



Land system science: From local decision making to global assessment

Peter Verburg

Content

■ Representing land use:

- *New ways of representing land use are needed to capture the essential characteristics of land use impacting climate, biodiversity and ecosystem services*

■ Modelling land use decision making:

- *Research is needed to better represent socio-economic variation and decision making structures in land allocation models, including adaptation*

■ Spatial and temporal complexity:

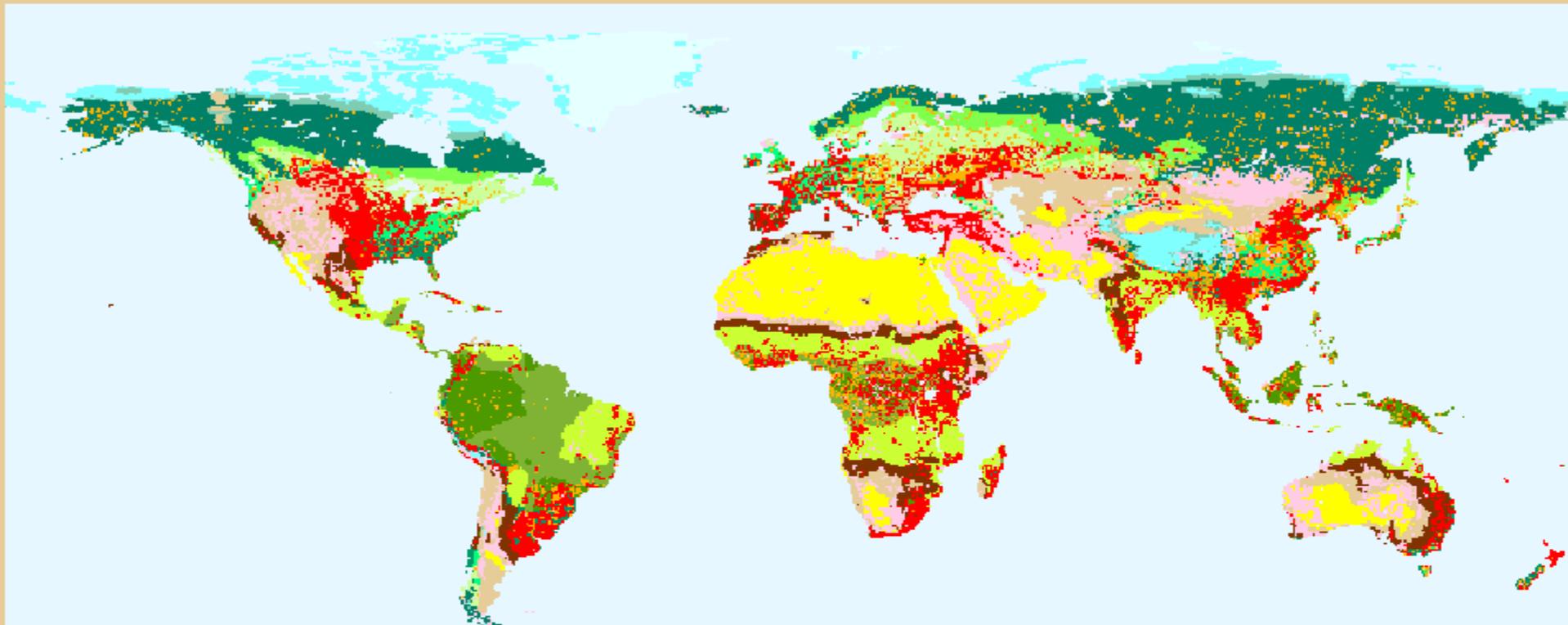
- *Better representation of spatial and temporal variability allows to address region/location specific policy intervention*

Content

■ Representing land use:

- *New ways of representing land use are needed to capture the essential characteristics of land use impacting climate, biodiversity and ecosystem services*

Landcover - 2100 - B1



M: Time Control

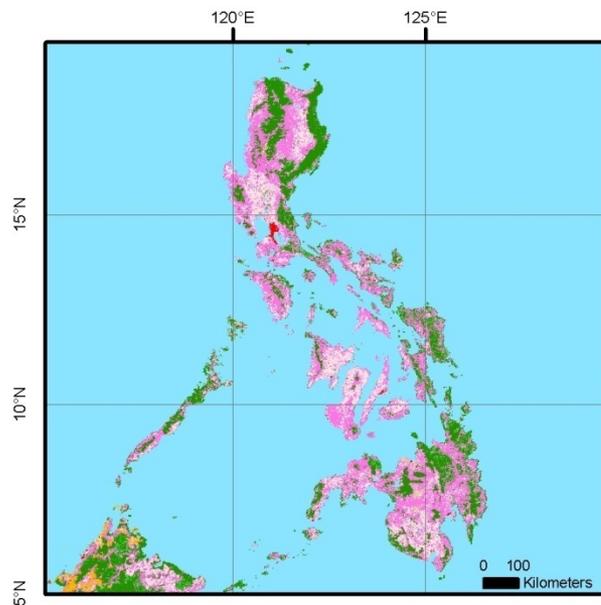
Time 2100

 Agricultural land	 Wooded tundra	 Warm mixed forest	 Tropical woodland
 Extensive grassland	 Boreal forest	 Grassland/Steppe	 Tropical forest
 Regrowth forest	 Cool conifer forest	 Hot desert	
 Ice	 Temp. mixed forest	 Scrubland	
 Tundra	 Temp. deciduous forest	 Savanna	



Land use in global models

GLC2000



Cropland cover

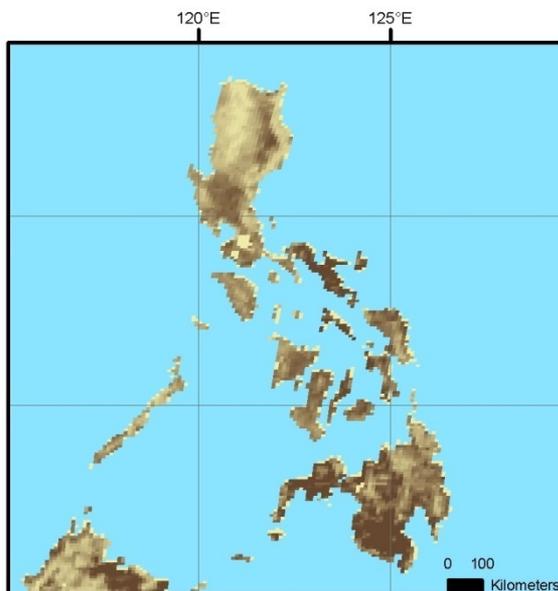
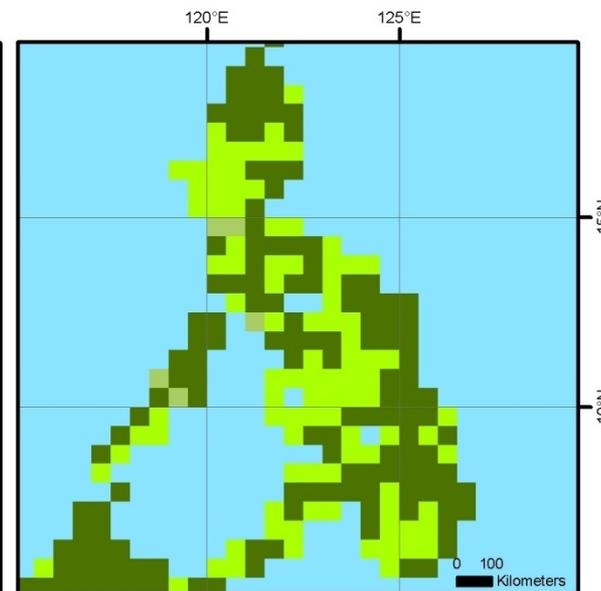


IMAGE land cover

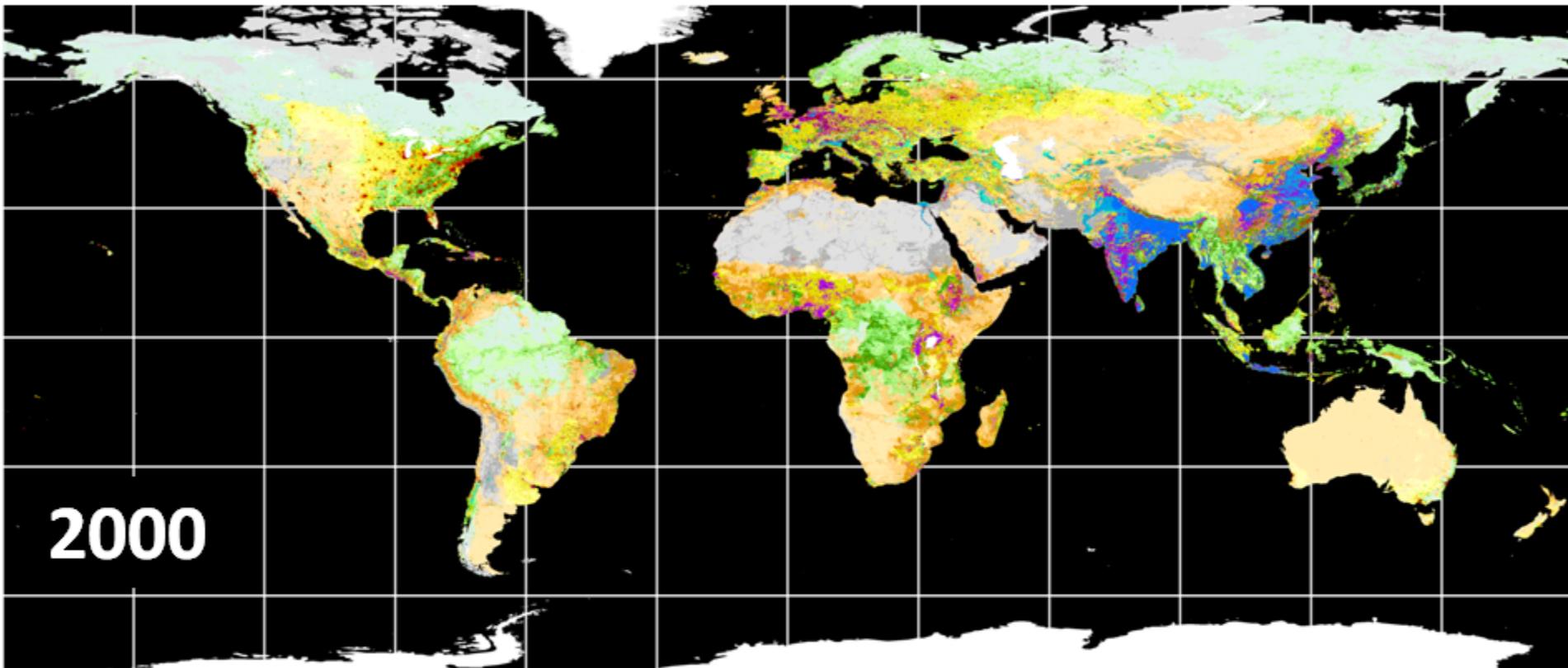


Land use





Anthropogenic biomes (Ellis et al., 2010)



2000

Used

Seminatural

Wild

Dense Settlements



Urban Mixed settlements

Villages



Rice Irrigated | Rainfed Pastoral

Croplands



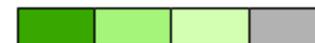
Residential Populated | Remote
Irrigated Rainfed

Rangelands



Residential Populated | Remote

Seminatural



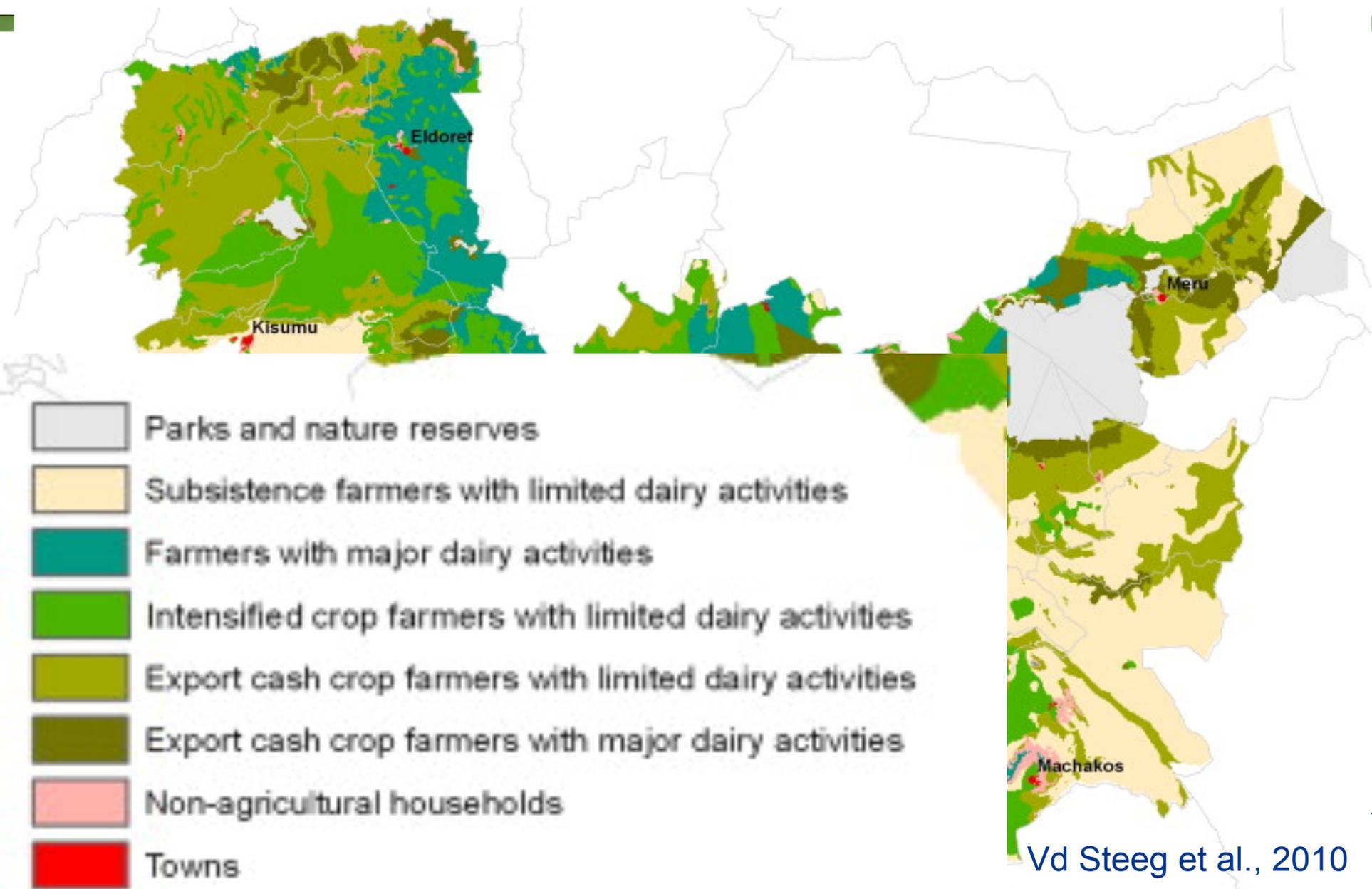
Woodlands | Treeless & Barren
Residential Populated | Remote

Wildlands



Woodlands | Treeless & Barren

Farming system distribution in Kenyan highlands

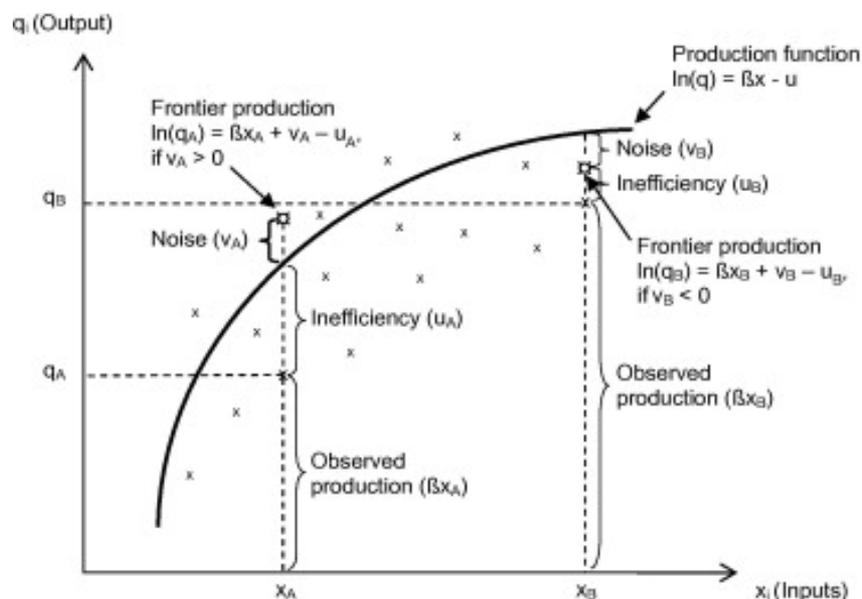


Classification input data

Main class	Input data
Land cover	Tree cover (%)
	Bare area cover (%)
	Cropland cover (%)
	Built-up area (%)
Livestock	Bovines, goats & sheep (number/km ²)
	Pigs & poultry (number/km ²)
Land-use intensity	Efficiency of agricultural production (0-1)

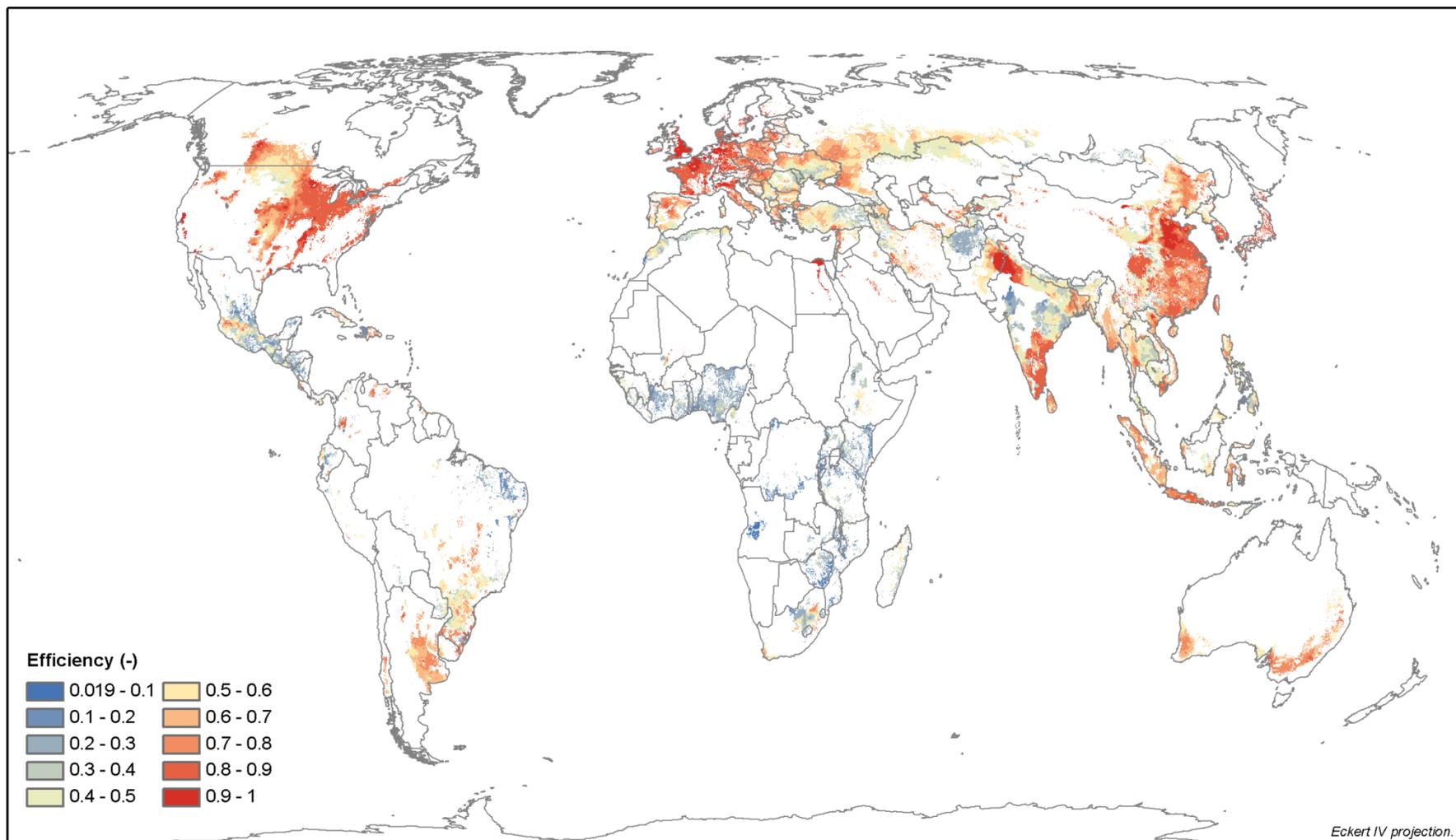
Agricultural efficiency

- Frontier production functions represents maximum crop yield for a set of environmental conditions.
- Difference with actual yields represents the efficiency of agricultural production at a certain location.



