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

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on behalf of the GLUES project

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?

Where does land use threaten 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)*

Dimensions of land-use intensity *(Erb et al. 2013, Kuehmerle 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.

Indicator of biodiversity
Spatial association between LUI and biodiversity

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

**Results:** Where does land use threaten biodiversity?
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.
Plant diversity is essential for human well-being
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

How does land use affect biodiversity?
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

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)?

Title search in Web of Science

$n_{total} = 375$
Land use effects mainly in accordance with existing theory

**Results:** Land-use effects on species richness

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*
**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*
**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

<table>
<thead>
<tr>
<th>Factor</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropland area</td>
<td>km² per grid cell</td>
</tr>
<tr>
<td>Cropland area trend</td>
<td>km² per grid cell</td>
</tr>
<tr>
<td>Pasture area</td>
<td>km² per grid cell</td>
</tr>
<tr>
<td>Pasture area trend</td>
<td>km² per grid cell</td>
</tr>
<tr>
<td>N fertilizer</td>
<td>kg ha⁻¹</td>
</tr>
<tr>
<td>Irrigation</td>
<td>Ha per grid cell</td>
</tr>
<tr>
<td>Soil erosion</td>
<td>Mg ha⁻¹ year⁻¹</td>
</tr>
<tr>
<td>Yields (wheat, maize, rice)</td>
<td>t ha⁻¹</td>
</tr>
<tr>
<td>Yield gaps (wheat, maize, rice)</td>
<td>1000 t</td>
</tr>
<tr>
<td>Total production index</td>
<td>index</td>
</tr>
<tr>
<td>HANPP</td>
<td>% of NPP₀</td>
</tr>
</tbody>
</table>

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**Nitrogen fertilizer**

**HANPP**

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**Data: global indicators of land systems**

Land-use inputs/outputs
Data: global indicators of land systems

2) Environmental conditions

<table>
<thead>
<tr>
<th>Factor</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>°C × 10</td>
</tr>
<tr>
<td>Diurnal temperature range</td>
<td>°C × 10</td>
</tr>
<tr>
<td>Precipitation</td>
<td>mm</td>
</tr>
<tr>
<td>Precipitation seasonality</td>
<td>coeff. of variation</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>W m⁻²</td>
</tr>
<tr>
<td>Climate anomalies</td>
<td>°C × 10</td>
</tr>
<tr>
<td>NDVI – mean, seasonality</td>
<td>index</td>
</tr>
<tr>
<td>Soil organic carbon</td>
<td>g C kg⁻¹ of soil</td>
</tr>
<tr>
<td>Species richness</td>
<td># of species</td>
</tr>
</tbody>
</table>

3) Socioeconomic conditions

<table>
<thead>
<tr>
<th>Factor</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Domestic Product</td>
<td>$ per capita</td>
</tr>
<tr>
<td>GDP in agriculture</td>
<td>% of GDP</td>
</tr>
<tr>
<td>Capital Stock in agriculture</td>
<td>$</td>
</tr>
<tr>
<td>Population density</td>
<td>persons km⁻²</td>
</tr>
<tr>
<td>Population density trend</td>
<td>persons km⁻²</td>
</tr>
<tr>
<td>Political stability</td>
<td>index</td>
</tr>
<tr>
<td>Accessibility</td>
<td>travel time</td>
</tr>
</tbody>
</table>

Mean annual temperature

Accessibility to cities and market places

Data: global indicators of land systems

Environmental & socioeconomic factors
Methods: Archetype classification

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

- 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
**Results: Land system archetypes**

- **Degraded forest/cropland systems in the tropics**
  - A: +cropland, ++soil erosion
  - B: trop. climate, +sp. richness
  - C: −GDP, +agr. GDP, −pol. stability

- **Boreal systems of the western world**
  - A: −inputs/outputs
  - B: boreal climate, −NDVI, −sp. richness
  - C: ++GDP, +pol. stability, −accessibility

- **Boreal systems of the eastern world**
  - A: −inputs/outputs
  - B: boreal climate, −NDVI, −sp. richness
  - C: −GDP, −pol. stability, −accessibility

- **High-density urban agglomerations**
  - A: +cropland, +inputs, +HANPP
  - B: varying environmental conditions
  - C: +++pop. density

- **Irrigated cropping systems w/ rice yield gap**
  - A: +cropland/inputs, +rice yields, +++rice yield gap
  - B: +temp. and precipitation, +sp. richness
  - C: −GDP, +agr. GDP, +++pop. density, −pol. stability

- **Irrigated cropping systems**
  - A: +cropland/inputs, +rice yields, +++wheat/maize yield gap
  - B: +temperature, +precip. seasonality, +clim. anomalies
  - C: −GDP, +agr. GDP, +++pop. density, −pol. stability

- **Intensive cropping systems**
  - A: +cropland, +N fertilizer, +++wheat/maize yields, +HANPP
  - B: temperate climate, −low seasonality, −NDVI
  - C: ++GDP, −agr. GDP, +pol. stability, +accessibility

- **Extensive cropping systems**
  - A: +cropland, +inputs, +yields, +yield gaps, +HANPP
  - B: varying environmental conditions
  - C: −GDP, +agr. GDP, +accessibility

- **Subsistence agriculture**
  - A: ++pasture, −inputs/outputs
  - B: +temperature, −precipitation, +seasonality
  - C: −GDP, +agr. GDP, −−pop. density

- **Extensive cropping systems**
  - A: +cropland, +inputs, +yields, +yield gaps, +HANPP
  - B: varying environmental conditions
  - C: −GDP, +agr. GDP, +accessibility

- **Barren lands in the developing world**
  - A: −cropland/pasture, −inputs/outputs, −HANPP
  - B: +temperatures, −precipitation, +seasonality, −−NDVI
  - C: −GDP, +agr. GDP, −pop. density, −pol. stability

- **Marginal lands in the developed world**
  - A: −cropland, +pasture, −inputs/outputs
  - B: +temperature, −precipitation, +sol. radiation
  - C: ++GDP, −agr. GDP, −pop. density, +pol. stability
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**

- closing yield gaps
- increasing cropping efficiency

But “one size does not fit all”

Foley et al., 2011

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

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Knowledge to cope with challenges of global change
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
Authors and contributors:
Ralf Seppelt, Sven Lautenbach, Katharina Gerstner, Laura Kehoe, Tobias Kuemmerle, Holger Kreft, Carsten Meyer, Christian Levers, Carsten Dormann, Anke Stein, Ameur Manceur
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
Self-organizing map with plotted codebook vectors, i.e. the combination of normalized variable values that best characterize each land system archetype.
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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Knowledge to cope with challenges of global change
**Land Use Intensity Input Metrics**

Concordance maps show different input metrics with biodiversity – endemism richness for mammals.
Land Use Intensity Output Metrics

Concordance maps show different output metrics with biodiversity – endemism richness for mammals.
Land Use Intensity System Metrics

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

HANPP

Rice Yield Gap

Maize Yield Gap