Towards long-term socio-ecological research platforms: Concepts, approaches and links to biodiversity

Helmut Haberl, Michael Mirtl

ALTER-Net Summer School „Biodiversity and Ecosystem Approaches“
Peyresq, August/September 2006
Overview

- From LTER to LTSER: why and how?
- From LTER sites to LTSER platforms: the issue of scale
- Grappling with society-nature interaction: socio-economic metabolism, complex systems
- Pressures on biodiversity: the HANPP approach
- Tentative conclusions
The ALTER-Net triangle

ALTER-Net is expected to integrate three main dimensions:
- society / economy
- ecosystem
- biodiversity

How do ecosystem functions (and their human-induced changes) influence biodiversity

How does biodiversity affect ecosystem functions

Material & Energy flow

Ecosystem management, land use

Socio-economic system

Biodiversity

Ecosystem function

Direct human impacts on biodiv.

Cultural aesthetic values of biodiv.
LTSER: Underlying assumptions

LTSER should produce knowledge that is useful to tackle society’s sustainability problems.

⇒ Sustainability as „dynamic equivalence“ between mode of production/lifestyle and respective historical natural conditions

⇒ Focused on coupled „socio-ecological“ (=human-environmental) systems

⇒ Focus on transitions between qualitatively different states of socio-ecological systems
Sustainability as dynamic balance between society and nature

- Society and nature are both autopoietic systems that interact, thus creating socio-ecological systems
- Over long time periods, society-nature interaction should be conceived as a co-evolutionary process
- Environmental history shows that sustainability cannot aim at a static equilibrium
Transitions in socio-ecological systems: e.g., the agrarian-industrial transition

- Energy: land-based ⇒ fossil fuels
- Land: scarce ⇒ abundant (yield increases by factor 5-10)
- Sustainability: balance population / land productivity ⇒ externalized to global atmosphere

Austria's energetic metabolism, 1830-1998

Farmland and forests, Austria 1830-2000

Per capita land use in Austria

Settlement and unused area
Non energetic use
Process heat
Draft Power
Human nutrition: Animal protein
Human nutrition: Vegetable Food
Transition towards .... sustainability?

Where many hope we are

Where we probably are

Where many of us want to go

Agrarian society

Industrial society: a transitory state

System state

Sustainable society

Industrial society: ± stable endpoint of a system transition; requires still some ± minor reshaping to be sustainable

Possibly unpleasant scenario

Social Ecology
From classical LTER to LTSER

Ecosystem

Socio-economic system

“Classical LTER”

“Extended LTER”

Long-term social ecological research, LTSER
Themes of LTSER

- **Socio-ecological metabolism**: material and energy flows in socio-ecological systems (i.e. human and ecological flows)

- **Land use and landscapes**: human use of ecosystems resulting in changes in land cover, patterns and processes in ecosystems (incl. biodiversity), and ecosystem services

- **Communication**: how societies use natural resources depends on the representation of environmental issues in communication processes.

- **Governance**: LTSER should help making better-informed decisions in a sustainability context.
Elements of LTSER platforms
(AKA MFRPs: multifunctional research platforms)

SPACE: axis connecting activities at different scales

- Landscape: socio-economic & historical land use entity
- Special areas: National Parks, Biosphere Reserves
- Supplementary sites: urban, agricultural, aquatic, forests
- Focal site(s), eg. LTER sites

increasing RESOLUTION (at all scales)
Basic design of LTSER platforms in Europe
Resolution: municipality
(e.g. Theyern 1829 and 2000)

Theyern 2000

Theyern 1829

Land use 1829
- Arable land
- Garden, permanent culture
- Pasture
- Meadow
- Woodland, coppice
- Other areas

300 0 300 600 Meters

Danube

St. Pölten
Resolution: farmstead (e.g., Ellmau valley, c1830)
LTSER platform Eisenwurzen
(„origin of the iron“)
Boundary of the Eisenwurzen LTSER platform, Reichraming

Eisenwurzen LTSER platform
- 91 Municipalities
- 5.522 km²
- Three provinces

Reichraming
- 102 km²
- 1880 Inhabitants
- 80% of the area forest
From LTER sites to LTSER platforms

- Use existing monitoring and research facilities
- Include not only social sciences, but also humanities (e.g., environmental history)
- Adopt a multi-scale approach:
  - LTSER platform must be seen in its larger (national, international) context
  - Links between different LTSER platforms must be established
- Grapple with the need to consider both natural boundaries (i.e. boundaries generated by steep environmental gradients) and socio-economic (administrative) ones
- Include stakeholders, work with local and national authorities
Society-nature interaction

- Nature: physical objects interact through physical effects, e.g. energy or material flows
- Culture/society: integrated by communication processes
- Biophysical structures of society: influenced by both „spheres of causation“
Socio-economic metabolism I

Global scale

Solar energy

Biosphere (ecosystem)

Input
Material Energy

Output
Wastes emissions heat dissipation

Heat dissipation to space (IR)

National scale

Boundary of the physical compartment of society

Socio-economic stocks:
Humans Livestock Artefacts

Import

Domestic extraction

Net addition to stocks

Export

Wastes Emissions etc.

