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SUSTAINABLE LAND MANAGEMENT

GLUES

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Approaches for synthesizing information on global patterns of land use and biodiversity

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on behalf of the GLUES project

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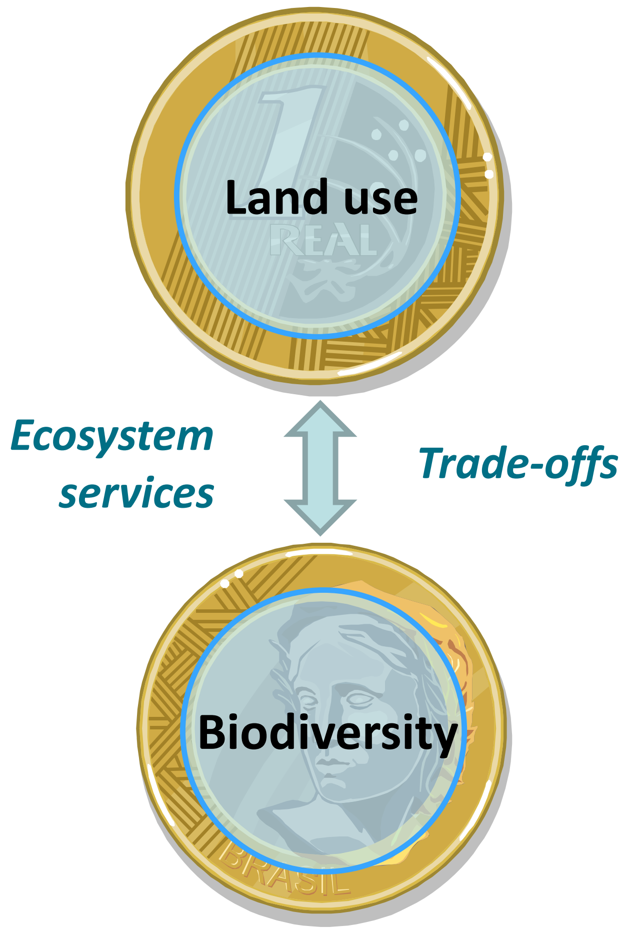
www.sustainable-landmanagement.net

Sustainable Land Management

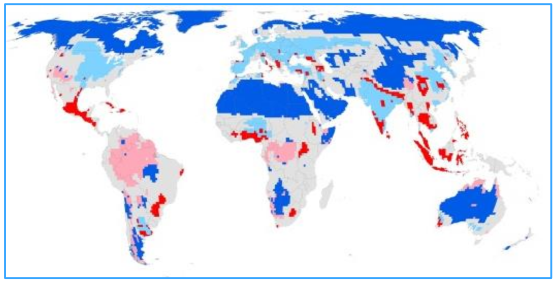
- Land use is a major driver of biodiversity loss
- Agriculture and biodiversity often regarded as separate concerns
- Land use linked with biodiversity via ecosystem services
- Trade-offs inherent in the need to conserve biodiversity while producing more food

Need for synthesis of knowledge on land use and biodiversity

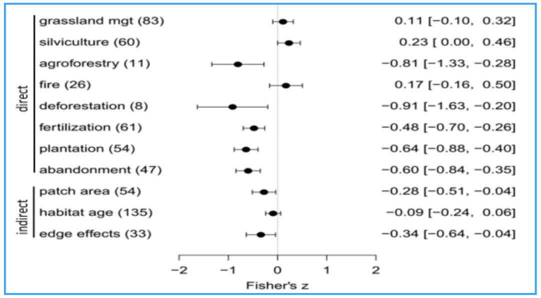


Synthesis of knowledge on land use and biodiversity

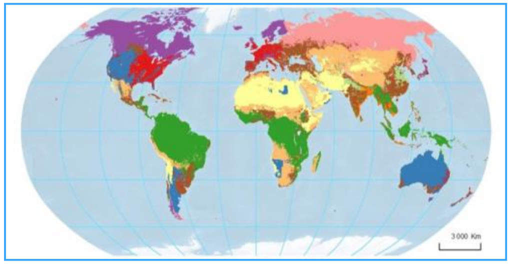
1. Where does land use threaten global biodiversity?



2. How does land use affects global biodiversity?



3. How to better represent land use and map it as land systems across the world?



1. Where does land use threaten biodiversity?

- More food, fibre and bioenergy needed in the future
- Sustainable intensification gaining support over expansion into natural areas
- Negative effects on biodiversity
  - irrigated areas doubled in size
  - fertilizer application up 500%

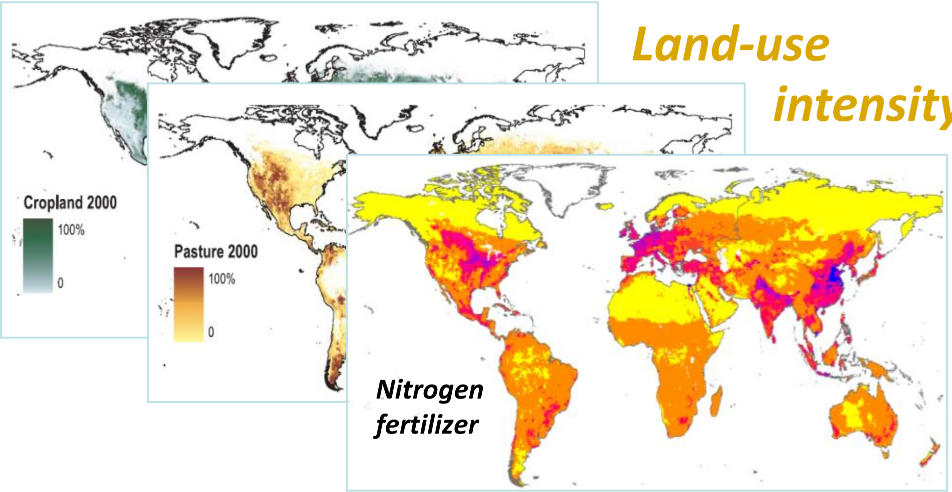
Problem:

- Research generally focuses only on **one metric** at **local to regional scale**

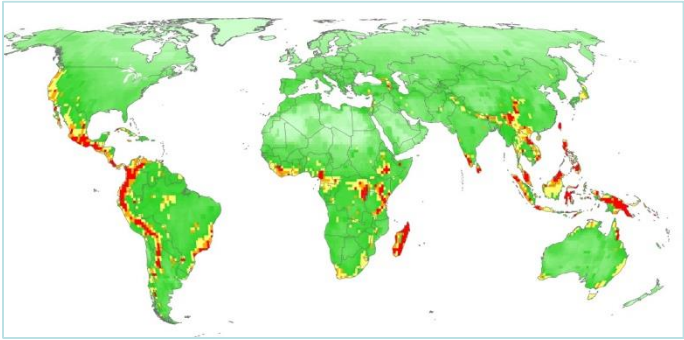
Research questions

1. How do patterns of land-use intensity relate to the spatial distribution of biodiversity?
2. Where are hotspots of potential conflict between high land-use intensity and high biodiversity?

Land-use intensity



Biodiversity



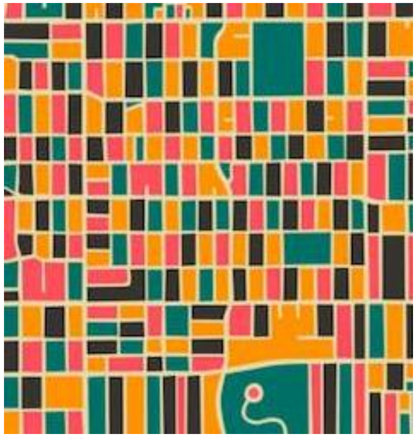
Land use intensity as a multidimensional issue

SYSTEM

- **HANPP** *(Haberl et al. 2007)*
- **Yield Gaps** *(Neumann et al. 2010)*

INPUTS

- **Cropland** *(Ramankutty et al. 2008)*
- **Livestock** *(Wint et al. 2007)*
- **Fertiliser** *(Potter et al. 2010)*
- **Irrigation** *(Siebert et al. 2005)*



OUTPUTS

- **Yields** - Rice, Maize & Wheat
- **Harvested Areas** - Soy & Palm Oil *(Monfreda et al. 2008)*

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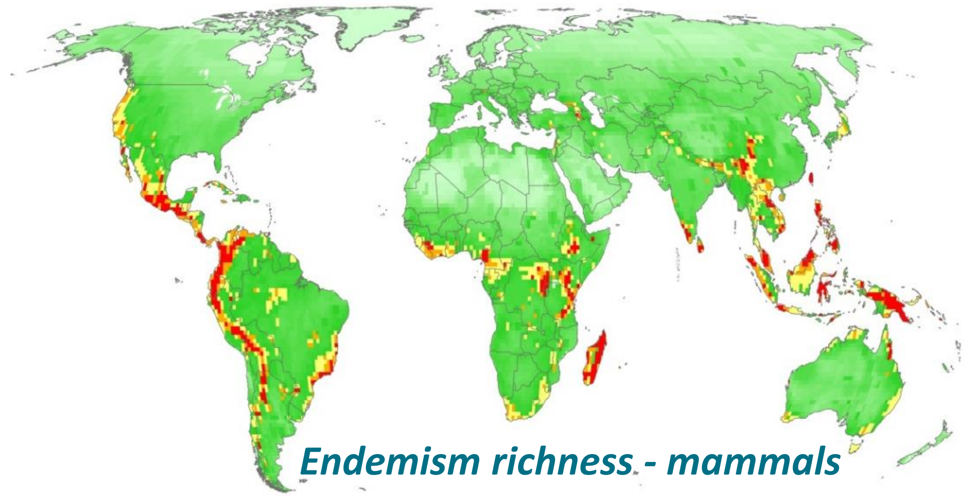
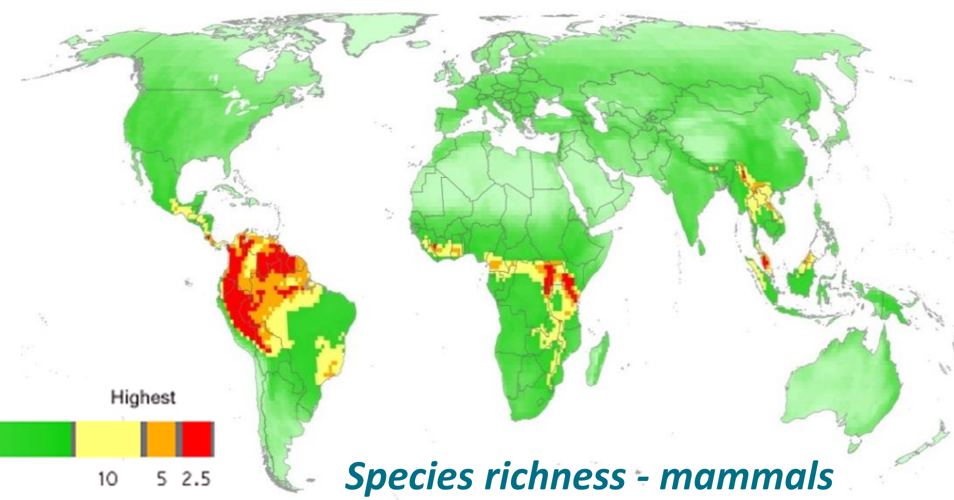
Dimensions of land-use intensity

(Erb et al. 2013, Kuemmerle et al. 2013)