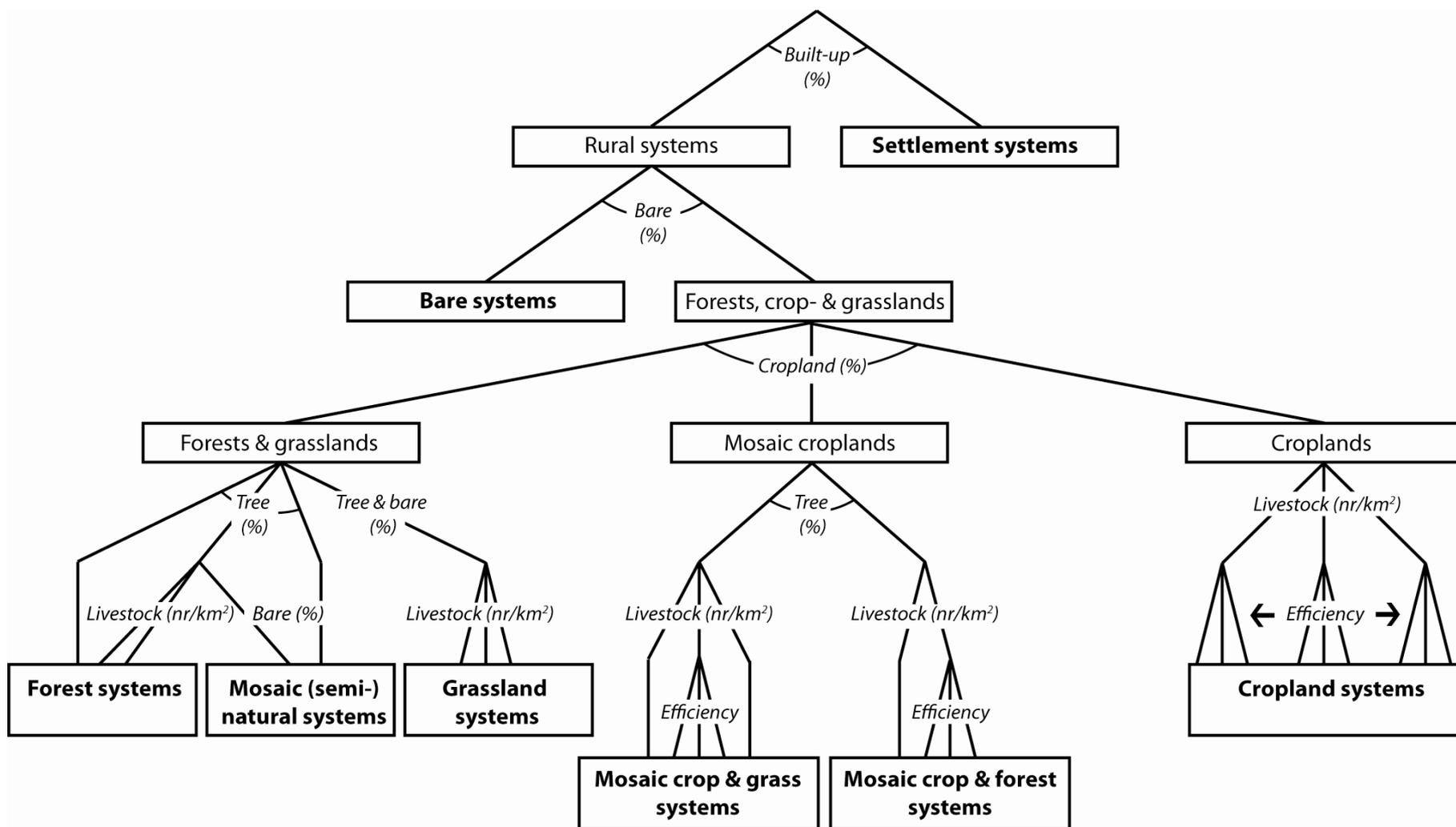
For details see: *Neumann et al. (2010), Agr. Syst. 103, p. 316-326.*

Efficiency map (cropland areas)

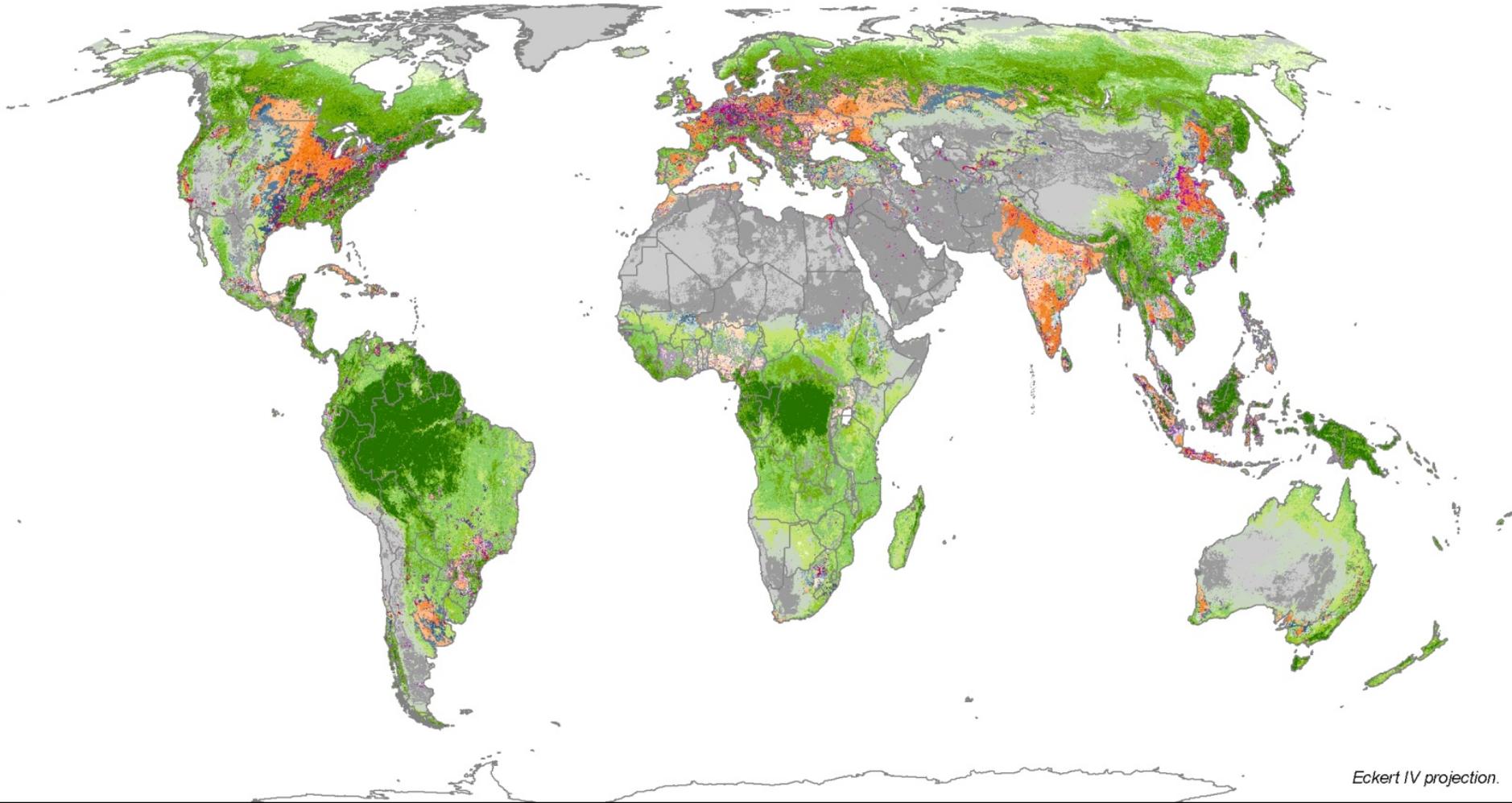


Based on Neumann et al. (2010), *Agricultural Systems* 103, 316-326.

Hierarchical classification



Land Systems classification



Legend Land Systems

Cropland Systems

-  Cropland; extensive with few livestock
-  Cropland; extensive with bovines, goats & sheep
-  Cropland; extensive with pigs & poultry
-  Cropland; medium intensive with few livestock
-  Cropland; medium intensive with bovines, goats & sheep
-  Cropland; medium intensive with pigs & poultry
-  Cropland; intensive with few livestock
-  Cropland; intensive with bovines, goats & sheep
-  Cropland; intensive with pigs & poultry

Mosaic cropland and grassland systems

-  Mosaic cropland and grassland with bovines, goats & sheep
-  Mosaic cropland and grassland with pigs & poultry
-  Mosaic cropland (extensive) and grassland with few livestock
-  Mosaic cropland (medium intensive) and grassland with few livestock
-  Mosaic cropland (intensive) and grassland with few livestock

Mosaic cropland and forest systems

-  Mosaic cropland and forest with pigs & poultry
-  Mosaic cropland (extensive) and forest with few livestock
-  Mosaic cropland (medium intensive) and forest with few livestock
-  Mosaic cropland (intensive) and forest with few livestock

Forest systems

-  Dense forest
-  Open forest with few livestock
-  Open forest with pigs & poultry

Mosaic (semi-)natural systems

-  Mosaic grassland and forest
-  Mosaic grassland and bare

Grassland systems

-  Natural grassland
-  Grassland with few livestock
-  Grassland with bovines, goats & sheep

Bare systems

-  Bare
-  Bare with few livestock

Settlement systems

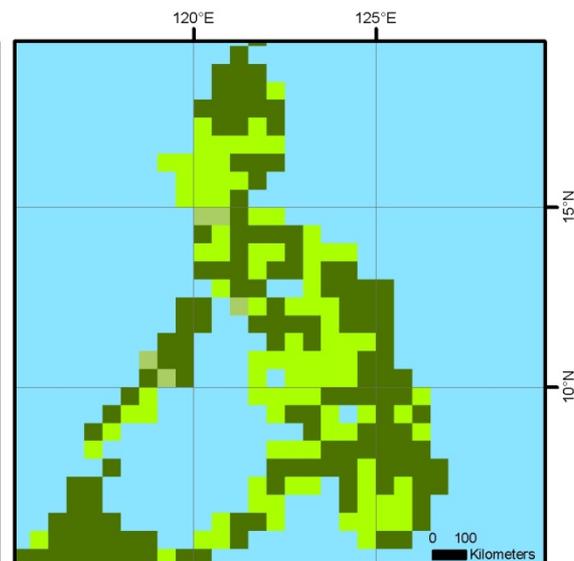
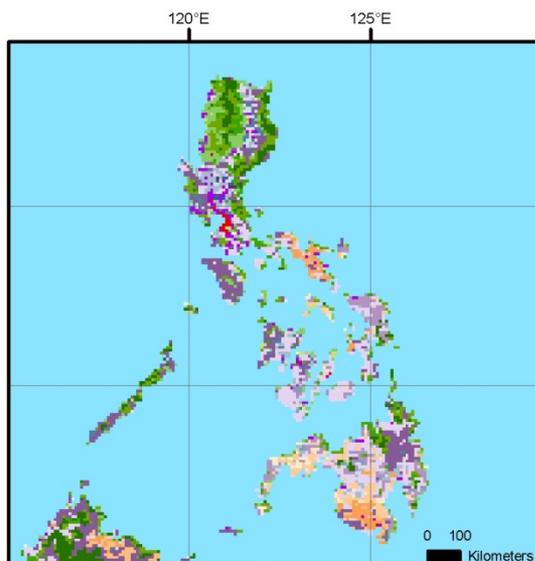
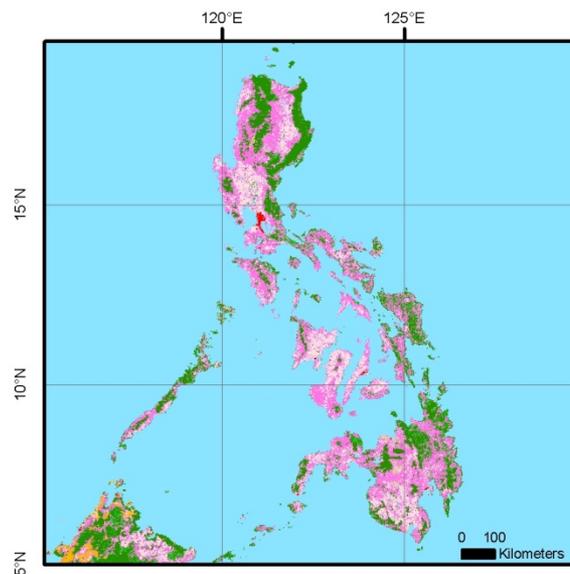
-  Peri-urban and villages
-  Urban

