The Chitwan ABM

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Introduction

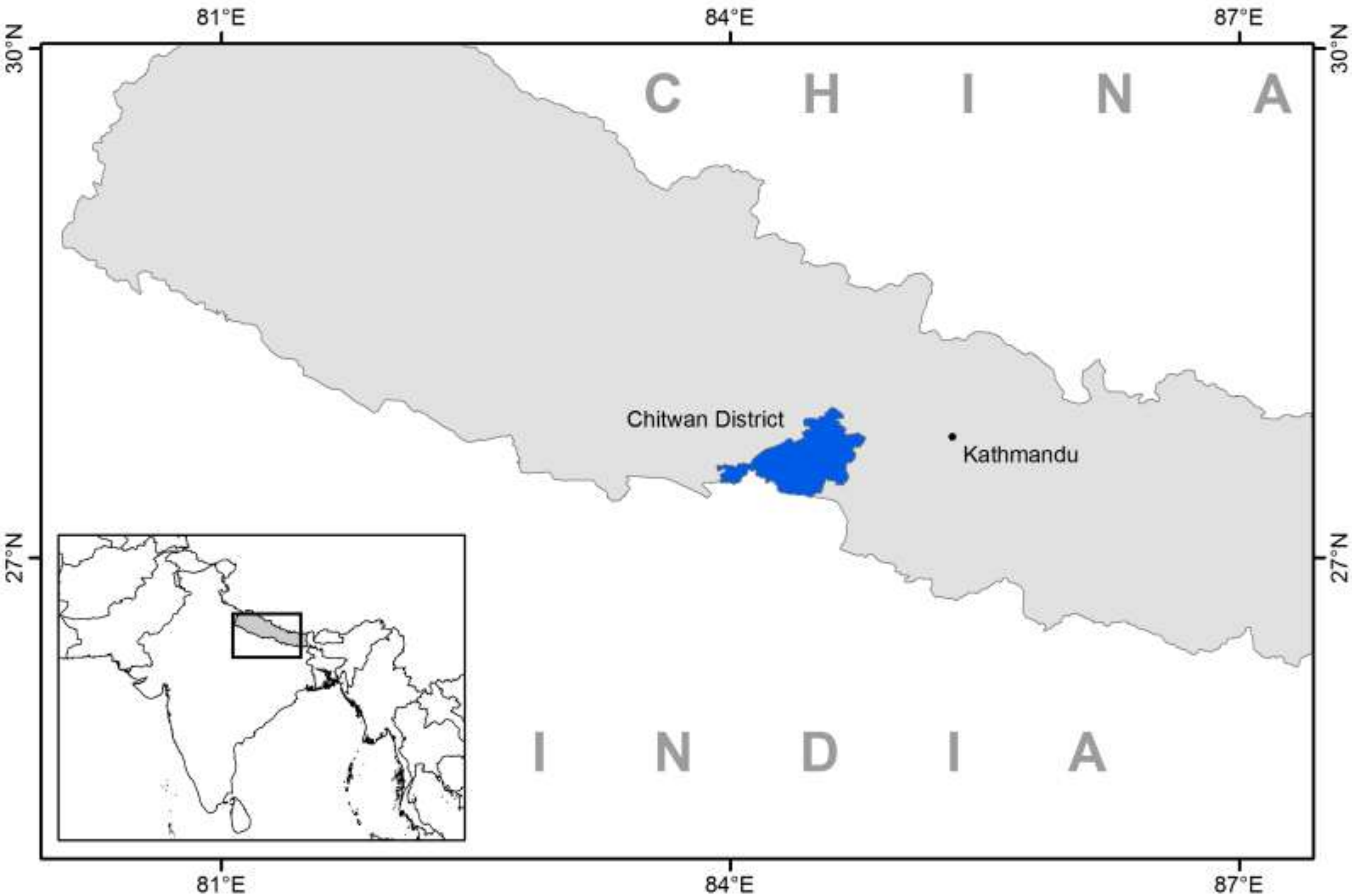
- Land-use and land-cover and human-decision making are intimately linked
- Micro-level decision-making can lead to broader scale ("emergent") patterns on the landscape

Introduction

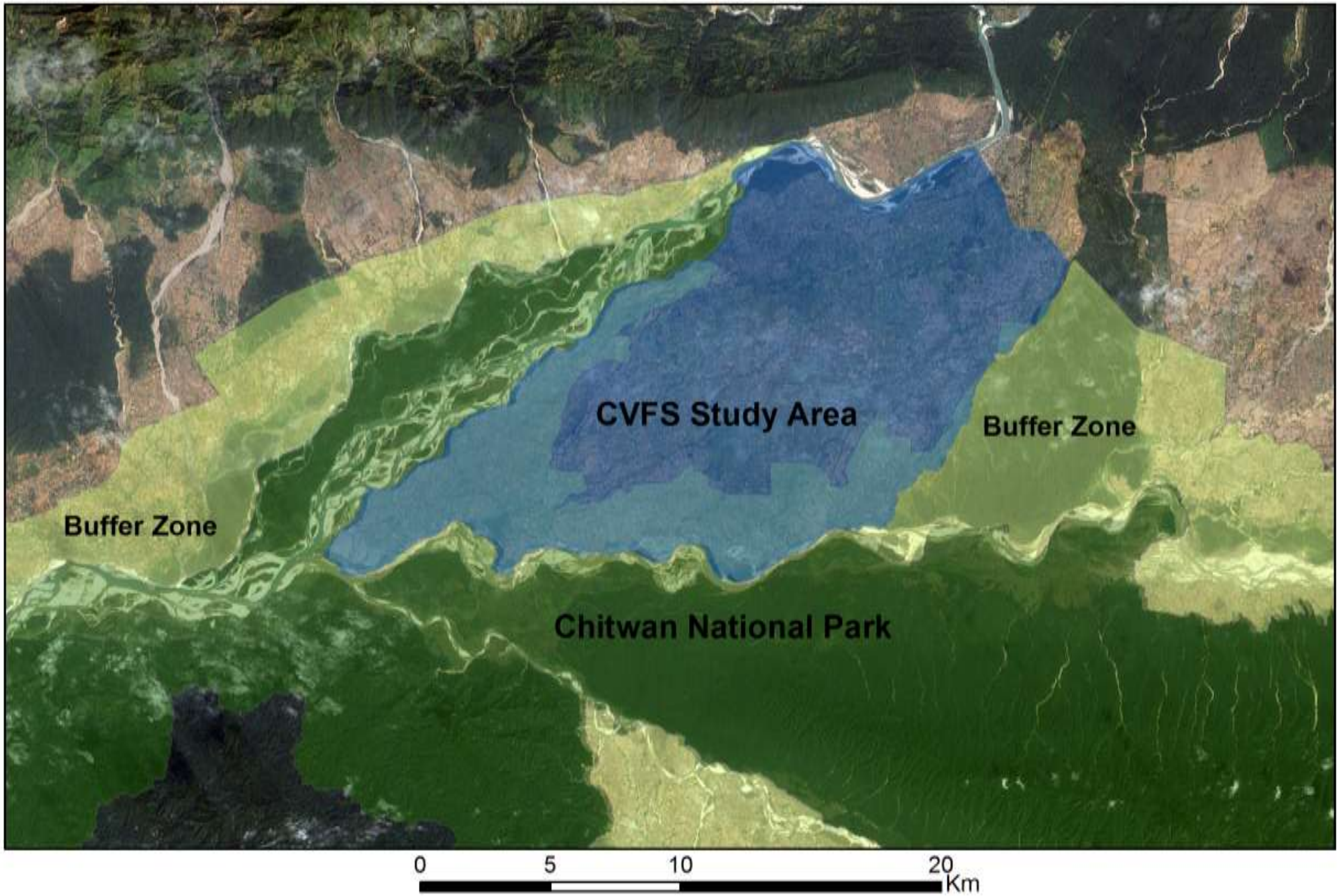
- How does micro-level demographic decision making impact macro-level resource consumption and land use and land cover (LULC)?

- What role do feedbacks play in this relationship?

Introduction



Introduction



Chitwan Valley Family Study

- Longitudinal survey – began in 1996
- Focuses 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)

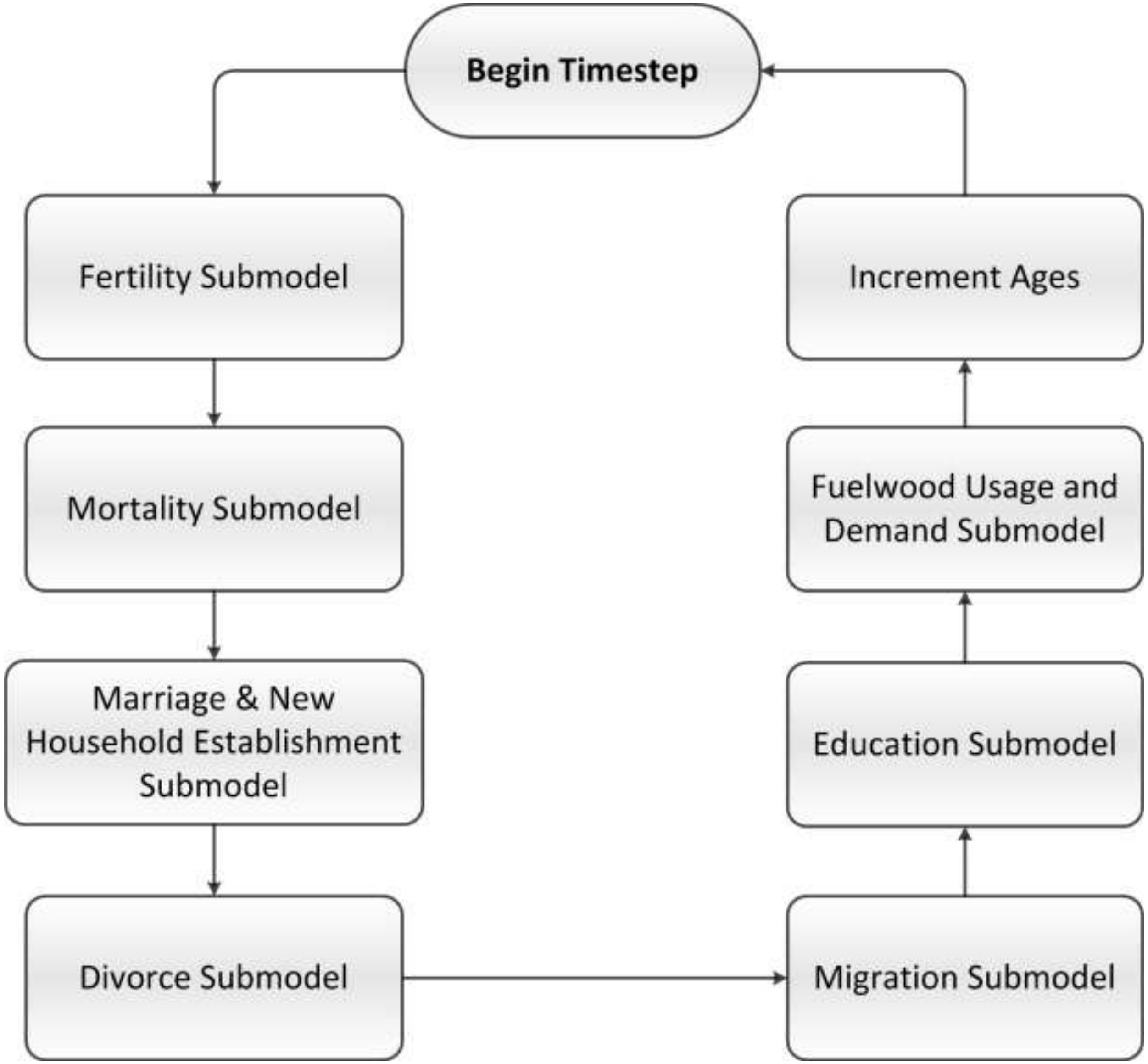
Methods

- 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

Submodels

Submodels


Begin Timestep
Fertility Submodel
Mortality Submodel
Marriage & New Household Establishment Submodel
Divorce Submodel
Migration Submodel
Education Submodel
Fuelwood Usage and Demand Submodel
Increment Ages

First-birth Timing

- First births after marriage are modeled separately from other births
- In each month following marriage, calculate probability of a live birth in that month based on regression results (based on Ghimire and Hoelter 2007 and Axinn and Ghimire 2010)
- Only live births are modeled

First-birth Timing Model (based on Ghimire and Axinn, 2010)

Variable	Odds Ratio	2-sided p-value
Percent land area under agriculture	1.002	0.458
Community characteristics		
Neighborhood area	0.420	0.428
Distance to urban center	1.007	0.548
Electricity in 1996	1.298	0.105
Non-family services within a 15-min walk	0.996	0.619
Controls		
Respondent's parents' characteristics		
Mother's number of children	0.977	0.504
Mother's education	0.922	0.678
Mother's work	0.930	0.686
Father's education	0.874	0.324
Father's work	0.721	0.021 *
Parents' contraceptive use	0.968	0.824
Respondent's ethnicity		
Low Caste Hindu	1.026	0.922
Hill Tibeto-burmese	0.539	0.003 **
Newar	0.619	0.210
Terai Tibeto-burmese	0.958	0.816

Continued on next slide.

First-birth Timing Model (based on Ghimire and Axinn, 2010)

Variable	Odds Ratio	2-sided p-value
Respondent's marital experiences		
Age at first marriage	0.968	0.201
Marriage duration		
Marriage duration before 1997	0.994	0.452
Marriage duration during obs. period		
Married for 1–6 months	11.300	<.001 ***
Married for 7–12 months	7.118	<.001 ***
Married for 13–18 months	5.386	<.001 ***
Married for 19–24 months	3.156	<.001 ***
Married for 25–30 months	1.523	0.236
Married for 31–36 months	2.278	0.010 *
Married for 37–42 months	1.300	0.476
Schooling		
4–7 years of schooling	1.621	0.043 *
8–11 years of schooling	2.345	0.063 .
12 or more years of schooling	3.688	0.019 *
Intercept	0.028	<.001 ***

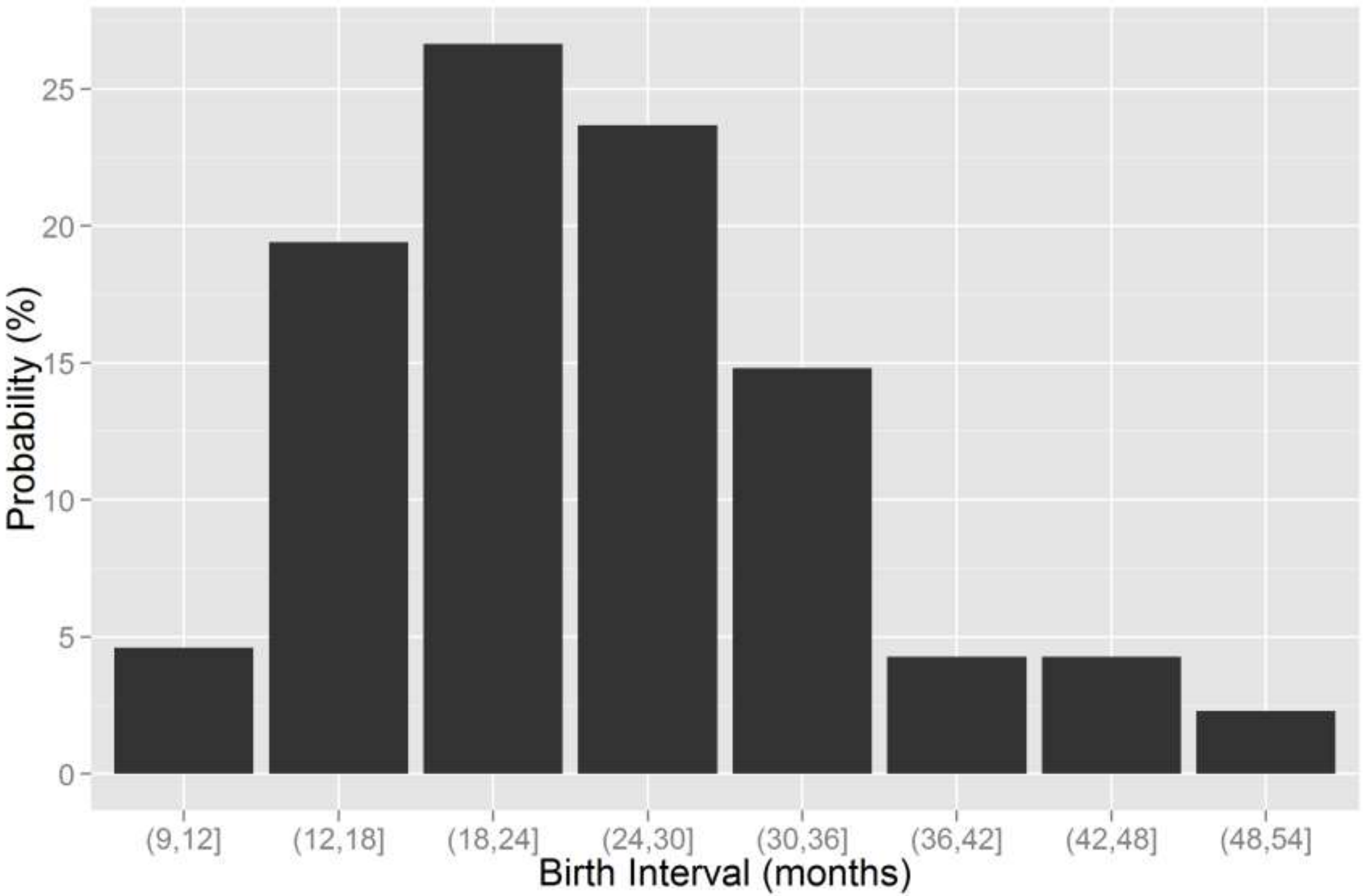
Model continued from previous slide.

