Hybrid models for ecological and anthropogenic drivers of pest invasion

Case study of *Tuta Absoluta* in Nepal

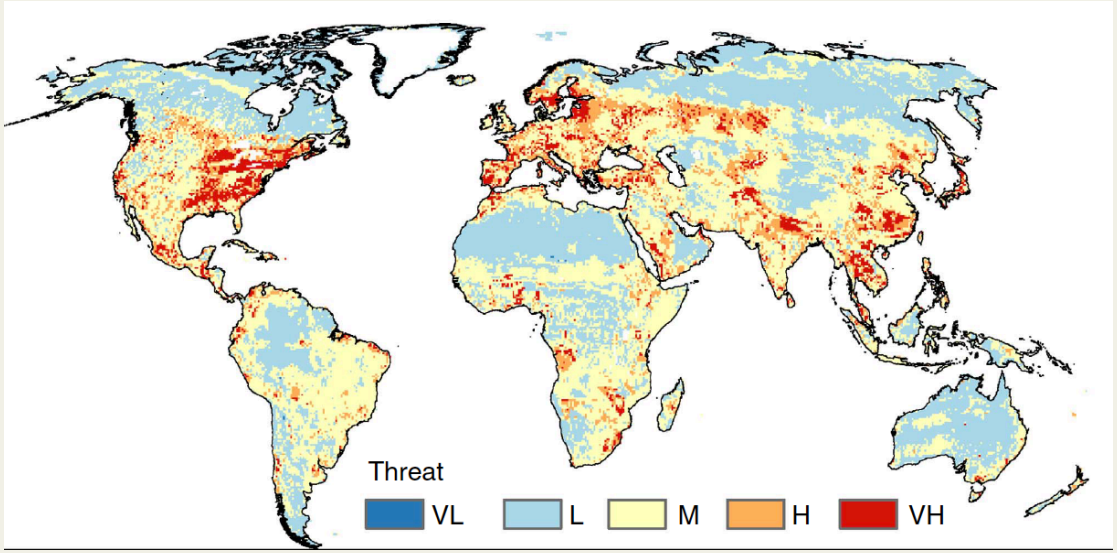
Srinivasan Venkatramanan

Team: Abhijin Adiga, Stephen Eubank, Bryan Kaperick, Achla Marathe, Madhav Marathe, Bowen Shi, Sichao Wu

https://www.bi.vt.edu/ndssl/projects/spread

Global Nature of Pest Invasion

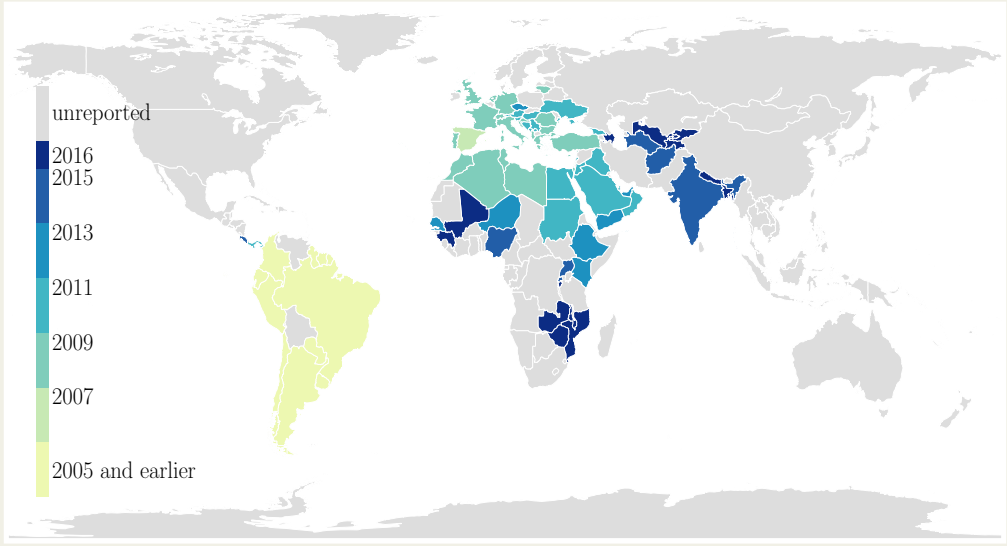
- Invasive alien species threaten global biodiversity
- Aggravated by climate change and globalization of trade and travel
- Direct impact on human livelihood
  - health, food security and economy
- One-sixth of the global land surface is highly vulnerable to invasion [1]
  - **developing economies and biodiversity hotspots**



[1] Early, R. et al. Global threats from invasive alien species in the twenty-first century and national response capacities. Nat. Commun. 7:12485 doi: 10.1038/ncomms12485 (2016).

