The ChitwanABM: Modeling Population-Environment Interactions and their Implications in the Chitwan Valley, Nepal

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Introduction

- Land-use and land-cover and human-decision making are intimately linked
- Micro-level decision-making can lead to broader scale ("emergent") patterns on the landscape
- The link between these micro-scale decisions and the macro-scale landscape can be crucial for ecosystem management

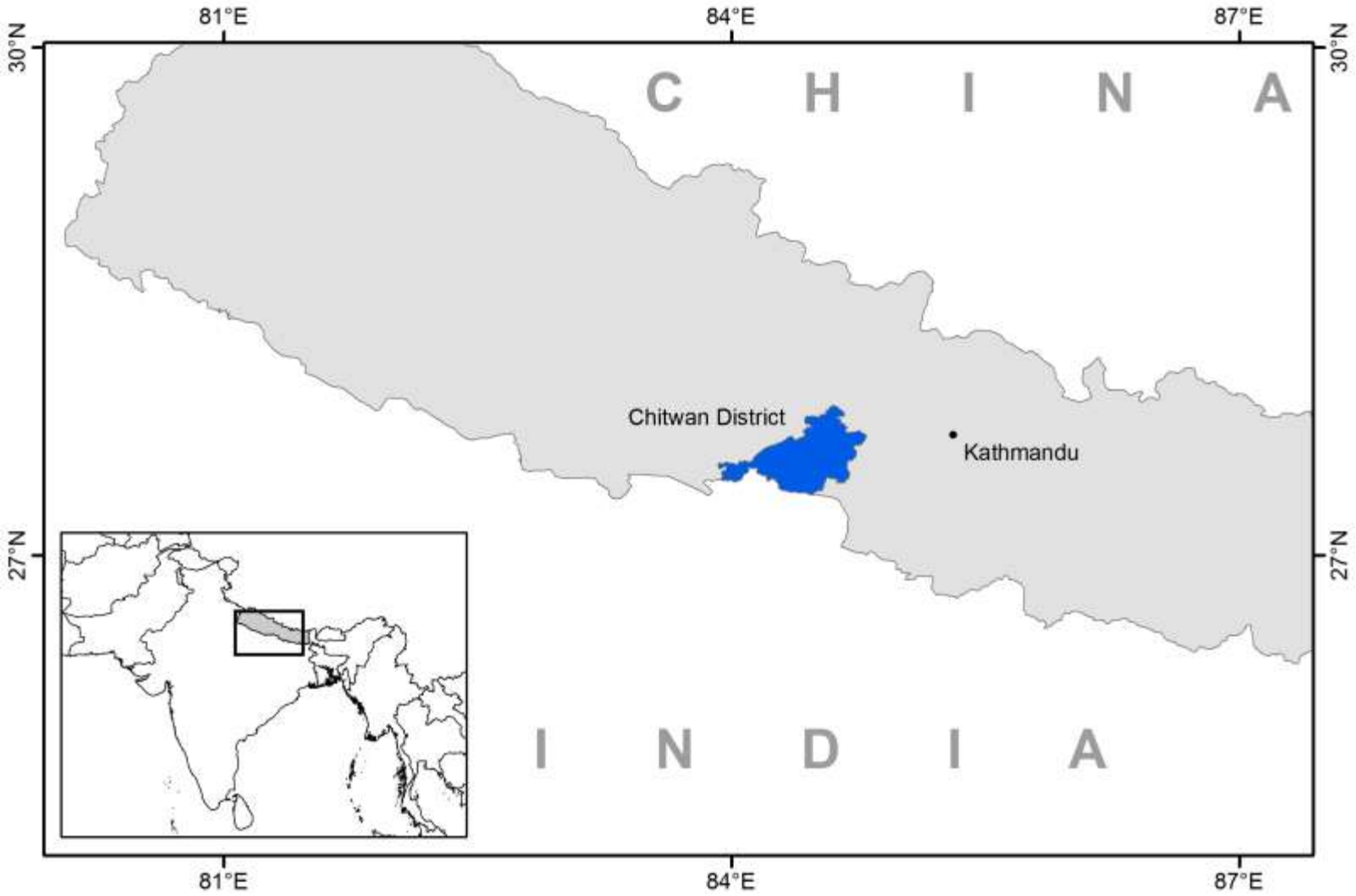
Primary Research Questions

- How does micro-level demographic decision making impact macro-level land use and land cover (LULC)?

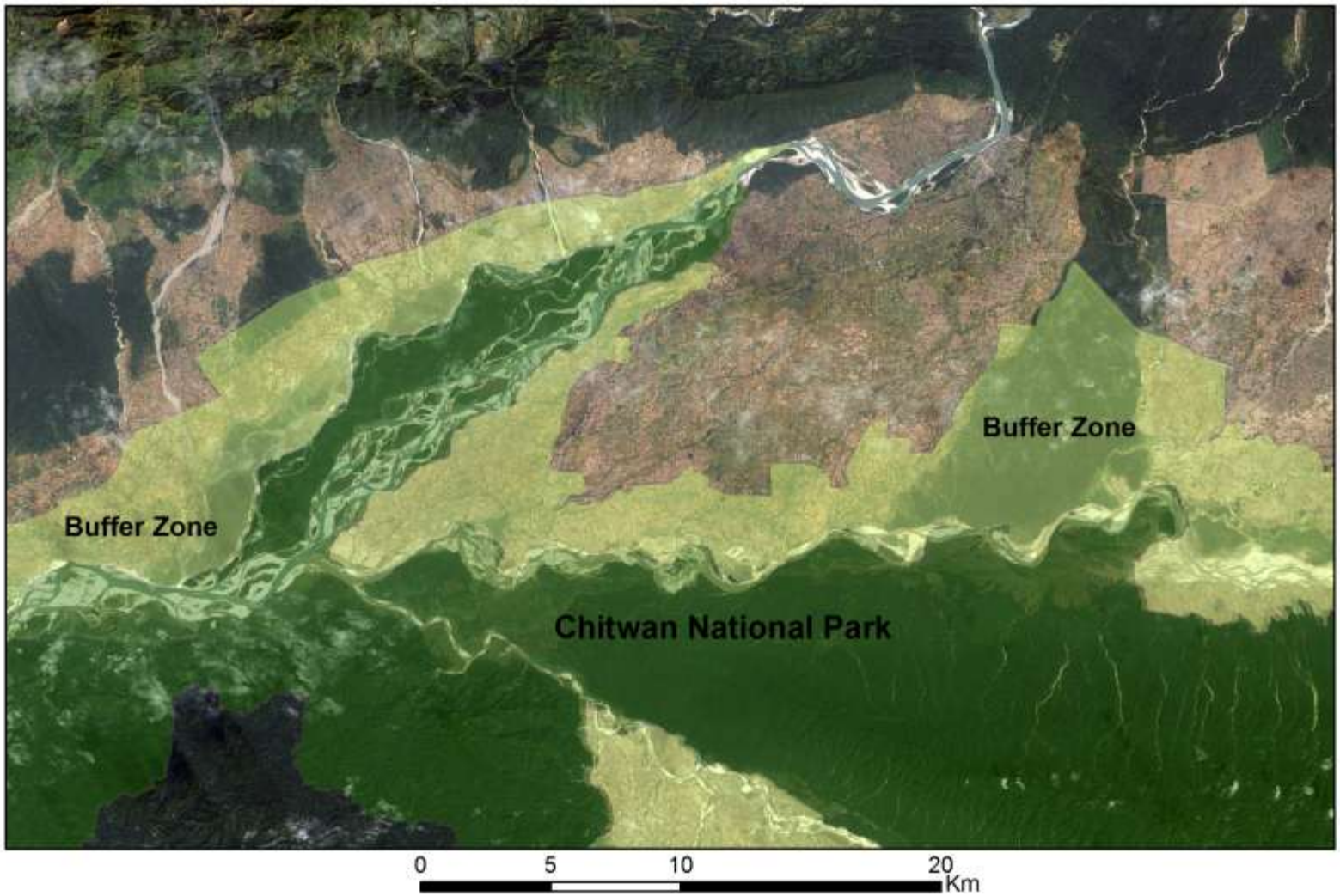
- What role do feedbacks play in this relationship?