Second and subsequent births

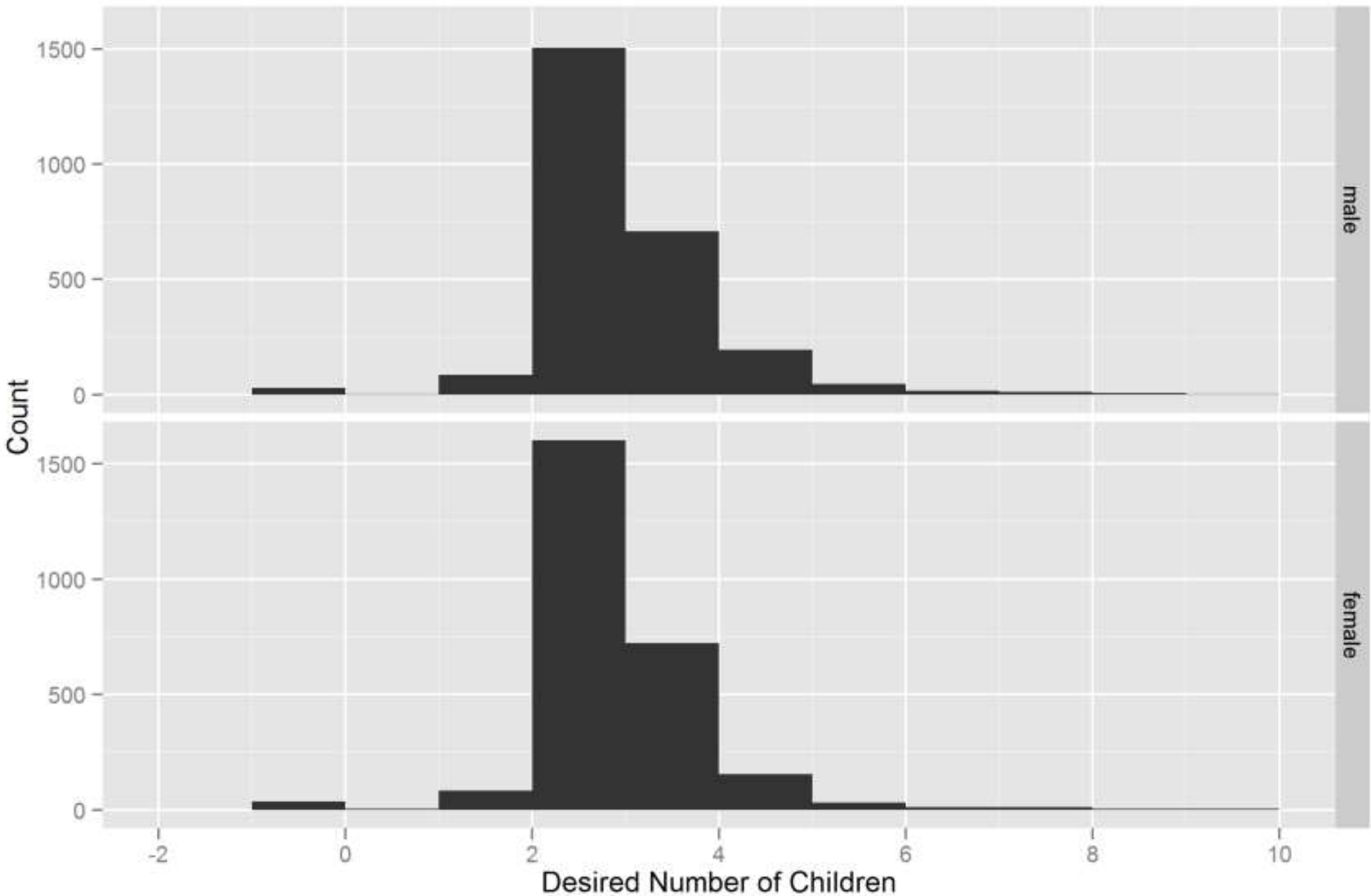
- For all other births, choose the interval until the next child from empirical probability distribution

- Births can occur until:
  - The desired number of children is reached
  - (or) woman reaches *maximum birth age* (45)
  - (or) woman dies/out-migrates

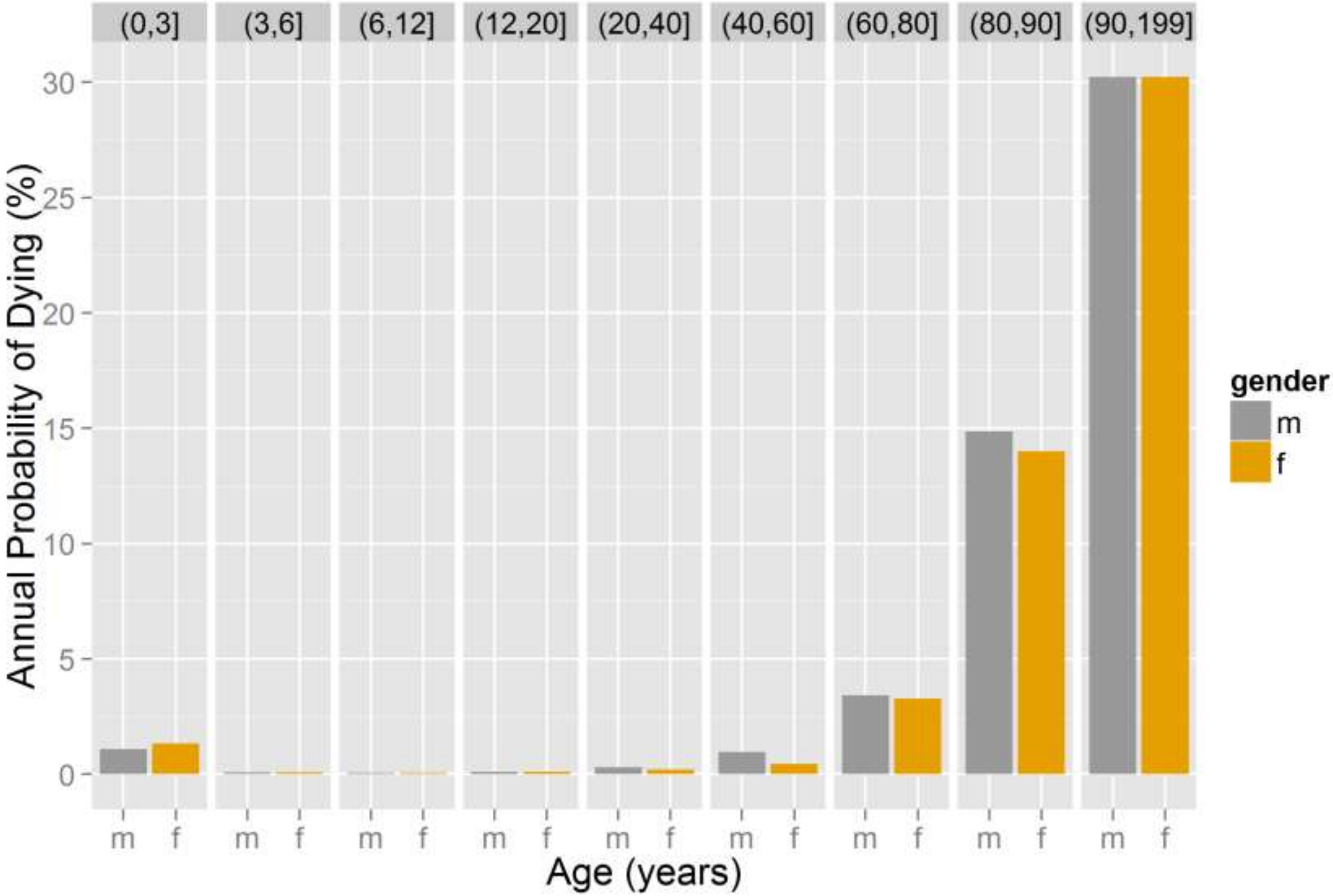
Birth Interval



Desired Number of Children



Mortality


(0,3]
(3,6]
(6,12]
(12,20]
(20,40]
(40,60]
(60,80]
(80,90]
(90,199]
Annual Probability of Dying (%)
30
25
20
15
10
5
0
m
f
Age (years)
gender
m
f

Marriage Timing

1. Minimum marriage age is 15
2. Beginning at minimum marriage age, calculate a probability (**p**) of marriage for each agent for that month
3. Draw a random number – if the random number is less than the probability **p**, add person to 'to be married' list

Note: Marriage timing regression model is based on Yabiku (2006a, 2006b)

Marriage Timing Model (based on Yabiku, 2006)

Variable	Odds Ratio	2-sided p-value
Log(Percent Agricultural Land (interpolated))	1.138	0.064 .
Nonfamily organizations (minutes by foot)		
School	1.012	0.138
Health post	0.999	0.711
Bus stop	1.005	0.282
Market	0.999	0.842
Employer	1.003	0.305
Schooling		
Years schooling completed	0.997	0.893
Enrolled in school	0.669	<.001 ***
Female	2.245	<.001 ***
Ethnicity		
Lower Caste Hindu	1.014	0.942
Newar	0.786	0.229
Hill Tibetoburmese	1.187	0.256
Terai Tibetoburmese	0.906	0.508
Age		
Age	2.107	0.004 **
Age-squared	0.986	0.018 *
Intercept	0.000	<.001 ***

Spouse choice

1. Once 'to be married' list is constructed, loop over list in random order
2. Each time through list, choose a person (**psn1**)
3. Calculate probability that **psn1** would marry each other person in the list
   - Assign zero probability to anyone from a different ethnic group or from the same sex
   - Calculate probability for all others based on age difference between spouses (using empirical data)
4. Choose a spouse (**psn2**) by sampling from the potential spouses with each potential spouse weighted by their calculated probability of marriage to **psn1**
5. Unpaired spouses marry in-migrants – with spouse age chosen using spouse age model

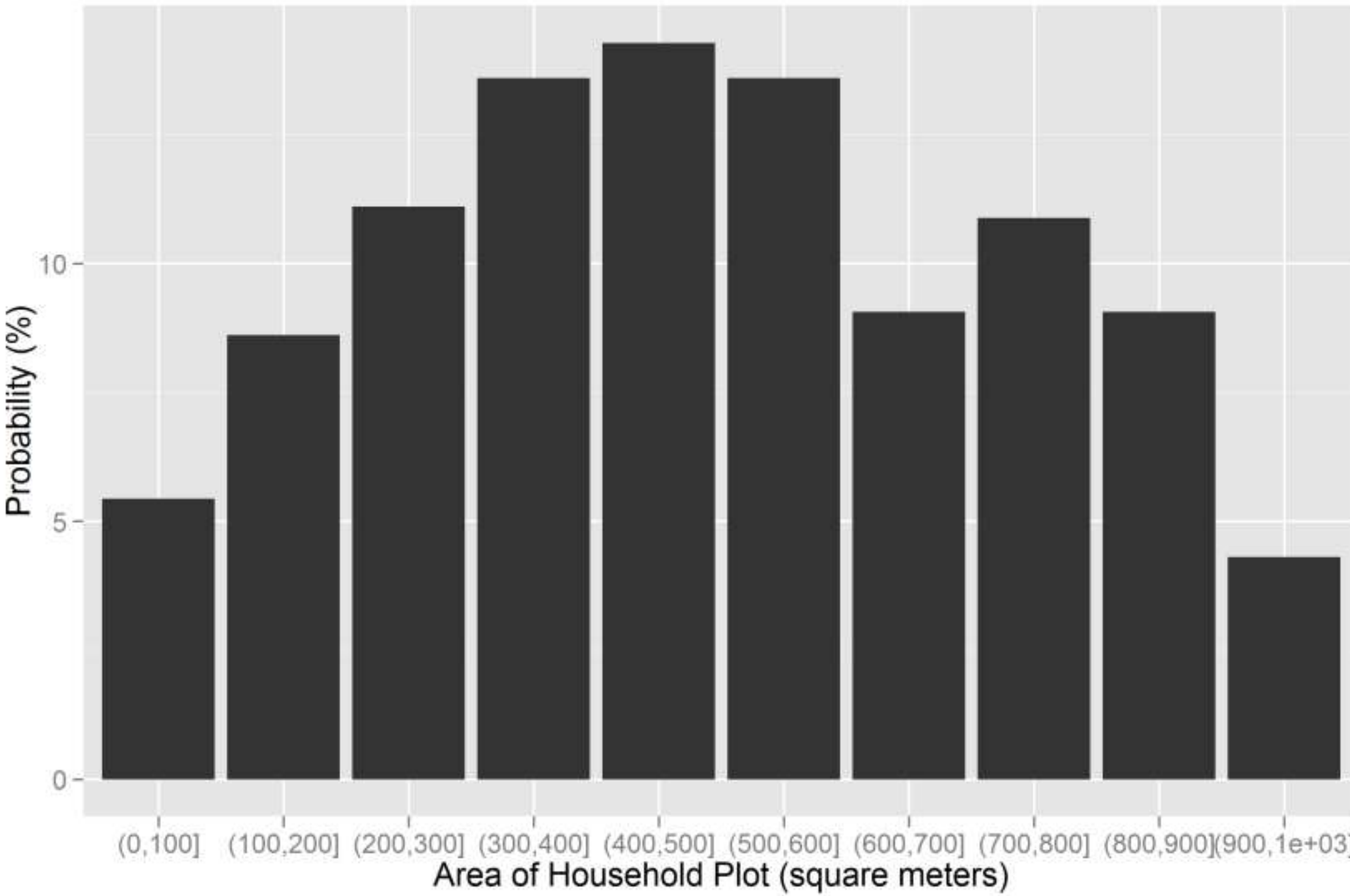
New household establishment (part 1)

1. Once a couple is formed, decide if couple will form a new household, by drawing a random number and comparing to the *household fission rate*

   – If a new household is **not** formed, move the new couple into the husband's household

   – If a new household **is** formed, draw the size (area in sq. m) of the household plot from empirical probability distribution

New Household Establishment (part 1)



New household establishment (part 2)

2. Find a neighborhood with sufficient free land (agricultural or non-agricultural vegetation, in that order) to build new household
   – First try husband's parent's neighborhood
   – Move outwards by distance from parent's neighborhood until first neighborhood with free land is found
3. Assign new household to chosen neighborhood

Divorce

- If a random number is less than the calculated divorce probability for a person, that person will divorce their spouse
- The woman will either:
  - Return to her parent's household
  - (or) If her parent's household no longer exists, she will establish a new household in a randomly selected neighborhood following the household establishment submodel
- The man will remain in the original household, together with any child agents

Note: this model is under devlopment – suggestions appreciated. Currently the divorce probability is set to a constant.

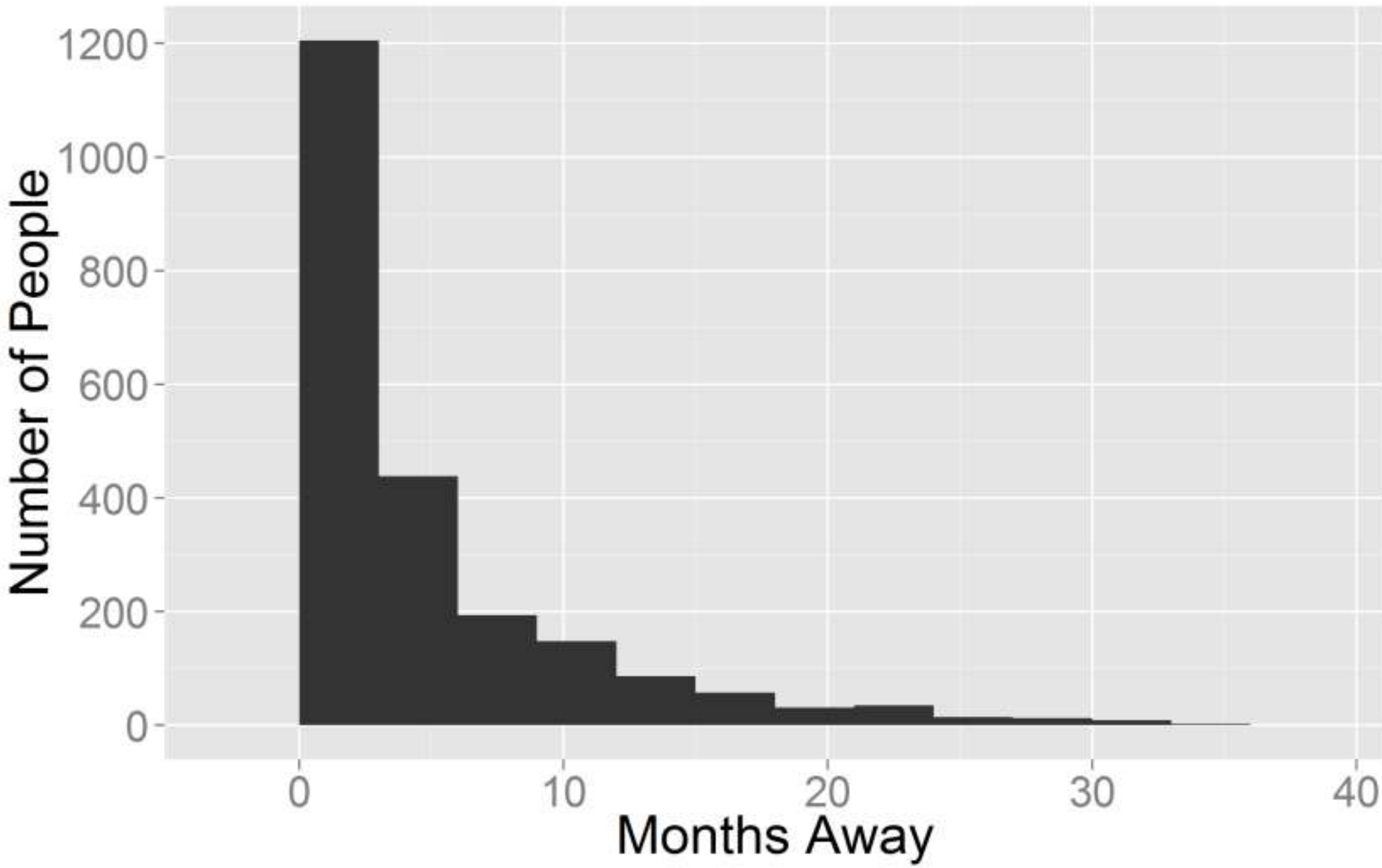
Individual out-migration: Prob. of out-migration

- For each individual older than the *minimum out-migration age*, a probability of migration is calculated for each timestep (following Massey et al. 2010)
- If a random number is less than the calculated migration probability for a person, that person will out-migrate
- For each migrating person:
  - Length of migration is drawn from empirically observed distribution
  - A portion of the migrants (determined by '*permanent out migration probability*') do not return
- After the duration of each person's migration is complete, they return to their household

Migration Model (based on Massey et al. 2010)

Variable	Odds Ratio	2-sided p-value
Enrolled in school	0.820	0.062 .
Years of schooling	1.075	<.001 ***
Female	0.624	<.001 ***
Physical capital		
Market access	1.026	0.516
Farmland	0.930	0.528
Age		
15-25	2.797	<.001 ***
25-35	1.544	0.021 *
35-45	0.940	0.751
45-55	1.050	0.807
Ethnicity		
Low-Caste Hindu	1.109	0.477
Hill Tibeto-Burmese	1.222	0.083 .
Newar	0.854	0.339
Terai Tibeto-Burmese	0.617	<.001 ***
Duration		
Month	0.568	<.001 ***
Month squared	1.123	0.050 .
Intercept	0.007	<.001 ***

Individual out-migration: Out-migration length



Household-level In/Out migration

- Household-level in and out-migration can be allowed by specifying a *probability of household out-migration* and/or a *probability of household in-migration*
- Households that out-migrate leave the model permanently, and their land is returned to agriculture
- Households that in-migrate randomly locate in a neighborhood with available land, following the household establishment model

Education

1. At age 6, calculate child's **final schooling level**
2. Increment education level each timestep until:
   - Person dies or outmigrates
   - (or) Final schooling level is reached

Education Model (ordinal logistic regression)

Variable	Odds Ratio	2-sided p-value
Neighborhood Level		
Avg. years non-family services (15 min. ft.)	1.050	< 0.001 ***
Individual Level		
Female	0.124	< 0.001 ***
Ethnicity		
Low-Caste Hindu	0.133	< 0.001 ***
Hill Tibeto-Burmese	0.227	< 0.001 ***
Newar	0.983	0.954
Terai Tibeto-Burmese	0.083	< 0.001 ***
Intercepts		
Years schooling greater than 0, less than 4	7.991	< 0.001 ***
Years schooling greater than 4, less than 8	3.890	< 0.001 ***
Years schooling greater than 8, less than 11	0.987	0.944
Years schooling greater than 11	0.186	< 0.001 ***

n = 715, pseudo R^2 = .435

Fuelwood Usage Probability

- Household-level fuelwood usage is modeled in two parts:
  1. Probability of fuelwood usage
  2. Quantity of fuelwood usage
- The predicted quantity of fuelwood usage is scaled by the probability of fuelwood usage
- This is consistent with Wolong ABM, and fact that not all households use fuelwood (though most do)

