



Workshop on Land Use/Land Cover  
Change and the Carbon Cycle  
8-9 June 2009, Ann Arbor, Michigan



NATURAL RESOURCES  
AND ENVIRONMENT  
UNIVERSITY OF MICHIGAN

# Integrated Modeling of Land Use/Cover and the Carbon Cycle

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Sponsored By:





# CCSP Science Plan (Land Use)



- Question 6.1: What tools or methods are needed to better characterize historic and present land-use and land-cover attributes and dynamics?
- Question 6.2: What are the primary drivers of land-use and land-cover change?
- Question 6.3: What will land-use and land-cover patterns and characteristics be 5 to 50 years into the future?
- ...



# CCSP Science Plan (Carbon)



- Question 7.1: What are the magnitudes and distributions of North American carbon sources and sinks on seasonal to centennial time scales, and what are the processes controlling their dynamics?
- Question 7.3: What are the effects on carbon sources and sinks of past, present, and future land-use change and resource management practices at local, regional, and global scales?
- Question 7.6: How will the Earth system, and its different components, respond to various options for managing carbon in the environment, and what scientific information is needed for evaluating these options?



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# CCSP Science Plan (Ecosystems)



- Question 8.1: What are the most important feedbacks between ecological systems and global change (especially climate), and what are their quantitative relationships?
- Question 8.2: What are the potential consequences of global change for ecological systems?
- Question 8.3: What are the options for sustaining and improving ecological systems and related goods and services, given projected global changes?



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# Themes in GLP



- *Theme 1:* Dynamics of Land Systems
- *Theme 2:* Consequences of Land System Change
- *Theme 3:* Integrating Analysis and Modeling for Land Sustainability

From GLP Science Plan, IGBP/IHDP, Ojima,  
Moran, et al., 2004

# Linking Land Use & Ecosystem Process

Example

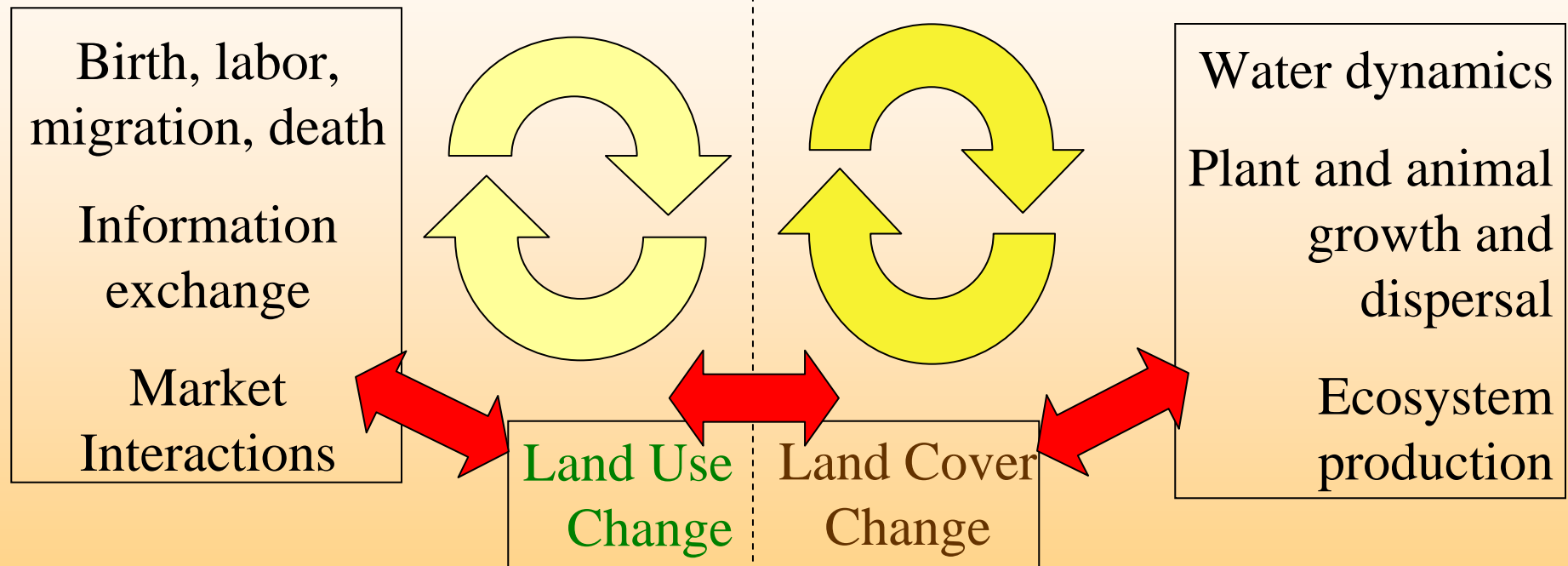
Processes:

*Social System*

*Natural System*

Example

Processes:

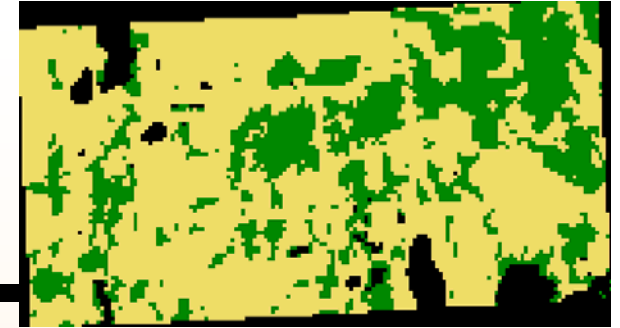


- It might be profitable to think about three key process linkages:
  - social processes interacting with land-use change,
  - biophysical processes interacting with land-cover change , and
  - land-use change processes interacting with land-cover change processes (**land management**)



