Coupling agent-based modeling and Bayesian networks to study natural resource use and human migration in the Ethiopian highlands

Source: Lisa Garbe

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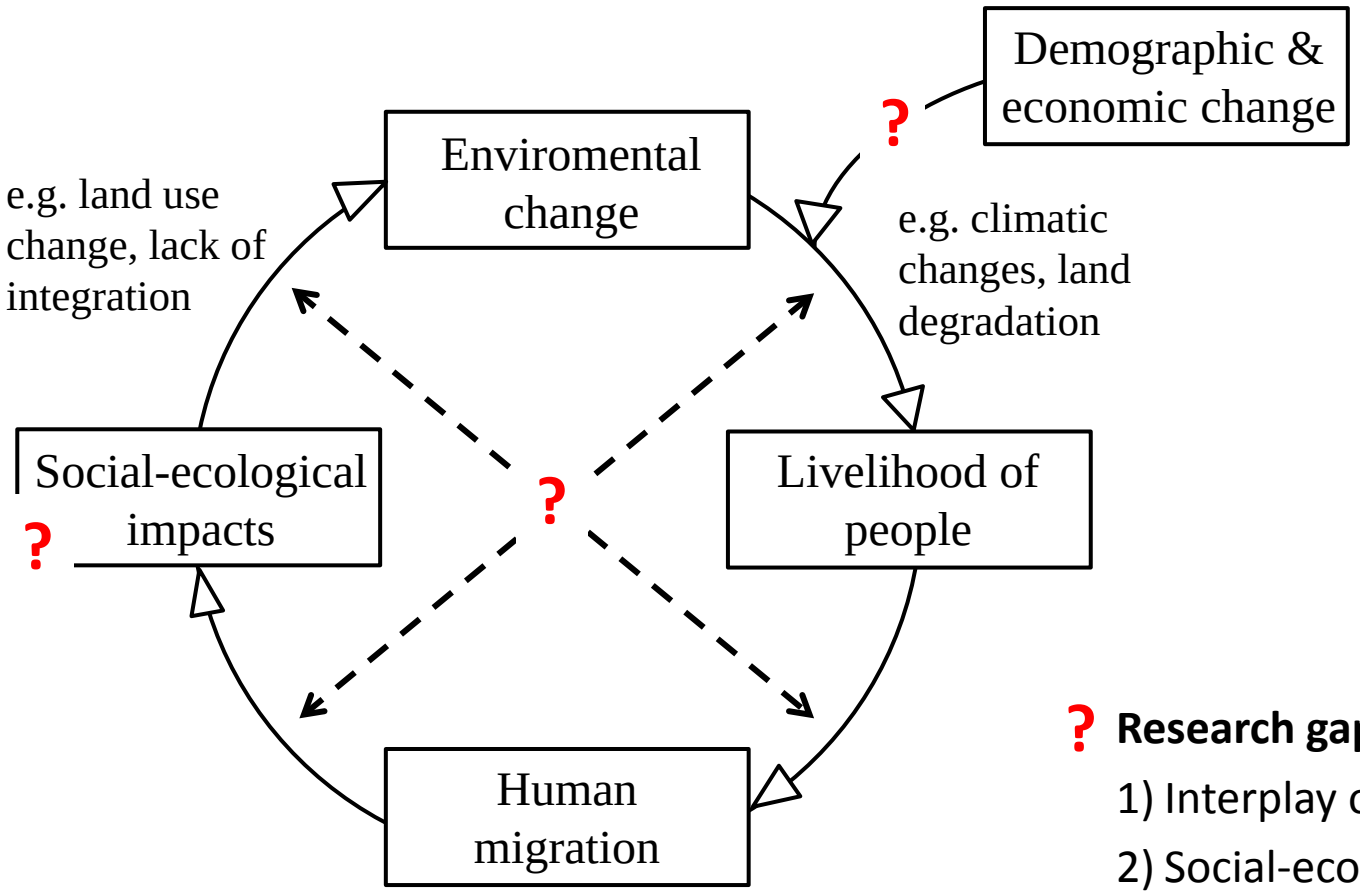
THE ENVIRONMENT-MIGRATION NEXUS



? **Research gaps:**

1) Interplay of influence factors
2) Social-ecological impacts
3) Circular relationship

POTENTIAL OF SIMULATION MODELS

Simulation models:

- Ability to study feedbacks between social and ecological systems & future trajectories under different scenarios
- Some aggregated modeling approaches exist[1]
- **But:** based on "regional-level assumptions regarding migration decisions"[2]
  → ignoring that migration emerges from individual decision-making

→ Agent-based modeling

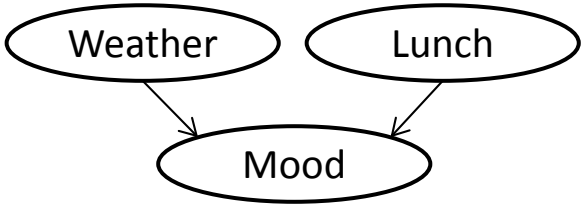
- Ability to depict individual behavior & social-ecological feedbacks[3]
- Recently increasing number of agent-based models (ABMs) that consider the role of the natural environment in rural migration processes[4]
- Often not considering fully-coupled social-ecological feedbacks & migration decisions modeled simplistically[5]