Probability of Fuelwood Usage

Variable	Odds Ratio	2-sided p-value
Neighborhood Level Covariates		
Electricity Available	0.272	0.102
Distance to Narayanghat	1.100	0.005 **
Closest forest is CNP	0.621	0.274
Household Level Covariates		
Household size	1.394	< .001 ***
Mean gender (1 = female)	2.683	0.029 *
Ethnicity		
Low-Caste Hindu	2.994	0.015 *
Hill Tibeto-Burmese	0.996	0.989
Newar	0.476	0.012 *
Terai Tibeto-Burmese	2.712	0.002 **
Intercept	2.814	0.240

n = 2125, Log likelihood = -464.3, Deviance = 928.6

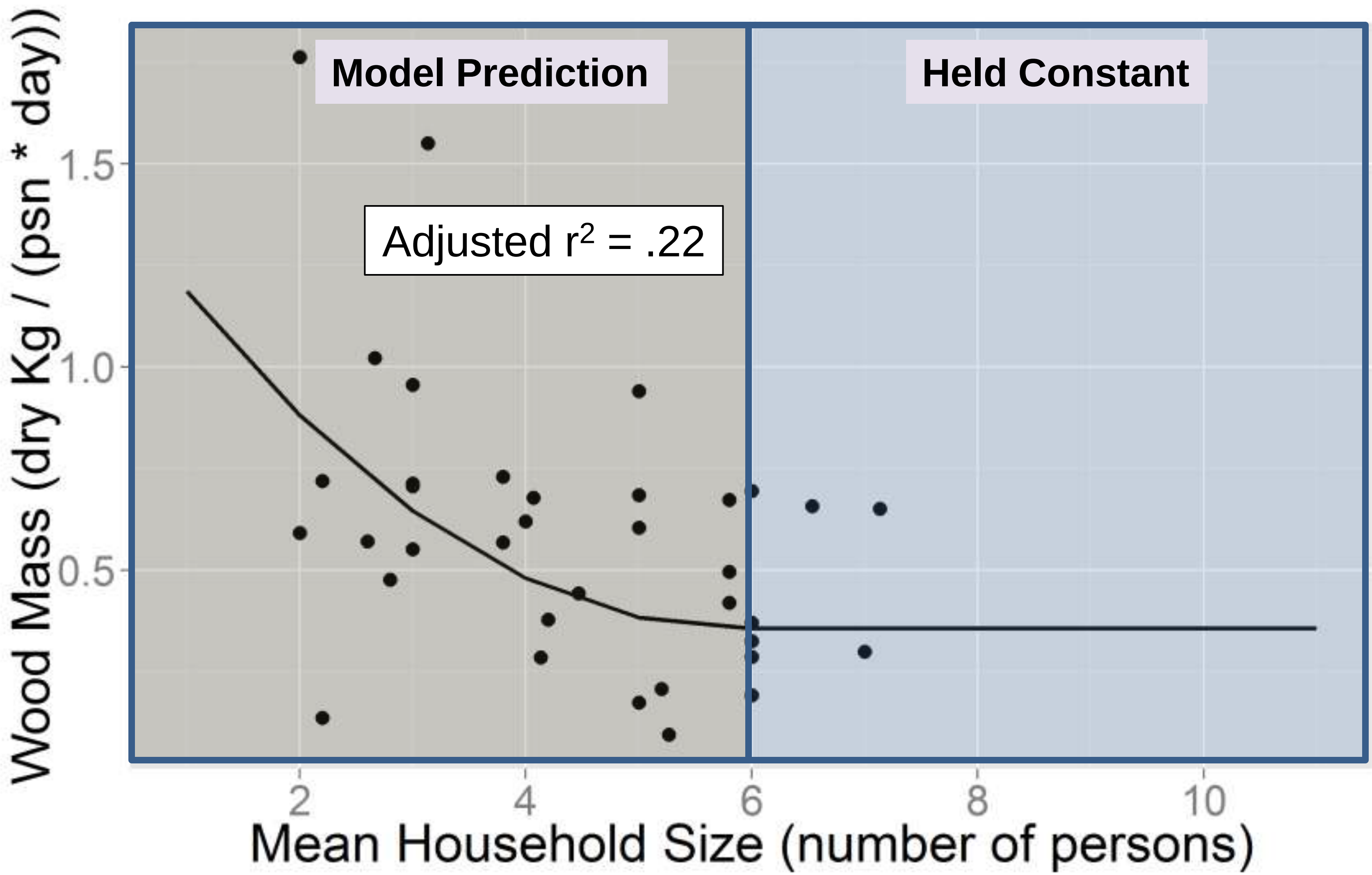
Fuelwood Usage Quantity

Dependent variable: dry kg firewood / (person * day)

Variable	Regression Coefficient	2-sided p-value
Intercept	1.816	<.001***
Mean household size	-0.408	.087 ·
Mean household size (squared)	0.034	.191
Upper Caste Hindu	-0.051	.655
Own any non-wood stove	-0.255	.044 *

Adjusted R^2: .22, n=37

Fuelwood Usage Quantity

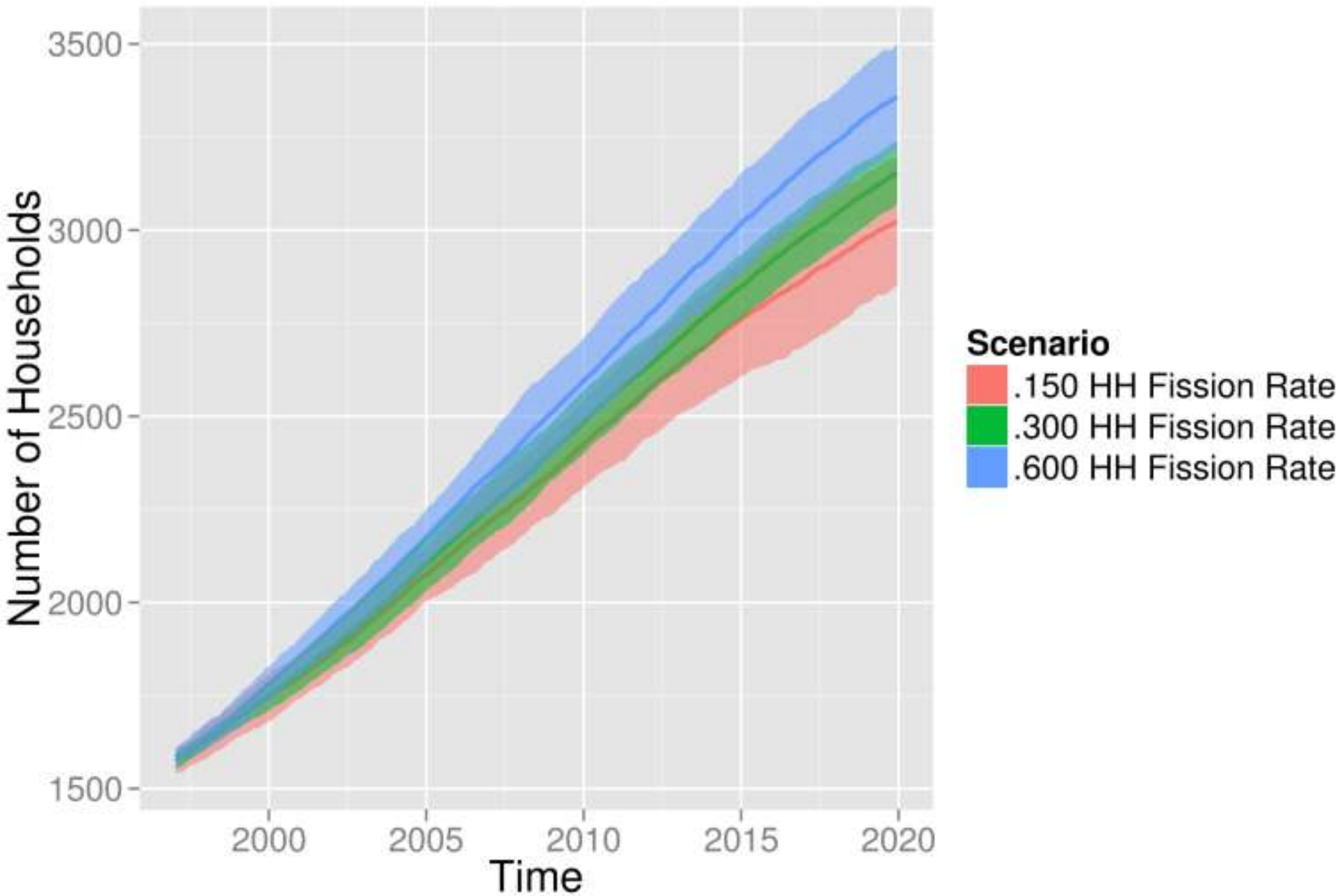


Results

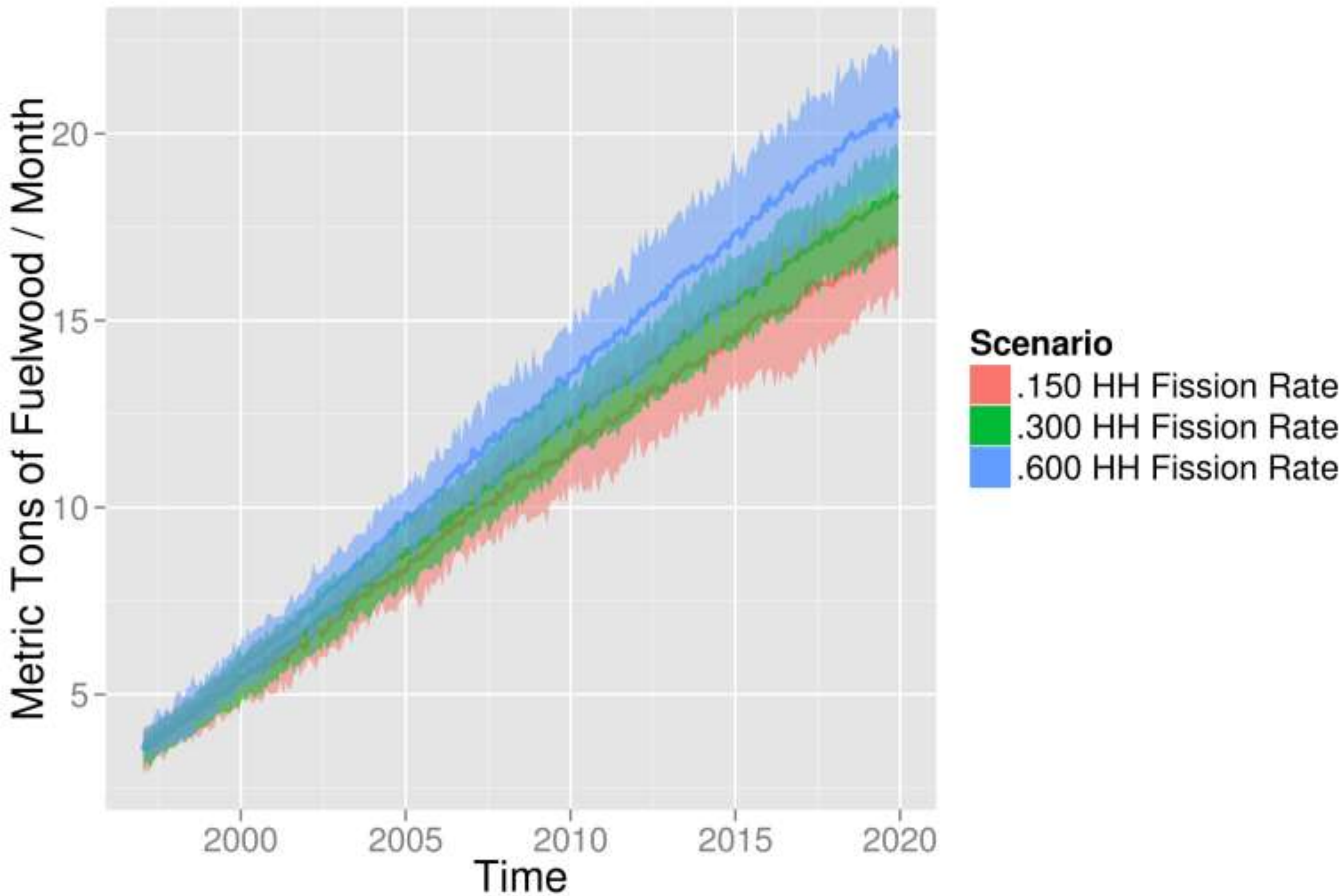
Scenarios

- We will explore several sets of scenarios exploring the impact of varying key variables on population, fuelwood consumption, and LULC
  - Household fission rate
  - Out migration rate
  - Desired number of children

