
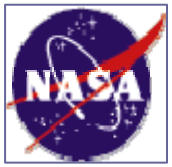


# Spatial analysis and agent-based modeling for understanding the population dynamics of changing human-environment landscapes

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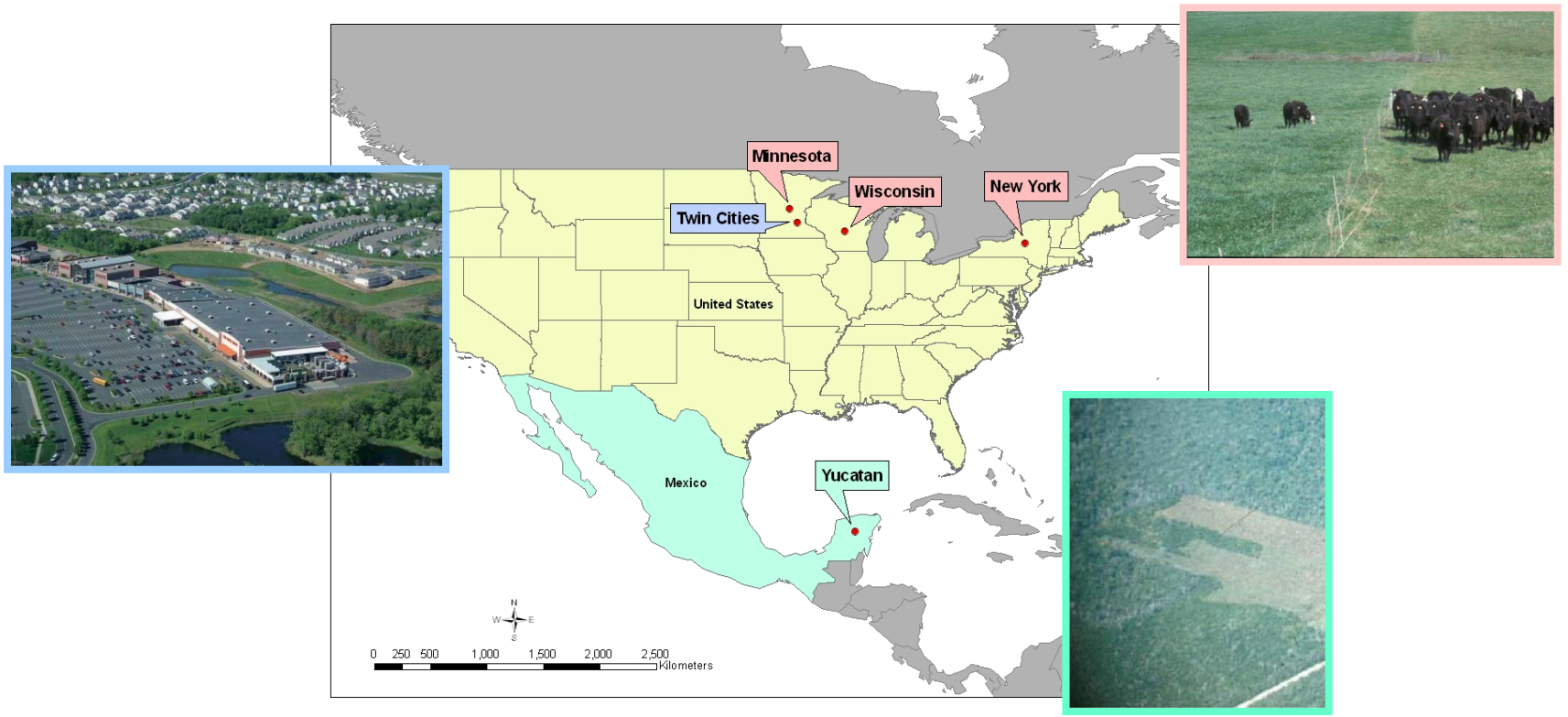
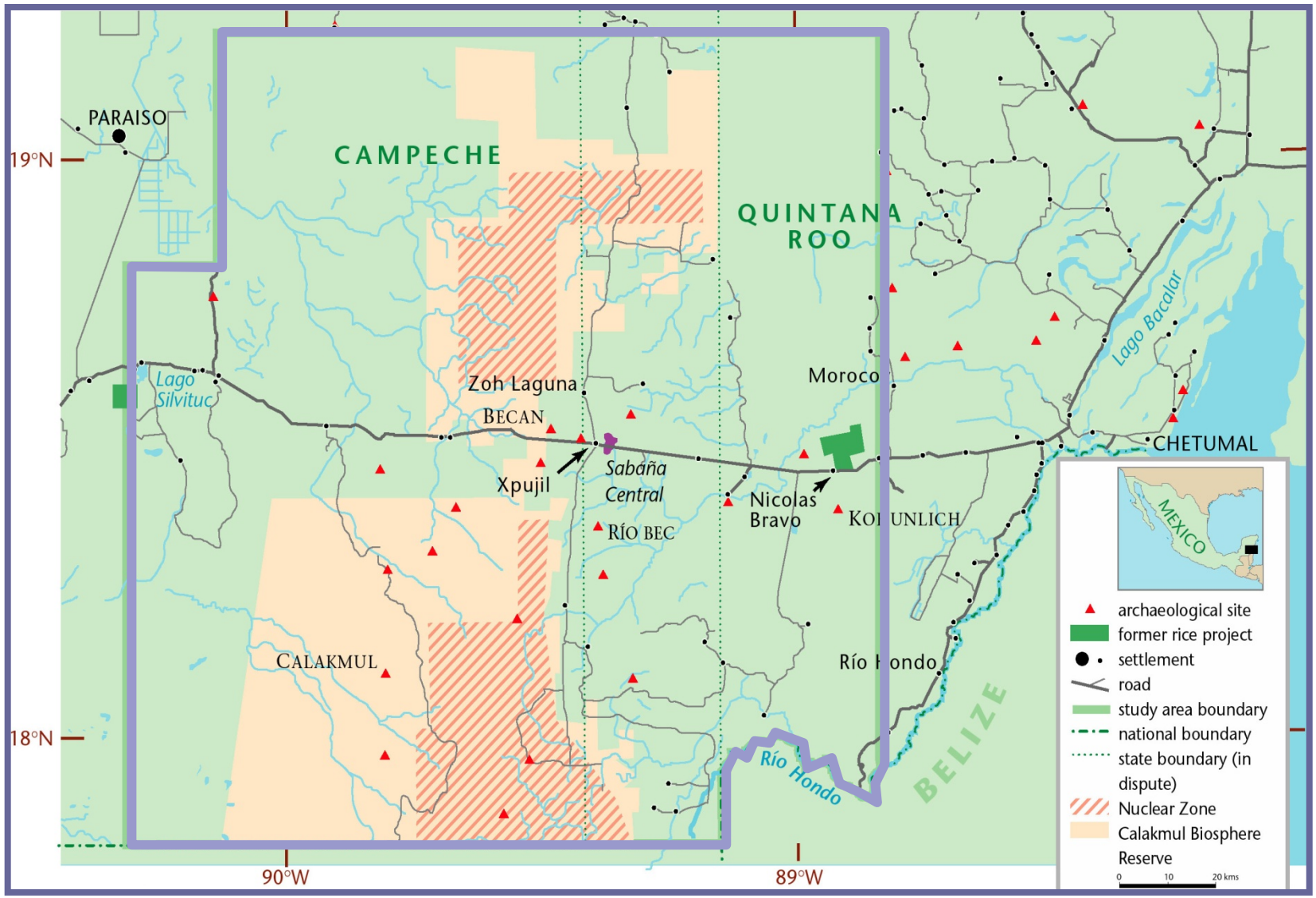
Brookings – December 2007

