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Mapping global land system archetypes

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www.sustainable-landmanagement.net

Land use is a major driver of global change

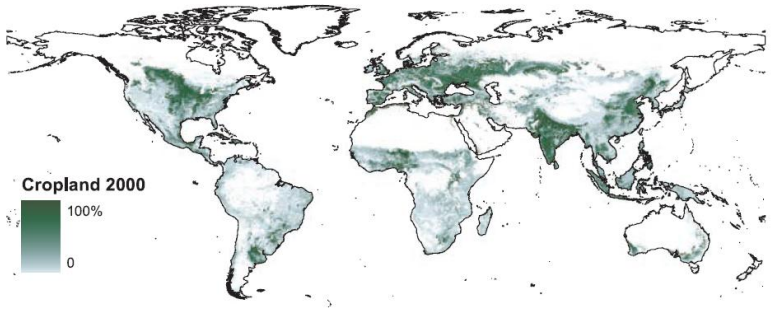
- Meeting future demands for food and other commodities will require land-based production to expand or intensify

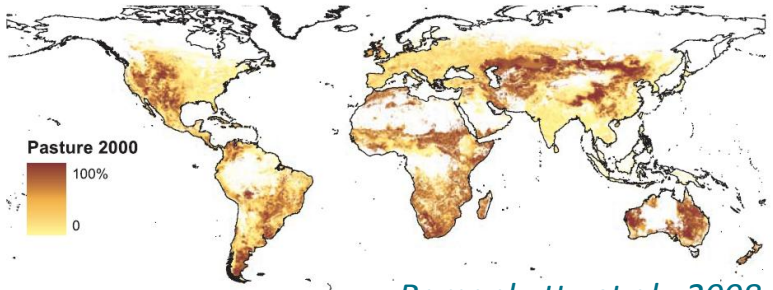
Problem:

- Agricultural expansion is well mapped but patterns of land-use intensity are poorly understood at the global scale

Solution:

- Integrated system approach
- Moving beyond mapping agricultural classes towards mapping land-use systems





Ramankutty et al., 2008

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Land use - major driver of global change

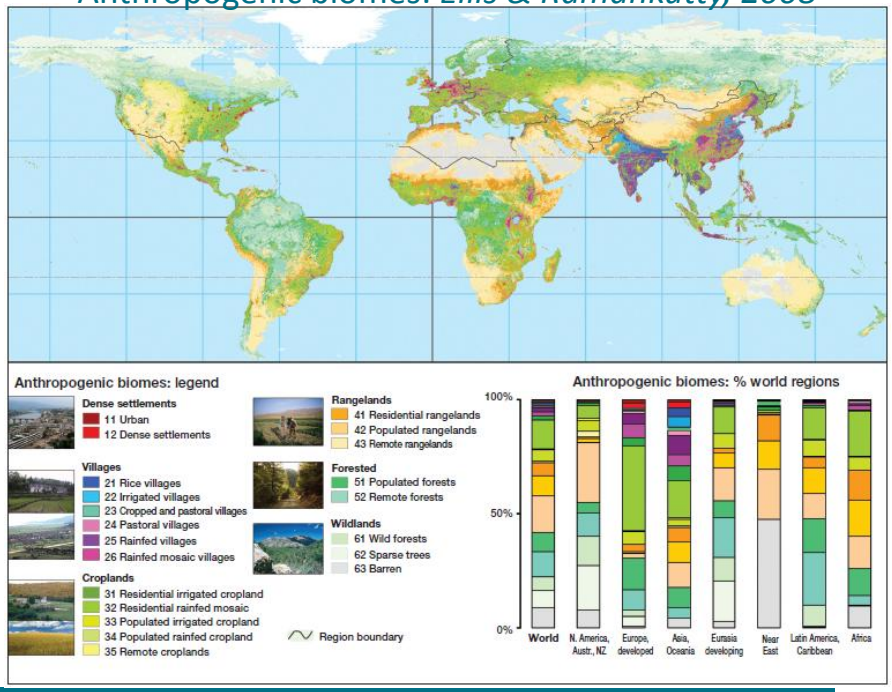
Current representations of land systems

- Models of land systems focus on broad-scale representations of land cover with limited consideration of human influence or land use intensity (GLC 2000; GlobCover)

Recent studies (Ellis & Ramankutty 2008, Letourneau et al. 2012, vanAsselen & Verburg 2012)

- Used indirect or a few direct indicators of land-use intensity (population, livestock density)
- Applied top-down approaches to define land system classes, e.g. “expert rules”

Anthropogenic biomes: *Ellis & Ramankutty, 2008*



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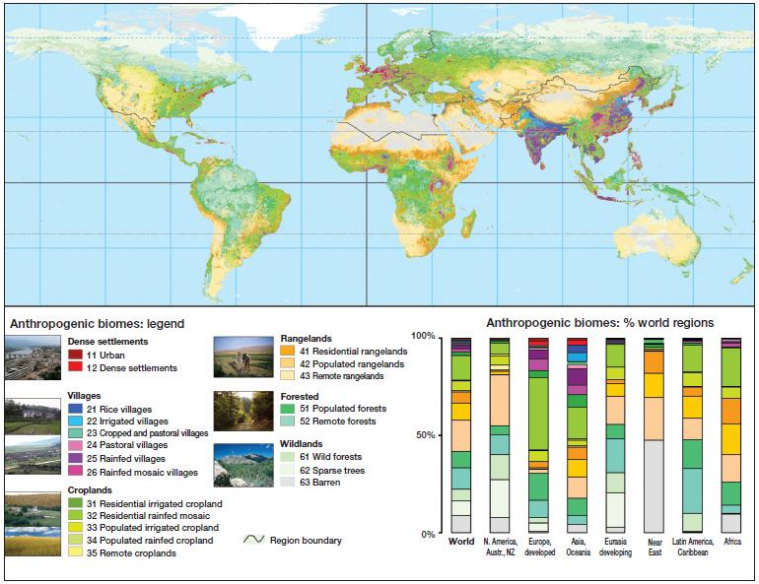
Aim: Mapping land system archetypes (LSAs)