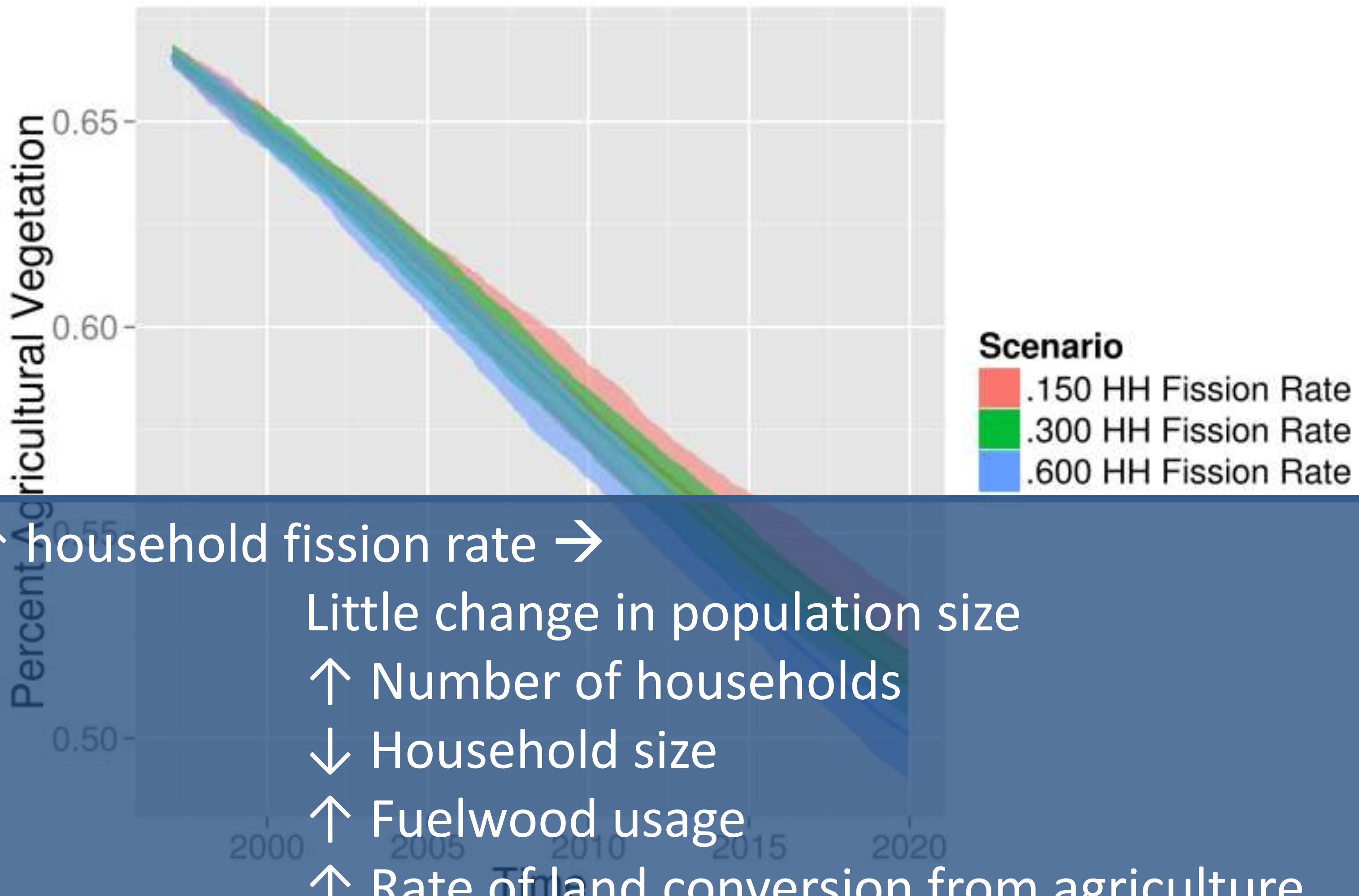
Results – Household Fission Scenario



Results – Household Fission Scenario



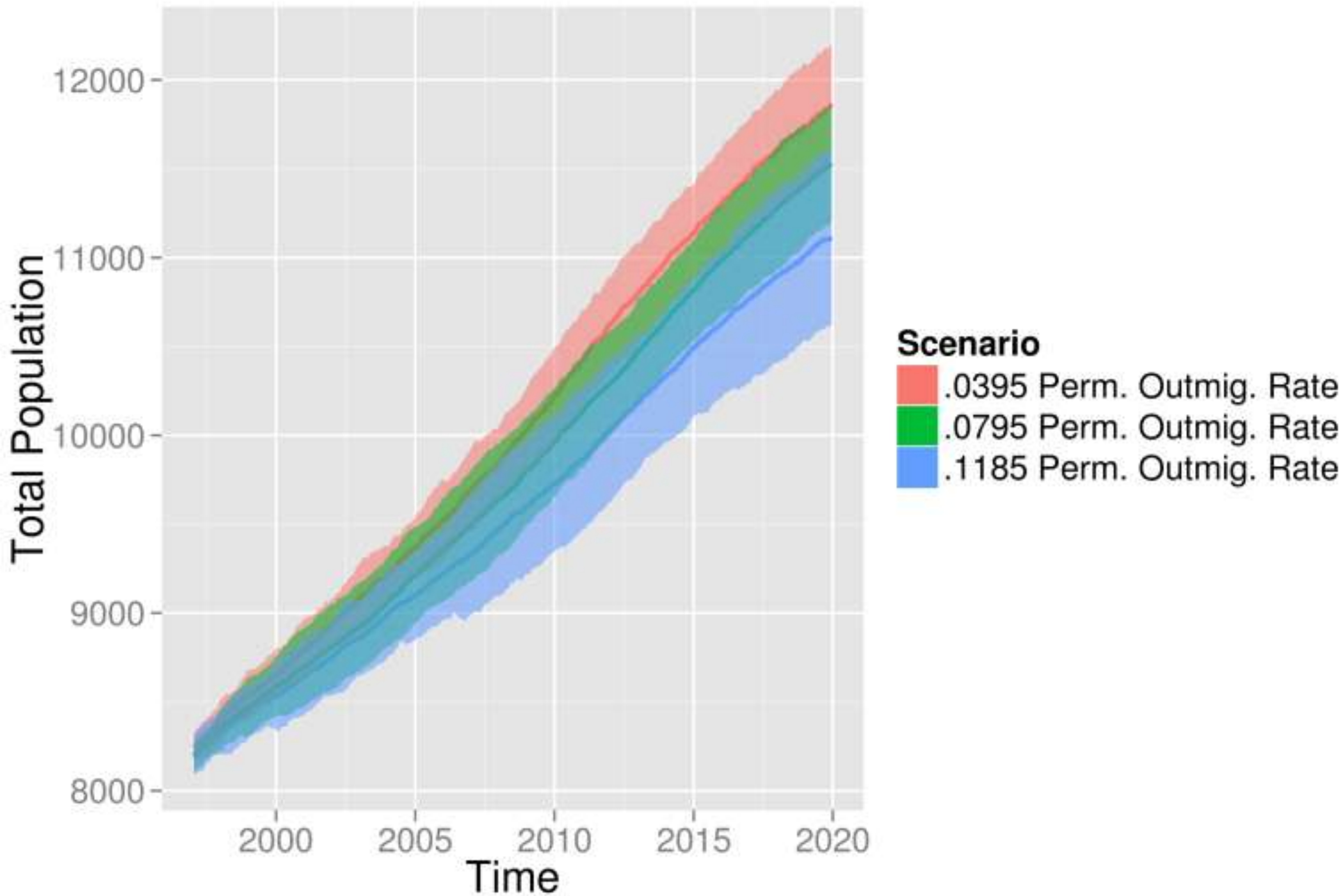
Results – Household Fission Scenario



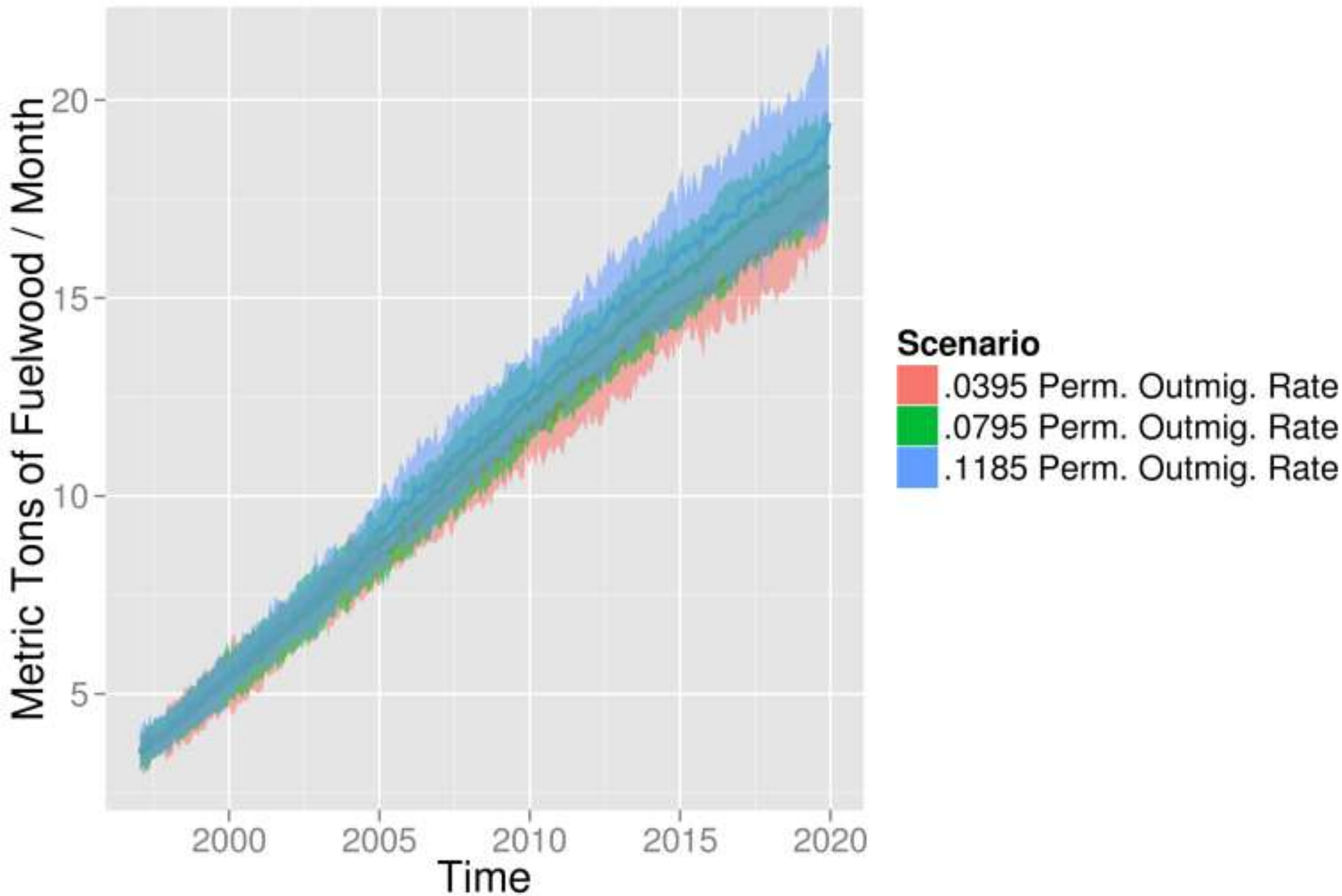
↑ household fission rate →

- Little change in population size
- ↑ Number of households
- ↓ Household size
- ↑ Fuelwood usage
- ↑ Rate of land conversion from agriculture

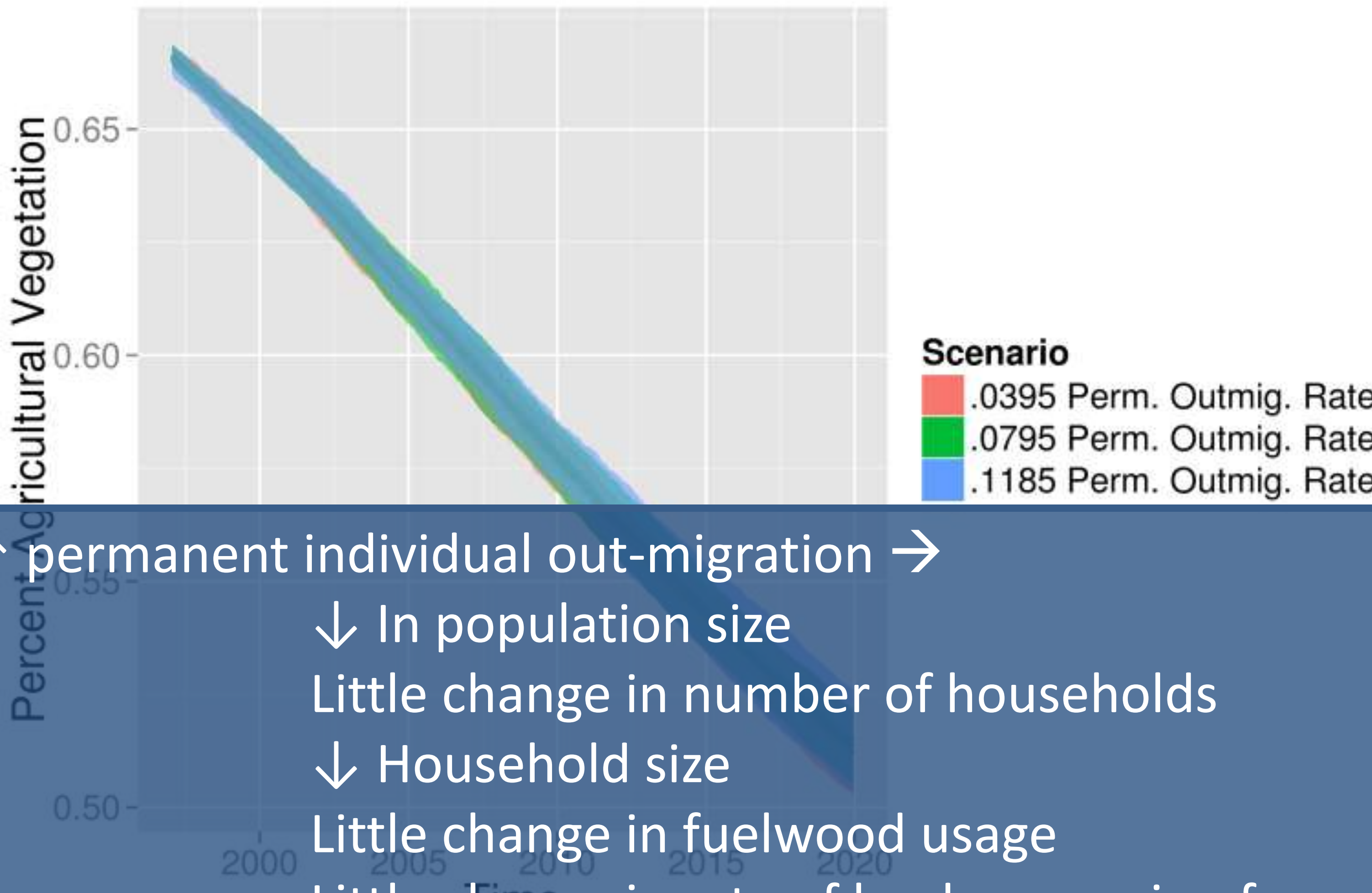
Results – Varying Permanent Out-migration



Results – Varying Permanent Out-migration



Results – Varying Permanent Out-migration



↑ permanent individual out-migration →

↓ In population size

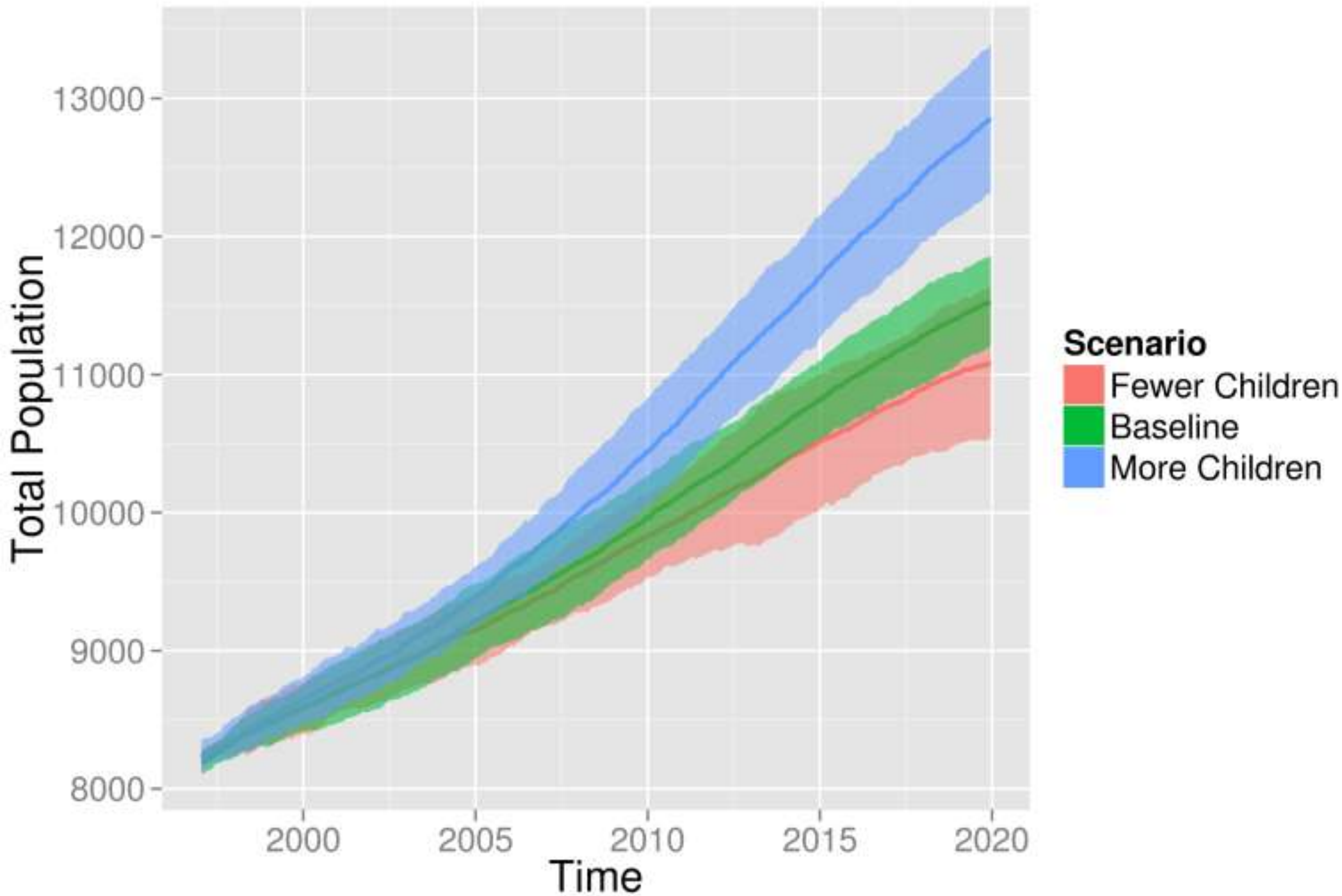
Little change in number of households

↓ Household size

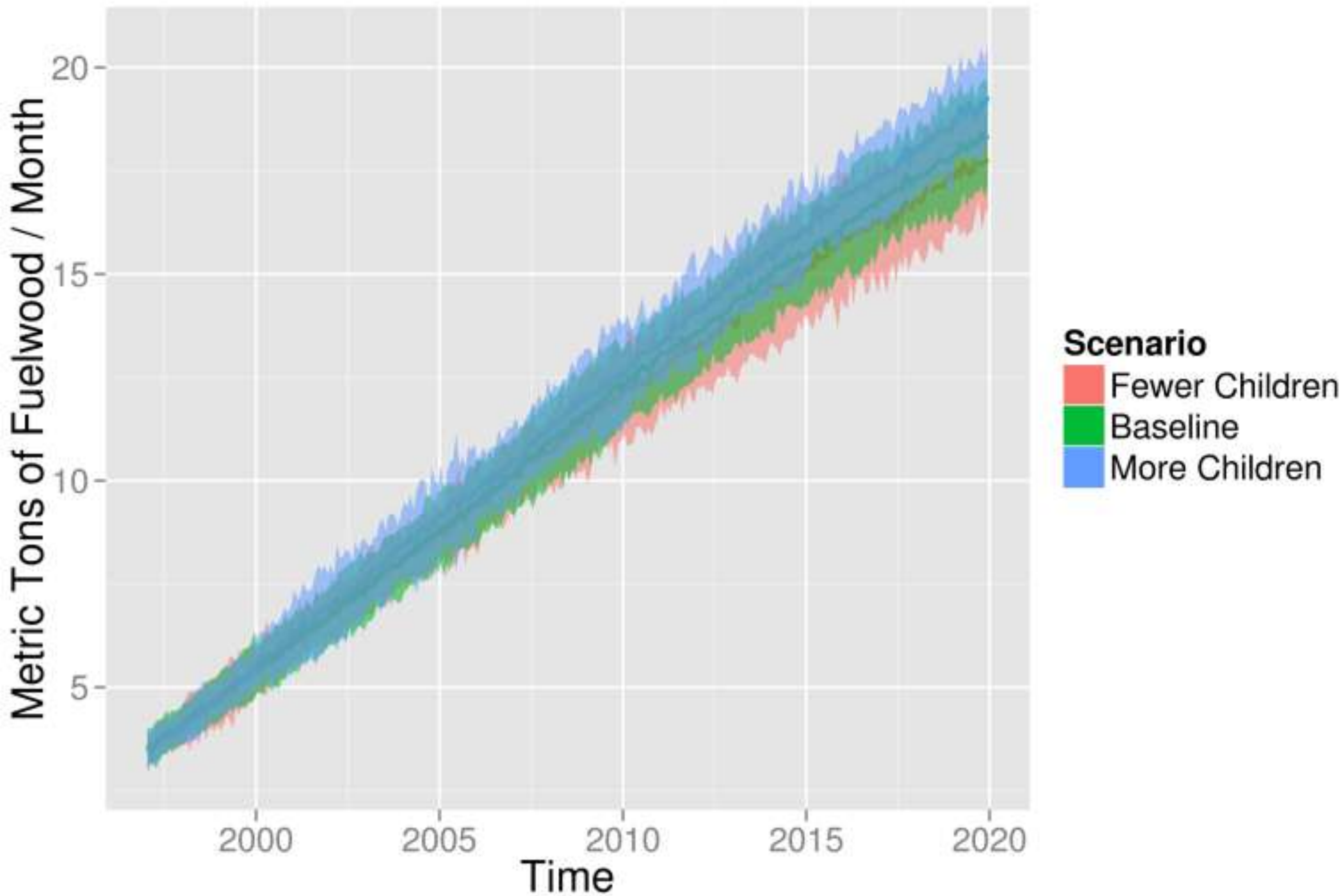
Little change in fuelwood usage

Little change in rate of land conversion from agr.