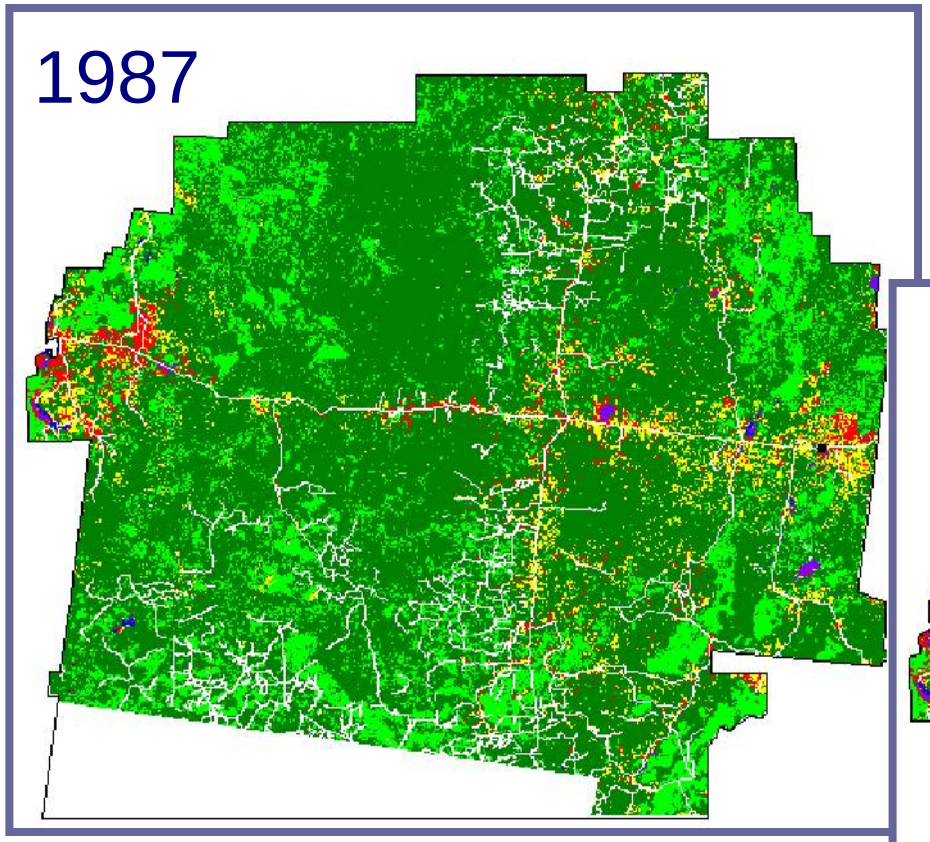
# Three North American Frontiers

- Twin Cities: urbanization, suburbanization, ex-urbanization
- MN/WI/NY: periurban/rural agriculture
- Yucatan: deforestation along Mexico's 'New Frontier'