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# Land Change Models



- Encode our knowledge of process
- Help test pattern-process links
  - Can help us examine feedbacks between ecosystem structure/function and human actions
- Provide dynamic landscapes for input to ecosystem process models
- Make projections of future landscape patterns
- Test alternative futures under various hypotheses, policies, practices, and incentives



# Scale and Timeframe

		<i>Timeframe for Projection</i>			
<i>Spatial Extent</i>	<i>Spatial Resolution</i>	Short (5yr)	Medium (20yr)	Long (50yr)	
	Local	10 - 100m	XXX	XX	X ?
	Regional	100m - 1km	XXX	XXX	XX
	National	1-10km	X?	XX	XXX
	Global	>10km	X ?	XX	XXX
					



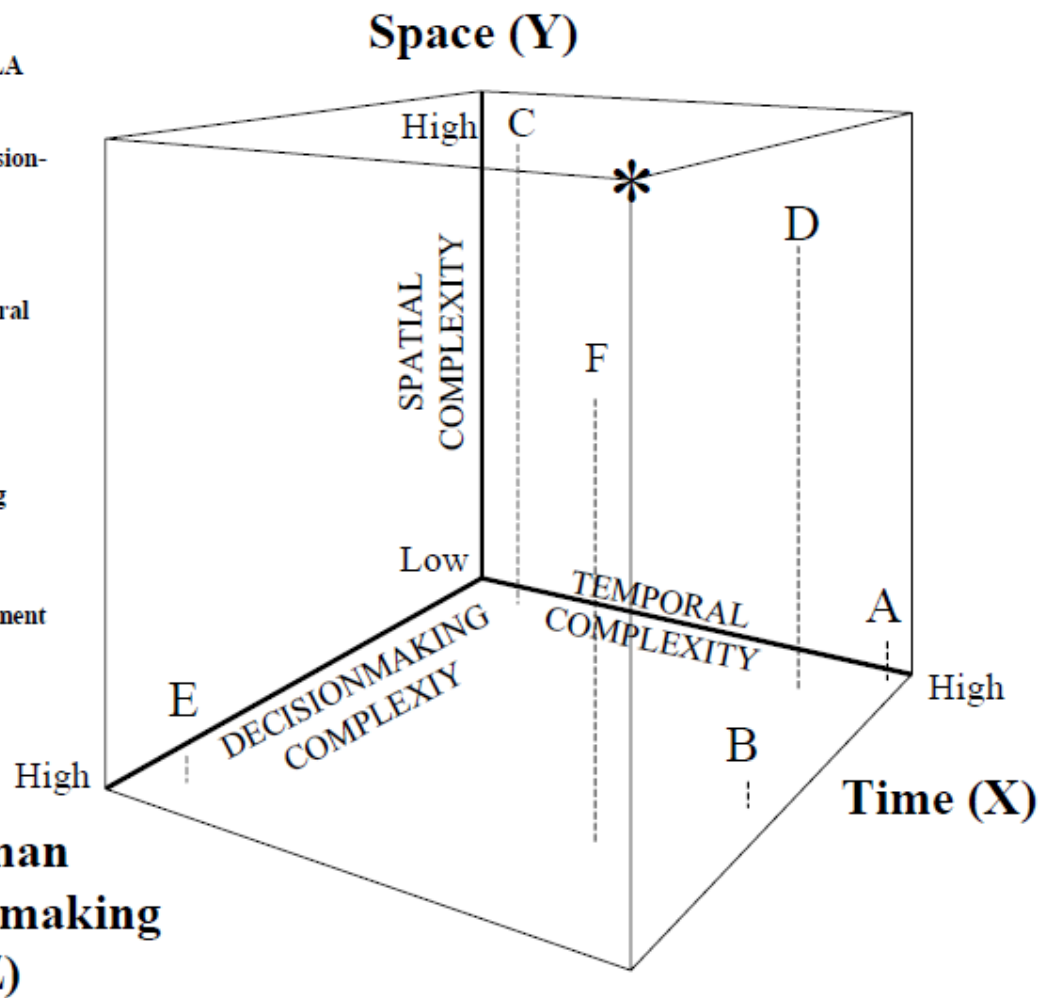
# Dimensions of Land Change Models



## Key

- A- Time series statistical models, STELLA models with no human dimension
- B- Time-series models with human decision-making explicitly modeled
- C- Most traditional GIS situations
- D- GIS modeling with an explicit temporal component (e.g., cellular automata)
- E- Econometric (regression) and game theoretic models
- F- SWARM and SME (spatial modeling environment)

\* The ultimate goal of human-environment dynamic modeling: high in all three dimensions



Agarwal et al. 2001



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# What is human agency?

- “Human agency is the capacity of human beings to make choices and to impose those choices on the world. It is normally contrasted to natural forces, which are causes involving only unthinking deterministic processes.”

from Wikipedia





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# Why represent human agency?



- We cannot afford to ignore ecosystems and habitats that are occupied by people.
- Human decisions shape landscapes, even when those decisions are to set them aside for preservation.
  - Because human decisions are also shaped by landscapes, there are feedbacks that can produce complex dynamics.
- By representing agency, a model includes mechanisms that represent the *processes* by which humans make decisions that affect the landscape, including land use and management.



