Systems methods for analyzing trade-offs between food security and conserving biodiversity – and how it can shed light on monitoring Target 1

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... structure, model, simulate & analyze dynamic interactions and behaviors of dynamic systems

... tools that can be used in evaluations, strategies, research, project and program design

• Systems diagrams
• Influence matrix
• Integrated land use modelling
Methodological contribution!

Demonstrate the applicability of three complementary methods for assessing the trade off between food security and biodiversity conservation in Uganda.

When used in evaluations, strategies, research, project and program design:

-> **Co-Design** with regional stakeholders and decision makers is essential to address regional needs and characteristics adequately!!!
Study design

Ugandan case study:

- Among the top 10 most biodiverse country globally (CBD 2024).
- Highest value of species richness in Africa per unit territory (Plumptre et al., 2019).
- Prevalence of food insecurity (25% of children under 5 in show a prevalence of stunting, height for age under 5, in 2020; World Bank 2024).
- Annual population growth rate is around 3% (in 2022; World Bank 2024).
- Agricultural land is the most single threat to biodiversity (Mwanjalolo et al. 2018).

-> Trade off between food security and biodiversity conservation.

-> Trade off likely to increase in the future.
Metrics: Trade-off analysis

Food security:

“number of people fed with an adequate diet from domestic agricultural production”

- Food availability dimension
  - FAO kcal content of crops and livestock
  - FAO recommendation of 2238 kcal per person in Sub-Saharan Africa (FAO 2015)

Biodiversity:

“cumulative habitat of threatened species”

- Habitat as criterion for estimating species extinction risks (IUCN Red List; Gupta et al., 2020)
  - IUCN Red List area and habitat preferences (IUCN 2013) for aves, amphibia and mammalia
  - Crosswalk table to link IUCN habitat preferences with land cover classification based on Foden et al. (2013)
Systems methods... are complementary!
Systems methods... are complementary!

### Key variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Active sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 People fed from domestic production</td>
<td>2</td>
</tr>
<tr>
<td>2 Cumulative habitat of threatened species</td>
<td>2</td>
</tr>
<tr>
<td>3 Domestic agriculture production</td>
<td>4</td>
</tr>
<tr>
<td>4 Agricultural yield</td>
<td>8</td>
</tr>
<tr>
<td>5 Agricultural area</td>
<td>7</td>
</tr>
<tr>
<td>6 Land use and land cover change</td>
<td>10</td>
</tr>
<tr>
<td>7 Land governance processes</td>
<td>7</td>
</tr>
<tr>
<td>8 Habitat quantity and quality</td>
<td>4</td>
</tr>
<tr>
<td>9 Spatial distribution of species</td>
<td>8</td>
</tr>
</tbody>
</table>

**Passive sum:**

|          | 3 | 3 | 6 | 7 | 6 | 11 | 7 | 6 | 3 |

#### Critical chain approach:

- Most often counted variables:
  - Variable 7 land governance: 6 times
  - Variable 4 agricultural yield: 5 times
Systems methods… are complementary!
The LandSHIFT land use change model (Schaldach et al., 2011)

**Input data on macro-level**
- Society
  - Population
  - Law enforcement
  - Planning etc.
- Agriculture
  - Crop production [t]
  - Livestock numbers
  - Intensification etc.

**Land-use dynamics**
- Settlement
- Crop cultivation
- Forestry
- Grazing
- Crop yields
- NPP forest
- NPP grassland

**LandSHIFT**

**Biomass productivity**

**Initialized basemap**

**Scenario driver**

**Socio-economic change:**
- Population, politics,
- Food demands,
- Production systems etc.

**Maps (micro-level)**
- Land-use type
- Production intensity
- Stocking density

**Input data on micro-level (1km² raster)**
- Landscape & zoning
  - Terrain slope
  - Distance to roads/markets
  - Conservation areas etc.
- State variables
  - Land-use type
  - Population density
  - Stocking density

**Simulated land use change scenarios**

**Maps (micro-level)**
- Change in: land-use types,
  - Production intensities,
  - Stocking densities etc.

Baseline

$t_0$

$t_n$
Socio-economic change – model driver for the land use change simulation:

- Climate Change Agriculture and Food Security Programme (CCAFS) and the International Food Policy Institute (IFPRI) scenario “Industrial Ants” (Vervoort et al. 2013).
  - population growth (+167%)
  - increase in agriculture production (+181%)
  - Increase in crop yields e.g. +71% for cassava, +100% for maize, and +127% for sorghum

This scenario assumes that future national governments in Eastern Africa will intensify cooperation in economic matters and take a more active role in food policy. It further assumes that investments in agriculture will focus on yield increases of “stable” crops for regional consumption (cassava, maize, plantains, potatoes, rice, sorghum, sweet potatoes, and yams).
Simulation experiment

Investigating some (policy) options for assessing the trade-off - identified by the critical chain approach:
- land governance processes
- agricultural yield
Simulation experiment: Results - maps of LUCC

Scenario A 2050

No ring-fencing of protected areas
No investments to improve yield

Scenario B
Investments to improve yield.