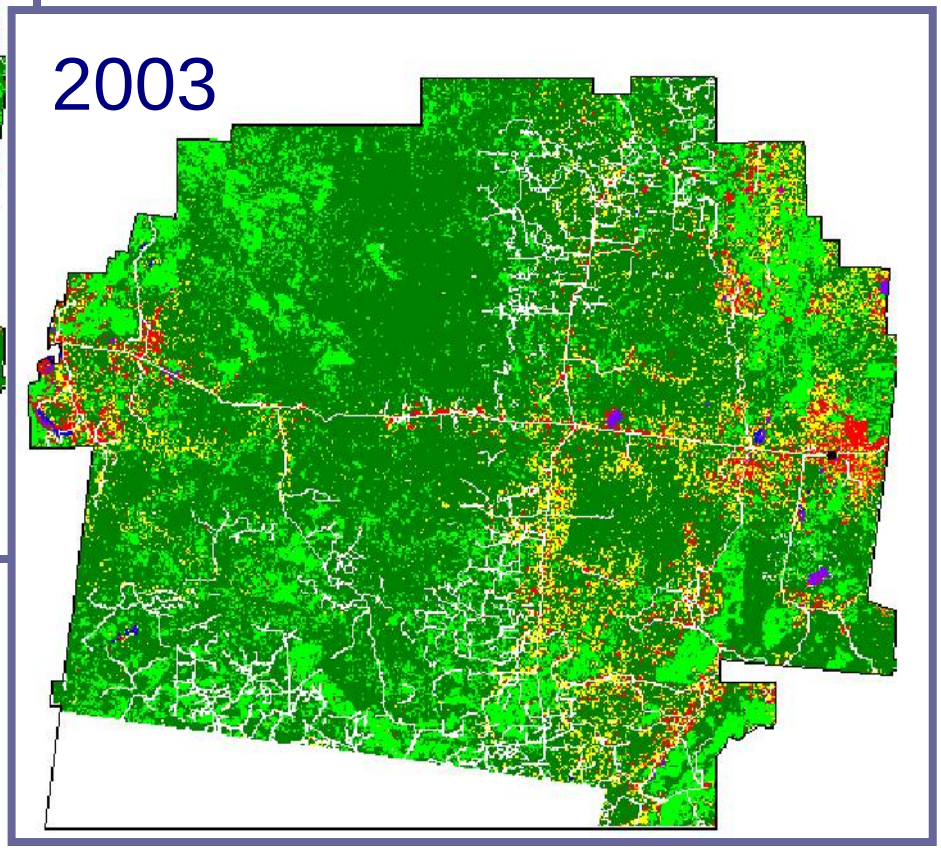


# Southern Yucatan Peninsular Region (SYPR)

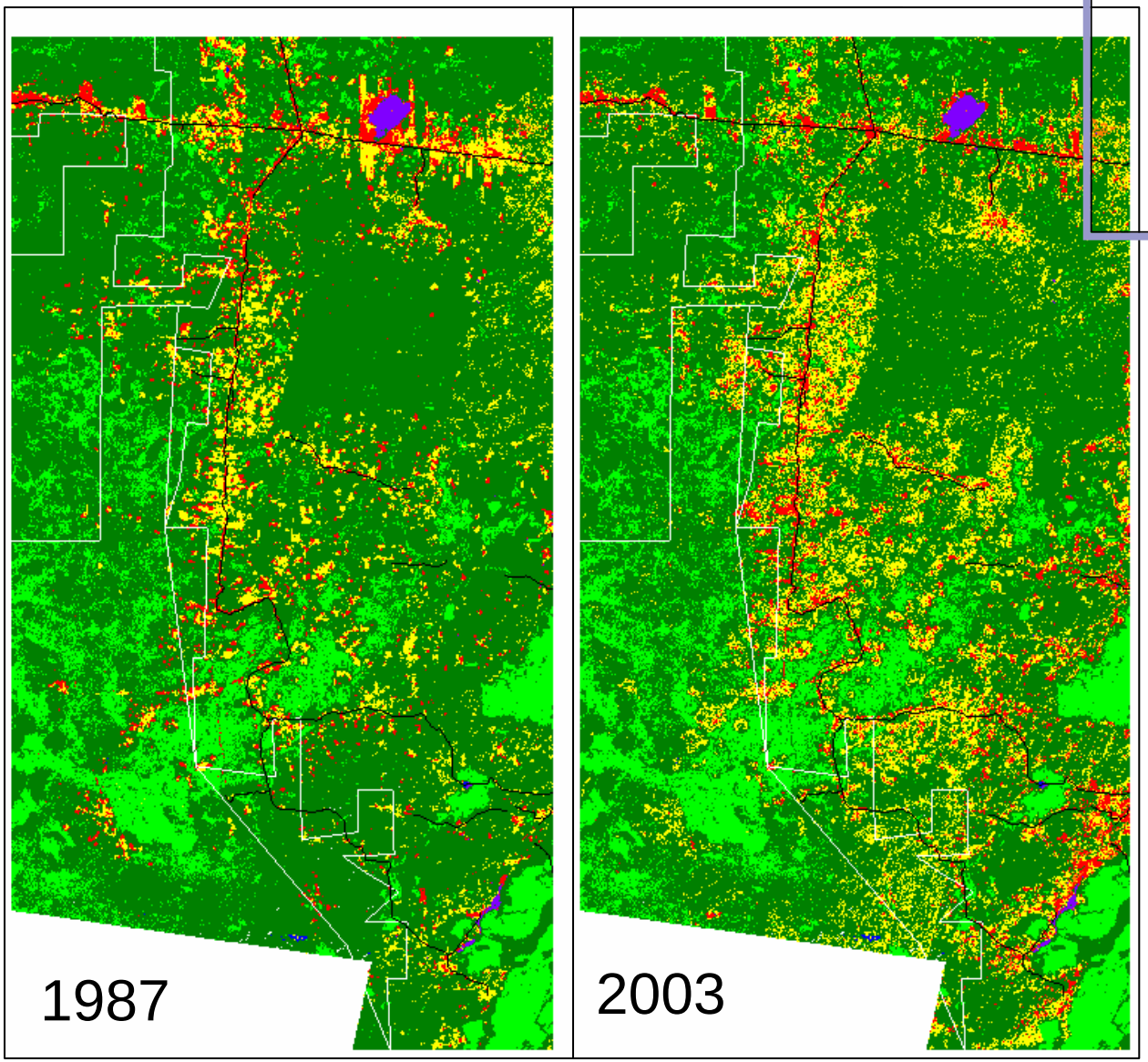





Land use = 1338 km$^2$ / 7.7 %

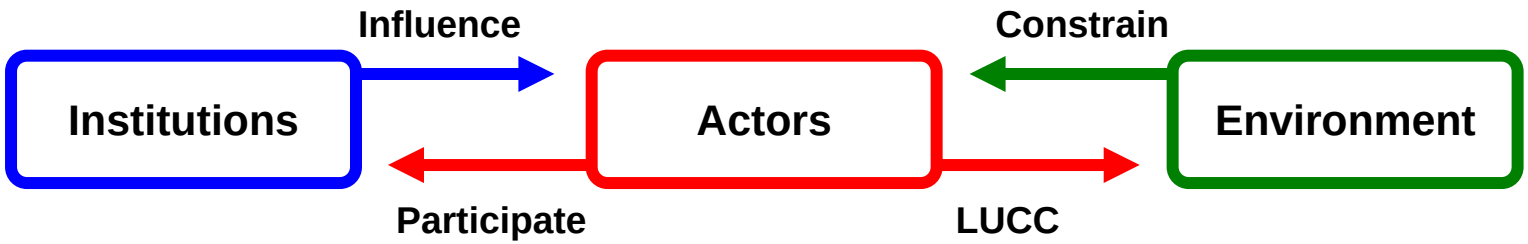



Land use = 2356 km$^2$ / 13.4 %


1987
2003

# HELIA (Human-Environment Land Integrated Assessment)

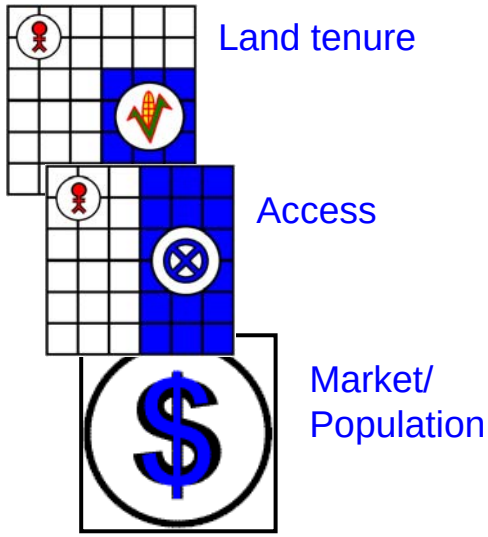
**Concepts**

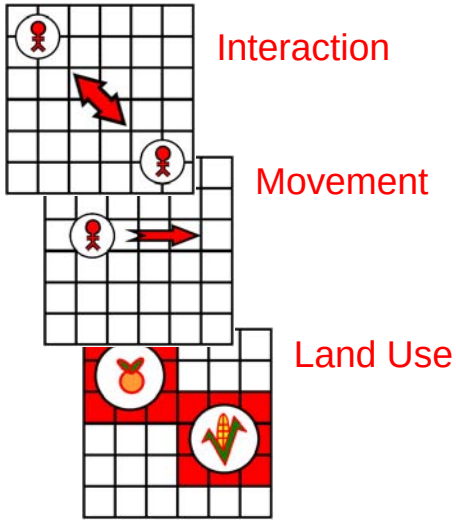


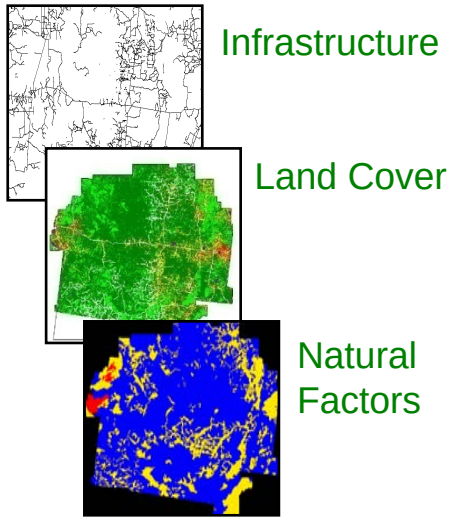

**Theory**

| Institutional Analysis and Development | Bounded Rationality Social Rationality | Ecological Findings Landscape Ecology |
|---|---|---|