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# Non-Behavioral Geographical Models



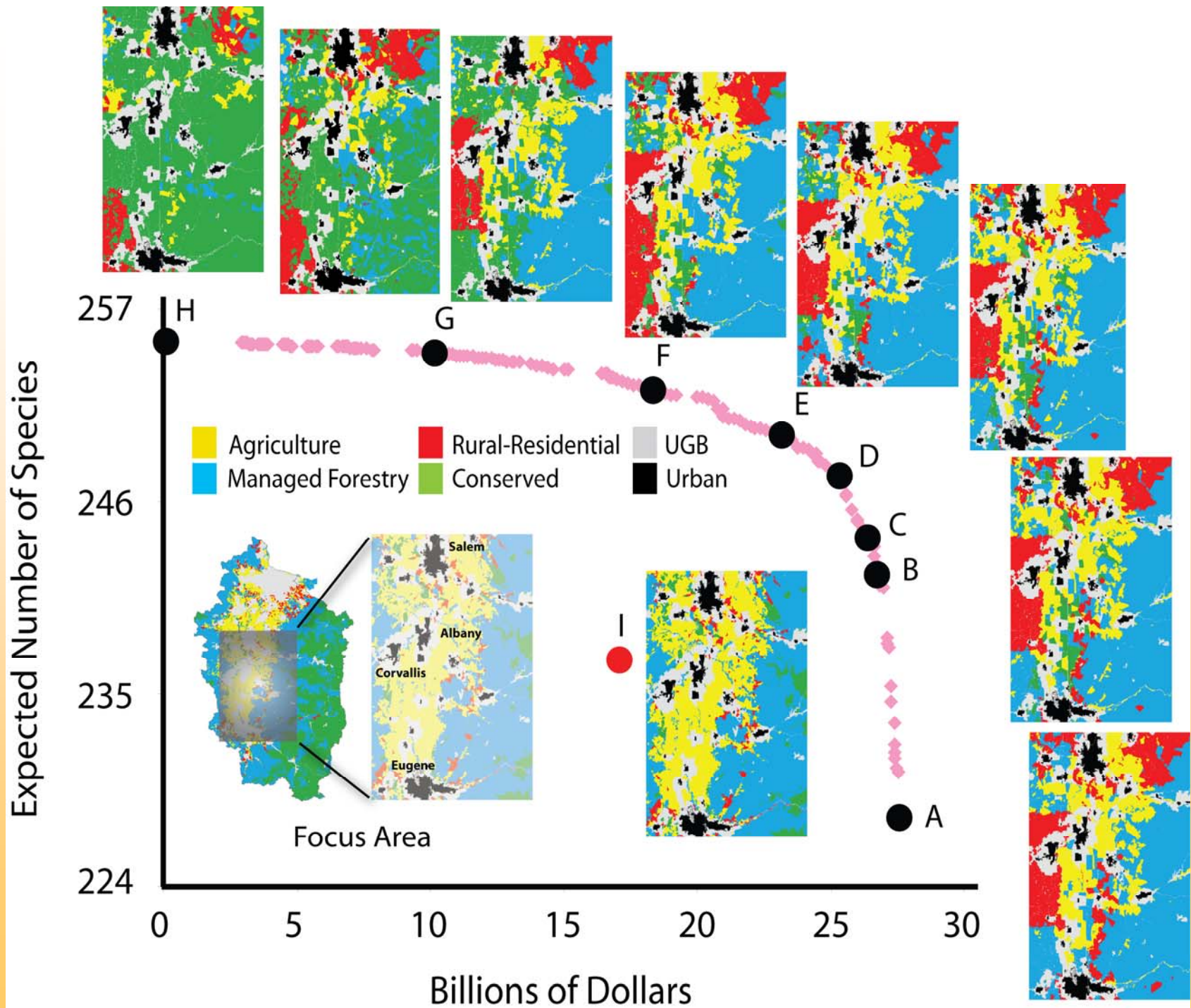
- Focus is often on reproducing or predicting patterns without explicitly representing the processes by which patterns come to be.
  - Useful for forecasting, but do not represent processes
- Based on specifications of demand for land uses and spatial patterns of land suitability.
  - Examples: CLUE, LTM
- Some involve dynamic interaction rules learned based on historical patterns
  - Example: SLEUTH, DUEM
- Land-use and LU change processes are either not represented explicitly, or represented with non-behavioral models (like CA transitions)



# Econometric Models



- Estimate model parameters from spatial and temporal data.
- Usually assume profit or utility maximization
- Economic theory informs explanatory variables and structure of relationships
- Econometric approaches lie at the heart of many regional and national policy assessments (e.g., INVEST)
  - Nelson et al. 2008, *PNAS*; Lubowski et al. 2006, *J Env. Econ and Mgt.*
  - Relevant examples at **Forestry and Agriculture Greenhouse Gas Modeling Forum** (<http://foragforum.rti.org/index.cfm>)





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# Issues in Representing Human Processes



- Various decision-making strategies
  - Rational actors, Bounded rationality, Satisficing
- Heterogeneity – not all people are alike
- Adaptability – people respond to changing contexts
- Interaction – people learn from each other
- Time and space scales – multiple processes acting at multiple scales
- Stochasticity – we can't model everything deterministically



