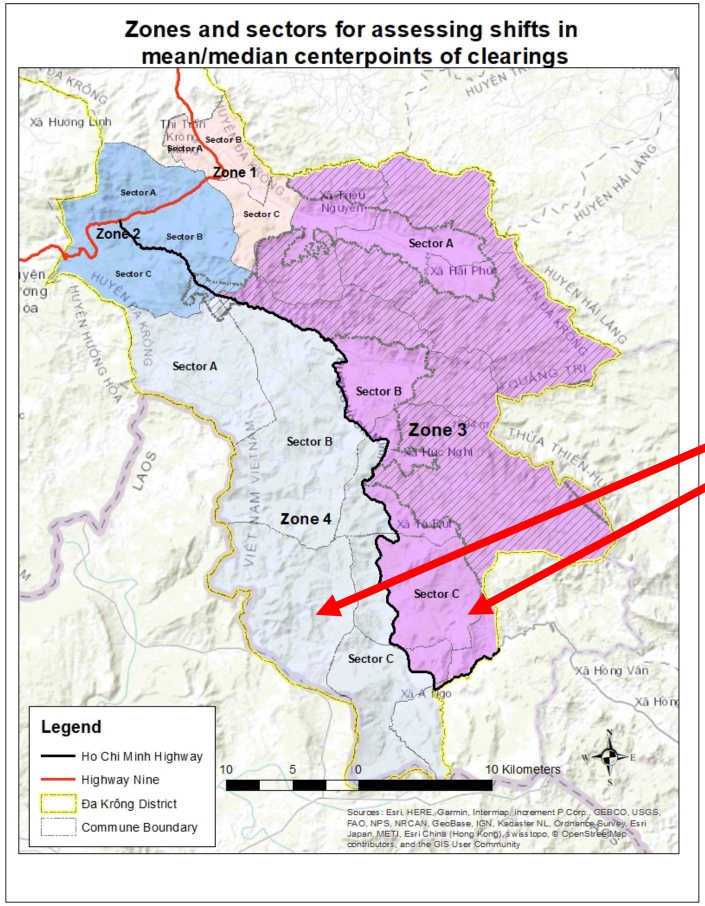


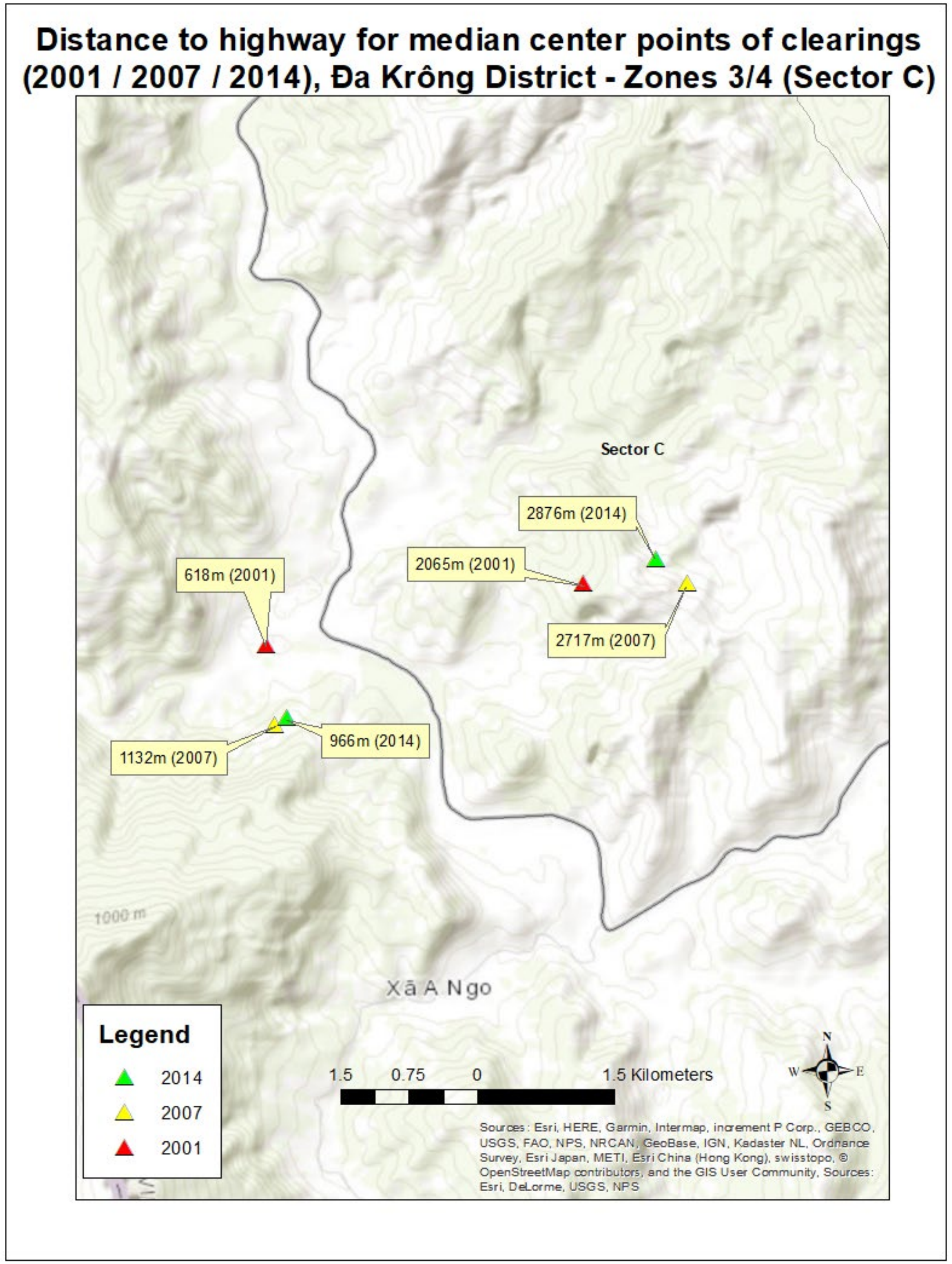
Results – median center points (Zones 3 / 4 – Sector B)