Endemism Richness

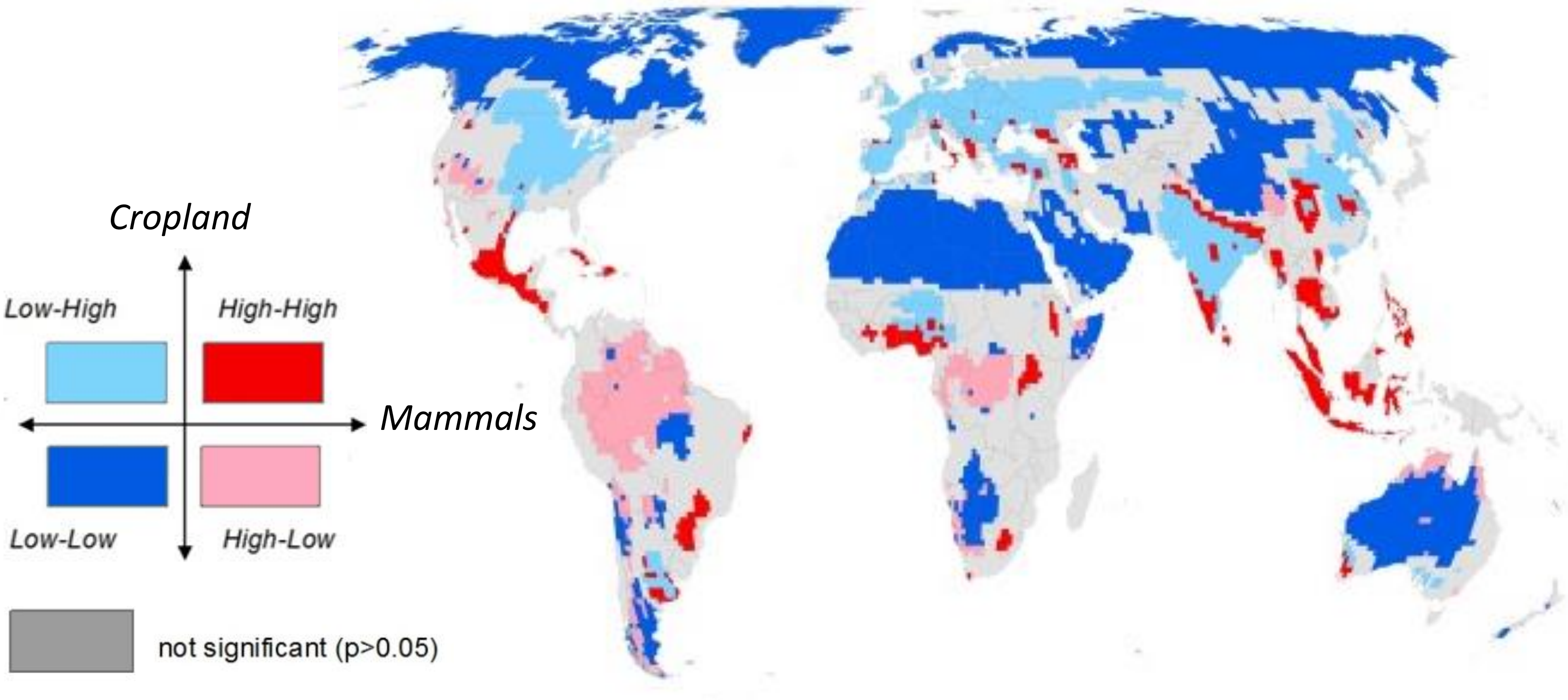
- Combines a range size-weighted species richness indicator
- Indicator of the importance of a grid cell for conservation
- Global maps for mammals , birds and amphibians from IUCN (2012) and Birdlife (2012) data.


Endemism richness - mammals


Species richness - mammals

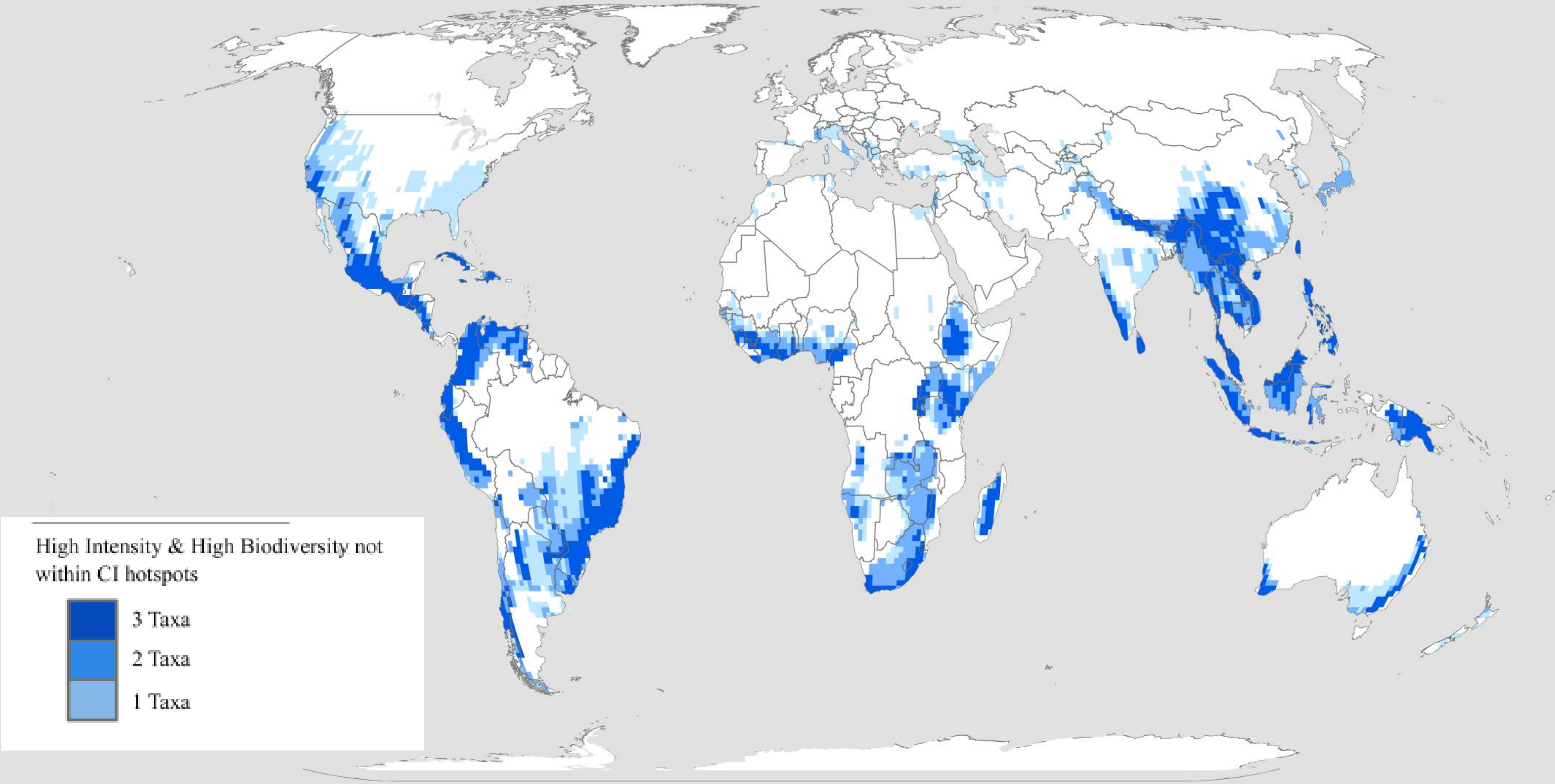
Spatial association between LUI and biodiversity

- Local indicator of spatial association (LISA, Anselin 1995)



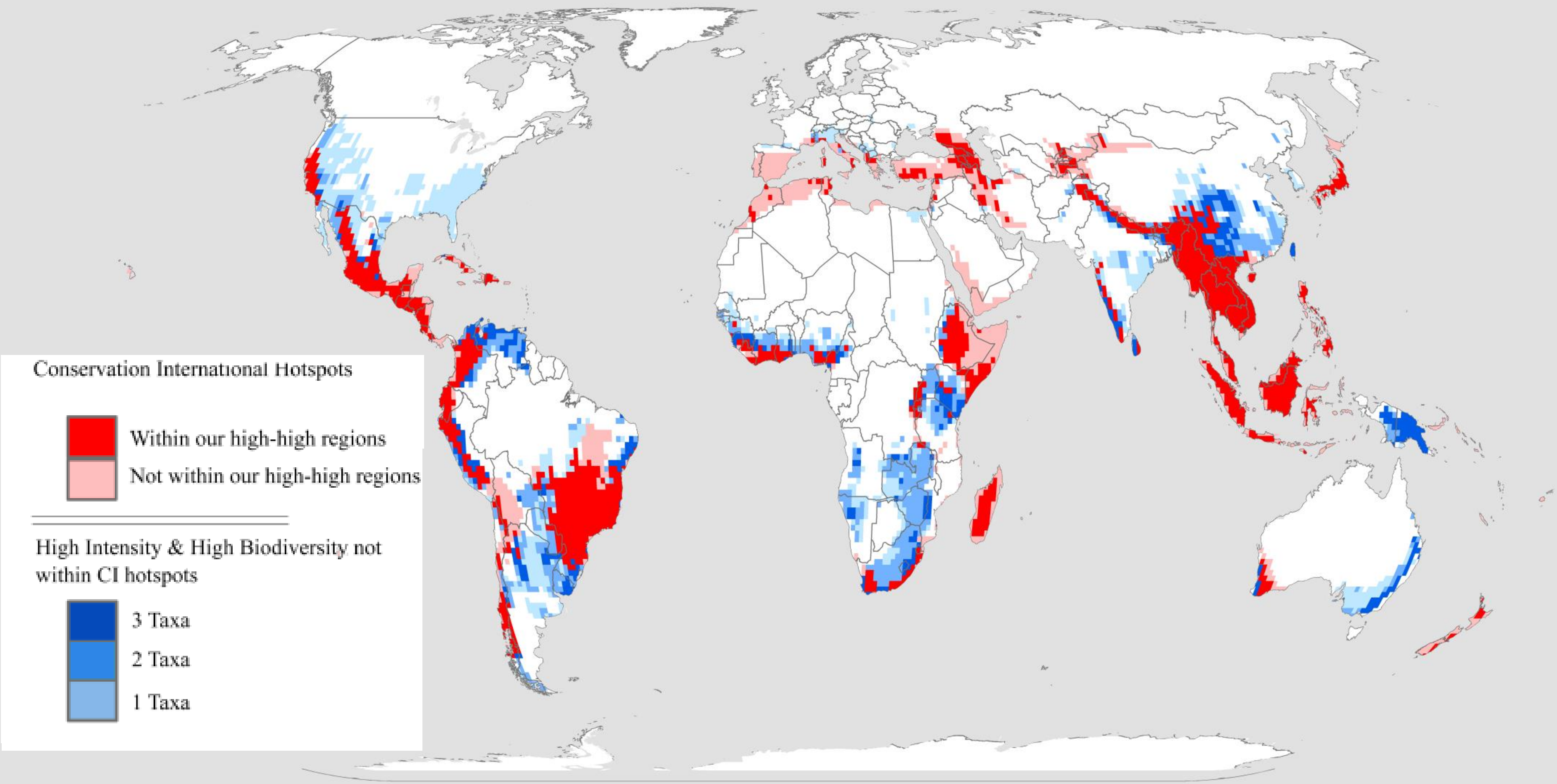
Spatial association of high LUI and high biodiversity