Study Site

Study Site: Western Chitwan Valley, Nepal



Study Site: Western Chitwan Valley, Nepal



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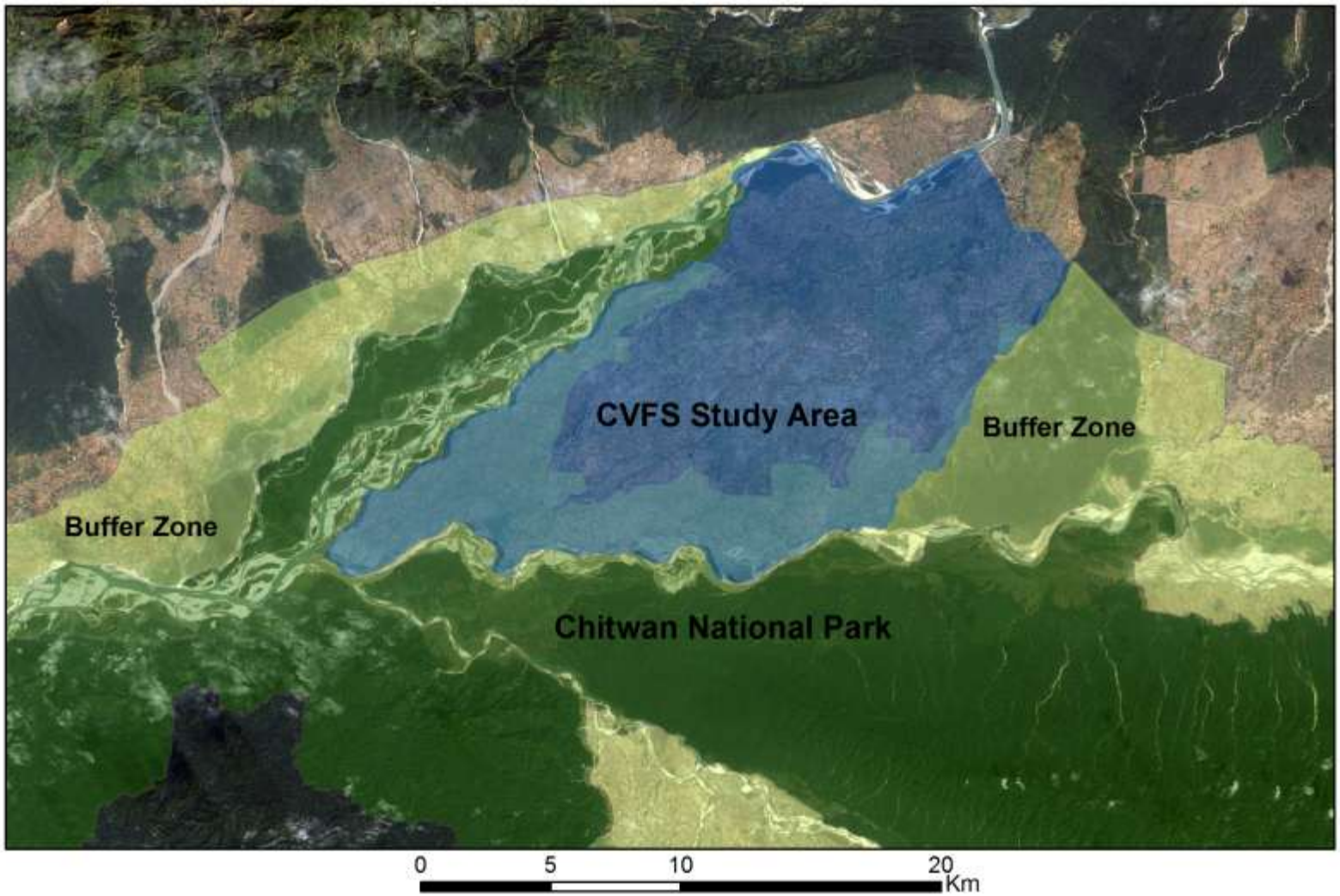
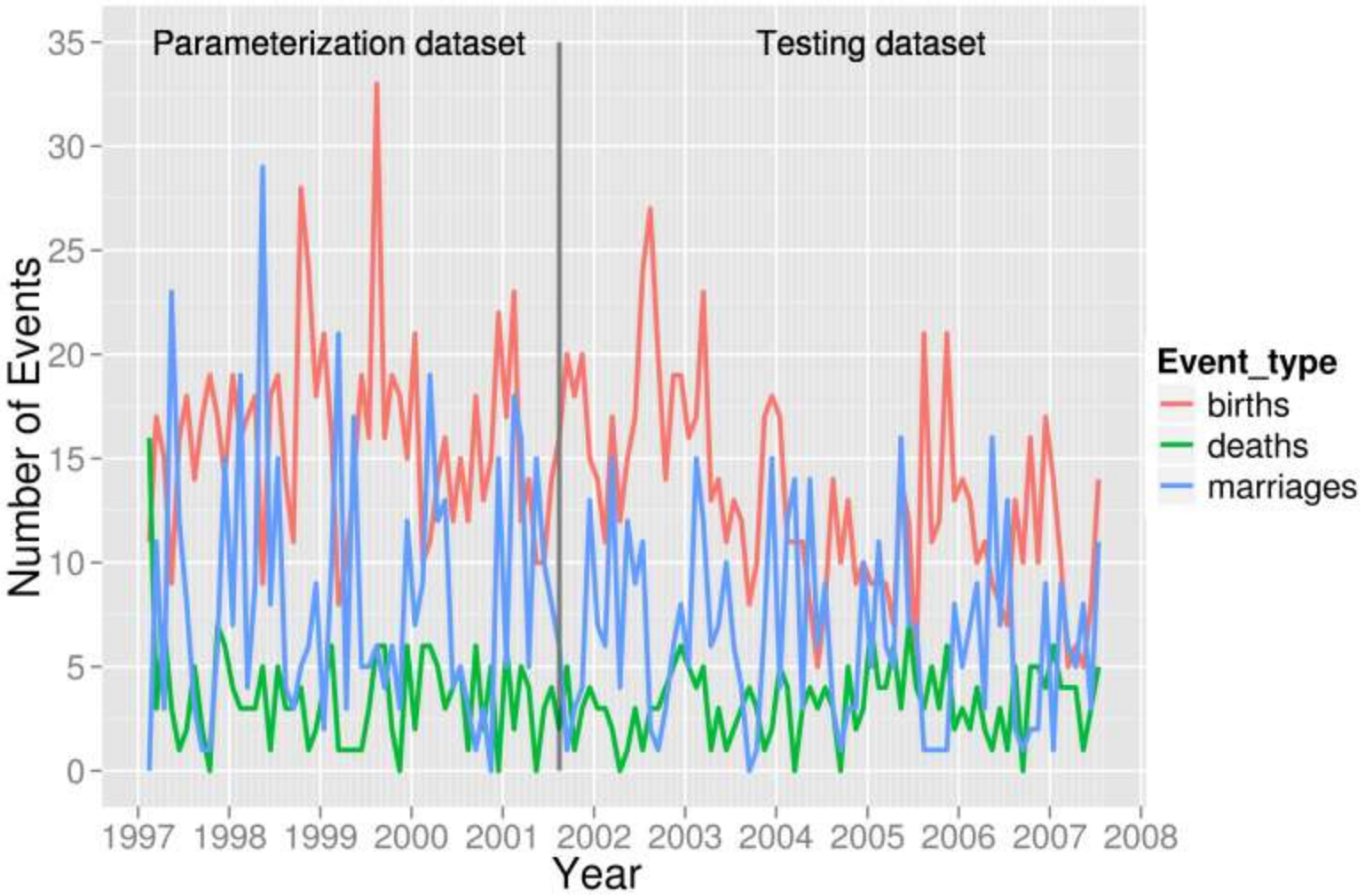


Chitwan Valley Family Study

- Longitudinal survey begun in 1996
- Focusing on social context and family formation
- Human survey data
  - Three detailed interviews (1996, 2001, 2008)
  - Household registry (monthly since Feb. 1997)
- Environmental data
  - Flora count (1996, 2000, 2007)
  - Neighborhood mapping (1997, 2000, 2007)

Chitwan Valley Family Study: Household Registry



Study Site: Overview

- Population ≈ 250,000
- National park: 932 Km^2
- Buffer zone: 766 Km^2
- Forest resources important
  - 93% use fuelwood
  - 76% gather fuelwood
- Ag. is dominant land-use
  - 80% of study area in 1996

Methods

Why an agent-based model?

- Agent-based models (ABM) represent individual “agents” and model their interactions
- ABM allows:
  - Representation of human-decision making
  - Consideration of feedbacks
  - Examination of system dynamics
  - Testing of alternative hypotheses

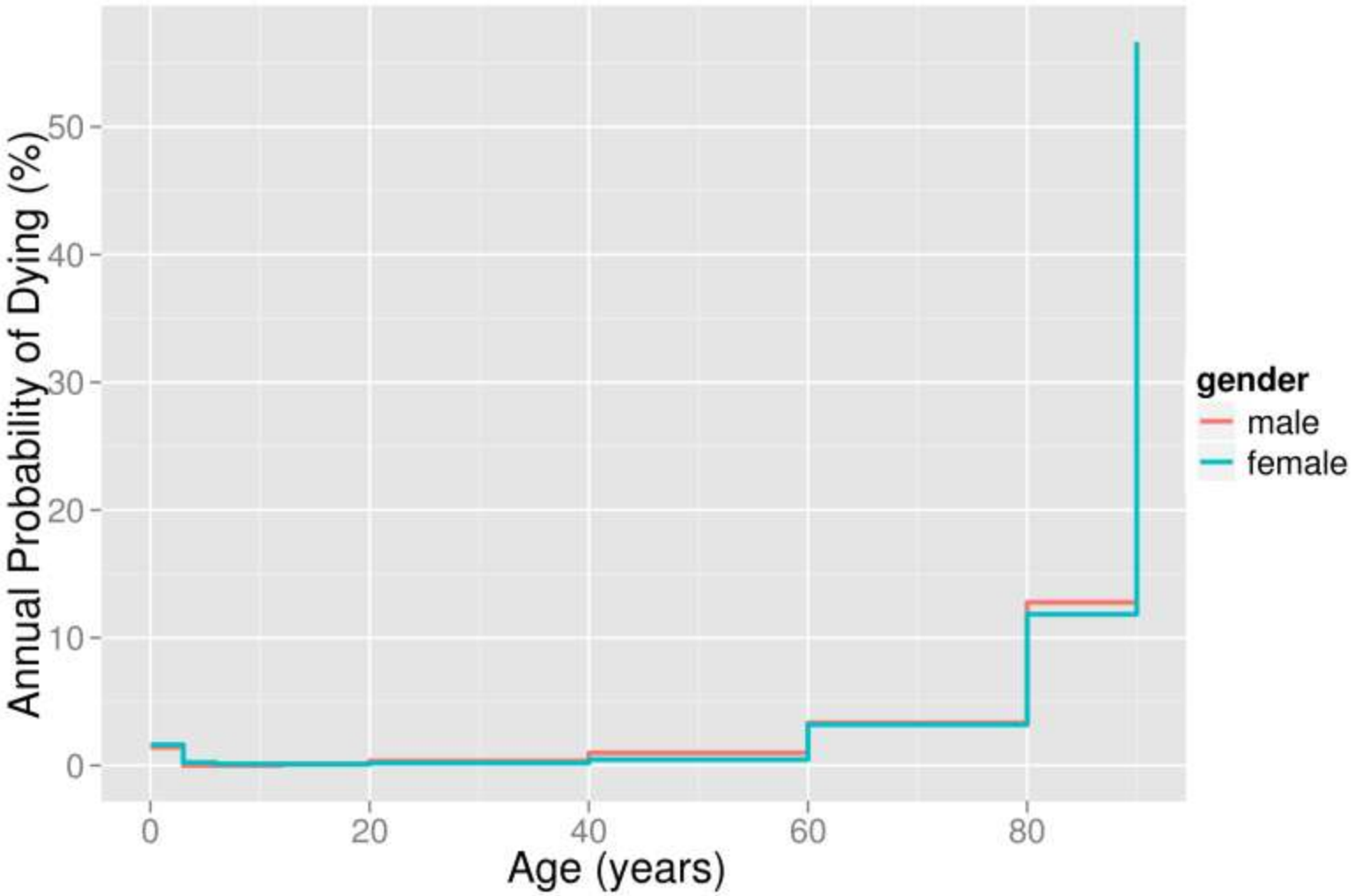
ChitwanABM Agent Hierarchy

- 151 neighborhood agents
  - 1551 household agents
    - 8415 individual agents

Parameterization

- Demographic processes represented in model
  - Fertility
    - First birth timing
    - Desired family size
  - Marriage
  - Migration
  - Mortality
- **Feedbacks** alter these processes
- LULC determined by decisions of household agents

Example Parameterization: Mortality



Land-use/land-cover Classes

- Land-use/land-cover classes
  - Agricultural vegetation
  - Non-agricultural vegetation
  - Private buildings
  - Public infrastructure
  - Other (ponds, silted riverbanks, etc.)