Results – median center points (Zones 3 / 4 – Sector C)





Results – median center points (Directional shifts)

Zone 1:

- Sector A: *toward* Highway 9 by 191m (24.3%)
- Sector B: *toward* Highway 9 by 224m (23%)
- Sector C: *no net movement observed*

Zone 2:

- Sector A: *toward* Highway 9 by 180m (19.3%)
- Sector B: *away from* Highway 9 by 12m (1.3%)
- Sector C: *toward* Ho Chi Minh Highway by 695m (35%)

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

Results – median center points (Directional shifts)

Zone 3:

- Sector B: *away from* Ho Chi Minh Highway by 283m (18.8%)
- Sector C: *away from* Ho Chi Minh Highway by Highway 9 by 811m (39.3%)

Zone 4:

- Sector A: *away from* Ho Chi Minh Highway by 304m (6.9%)
- Sector B: *toward* Ho Chi Minh Highway by 361m (20.7%)
- Sector C: *away from* toward Ho Chi Minh Highway by 348m (56.3%)

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
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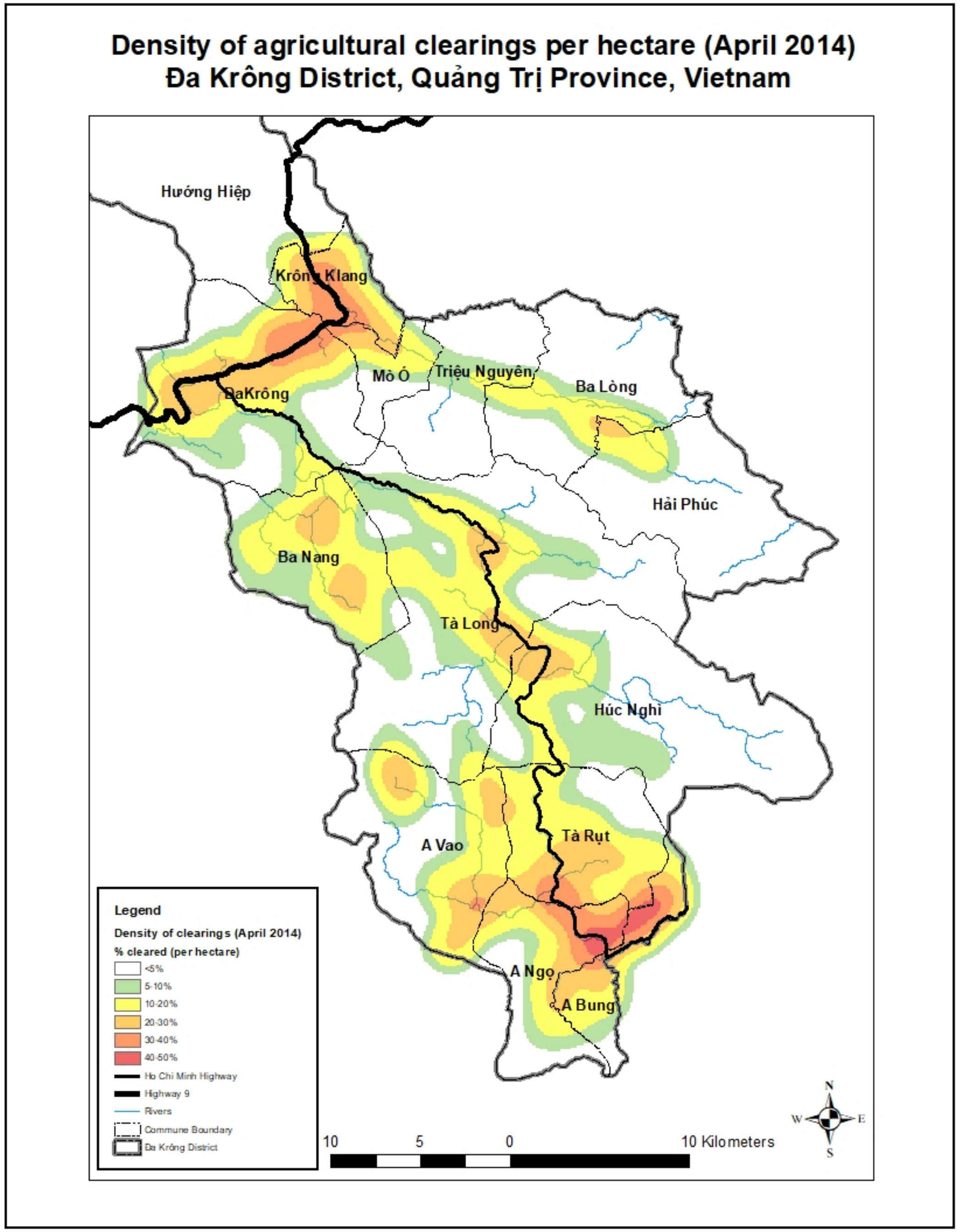
3	B	1507	1790	-283	-18.78	away from road	HCM Highway
	C	2065	2876	-811	-39.27	away from road	HCM Highway
4	A	4407	4711	-304	-6.90	away from road	HCM Highway
	B	1744	1383	361	20.70	toward road	HCM Highway
	C	618	966	-348	-56.31	away from road	HCM Highway

Results –
kernel density surfaces (clearings per hectare)

- Clearings grouped into classes by density per hectare:
  - > 0% and < 5% cleared
  - 5-10%
  - 10-20%
  - 20-30%
  - 30-40%
  - 40-50%
- Clearings at densities > 40% not observed prior to 2014 (n.b. sizeable temporal gaps exist)



Results – kernel density surfaces (clearings per hectare)

- Net *decrease* in the total extent of *lower density* cultivation (0-10% per hectare cleared) which tend to occur further from roads
- Net *increase* in the total extent of *higher density* cultivation (10-30% per hectare), which tend to occur closer to roads

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	

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	

Discussion of change detection analysis

Questions

- Do the data show a trend in land-cover change?
- If so, what pattern emerges?
- Does this pattern support or refute the hypothesis?