Tuta absoluta

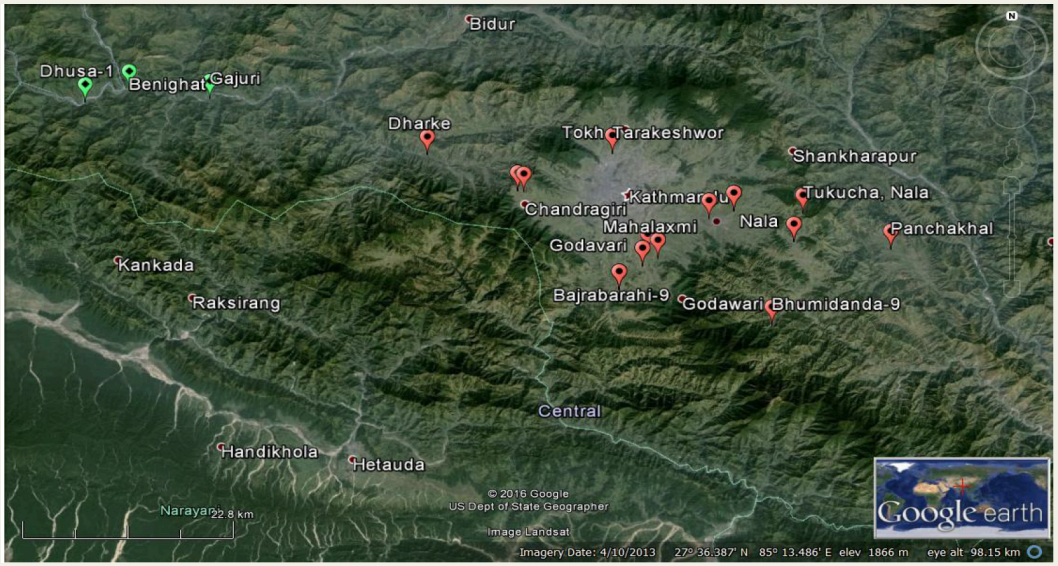
- *Tuta absoluta*, the South American tomato leafminer
  - major pest for tomato crops - can cause up to 80-100% crop loss
  - also affects other solanaceous crops, such as potatoes, peppers, and eggplants
- Native to South America and accidentally introduced to Spain in 2006
- **Within ten years quickly spread across most of Europe, Africa, Middle East**
- No known effective natural predators



Source: Dr. Muniappan

T. Absoluta Presence in Nepal

- Introduction to Maharashtra (India) in October 2014
- Nepal – First Report on May 2016 [2]
  - Commerical tomato farm of Balaju, Kathmandu
- 17 locations surveyed during May-June 2016
  - T. absoluta found in 14 locations
  - Major tomato growing areas – Kathmandu, Lalitpur, Bhaktapur, Kavrepalanchowk
- More **recent reports far from Kathmandu**- Salyan, Surkhet, Banke [3]



[2] Ajaya Shree Ranta Bajracharya et al., The first record of South American tomato leaf miner, *Tuta absoluta* (Meyrick 1917) (Lepidoptera: Gelechiidae) in Nepal, Journal of Entomology and Zoology Studies 2016; 4(4): 1359-1363
[3] Lalit Sah (IDE Global) and Harish Devkota (KISAN) , private communication