- combined results for all land-use intensity metrics

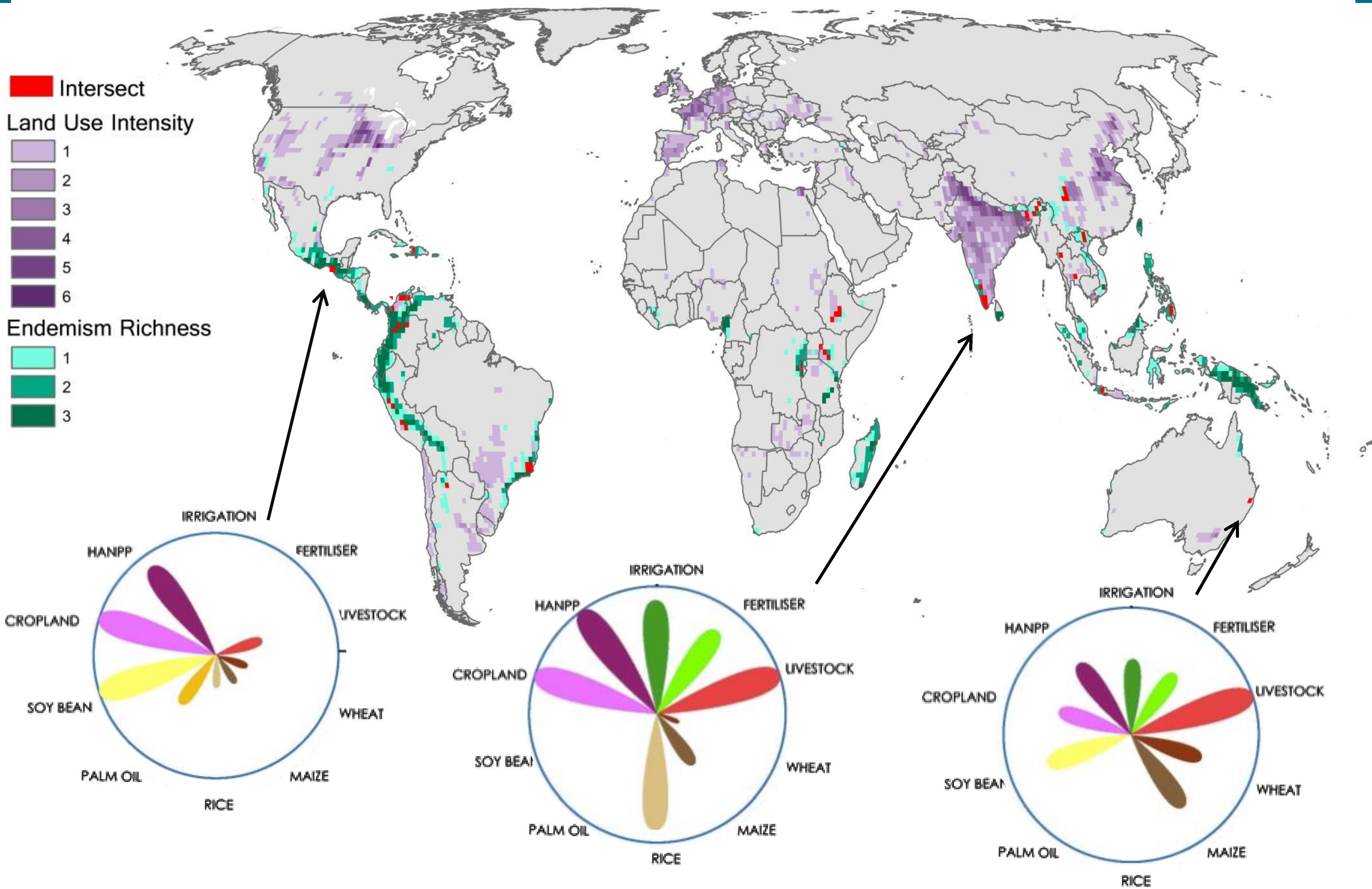


Spatial association of high LUI and high biodiversity

- compared to Conservation International (CI) hotspots



Top 2.5% Regions of Land Use Intensity and Biodiversity



Conclusions

- Most assessments of land-use impacts on biodiversity either disregarded LUI or include a single metric to measure it. This can underestimate biodiversity threat.
- A wider spectrum of relevant LUI metrics should be considered when balancing the needs of agricultural production and biodiversity.


Image: Landscapes Blog

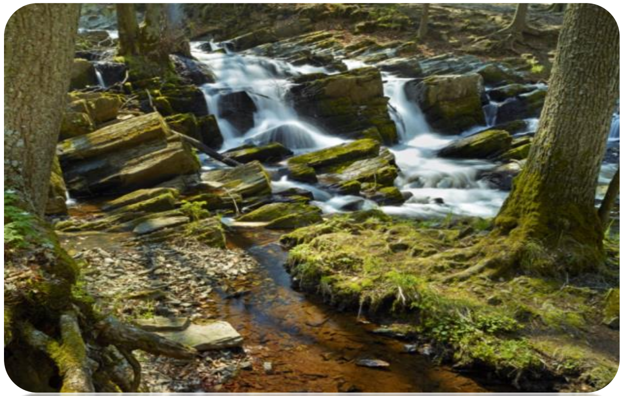
2. How does land use affects diversity of plants?

- Plant diversity is essential for human well-being

Food provisioning

Wood production

Climate regulation



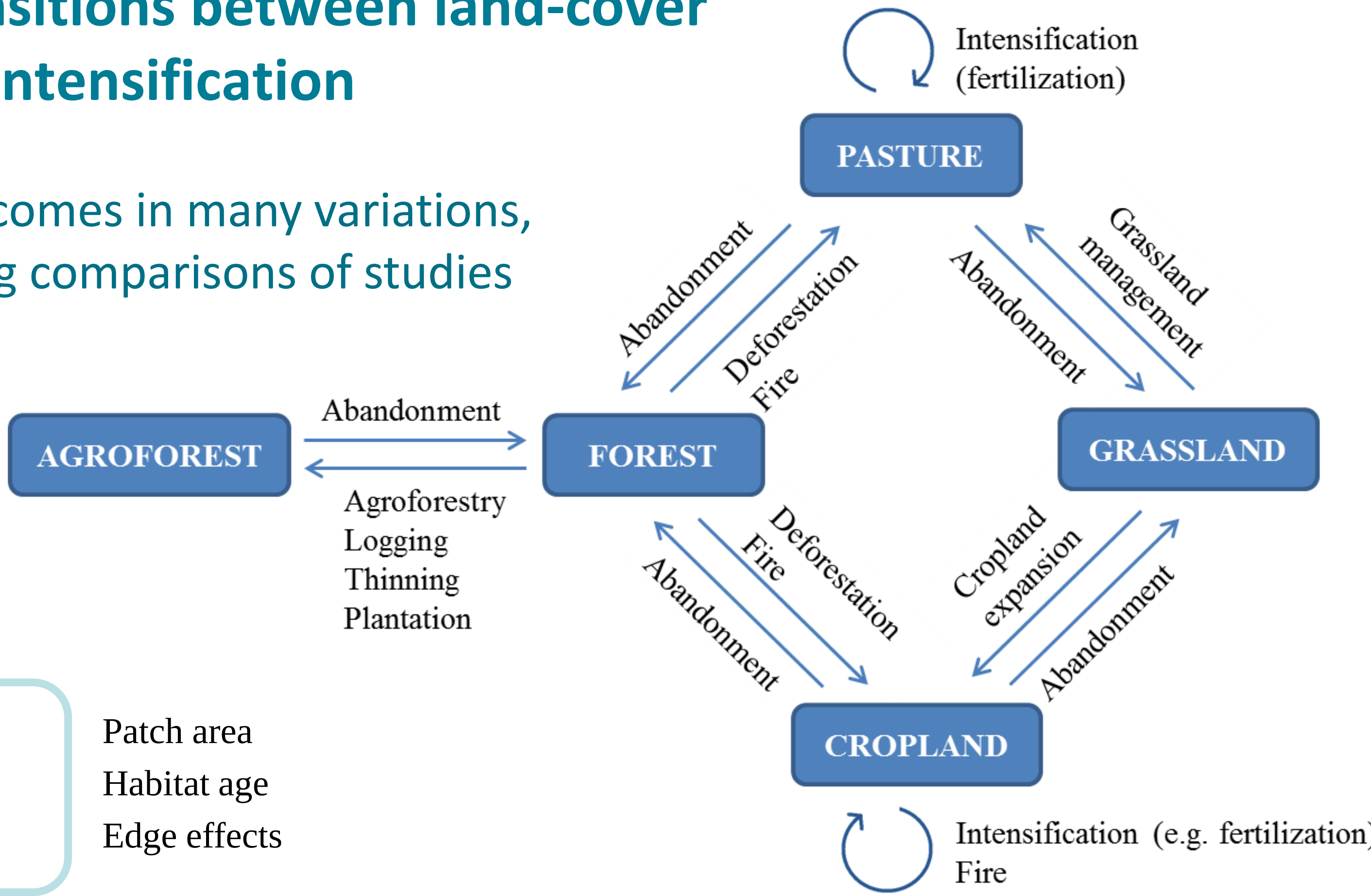
Water purification

Land use is the main driver of global decline in plant diversity

- Numerous studies examined land use effects on plant diversity at local to regional scales
- Evidence for declining species diversity is mixed

Typical transitions between land-cover states and intensification

- Land use comes in many variations, hampering comparisons of studies



INDIRECT EFFECTS

Patch area
Habitat age
Edge effects

Effects of land use on plant diversity – A global meta-analysis

Research questions

1. What is the direction and magnitude of effects of different land-use options on plant species richness worldwide?
2. How important are land-use specific and study-specific covariables (study design, environmental and socio-economic context)?

Effects of land use on plant diversity – A global meta-analysis

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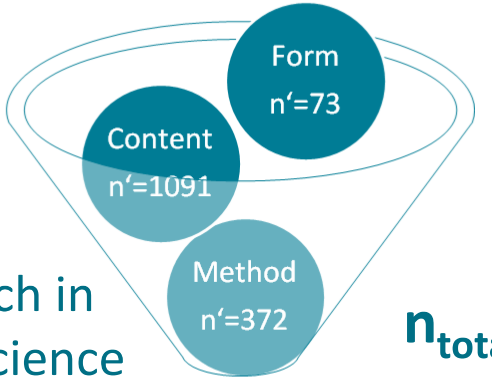
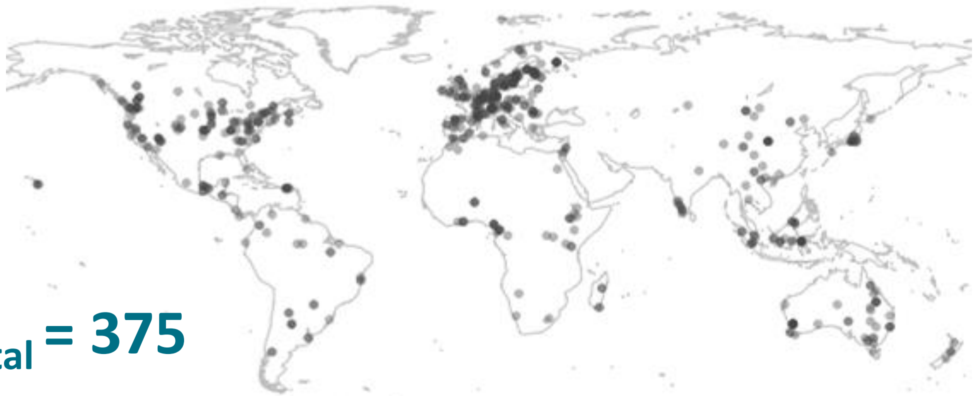
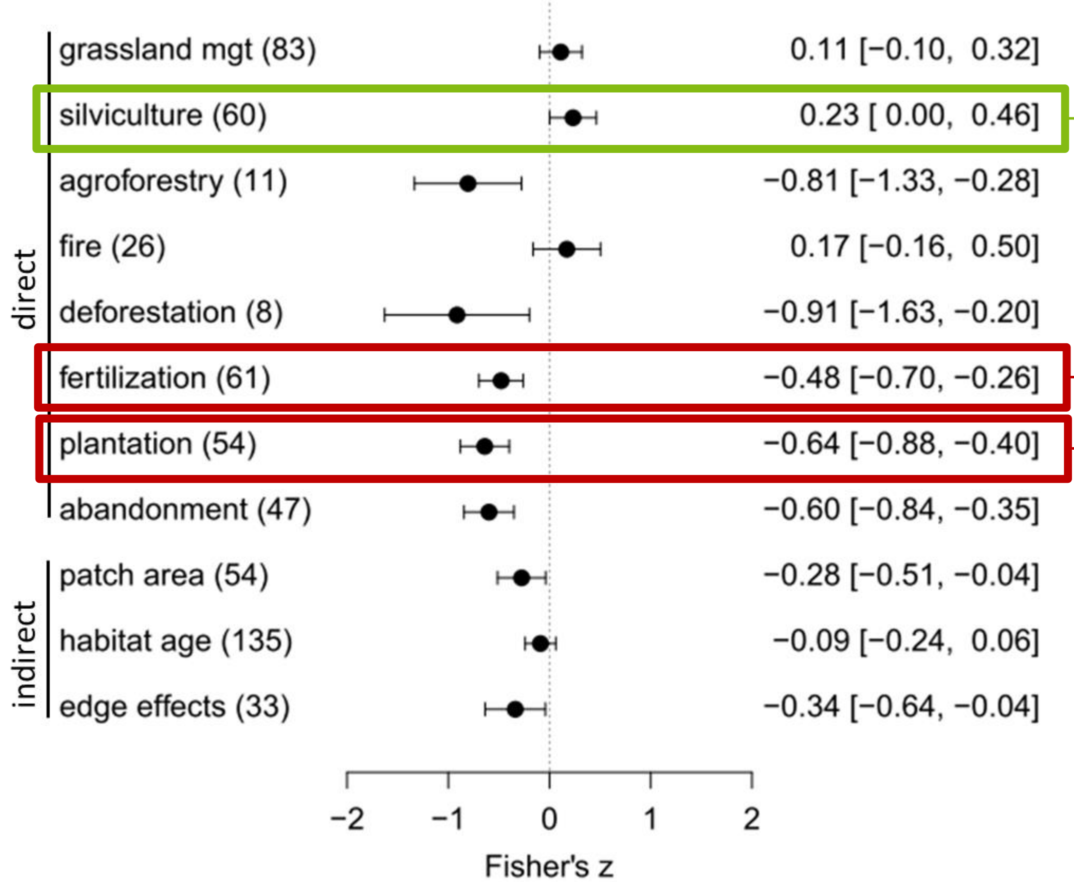
- Title search in Web of Science