General finding: “Signal to noise” issue

- Lack of a clear and consistent trendline in clearings across study area due to large variability in the data at the district level from one time step to the next

- *Possible* indications of agrarian transition at sub-district level:
  - Median center point analysis shows
    - signs of intensification along Highway 9 corridor (Zones 1 / 2)
    - shifts away from HCM Highway (Zones 3 / 4)
  - Kernel density shows
    - slight increase in clearings along intensive margin (closer to roads) in Highway 9 corridor (Zones 1 / 2)
    - intensification in southernmost end of study area (Zone 4 / Sector C)

Discussion of change detection analysis – fundamental factors and drivers of change

- Land use is a function (*f)* of:
  - pressures *f* (population of resource users, labor availability, quantity of resources, and sensitivity of resources);
  - opportunities *f* (market prices, production costs, transportation costs, and technology);
  - policies *f* (subsidies, taxes, property rights, infrastructure, and governance);
  - vulnerability *f* (exposure to external perturbations, sensitivity, and coping capacity); and
  - social organization *f* (resource access, income distribution, household features, and urban-rural interactions)

  (Lambin et al. 2003: 226)

- *Proximate (or direct) causes* of land-cover change are defined as "human activities or immediate actions that originate from intended land-use and directly affect landcover" and "generally operate at the local level"
- *Underlying (or indirect) causes* are "fundamental forces that underpin the more proximate causes of land-cover change…(and) operate more diffusely" (Lambin et al. 2013: 216). Such causes "may originate from regional…or even global levels" and "are often exogenous to local communities managing land and thus uncontrollable by these communities"

(Lambin et al. 2013: 216-217)

Discussion on change detection analysis – relevance of theoretical frameworks

- Land use is a function (*f)* of:
  - pressures *f* (population of resource users, labor availability, quantity of resources, and sensitivity of resources);
  - **opportunities *f* (market prices, production costs, transportation costs, and technology)**;
  - policies *f* (subsidies, taxes, property rights, infrastructure, and governance);
  - vulnerability *f* (exposure to external perturbations, sensitivity, and coping capacity); and
  - social organization *f* (resource access, income distribution, household features, and urban-rural interactions) (Lambin et al. 2003)

Relevance of von Thünen's theory of land rent to proximate causes of LULC change

- Land rent rises in response to
  - Higher agricultural prices (*p*)
  - Increased yields (*y*)
  - Lack of off-farm work opportunities (*w*)
  - Reduction in transport costs (*v*)
- Roads *directly reduce* value of *v* by up to 50% (Jacoby & Minten 2009; Warr 2008)
- Roads *enable shifts* in values of *p* and *y* by enabling intermediaries (e.g. commodities brokers) in communities at the village level (Leisz et al. 2016)
- This combination of factors is highly correlated with agricultural intensification (Angelsen & Kaimowitz 1999)

Discussion on change detection analysis – relevance of theoretical frameworks

- Land use is a function (*f)* of:
  - pressures *f* (population of resource users, labor availability, quantity of resources, and sensitivity of resources);
  - opportunities *f* (market prices, production costs, transportation costs, and technology);
  - **policies *f* (subsidies, taxes, property rights, infrastructure, and governance);**
  - vulnerability *f* (exposure to external perturbations, sensitivity, and coping capacity); and
  - social organization *f* (resource access, income distribution, household features, and urban-rural interactions)
    (Lambin et al. 2003)

- Relevance of teleconnections / telecoupling in influencing proximate causes of LULC change
  - EWEC road project was enabled by distal, exogenous sending systems
    - International investors (ADB / JICA)
    - National government (Hanoi, Vietnam)
  - Introduction of new crops by government programs and commercial actors
    - Acacia - Program 327 (1995)
    - Cassava
  - Demand for products from exogenous markets incentivizes supply
    - Provincial (Dong Ha)
    - National (Hanoi)
    - Foreign (China / Malaysia)

    (Leisz et al. 2016)

Other factors relevant to the future trajectory of LULC change

- Land use is a function (*f)* of:
  - **pressures *f* (population of resource users, labor availability, quantity of resources, and sensitivity of resources);**
  - opportunities *f* (market prices, production costs, transportation costs, and technology);
  - policies *f* (subsidies, taxes, property rights, infrastructure, and governance);
  - **vulnerability *f* (exposure to external perturbations, sensitivity, and coping capacity);** and
  - **social organization *f* (resource access, income distribution, household features, and urban-rural interactions)** (Lambin et al. 2003)

- Population, vulnerability, and social organization are also considered important but over a longer time horizon (i.e. medium to long term)
  - Population dynamics:
    - Natural increase: recent and current population growth rates moderate (World Bank 2015)
    - Migration: little net in-/out-migration occurring, including seasonal labor flows between rural and urban areas
  - Vulnerability dynamics
    - Increasing risk to crop yields from drought / flood events due to climate change trends (Quan 2013)
    - Increasing influence of corporate land users (Barr 2012)
  - Social organization dynamics
    - Potential for class division with increasing income disparities in the future
    - Potential for changes in household structure and function with rural-to-urban labor migration

Discussion of change detection analysis results

Assessing initial hypothesis / probable causation

- Results of the analysis of best available data for this spring time series (2001 to 2014) *do not provide compelling evidence* to support asserting a causal link at this time.
- However, it would also appear premature to assert that the null hypothesis, i.e. that the road exerts no influence on the pattern of cultivation, based on findings of fieldwork for several villages (Leisz et al. 2016).

Revising hypothesis / possible correlation

- It seems reasonable to assert that at least a *possible correlation* exists between LULC change since 2007 and road improvements completed under the EWEC project based on initial findings along Highway 9.
- Reaching a more definitive conclusion on this hypothesis requires more / better data within and beyond the current time series (census data, market prices, satellite imagery), as well as follow-up visits for fieldwork.