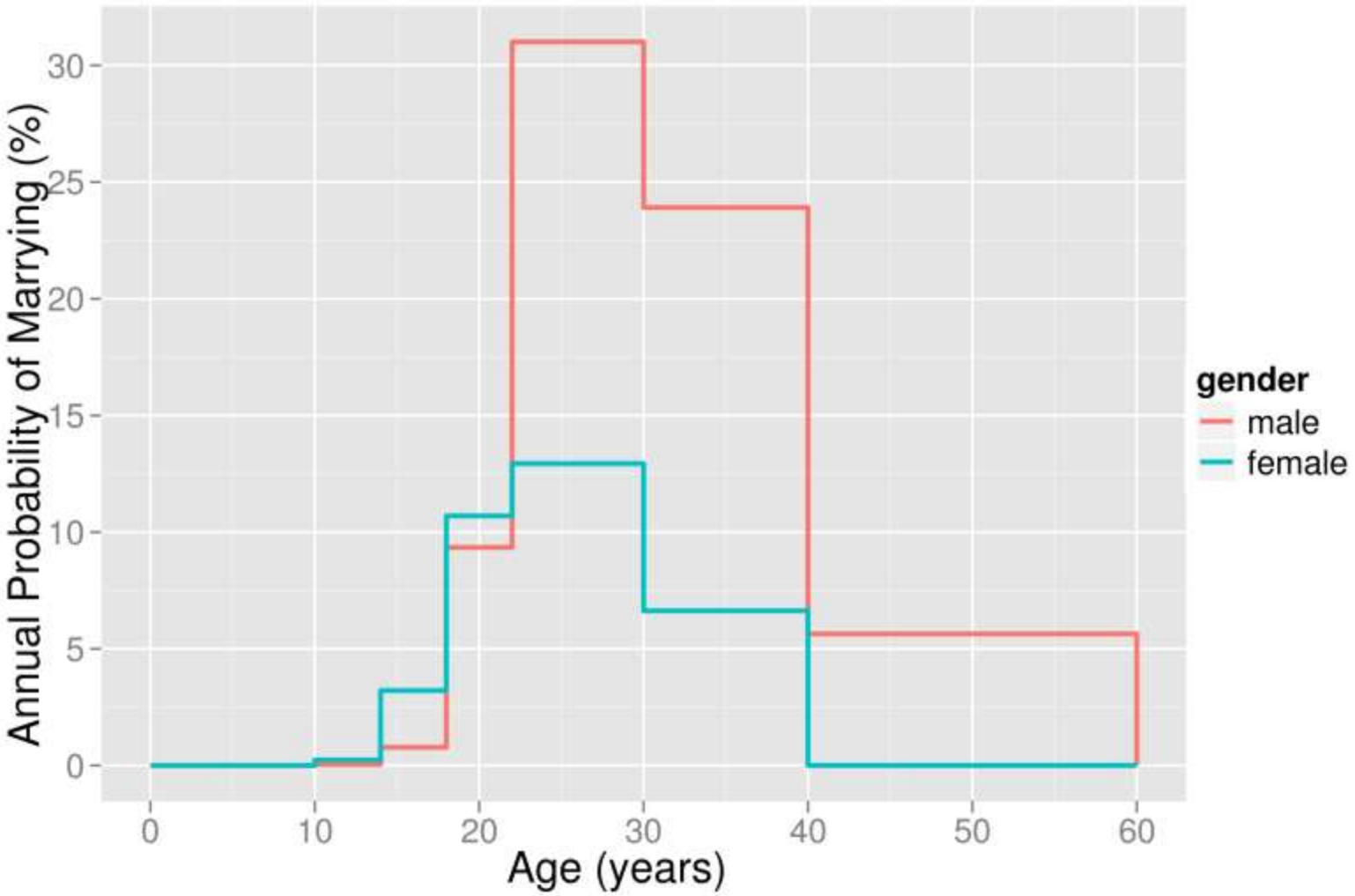
Land-use/land-cover Change – 1996-2006

Class	1996	2001	2006
Agricultural Vegetation	879.9 (80.0%)	875.6 (79.4%)	854.2 (77.6%)
Non-agricultural Vegetation	50.2 (4.6%)	35.3 (3.2%)	54.4 (4.9%)
Private Buildings	82.3 (7.5%)	88.4 (8.0%)	94.4 (8.6%)
Public Buildings	59.2 (5.4%)	64.3 (5.8%)	66.9 (6.1%)
Other	28.4 (2.6%)	39.5 (3.6%)	31.2 (2.8%)
Total	1100.1 (100%)	1103.1 (100%)	1101 (100%)

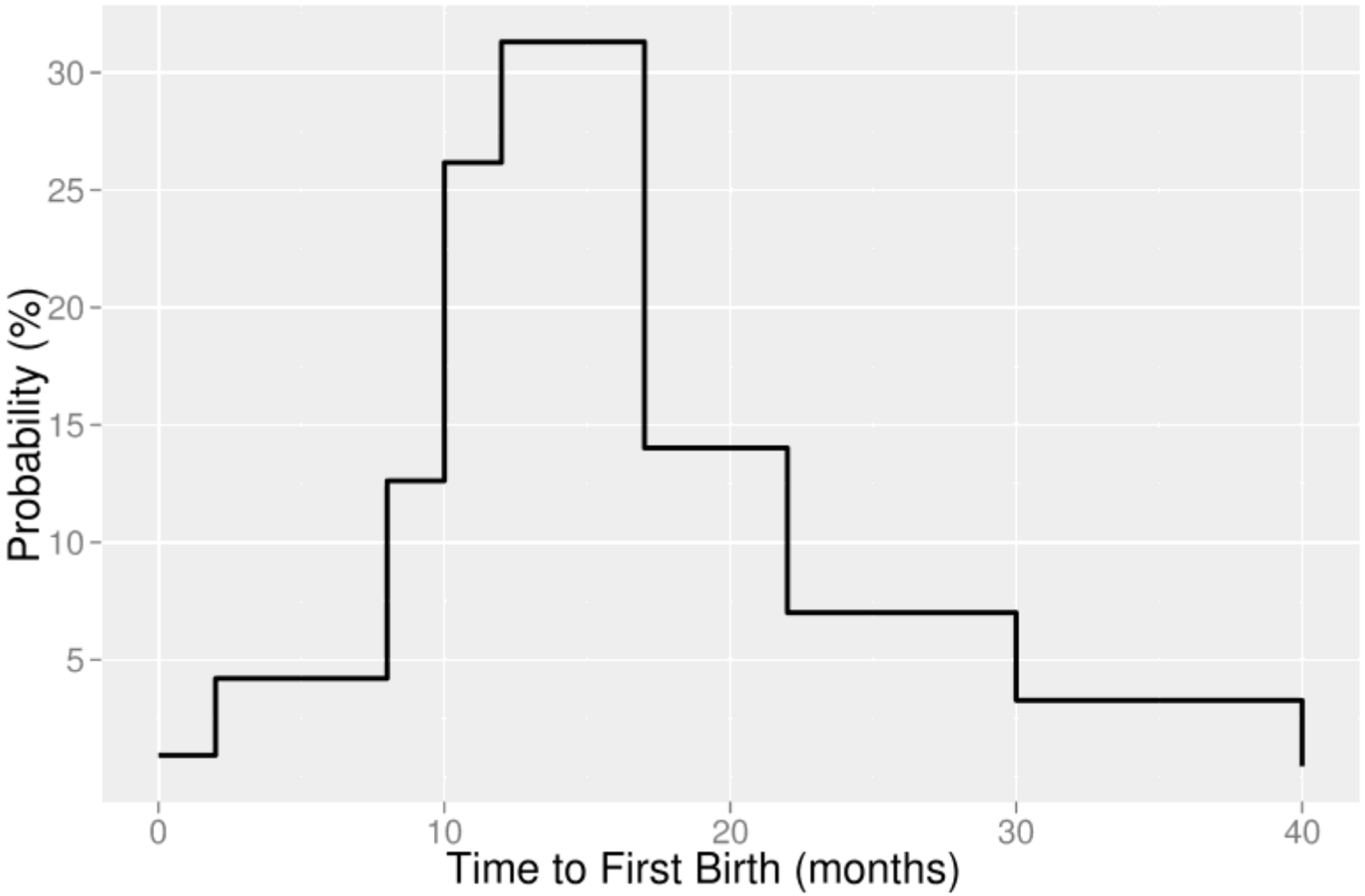
Objective: Explore Four Scenarios

- Scenario 1:
  - Baseline scenario
- Scenario 2:
  - LULC – marriage timing feedback scenario
- Scenario 3:
  - LULC – first-birth timing feedback scenario
- Scenario 4:
  - Combined feedback scenario (both feedbacks)

Scenario 1 (simple model)



Scenario 1 (simple model)



Scenario 2

- Prior work (Yabiku, 2006) has shown marriage timing
  - Highly correlated with age, sex, ethnicity
  - Positively related to agricultural land
    - Higher percentage agricultural land leads to earlier marriage (get married younger)
- We explore two scenarios
  - Baseline scenario (no feedback)
  - Positive feedback of percent agricultural land on marriage rate (Yabiku, 2006)

LULC and Marriage Timing (based on Yabiku, 2006)

Variable	Odds-ratio	Signif
% Neighborhood Land Agricultural (log)	**1.109**	
School (min foot)	1.003	
Health post (min foot)	0.996	
Bus stop (min foot)	1.007	
Market (min foot)	0.998	
Employer (min foot)	**1.007**	*
Born in 1996 neighborhood	0.970	
Living outside 1996 neighborhood	0.863	
Female	**2.380**	**
Lower Caste Hindu	1.261	
Newar	0.890	
Hill Tibetoburmesea	1.333	
Terai Tibetoburmesea	1.067	
Age	**2.341**	**
Age-squared	**0.984**	**

Scenario 3

- Prior work (Ghimire and Axinn, 2010) has shown first birth timing is:
  - Highly correlated with schooling, parental characteristics
  - Positively related to agricultural land
    - Higher percentage agricultural land leads to earlier first birth timing (higher probability of first birth in a given month)
- We explore two scenarios
  - Baseline scenario (no feedback)
  - Parameterization based on Ghimire and Axinn (2010)

LULC and First Birth Timing (based on Axinn and Ghimire, 2010)

Variable	Odds-ratio	Signif
Percent ag	1.01	**
Avg years non-fam	0.98	
School w/in 1 hr	0.66	
Health w/in 1 hr	1.24	
Bus w/in 1 hr	0.66	**
Emp w/in 1 hr	1.07	
Dist to narayanghat	0.98	
Nbh elec	1.05	
NBH wealth index	1.01	
Age at 1st marr	1.03	
Marr duration before 1997	0.98	***
Low caste hindu	1.08	
Hill Tibeto-Burmese	0.92	
Newar	1.08	
Terai Tibeto-Burmese	1.33	

Variable	Odds-ratio	Signif
Schooling (4-7 years)	1.44	
Schooling (8-11 years)	1.44	***
Schooling (> 11 years)	2.07	***
Parent's contraceptive use	0.69	***
Fathers work	0.71	**
Fathers schooling	1.23	
Mothers work	1.11	
Mothers schooling	1.45	
Mothers number of children	0.95	
Hazard duration 1-6	1.79	**
Hazard duration 7-12	1.57	*
Hazard duration 13-18	1.76	*
Hazard duration 19-24	1.06	
Hazard duration 25-30	0.73	
Hazard duration 31-36	1.25	
Hazard duration 37-42	0.64	