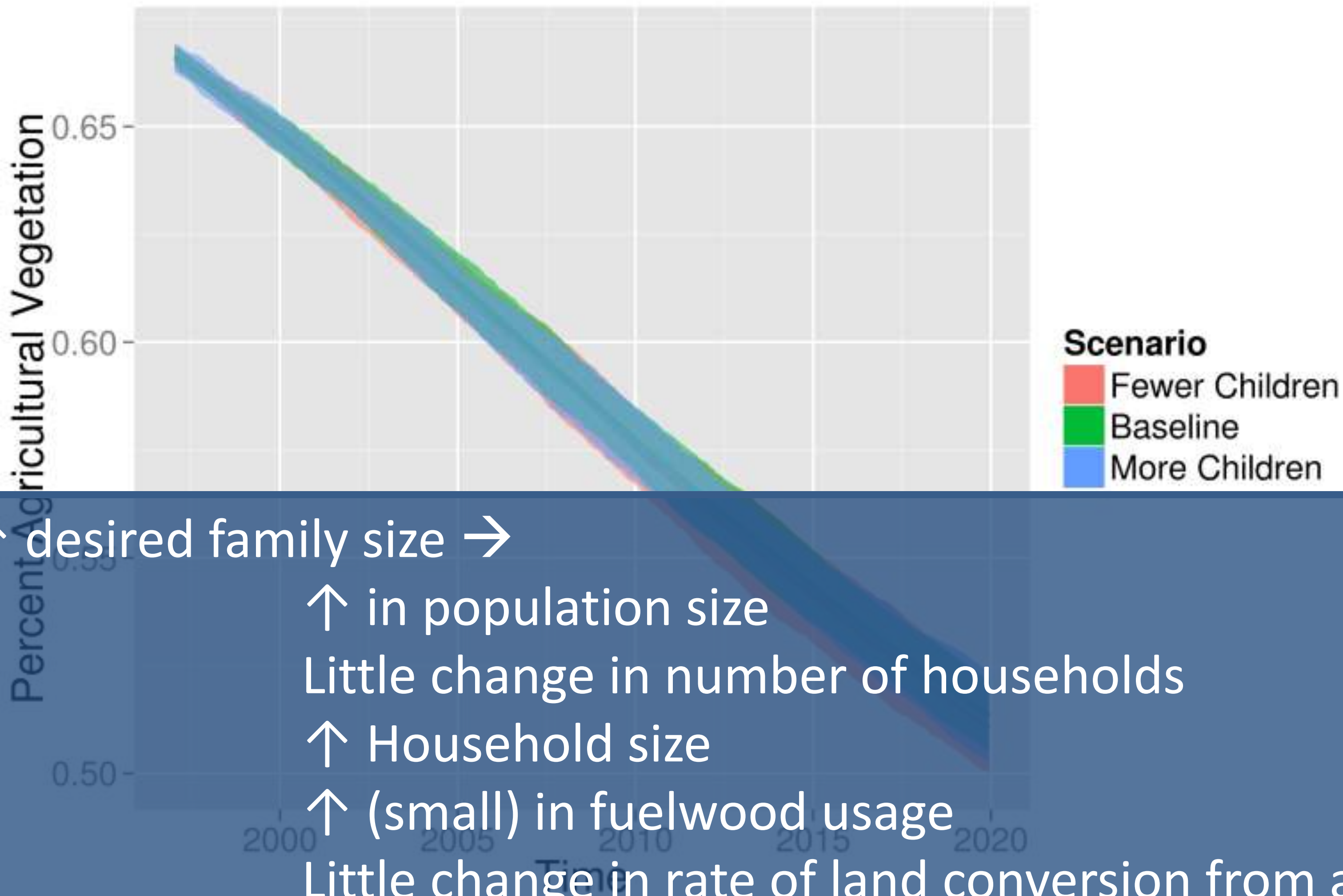
Results – Varying Desired Family Size



Results – Varying Desired Family Size



Results – Varying Desired Family Size



↑ desired family size →

↑ in population size

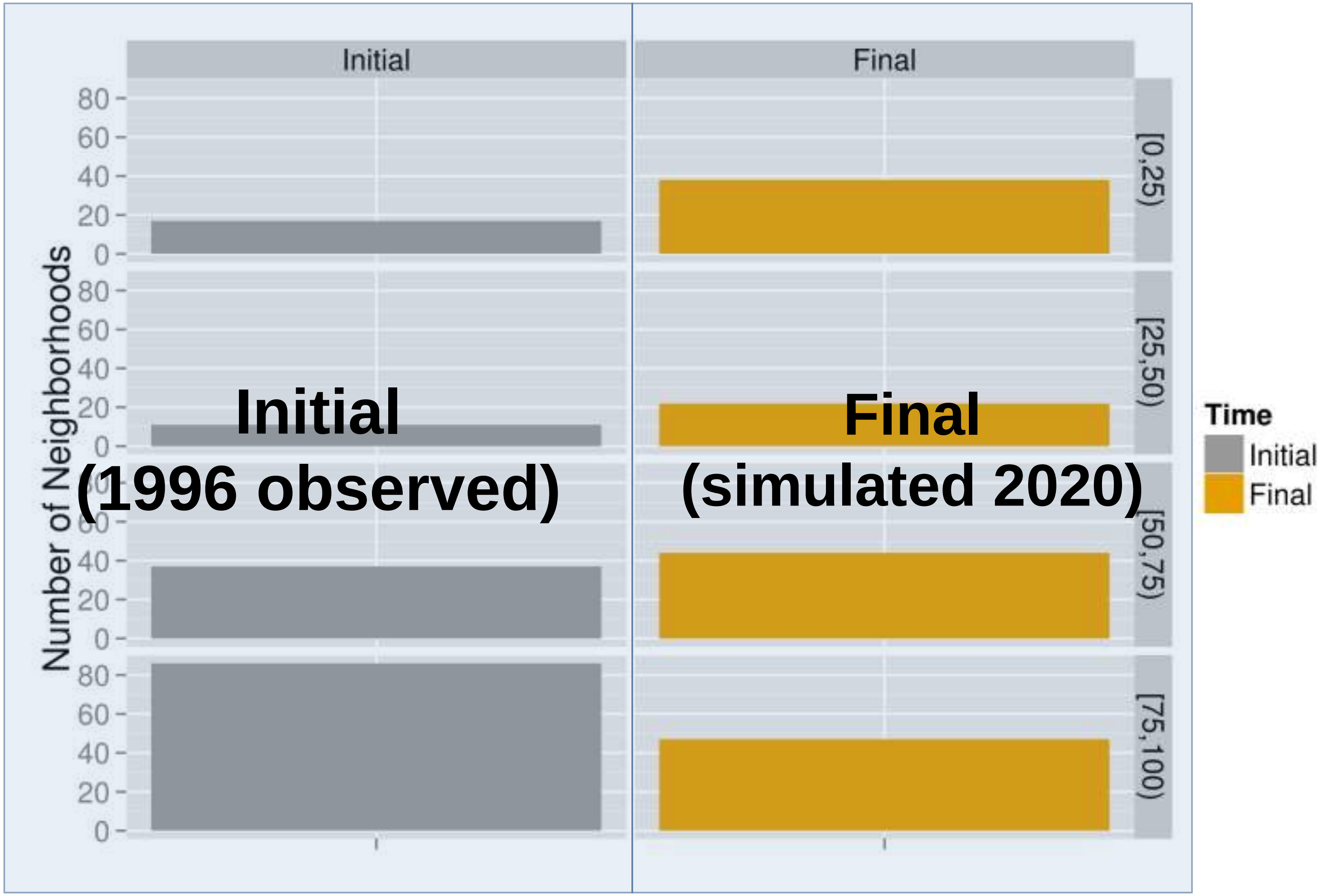
Little change in number of households

↑ Household size

↑ (small) in fuelwood usage

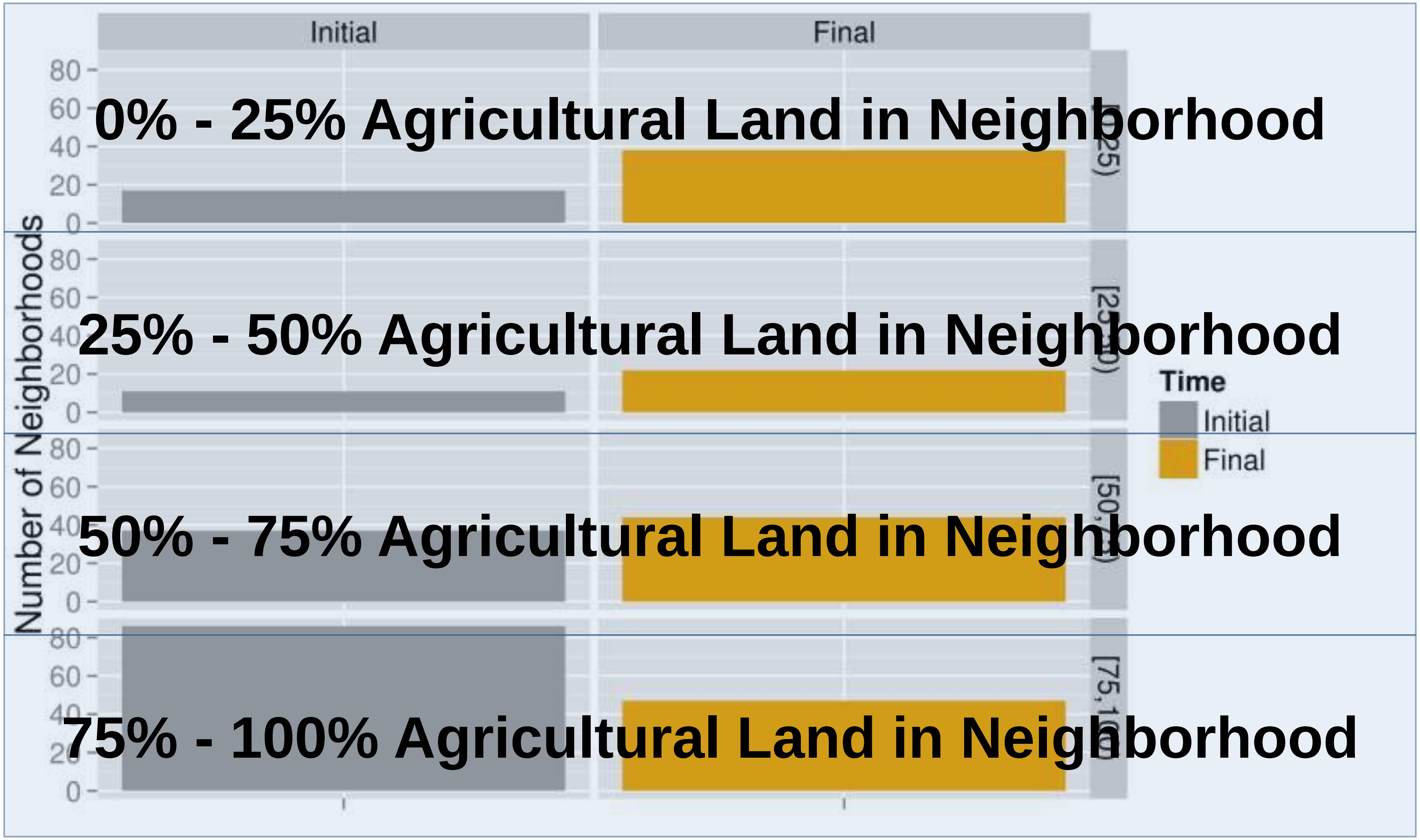
Little change in rate of land conversion from ag.

Where is LULC occurring?



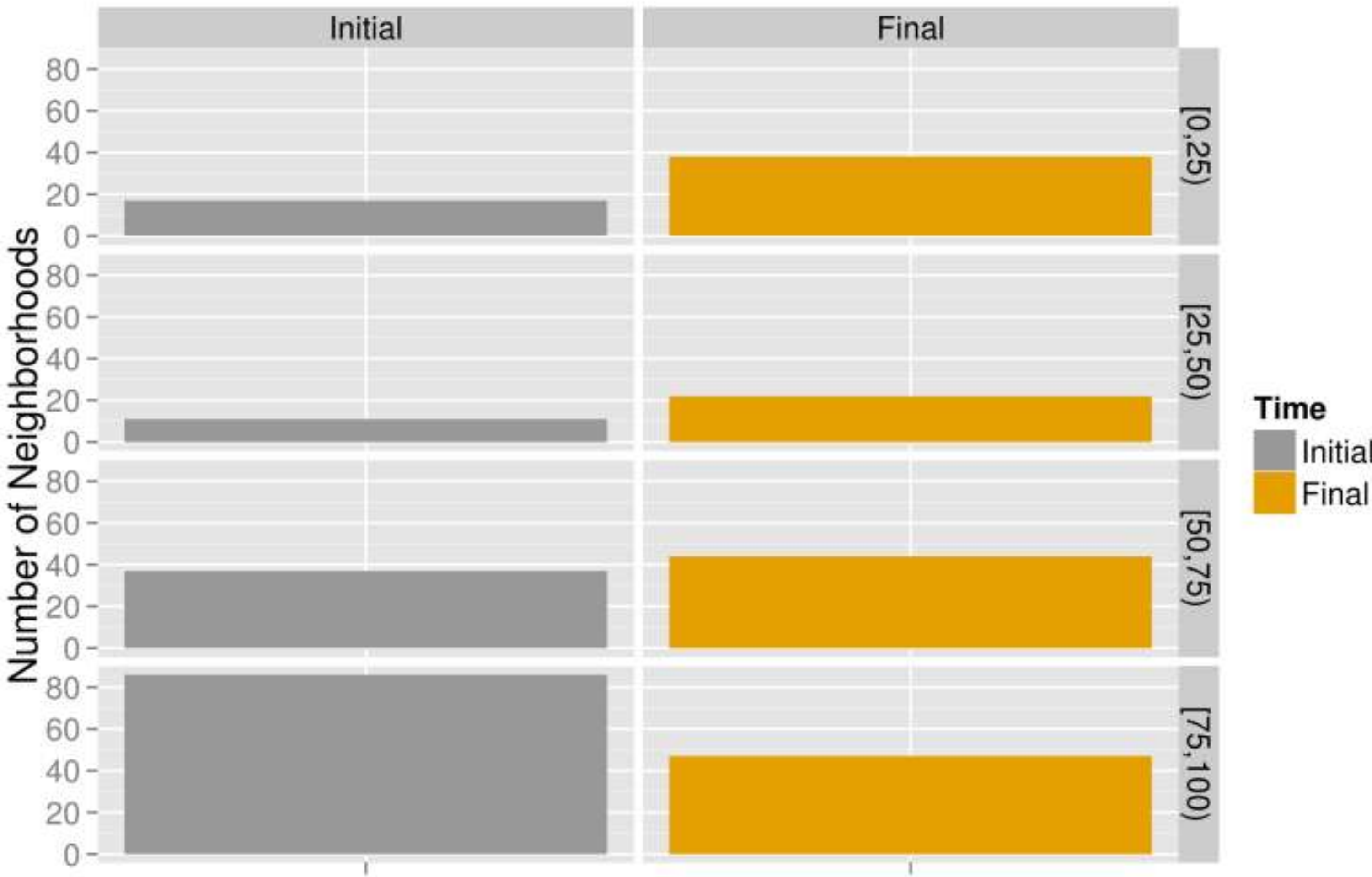
(.150 household fission rate)

Where is LULC occurring?



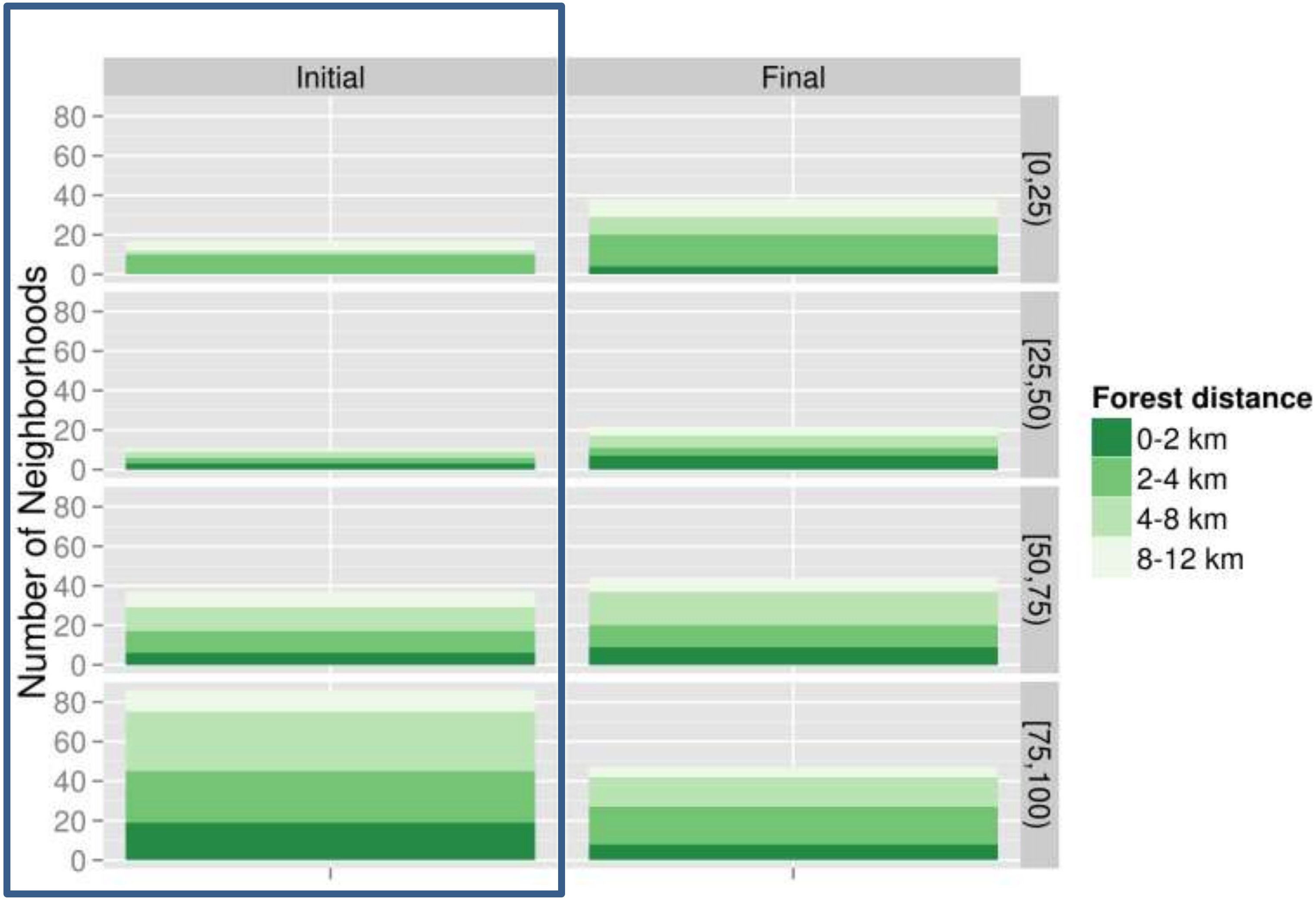
(.150 household fission rate)

Where is LULC occurring?



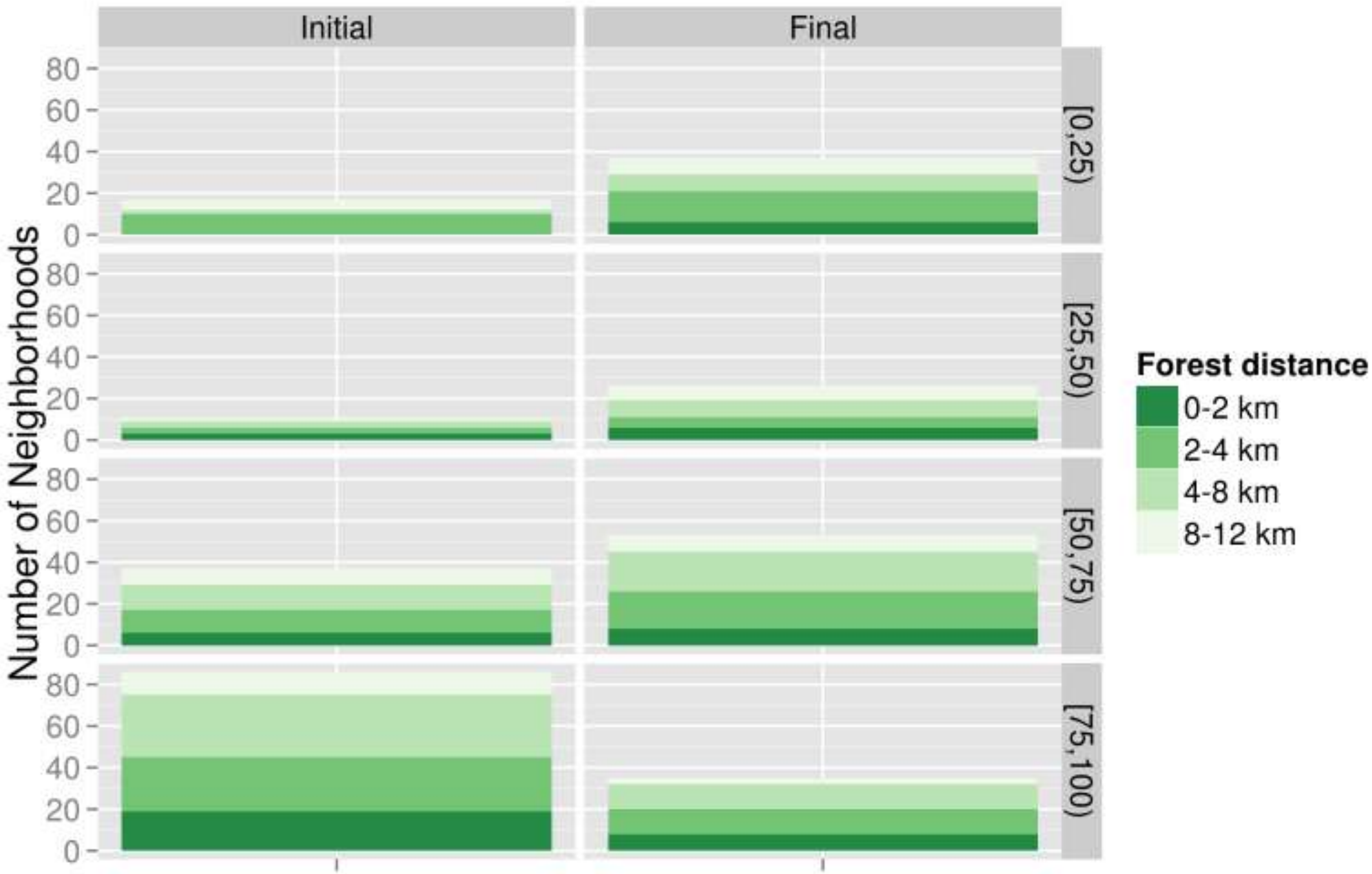
(.150 household fission rate)

Where is LULC occurring?



(.150 household fission rate)

Where is LULC occurring?