Overview of agent-based modeling (ABM)

Question

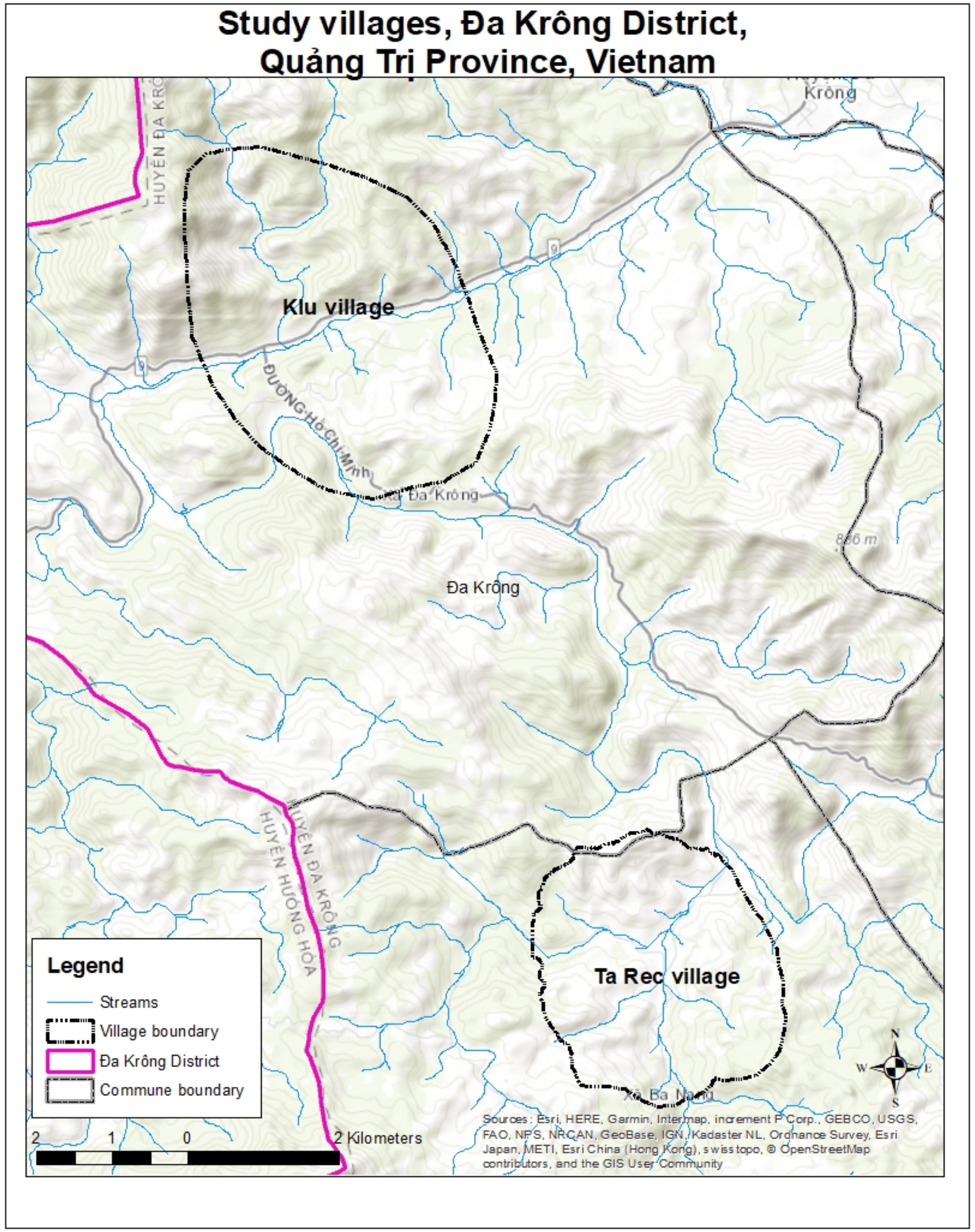
- Can processes of LULC change be modeled down to the household level and/or village scale
  - for a population engaged in shifting cultivation?
  - that is moving from autarky to market integration?

Noteworthy efforts to date

- Africa
  - Cameroon (Brown 2008)
  - Guinea (Gilruth et al. 1995)
- Latin America
  - Mexico (Manson & Evans 2007)
  - Venezuela (Riris 2018)
- Asia
  - Indonesia (Sulistyawati et al 2005)
  - Laos (Wada et al. 2007)
  - Philippines (Overmars & Verburg 2014)
  - Vietnam (Castella et al. 2007; Castella et al. 2007; Jepsen et al. 2006; Ngo et al. 2009)

Scope of ABM

- Spatial scope: two villages in the rural uplands of central Vietnam
  - Klu, Đa Krông commune
    - Area: 15 sq. km
    - Population: 134 households
  - Ta Rec, Ba Nang commune
    - Area: 10 sq. km
    - Population: 80 households
- Temporal scope: 1991 to present
  - Livelihoods pre-2007 based on shifting cultivation, animal husbandry, and forest-based activities (e.g. hunting/gathering)
- Software platform:
  - NetLogo (Wilensky 1999)
  - NetLogo GIS extension



Purpose of ABM

- **Baseline agricultural land-use** in a semi-realistic simulated landscape for each village
  - traditional subsistence-oriented practice of shifting cultivation (fifteen years, 1991-2006)
  - transition to mixed mode system of agricultural production involving subsistence cropping (dry rice) and market-oriented cash cropping (hybrid cassava)
- **Experimentally test** the effects of certain “controlling variables” on land-cover (“response variable”)
  - Endogenous factors
    - Agronomy
    - Demography
  - Exogenous factors
    - Climate variability
    - Market prices
    - Terrain constraints

Methods (ABM): Household and landscape agents

- Households agents (i.e. humans)
  - Mobile across landscape
  - Have endowments (capital, food-stock, labor)
  - Have annual rice requirement
  - Modify land-cover for agricultural land-use
    - Subsistence cropping (dry rice)
    - Cash cropping (cassava)
  - Reproduce through "fissioning" to generate new households
- Landscape (i.e. environment)
  - Fixed in location
  - Consist of patches measuring 900 square meters
  - Arable patches undergo fertility and land-cover change based on
    - agricultural land-use, if cropped
    - vegetative succession, if fallowed
  - Non-arable patches cannot be cropped and remain fixed / in a constant state

Methods (ABM): Rules for household interaction with landscape

- Patch selection *exclusion* criteria:
  - built-up areas (slope < 5 degrees)
  - overly steep slopes (slope > 40 degrees)
  - roads
  - streambeds
  - lands outside recognized village boundary
- Patch selection hierarchy of preference based on land-cover of non-excluded patches:
  - Recently cleared areas, if years of re-use < maximum allowable value
  - Secondary regrowth (late fallow)
  - Bush-grass (early fallow)
  - Woodlands / forest