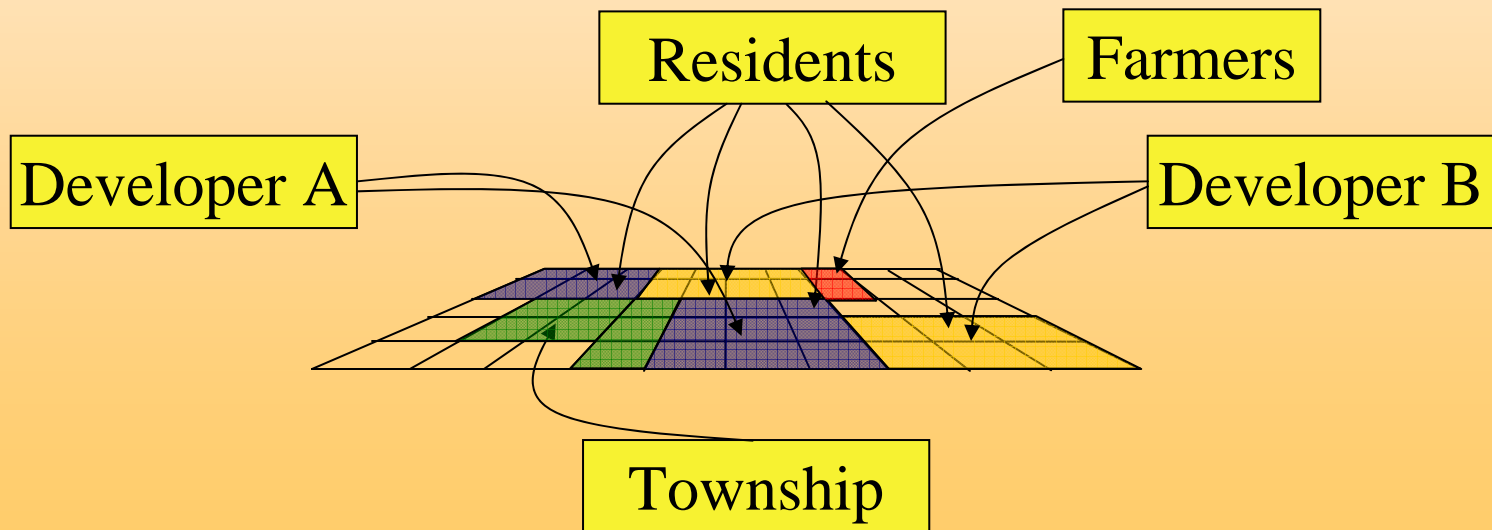
# Process Simulation Models



- Focus is on describing the process dynamics of change.
- Predictions can be difficult to interpret in presence of non-linear dynamics;
  - Multiple equilibria, path dependence
- System dynamics
  - Useful for aspatial models, or with few well-mixed regions.
  - Process descriptions in terms of stocks and flows
- Agent-based models
  - Useful where heterogeneous actors interact
  - Process descriptions in terms of agent decisions

# Dynamic Ecological Exurban Development (DEED) Model

- *Townships* — purchase land to **preserve**
- *Farmers* — can sell **rural lot** from part of farm field
- *Developers* — convert farms to **subdivisions** of different types
- *Residents* — select residential lots based on preferences



Brown et al. 2008. *Geoforum*.



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# DEED in ArcGIS



matium\_2007\_01\_24.mxd - ArcMap - ArcInfo

File Edit View Insert Selection Tools Window Help

1:15,076

Counter : 20

### DEEDS Simulation Parameter Window

Parameter File: deeds.prm [Clear] [Load]

Parameters:

- Number of Residents Per Turn: 10
- Number of Developers: 3
- Stop Time: 20
- Probability of Farm For Sale: 0.02
- Number of Res. Test Sites: 15
- Debug Level: 0
- Minimum Lot Size: 9
- Subdivision Full Threshold: 0.75
- Preserve Mode: 1
- Proportion in Preserve: 0.1

Operation Mode:

Probability Develop Farm: 0.5

Random  Batch mode

SLUCE Seed: 9999

File Information:

Display Source Selection ABM Params

### Identify Results

Layers: <Top-most layer>

agentWorld1

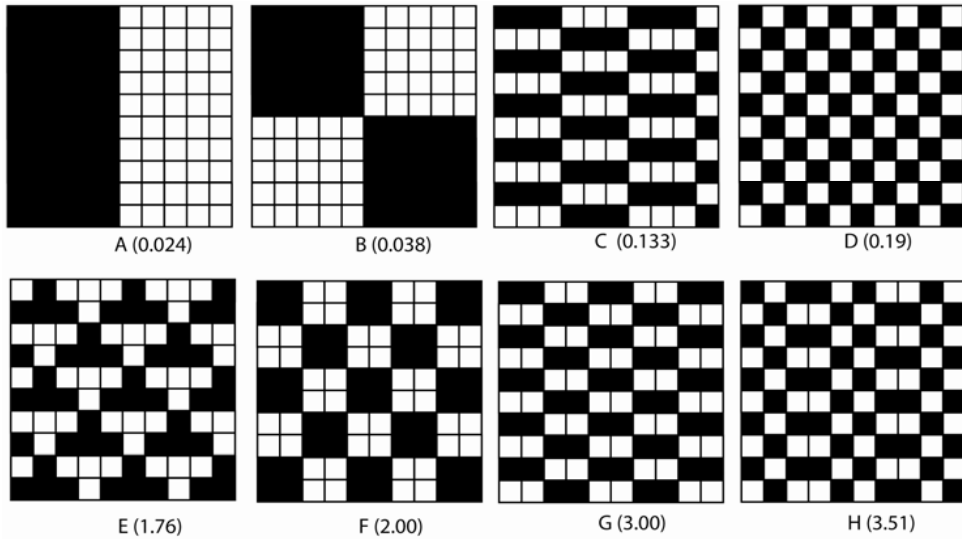
99

Location: [263661.349789 4683256.311889]

Field	Value
FID	99
Shape	Point
ID	99
Ini_util	0.604707
X	263664.001122
Y	4683255.10341
oAlphaA	0.559601
oAlphaS	0.211997
oAlphaT	0.632538
sAlphaA	0.398538
sAlphaS	0.150980
sAlphaT	0.450482