**Model Components (Examples)**




**Methods**

| Agent-Based Model System Model | Agent-Based Model Artificial Intelligence | Cellular Model |
|---|---|---|

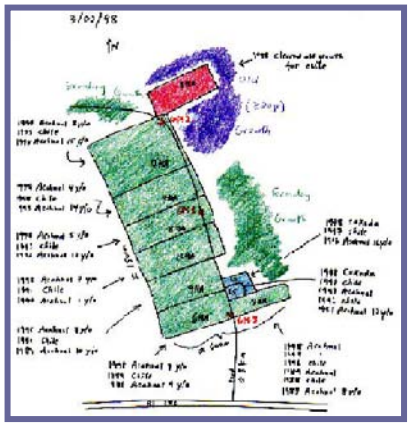
# Data

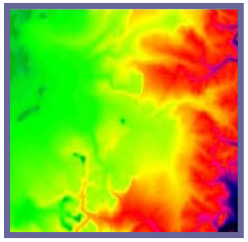
## Surveys (1996, 2003, 2006)

Household
Labor
Production
Institutions

## Archival (Ongoing)

Land use
Institutions
Climate





## Spatial

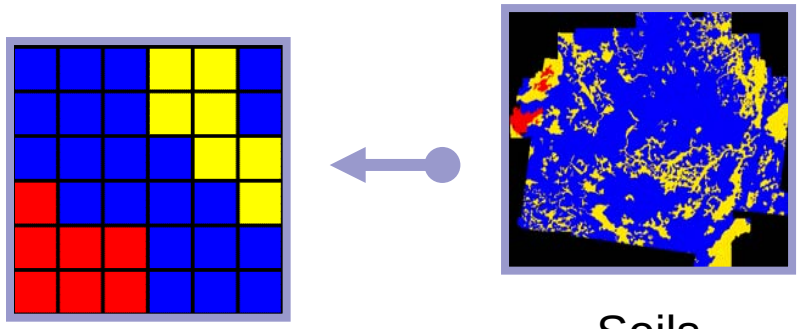
Satellite imagery (1975 - Present)
Aerial photography (1969, 1980s)
Environmental GIS layers (Ongoing)
Land-use/cover maps (1970 - Present)

## Ecological (Ongoing)

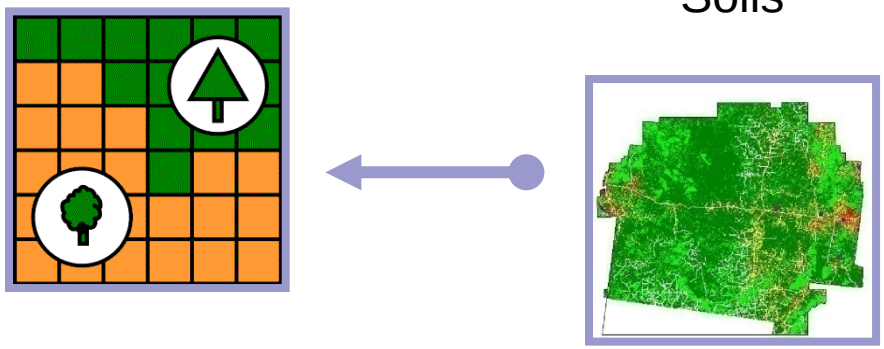
Structure / function
Nutrient flows
Biodiversity