(.600 household fission rate)

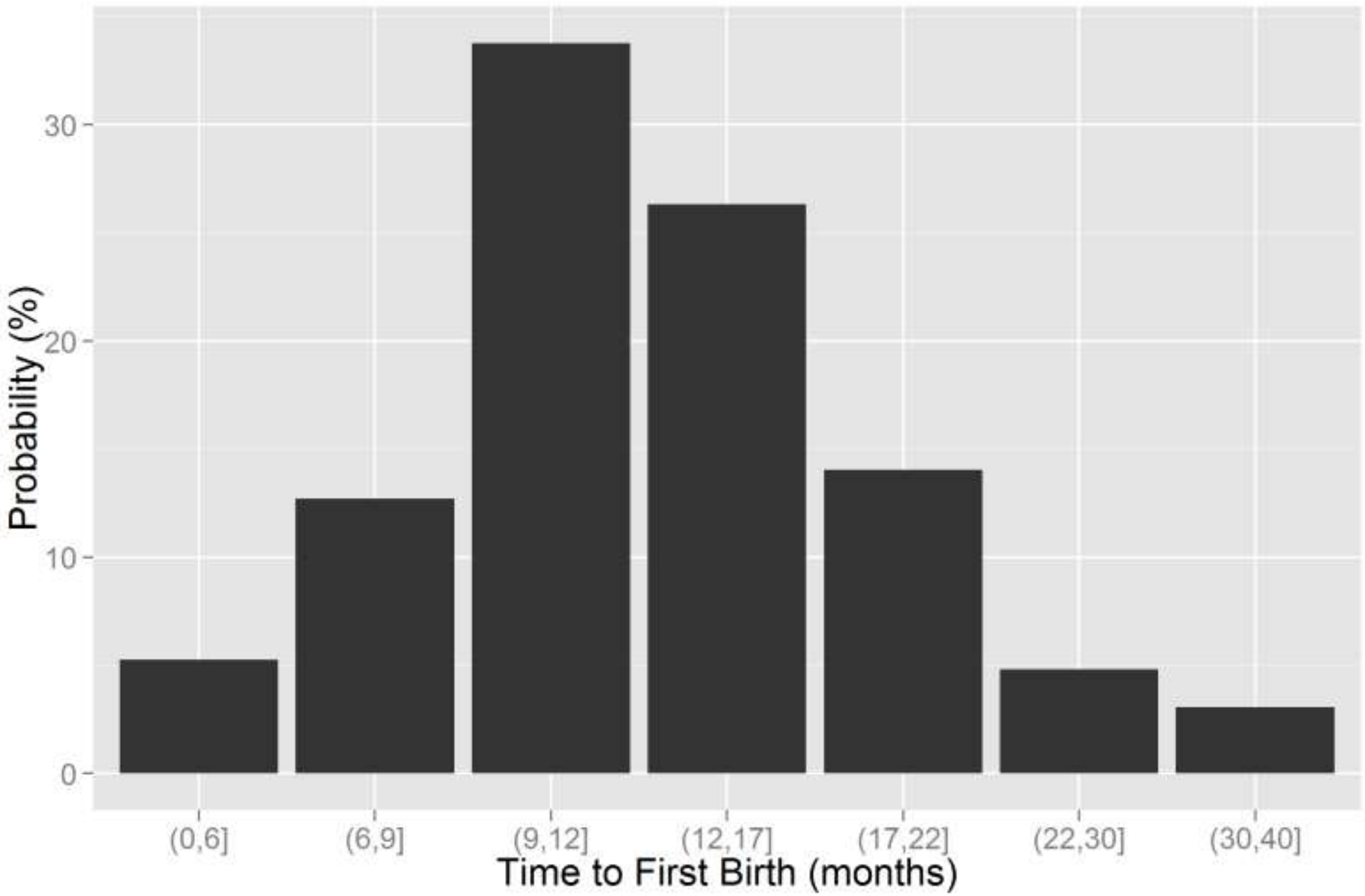
Verification and Validation

Verification and Validation

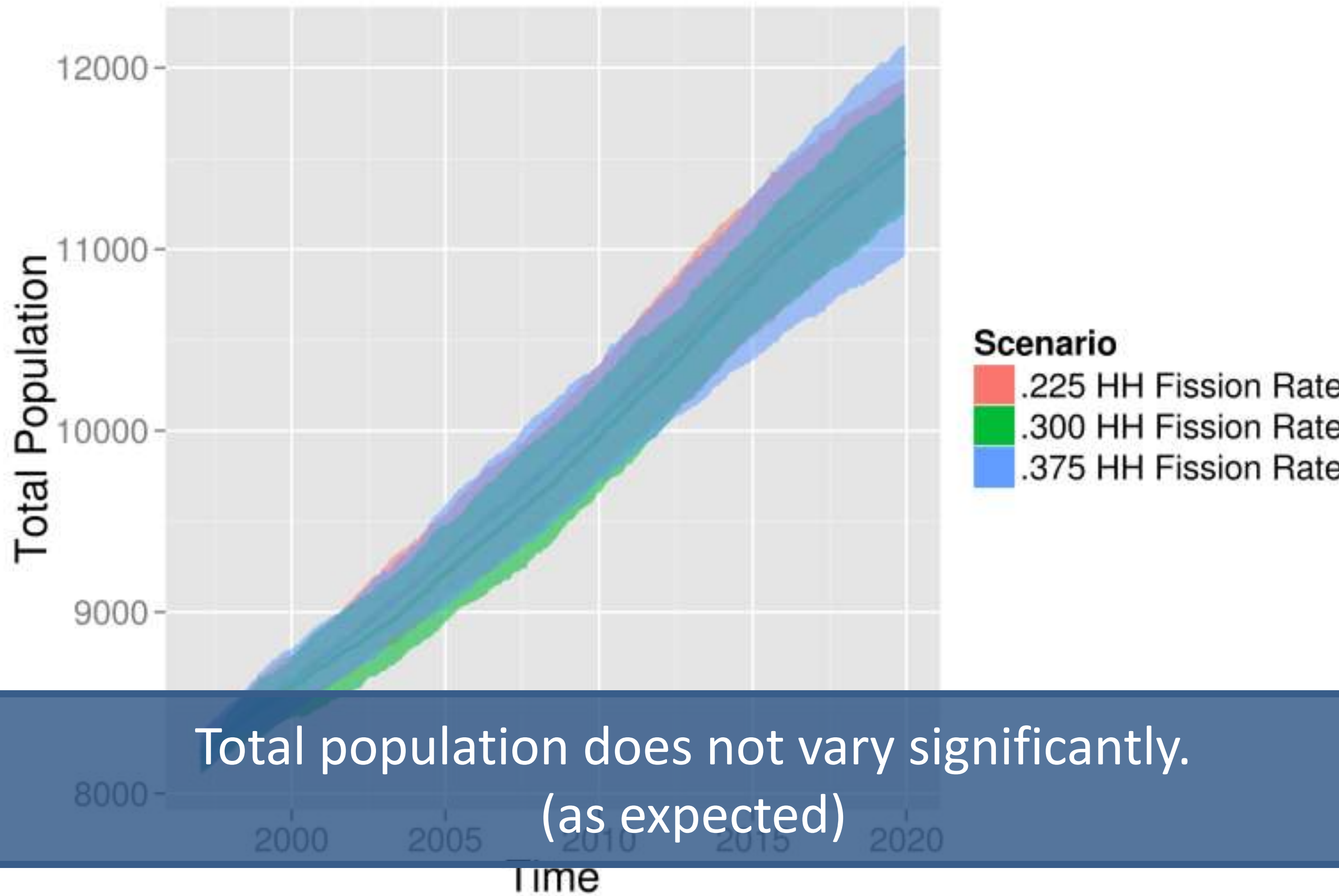
1. Progress model building and debugging
2. Uncertainty testing (extreme test, and extreme combination test)
3. Empirical validation—comparing model output data to empirical data
4. Sensitivity analysis—examining how model outcomes vary with a small change in key parameters, and
5. Experience or expert opinion

(from An et al. 2005)

Simplified First Birth Model (for verification)

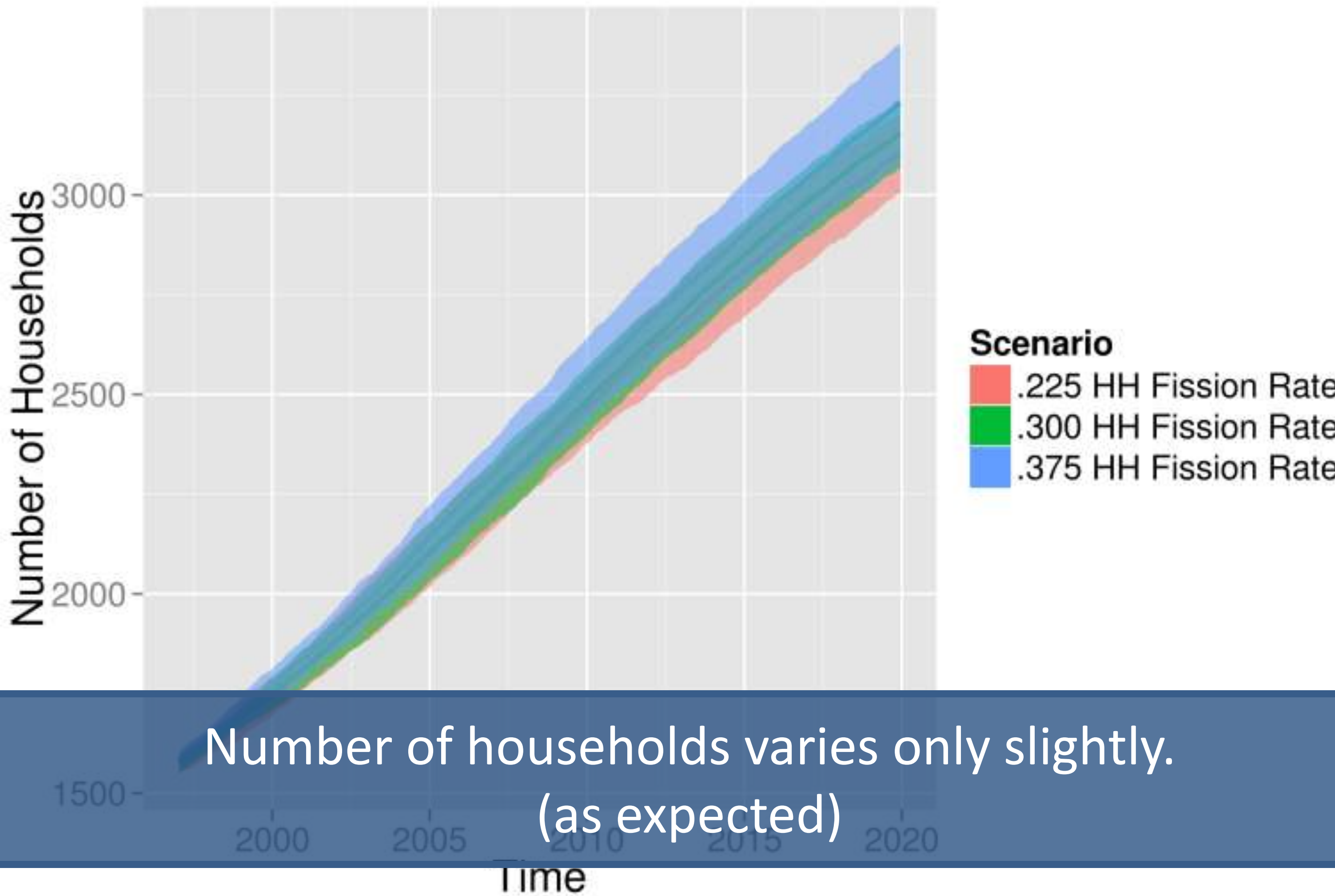


Sensitivity Analysis – Example Household Fission Rate



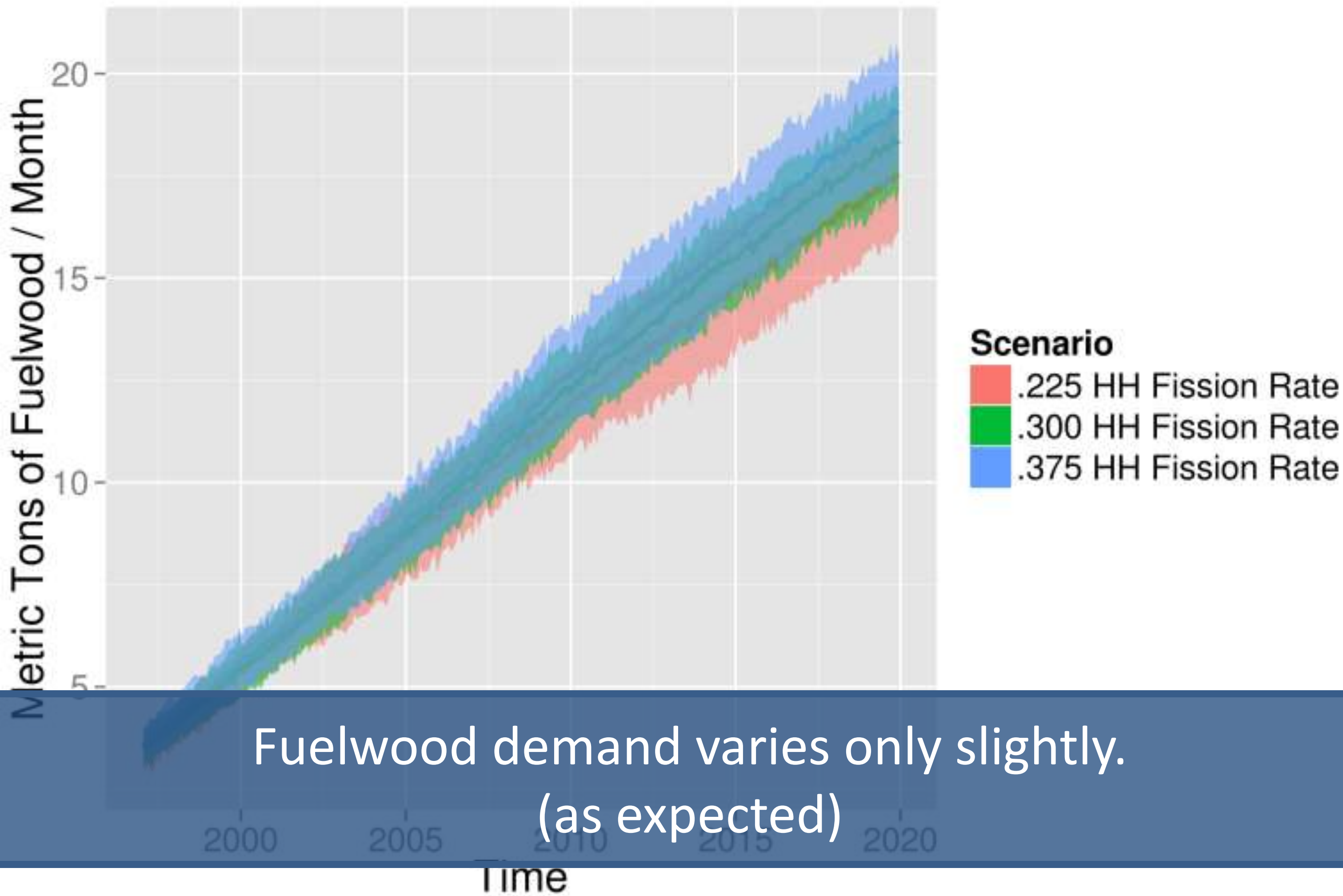
Total population does not vary significantly.
(as expected)

Sensitivity Analysis – Example Household Fission Rate



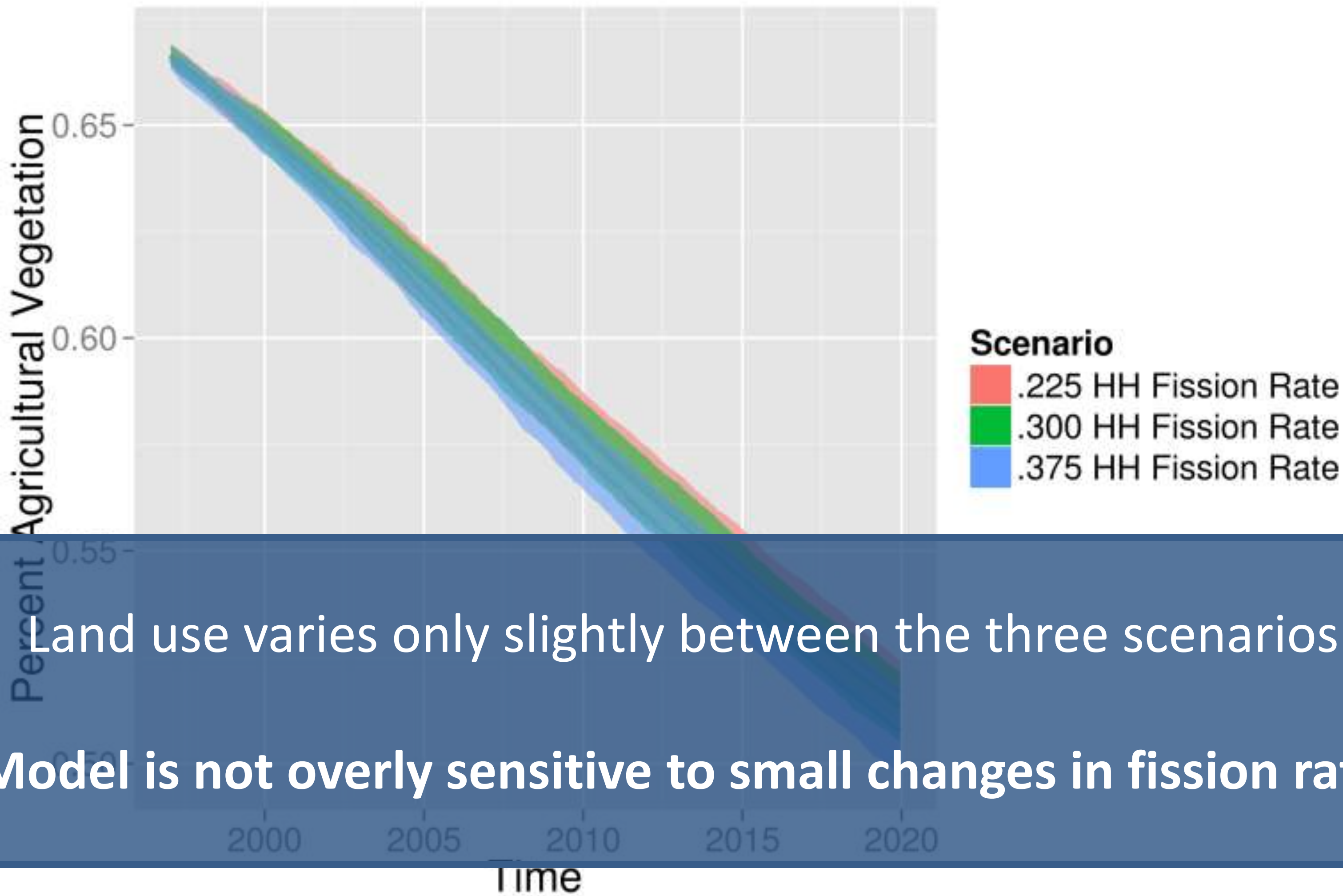
Number of households varies only slightly.
(as expected)

Sensitivity Analysis – Example Household Fission Rate



Fuelwood demand varies only slightly.
(as expected)

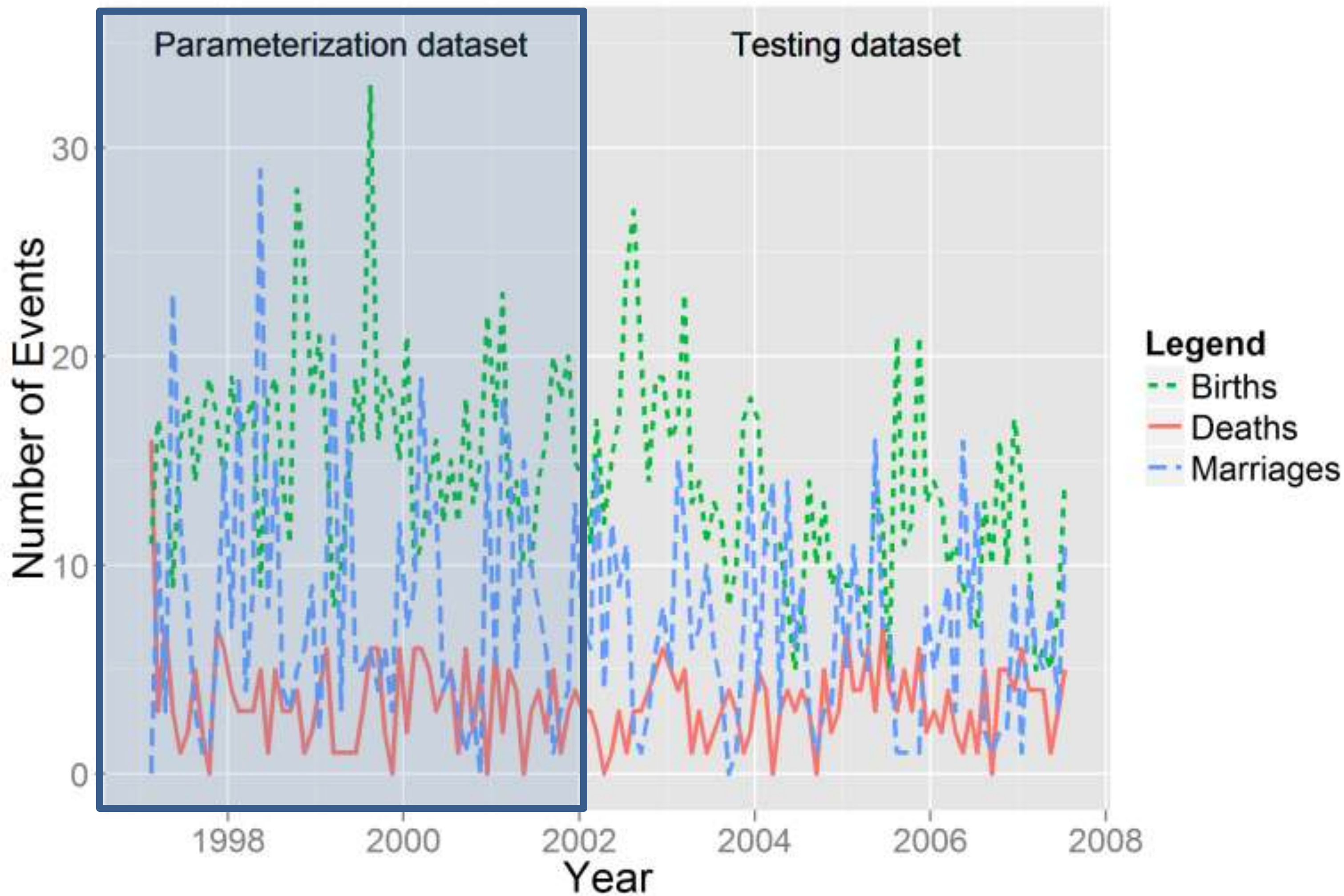
Sensitivity Analysis – Example Household Fission Rate