[1]Krol & Bronstert 2007; Rigaud et al. (2018); [2]Neumann & Hilderink 2015;
[3]Schlüter et al. 2012; [4]McLeman 2013; Klabunde & Willekens 2016, [5]Thober et al. 2018

MODELING MIGRATION DECISIONS USING BAYESIAN NETWORKS (BNs)

BNs are probabilistic models consisting of…

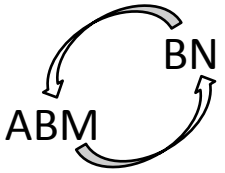
- Directed acyclic graph of nodes (i.e. variables) connected by edges (i.e. statistical relationships between two variables)
- Conditional probabilities for each variable given its parents in the graph
- Incorporation of qualitative as well as quantitative data[1]
- Intuitive graphical interface enables participative processes[1]



	good	bad
sun, yummy	0.95	0.05
sun, yucky	0.70	0.30
rain, yummy	0.75	0.25
rain, yucky	0.1	0.9

Advantages of coupling ABMs and BNs

- spatial and temporal processes; multiple human actors; social interactions[1]
- Couplings of ABM and BN are still rare (e.g. Kocabas & Dragicevic 2013, Pope et al. 2015, Abdulkareem et al. 2018, 2019)

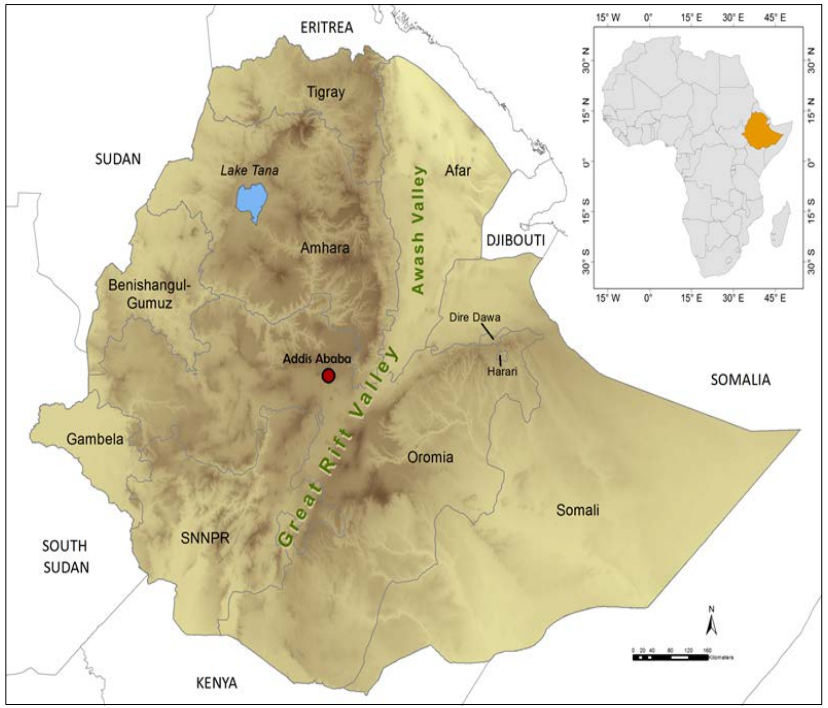


[1]Sun & Müller 2013

THE ETHIOPIAN HIGHLANDS

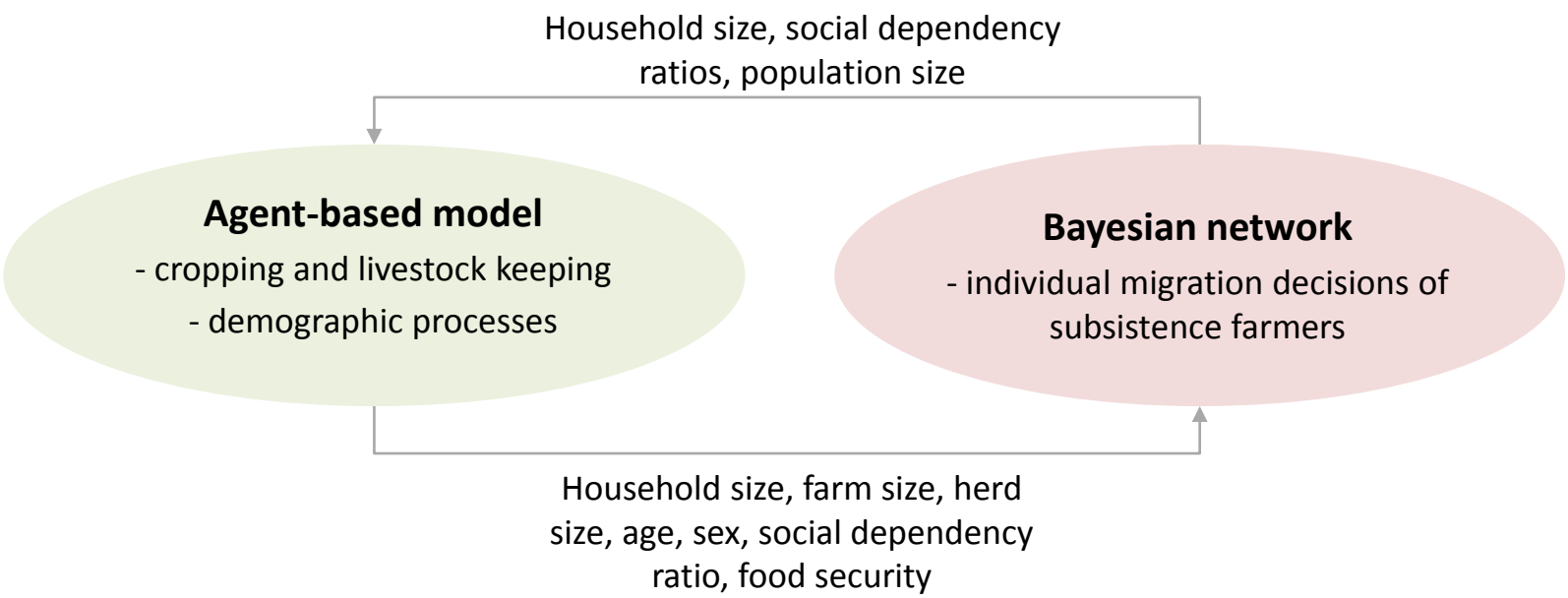
- 1200 up to 4550 masl
- Precipitation: unimodal/bimodal distribution; >700mm annually[1]
- Rainfed subsistence agriculture (i.e. cropping, livestock keeping)[2]
- Livelihoods are challenged by
  - decreasing amount & increasing variability of precipitation
  - Frequency and intensity of droughts
  - Land degradation
  - Population increase