263665.62 4682638.03 Meters

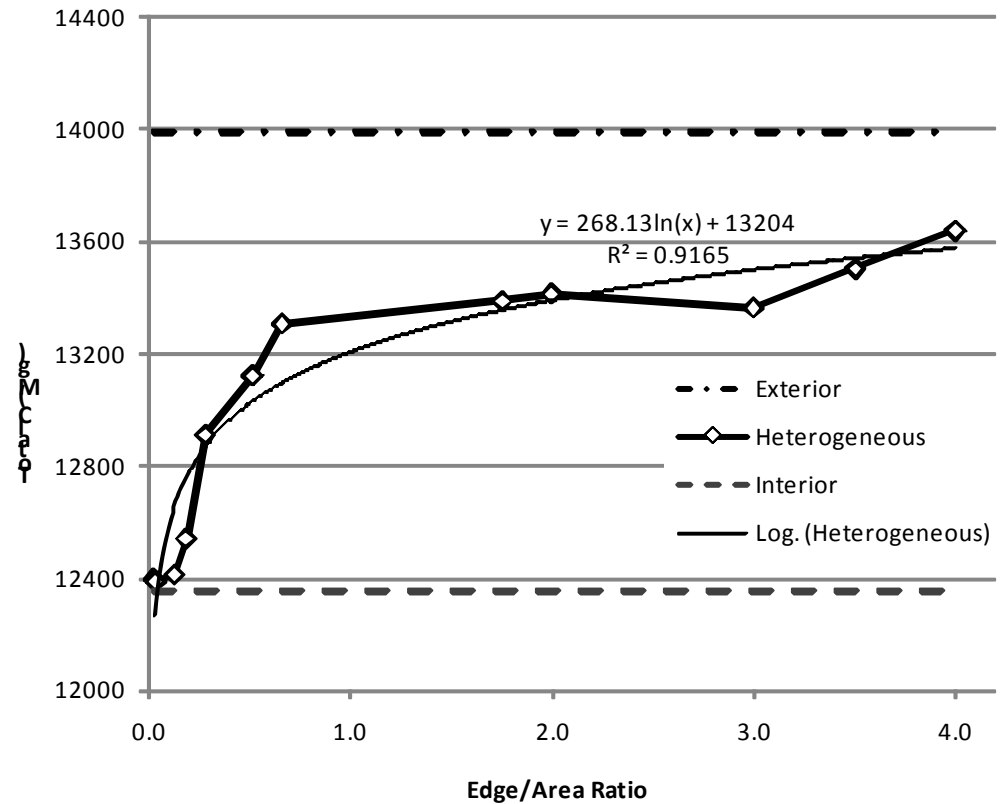
Developed by Derek Robinson (Robinson and Brown, 2009)



## Simulated landscapes with varying edge/area ratios

BIOME-BGC estimates of total C for different patterns by edge/area ratio. Edge effects based on observed temperature variations in a SE Michigan patch.

Robinson et al. 2009. *Ecol. Mod.*

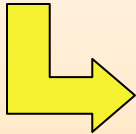


# Scenario-based Integration

## Public Land Harvest Scenarios

(2010-2050)

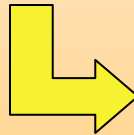
- BAU (RPA)
- No Harvest
- Pre-1989 levels