Methods (ABM): Household decision-making

- Before commencing the cultivation cycle, households test whether the highway improvement project has occurred (as proxy for market access).
- If negative, households cultivate in default subsistence mode (i.e. dry rice by traditional shifting cultivation practice)
- If affirmative, households weigh
  - a) projected proceeds (i.e. revenue) from the sale of the anticipated cassava harvest (based on average yield); and
  - b) the household's annual rice cost (based on prevailing market prices for rice)
- If a > b ***and*** the household has savings sufficient to cover one year of annual rice costs (buffer in the event of harvest failure), cash cropping deemed worthwhile risk to assume in current cropping cycle and cultivated concurrently with dry rice.
- If a > b by a larger (user-specified) margin, household can cultivate cash crop ***only*** (i.e. cassava for sale to market).
- If a < b, or a > b ***but*** household lacks sufficient cashbox, household engages in subsistence only agricultural production.

Methods (ABM): Agricultural cultivation cycle

- Join group, if site already established by one of its other members (with group size set at four)
- Survey landscape
- Select patches
- Clear patches
- Plant crops
  - Subsistence crop (dry rice)
  - Cash crop (cassava)
- Harvest crops
- Compute yields of either or both crops
- Simulated occurrence of drought or flood events, based on random probability, reduces crop yields by 50%

Dry rice yield based area cleared and fallow length per Jepsen et al. (2006)

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

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

Cassava (K94 varietal) yield based on findings of fieldwork (Leisz et al. 2014):

- 10,000kg/hectare (first year)
- 6,000kg/hectare (second year)
- 4,000kg/hectare (third year)

Methods (ABM): End of cycle updates

- Per time step
  - Household agents update cashbox and energy levels based on meeting rice requirement and net income (revenue minus expenditures)
  - Landscape agents update land-cover and fertility if in fallow status; patches in recent use are reverted to fallow status

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)

Methods (ABM): Baseline and BehaviorSpace experiments implemented in NetLogo

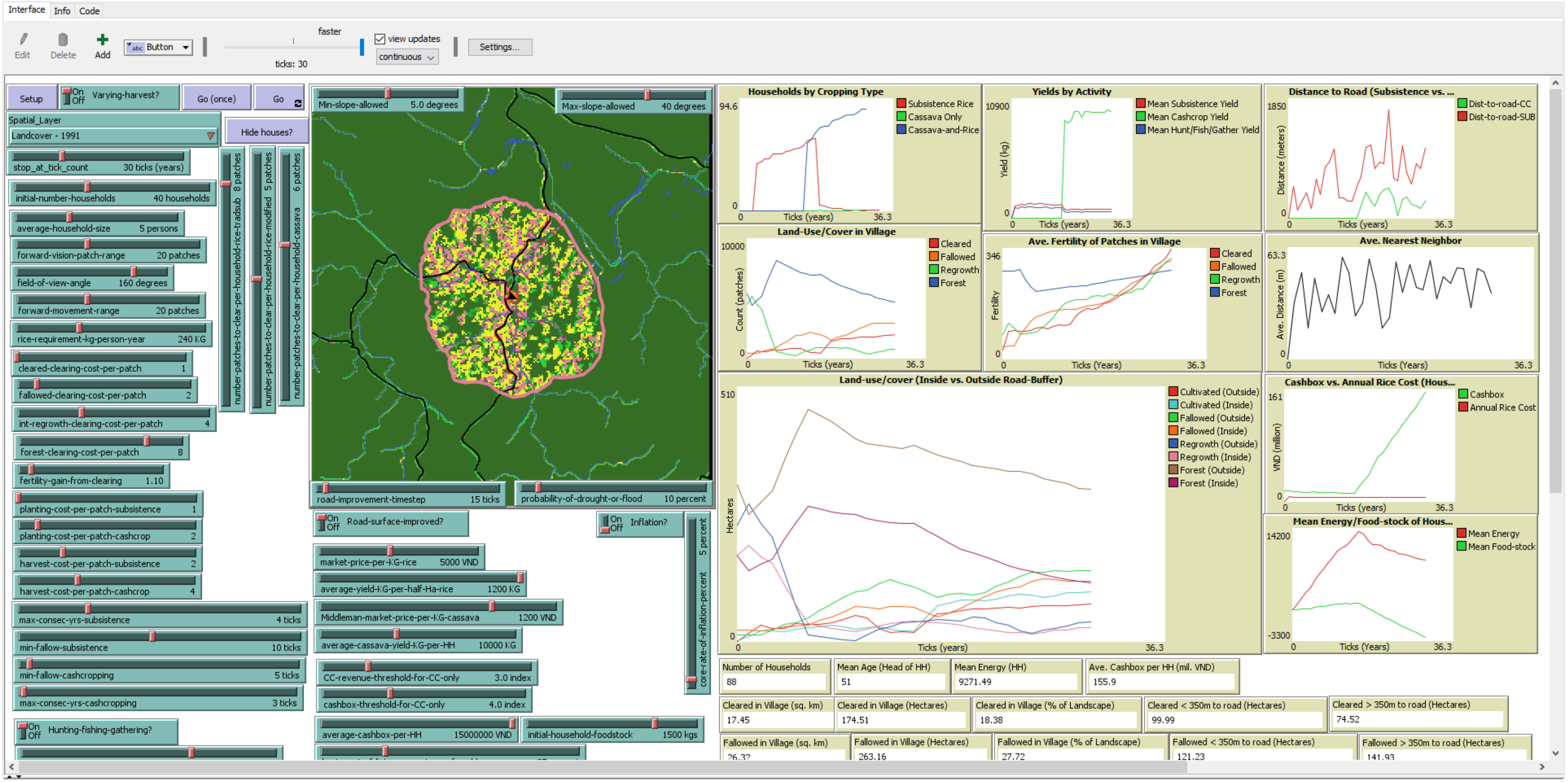
Baseline scenario (30 runs)

- Model runs for 30 timesteps with defaults as currently configured
  - Years 1-15 (1991-2006) in subsistence cropping mode
  - Years 16-30 (2006-2021) in mixed mode (subsistence plus cash cropping)
- Seed values tied to run number, to allow for reproducibility of results.