# Environment

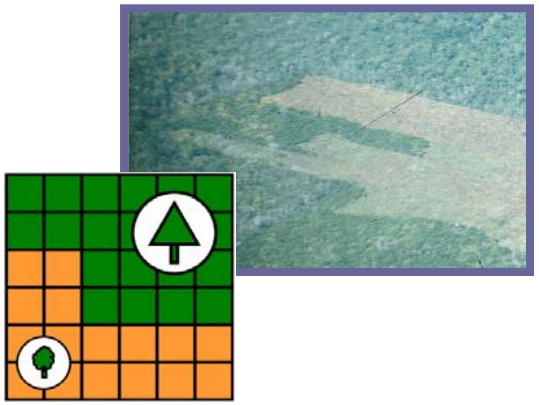
- Environmental concepts
  - Endogenous functions
  - Exogenous impacts
- Environmental cellular model
  - States in spatial factors
  - Rules

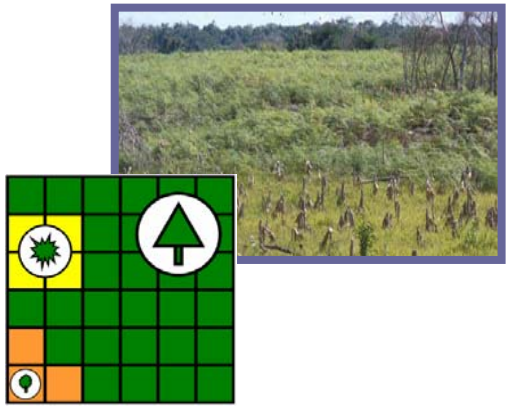


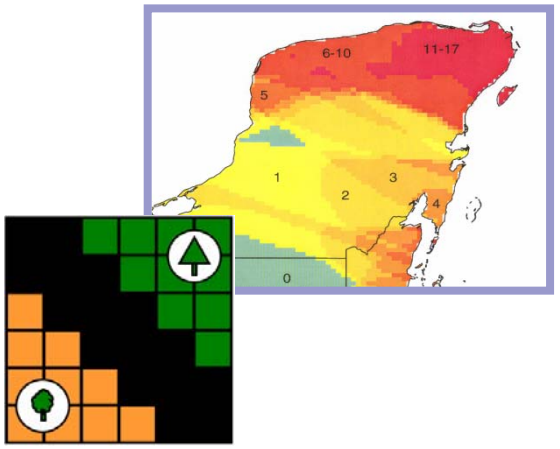
Soils



Land Cover



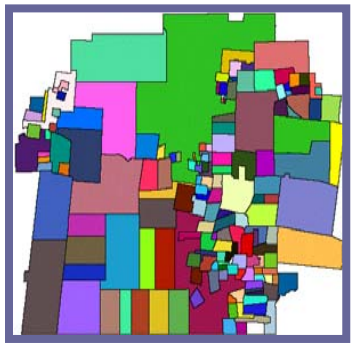




# Institutions

- Institution concepts
  - Influence actors
  - Channel drivers
- Institutional agent-based model
  - Direct change of actor resources
  - Indirect change of spatial factors

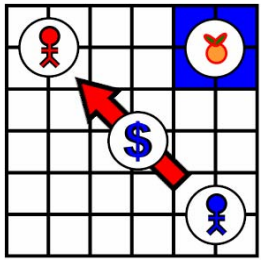
Targeted Market



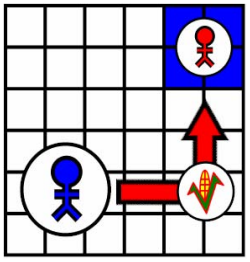
*Ejidos*

Culture

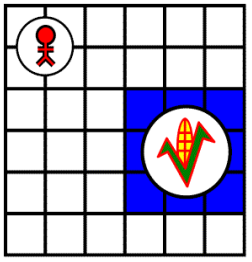
Market



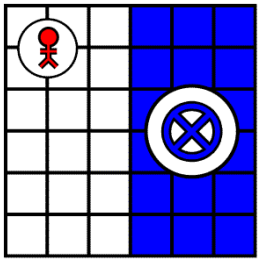
Targeted Market



Tenure



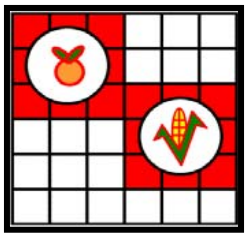
Group Affiliation



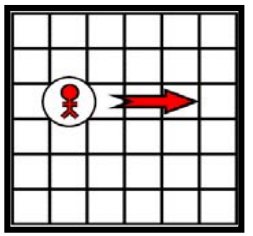
Access

# Actors

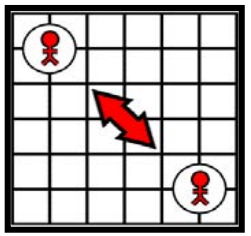
- Actor concepts
  - Decision making
    - Bounded rationality vs. perfect rationality
    - Learning under risk/uncertainty
    - Networks/Ties/Formation
  - Population/Demographics
    - Household dynamics
    - Migration at multiple scales
- Actor agent-based model



Land Use



Movement

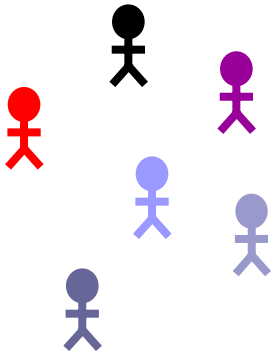


Interaction/
Networks

# Agent-Based Model

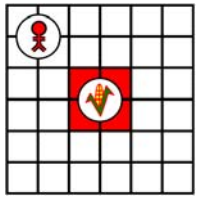
- Standard approaches tend to focus on:
  - General assumptions
  - General model of decision making
  - Analytical tractability (i.e., math/stats)
  - Power/elegance