Modeling Challenges

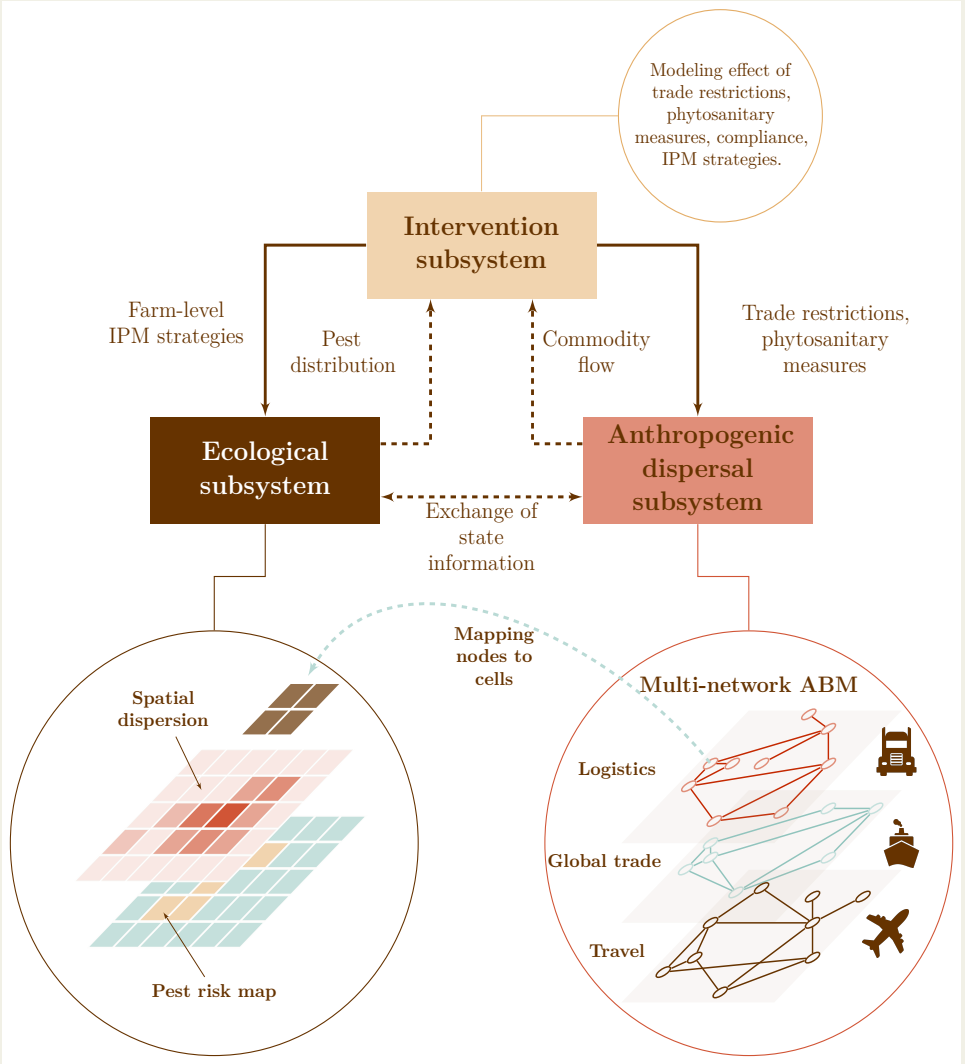
- Human-mediated spread is widely acknowledged
  - Strong evidence of various pathways
    - International trade and migratory workers
    - Regional commodity flow and supply chain logistics
  - Modeling efforts still in preliminary stages
- Unavailability and inaccuracy of ground truth data for validating the models
- Need to bring data and expertise from various domains
  - Entomology, Ecology, Epidemiology, Transportation, Computer Science, Economics

Lack of Hybrid Models

- Existing pest risk models account only for eco-climatic factors, e.g. CLIMEX
  - Increasingly insufficient due to protected cultivation
- Spatial diffusion models have been proposed but cannot incorporate human-mediated spread
- Cannot be used to study the impact of interventions and make policy recommendations
- There is need for a modeling framework that allows development, interaction and integration of the above modules

Our Contribution

- Hybrid modeling approach
- Each module can be developed, tested and improved independently
- Data integration from various sources
- Module granularity depends on:
  - Data availability
  - Questions of interest
- Across spatial resolutions
  - Global vs regional models
- Predictive and prescriptive

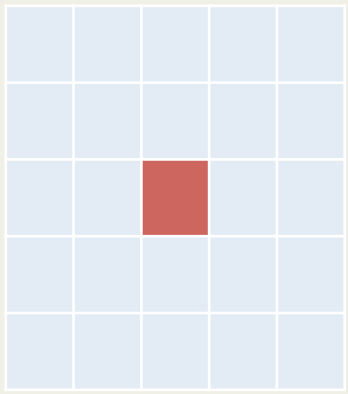
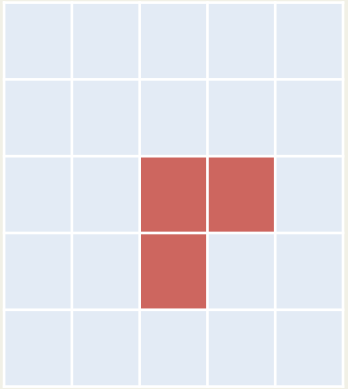
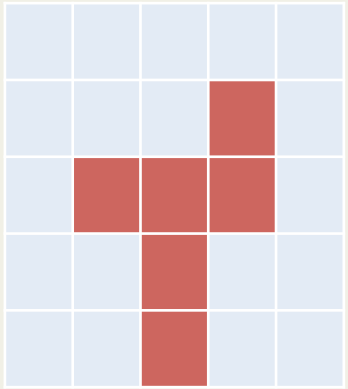
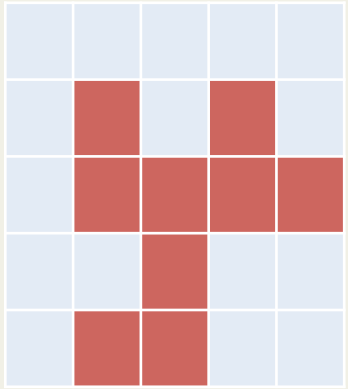


T. absoluta in Nepal (work in progress):

- Spatial *cellular automata* model from literature
- Partial equilibrium approach for economic analysis