Land Systems map Philippines

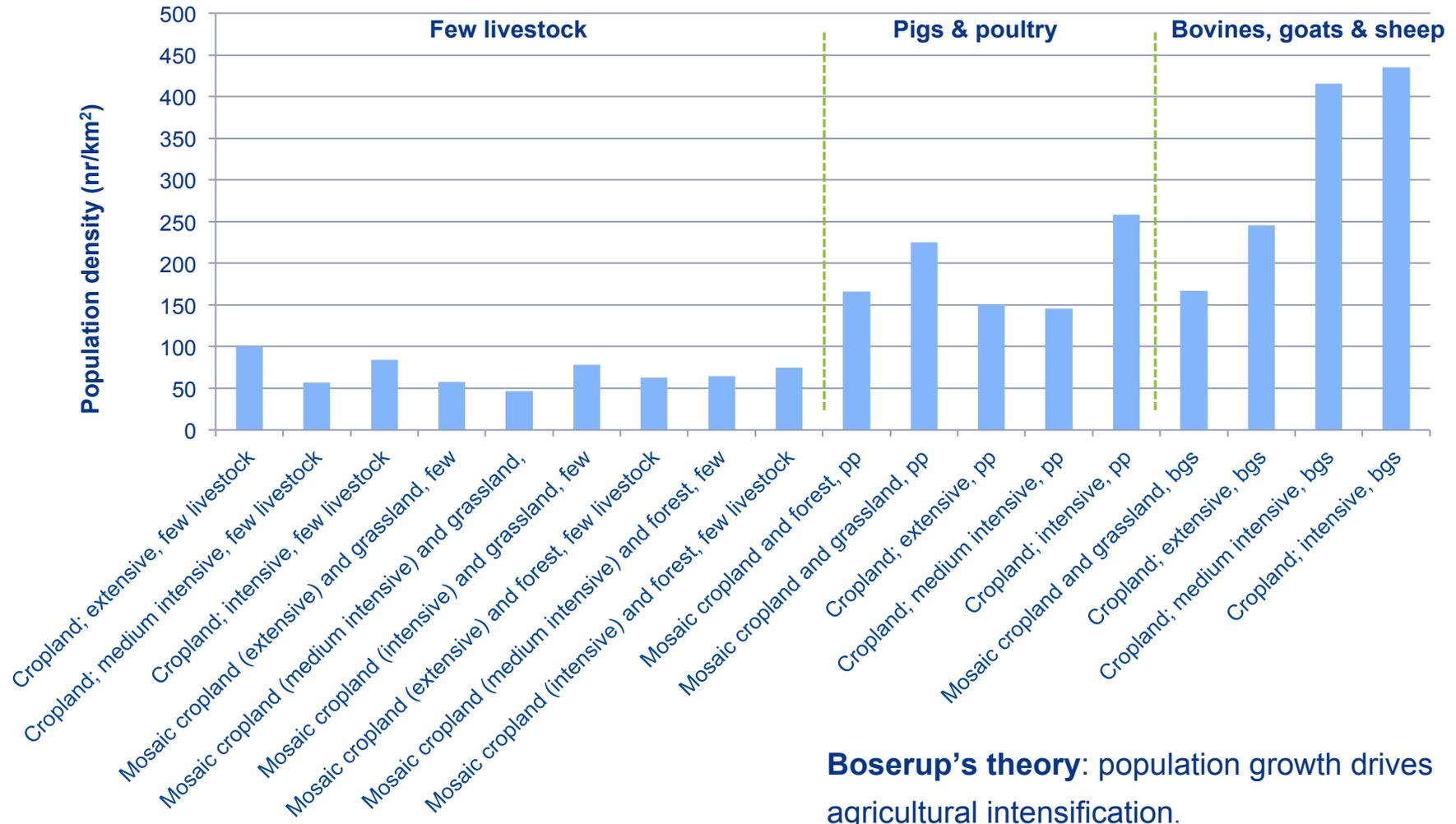
GLC2000

LS map

IMAGE land cover

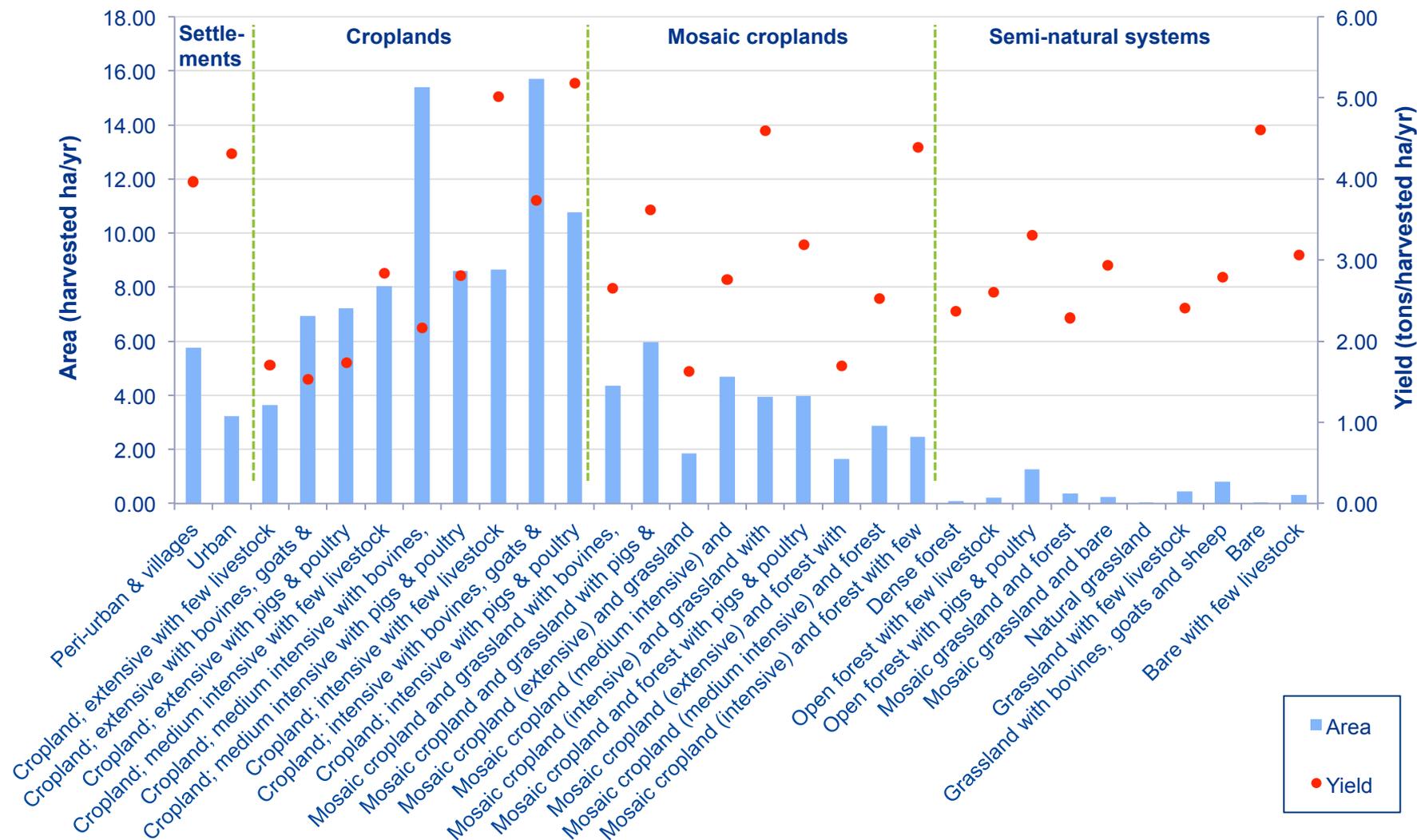


Land Systems: livestock & population density

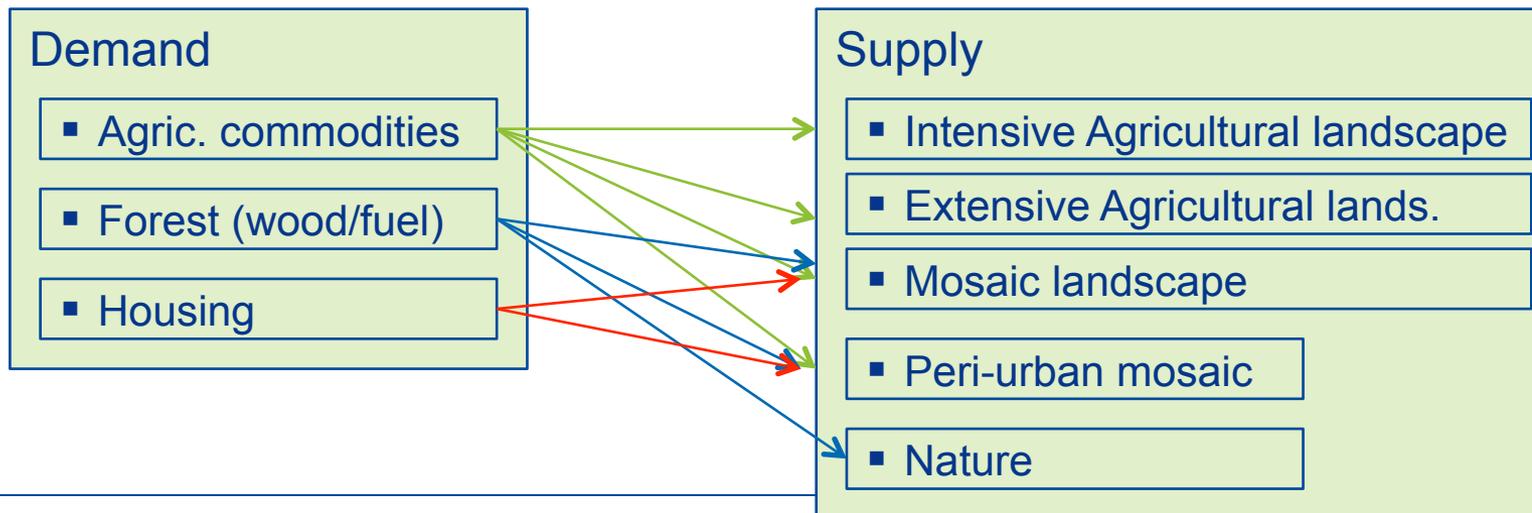
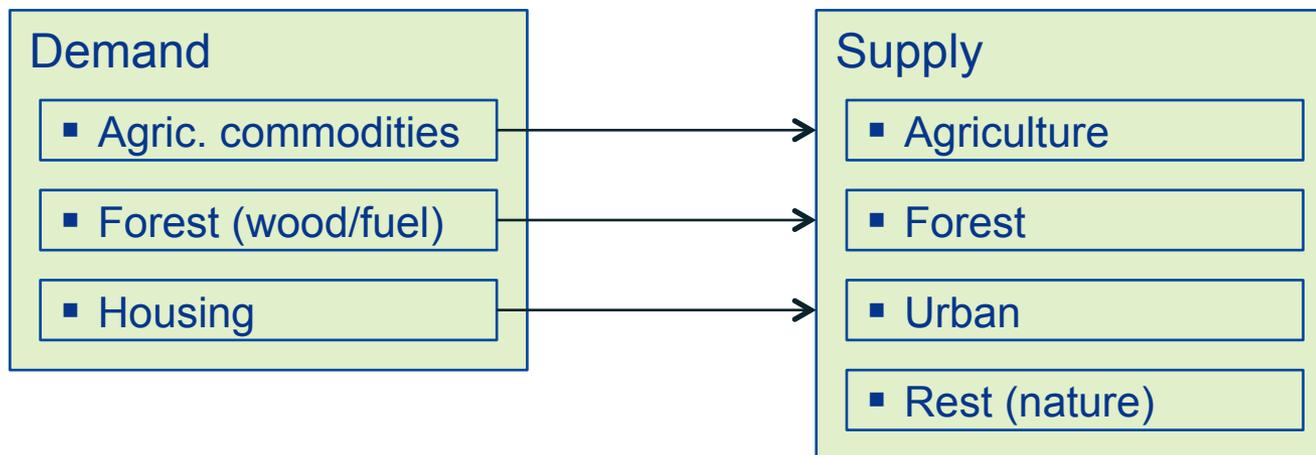


Boserup's theory: population growth drives agricultural intensification.

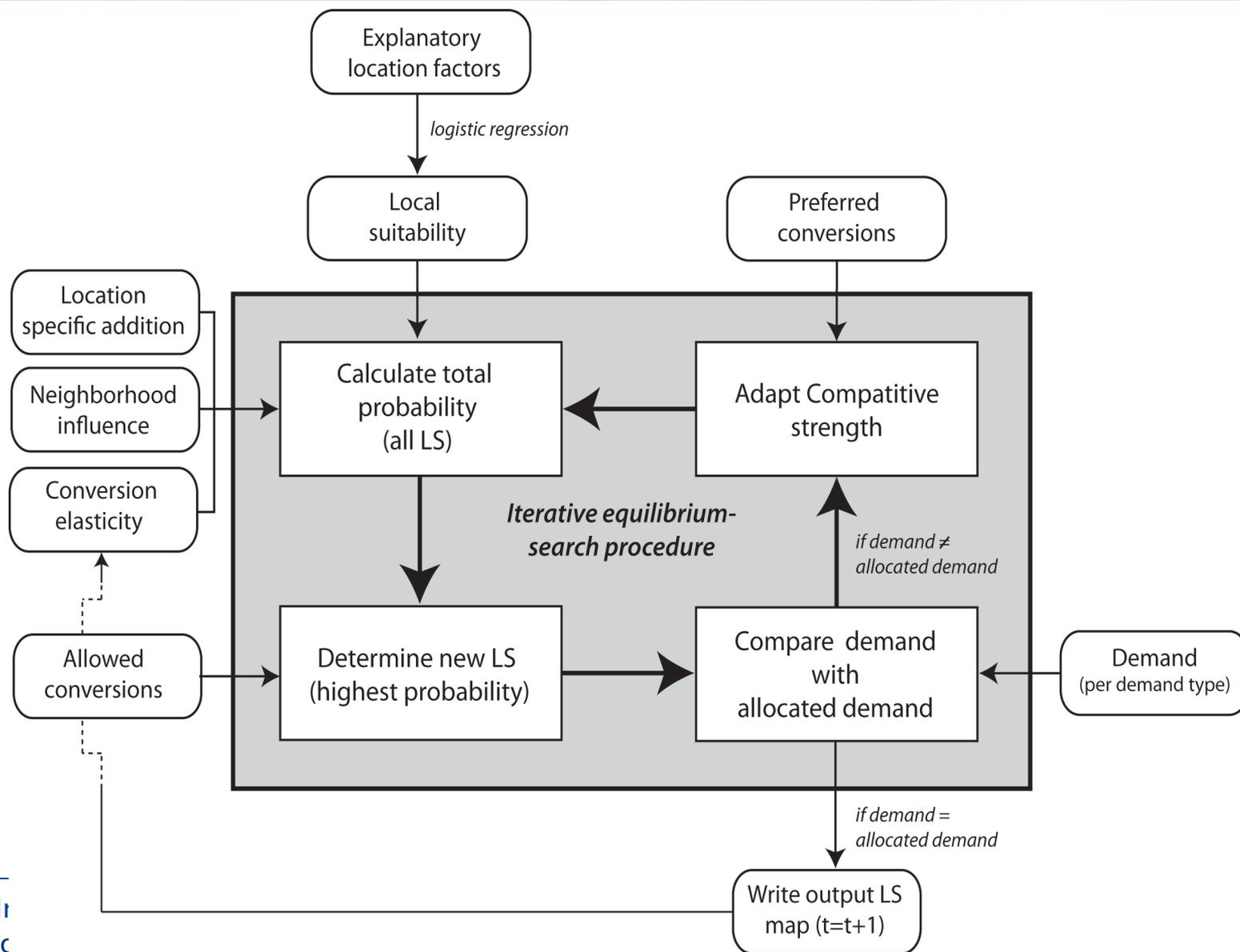
Average area & yield of maize, rice and wheat



Modelling land system changes

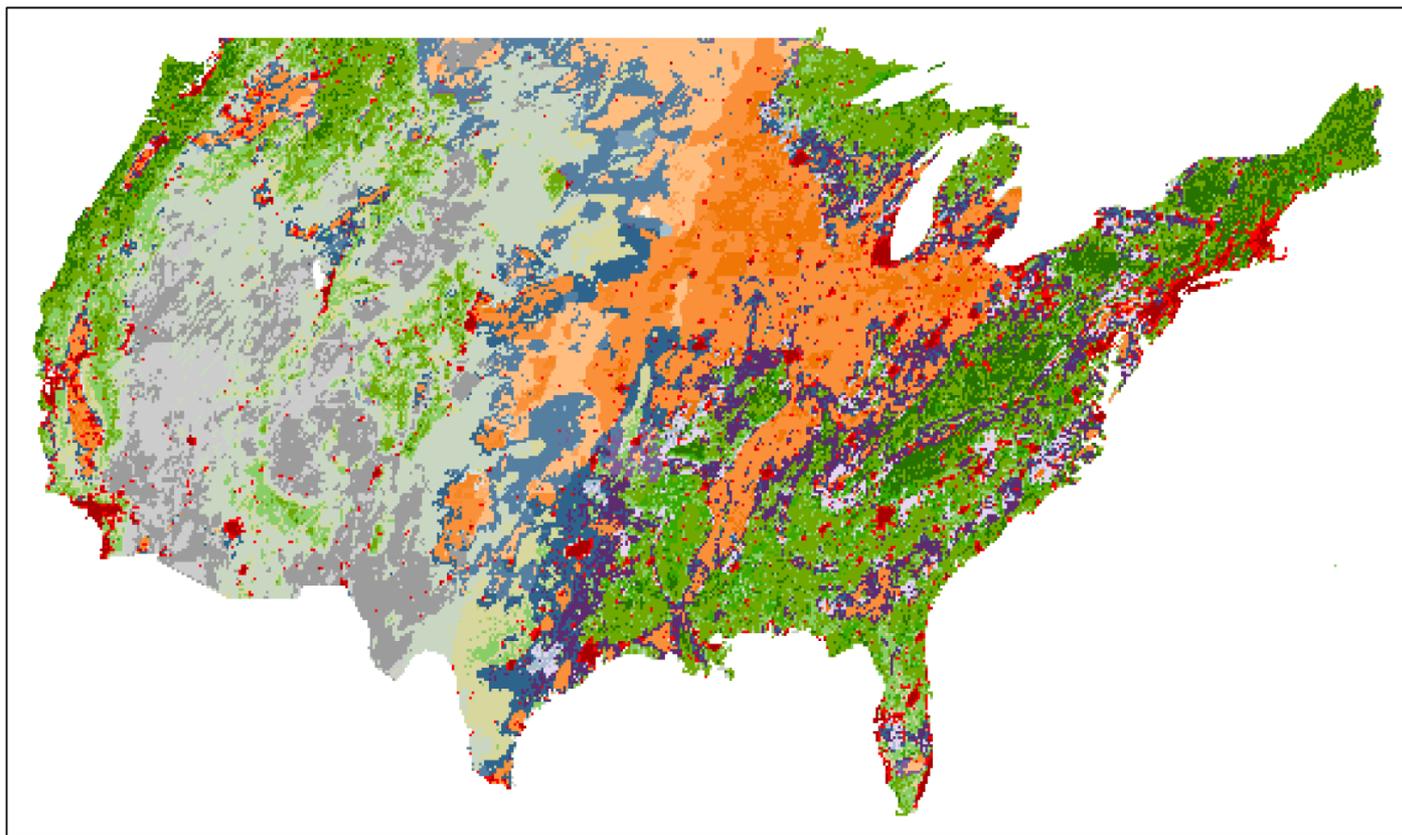


Model structure CLU-Mondo

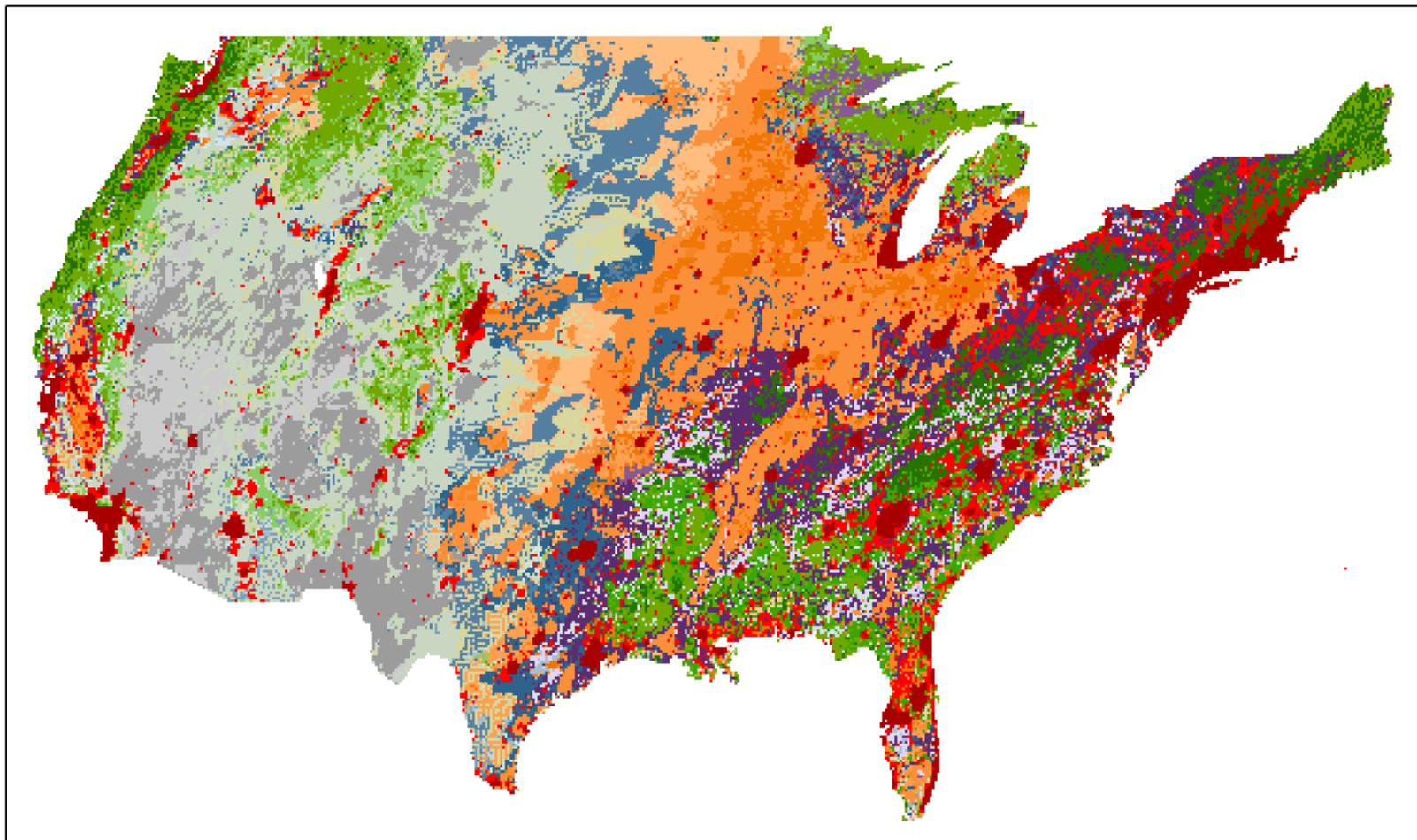


Model CLU-Mondo USA

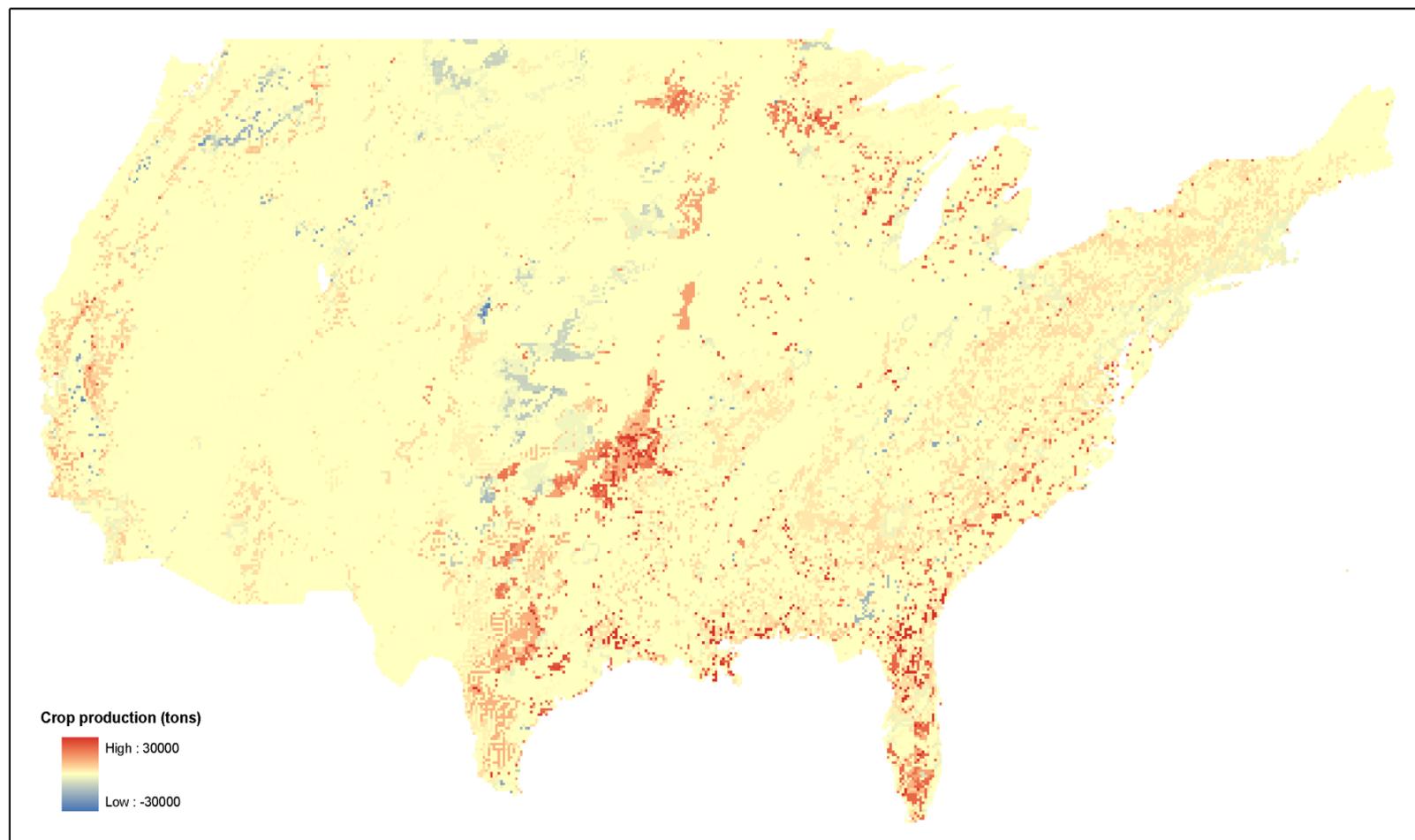
- Scenario: increasing demand for crop production, livestock & built-up area (40 time steps). Initial Land System map:



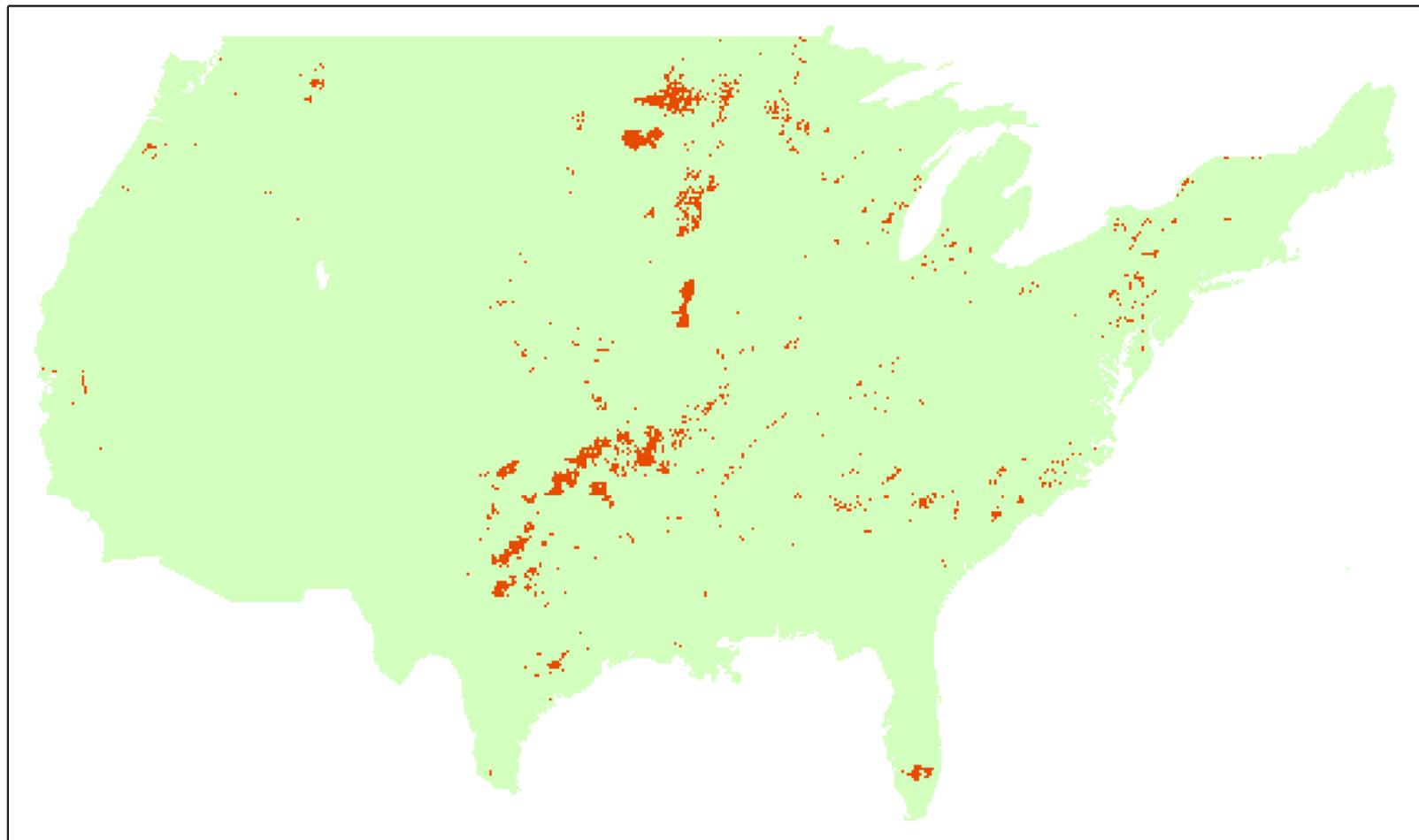
Model run USA: LS map yr 40



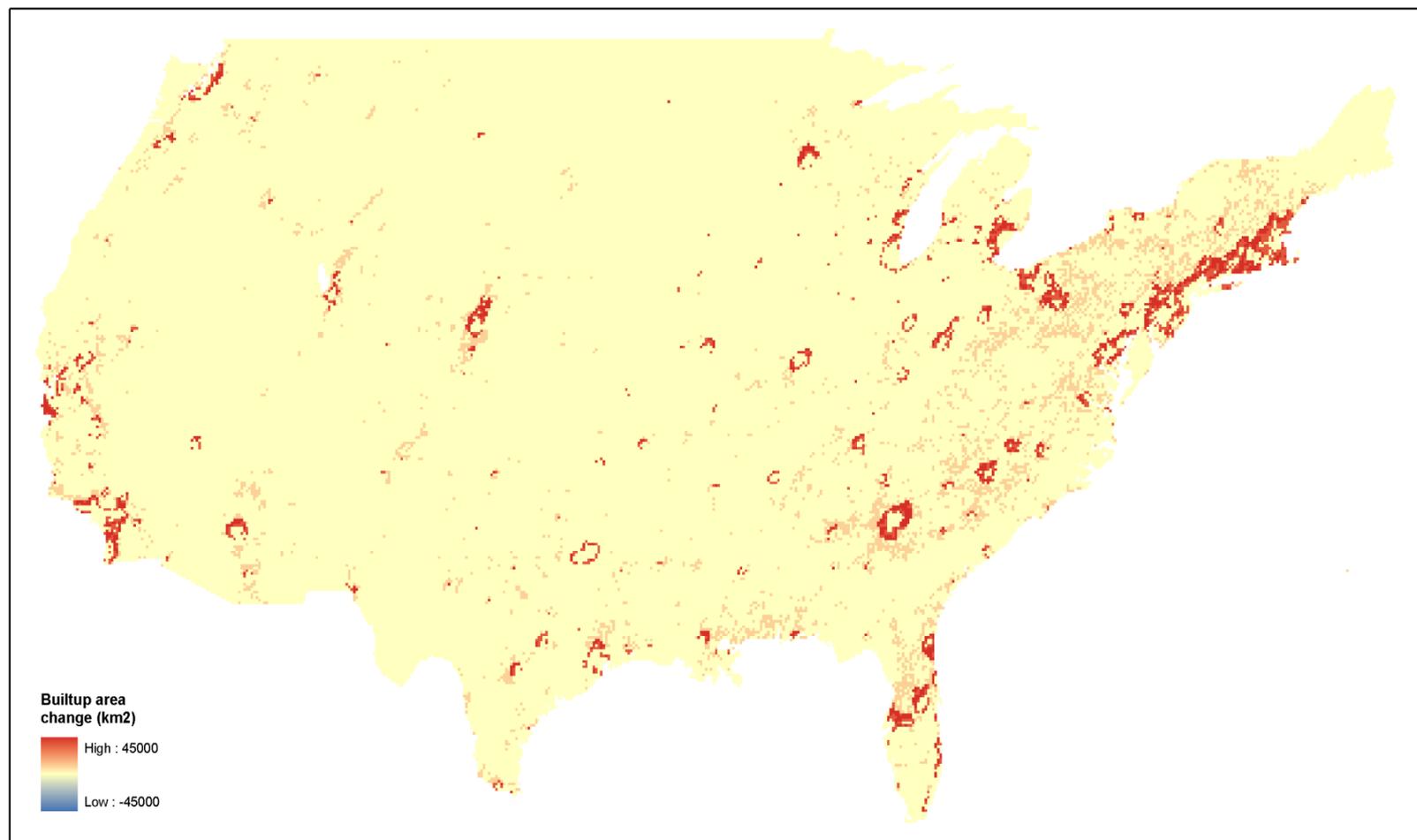
Model run USA: change in crop production



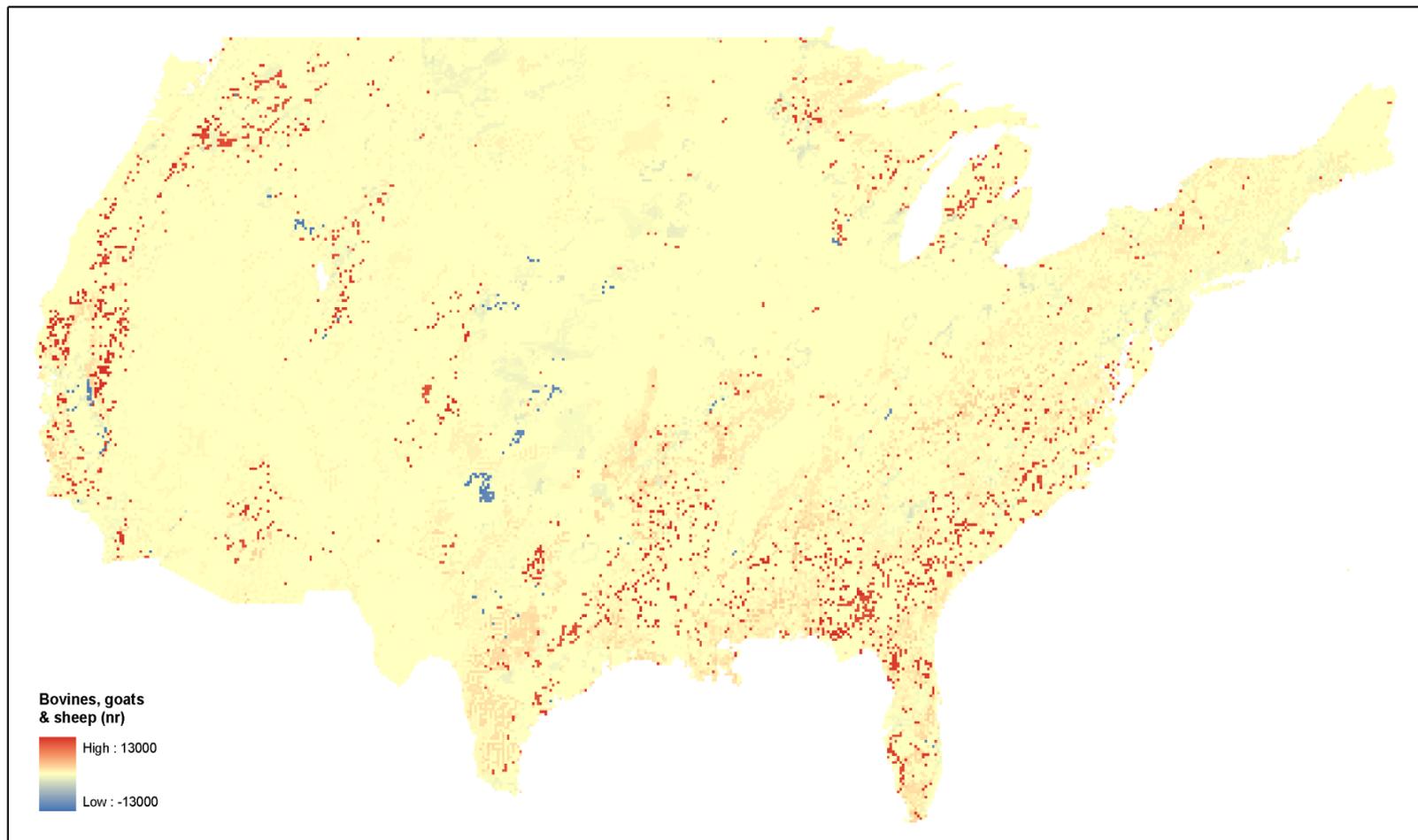
Model run USA: intensification



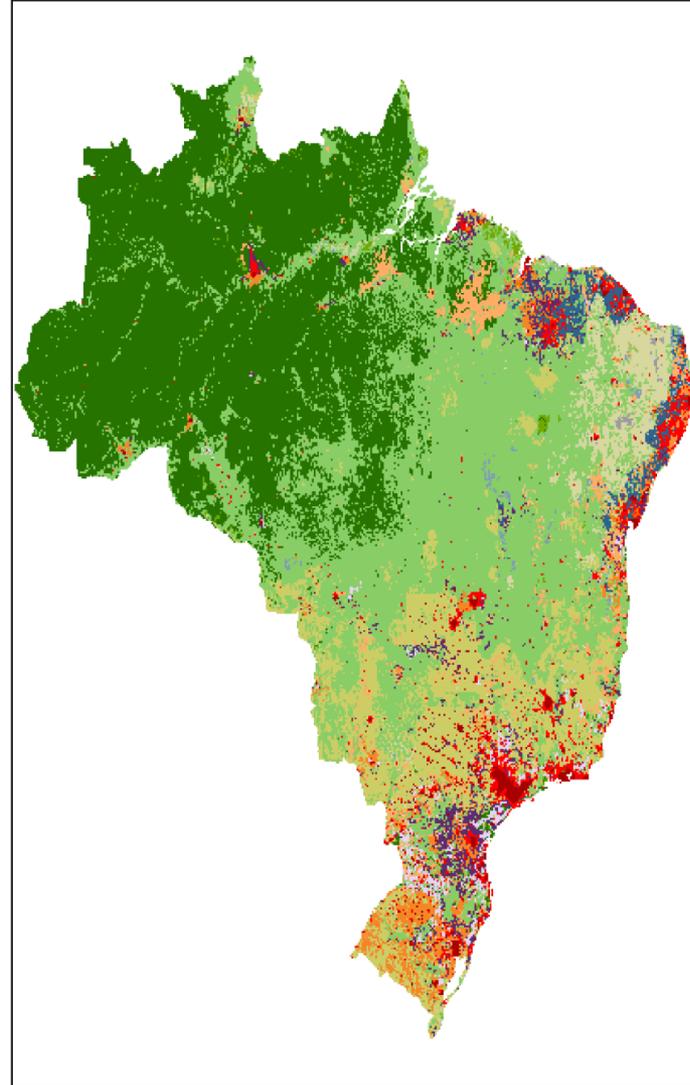
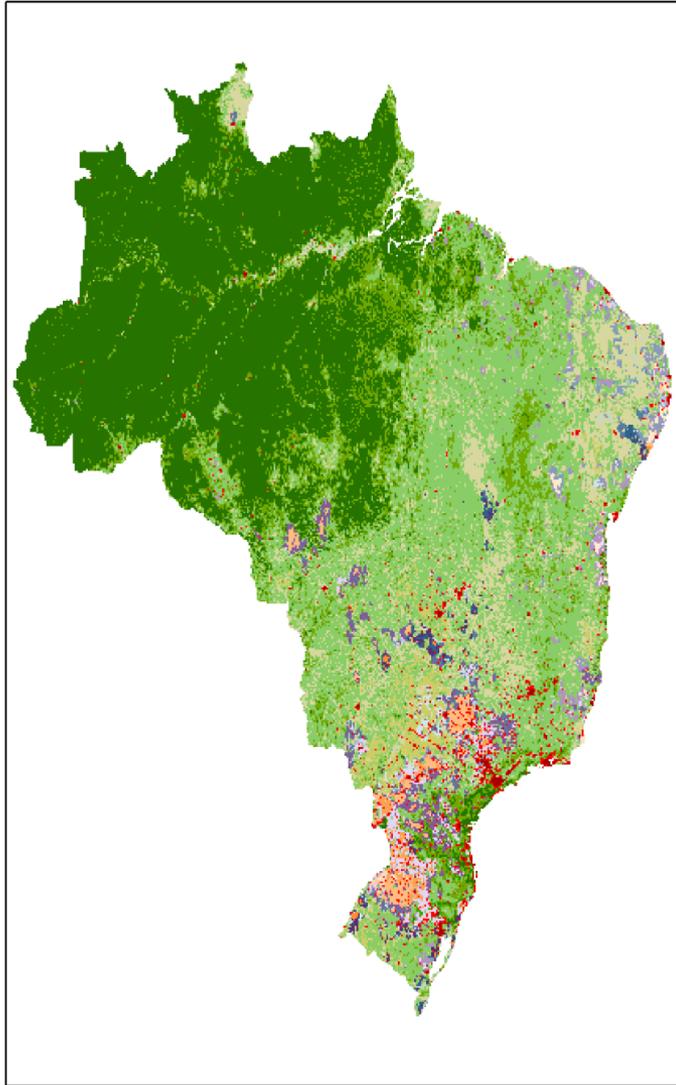
Model run USA: change in built-up area



Model run USA: change in bovines, goats & sheep



Model run Brazil: increasing demand scenario



Global land system change model

- Simulates location specific trajectories: intensification vs area expansion
- Captures subtle changes in land use mosaic, including peri-urban developments
- Takes livestock as an integral part of the land use system, including landless and pastoral systems
- Explicitly models land use competition
- Allows for region-specific allocation rules

- **Modelling land use decision making:**
 - *Research is needed to better represent socio-economic variation and decision making structures in land allocation models, including adaptation*