→ **Food insecurity & migration**



[1]USAID 2010, [2]Hermans & Garbe 2019

STUDY APPROACH & AIM



Study aim: (1) understand the current and future state in the Ethiopian highlands and (2) formalize causal relationships between environmental change, livelihoods and migration

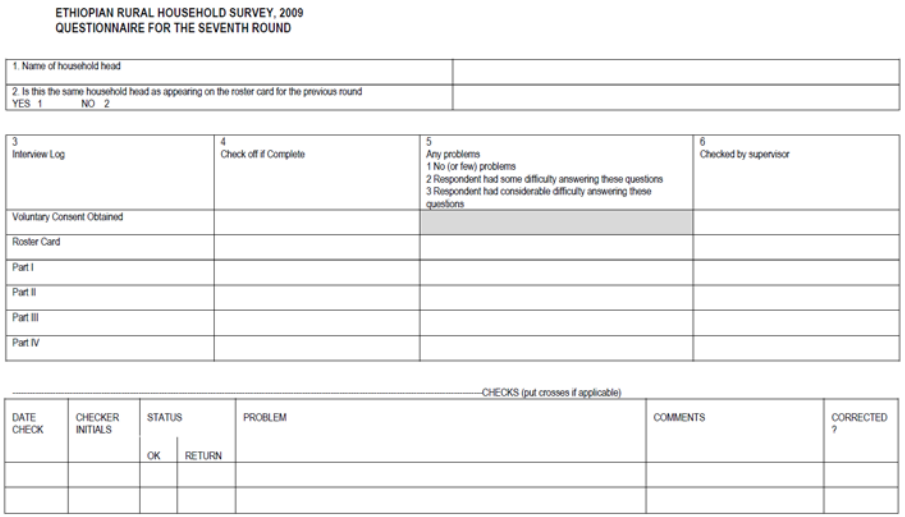
SETTING UP THE BAYESIAN NETWORK

Influence factors of out-migration (based on 19 published empirical studies):

- Age at migration
- Sex
- Household size
- Farm size
- Social dependency ratio
- Poverty
- Number of livestock unit (TLU)
- Food security

→ used to set-up network structure

Combined with household survey data:



ETHIOPIAN RURAL HOUSEHOLD SURVEY, 2009
QUESTIONNAIRE FOR THE SEVENTH ROUND

1. Name of household head	
2. Is this the same household head as appearing on the roster card for the previous round YES 1 NO 2	