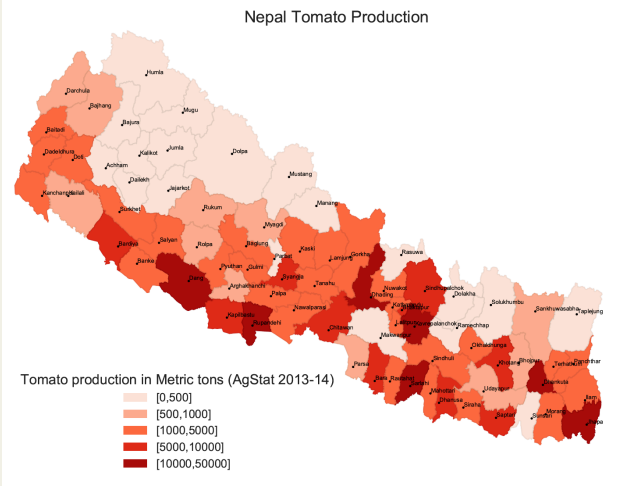
Cellular Automata – Quick Primer

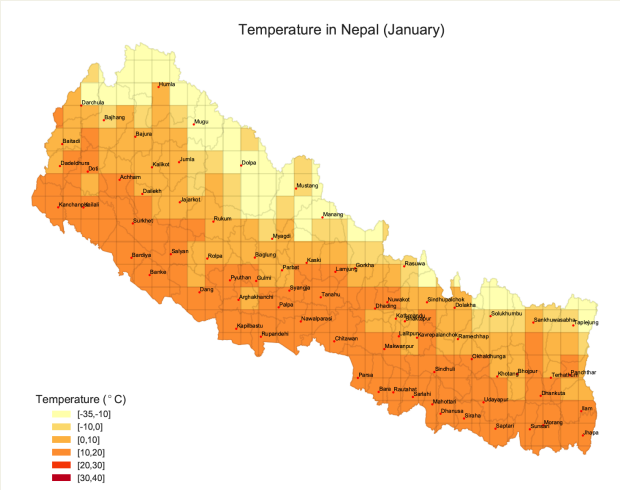
- Cellular Automata (CA) are commonly used for modeling spatial diffusion
- Space is divided into grid cells of fixed resolution
- Each cell has a state and certain properties
- Some cells are marked initially infected and all others cells are susceptible
- Cell states are updated in discrete time steps based on states of neighboring cells and the CA rules

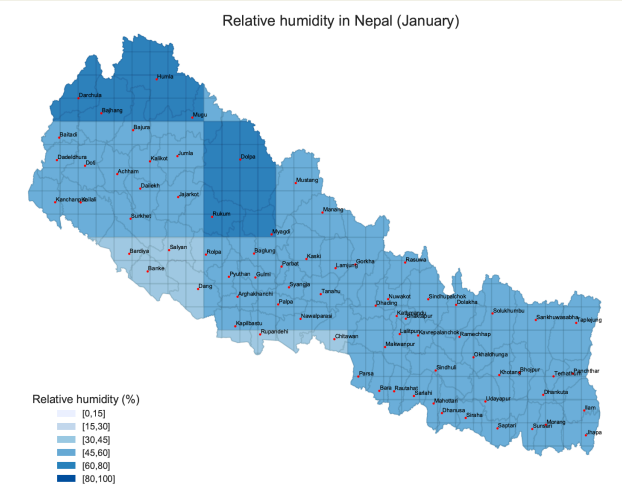





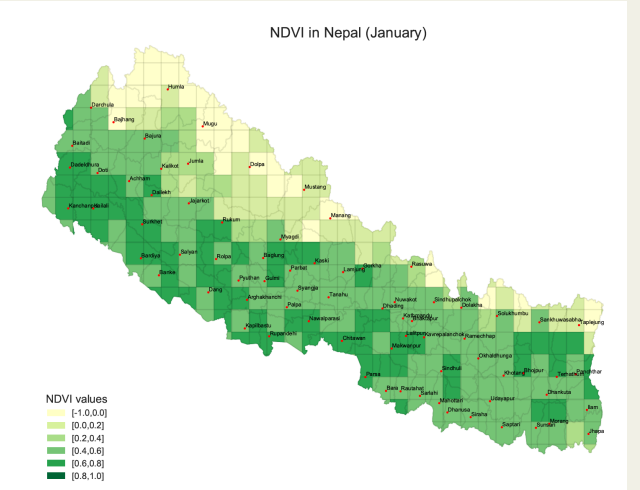
Base Datasets

- Eco-climatic data available at monthly resolution
  - NDVI – Normalized Difference Vegetation Index
    - Obtained from NASA Earth Observations [4] - 0.1 arc degree resolution
  - Temperature data obtained from WorldClim database[5] – 2.5 arc minute resolution
  - Relative humidity from NASA[6] – 1 arc degree
- All data mapped to 25 * 25km resolution
- Tomato production data: From AgStat 2013-14
  - Harvest area, production, yield per district