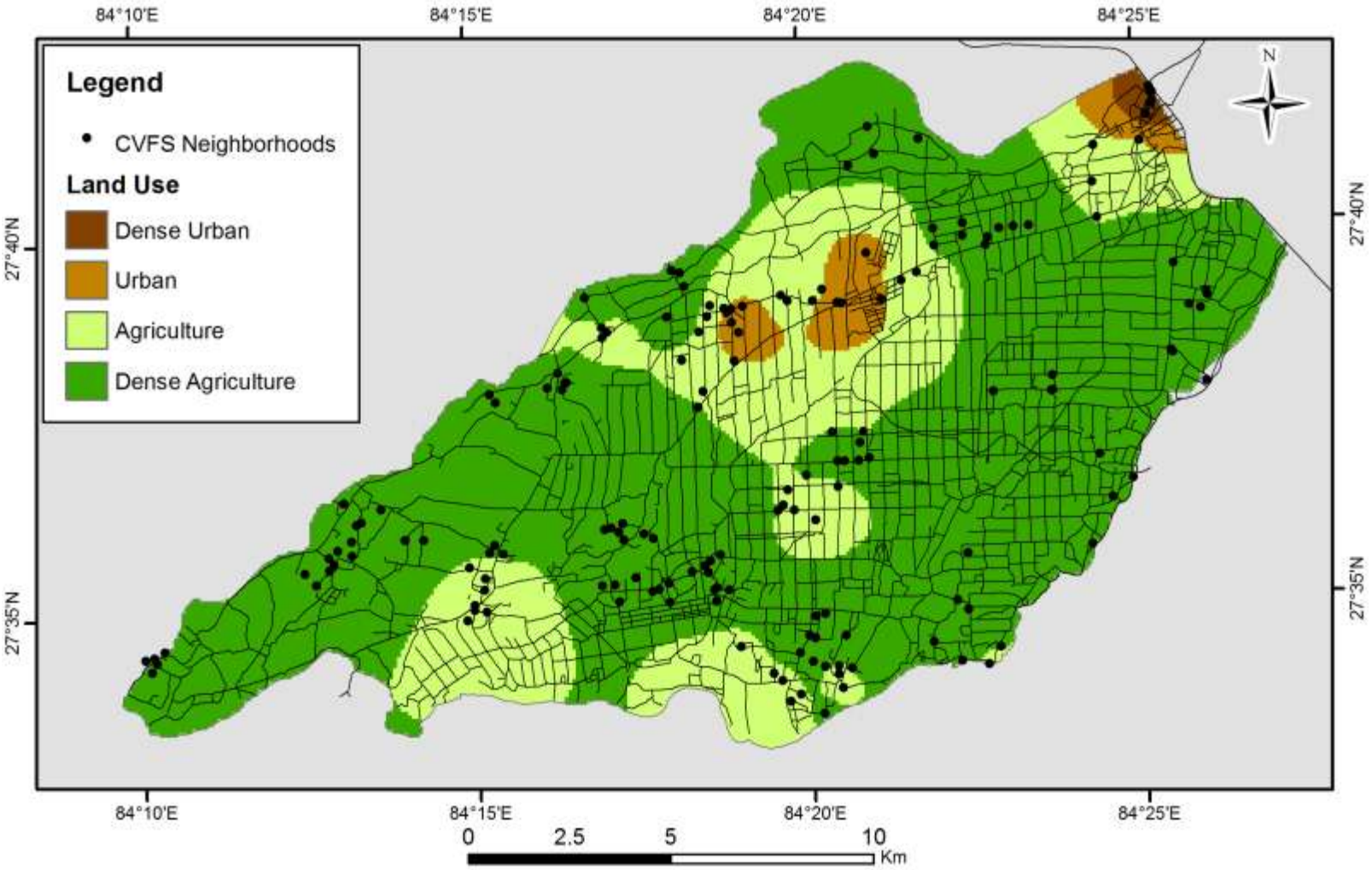
Scenario 4

- Use both detailed parameterizations:
  - Axinn and Ghimire (2010)
  - Yabiku (2006)