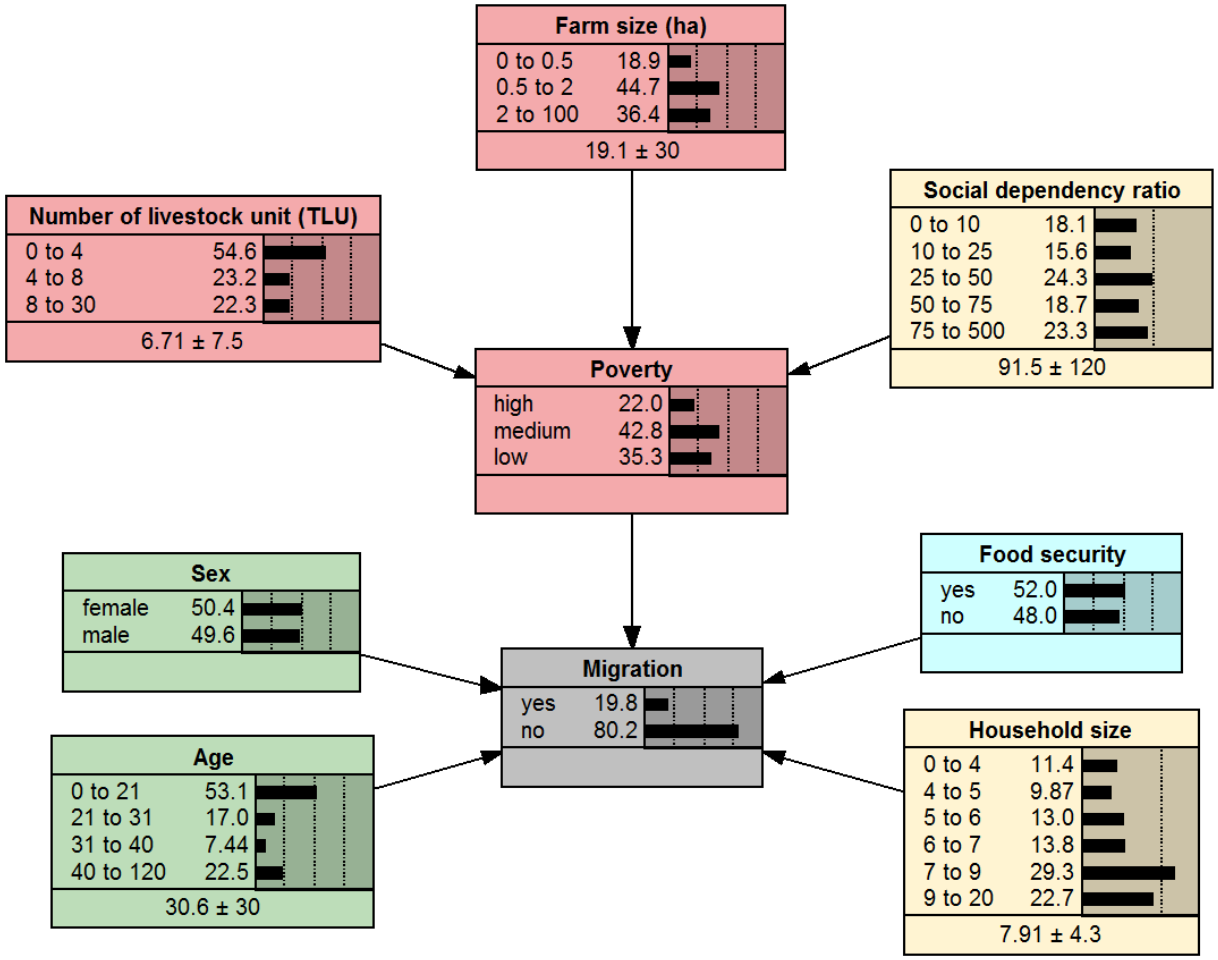
3 Interview Log	4 Check off if Complete	5 Any problems 1 No (or few) problems 2 Respondent had some difficulty answering these questions 3 Respondent had considerable difficulty answering these questions	6 Checked by supervisor
Voluntary Consent Obtained			
Roster Card			
Part I			
Part II			
Part III			
Part IV			

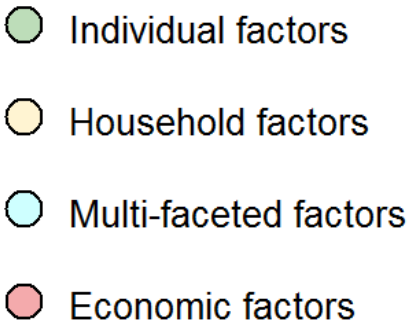
CHECKS (put crosses if applicable)