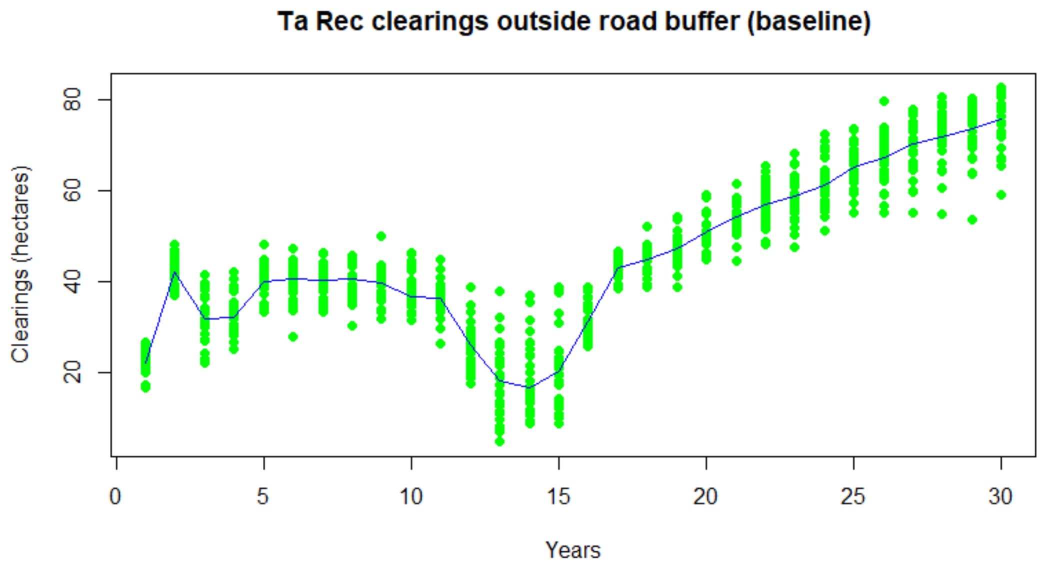
BehaviorSpace scenarios (30 runs per combination of variables)

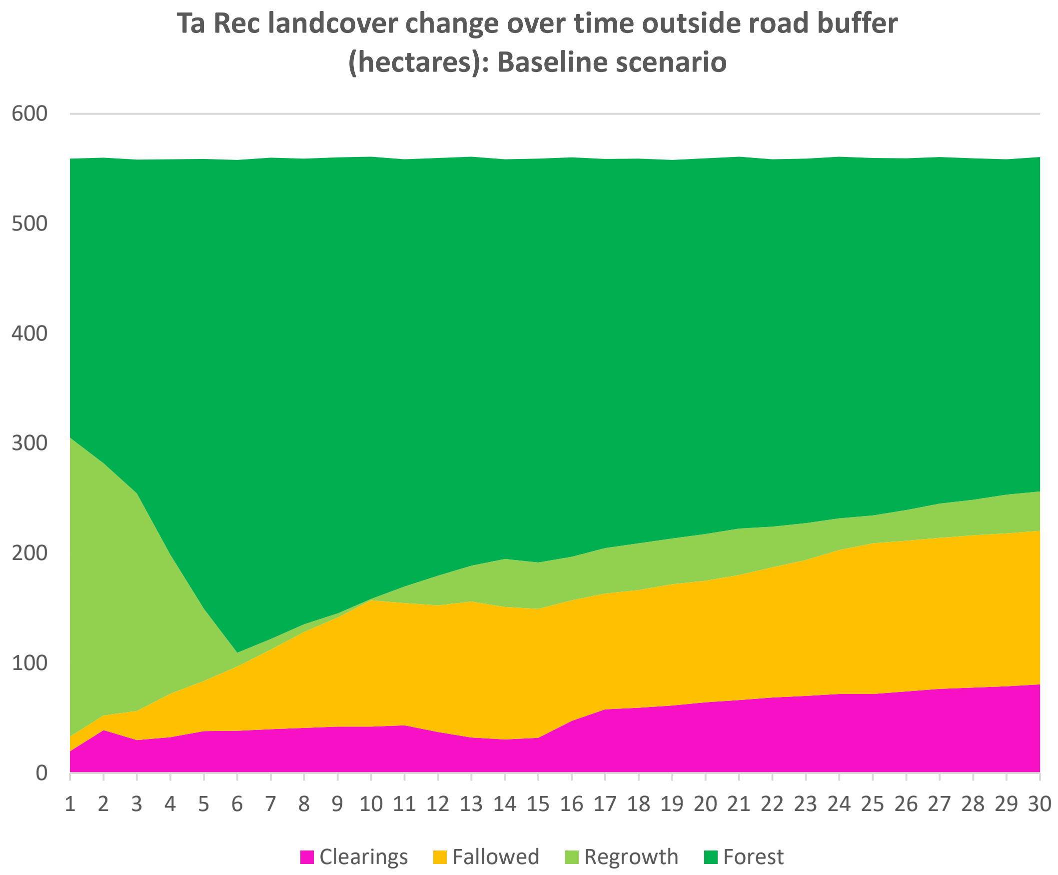
- Agronomy
  - Maximum consecutive patch re-use
  - Minimum fallow length
- Demography
  - Initial number of households
- Climate variability
  - Probability of extreme event (drought/flood)
- Market prices
  - Rice (market cost to buy rice)
  - Cassava (pseudo-market cost for selling cassava)
- Terrain constraints
  - Maximum allowable slope

Results (ABM): Baseline testing for TaRec village (NetLogo v. 6.0.2)