- Develop a new approach for representing human-environment interactions
  - Using unbiased, bottom-up approach driven by data
  - Accounting for multidimensional aspects of land-use intensity

- **Land system archetypes:** unique patterns of:
  - land-use inputs/outputs
  - environmental conditions
  - socioeconomic factors

  that appear repeatedly across the terrestrial surface of the earth

Anthropogenic biomes: *Ellis & Ramankutty, 2008*



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Aim: Mapping archetypical patterns of land systems

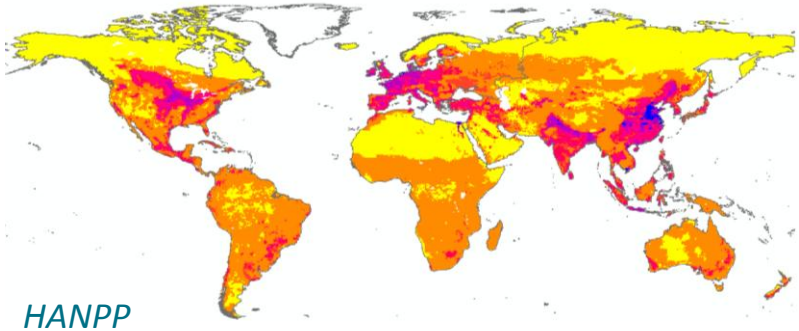
Data: global indicators of land systems

- 32 global variables at 5 arc-minute resolution (~9.3×9.3 km at the equator)

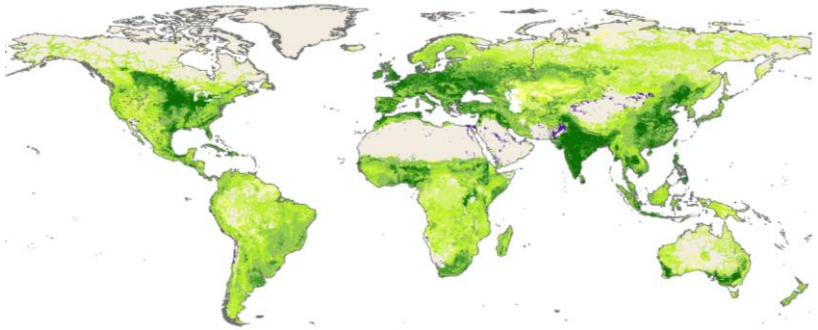
1) Land-use inputs/outputs

Factor	Unit
Cropland area	km^2 per grid cell
Cropland area trend	km^2 per grid cell
Pasture area	km^2 per grid cell
Pasture area trend	km^2 per grid cell
N fertilizer	kg ha^{-1}
Irrigation	Ha per grid cell
Soil erosion	Mg ha^{-1} $year^{-1}$
Yields (wheat, maize, rice)	t ha^{-1}
Yield gaps (wheat, maize, rice)	1000 t
Total production index	index
HANPP	% of NPP_0

Nitrogen fertilizer



HANPP



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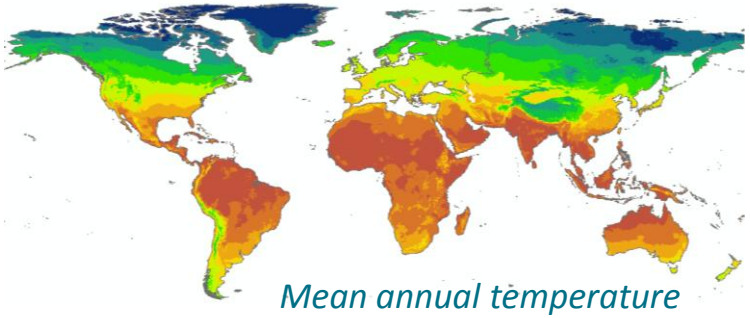
Data: global indicators of land systems

2) Environmental conditions

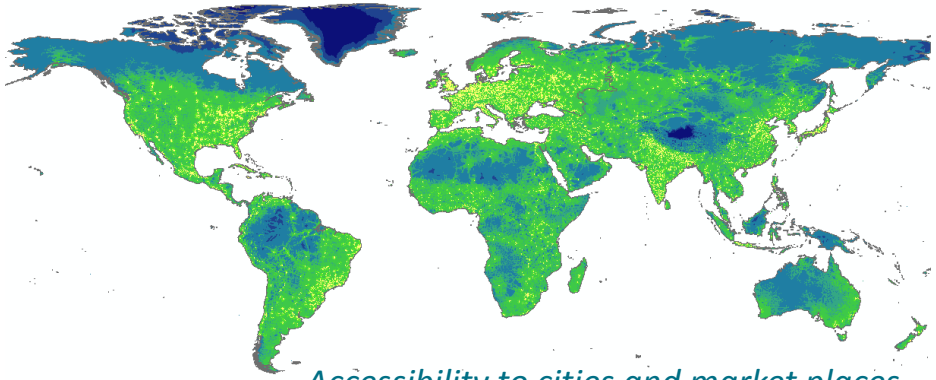
Factor	Unit
Temperature	°C × 10
Diurnal temperature range	°C × 10
Precipitation	mm
Precipitation seasonality	coeff. of variation
Solar radiation	W m^{-2}
Climate anomalies	°C × 10
NDVI – mean, seasonality	index
Soil organic carbon	g C kg^{-1} of soil
Species richness	# of species