Land use in a teleconnected world



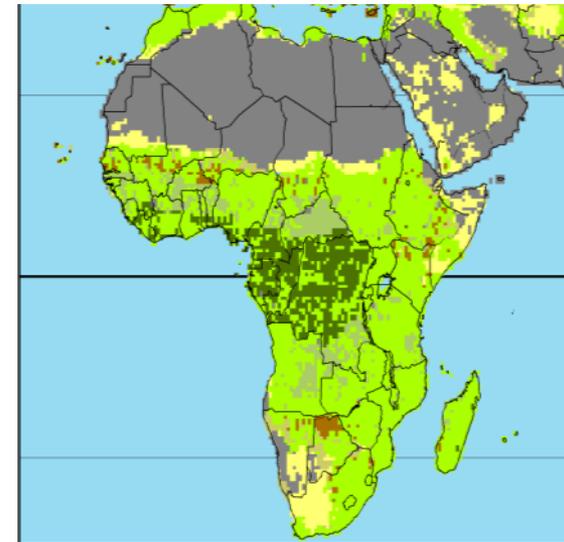
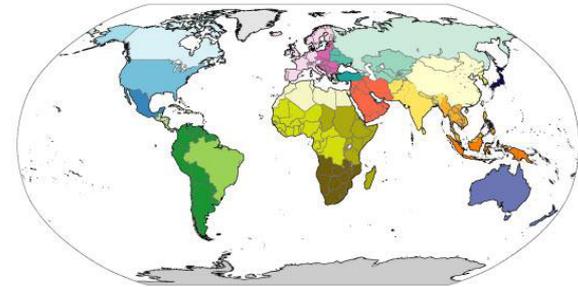
General approach to modelling land change

World region economic calculation of agricultural areas



Grid allocation of land change

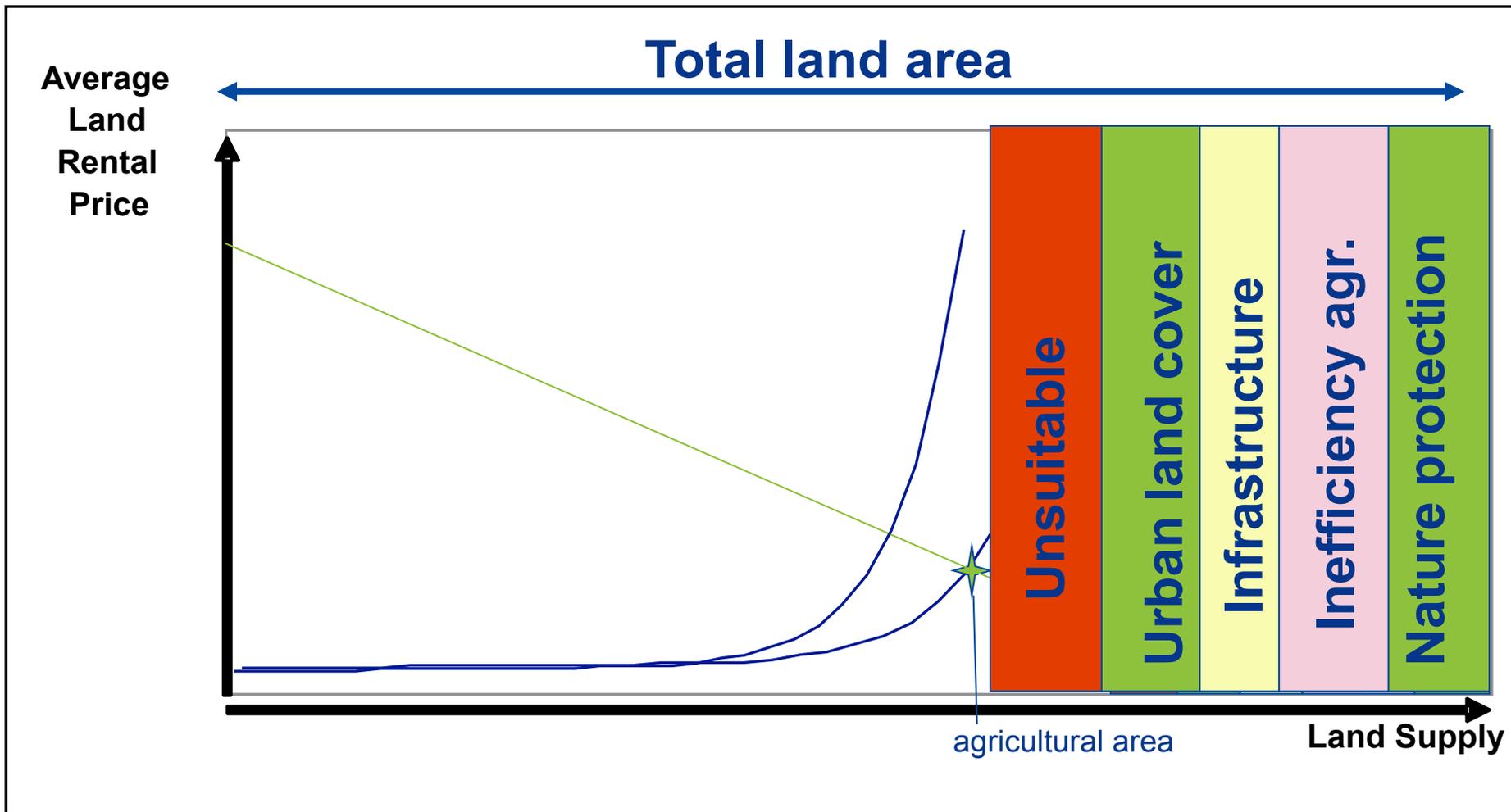
IMAGE regional breakdown



General/partial equilibrium models

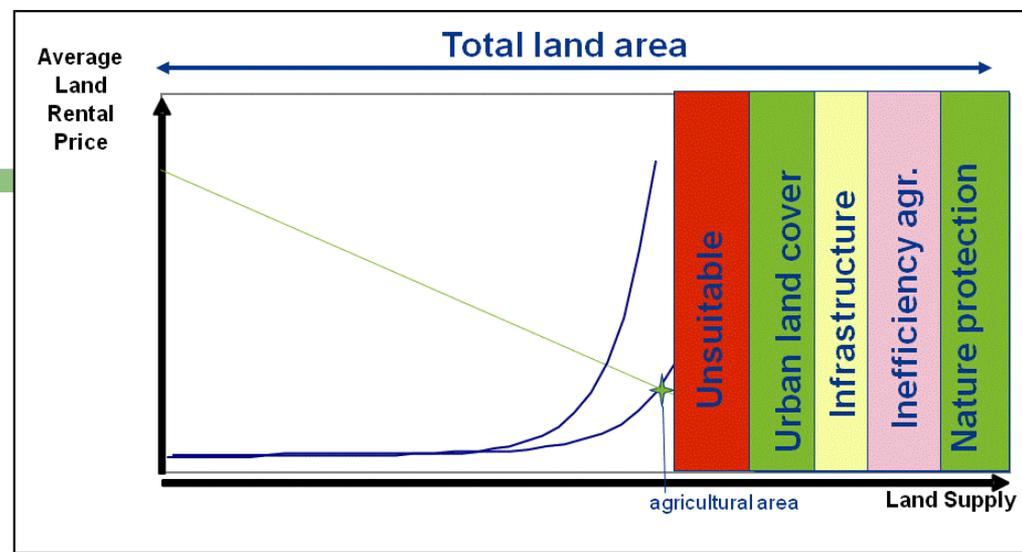
- World-region level
- one profit optimizing 'average/representative' farm
- Three choices to respond to increase in demand:
 - Expand land area
 - Increase inputs/outputs
 - Import
- Price determines choice
- Land suitability used as indicator of land price

Land supply curve



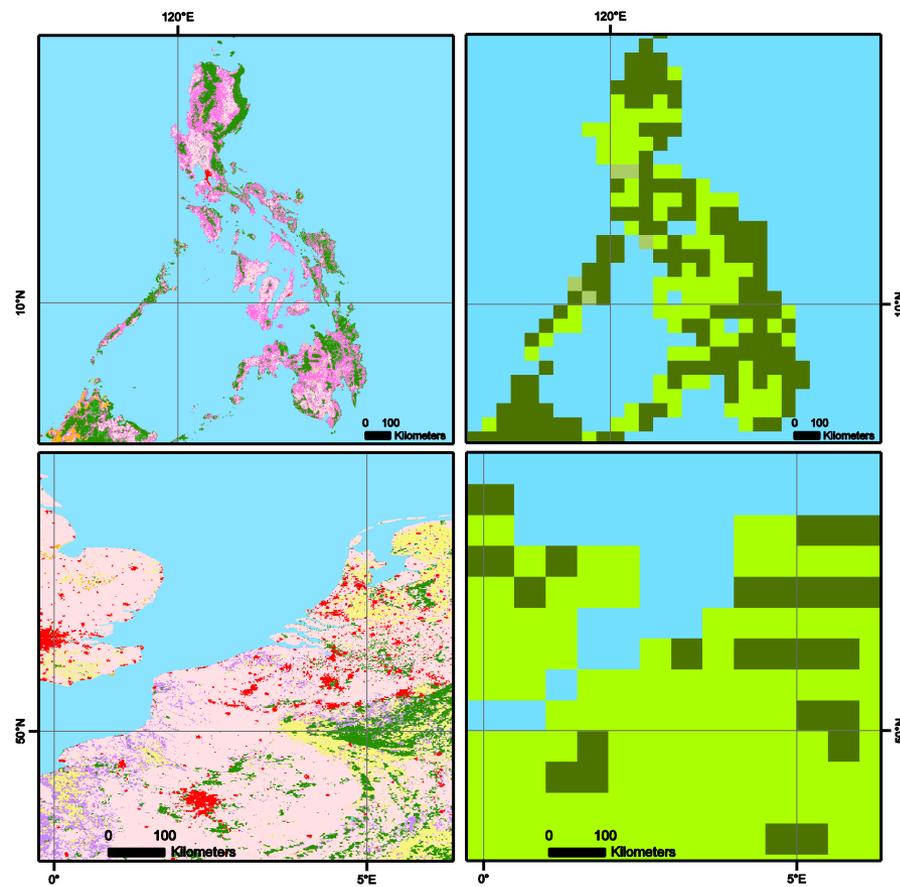
Challenges

- Empirical estimation of land supply curves / spatial data
- Validity of approach (economic rational agents)
- Disentangling price effects of competition between land resources and land quality
- Calculation of available land areas: in general a strong over-estimation of potential land areas



Allocation rules

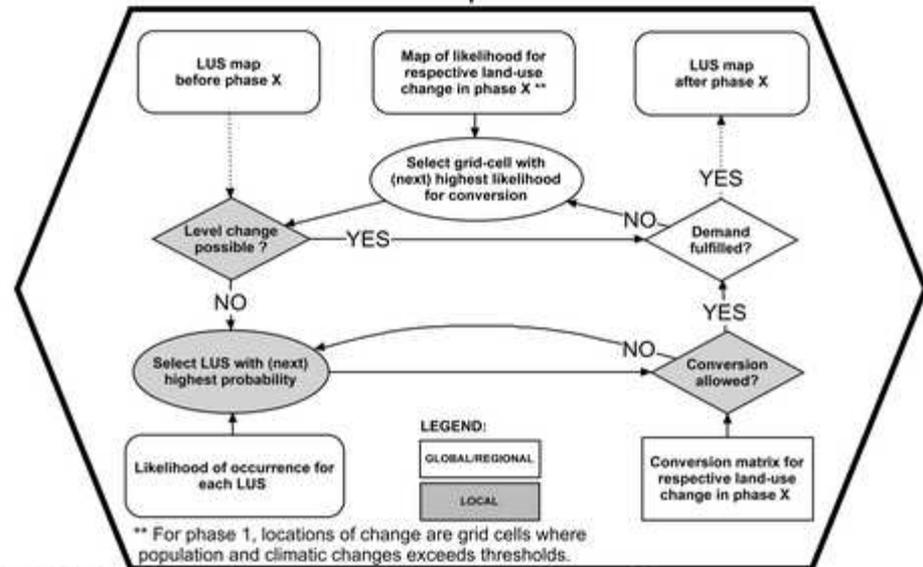
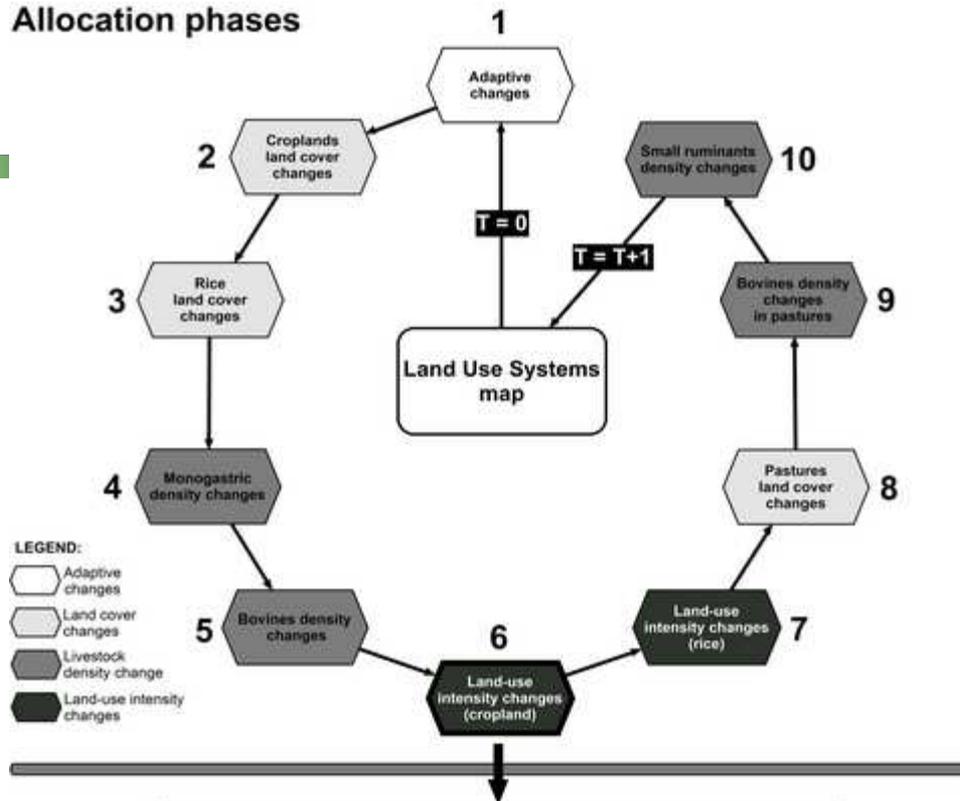
- Very simple, only biophysical factors
- One uniform rule worldwide or optimization based on profit optimization



Advances

- Higher spatial resolution / strong coupling to biophysical models (LandShift; Schaldach et al., 2011)
- Land system approach (IMAGE module; Letourneau et al., EnvSoft, 2012)
- CLU-Mondo land system approach (Asselen, Verburg and Stehfest, in preparation)

Allocation phases



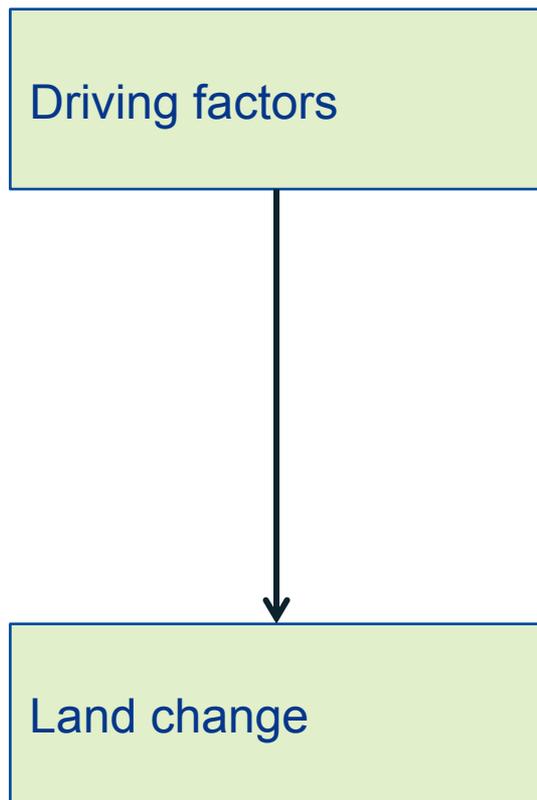
Detailed allocation procedure for phase X

Challenges

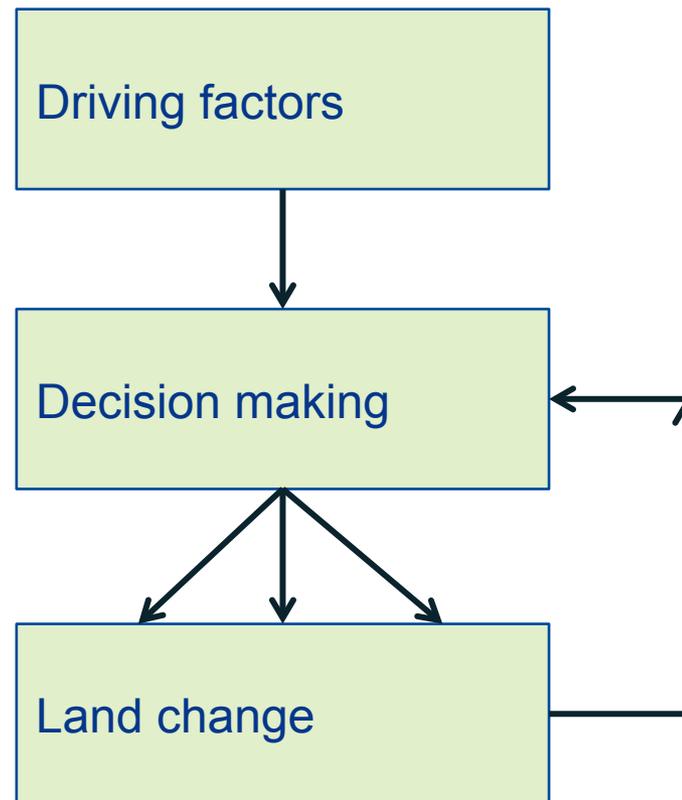
- Integrate variation in human decision making
- Include feedbacks from allocation to demand, including adaptation

Approaches

Spatial models



Multi-agent models



Scaling agent-based models

- Out-scaling:
 - Model all global actors individually
 - Simplify through typology of actors that have similar behaviour
 - Explicitly model higher-level agents/institutions

- Up-scaling:
 - Model aggregate decision making (e.g. community level agents)
 - Simplify through typology of aggregate decision strategies or through nested detailed models
 - Institutions may be embedded in aggregate decision making

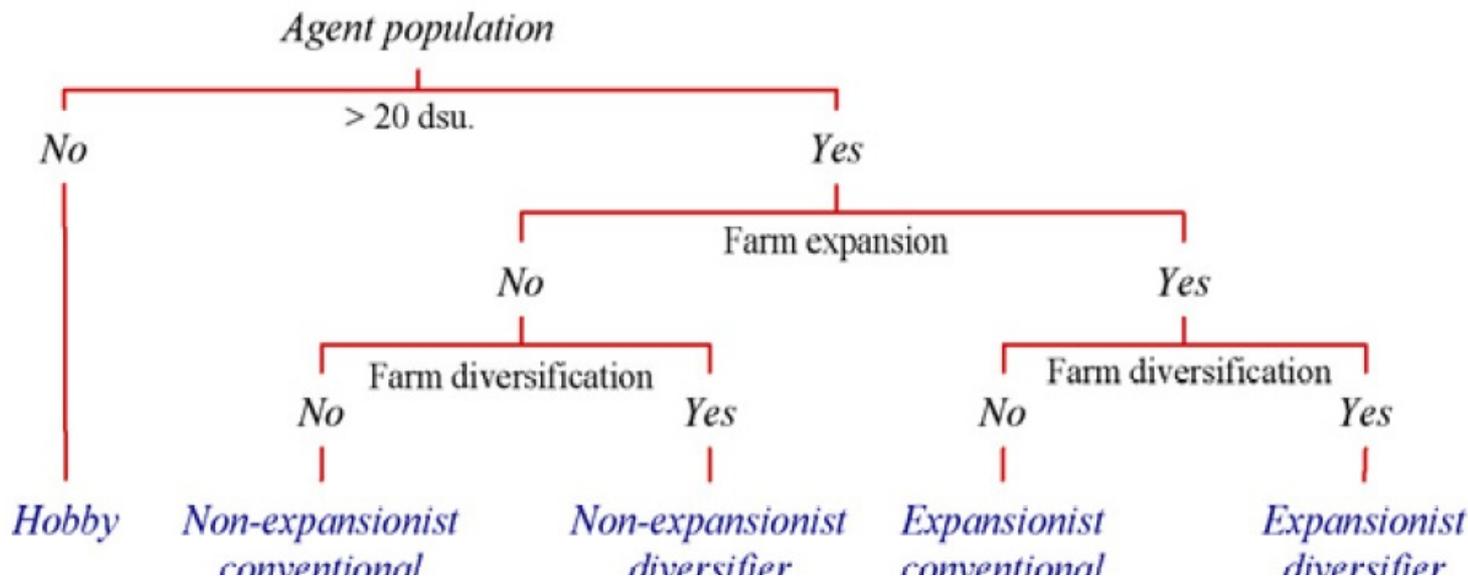
Scaling agent-based models

- Out-scaling:
 - Model all global actors individually
 - Simplify through typology of actors that have similar behaviour
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Out-scaling