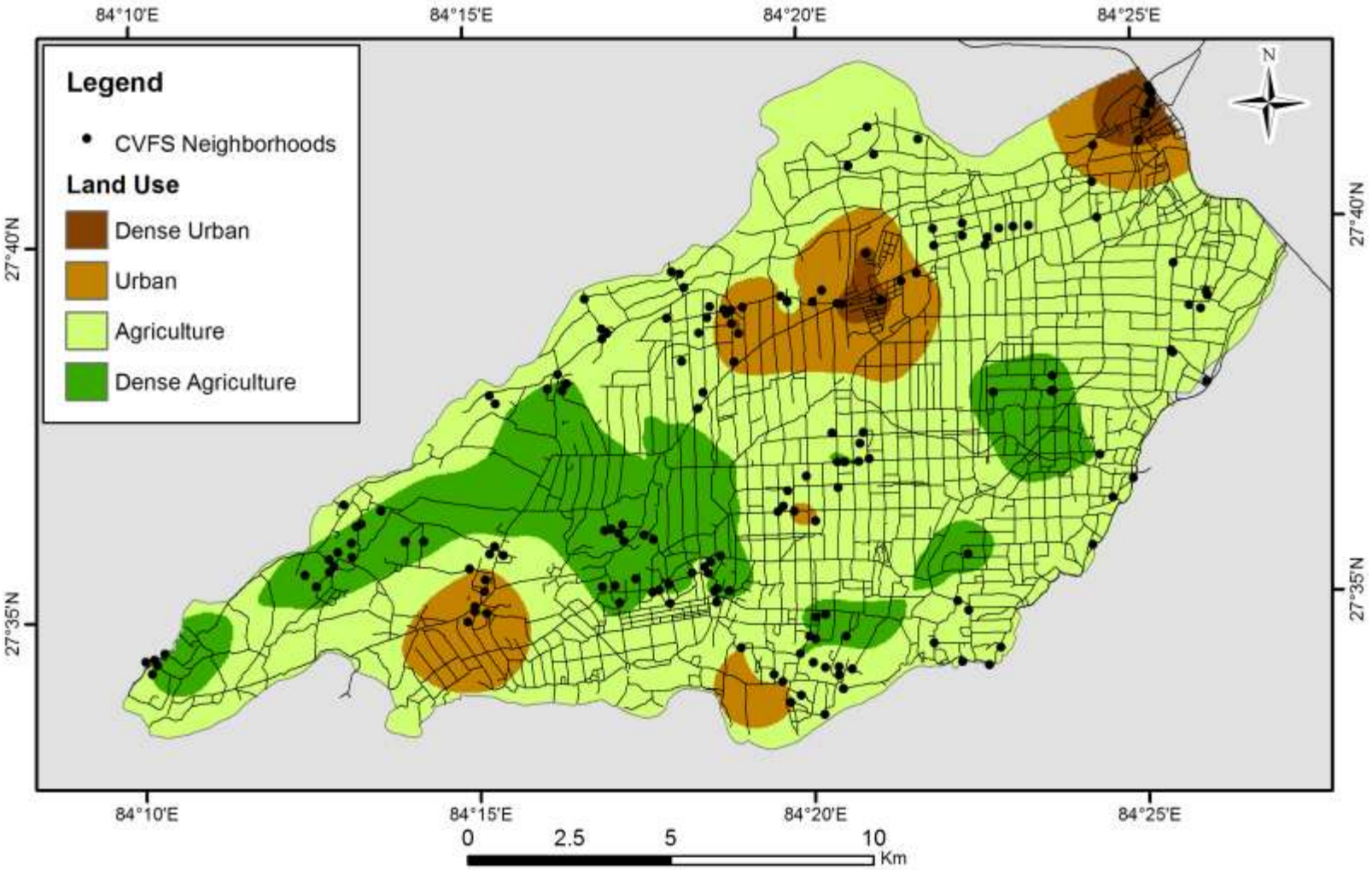
- Compare to baseline model

SCENARIO COMPARISON

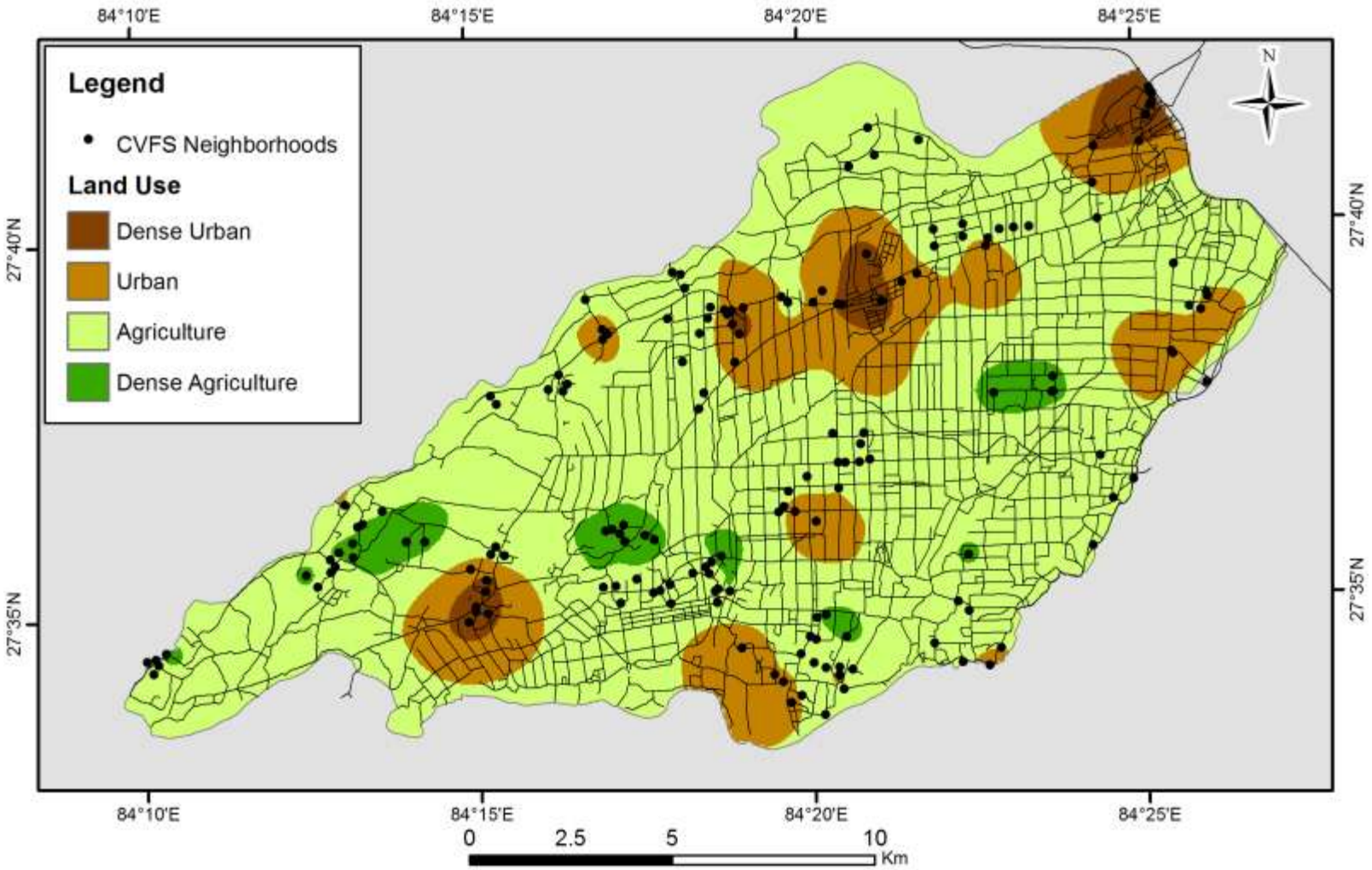
Time Zero: Percent Vegetation



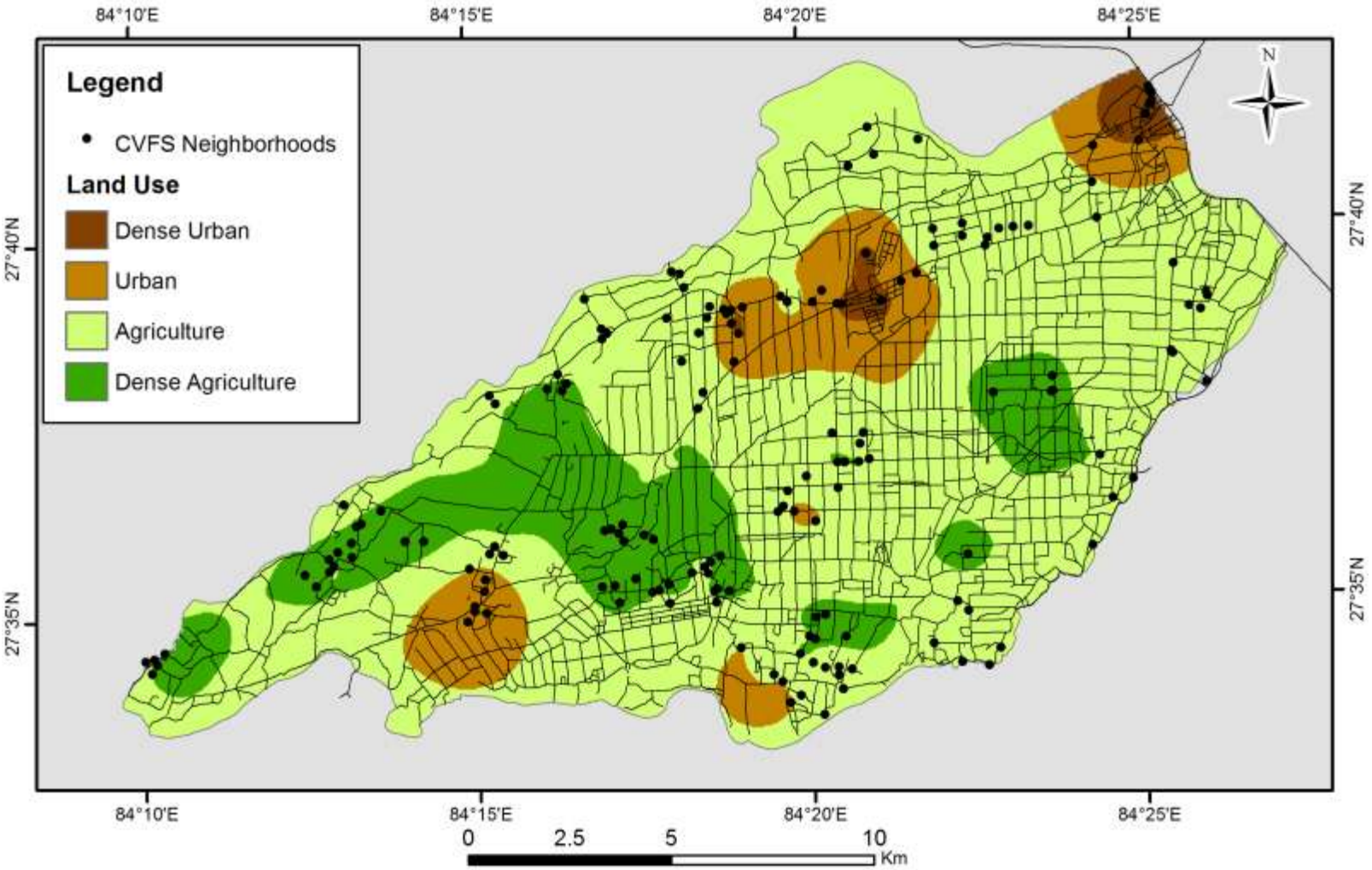
Scenario 1 (baseline): LULC



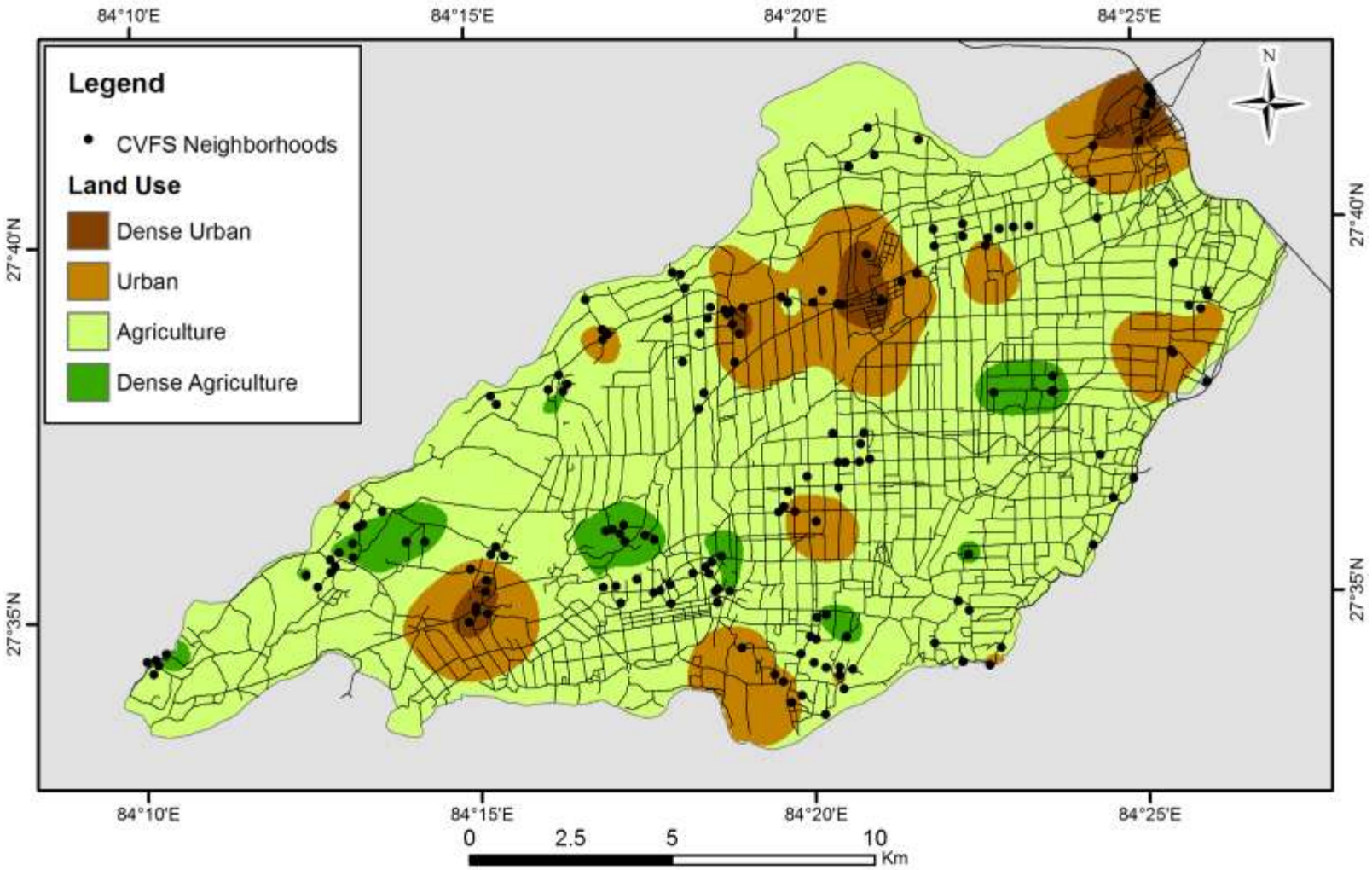
Scenario 2 (marriage)



Scenario 3 (first birth)



Scenario 4 (combined)



Discussion: Marriage Scenario

- Feedback of LULC on marriage timing:
  - Shows little impact at the aggregate level
  - Shows large impact spatially
- Considering feedback
  - Agricultural areas grow quicker
  - Urbanized areas grow more slowly

Discussion: First Birth Scenario

- Feedback of LULC on marriage timing:
  - Shows little impact at the aggregate level
  - Also shows little impact spatially

- Though first birth timing is influenced by agriculture, the feedback (on LULC) of changing is *smaller* than changing marriage timing

Conclusions

- Impact of changing marriage patterns more important for LULC than of changing first birth
- Must consider spatial context of decision-making to understand feedbacks between LULC and population
- Given the importance of new households on LULC, changes in household size likely to be important

Future Work

- Incorporate feedbacks between biomass harvesting ↔ LULC
  - Household size critical
  - Biomass mapping work
- Link LULC change to tiger habitat change
  - Cooperation with Carter
  - Fall 2011 data collection in core of park
- Digitization of neighborhood boundaries

Future work:
Biomass Usage and Landscape Change

Research Question

- How does woody biomass harvesting impact habitat quality in the Chitwan National Park and buffer zone?

- How is woody biomass distribution in the Chitwan Valley changing over time?

Study Site: Role of Woody Biomass in Local Area

- Woody biomass a key ecosystem service
  - 93% of households use fuelwood
  - 76% of households gather fuelwood

- Prior work has established a relationship between resource degradation and migration[5]
  - ↑ time to collect → ↑ local migration

[5]Massey, Axinn and Ghimire, 2010

Household Fuelwood Usage Survey: Part 1

- Question:
  - What are the (wood) resource requirements for an average household in Chitwan? How do these requirements relate to social variables?
- What is a household?
  - Defined as a group of people who eat and sleep in the same place at least 5 days per week.
- Approach:
  - 2 part survey of 80 households in southeastern Chitwan:
    - 80 households detailed survey
    - 40 households followed for 15 days (with visits every 3 days)

Household Fuelwood Usage Survey: Part 2

- Measurement of wood usage
  - Wood used within the household (on their grounds)
    - For cooking, heating, livestock, etc.
    - Not wood for construction
  - Wood used within the 15 day survey period

- Sample – 40 households
  - Resource usage and collection measured over five 3-day periods

Biomass survey

- Question:
  - What are the direct impacts of fuelwood and timber collection on land cover in the Chitwan Valley?