n_{total} = 375



Land use effects mainly in accordance with existing theory

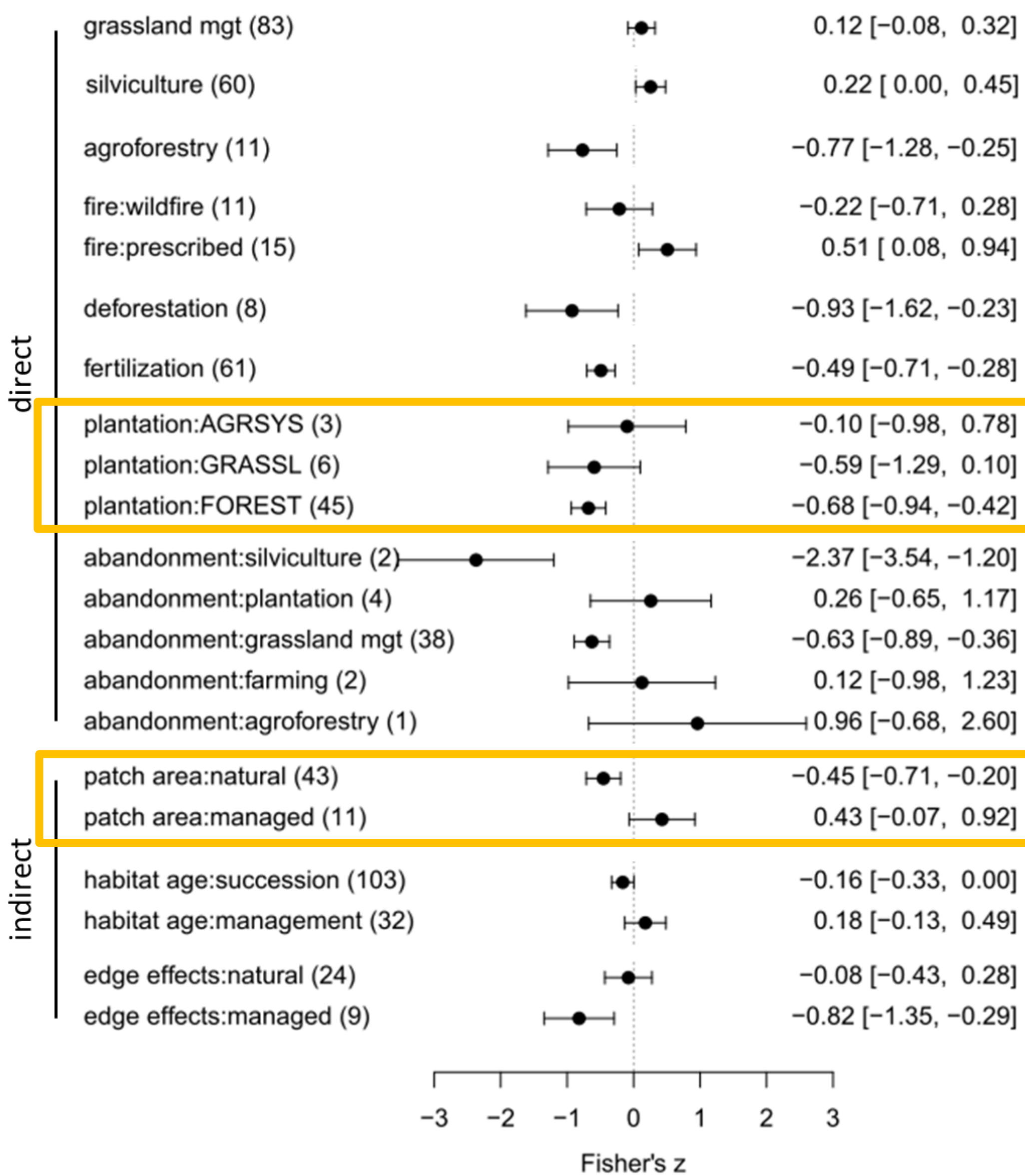


Positive effect on species richness due to moderate disturbance

Negative effect because high amounts of nutrients only favour single species, which then dominate the community

Negative effect because dominant species in monoculture plantations compete for light, etc.

Most of the variation explained by land-use specific covariables



Negative effects of ***plantations*** *only apparent when plantations replaced forest rather than agroecosystems or grasslands*

Land-use expansion*, i.e. the patch size increase of managed area at the expense of remaining natural land, showed negative effects.*

Results: Effect of land-use specific covariables

Confounding effects and limitations

- Less widespread forms of land use not considered (e.g pesticide application, restoration)
- Possibly missed studies due to data requirements or inconsistent terminology
- Need for a consistent land use classification scheme
- Need to analyze other metrics than species richness (diversity, composition)

Biodiversity measure → ***Ecosystem functioning*** → ***Ecosystem services***

3. How to represent and map land systems?

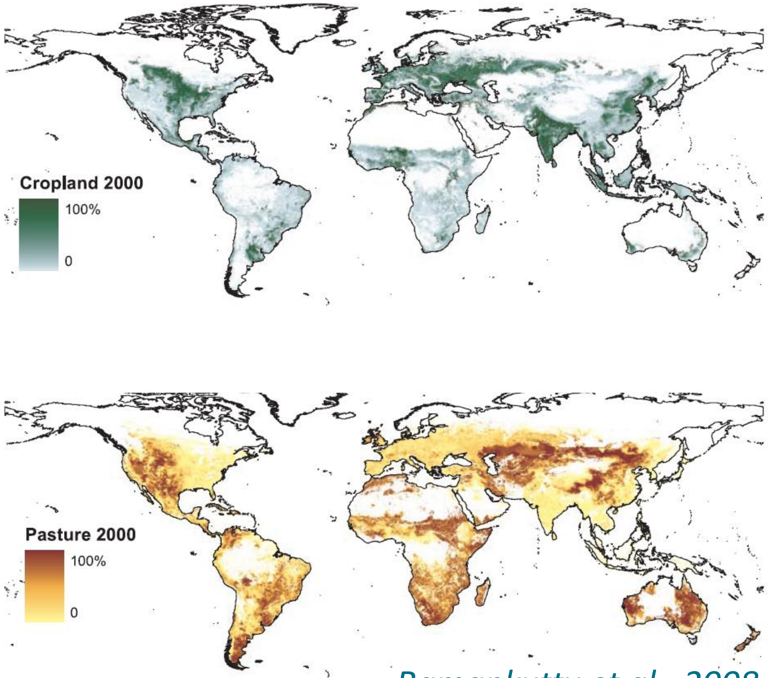
- Meeting future demands for food and other commodities will require land-based production to expand or intensify

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



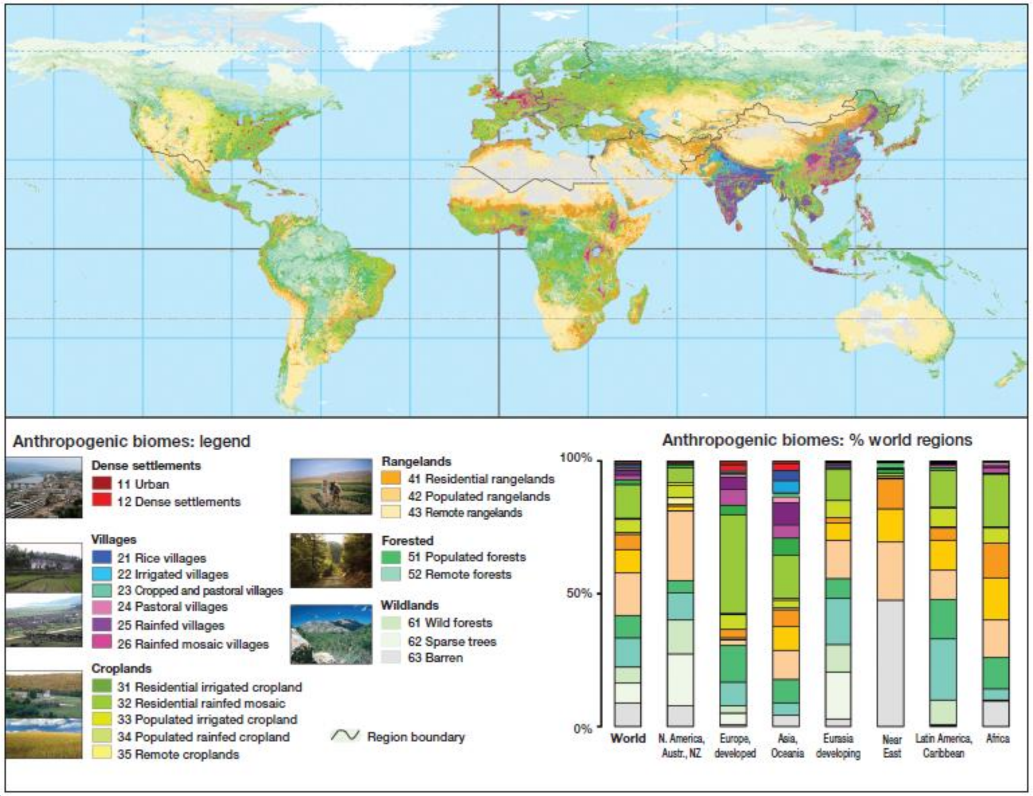
Ramankutty et al., 2008

Current representations of land systems

Recent studies (Ellis & Ramankutty 2008, 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*



Current representations of land systems

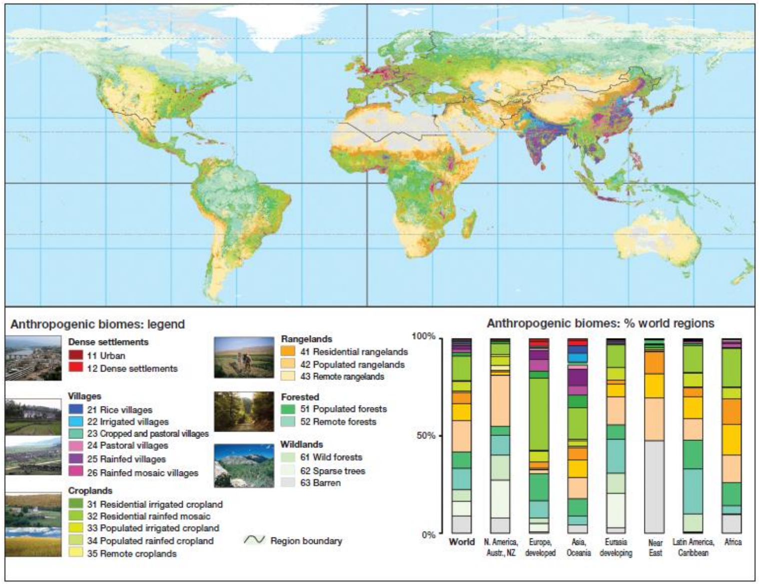
Aim: Mapping land system archetypes (LSAs)

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

- **Land system archetypes:** unique patterns of:
  - land-use intensity
  - 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