Agent typology

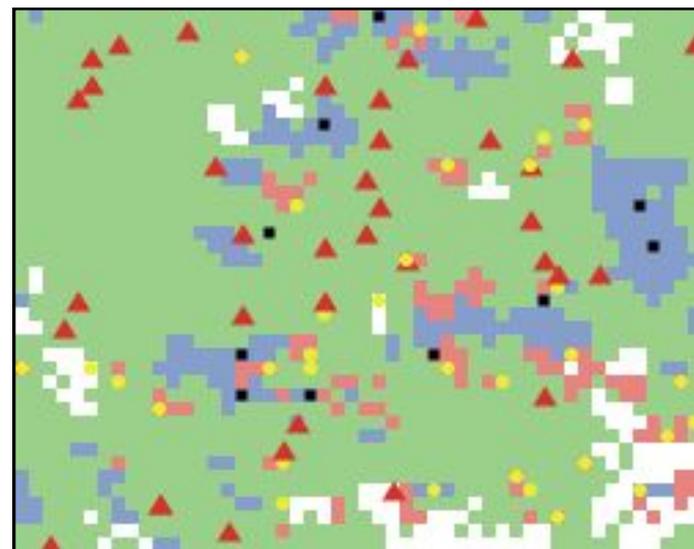
Agent typology



Agent type parameterization: production strategies

Agent type	Stop farming	Increase production	Decrease production	Diversify farm practices	Compensation schemes	Tourism and recreation
Hobby farm	+	-	+	-	-	+
Non-expansionist conventional	+	-	+	+/-	+/-	+
Non-expansionist diversifier	+	-	+	+	+	+
Expansionist conventional	-	+	-	-	-	-
Expansionist diversifier	-	+	-	+	+	+

Out-scaling



Out-scaling

Strengths:

- Individual behaviour, no scaling problems
- Diversity of decision-making within the landscape

Weaknesses:

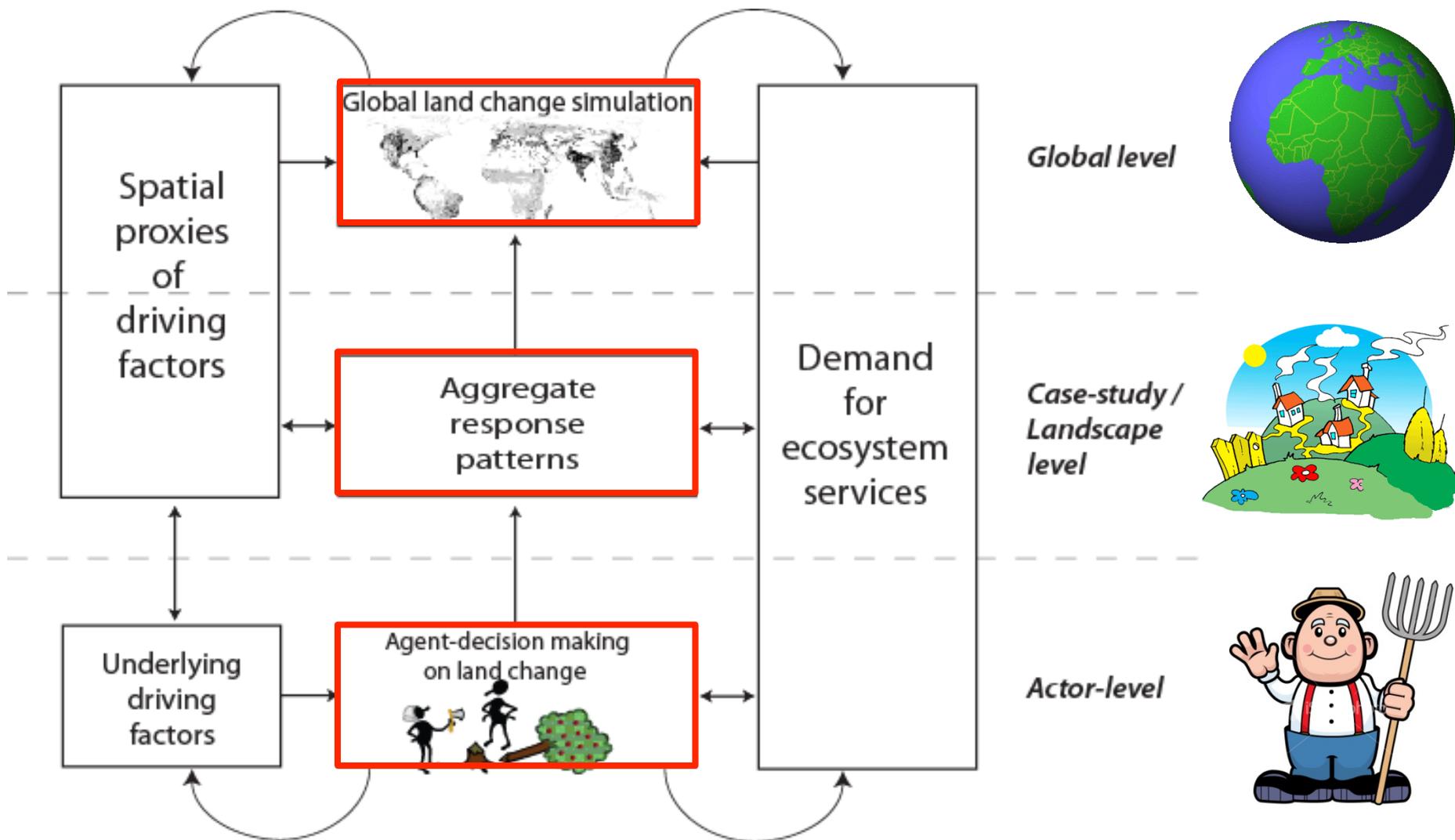
- Out-scaling of typology requires detailed census data
- Extensive surveys at individual/household level are needed to parameterize decision making
- Typology can become large when accounting for regional differences

Scaling agent-based models

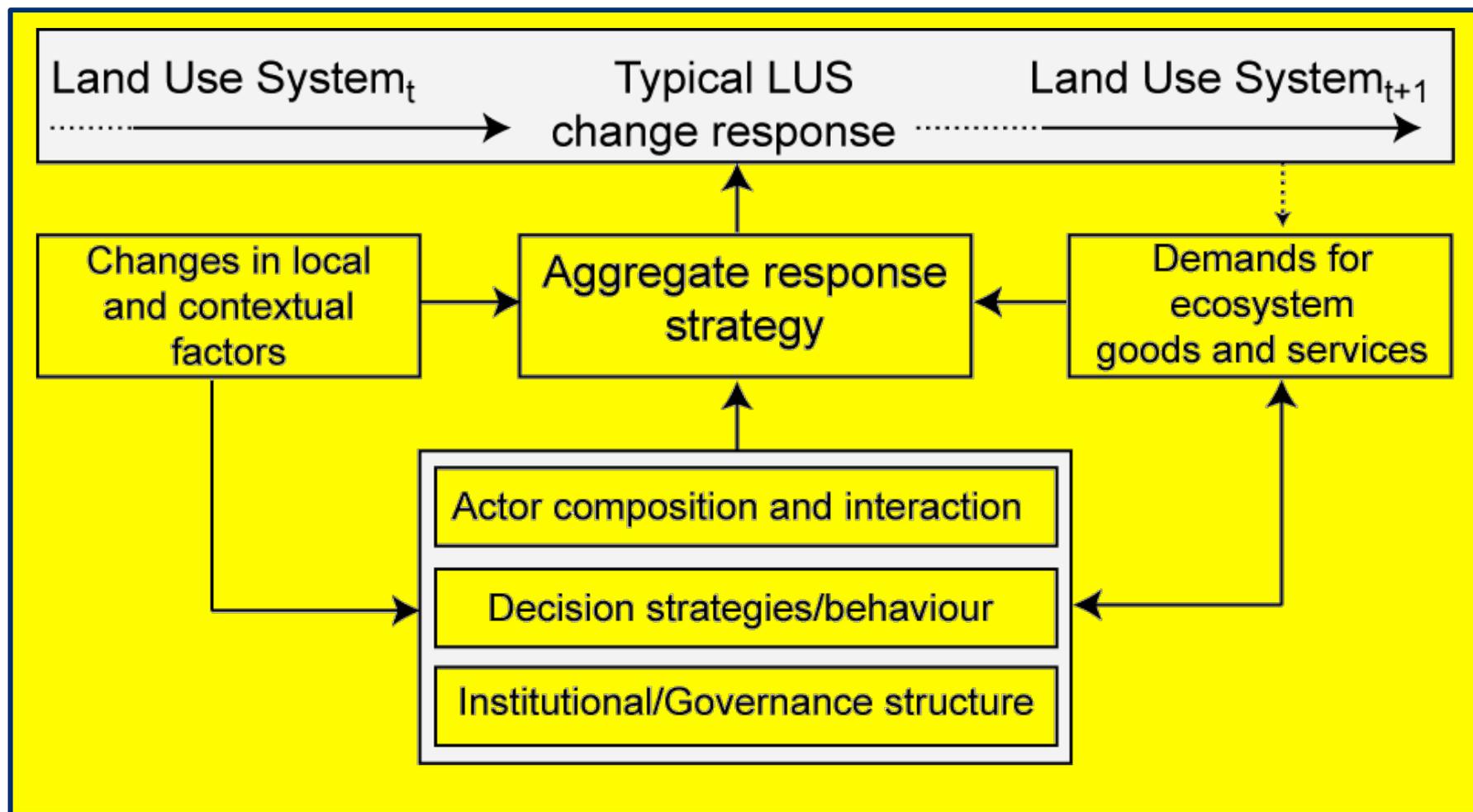
■ Up-scaling:

- Model aggregate decision making (e.g. community level agents)
- Simplify through typology of aggregate decision strategies or through nested detailed models
- Institutions may be embedded in aggregate decision making

Up-scaling/nesting



Up-scaling



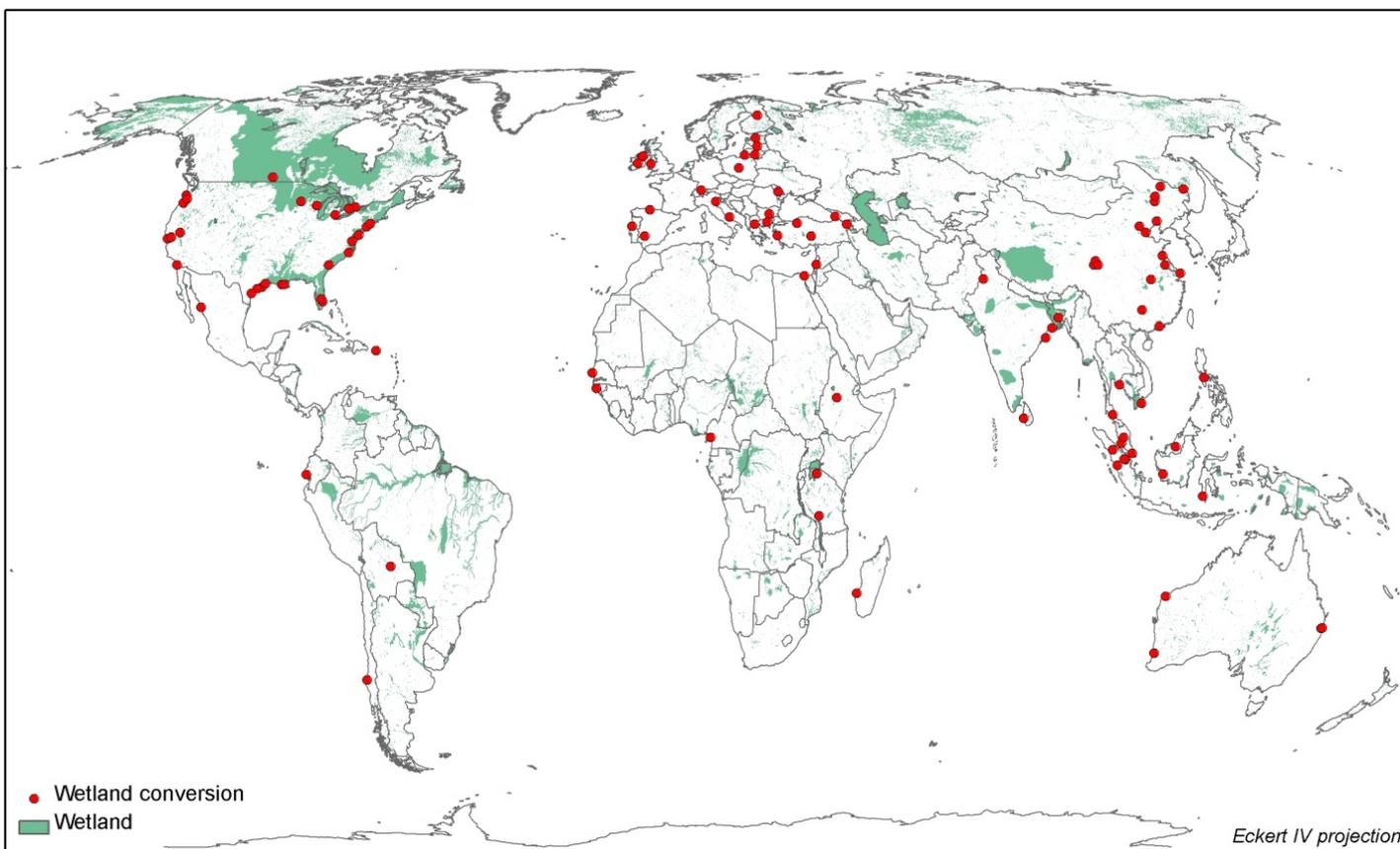
Meta-analysis of local case studies

- Deforestation: Geist&Lambin / Rudel
- Desertification: Geist
- Agricultural intensification: Keys&McConnell
- Swidden agriculture: vanVliet et al



Wetland conversion meta-analysis

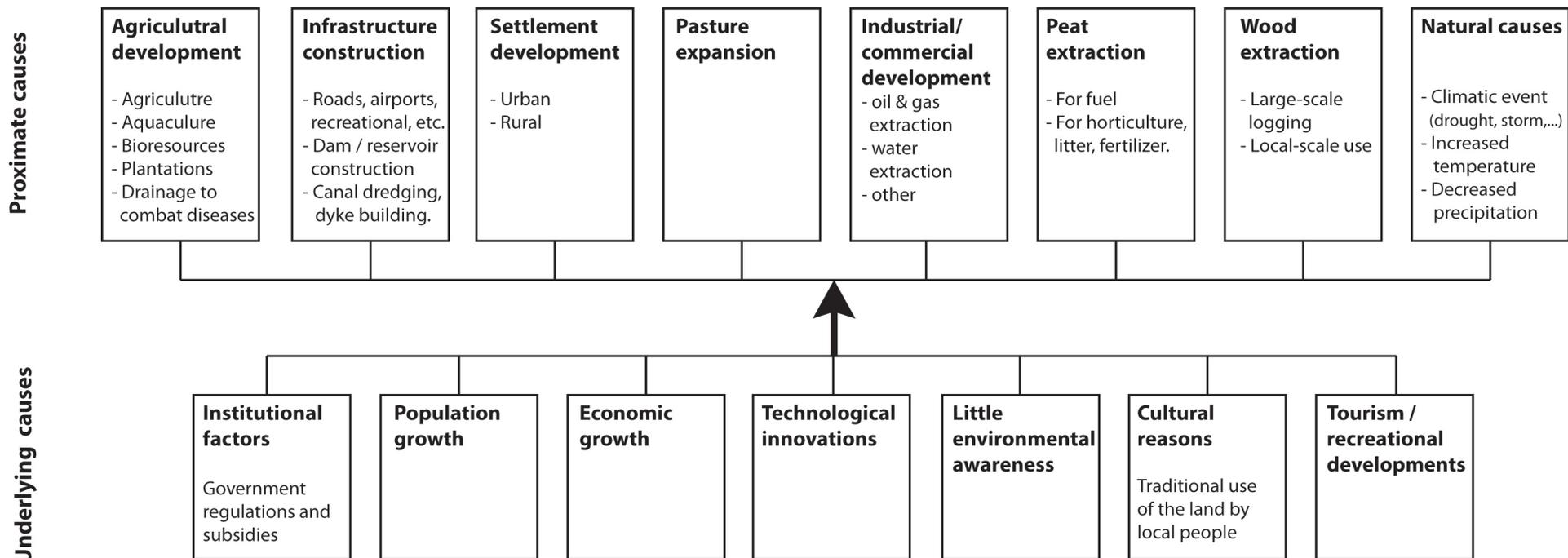
Collected 105 case-study papers on wetland conversion from Sciencedirect & Web of Science.