DATE CHECK	CHECKER INITIALS	STATUS		PROBLEM	COMMENTS	CORRECTED ?
		OK	RETURN			

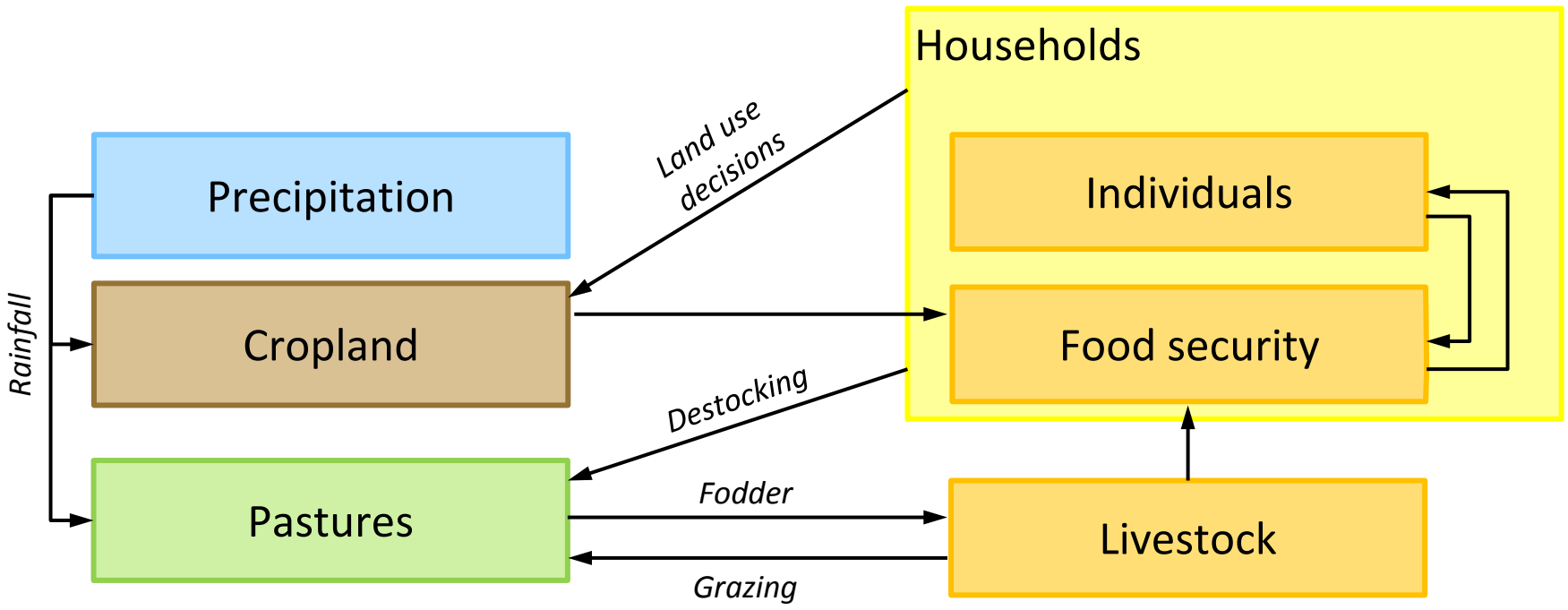
→ used for quantifying the relationships

THE BAYESIAN NETWORK FOR MIGRATION DECISIONS





CONCEPTUAL OVERVIEW OF ABMig



Space: 50 x 50 patches à 0.1 ha; spatial heterogeneous land use, altitude, slope and soil quality.

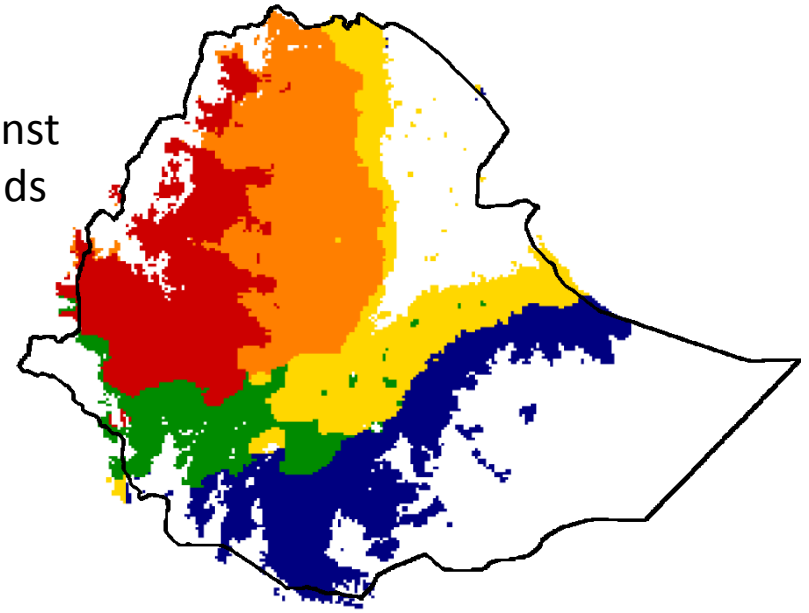
Time: Monthly time steps

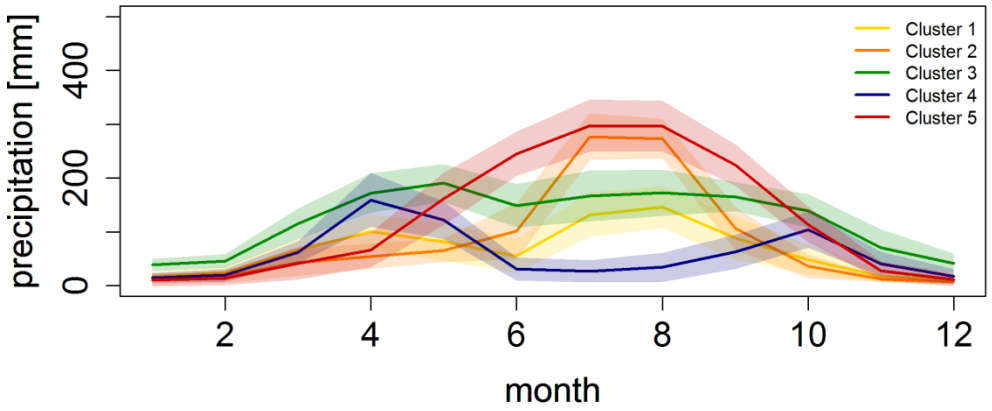
NetLogo 6.1.0

MODEL DESCRIPTION OF ABMig
PRECIPITATION

Approach:

- Based on global CHIRPS dataset[1]; validated against data from weather stations in Ethiopian highlands
- Clustering of CHIRPS data based on kmeans & identification of five spatial clusters

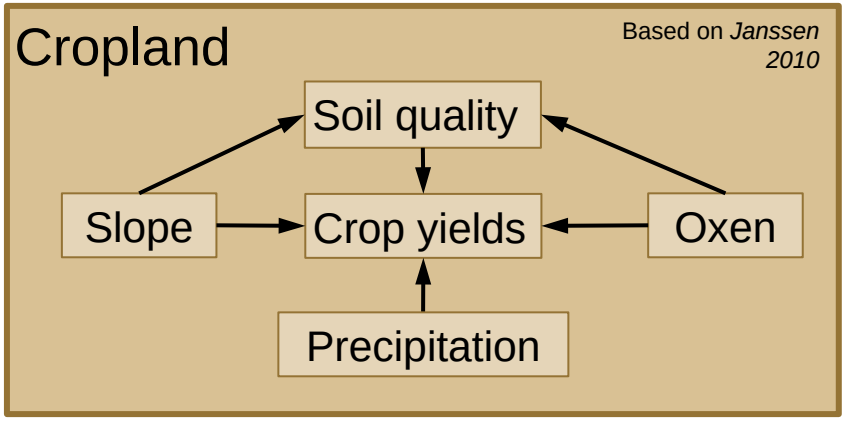


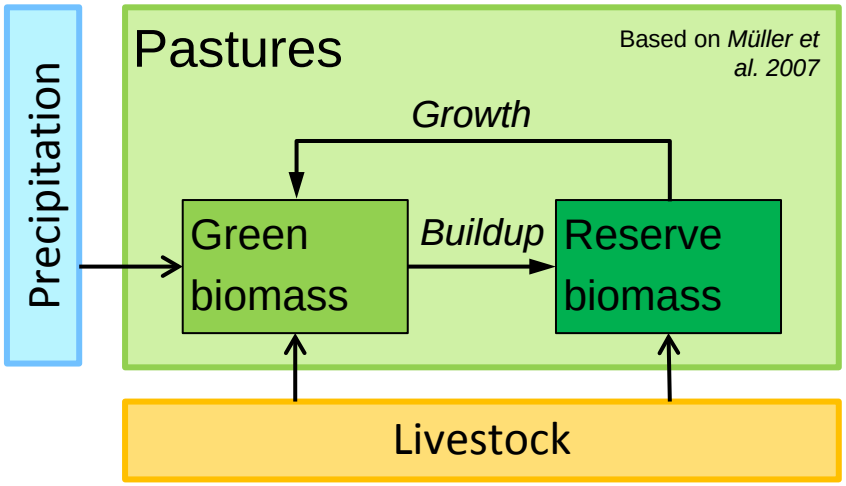


→ Estimation long-term monthly precipitation climatology and fitted a lag-1 autoregressive model to the monthly residuals as input for the ABM

[1]Funk 2010

MODEL DESCRIPTION OF ABMig
CROPLAND AND PASTURE PRODUCTIVITY



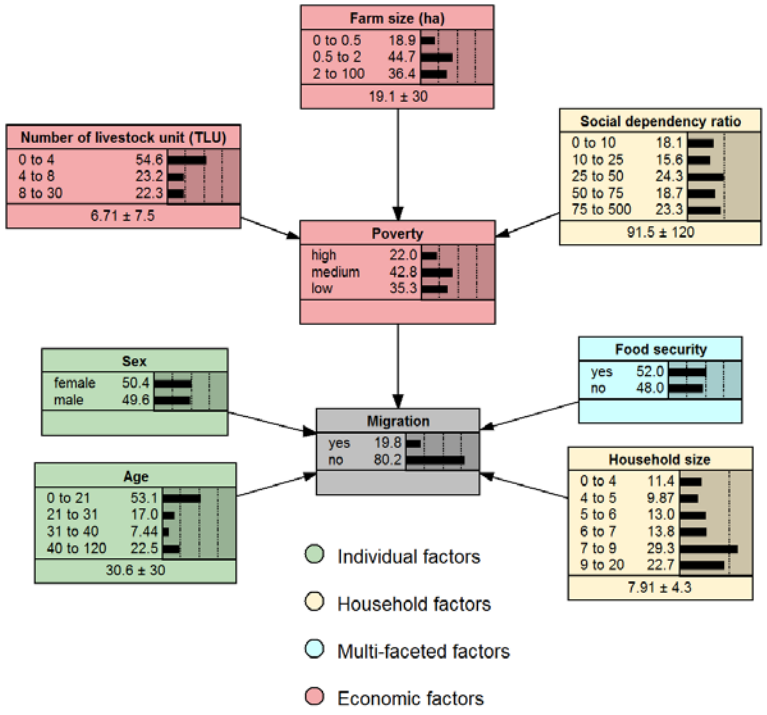


↑ Increase in altitude leads to..