- Agent-based models focus on:
  - Varying decision making models
  - Varied actors
  - Actor interaction
  - Local interactions
  - Simplicity leading to complexity



## Example Dynamics

**Actor** must grow crops to meet needs



Land access influenced by **institution**

Potential for **environmental** degradation

## Example Simulation

**Year 1**

Actor plants on available land

**Year 2**

Current field invaded by weeds

**Year 3**

Actor plants on next parcel

**Year 4**

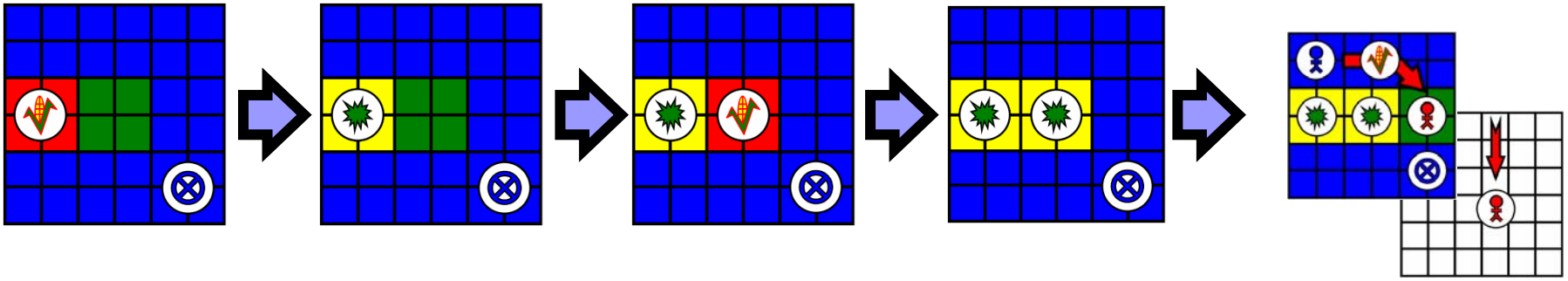
Field invaded by weeds: no more land available

**Year 5**

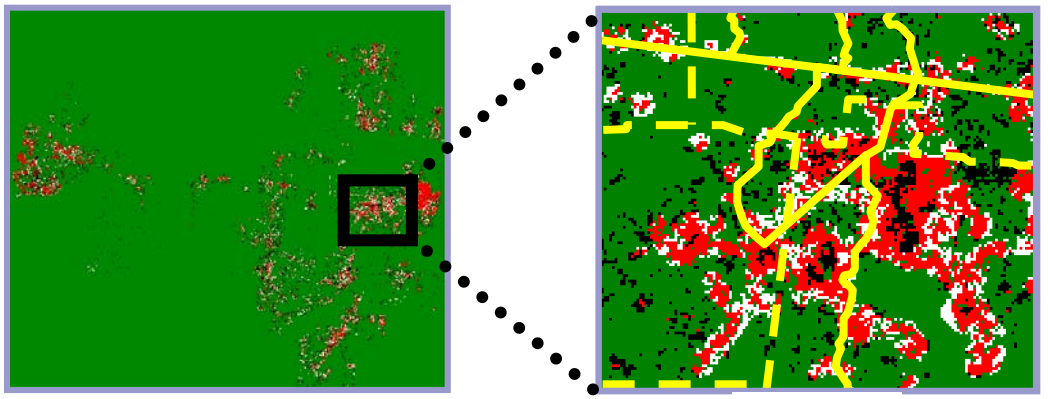
Institution grants land access

OR

Actor leaves



Model output: the aggregate results of the modeled subsystems (actors, institutions, environment) can be seen in (a) spatially-explicit mappings of LUCC, (b) estimates of correlation between LUCC and various factors, and (c) statistics for individual households. All of these results in turn can be applied to social and environmental scenarios.

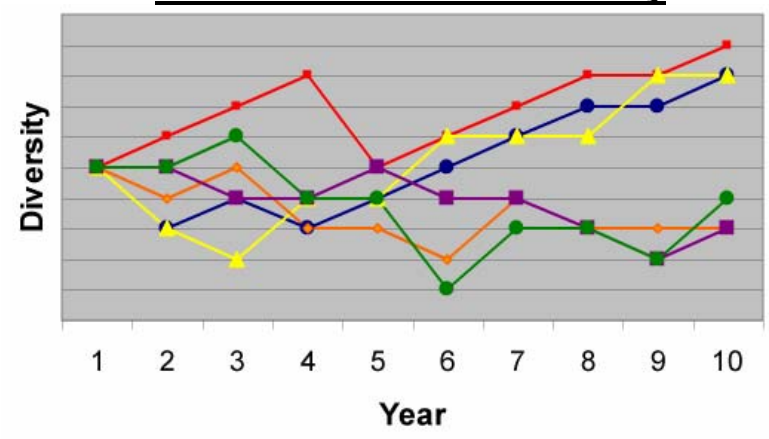


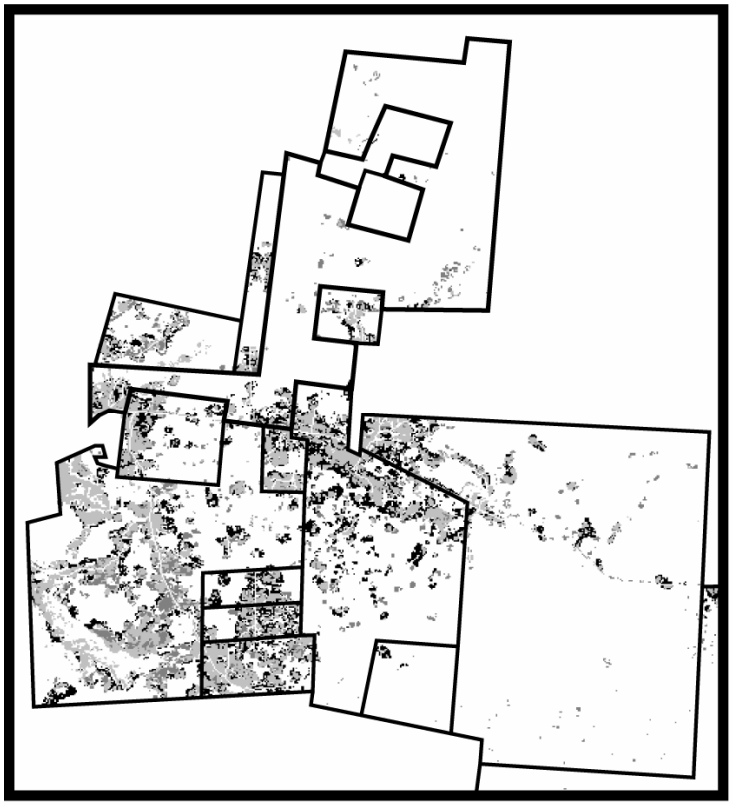
(a)