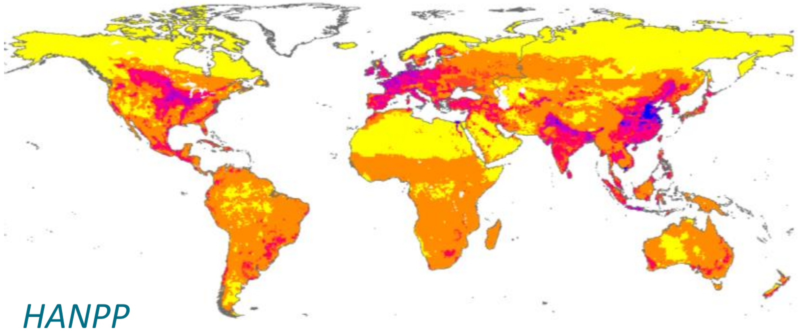
Data: global indicators of land systems

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

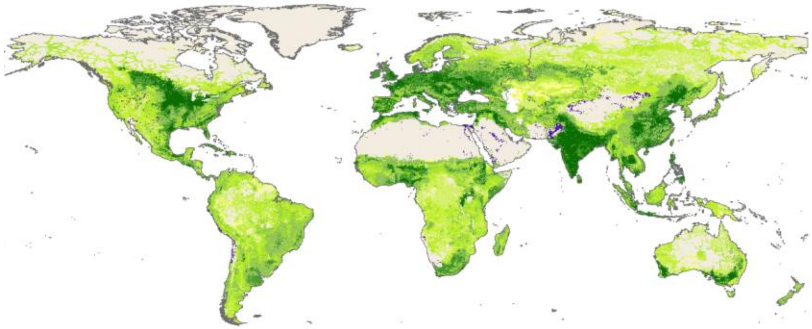
1) Land-use intensity

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



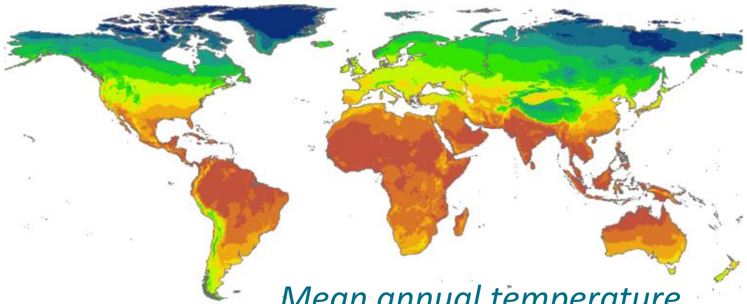
HANPP



Data: global indicators of land systems

2) Environmental conditions

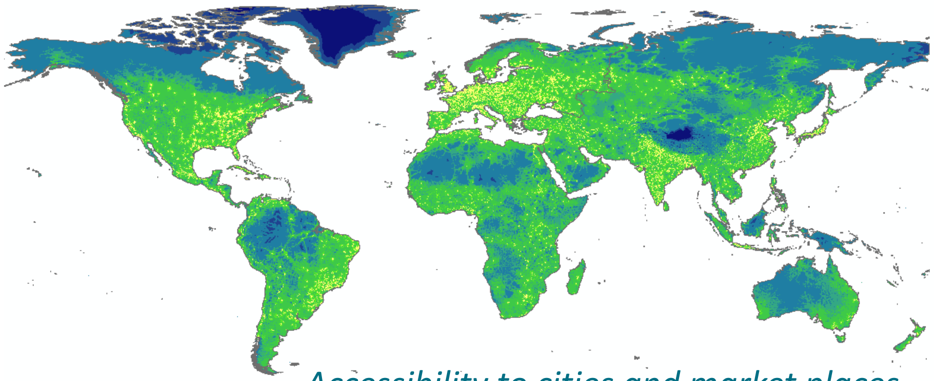
Factor	Unit
Temperature	°C × 10
Diurnal temperature range	°C × 10
Precipitation	mm
Precipitation seasonality	coeff. of variation
Solar radiation	W m^{-2}
Climate anomalies	°C × 10
NDVI – mean, seasonality	index
Soil organic carbon	g C kg^{-1} of soil
Species richness	# of species



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

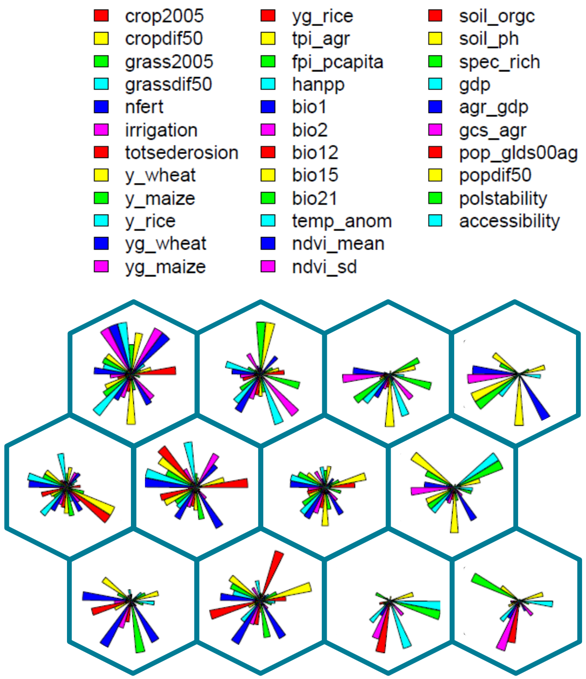


Accessibility to cities and market places

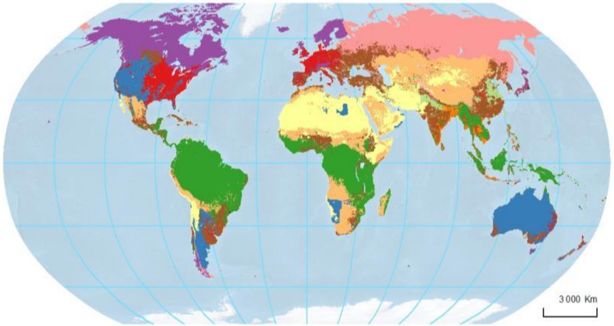
Methods: Archetype classification

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

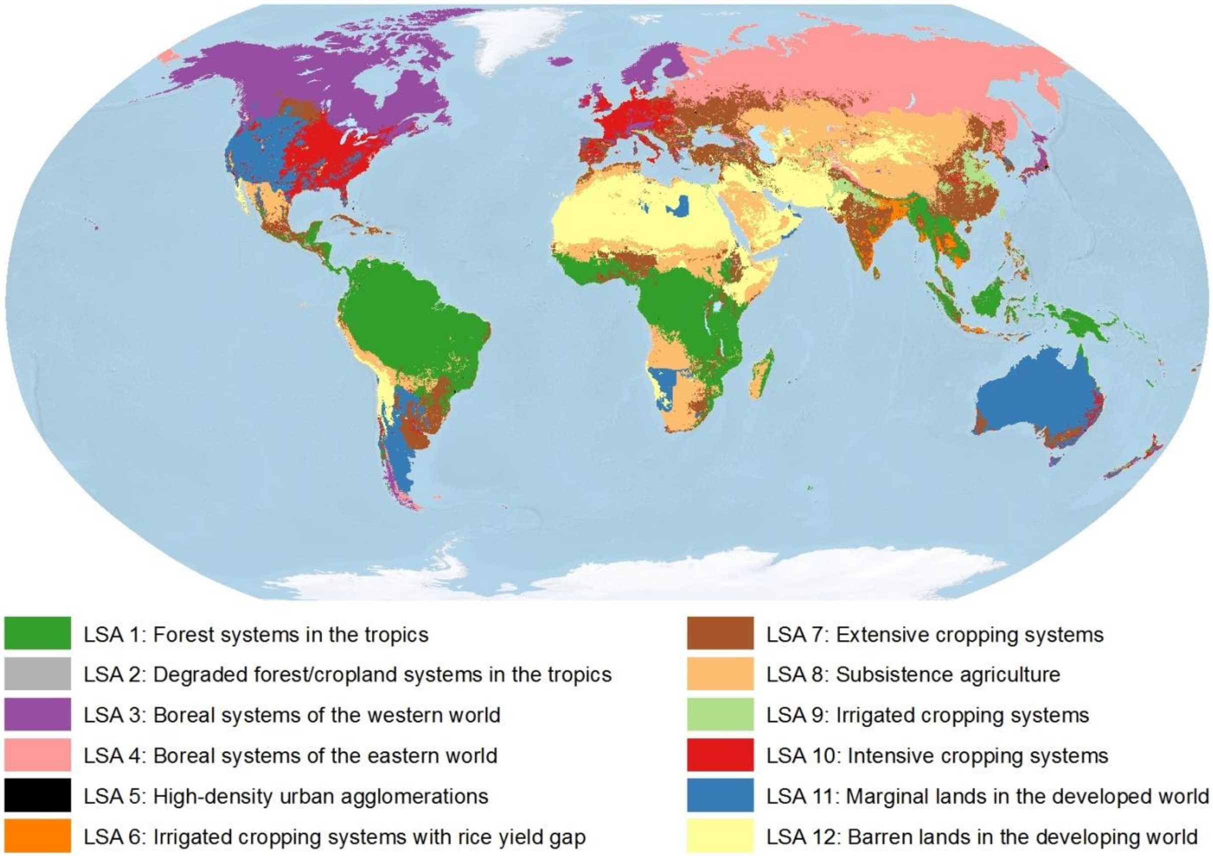
2D topology of SOM



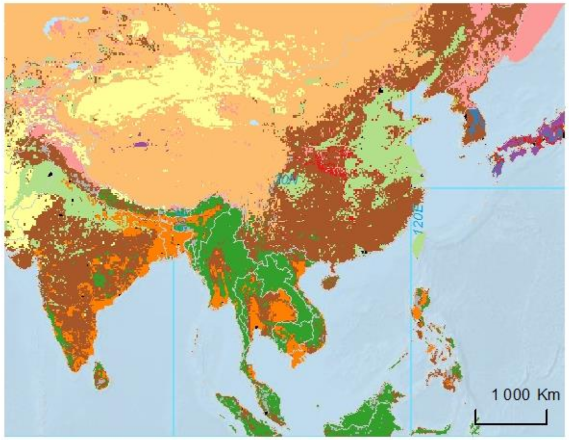
- Visualizing complex datasets by reducing their dimensionality to 2D
- Performing cluster analysis by grouping observations based on their similarity
- Euclidean distance interpreted as a measure of (dis)similarity



Results: Land system archetypes



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



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Results: Land system archetypes

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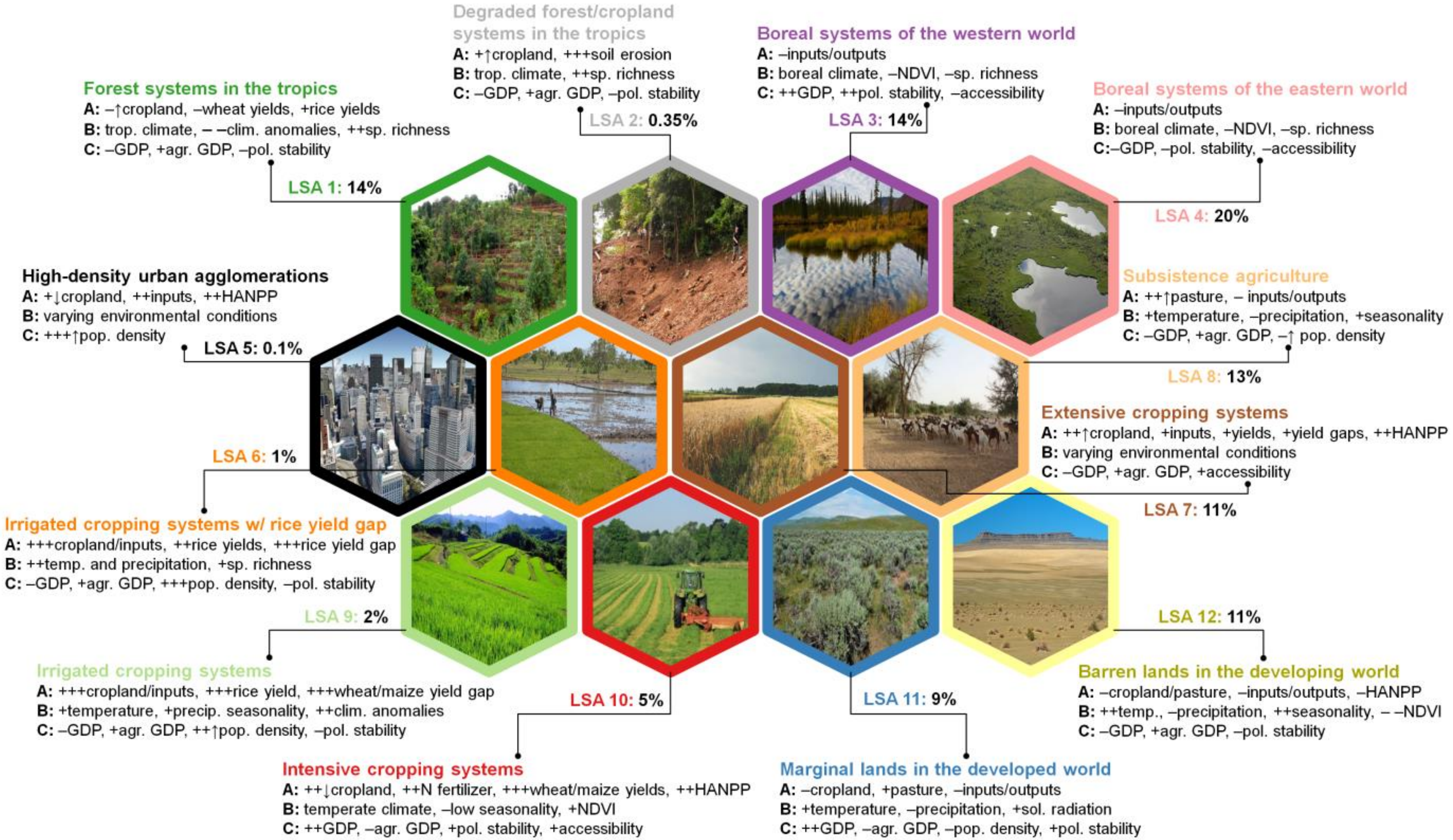