↓ ..decrease in rain use efficiencies, maximum capacities and ratio of green/reserve biomass[1]

[1]Du et al. 2018, Fensholt et al. 2011, Gudina et al. 2015, Nemera 2016, Li et al. 2008, Ma et al. 2010

MODEL DESCRIPTION OF ABMig
MIGRATION & DEMOGRAPHIC PROCESSES



Migration processes:

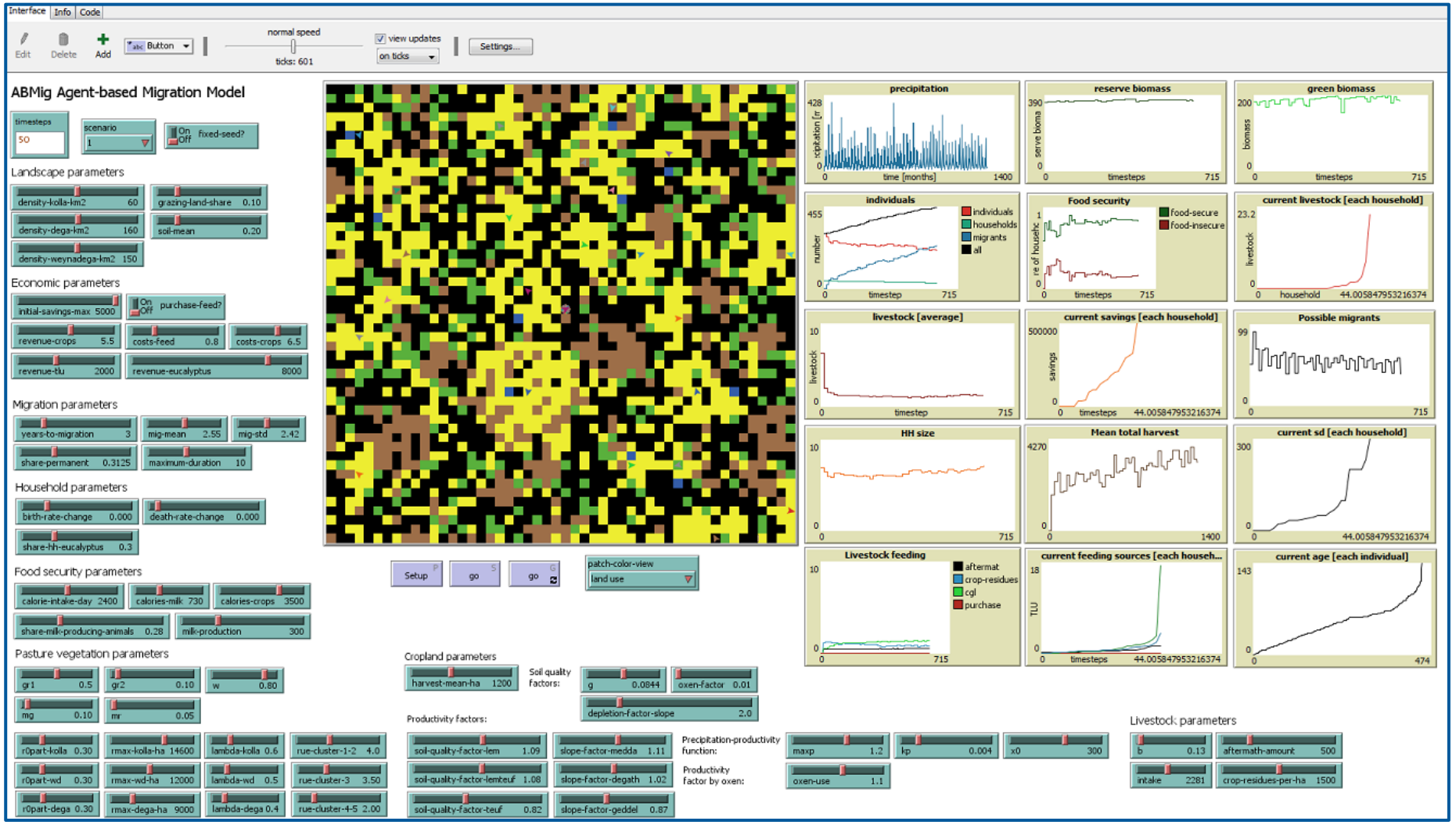
- Individuals decide to migrate or not based on probability derived with BN
- Share of migrants stay permanently
- Others stochastically return following a lognormal distribution

Demographic processes:

- Individuals die and are born based on age-specific fertility and death rates[1]