Mean annual temperature

3) Socioeconomic conditions

Factor	Unit
Gross Domestic Product	$ per capita
GDP in agriculture	% of GDP
Capital Stock in agriculture	$
Population density	persons km^{-2}
Population density trend	persons km^{-2}
Political stability	index
Accessibility	travel time



Accessibility to cities and market places

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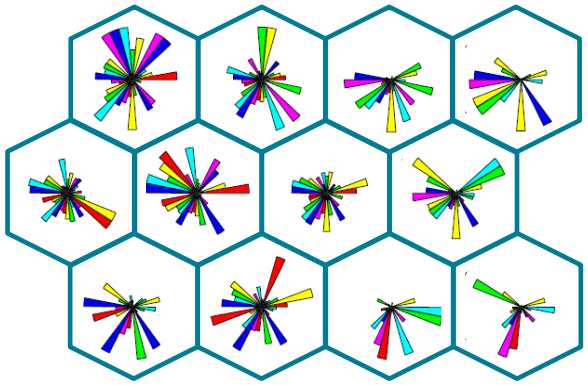
Methods: Archetype classification

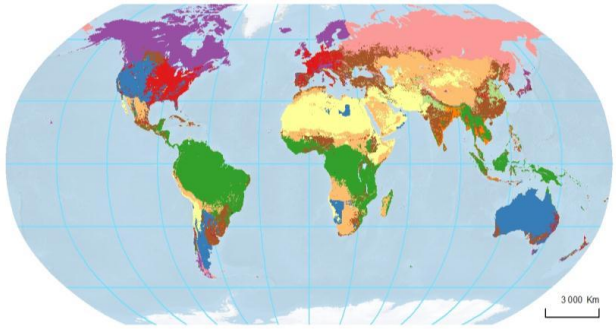
- **Self-organizing maps (SOM)** – unsupervised classification algorithm

2D topology of SOM

crop2005	yg_rice	soil_orgc
cropdif50	tpi_agr	soil_ph
grass2005	fpi_pcapita	spec_rich
grassdif50	hanpp	gdp
nfert	bio1	agr_gdp
irrigation	bio2	gcs_agr
totsederosion	bio12	pop_glds00ag
y_wheat	bio15	popdif50
y_maize	bio21	polstability
y_rice	temp_anom	accessibility
yg_wheat	ndvi_mean	
yg_maize	ndvi_sd	



- Visualizing complex datasets by reducing their dimensionality to 2D
- Performing cluster analysis by grouping observations based on their similarity
- Euclidean distance interpreted as a measure of (dis)similarity



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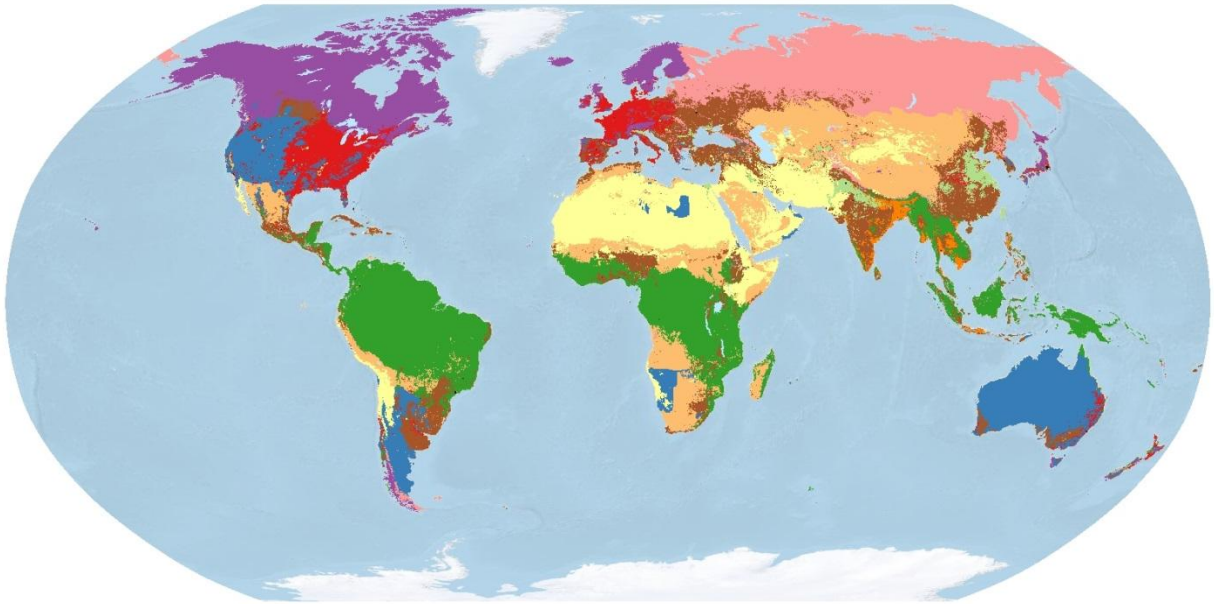
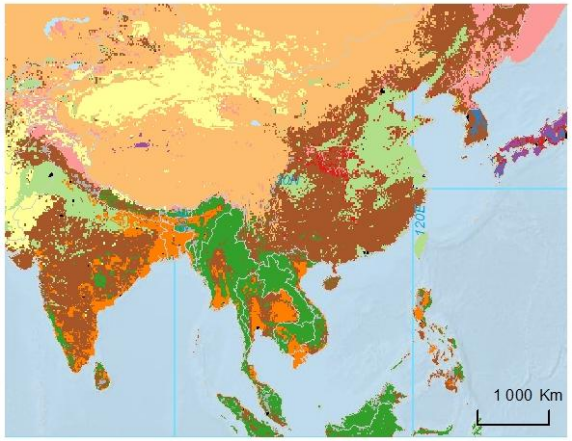
Results: Land system archetypes