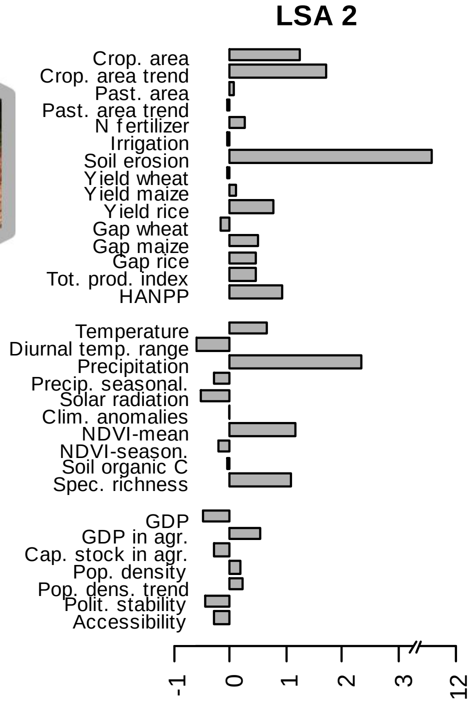
SUSTAINABLE LAND MANAGEMENT

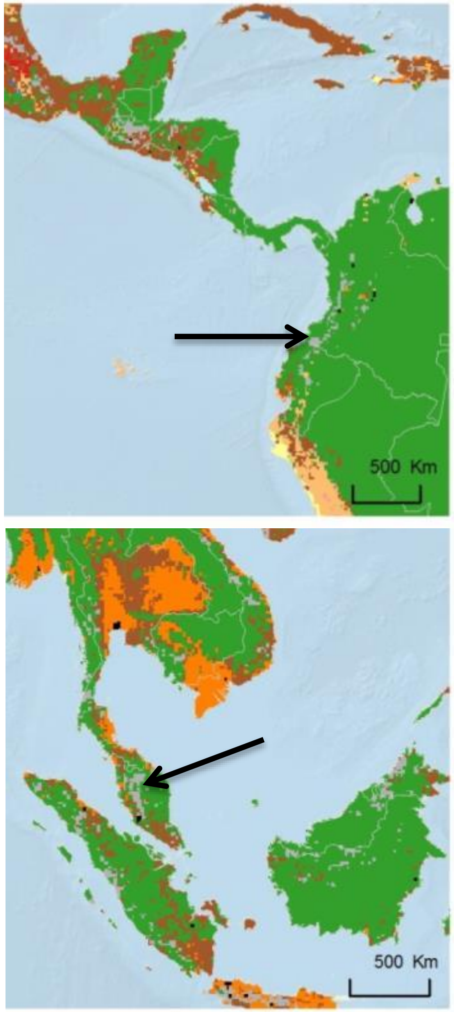
Interpreting land system archetypes

- 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

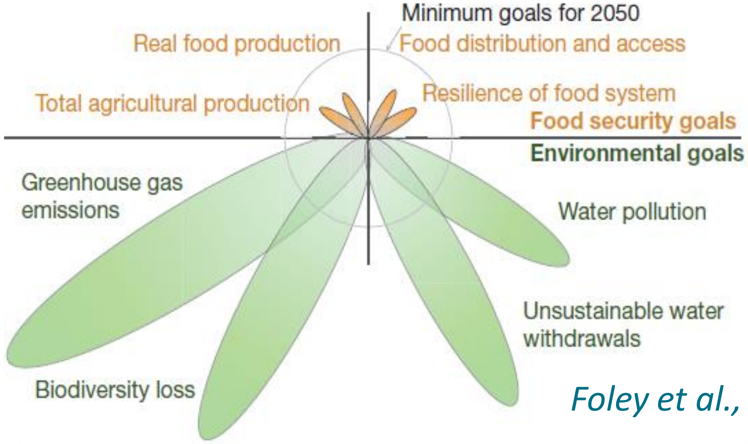
Interpreting land system archetypes

- 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"

Interpreting land system archetypes

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Example: **Yield improvements**

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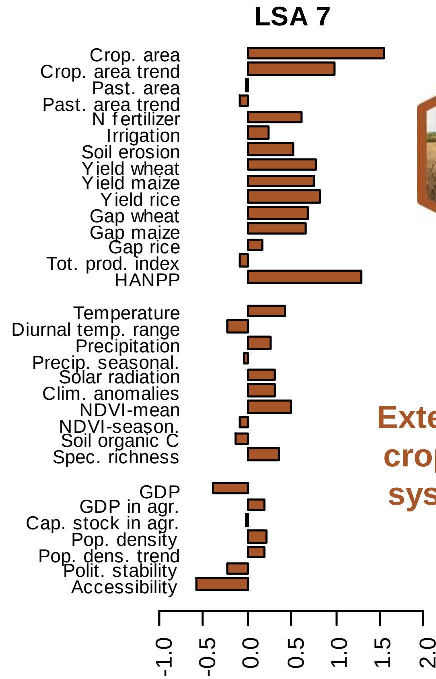
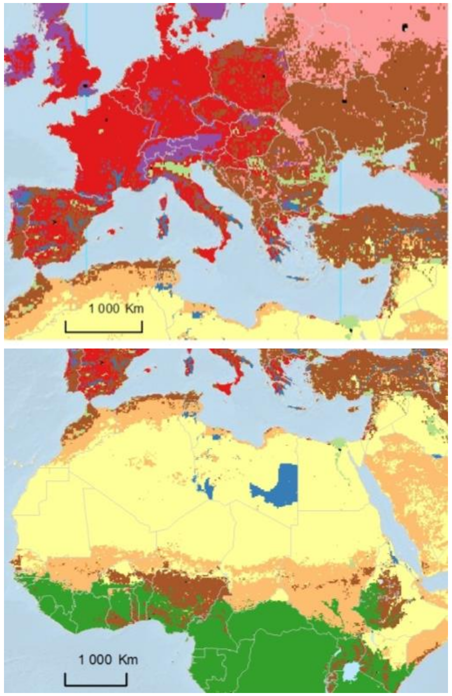
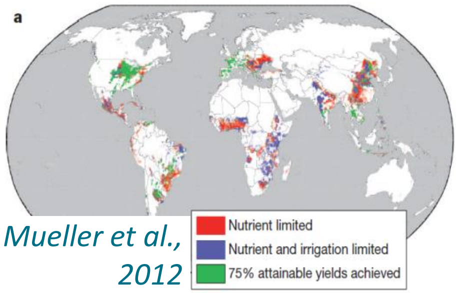


Extensive cropping systems

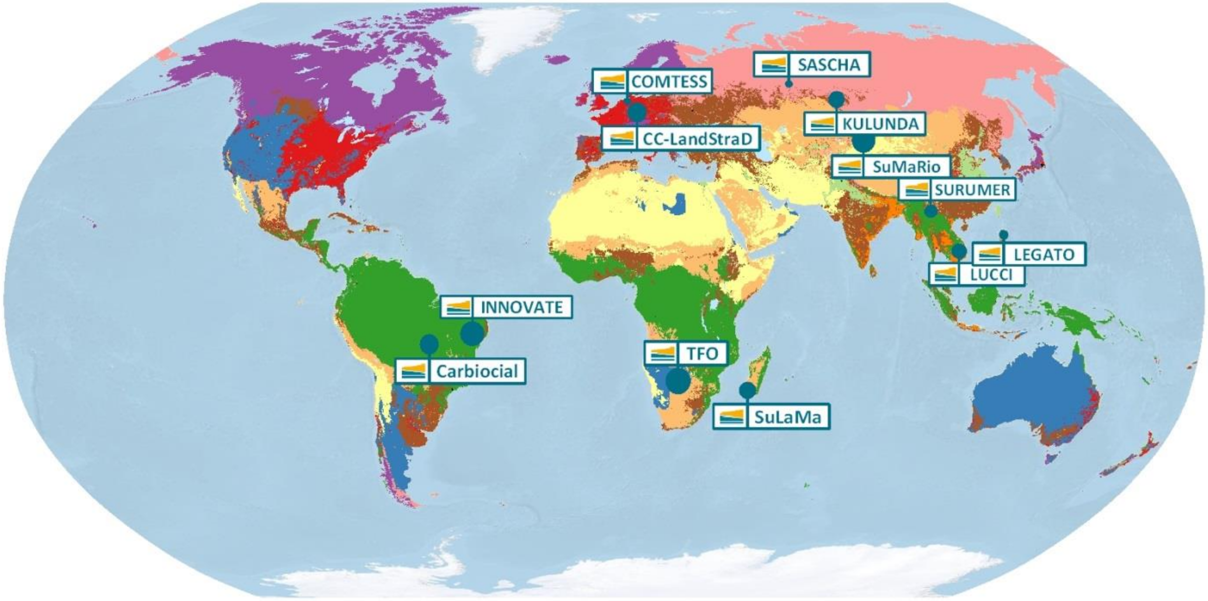




Mueller et al., 2012

Land system archetypes as a framework for synthesis

- How does this translate in the specific regions?
- How does this concept support transfer of results?
- *How the choice of alternative land use strategies affect production and what are the envir. and social outcomes*



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

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SCIENTIFIC COORDINATION AND SYNTHESIS GLUES*

Objectives

- Provide scientific synthesis on general patterns of land use and biodiversity at the global scale
- Develop methods, system solutions and strategies that can be implemented as policies and transferred to other regions