[1]CSA 2007

PRELIMINARY RESULTS

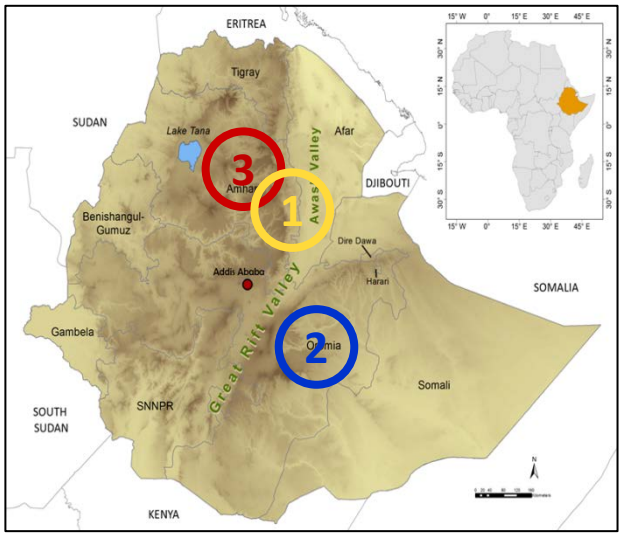


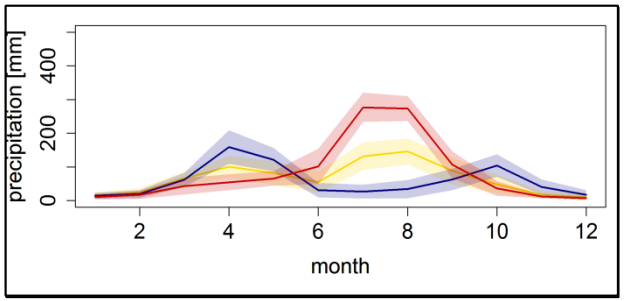
PRELIMINARY RESULTS
REGIONAL DIFFERENCES

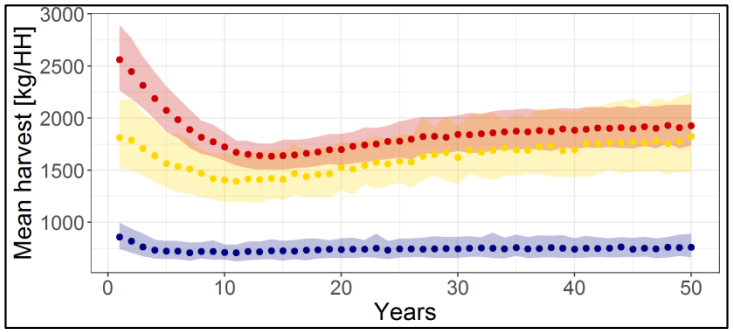
Region 1:
Eastern Amhara; bimodal; annual mean 800 *mm*

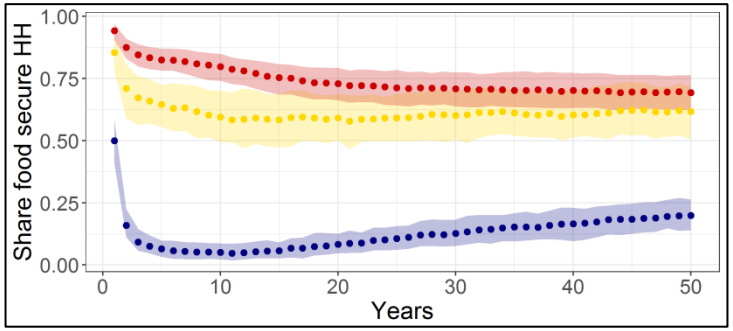
Region 2:
Southern Highlands; bimodal; annual mean 1050 *mm*

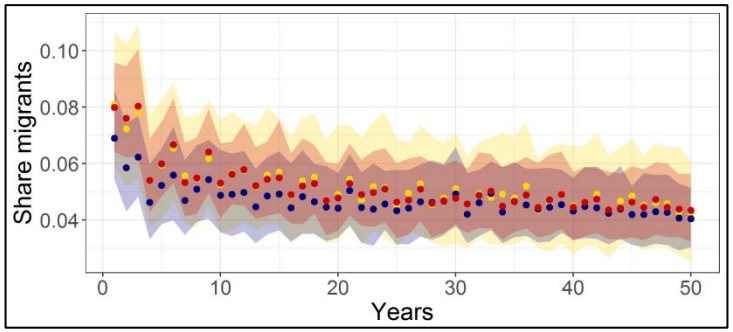
Region 3:
Eastern Amhara; unimodal; annual mean 1500 *mm*







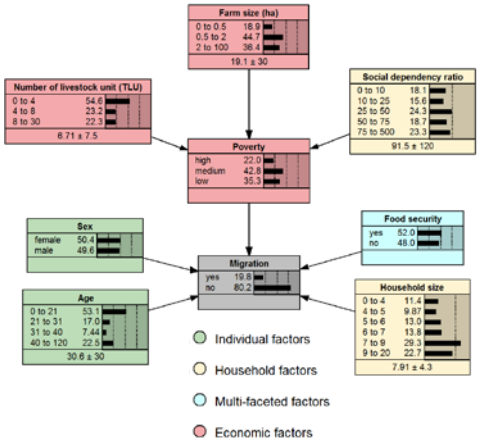




DISCUSSION & OUTLOOK

1) Bayesian network of migration decisions

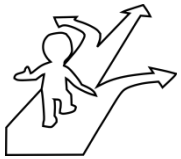
- Represent feedbacks in BN not possible; but in combination with ABMs!!
- Set of migration influence factors in BN –> neglects other possible factors and is static



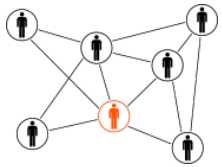
2) Model validation & analysis

3) Future model extensions

- Destination system



- Social interactions via networks and/or collateral use of land



THANK YOU FOR YOUR ATTENTION!

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MIGSOKO

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FONA Social-Ecological Research BMBF

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