- LSA 1: Forest systems in the tropics
- LSA 2: Degraded forest/cropland systems in the tropics
- LSA 3: Boreal systems of the western world
- LSA 4: Boreal systems of the eastern world
- LSA 5: High-density urban agglomerations
- LSA 6: Irrigated cropping systems with rice yield gap
- LSA 7: Extensive cropping systems
- LSA 8: Subsistence agriculture
- LSA 9: Irrigated cropping systems
- LSA 10: Intensive cropping systems
- LSA 11: Marginal lands in the developed world
- LSA 12: Barren lands in the developing world

- Similarities in land systems across the globe but still a diverse pattern at the sub-national scale



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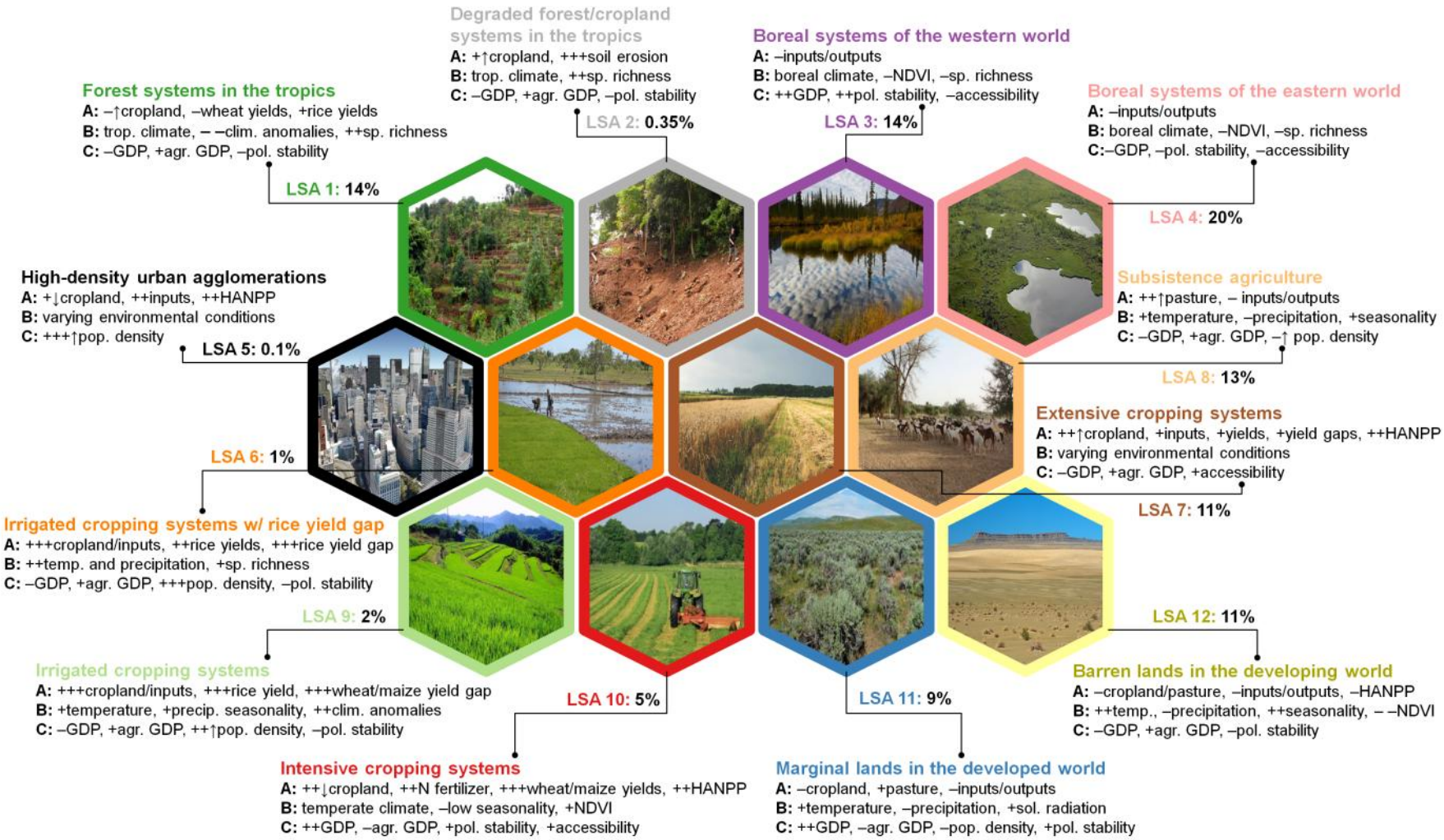

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Results: Land system archetypes