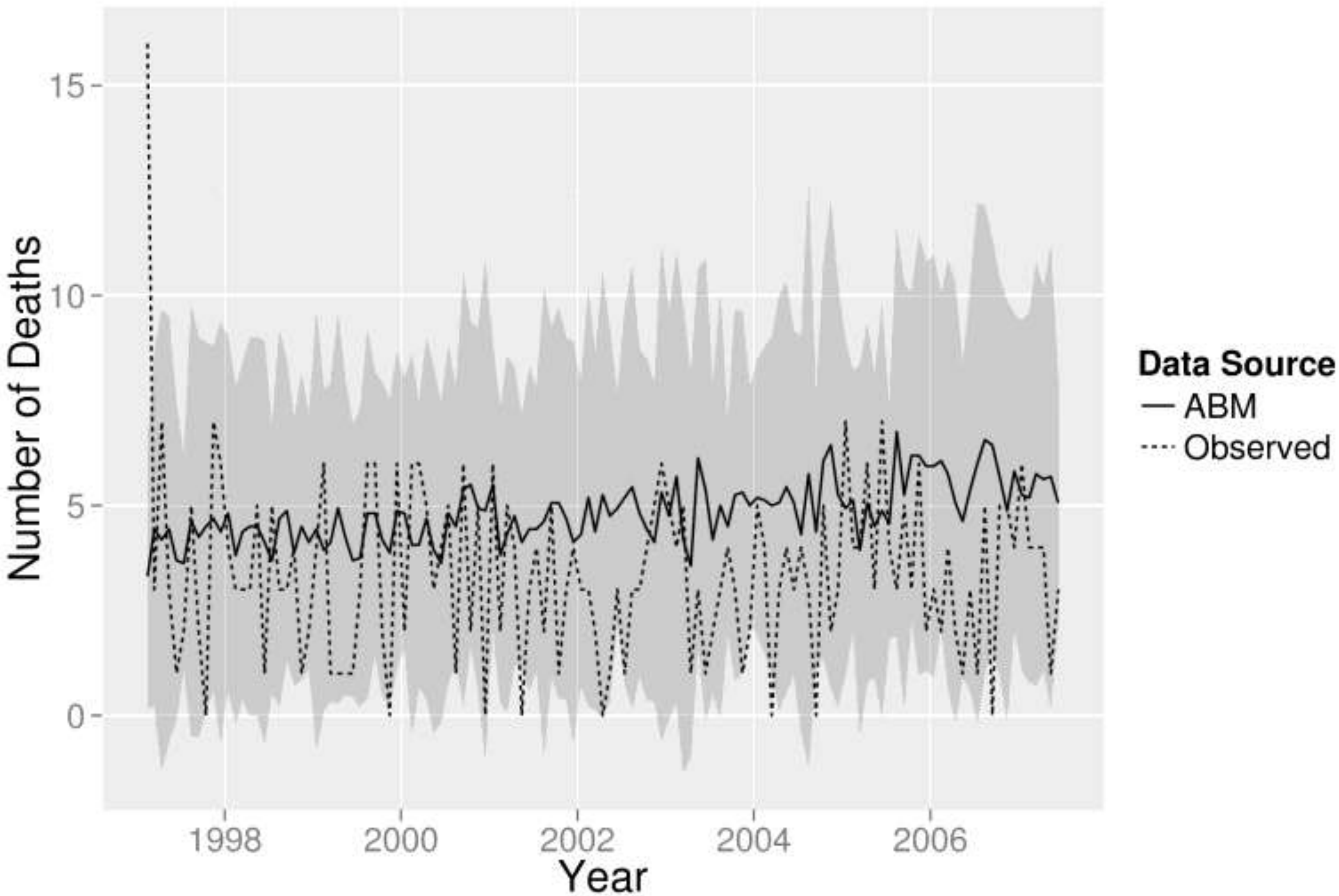
Land use varies only slightly between the three scenarios.

Model is not overly sensitive to small changes in fission rate.

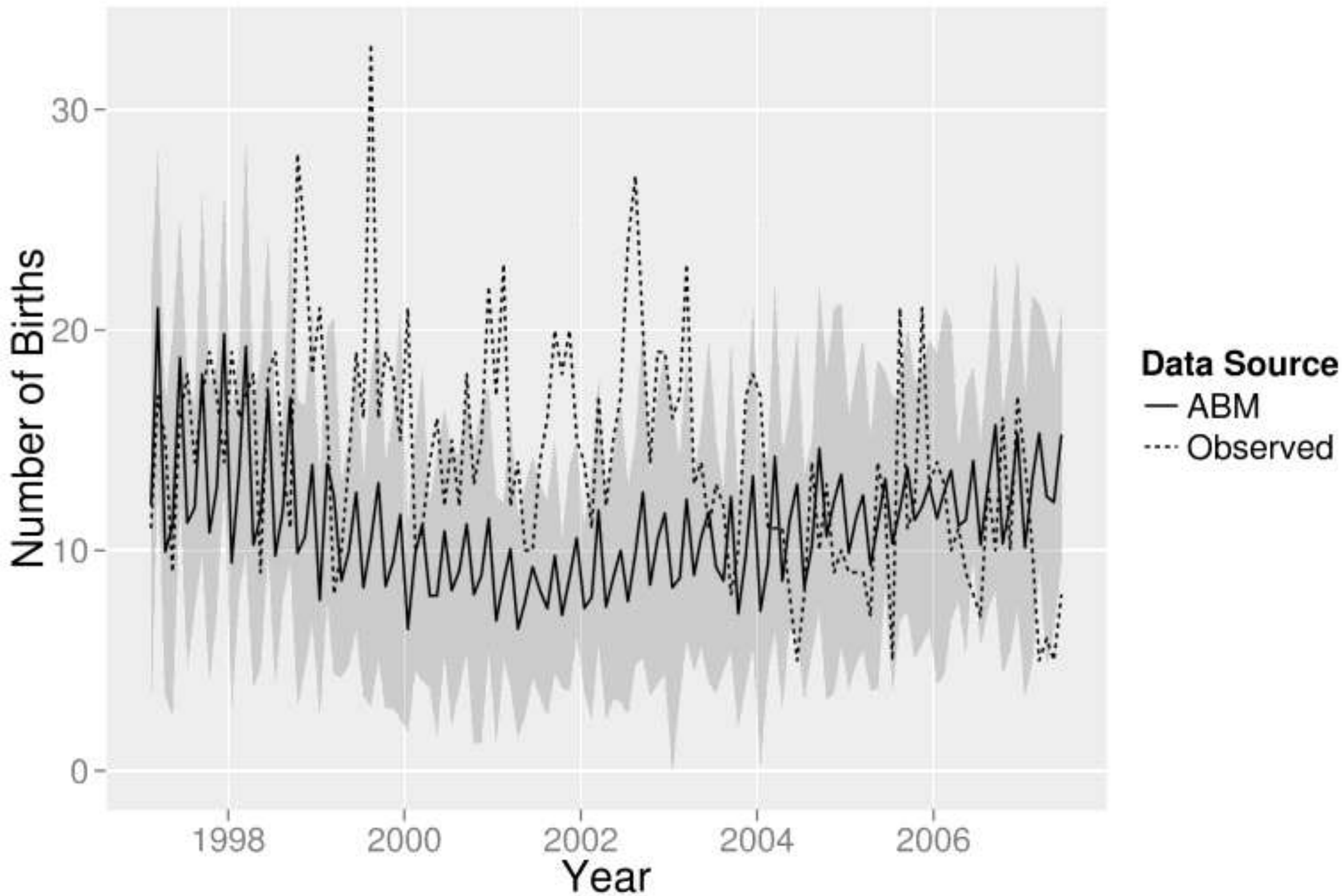
Parameterization Dataset



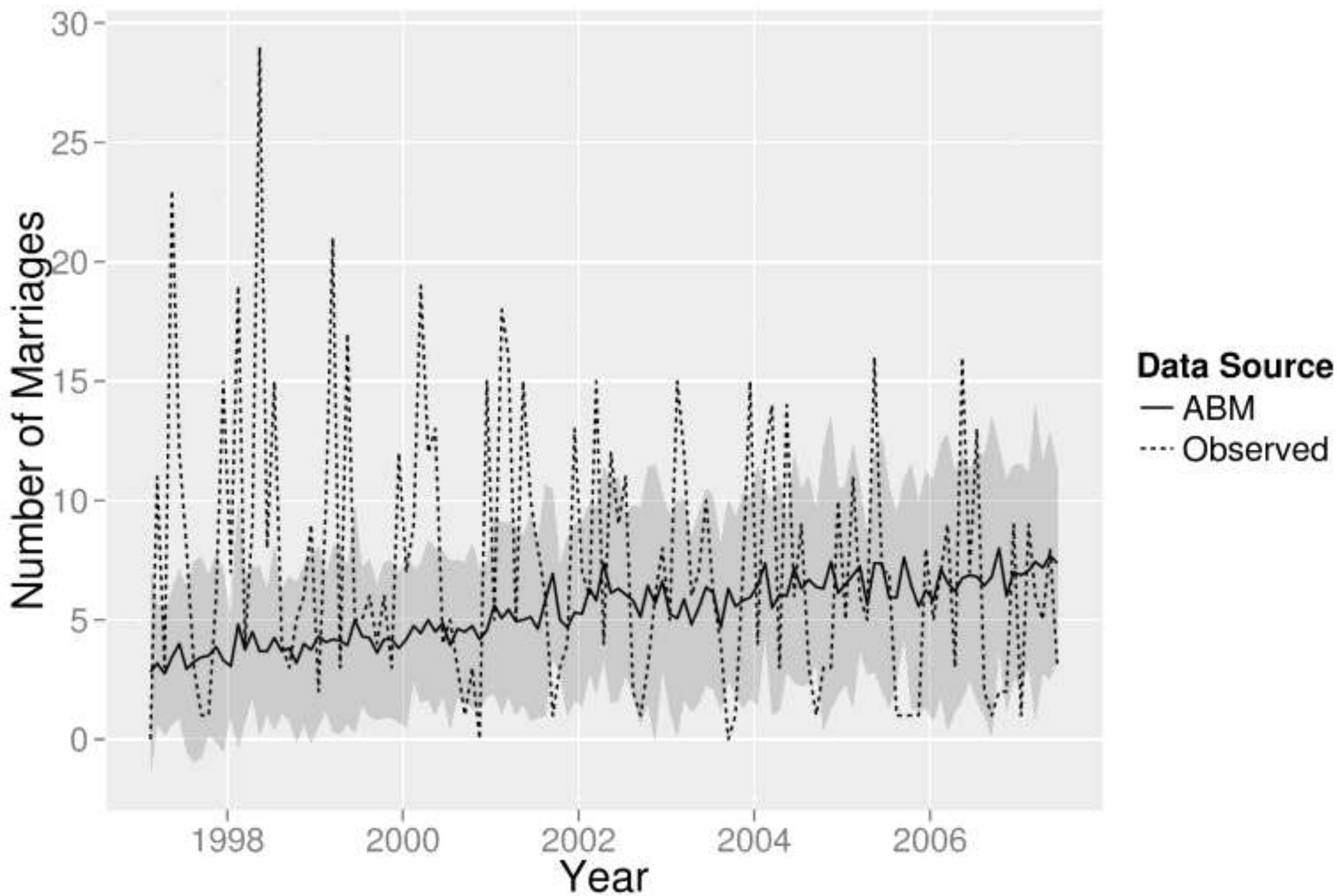
Simulated vs. Observed – Deaths



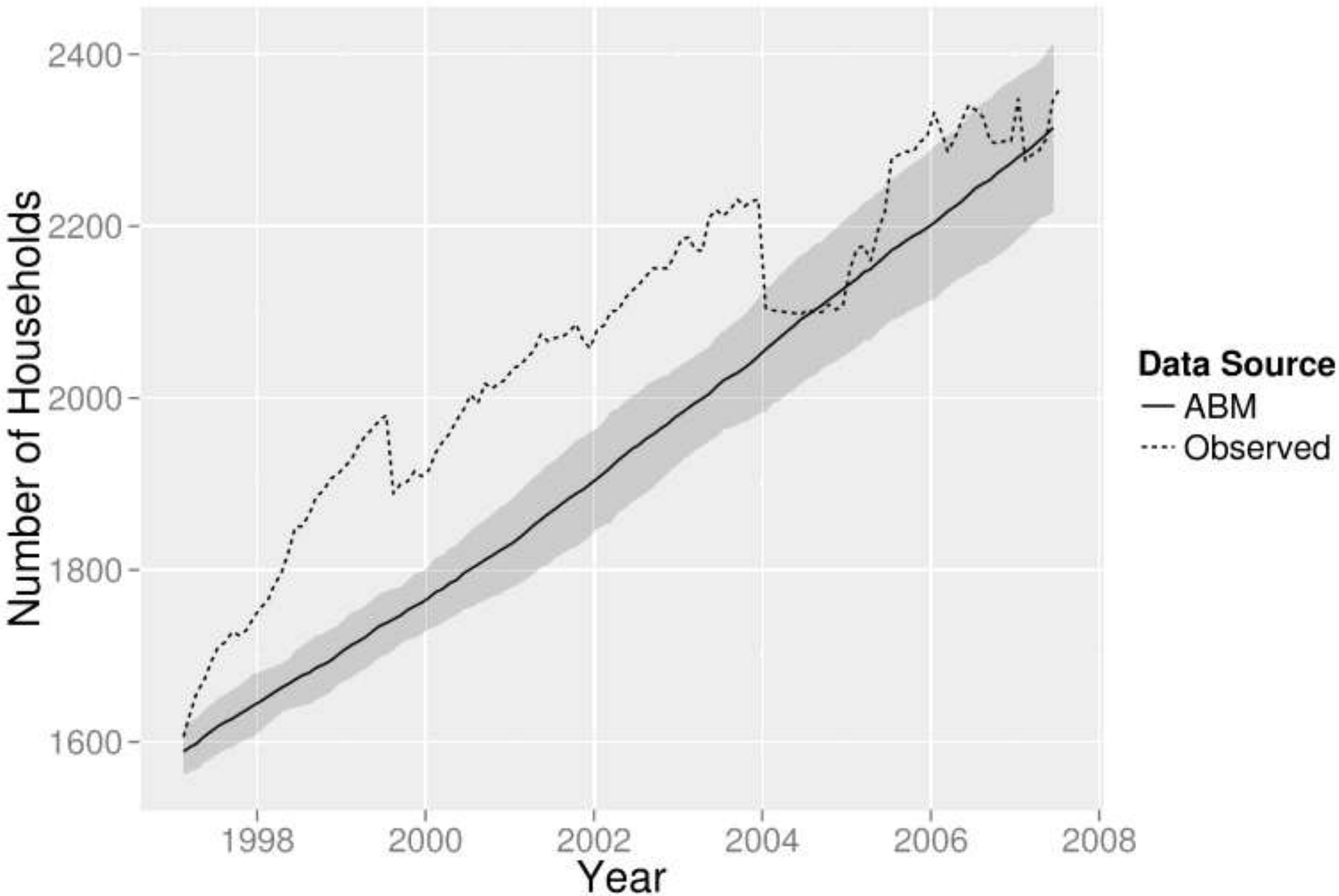
Simulated vs. Observed – Births



Simulated vs. Observed – Marriages



Simulated vs. Observed – Number of Households



Discussion

Discussion

- The Chitwan ABM tends towards a higher degree of demographic detail than other comparable ABMs
  - This enables controlling for many covariates, and can 'drop-in' existing regression models
  - But: can complicate interpretation of results

- Step-by-step approach can untangle complicated reciprocal relationships

Discussion – Key Findings

- As in Wolong, household size is key to resource consumption
  - But: smaller households in Chitwan are also more likely to transition away from fuelwood
  - Out-migration may be as important as fission rate
- Though household size is main driver of consumption in Chitwan, consumption of downed wood is difficult to tie directly to CNP habitat
- Though areas bordering the CNP are currently primarily agricultural, they will soon be more densely populated

Conclusions

- Out-migration and household size are key determinants of consumption patterns and LULC change
- Areas bordering the national park are likely to transition away from dense agriculture in near future
- Future areas of work:
  - Directly explore and model human-wildlife interactions along park perimeter, taking into account spatial patterns of growth
  - Model spatial impact of feedbacks between LULC and demography (scheduled for submission in the fall)

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- Krishna Shrestha
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Built with:

python

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References

Chitwan Valley Family study (CVFS):

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ABM:

- An, L., M. A. Linderman, J. Qi, A. Shortridge, et al. 2005. Exploring complexity in a human environment system: An agent-based spatial model for multidisciplinary and multiscale integration. *Annals of the Association of American Geographers* 95 (1):54–79.
- An, L., G. He, Z. Liang, and J. Liu. 2006. Impacts of demographic and socioeconomic factors on spatio-temporal dynamics of panda habitat. *Biodiversity and Conservation* 15 (8):2343–2363. (last accessed 15 May 2010).
- Grimm, V. et al. 2006. A standard protocol for describing individual-based and agent-based models. *Ecological Modelling* 198 (1–2):115–126.
- ———. 2010. The ODD protocol: A review and first update. *Ecological Modelling* 221 (23):2760–2768. (last accessed 27 April 2012).

First birth timing:

- Ghimire, D. J., and W. G. Axinn. 2010. Community context, land use, and first birth. *Rural Sociology* 75 (3):478–513.
- Ghimire, D. J., and L. F. Hoelter. 2007. Land use and first birth timing in an agricultural setting. *Population & Environment* 28:289–320.

Marriage timing:

- Yabiku, S. T. 2006a. Land use and marriage timing in Nepal. *Population & Environment* 27 (5):445–461.
- ———. 2006b. Neighbors and neighborhoods: effects on marriage timing. *Population Research and Policy Review* 25 (4):305–327.

Migration:

- Massey, D. S., W. G. Axinn, and D. J. Ghimire. 2010. Environmental change and out-migration: evidence from Nepal. *Population and Environment*.

Fuelwood usage:

- Macht, C., W. G. Axinn, and D. J. Ghimire. 2007. *Household energy consumption: community context and the fuelwood transition*. Population Studies Center.
- 2009 and 2011 field surveys (Zvoleff).

ChitwanABM is free and open-source:

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

PyABM is an free and open-source ABM toolkit for Python:

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

Thank you. Questions?