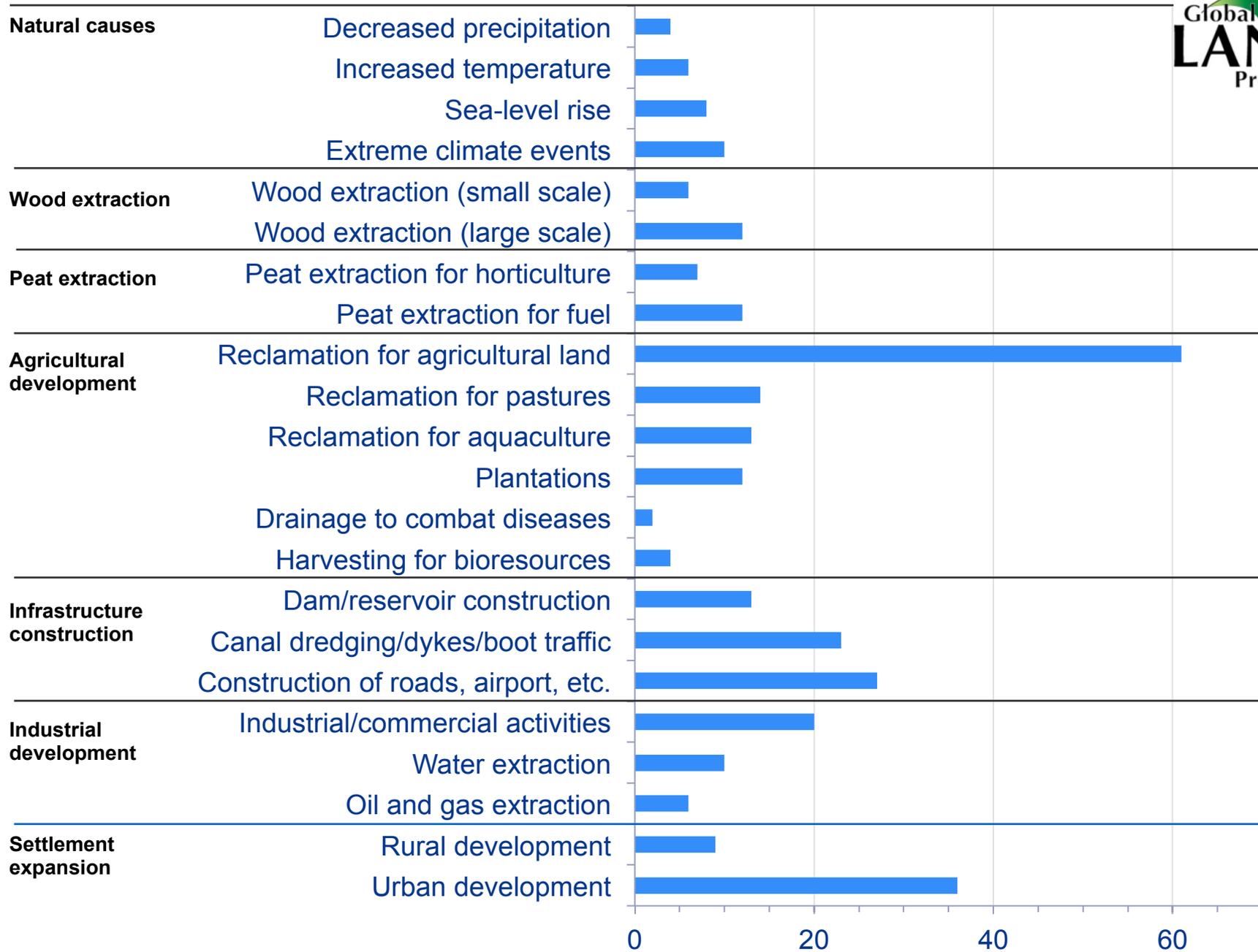


Processes driving wetland conversion

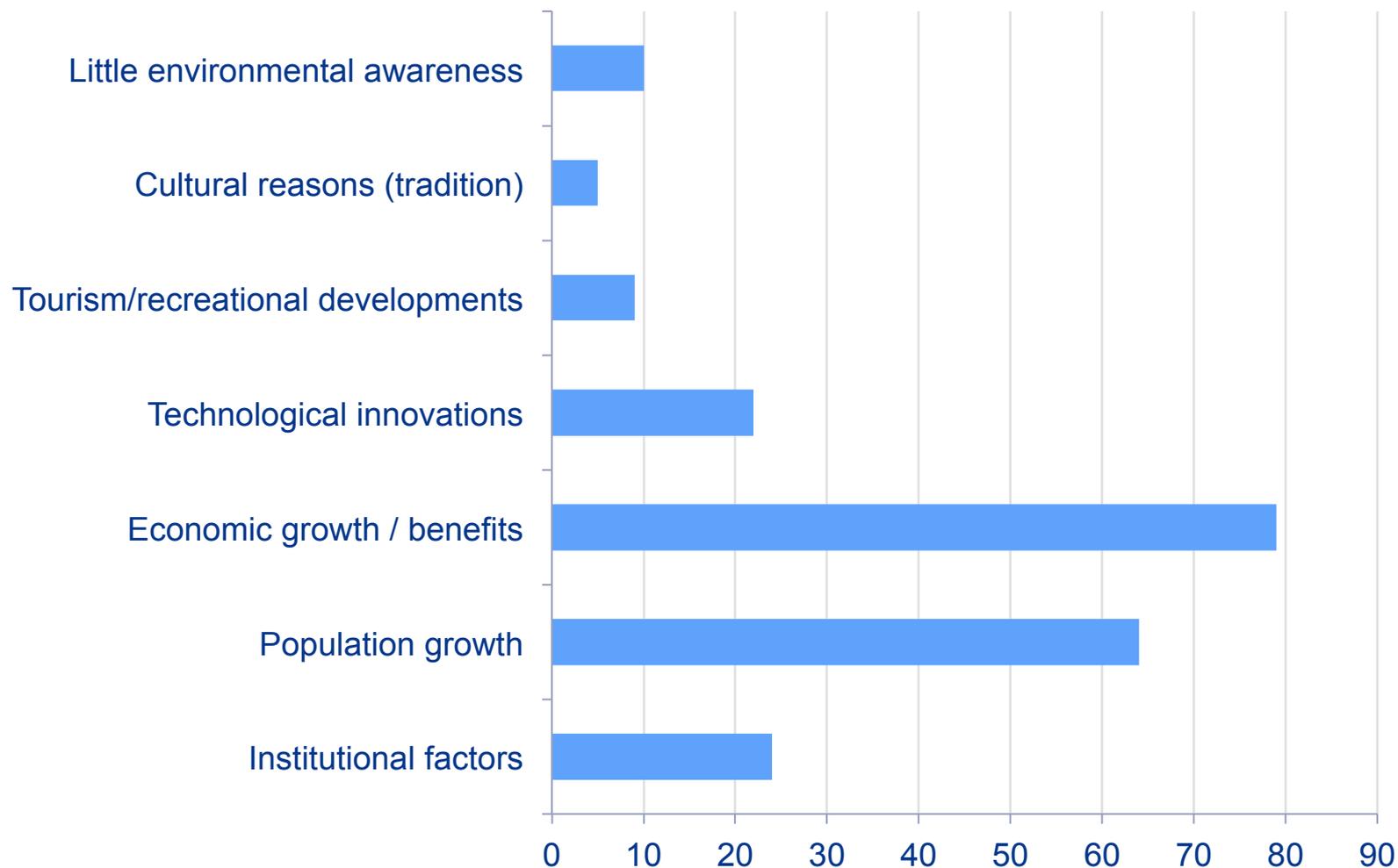
Followed method of Geist & Lambin (2002, 2004):

- **Proximate causes:** human activities or immediate actions at the local level that originate from intended land use and directly impact land cover.
- **Underlying causes:** fundamental societal processes, such as human population dynamics or agricultural policies, that drive the proximate causes and either operate at the local level or act as an indirect forcing from the national or global level.

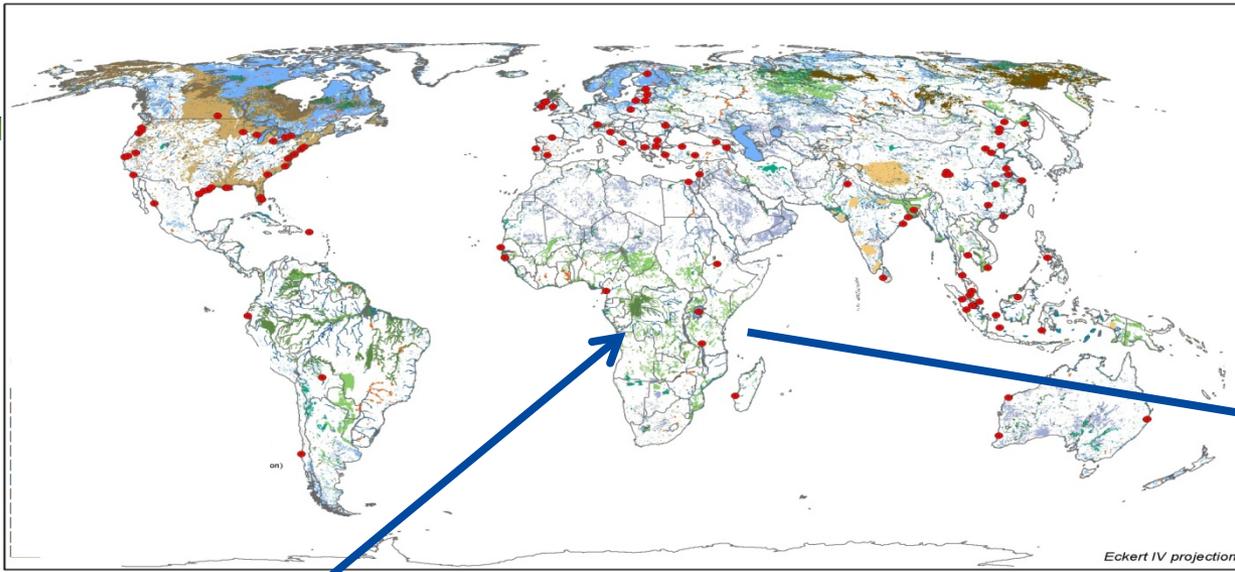




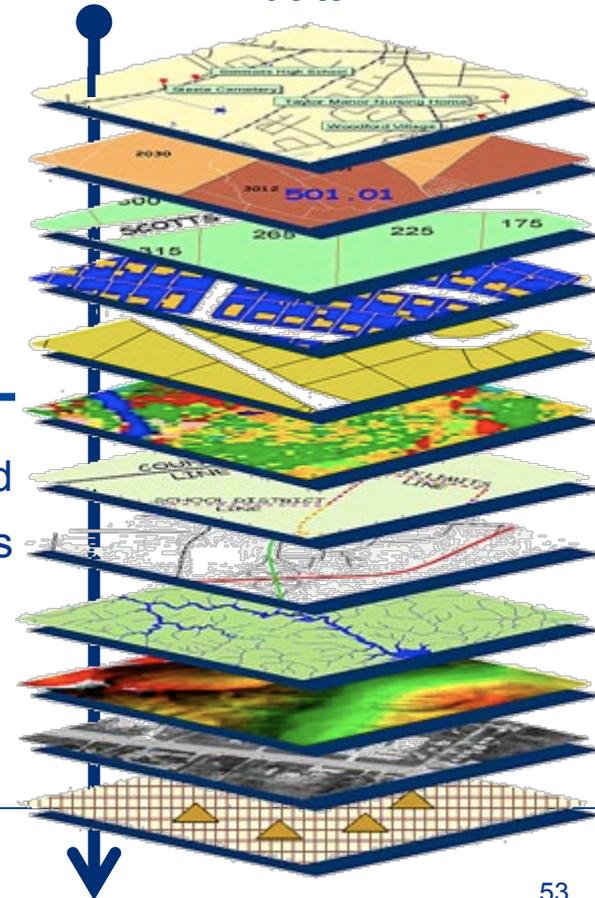
Wetland conversion: underlying causes



Meta-analysis of case-studies



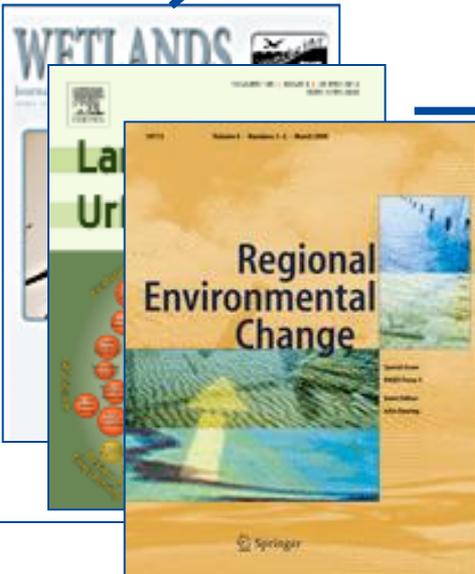
Georeferenced data



META-ANALYSIS

Drivers according to case-study description

Contextualized Location factors



Literature case studies

Regression analysis: explanatory variables

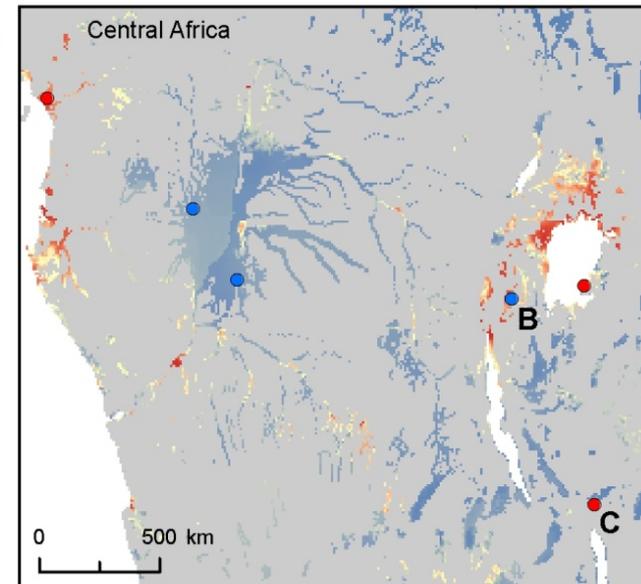
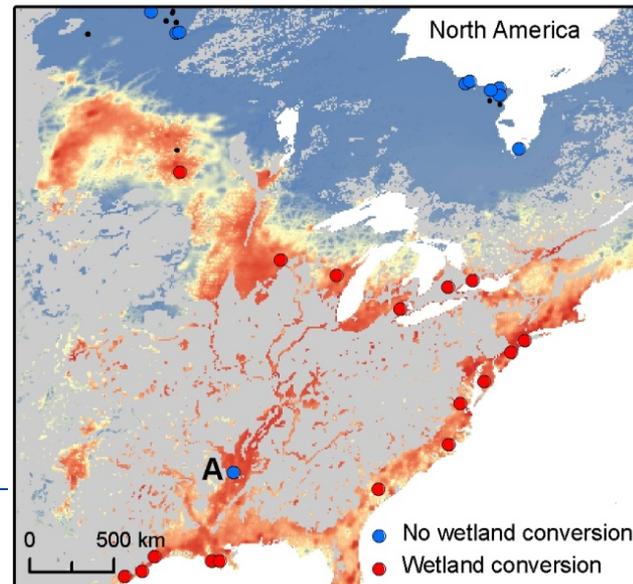
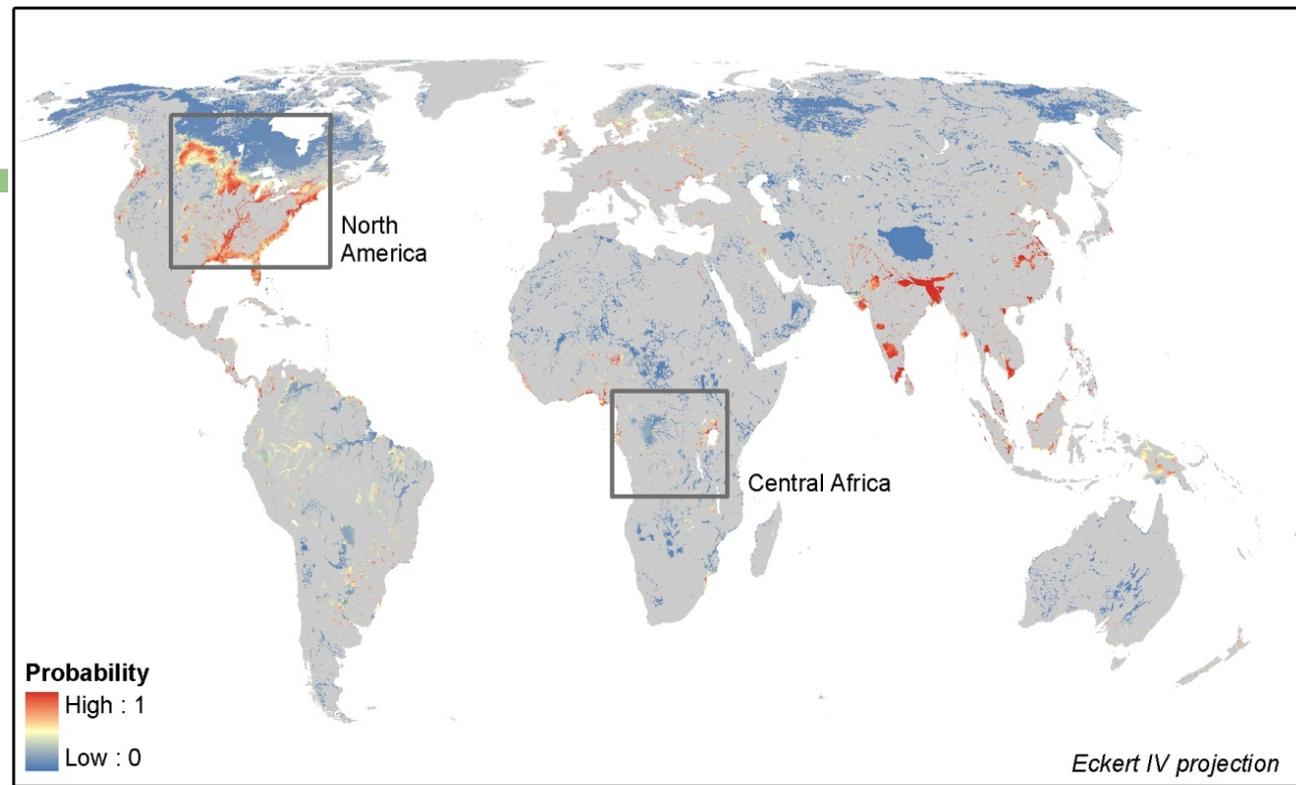
	Explanatory factor	Description	
Biophysical factors	Temperature	Annual mean (mean of monthly mean).	
	Precipitation	Annual mean (mean of monthly mean).	
	Slope	Derived from Altitude 30 sec map.	
	Organic content	Percentage of organic carbon.	
	Histosol	Percentage of histosols.	
	Wetlands	Percentage of wetlands within a 3x3 grid cell area.	
Socio-economic factors	Cropland cover	Average cropland cover within a 3x3 grid cell area.	
	Agricultural efficiency	Relative measure of land-use intensity.	
	Built-up area	Global urban land for c. 2001-2002 based on (MODIS) 500-m satellite data.	
	Population density	Average population density within a 3x3 grid cell area.	
	Distance to roads	Distance to nearest road	
	Market accessibility	Indicator for the accessibility to markets.	
	Market influence	Indicator for market influence.	
	Governance Indicators	Voice and accountability	
		Regulatory quality	
Government effectiveness			
	Rule of Law		

Probability of wetland conversion

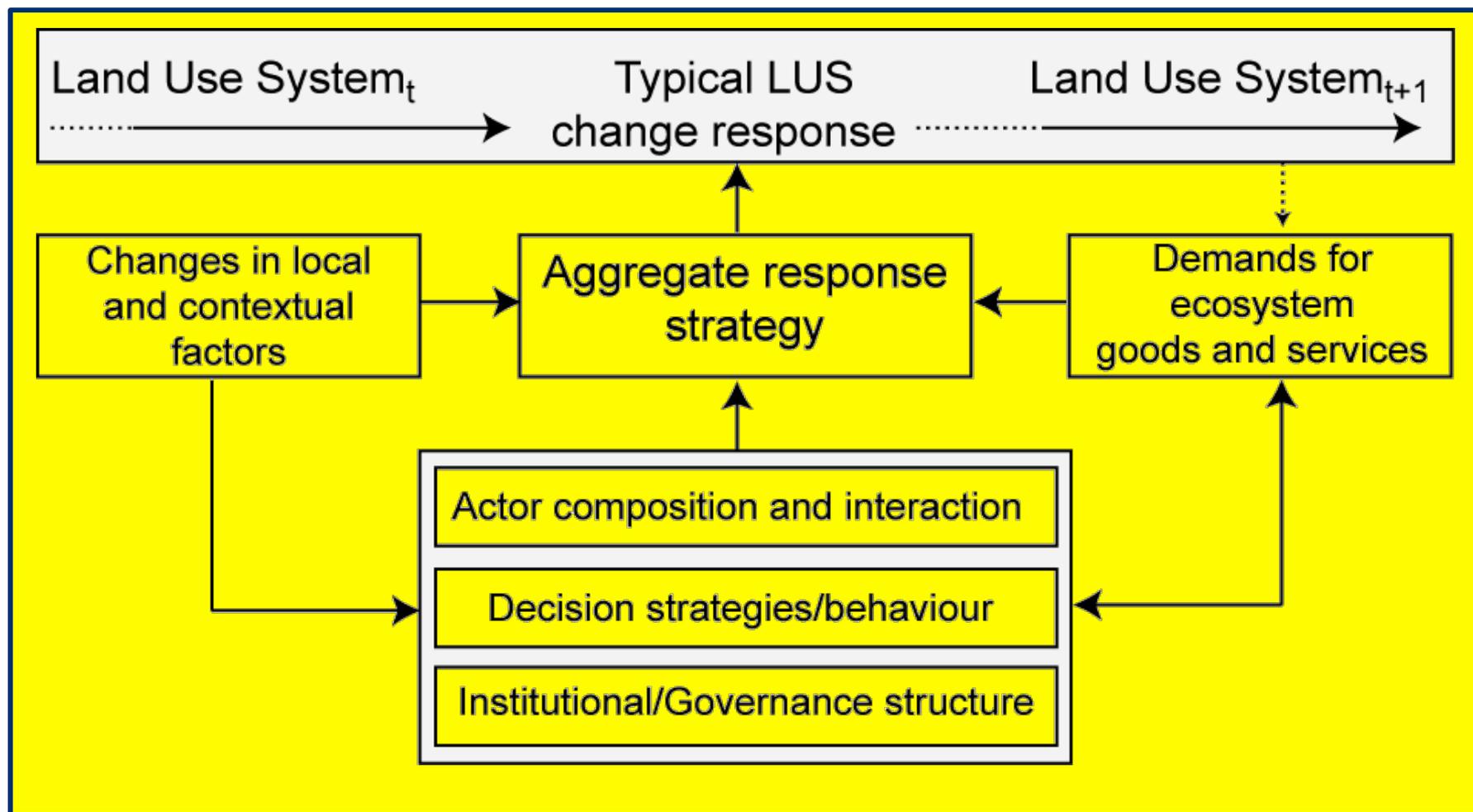
Logistic regression:

Probability =
f(precipitation (+),
market influence (+),
population density (+),
cropland in
neighborhood (+)).