Timber harvest levels

## Forest Inventory Projection Model

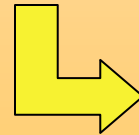
ATLAS



Growing stock projections

## Carbon Accounting Model

ForCARB2



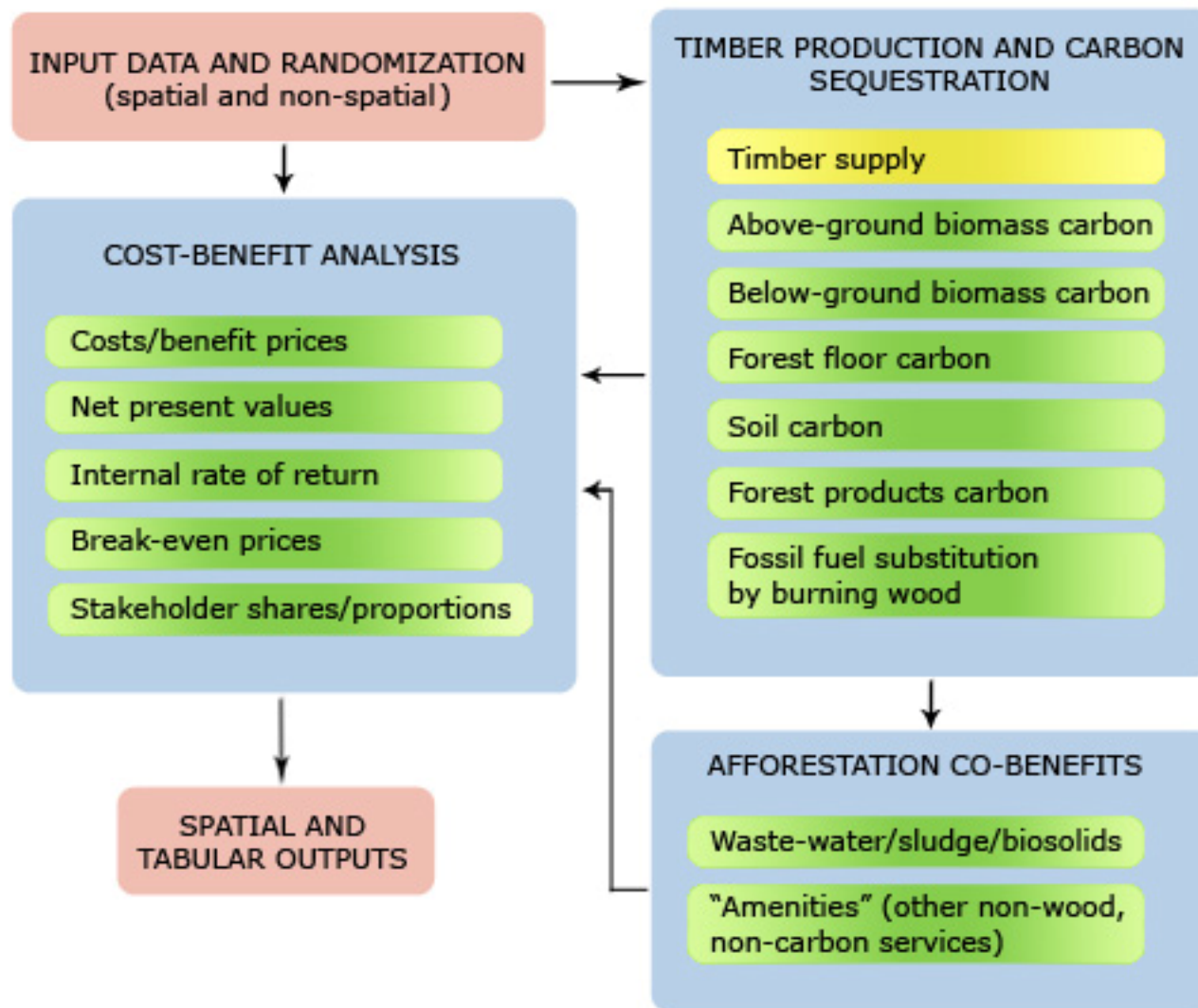
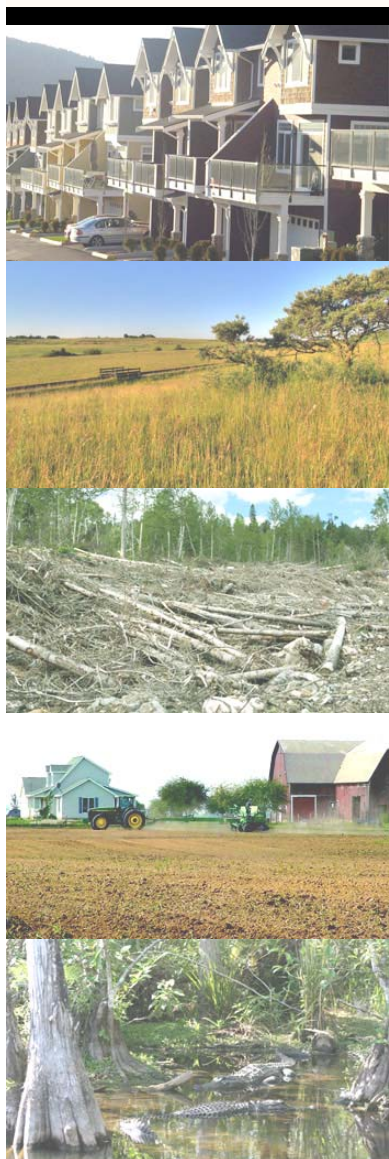
***Carbon Stock Projections:  
2010-2050***