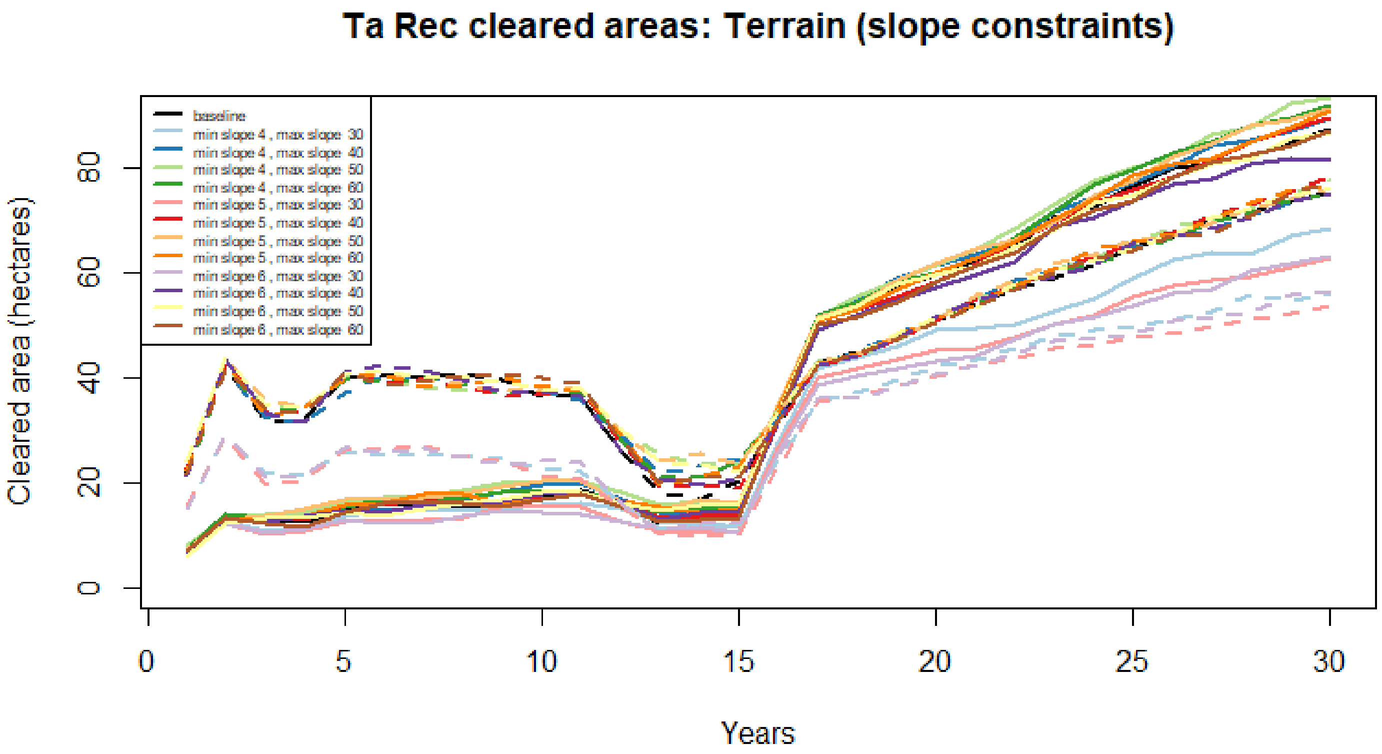
Results (ABM): Baseline testing, Ta Rec village





Results (ABM): BehaviorSpace testing

- Agronomy
- Climate change
- Demography
- Market prices
- Terrain constraints



Discussion (ABM): Baseline testing

Expected behaviors

Baseline scenario exhibits the following trends:

- a relatively consistent pattern of dispersed land-use for the first half of the model run (years 1-15, representing the years 1991-2006)
- 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
- a persistence of rice cropping (years 16-30), at a slightly reduced level per household but with a rising level aggregately area for the village as a whole outside the road buffer zone
- expected behavior hinges on the break-even crop decision-making rule, as currently configured

Factors influencing emergence in LULC

Collective impact on village landscape is a result of interactions with the following stochastic processes:

- 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
- varying patch counts cropped by household by cropping type, based on household cashbox level relative to annual household cost of rice
- continually varying fertility levels of landscape patches under cultivation / fallowed patches
- the random occurrence, however infrequent, of a severe climate event (i.e. drought or flood)

Discussion (ABM): Market prices

- Households exhibit predictable, rational response by growing the cash crop when in higher demand, but rarely exclusively
- Scenario is highly simplified but consistent with von Thünen's "first ring of free cash cropping" as well as cultural norms regarding rice cultivation.

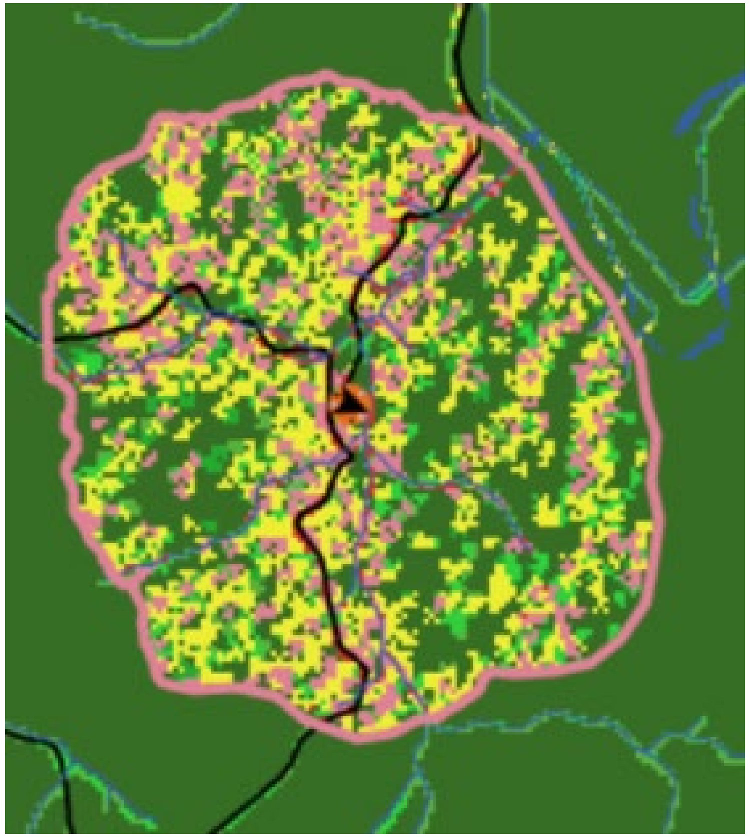
Rice		Cassava			
Direction of change in price	**Magnitude of change in price (%)**	**Direction of change in price**	**Magnitude of change in price (%)**	**Direction of LULC change (inside road buffer)**	**Direction of LULC change (outside road buffer)**
Reduced	50	Reduced	50	Increased area cleared	Increased 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