ROC = 0.9



Up-scaling



Up-scaling/nesting

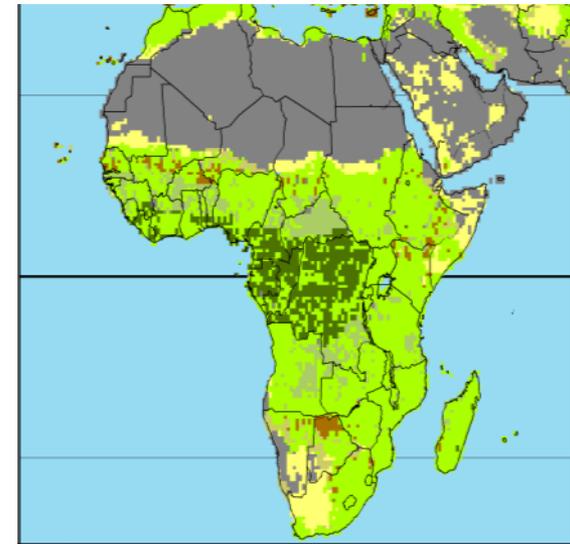
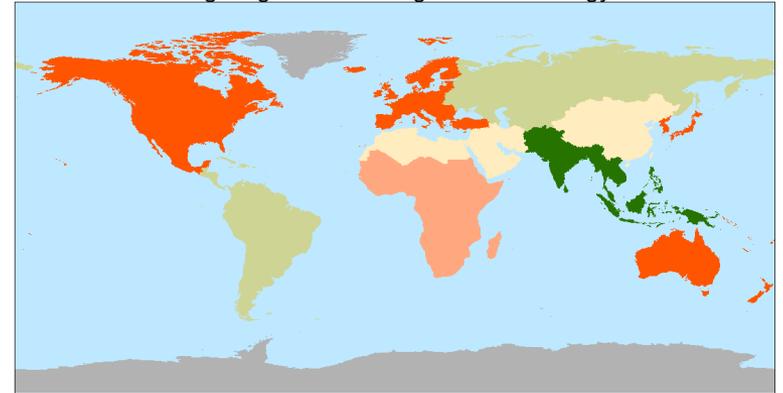
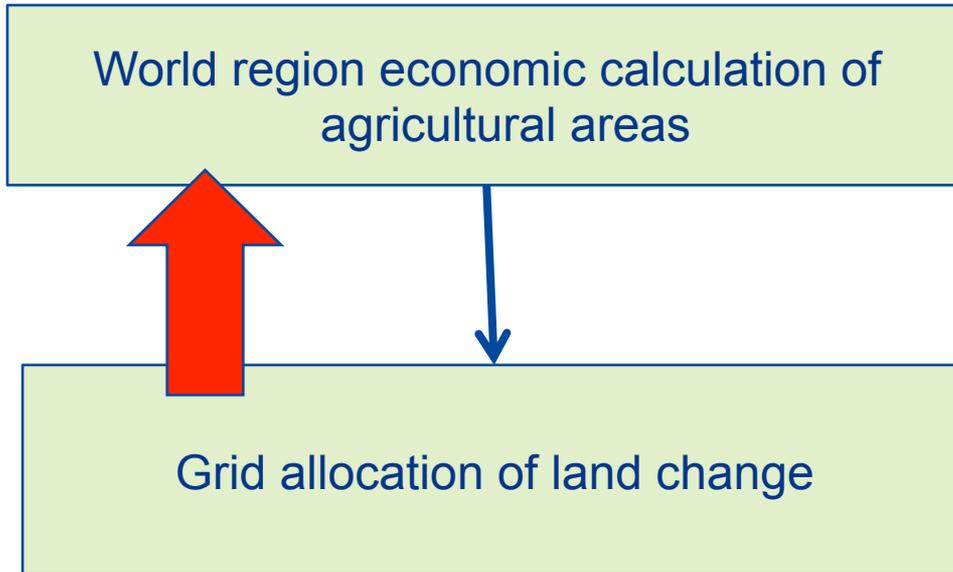
Strengths:

- Use empirical evidence of case-studies worldwide
- Reduced complexity while accounting for diversity
- Nesting of more complex agent models is possible

Weaknesses:

- Decision-making strategies/environmental cognition poorly reported in case studies
- Typology not static, communities move between agent-types
- Requires scaling of behaviour

Challenges: feedback to global trade assessment



- Agricultural productivity depends on allocation
- Change vs. Net Change (shifts in pattern)
- Adaptation
- Technology impacts

Embedding bottom-up model results in partial equilibrium models



Land Use Policy

Volume 30, Issue 1, January 2013, Pages 446–457



Policy reform and agricultural land abandonment in the EU

Alan Renwick^a,  , Torbjorn Jansson^b, Peter H. Verburg^c, Cesar Revoredo-Giha^a, Wolfgang Britz^d, Alexander Gocht^e, Davy McCracken^a



Agriculture, Ecosystems & Environment

Volume 142, Issues 1–2, July 2011, Pages 40–60

Scaling methods in integrated assessment of agricultural systems



Modelling of land cover and agricultural change in Europe: Combining the CLUE and CAPRI-Spat approaches

Wolfgang Britz^a,  , Peter H. Verburg^b, Adrian Leip^c

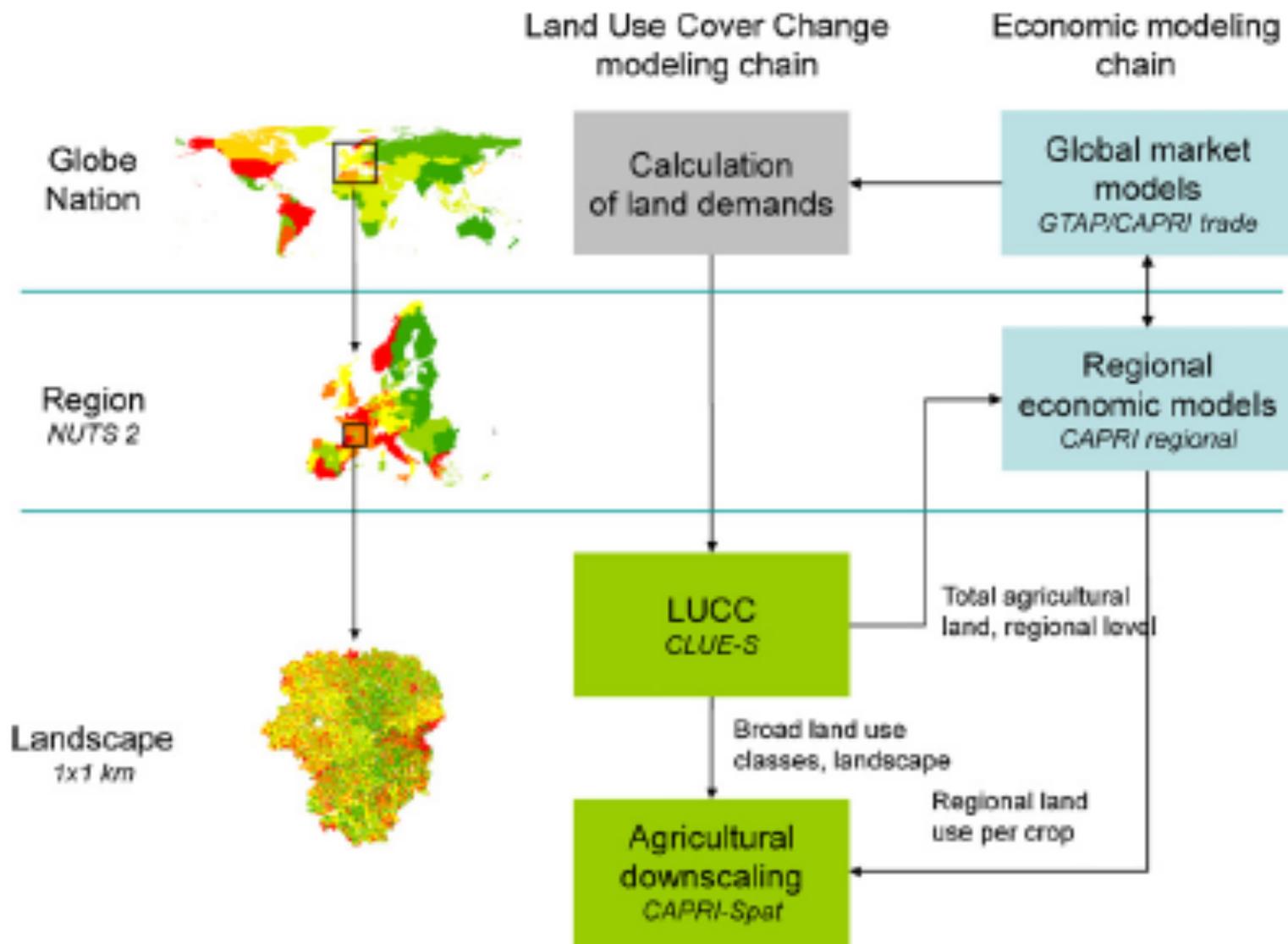
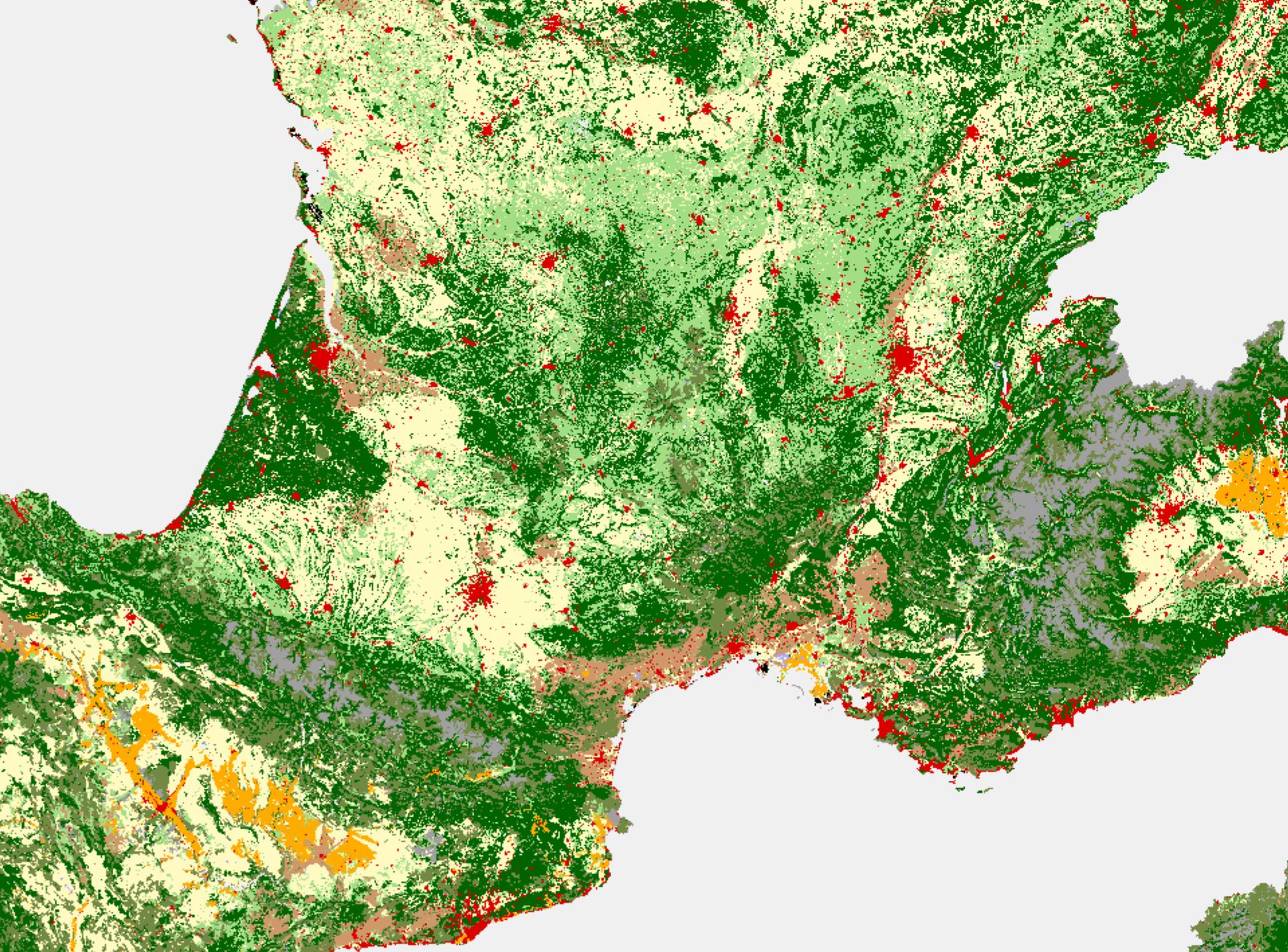


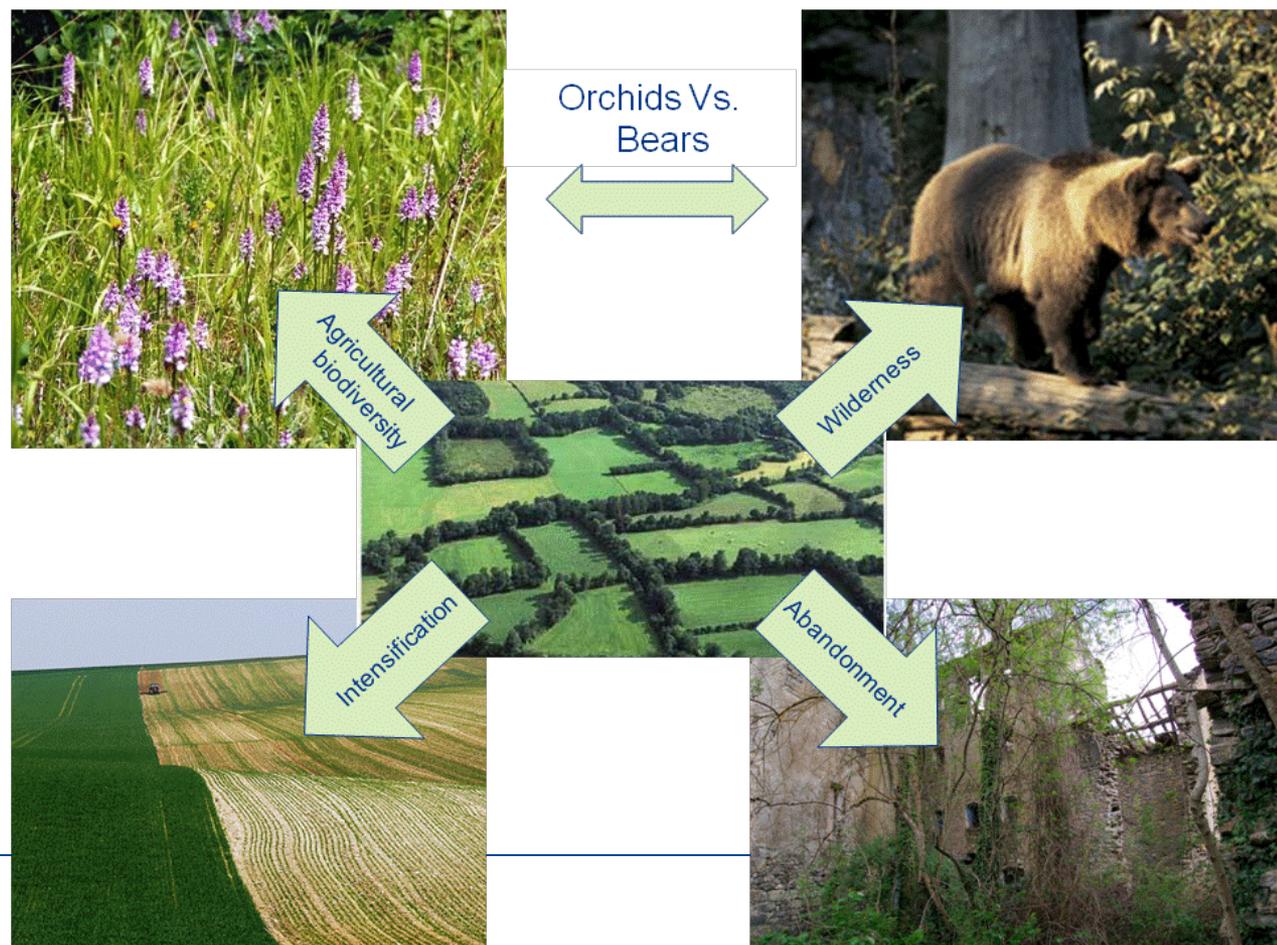
Fig. 2. Overview of the possible model linkages.



- **Spatial and temporal complexity:**
 - *Better representation of spatial and temporal variability allows to address region/location specific policy interventions*

Complexity

- No 'simple' messages. Same driver has location dependent impacts that may be judged differently



Complexity

- Use narrative approaches to explain dynamics resulting from simulations
 - Study region-specific impacts/effectiveness of policy options
 - Clarify spatial spill-overs and trade-offs
-
- **Adding complexity to land use simulations not only improves the simulation results**
 - Insight in mechanisms
 - Insight in spatial and temporal variations
 - Link to stakeholder perception of landscape
 - Insights into the decision-making processes to influence

Conclusion

■ Representing land use:

- *New ways of representing land use are needed to capture the essential characteristics of land use impacting climate, biodiversity and ecosystem services*

■ Modelling land use decision making:

- *Research is needed to better represent socio-economic variation and decision making structures in land allocation models, including adaptation*

■ Spatial and temporal complexity:

- *Better representation of spatial and temporal variability allows to address region/location specific policy interventions*

Thank you!



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