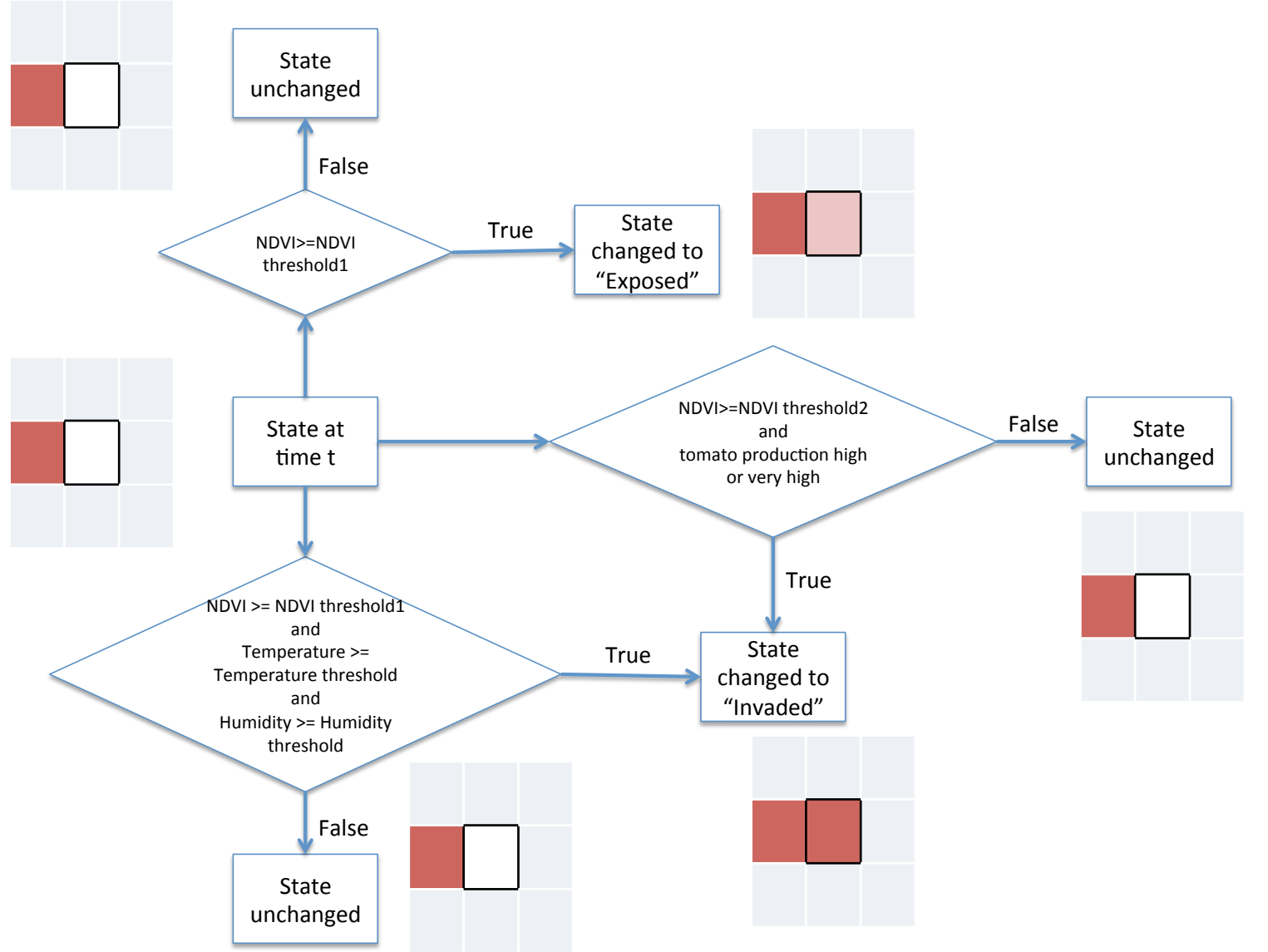






[4] https://neo.sci.gsfc.nasa.gov
[5] http://worldclim.org/
[6] https://eosweb.larc.nasa.gov/sse/