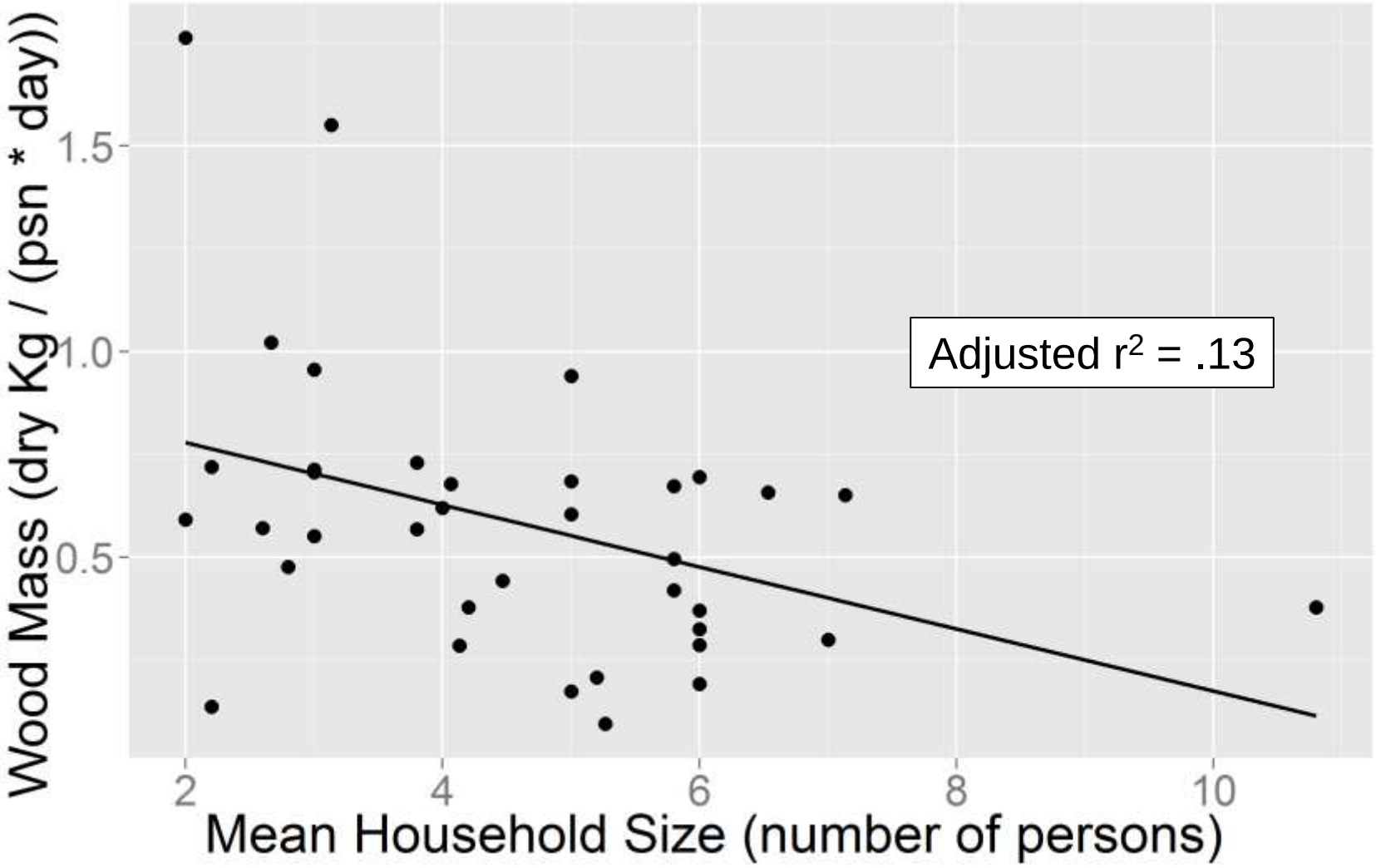
- Approach:
  - Survey of fifty-eight 20 m × 20 m field plots
  - Survey focuses on woody biomass
    - Standing woody biomass (live)
    - Woody detritus (dead)

Wood usage - summary statistics

- 37 households total, 5 observation periods

Variable	Mean	Standard Deviation
Household size	4.57 (num. people)	1.83
Wood usage	2.43 (dry Kg / HH × day)	1.22
Own any non-wood stove 0=No 1=Yes	.76	

Biomass Usage Model



Biomass Usage Model

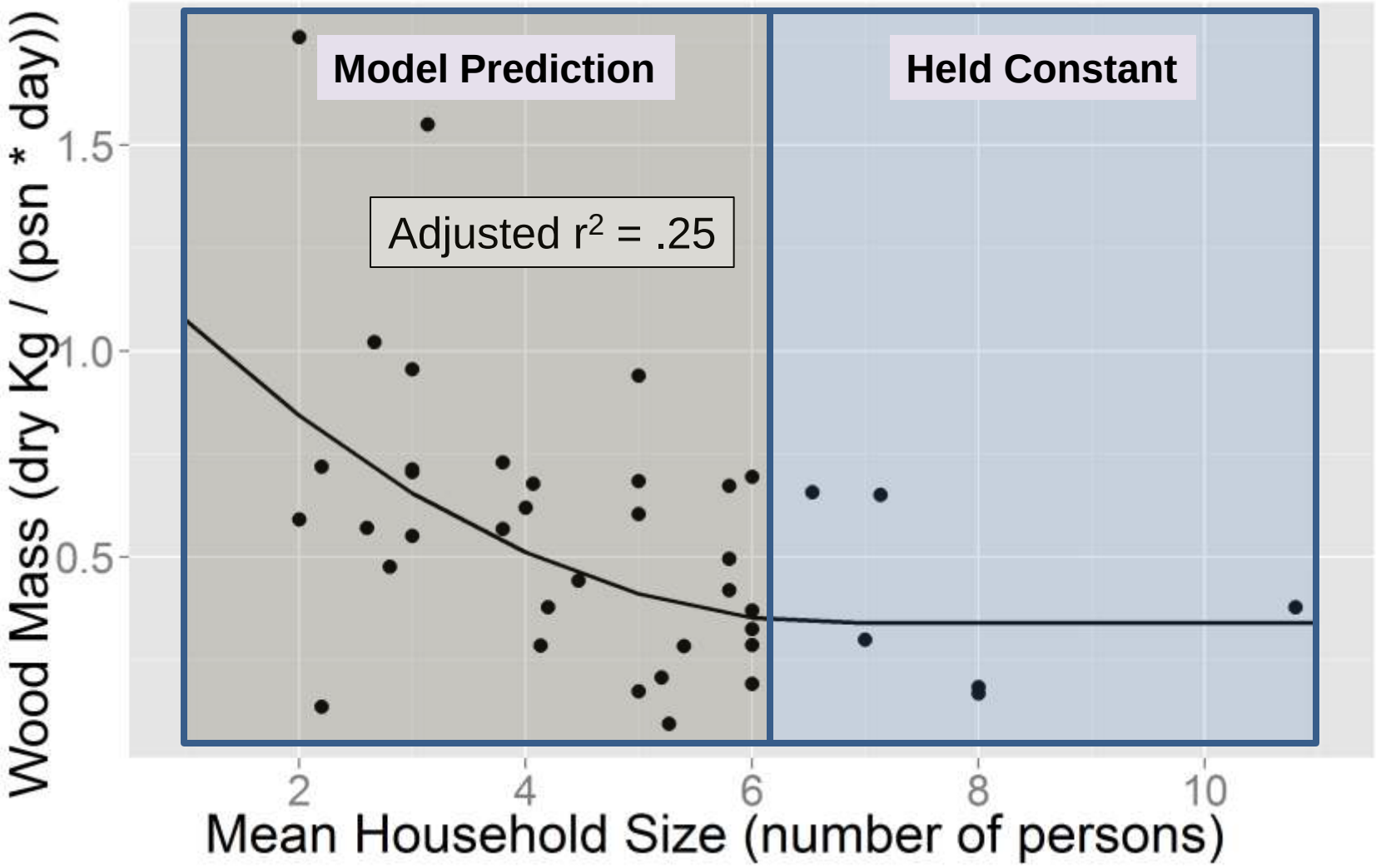
Variable	Regression Coefficient	2-sided p-value
Intercept	1.59	<.001***
Mean household size	-0.29	.034**
Mean household size (squared)	0.88	.008*
Hill Tibeto-Burmese[1]	0.10	.208
Lower-caste Hindu[1]	0.09	.615
Newar[1]	-0.21	.499
Terai Tibeto-Burmese[1]	-0.24	.228
Own any non-wood stove	-1.02	.047*