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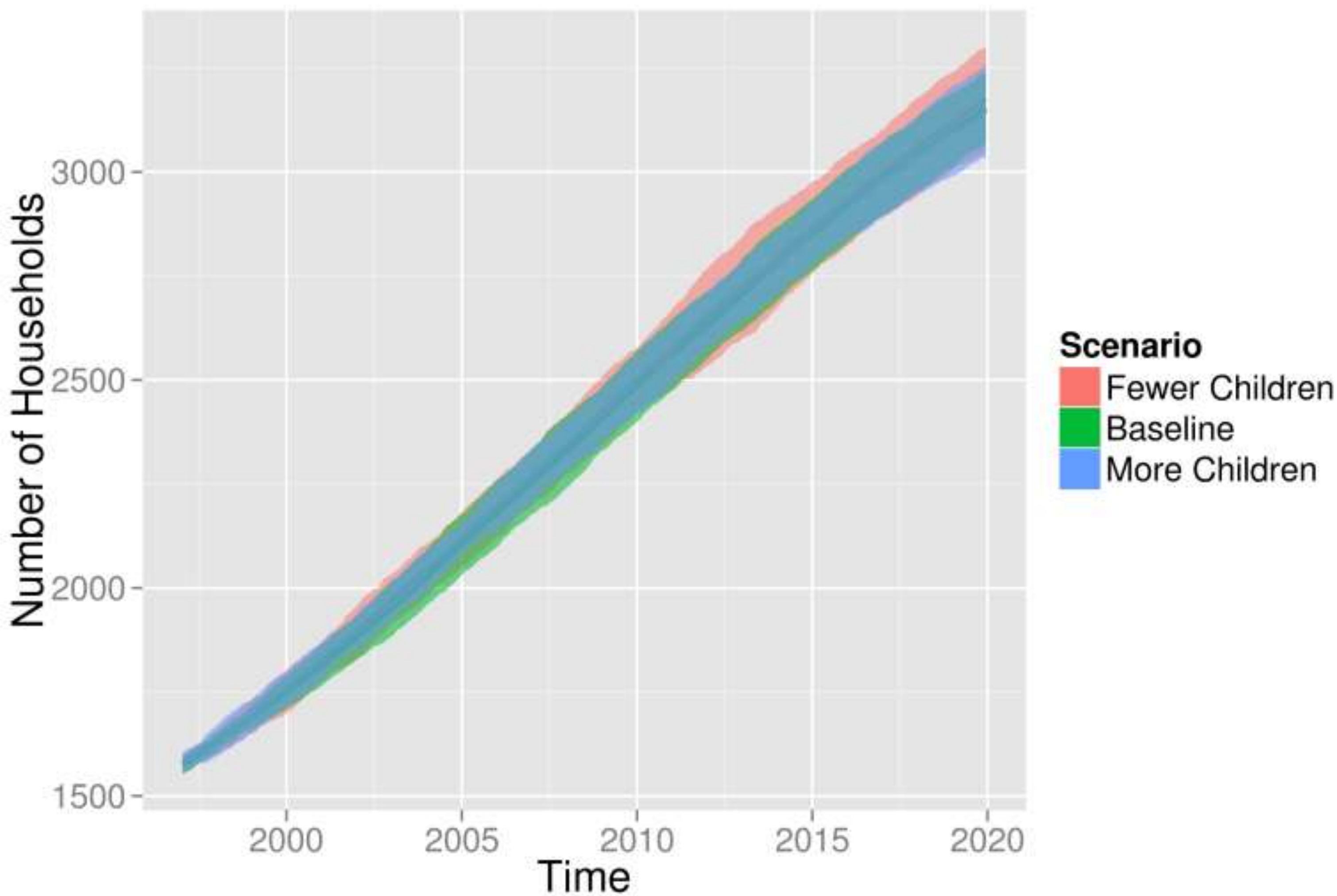
http://rohan.sdsu.edu/~zvoleff/

End of show.

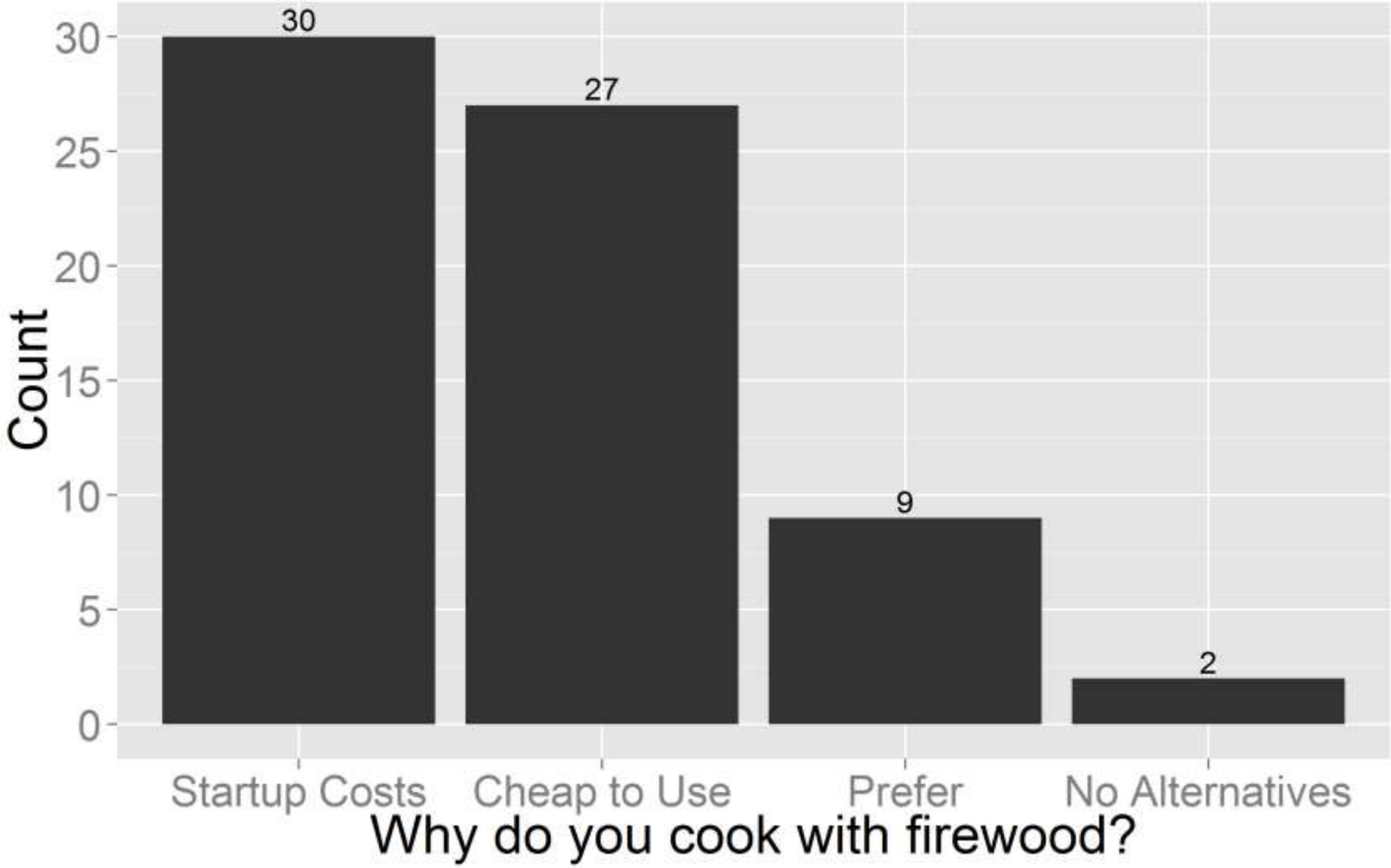
Results – Varying Desired Family Size



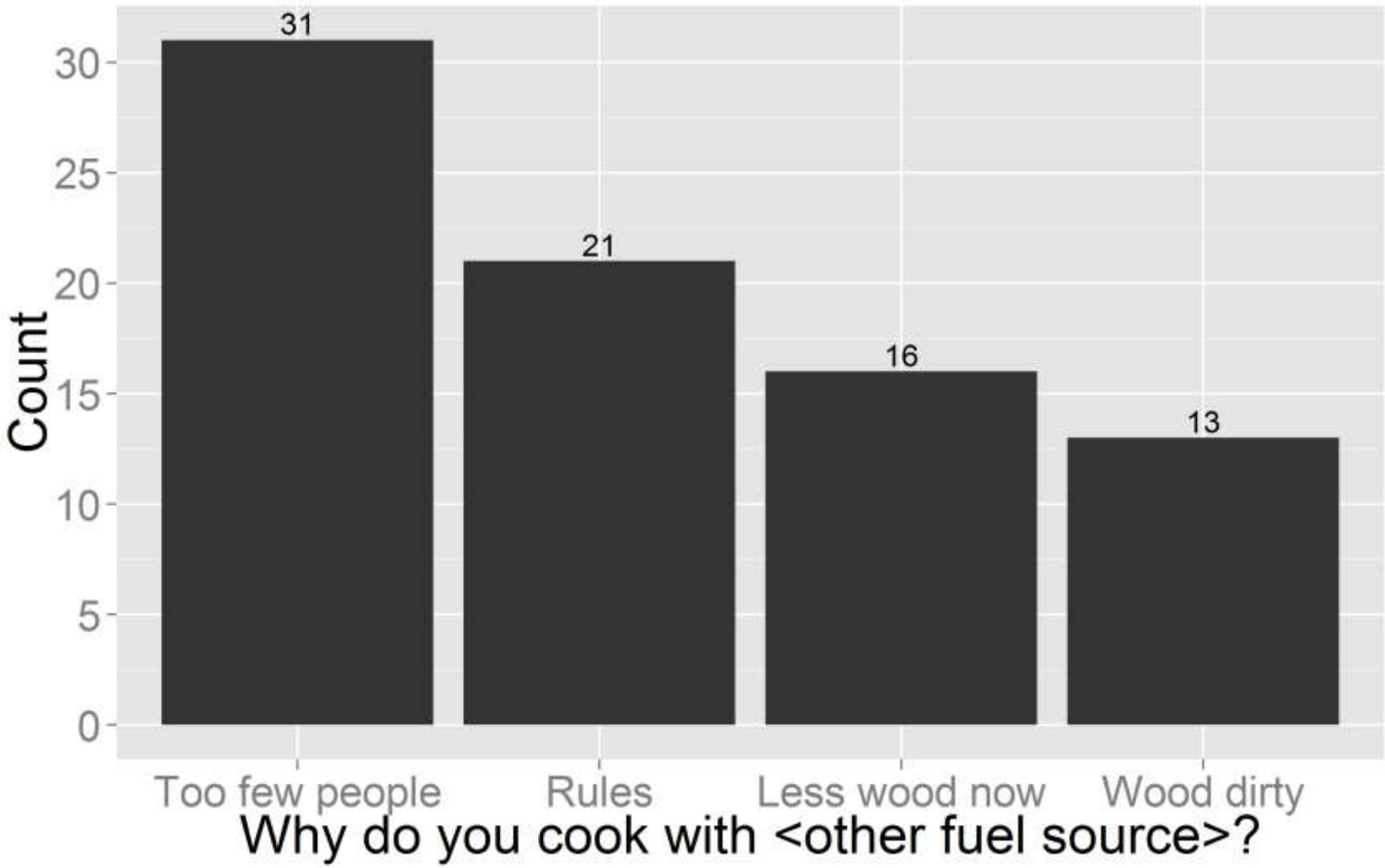
Land-use and land-cover change: 1996-2006

Class	1996	2001	2006	2006-1996
Agricultural Vegetation	879.9 (80.0%)	875.6 (79.4%)	854.2 (77.6%)	-25.7 (-2.4%)
Non-agricultural Vegetation	50.2 (4.6%)	35.3 (3.2%)	54.4 (4.9%)	+3.2 (+.03%)
Private Buildings	82.3 (7.5%)	88.4 (8.0%)	94.4 (8.6%)	+12.1 (+1.1%)
Public Buildings	59.2 (5.4%)	64.3 (5.8%)	66.9 (6.1%)	+7.7 (+.07%)
Other	28.4 (2.6%)	39.5 (3.6%)	31.2 (2.8%)	+2.8 (+.02%)
Total:	1100.1 (100%)	1103.1 (100%)	1101 (100%)	

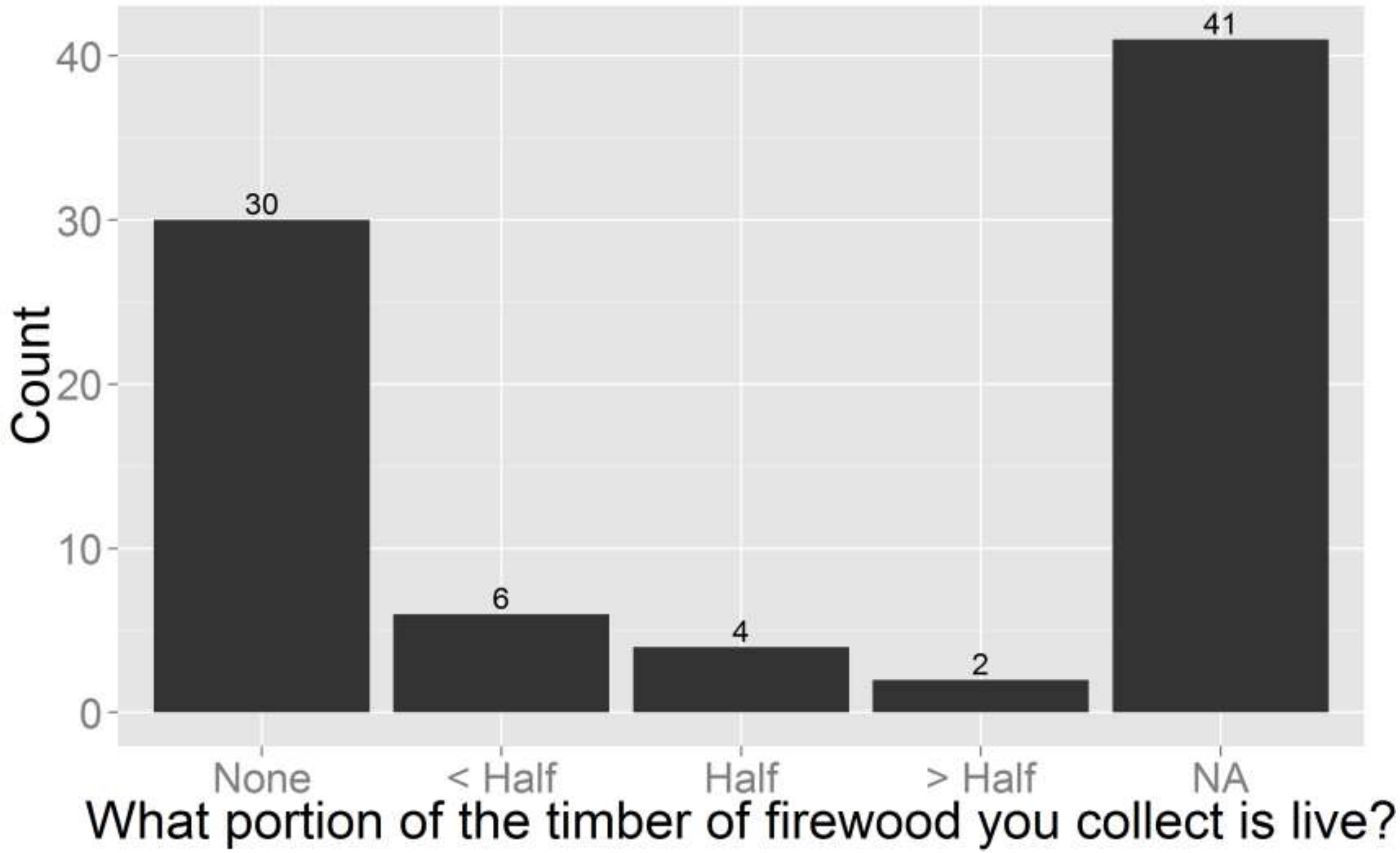
Why do you cook with firewood?



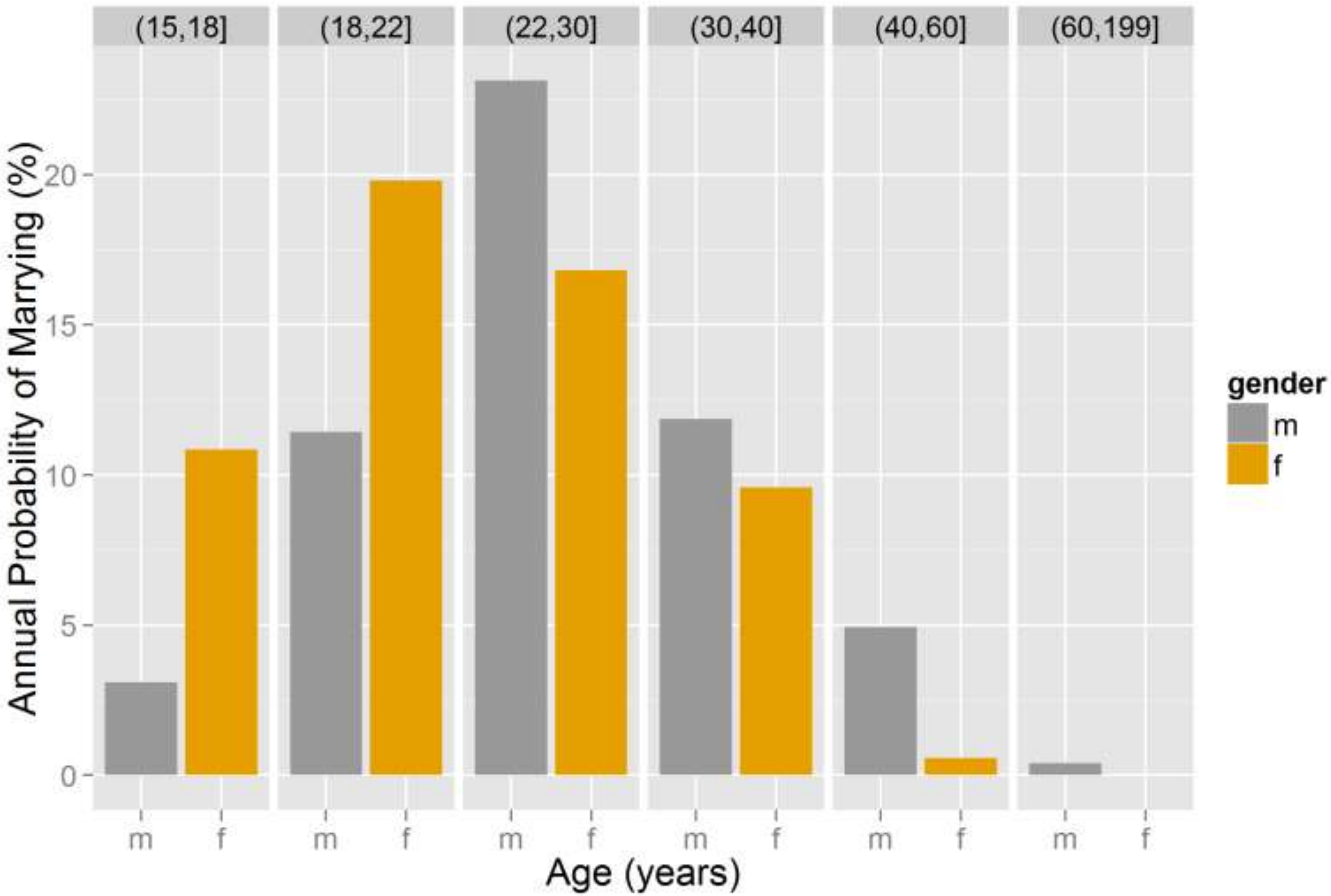
Why do you cook with ….?



What portion of the firewood you collect is live?



Simplified Marriage Timing Model (for verification)



Ordinal Logistic Regression (Proportional Odds Model)

Ordinal logistic model, for a response variable equal to 0,1,2,...,k, is:

$$\Pr[Y \geq j|X] = \frac{1}{1 + e^{-(\alpha_j + X\beta)}}$$

where j=1,2,...,k. (Harell, 2001)

For example, in our case, for education:

$$\Pr[Y = 1|X] = 1 - \Pr[Y \geq 2|X]$$

$$\Pr[Y = 2|X] = 1 - \Pr[Y = 1|X] - \Pr[Y \geq 3|X]$$

$$\Pr[Y = 3|X] = 1 - \Pr[Y = 1|X] - \Pr[Y = 2|X] - \Pr[Y \geq 4|X]$$

$$\Pr[Y = 4|X] = 1 - \Pr[Y = 1|X] - \Pr[Y = 2|X] - \Pr[Y = 3|X]$$

Harrell, F. E. 2001. *Regression Modeling Strategies: With Applications to Linear Models, Logistic Regression, and Survival Analysis*. New York: Springer.