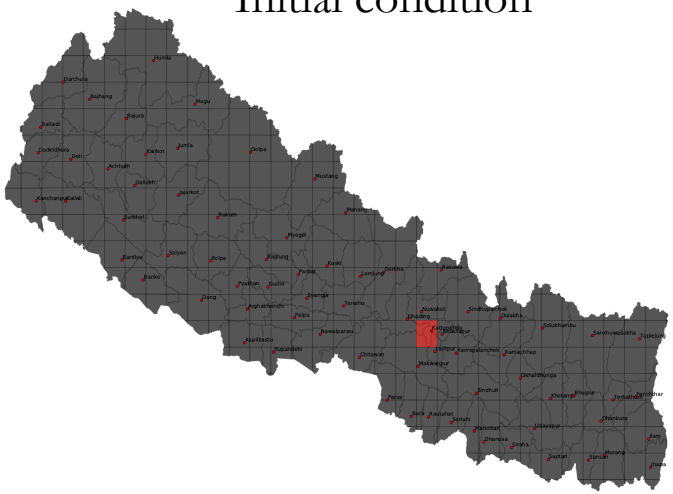
Guimapi CA model



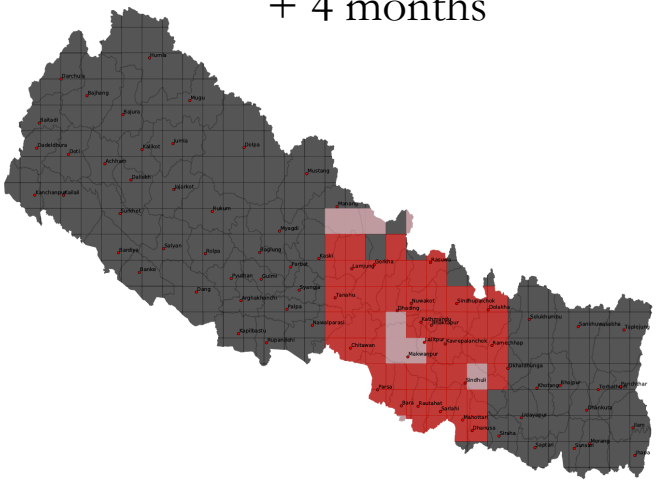
Adapted from: [7] R.Y.A. Guimapi, et al., Modeling the risk of invasion and spread of Tuta absoluta in Africa, Ecol. Complex. (2016), http://dx.doi.org/10.1016/j.ecocom.2016.08.001

Spread Results

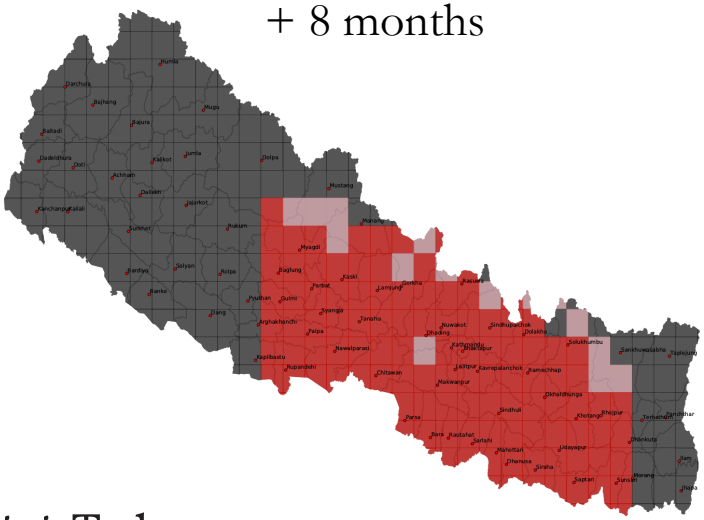
Initial condition



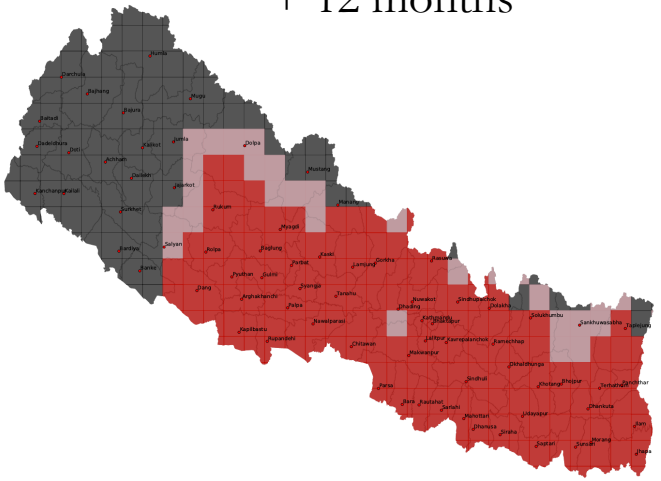
+ 4 months



+ 8 months



+ 12 months



Limitations of Guimapi CA model

- Homogeneous spread
  - Uses NDVI as a surrogate for presence of tomato farms
  - Most regions around the valley and southern Nepal have similar NDVI, humidity, temperature profiles
- Rapid spread
  - Calibrated for Africa without explicitly accounting for human-mediated spread
  - Uncertainty in time scale