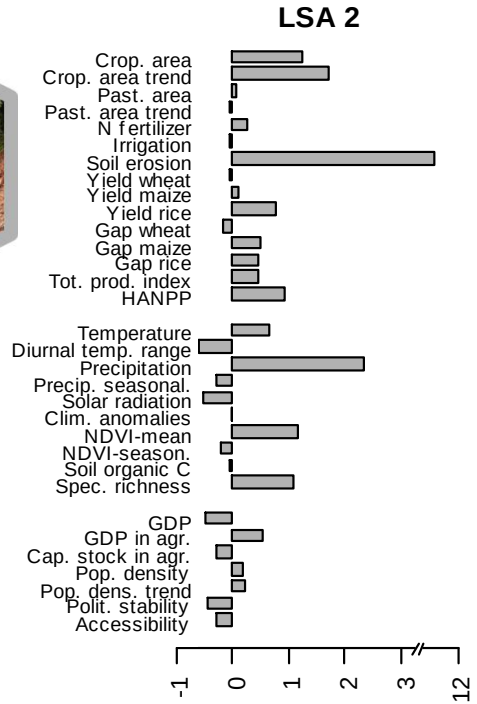
Interpreting land system archetypes

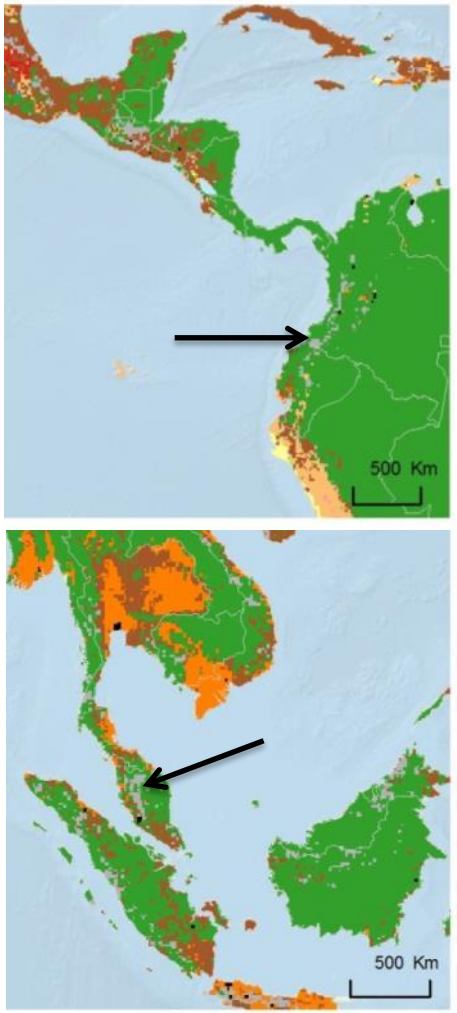
- LSAs provide opportunities to detect major land pressures and environmental threats

Example: Soil erosion

- LSA: **Degraded forest/ cropland systems in the tropics**

- Particularly vulnerable to loss of soil fertility due to:
  - High agricultural inputs
  - Low GDP
  - Strong dependence on agricultural production





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Land pressures and environmental threats

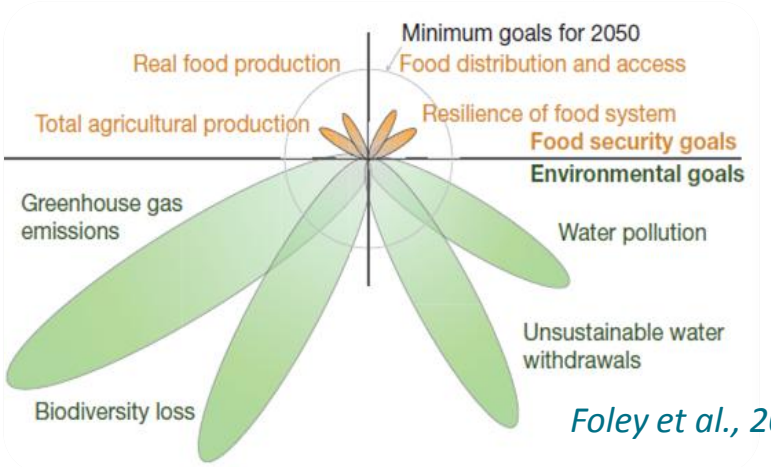
Interpreting land system archetypes

- Knowledge for regionalized strategies to cope with the challenges of global change

Example: Yield improvements

- Large differences between realized and attainable yields
- Large production gains could be achieved if yields were increased to only 50% of attainable yields

Meeting goals for food security and environmental sustainability



Foley et al., 2011

- ***closing yield gaps***
- ***increasing cropping efficiency***

But "one size does not fit all"

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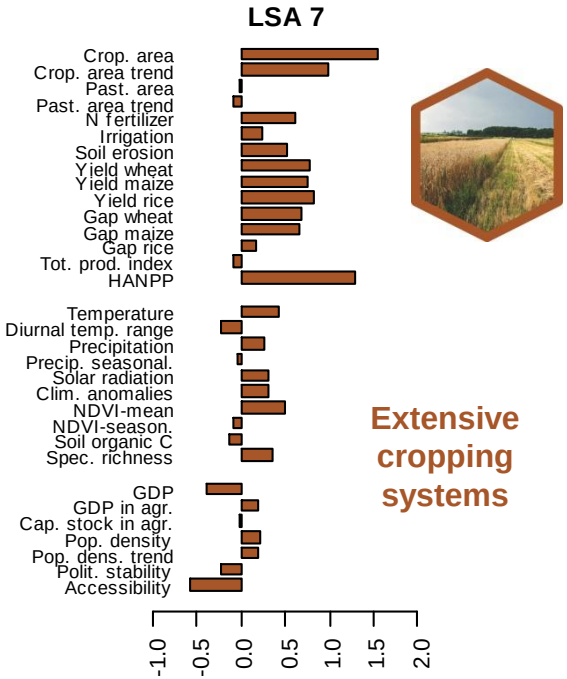
Knowledge to cope with challenges of global change