Discussion (ABM): Other BehaviorSpace scenarios tested

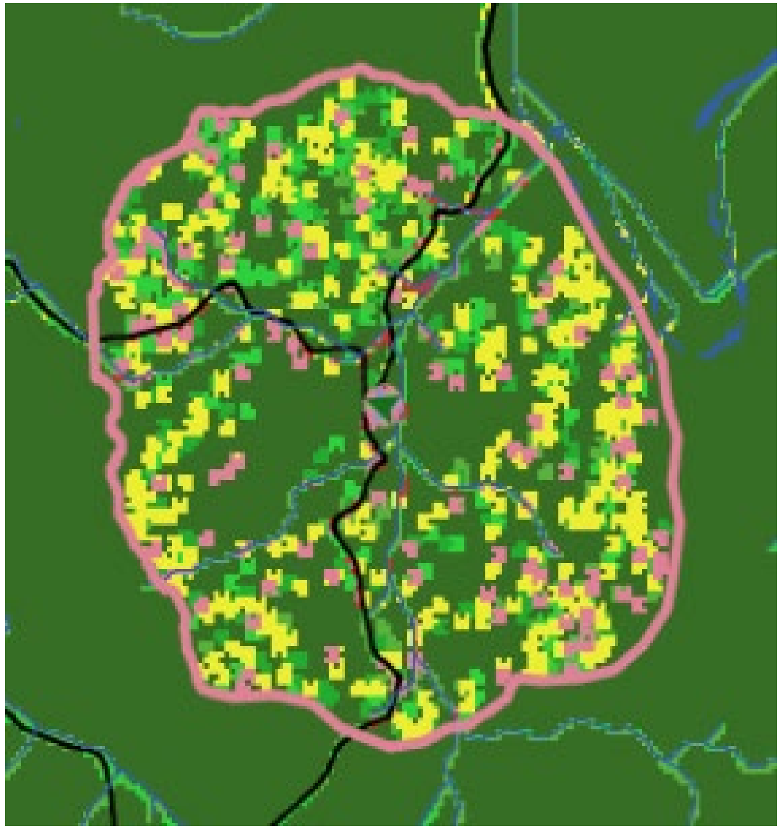
- Outcomes are consistent with expectations for the following scenarios:
  - Agronomy: long fallows (10 years) markedly decrease levels of cash cropping inside road buffer
  - Climate change: higher occurrence of drought / flood increase overall land-use at village level
- Demography: higher initial population levels increase overall level of land-use in direct proportion / vice versa
- Terrain: lowering the maximum slope constraint reduces overall land-use at village level
- Disclaimer: variables tested do not operate in isolation, but rather interact synergistically in the real world (Lambin et al. 2003)

Model validation: “face validation”

Baseline scenario with road improvement (end-state land-cover)



Baseline scenario *without* road improvement (end-state land-cover)



Model validation (ABM): Observed vs. model outputs

Klu village

- Cleared area: mean of model outputs lower (~ 25%)
- Clustering of clearings: mean of model outputs lower (~ 3.4%)
- Distance of clearings to roads: mean of model outputs higher (~ 11%)

Ta Rec village

- Cleared area: mean of model outputs higher (~ 11%)
- Clustering of clearings: mean of model outputs lower (~41%)
- Distance of clearings to roads: mean of model outputs higher (~ 44%)

Future work (ABM): Enhancing agents

Household agents

- giving households "memory" whereby they factor the past (up to a certain number of years) into their present decision-making process
- simulating a "social component" to site selection – could be based on kinship networks (if available)
- varying agronomic practices to allow households to intercrop, which is prevalent practice based on observations from fieldwork, rather than simply engage in monocropping

Landscape agents

- Improving representation of soil at start of model run and updating soil conditions to reflect the differing impacts of subsistence vs. cash cropping on degradation, erosion, and loss of soil
  - "Bru, Katu, and Sedang informants report that they look for ***black*** or ***brown*** soil, *avoiding* ***red*** *soil*" (Hickey 1982: 441)
- improving the process of vegetative succession to more accurately represent transitions between cover states
- linking crop yields to improved modeling of soil, land-cover, and climate conditions, as well as agronomic practice

Future work (ABM): Enhancing socio-economic realism

Possible enhancements to socio-economic realism could include

- Permitting mobility beyond the village boundary for
  - non-timber forest products (NTFP) harvest
  - agriculture / agroforestry
  - off-farm work
- Adding general market dynamics
  - inflation
  - volatility in commodity prices
- Allowing for outside actors in surrounding landscape
  - extraction agents, e.g. timber companies
  - conversion agents, e.g. commercial plantations

Summary of CDA and ABM efforts

Change detection analysis

- Change detection analysis of satellite imagery shows a high degree of variability at the district level spatially and temporally
- Possible evidence of patterns of agricultural intensification along the Highway 9 corridor as of 2014
- Additional data are needed to better evaluate patterns of LULC change

Agent-based simulation modeling

- Agent-based model simulations of LULC change dynamics at the village level show expected behaviors under both Baseline and BehaviorSpace experiments
- Direction of LULC change in the models is consistent with predictions of land rent theory, but there are moderate to large discrepancies in the magnitude of change compared to available imagery dates
- Further calibration and validation are needed before applying this model as a decision support tool

Concluding remarks

- Efforts to more accurately assess LULC change and predict future trajectories of change will require more / better data
  - On the ground (i.e. fieldwork)
  - RS (e.g. satellite imagery with sufficient spatial resolution and higher temporal resolution)
- Alternative land-use systems to traditional shifting cultivation need to meet three standards for the populations under consideration (Ngo et al. 2009):
  - Commercial viability
  - Cultural acceptability
  - Ecological sustainability

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