[1]Upper-caste hindu as the reference class

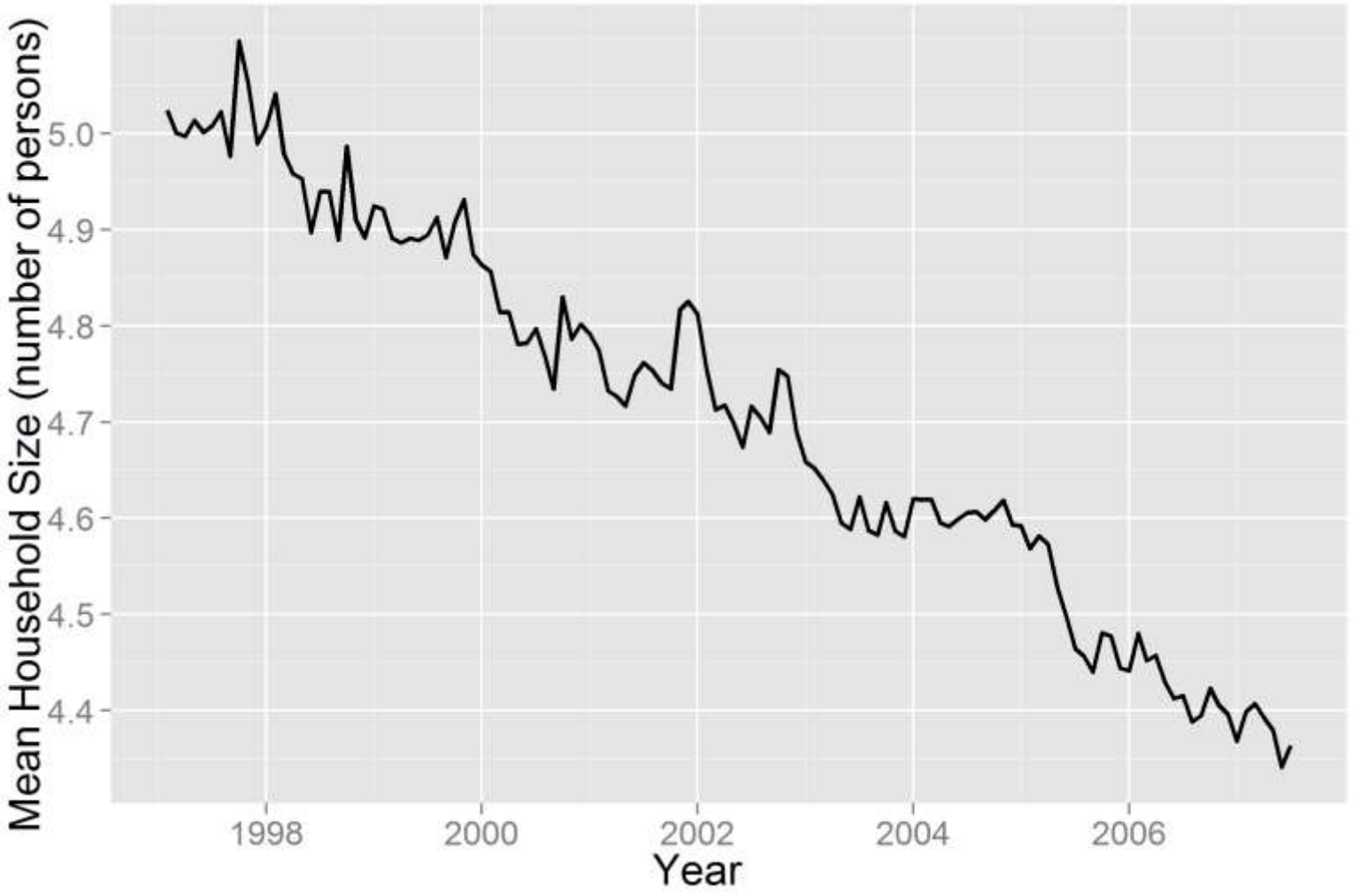
*** = p < .001, ** = p < .01, * = p < .1

Adjusted r-squared: .25

Biomass Usage Model



Actual Trends in Household Size in Chitwan



Biomass Mapping

- Will be discussed in detail in a moment…

Acknowledgements

With thanks to:

- Dr. William Axinn, UM
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- Dr. Dirgha Ghimire, UM
- Dr. David López-Carr, UCSB
- The staff of ISER-Nepal

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SAN DIEGO STATE UNIVERSITY

ChitwanABM is free and open-source:

http://rohan.sdsu.edu/~zvoleff/ChitwanABM.php

PyABM – an open-source ABM toolkit for Python (

http://rohan.sdsu.edu/~zvoleff/PyABM.php

Thank you. Questions?

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References

1. Axinn, W. G. et al. 2007. *Chitwan Valley Family Study*. University of Michigan, Population Studies Center and Survey Research Center.
2. Yabiku, S. 2006. Land Use and Marriage Timing in Nepal. *Population & Environment* 27 (5):445–461.
3. Ghimire, D. J., and W. G. Axinn. 2010. Community Context, Land Use, and First Birth. *Rural Sociology* 75 (3):478-513.
4. Axinn, W. G., and D. J. Ghimire. 2011. Social Organization, Population, and Land Use. *American Journal of Sociology* 117 (1).
5. Massey, D. S., W. G. Axinn, and D. J. Ghimire. 2010. Environmental change and out-migration: evidence from Nepal. *Population and Environment*.

End of show.

PyABM – An Open Source ABM Toolkit

- To encourage ABM development and inter-comparison, we have produced PyABM – an open source ABM toolkit written in Python
- Python is
  - A widely used programming language (particularly in the geospatial community)
  - Easy to learn, quick to code

PyABM – An Open Source ABM Toolkit

- PyABM facilitates:
  - Standardization of model development
  - Model verification and validation
    - Facilitates sensitivity analysis
    - Ensures repeatability of ABM results
    - Supports tracking model versions
  - Development of new models without duplicating past work on coding model basics
  - Free release of models online to the ABM community
- Available at:
  - http://rohan.sdsu.edu/~zvoleff/PyABM.php

Measures of Non-family Services

- Continuous or dichotomous?
- (or) Average number of services?

Axinn and Ghimire (2010, p504)

Childhood nonfamily services

School within one-hour walk

Health service within one-hour walk

Bus stop within one-hour walk

Employer within one-hour walk

Yabiku (2006, p456)

Nonfamily organizations (minutes by foot)

School

Health post

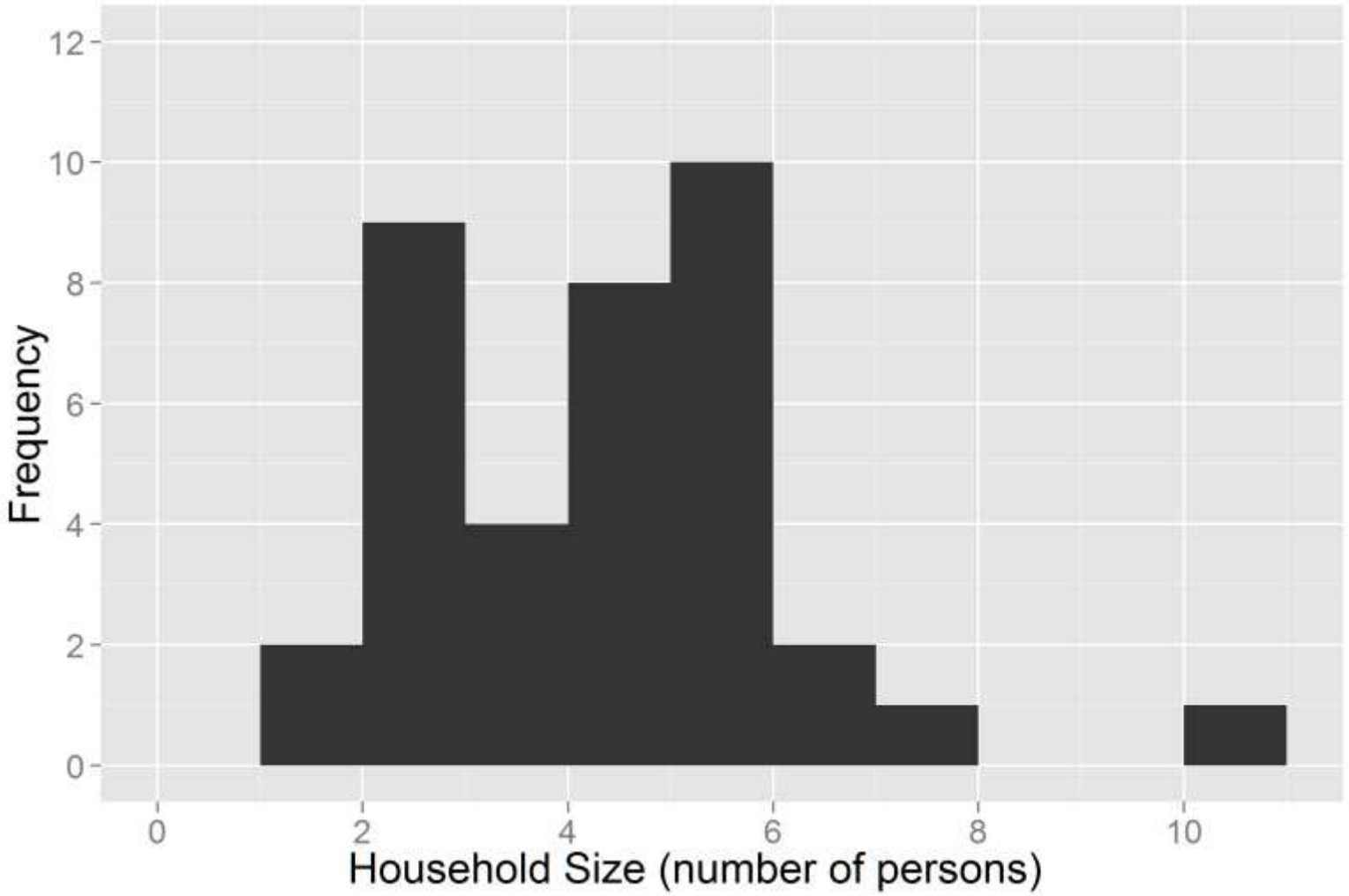
Bus stop

Market

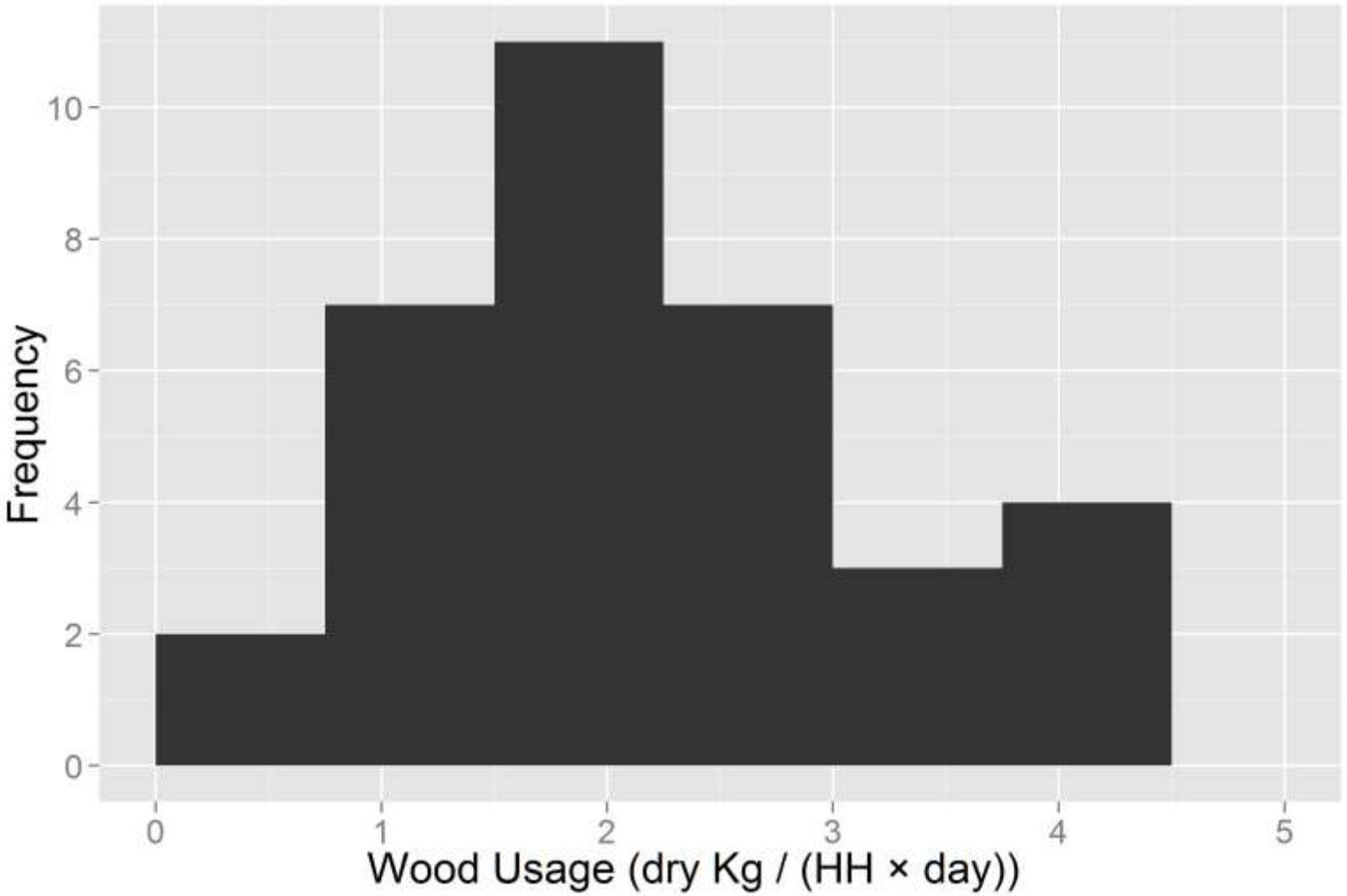
Employer

EXTRA SLIDES - Biomass

Household Size (number of persons)