(b)

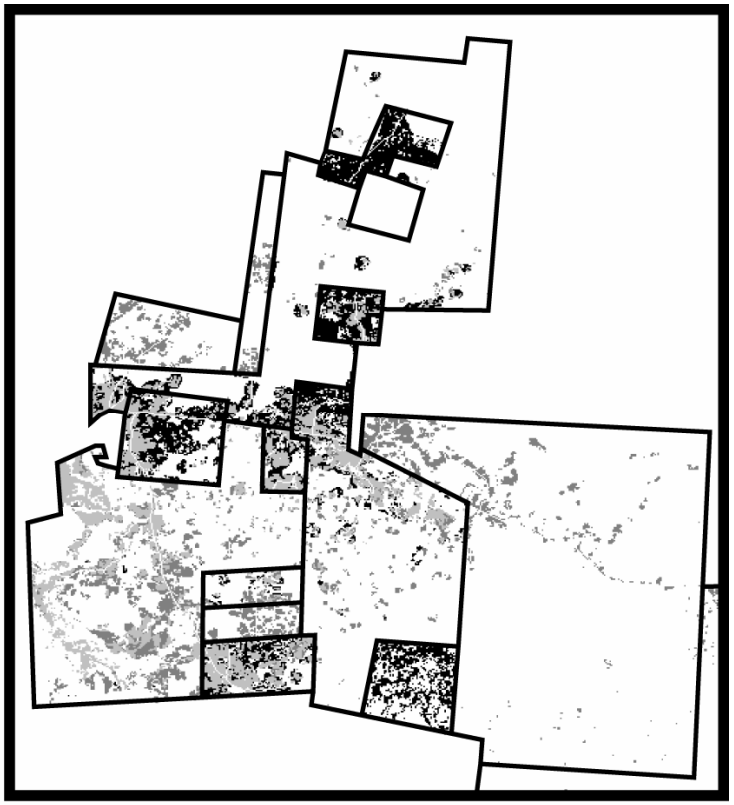
| Factors | Importance |
|---|---|
| Population | 7.30 |
| Environment | 6.85 |
| Institutions | 28.33 |
| Ejidal | 12.86 |
| Market | 15.47 |
| Land Use/Cover | 7.52 |
| Fragmentation | 20.45 |
| Distance | 20.47 |
| Cover type | 16.60 |
| Total | 100 |

(c)