Interpreting land system archetypes

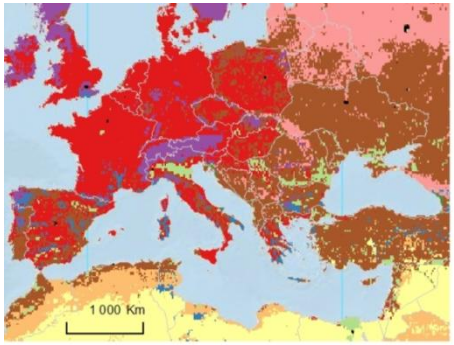
- Knowledge for regionalized strategies to cope with the challenges of global change

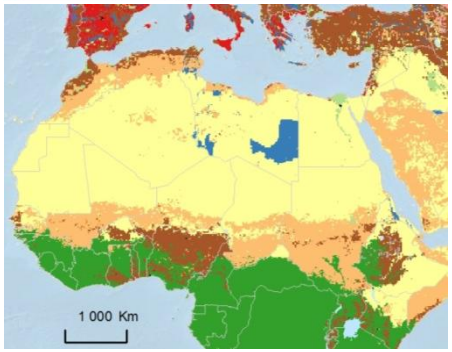
Example: Yield improvements

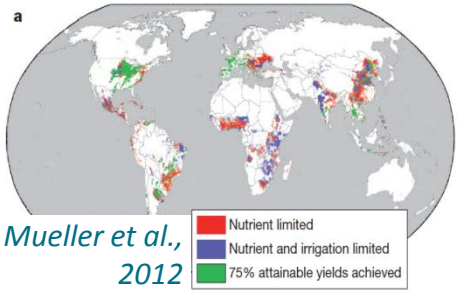
- Large differences between realized and attainable yields
- Large production gains could be achieved if yields were increased to only 50% of attainable yields



Extensive cropping systems







Mueller et al., 2012

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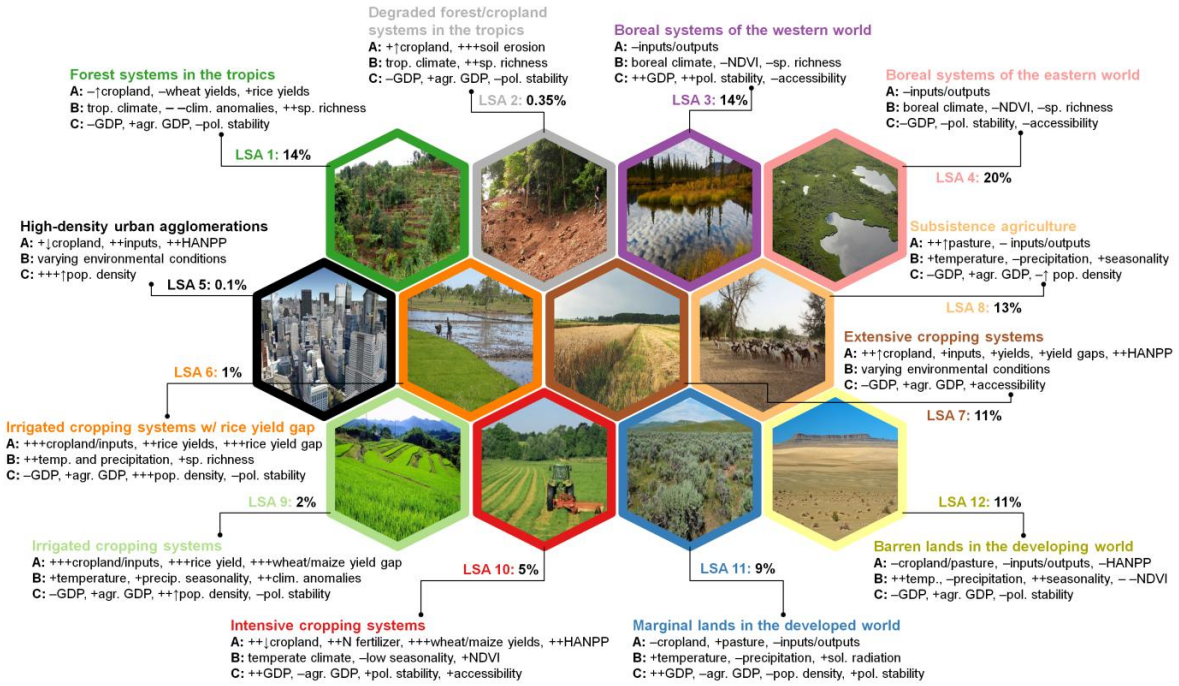
Knowledge to cope with challenges of global change

Future application of land system archetypes

- **Land change models**
  - spatially examine scenarios of land system changes based on shifts in driving factors

Conclusions

- First step for a comprehensive understanding of the driving forces and environmental and social impacts of land use dynamics



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Mapping global LSAs: Applications and conclusions