Dry Biomass Used for Cooking



EXTRA SLIDES- Kriging

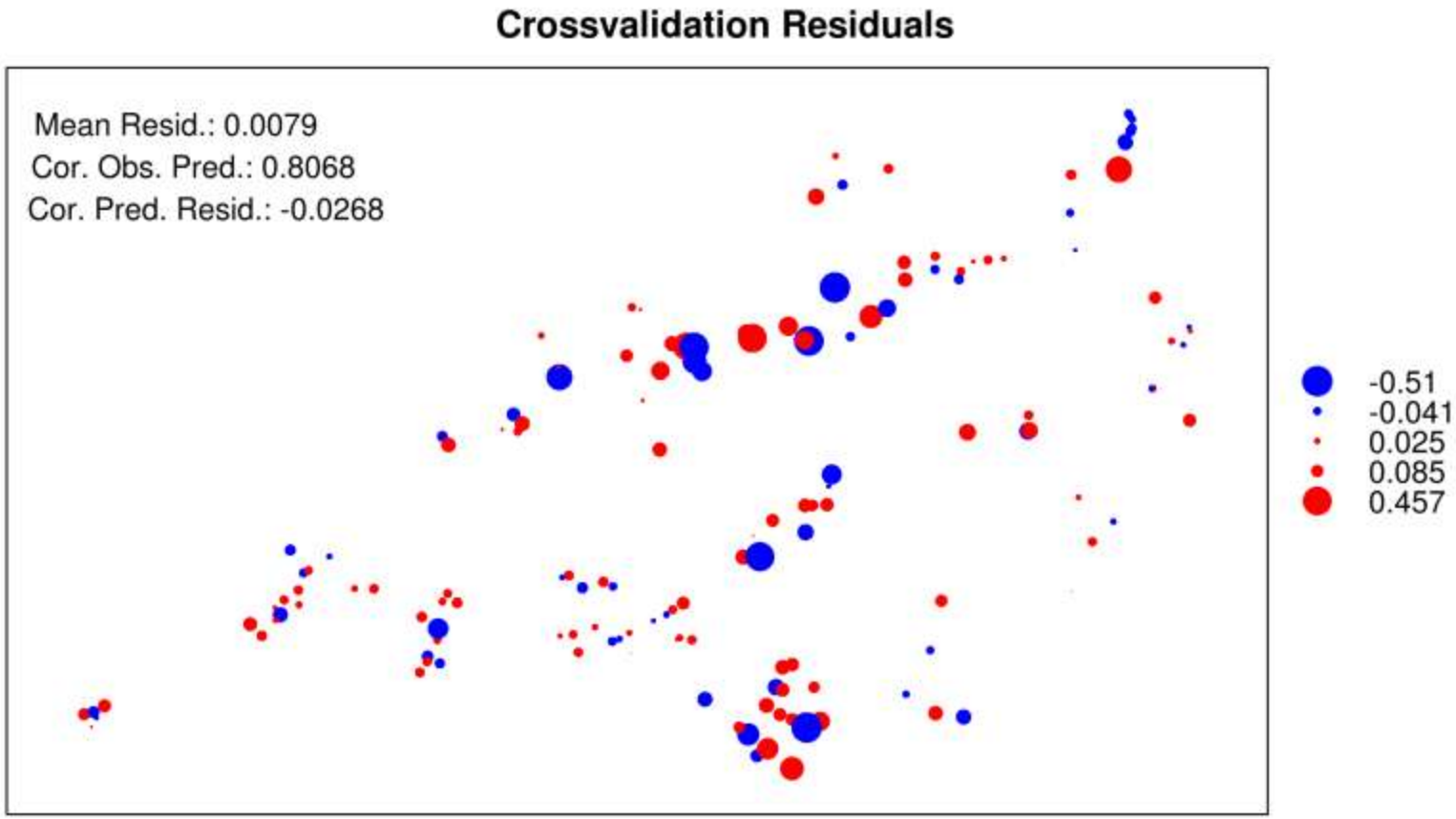
Problem: Handling Partial Sample

- Problem: CVFS sample covers only a portion of the full study area population
  - To understand LULC we need FULL space
- Solution 1:
  - Sample is representative of full population (by design)
  - Scale up to full population
  - Drawback: SLOW – over 200,000 agents

Problem: Handling Partial Sample

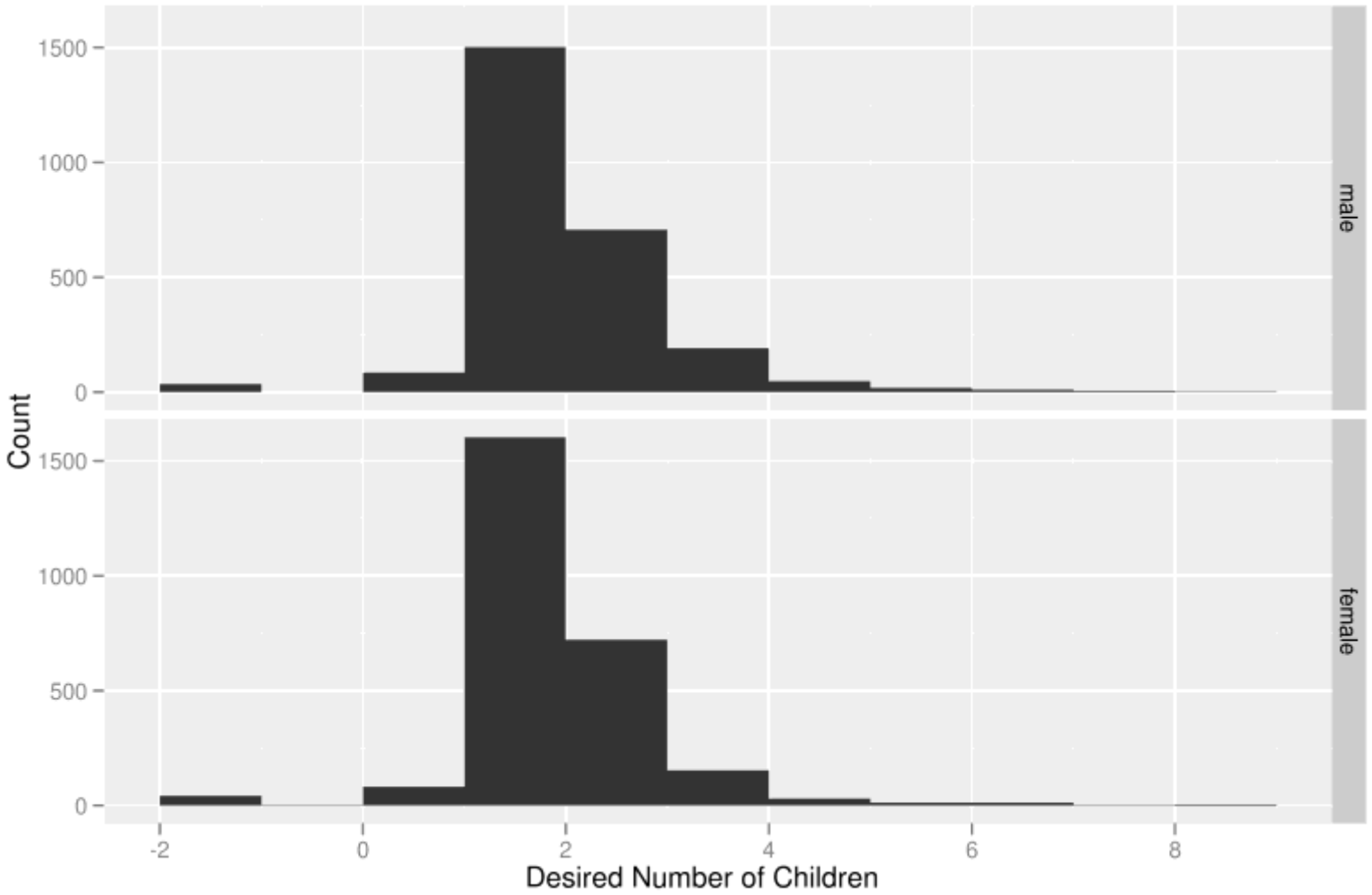
- Solution 2:
  - Remember: sample is representative
  - Therefore: model only the representative sample neighborhoods
  - Then: use the demographic and LULC characteristics of these sample neighborhoods to impute LULC in missing areas

Time Zero: Kriging Crossvalidation



EXTRA SLIDES- ABM parameterization

Desired Number of Children Distribution



LULC Change

- Private built infrastructure (new households) deduct from agricultural vegetation
- Fuelwood harvesting deducts from nonagricultural vegetation and forest cover
- Birth event leads to higher vegetation consumption
- Public infrastructure (NFOs) deduct from agricultural vegetation or nonagveg

New Household Land Area

- Where are new households established?
  - Agveg land (based on neighborhood mapping data)
- How much land is occupied by a household?
  - Based on my analyis of BASIC datafiles from ISER
    - Mean household area = 1176 m2
    - Standard deviation = 1484 m2
    - n = 769
- In the ABM, the area of each new household is drawn from a probability distribution

NFO Land Area

- NFO land area less clear
- Using 2008 data there are:
  - 15 Temples
  - 9 Schools
  - 1 Health center
- Very few datapoints
  - Mean NFO area = 3229 m2
  - Standard deviation = 3735 m2
  - n = 27