Economic Impact Analysis

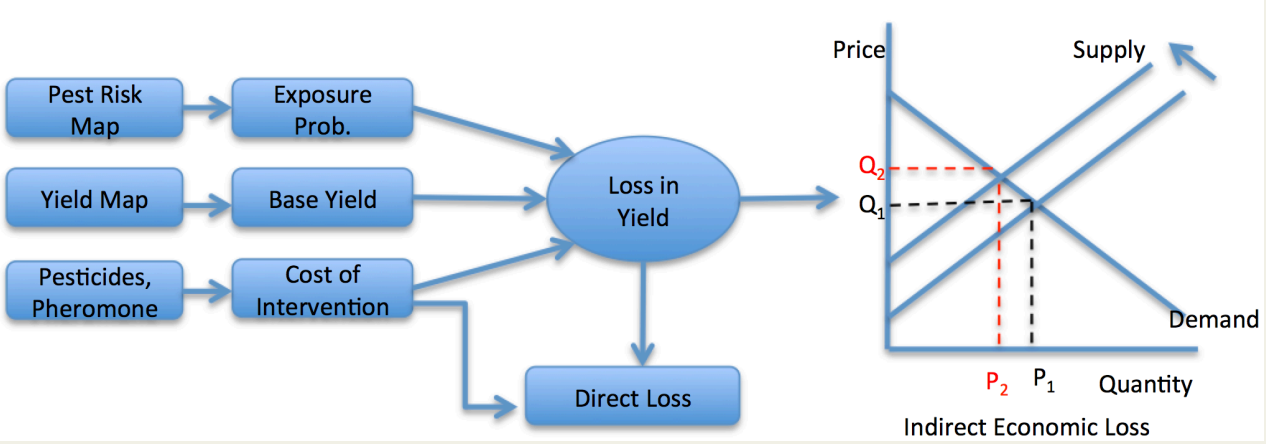
- Two measures of economic impact from [8]
  - Direct impact
    - Direct revenue lost from tomato crop loss
  - Total impact
    - Partial equilibrium approach
    - Sum of change in consumers' and producers' surplus

Initial estimates based on following assumptions:

- Crop loss = 25%
- No intervention
- Original price = $550 per ton
- Demand elasticity = 0.6
- Supply elasticity = 0.5

New Equilibrium price = $623 per ton
Direct Impact = -$10.91 million

Change in Consumer surplus = -$20.55million
Change in Producer surplus = $12.4 million
Total change in Social welfare = -$8.15 million



[8] Soliman T et al. (2012) Framework for Modelling Economic Impacts of Invasive Species, Applied to Pine Wood Nematode in Europe. PLoS ONE 7(9): e45505. doi:10.1371/journal.pone.0045505

Future Directions

- Higher resolution data on location of tomato farms
- Location and quality of greenhouse cultivation
- Integrating movement of tomatoes within Nepal
  - Location of major markets and seasonal flow
- Accounting for imported tomatoes from India
- Modeling the effect of interventions
  - Farm level (cost and efficacy of pesticides)
  - Trade and commodity flow restrictions
- Calibration using data collected from recent pheromone traps

Conclusions

- Initial version of hybrid modeling framework for studying pest spread
- Can be quickly adapted for different regions and pests
- Each module can be improved with domain expertise and availability of better data
- Take advantage of recent advances in computational epidemiology to study biological invasions

Related Research

Projects

PREMPT

Potential risk to United States

Global spread of *Tuta Absoluta*

Impact analysis for Nepal

Modules

Ecological modeling

Commodity flow analysis

Diffusion Dynamics

Economic impact analysis

Ecological Index (EI)

NDVI, Temperature, Humidity

International trade network analysis

Regional (US) freight flow analysis

Spatial disaggregation models

Spatial diffusion (cellular automata)

Network diffusion (trade network)