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Thank you

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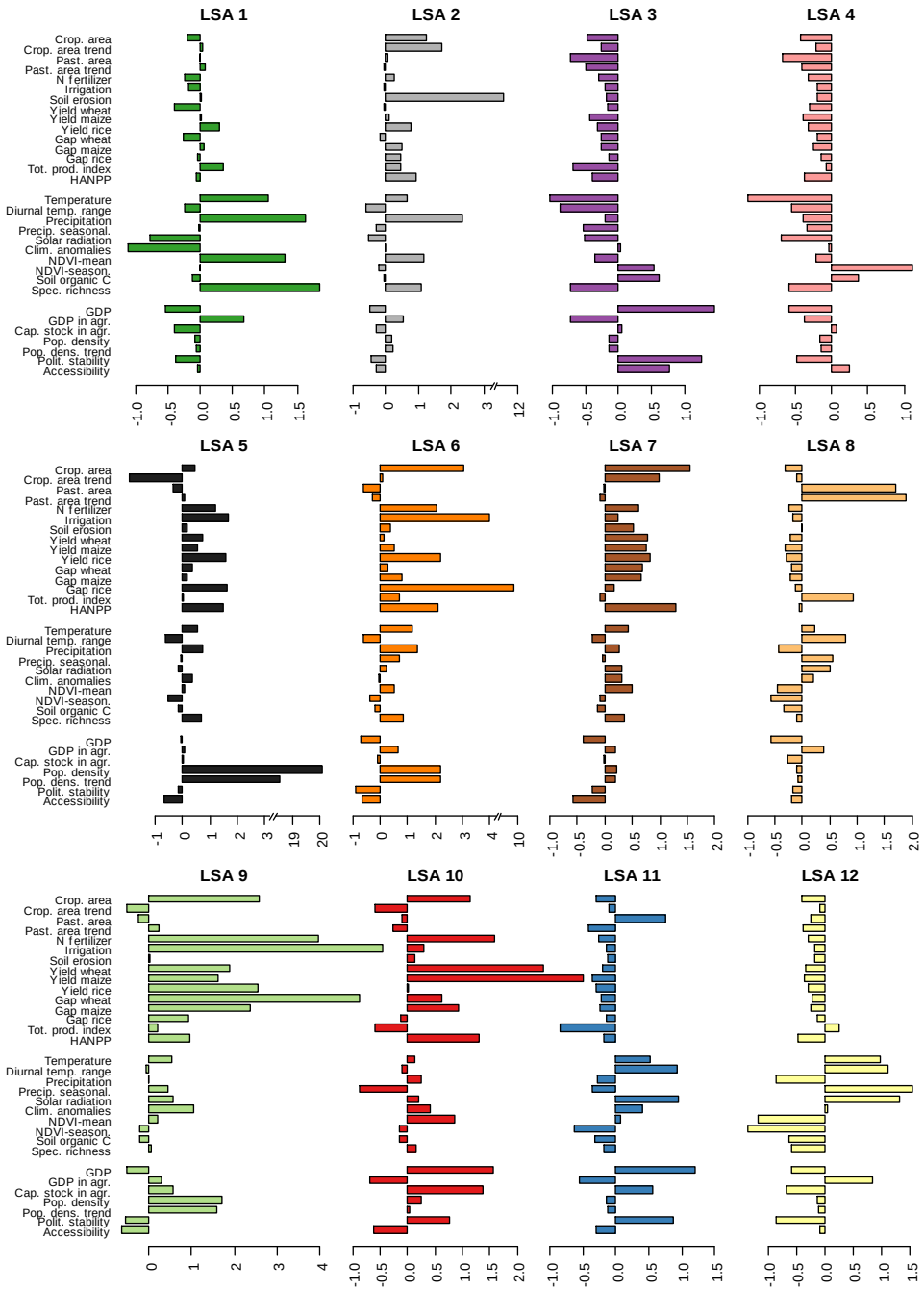
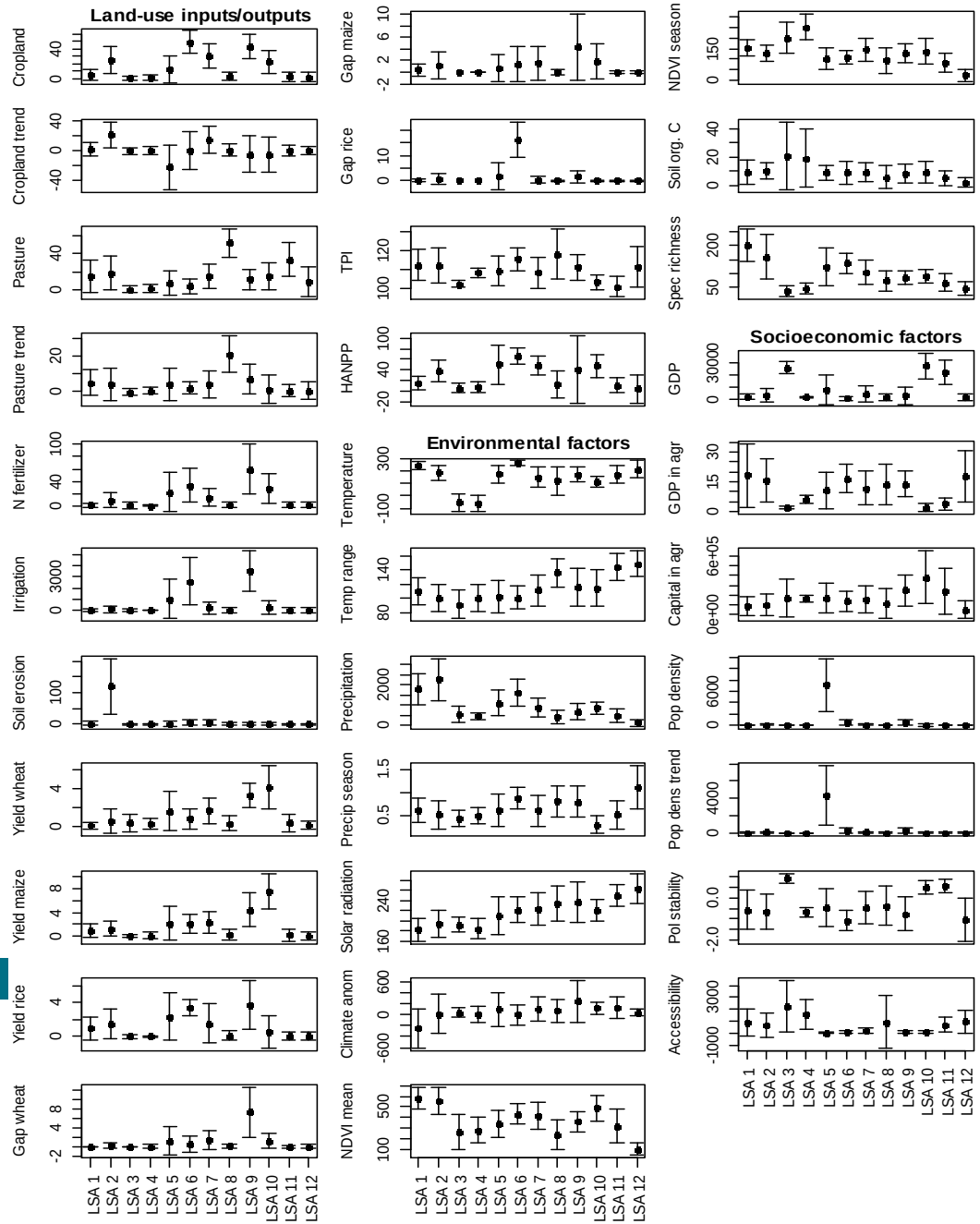