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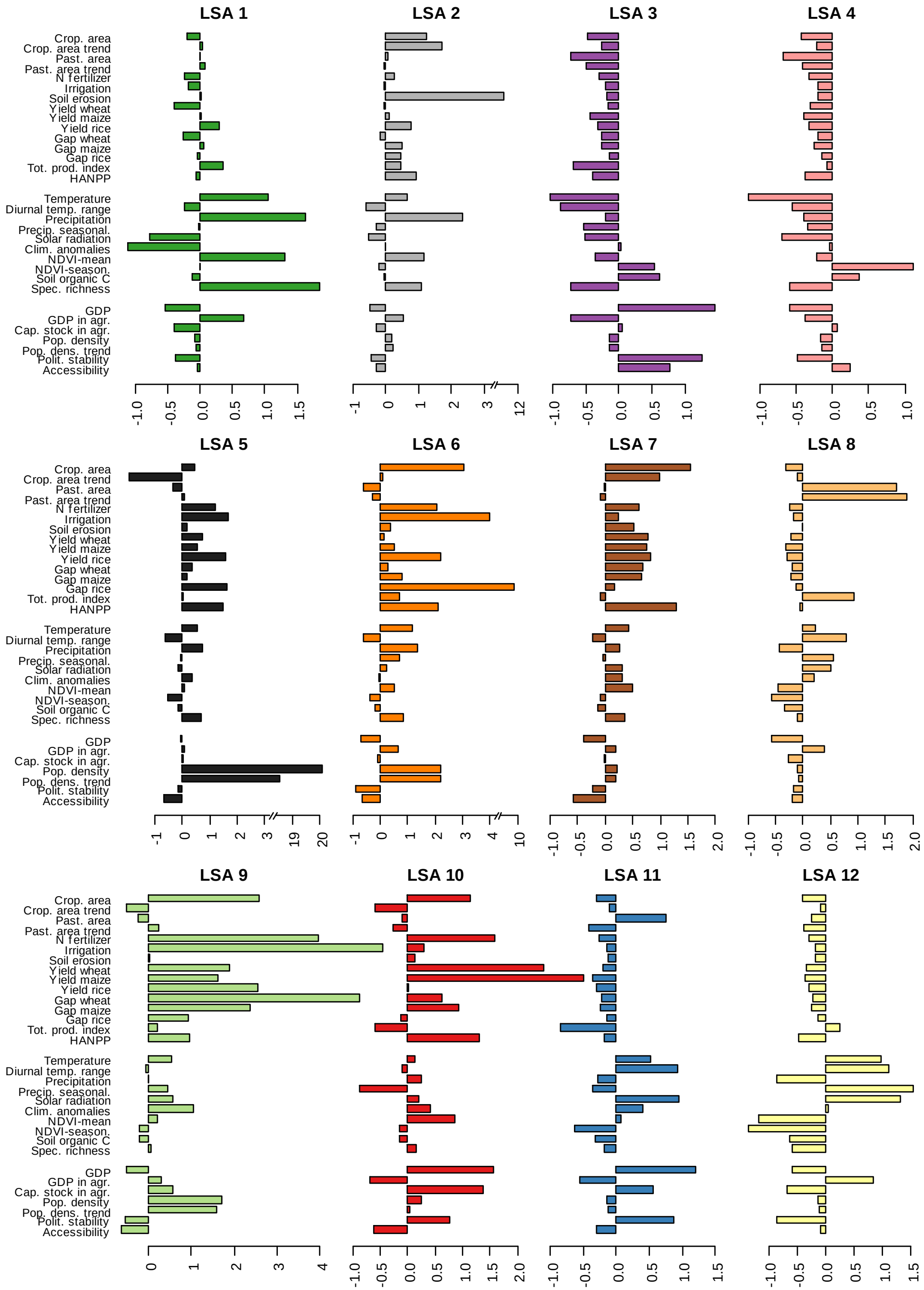
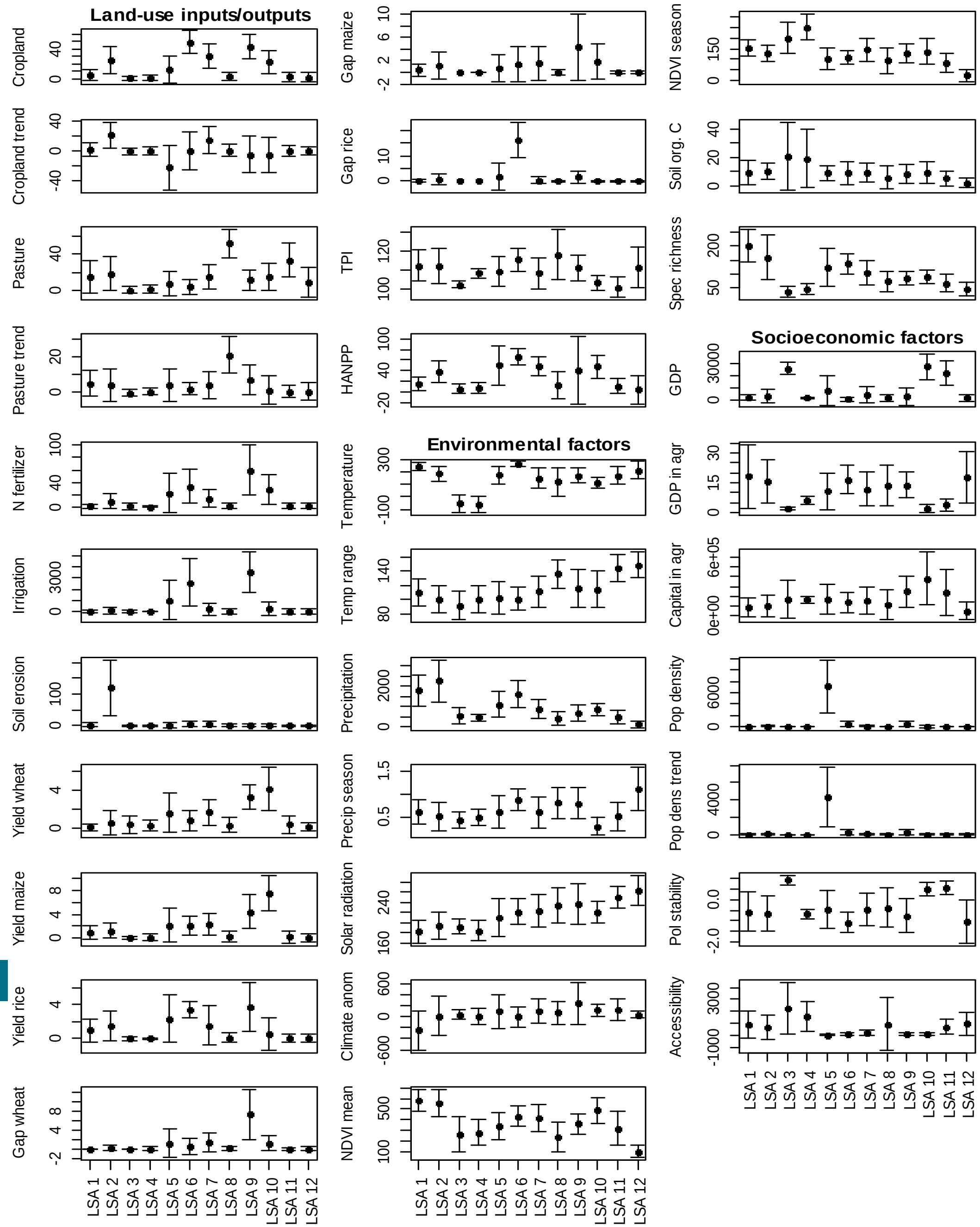
Global Assessment of Land Use Dynamics, Greenhouse Gas Emissions and Ecosystem Services



- 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

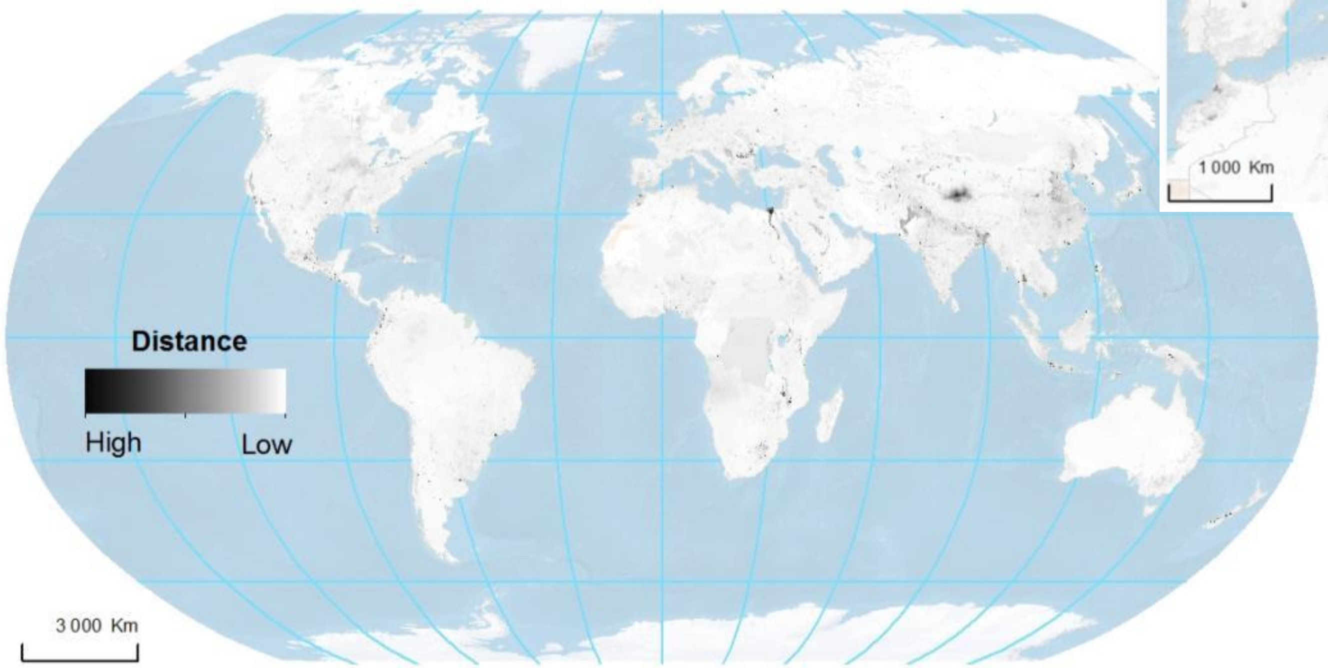


- Comparison of land-use input/output indicators, environmental conditions and socioeconomic factors that characterize each land system archetype
- Dots represent mean values; whiskers represent standard deviations

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

Interpreting land system archetypes

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Example: Yield improvements

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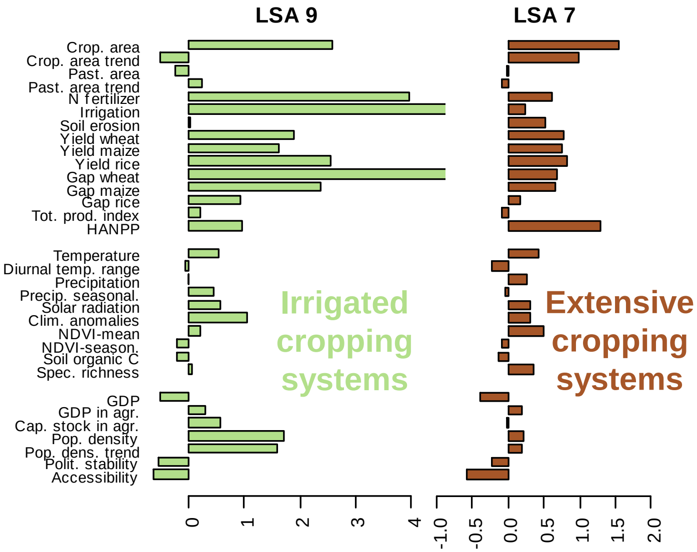
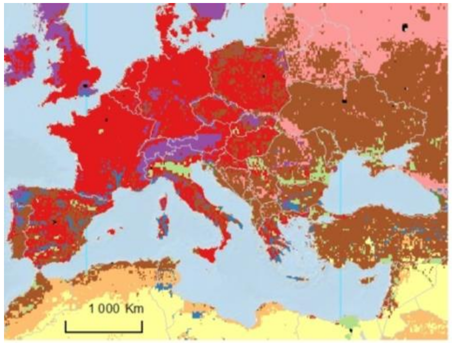
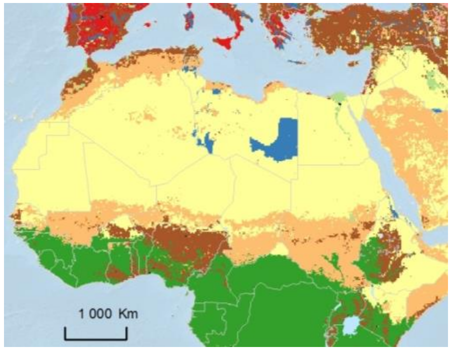
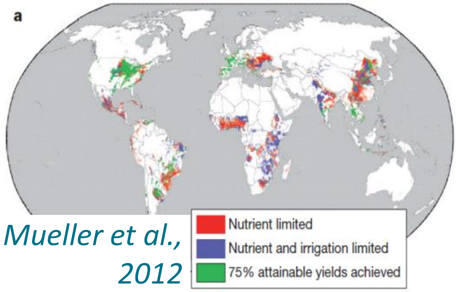