Scenario C

No ring-fencing of protected areas

Scenario A
Scenario B
Scenario C
Scenario D

Scenario B 2050

Baseline

Scenario D 2050

Legend:
- Natural land
- Water
- Urban
- Cropland
- Pasture
## Simulation experiment: Results – statistics of LUCC

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Year</th>
<th>Agricultural land (km²)</th>
<th>Natural land (km²)</th>
<th>Crop yield (t/ha)</th>
<th>Agricultural production (kt)</th>
<th>Agricultural production (M kcal)</th>
<th>Food security (M people)</th>
<th>Cumulative habitat of threatened species (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>2005</td>
<td>114,791</td>
<td>86,722</td>
<td>3.1</td>
<td>27,565</td>
<td>26,964,900</td>
<td>33.0</td>
<td>1,297,682</td>
</tr>
<tr>
<td>A</td>
<td>2050</td>
<td>198,229</td>
<td>0</td>
<td>2.7</td>
<td>54,064</td>
<td>48,532,590</td>
<td>59.4</td>
<td>669,634</td>
</tr>
<tr>
<td>B</td>
<td>2050</td>
<td>165,278</td>
<td>32,951</td>
<td>5.7</td>
<td>77,376</td>
<td>69,282,270</td>
<td>84.8</td>
<td>950,990</td>
</tr>
<tr>
<td>C</td>
<td>2050</td>
<td>170,641</td>
<td>27,588</td>
<td>2.7</td>
<td>47,294</td>
<td>42,455,147</td>
<td>52.0</td>
<td>871,712</td>
</tr>
<tr>
<td>D</td>
<td>2050</td>
<td>166,489</td>
<td>31,740</td>
<td>5.7</td>
<td>77,376</td>
<td>69,282,270</td>
<td>84.8</td>
<td>996,335</td>
</tr>
</tbody>
</table>
Literature on trade-off analysis often shows lack of comparable indicators/studies. The basic idea of “our” trade-off coefficient is simple - expressing the main trade-offs as a ratio of normalized changes.

Trade-off coefficient:

\[ t_{off} = \frac{A_t'}{P_t'} \]

\[ A_t' = \text{normalized deviation of “cumulative habitat of threatened species” at time } t \text{ from its value in the base year } t_0, \]

\[ A_t' = \frac{A_t - A_{t_0}}{A_{t_0}} \]

\[ P_t' = \text{the normalized deviation of number of “people fed from domestic agricultural production”} \]

\[ P_t' = \frac{P_t - P_{t_0}}{P_{t_0}} \]
“Investments to improve yields” can reduce the trade-off between food security and biodiversity (scenario B). “Ring-fencing protected areas” is very beneficial for protecting threatened species, but did not reduce the trade-off (scenario C). This is because ring-fencing restricts the needed area for future food production. If productive land become less scarce in the future (e.g., due to improved yields) then ring fencing will also make a contribution to reducing the trade-off (scenario D).

Trade-off coefficient \((t_{off})\) for the land use modelling scenarios investigated. **The larger the negative number the larger the trade-off.**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Year 2030</th>
<th>Year 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Reference case</td>
<td>-0.43</td>
<td>-0.62</td>
</tr>
<tr>
<td>B Investments to improve yield</td>
<td>-0.15</td>
<td>-0.17</td>
</tr>
<tr>
<td>C Ring-fencing protected areas</td>
<td>-0.36</td>
<td>-0.57</td>
</tr>
<tr>
<td>D Both policies</td>
<td>-0.14</td>
<td>-0.15</td>
</tr>
</tbody>
</table>
Conclusion

While being mindful of their limitations, systems methods can provide a useful and transparent methodology to:

• assess the important trade-offs between food security and conservation of biodiversity
• to shed light on monitoring target 1 (?)
Thank you for your kind attention!
Land demand of each sector (macro level) is allocated to the most suitable calculated cells until all demands are fulfilled.

- Cell suitability is calculated based on a Multi Criteria Analysis (MCA)
  - At the grid cell level
  - For each sector

\[
\Psi_k = \sum_{i=1}^{n} w_i f_i(p_{i,k}) \cdot \prod_{j=1}^{m} g_j(c_{j,k})
\]

- \(\Psi_k\): Suitability value \([0,1]\) of specific grid cell \(k\)
- \(w_i\): Weight of suitability factor \(i\)
- \(p_{i,k}\): Suitability factor \(i\)
- \(c_{j,k}\): Land use constraint \(j\)