- Forest Carbon*
- Wood Products*

Depro et al. 2007. *Forest Ecol & Mgt.*

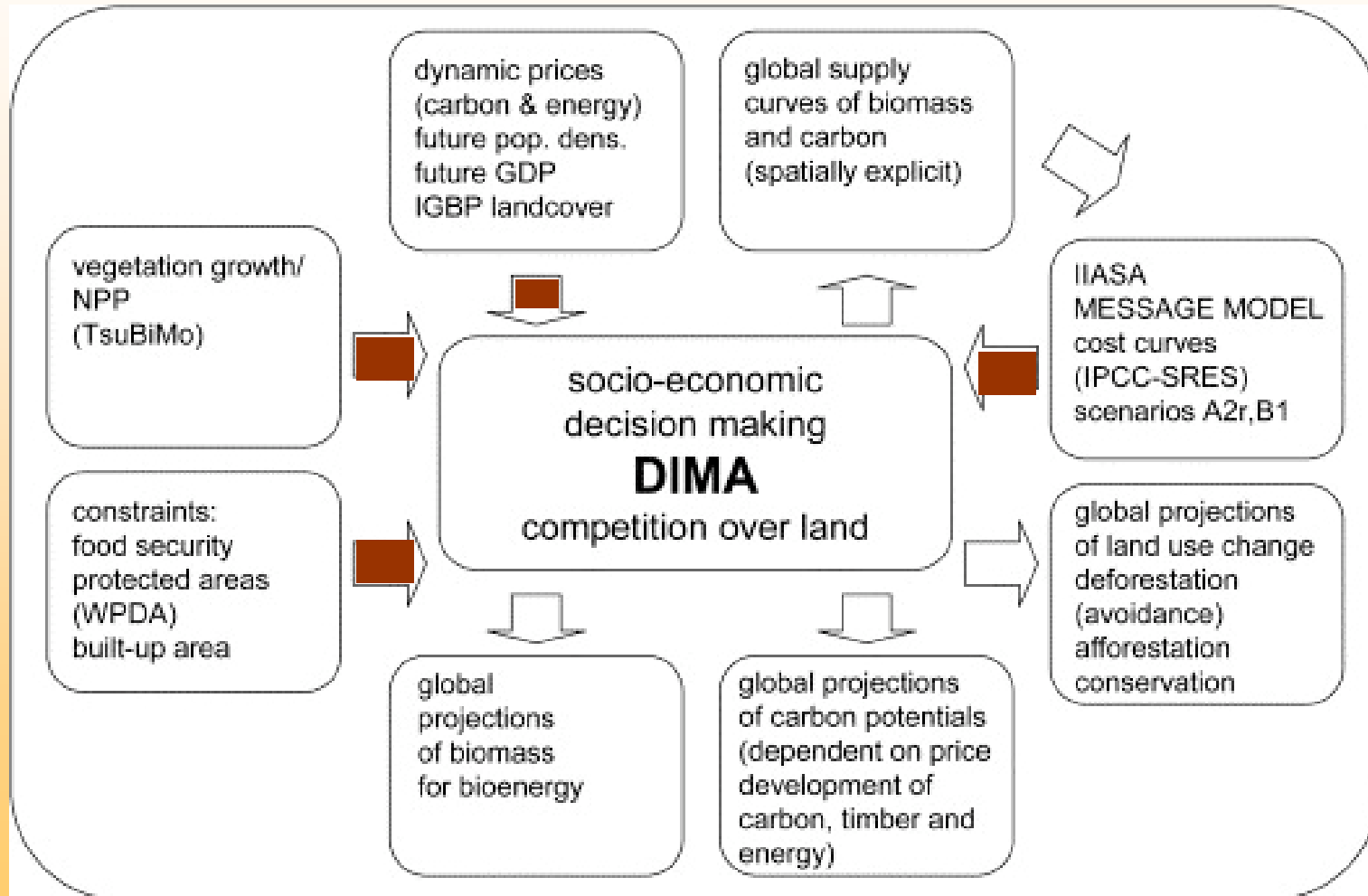


# Bioeconomic Analysis



# Dynamic Integrated Model of Forestry and Alternative Land Use (DIMA)

Global scale

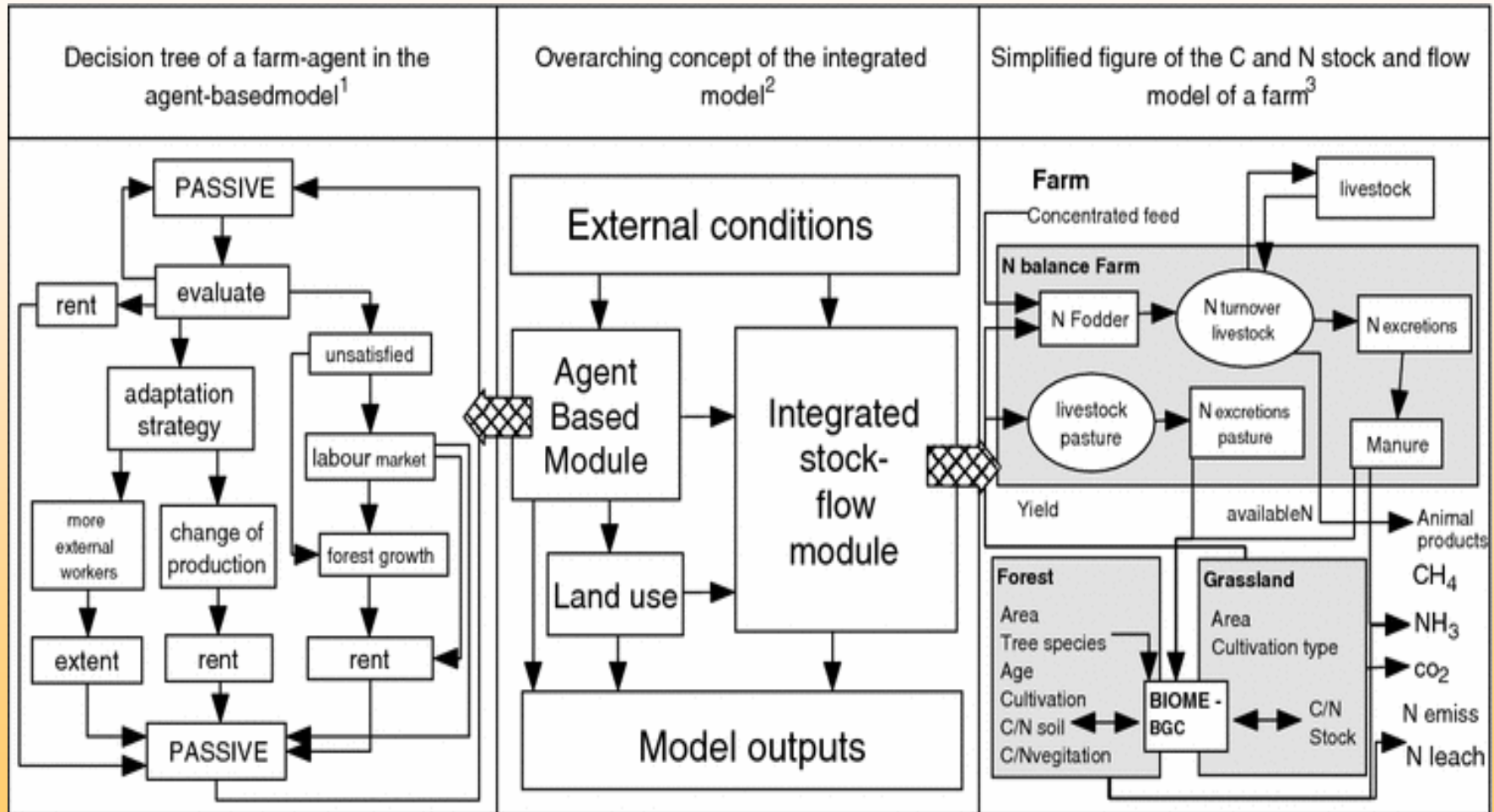


Resolution =  
0.5 degree

Rokityanskiy et al. 2007. *Technological Forecasting and Social Change*

# Simulation of Ecological Compatibility of Regional Development (SERD)

Local to regional scale



Gaube et al. 2009. *Landscape Ecology*.