Partial equilibrium analysis

Elasticity modeling

Acknowledgments

Sponsors

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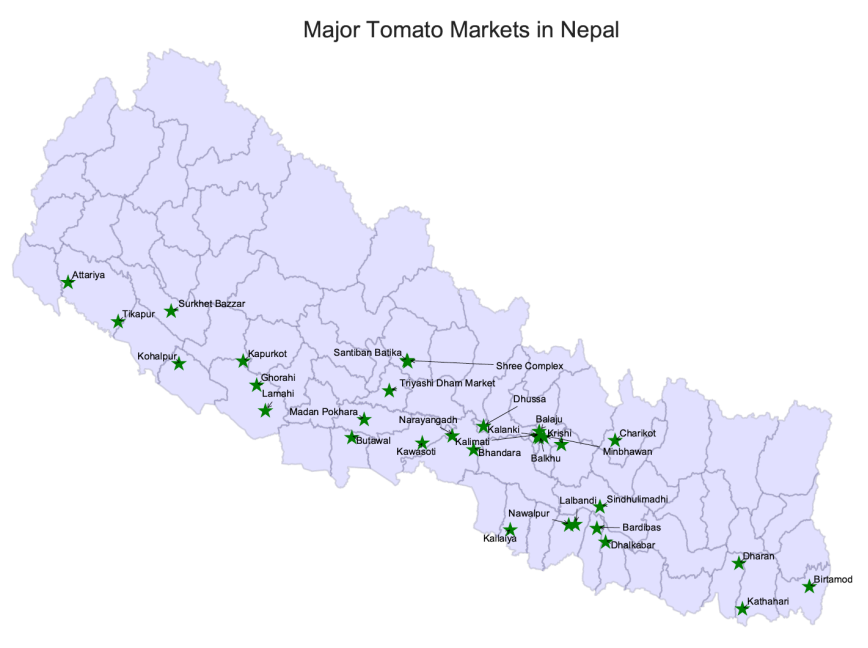
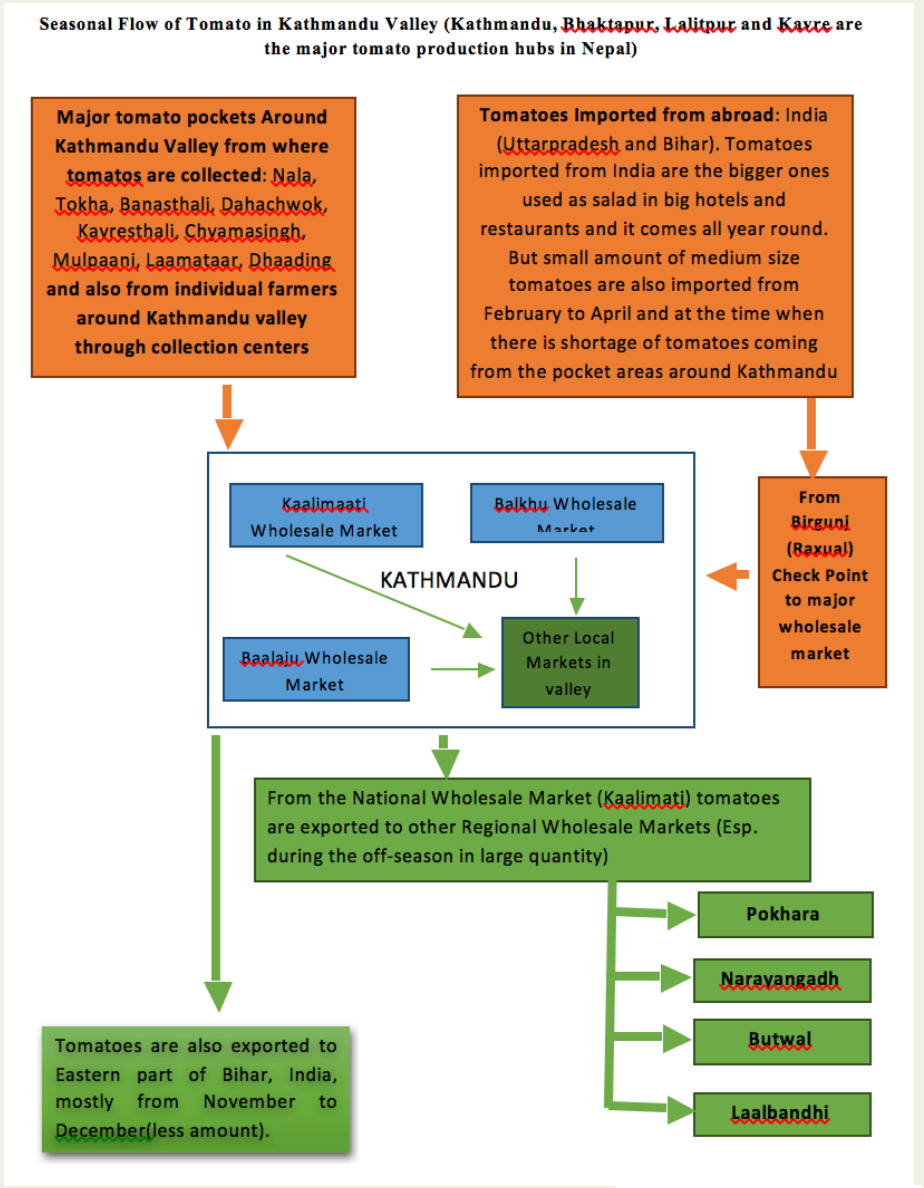
Questions?

Tomato Movement in Nepal

- Commodity flow driven by population density (demand) and production centers (supply)
- Wholesale markets serve as additional enablers of spread
- Seasonal fluctuations in supply affect the flow (esp. of imported tomatoes)





Source: Lalit Sah, IDE Global