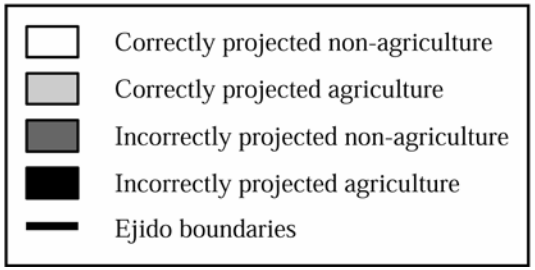




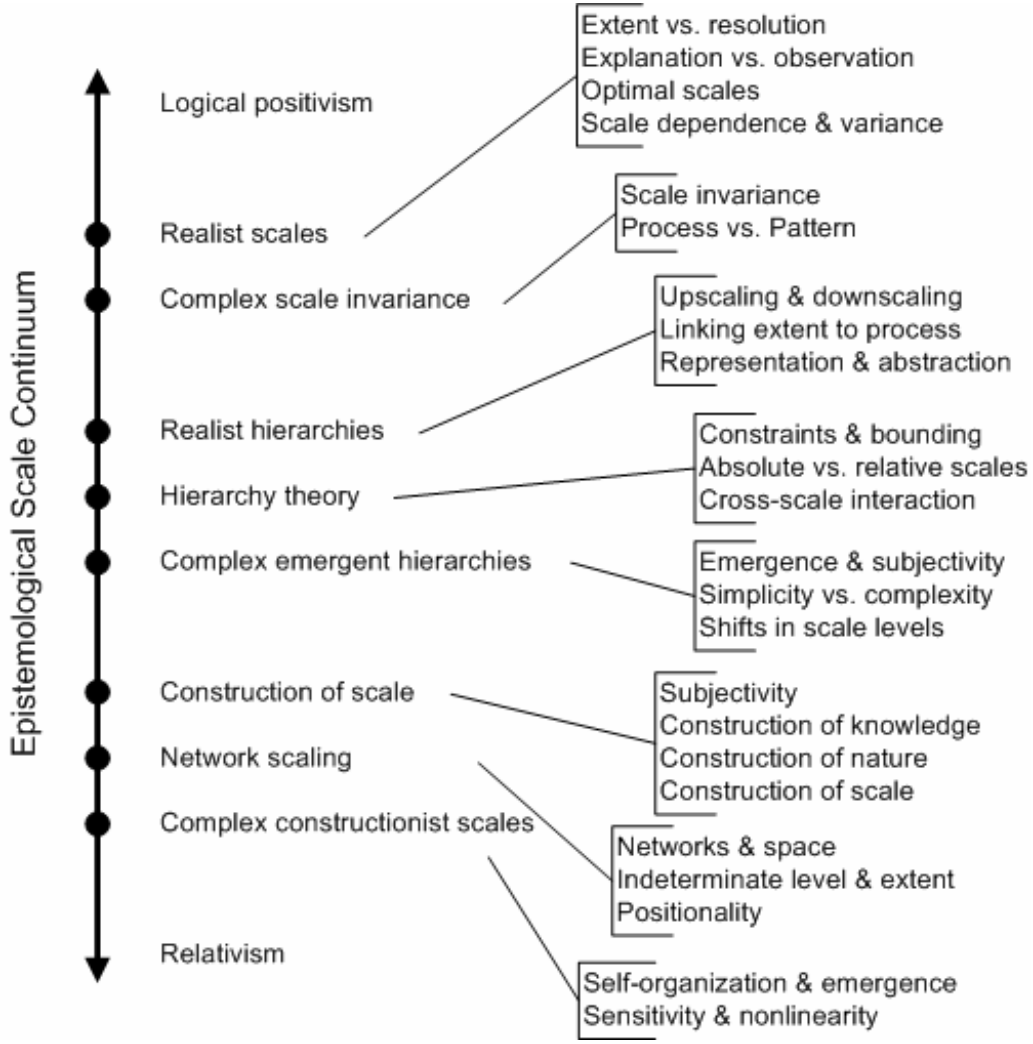
No Ejidal Limits



Ejidal limits

# Complex Scales of Reality

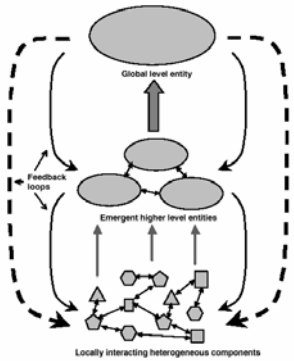



# Complex Reality, Complex Models

Sensitivity

Initial conditions
Parameter sensitivity
Nonlinearity

Scale




Emergence
Supervenience
Scalar distributions

Simplicity vs. Complexity

Deduction by analogy
Equifinality
Pattern/Process conflation

Pattern vs. Process

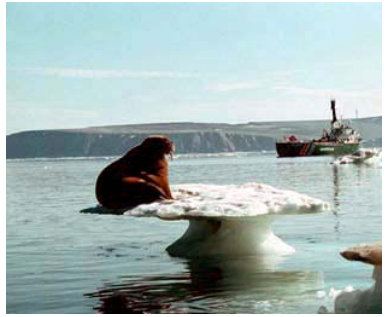
Confounding behavior
Uncertainty

Deduction by analogy

Science-policy Gap

Deep uncertainty
Surprise

Post-normal Science



# Conclusion

- Regional modeling needs
  - Actors + Environment + Institutions
  - Scale
  - Complexity

- Future research
  - Continued socioeconomic & ecological integration
  - HELIA
    - SYPR (NASA)
    - Twin Cities region (NASA)
    - Rotational grazing in MN, WI, and NY (NSF)

Manson, S. M. and T. Evans (2008). Agent-based modeling of deforestation in southern Yucatán, Mexico, and reforestation in the Midwest United States. *Proceedings of the National Academy of Sciences* (Accepted, in press).

Manson, S. M. (2008). Does scale exist? An epistemological scale continuum for complex human-environment systems. *Geoforum* (Accepted, in press).

Sander, H. and S. M. Manson (2007). Heights and locations of artificial structures in viewshed calculation: how close is close enough? *Landscape and Urban Planning* 82(4): 257-270.

Manson, S. M. (2007). Challenges in evaluating models of geographic complexity. *Environment and Planning B* 34(2): 245-260.

Manson, S. M. (2006). Bounded rationality in agent-based models: experiments with evolutionary programs. International Journal of Geographic Information Science 20(9): 991-1012.

Manson, S. M. and M. Bauer (2006). Changing Landscapes in the Twin Cities Metropolitan Area. *CURA Reporter* 36(3): 3-11.

Manson, S. M. (2006). Land use in the Southern Yucatan Peninsular Region of Mexico: scenarios of population and institutional change. *Computers, Environment, and Urban Systems* 30(3): 230-253.

Manson, S. M. and D. O'Sullivan (2006). Complexity theory in the study of space and place. *Environment and Planning A* 38(4): 677-692.

Manson, S.M., (2005). Agent-based modeling and genetic programming for modeling land change in the Southern Yucatan Peninsular Region of Mexico. *Agriculture, Ecosystems and Environment* 111(1): 47-62.

Manson, S. M., J. Geoghegan and B. L. Turner, II (2006). State of the art in describing future changes in ecosystem services: forecasting changes in land use and land cover. In Millennium Ecosystem Assessment: Ecosystems and Well-Being (Volume 2: Scenarios). H. Mooney and A. Cropper (eds). Geneva, Switzerland: Island Press, pp. 74-76..

Manson, S. M. (2004). The SYPR integrative assessment model: complexity in development. In Integrated Land-Change Science and Tropical Deforestation in the Southern Yucatán: Final Frontiers. B. L. Turner, D. Foster and J. Geoghegan (eds). Oxford, United Kingdom: Clarendon Press of Oxford University Press, pp. 271-291.

Brown, D. G., R. Walker, S. M. Manson and K. Seto (2004). Modeling land use and land cover change. In Land Change Science: Observing, Monitoring, and Understanding Trajectories of Change on the Earth's Surface. G. Gutman, A. Janetos, C. Justice, E. Moran, J. Mustard, R. Rindfuss, D. Skole and B. L. Turner II. (eds). Dordrecht, Netherlands: Kluwer Academic Publishers, pp. 395-409.

Manson, S. M. (2003). Validation and verification of multi-agent models for ecosystem management. In Complexity and Ecosystem Management: The Theory and Practice of Multi-Agent Approaches. M. Janssen (ed). Northampton, Massachusetts: Edward Elgar Publishers, pp. 63-74.

Parker, D. C., S. M. Manson, M. Janssen, M. J. Hoffmann and P. J. Deadman (2003). Multi-agent systems for the simulation of land use and land cover change. *Annals of the Association of American Geographers* 93(2): 314-337.

Manson, S. M. (2001). Simplifying complexity. *Geoforum* 32(3): 405-414.

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