Resolution = parcels



# Challenges



- Understand more about land management choices and their effects.
- Synthesizing lessons learned from modeling projects all over the world and with many different approaches.
- Scale integration of multiple models.
  - ABMs are still largely focused on local applications.
  - Ecosystem process models tend to be regional to global and don't deal well with heterogeneity
  - Time scales and variability of both are challenging
- Developing metrics of and improving “skill” in forecasts that are still process based.
- Path dependence in land change processes.



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# Proposal for NRC Modeling Study



- Statement of work in your packets.
- Would focus on
  - Evaluation of strengths and weaknesses of various approaches
  - Issues associated with coupling models of land change with other biophysical and social models
  - How to calibrate and validate dynamic spatial models of land change. Need standards of evidence.
  - Implications of spatial patterning of land use and cover for ecosystem and social outcomes



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# A Community Land-Use Model



- Idea within LCLUC community to contribute to global change research through development of a model or models of land use and cover that couple to and interact with general circulation models and ecosystem process models.
- Such models would build on the experience of the community.



# Questions for Breakout



- What are the key land use/land management processes that need to be represented?
- How do we integrate models at multiple scales?
- What is needed to couple land use and ecosystem models?



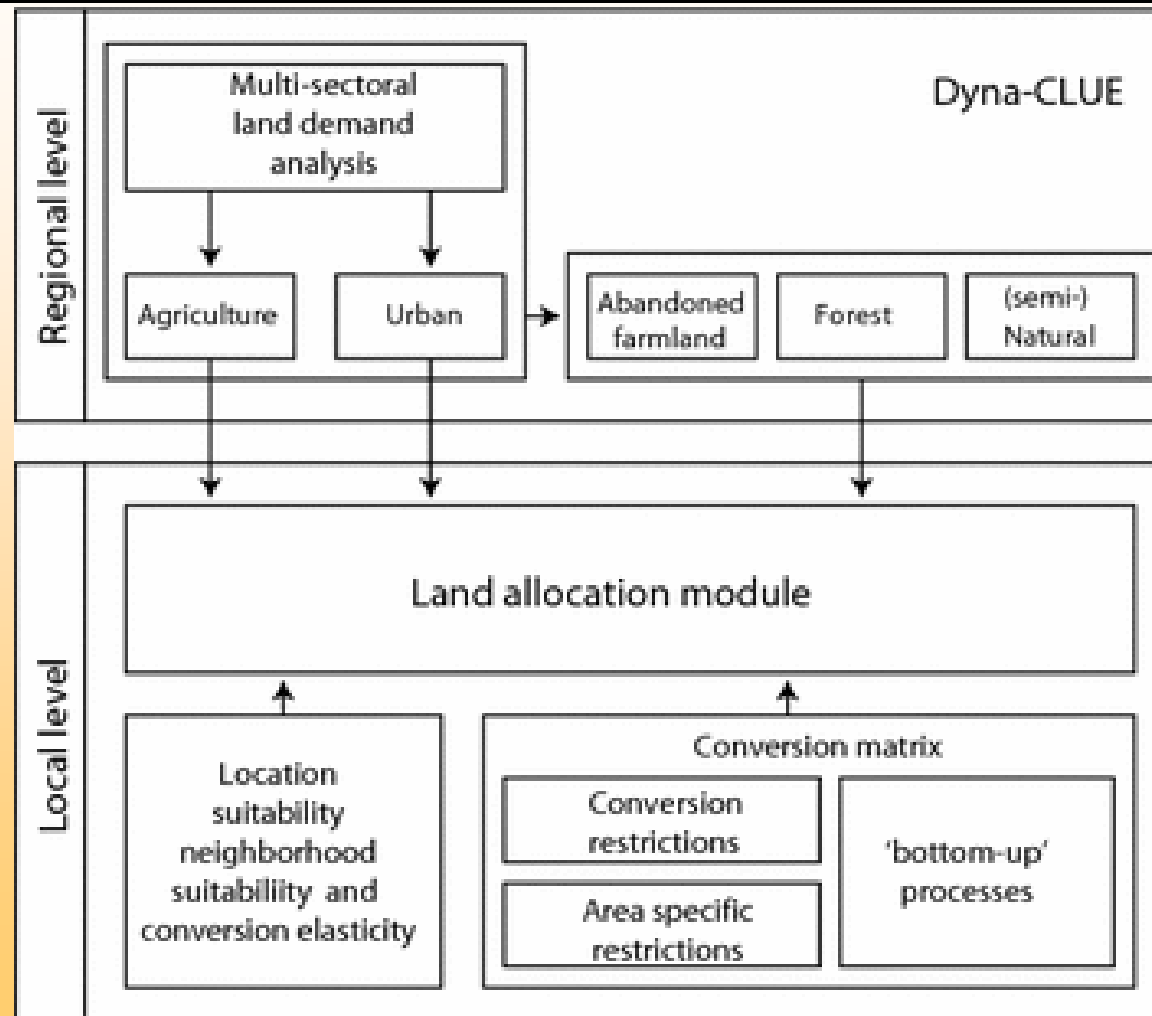
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■ Extra Slides





# Allocation Approaches to Scale Integration



Verburg and Overmars, 2009. *Landscape Ecology*<sup>29</sup>



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# Estimation Challenges



- Temporal non-stationarity
- Spatial autocorrelation and non-stationarity
- Non-linearity in relationships
- Heterogeneity in household/agent characteristics
- Aggregate vs. disaggregate data
- Endogenous interactions and feedbacks
- Data availability