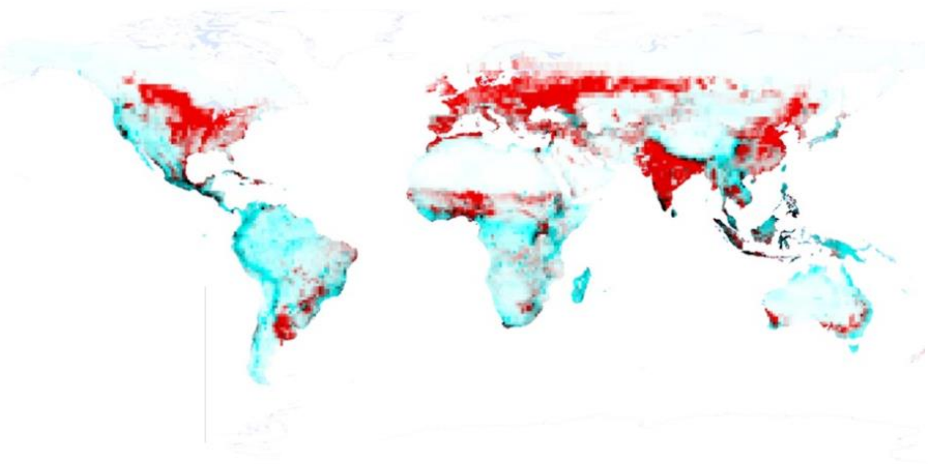






Mueller et al., 2012

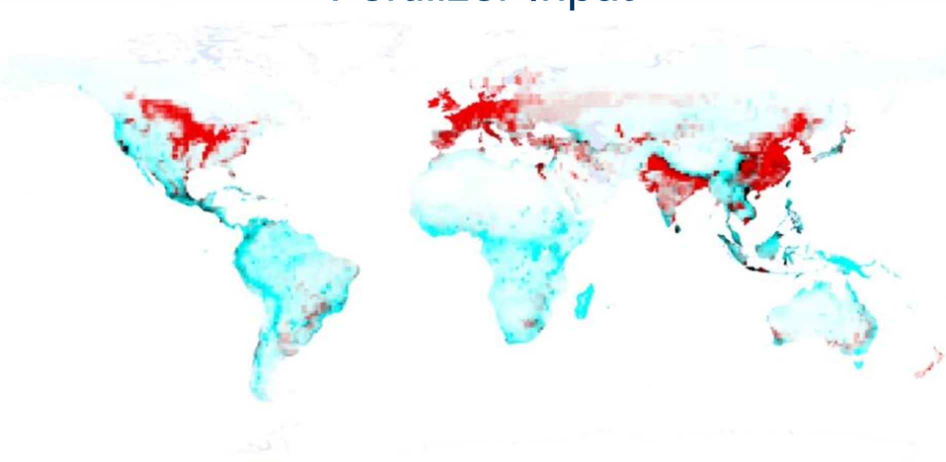
Cropland Cover



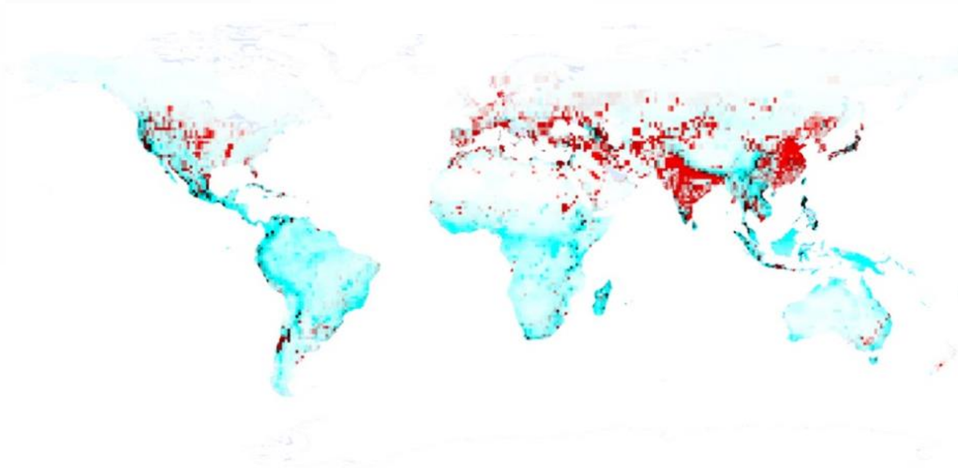
Land Use Intensity Input Metrics

Concordance maps show different input metrics with biodiversity – endemism richness for mammals

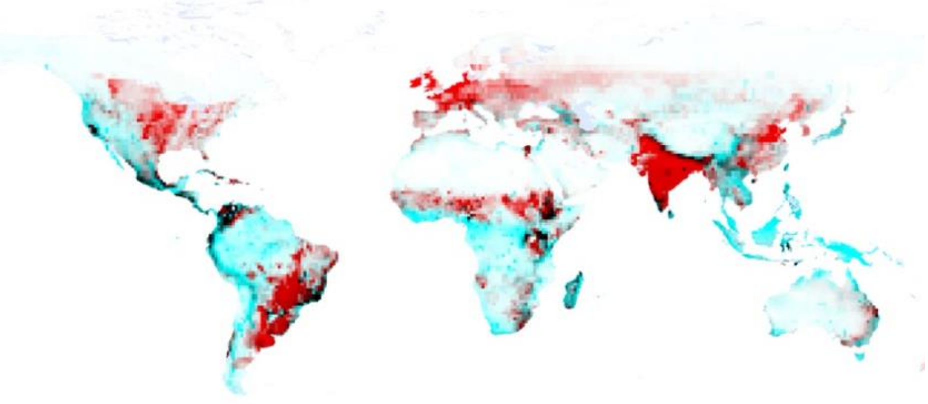
Fertilizer Input



Irrigated Areas



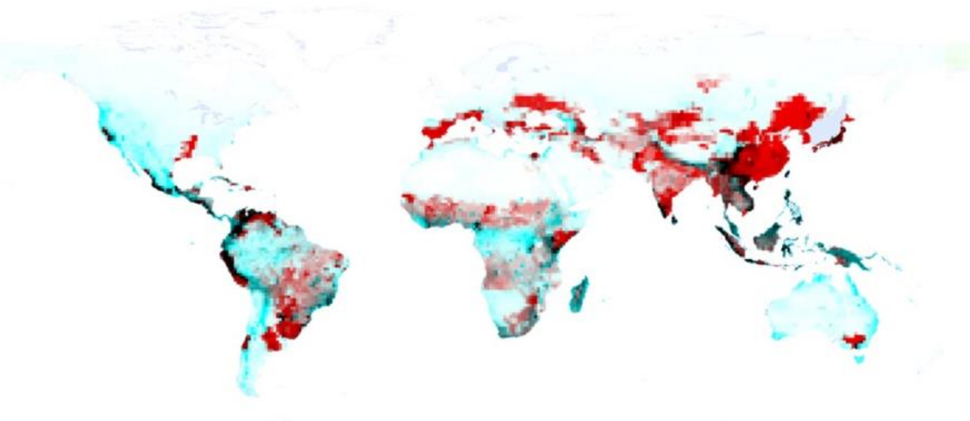
Livestock Density



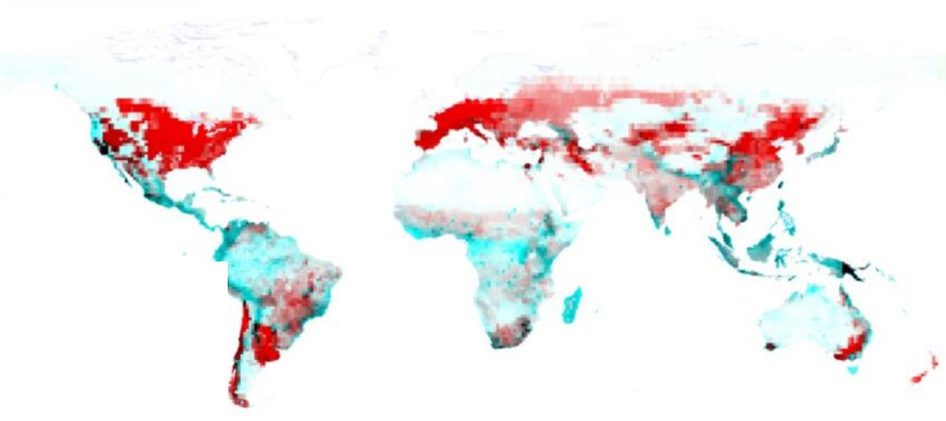
Land Use Intensity Output **Metrics**

Concordance maps show different output metrics with biodiversity – endemism richness for mammals

Rice Yield



Maize Yield



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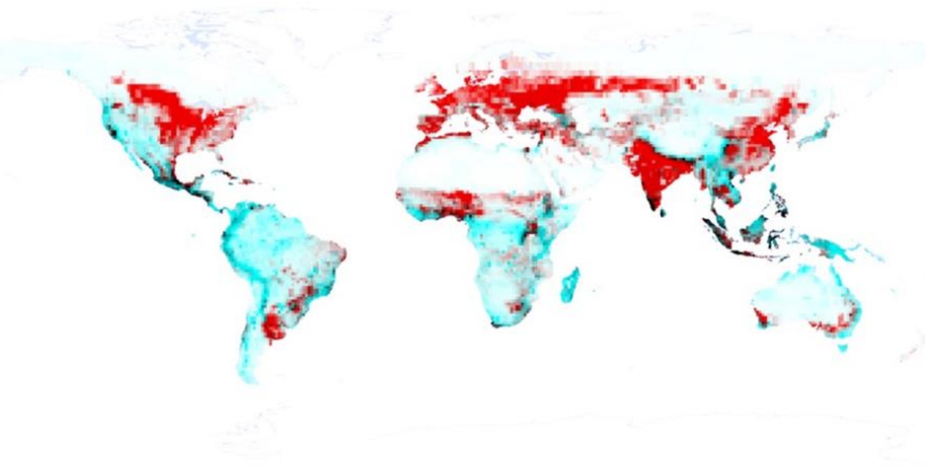
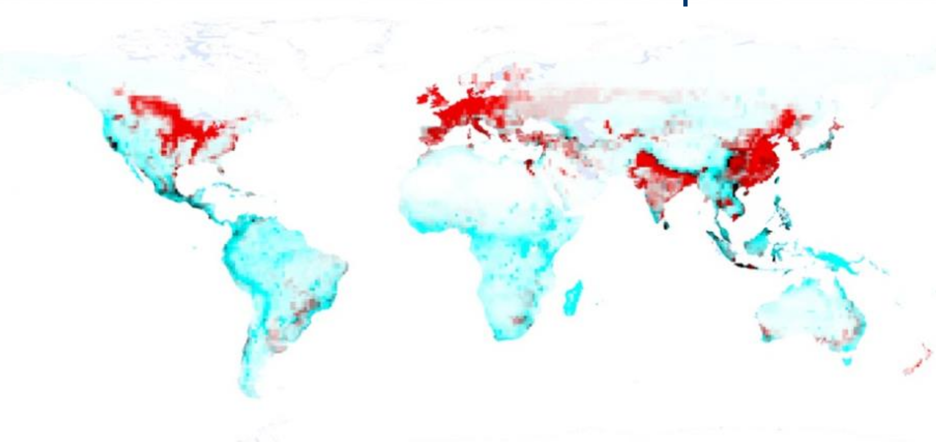


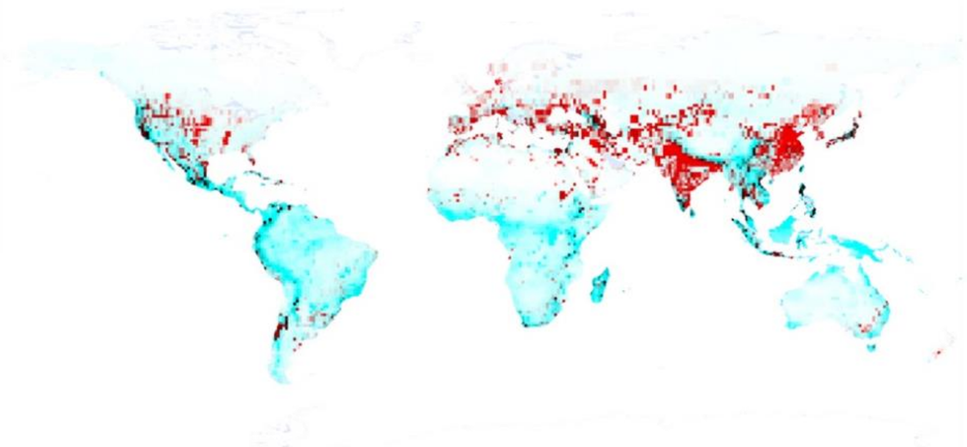
Land Use Intensity System Metrics

Concordance maps show different system metrics with biodiversity – endemism richness for mammals

Rice Yield Gap



Maize Yield Gap



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