- Self-organizing map with plotted codebook vectors, i.e. the combination of normalized variable values that best characterize each land system archetype

Self-organizing map

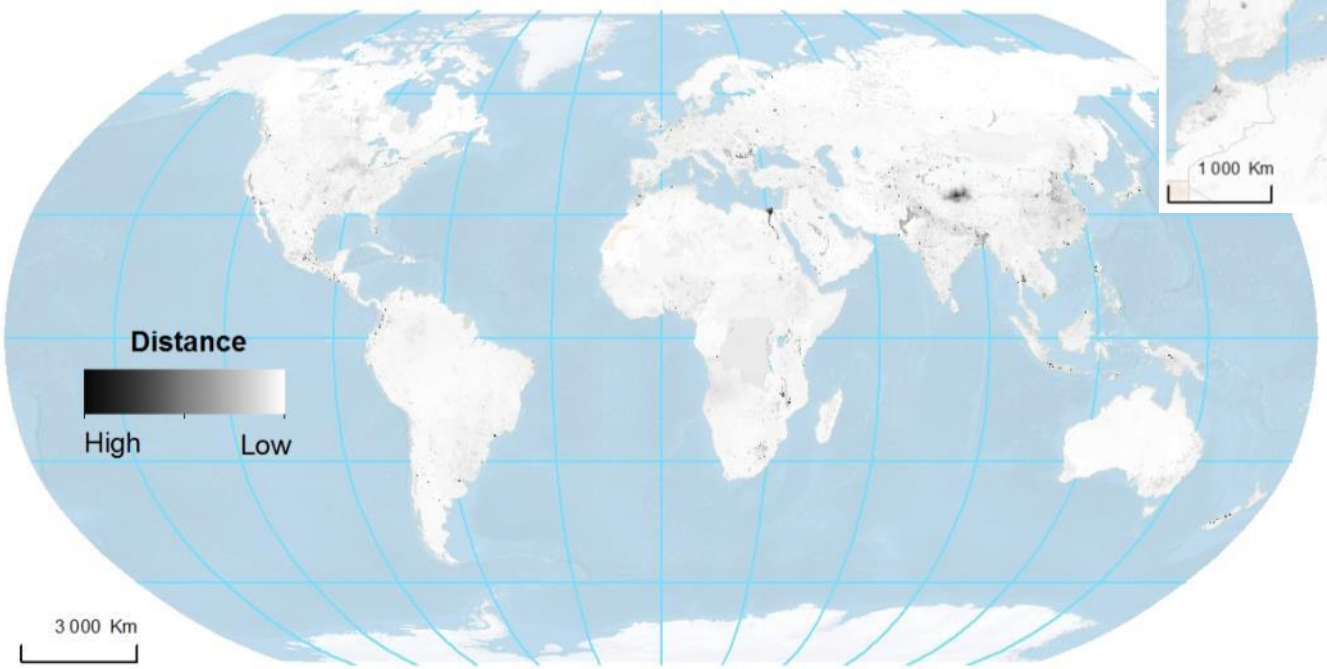


- Comparison of land-use input/output indicators, environmental conditions and socioeconomic factors that characterize each land system archetype
- Dots represent mean values; whiskers represent standard deviations

Self-organizing map

Quality assessment: distance map

- Distance of each grid cell, mapped to a particular cluster, to the codebook vector of that cluster



- Low values indicate good quality of mapping

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