Similar:
Cities, villages, municipalities, households, etc.
Socio-economic metabolism II

- Socioeconomic materials and energy flows are interrelated with
  - Quality of life, time use
  - Economic growth
- These interrelations are mediated by factors such as
  - Technology
  - Production structure
  - Market/subsistence
  - Income distribution
  - Lifestyles, etc.
Nitrogen flows 1830
Theyern

Local land use system

Production system

Imports
0 kg/ha

Natural
14 kg/ha

Harvest
26 kg/ha

Exports
2 kg/ha

Manure
10 kg/ha

Nitrogen flows 1830
Theyern
Nitrogen flows 1995
Theyern

Local land use system

Imports 69.6 kg/ha
Natural 19 kg/ha

Harvest 77 kg/ha

Production system

Fertilizer 69.6 kg/ha
Exports 39.1 kg/ha

Manure 19 kg/ha

Natural 19 kg/ha

Imports 69.6 kg/ha
Pre-industrial versus modern agriculture

- Self-sufficient, integrated local systems ⇝ homogenous throughput systems
- Low input-low output ⇝ high input-high output
- Energy-efficient ⇝ area- and labor efficient
- Surging transport intensity
- Globalization of environmental pressures

- Urban population
- Arable
- Grassland
- Forest
Understanding dynamics: Coupling Actors models with socio-ecological metabolism
(e.g., The Reichraming project)

- Creation of an integrated model that should help to analyze the interrelations between socio-economic dynamic, land use and substance/material flows:
  - Agent-based model to simulate behavior of actors
  - Stock-flow model simulates integrated socio-ecological material/substance flows: agricultural/forest harvest, fossil fuels, plant growth, etc.

- Causes and effects of long-term changes in society, the economy, land use and ecosystems

- Supports sustainable development initiatives of local stakeholders
Model concept

Functions:

- **Future scenarios, depending on:**
  - Socio-economic conditions
  - Climate
- **Reconstruction of past system states:**
  - Creation of „possible pasts“
  - Consistent with available (spotty) data
Use of models in a participatory process

System model (integrates agents with stocks and flows)

Simulation

Modelling

Formalization

Scenarios

Results

Heuristic model, visualization of results

Agents, activities
Stocks-flows
Landscape
Etc.

Interpretation

Conclusions

Stakeholders in a participatory process
Definition of HANPP

\[
\text{HANPP} = \text{NPP}_0 - \text{NPP}_t
\]

\[
\text{NPP}_t = \text{NPP}_{\text{act}} - \text{NPP}_{\text{h}}
\]

\[
\text{HANPP} = \Delta \text{NPP}_{\text{LC}} + \text{NPP}_{\text{h}}
\]

- \(\text{NPP}_0\) … NPP of potential natural vegetation
- \(\text{NPP}_t\) … NPP remaining in ecosystems
- \(\text{NPP}_{\text{act}}\) … NPP of the currently prevailing vegetation
- \(\text{NPP}_{\text{h}}\) … NPP harvested by humans.
- \(\Delta \text{NPP}_{\text{LC}}\) … changes in productivity induced by land use (= \(\text{NPP}_0 - \text{NPP}_{\text{act}}\))
Impacts of HANPP on ecosystems

- Changes the amount of trophic (=food) energy available for all other species than humans and their livestock
- Alters stocks and flows of carbon in the ecosystem
- Changes patterns and processes in the ecosystem
- May affect ecosystem services such as self-regulating capacity, buffering capacity, etc.
The species-energy hypothesis

- **Basic claim:** The number of species is positively related to the flow of energy in an ecosystem.

- **Corollary:** If humans reduce energy flow (e.g., through HANPP), then species richness will decline.

- **Notes**
  - Can explain species diversity gradient from equator to poles.
  - Controversial. Competing (complementary) hypotheses exist (e.g., intermediate disturbance hypothesis).

---

Difficulties of observing HANPP-related reductions in biodiversity

- Tests of the HANPP/biodiversity hypothesis need to be based on broad taxonomic groups, because HANPP may favour some species at the expense of others ⇒ problems of biodiversity data availability

- A change in energy flow ($\Delta E = NPP_0 - NPP_t = \text{HANPP}$) should result in a change in species richness ($\Delta S = S_0 - S_t$), but few if any data exist on $\Delta S$, because $S_0$ is unknown.

- Only indirect tests are possible: Comparisons of spatial patterns of HANPP and $S_t$ are useless unless $S_0$ is similar across space. ⇒ relating $S_t$ to $NPP_t$

- Consistent time series of species richness are lacking ⇒ time-series analyses are almost impossible
Case study 1: HANPP and species richness in an East-Austrian transect

- The study referred to **38 squares** sized 600x600m located south of Vienna
- **Seven taxonomic groups** were included: vascular plants, bryophytes, orthopterans, gastropods, spiders, ants, and ground beetles
Results of case study 1

\[ Y = -2.420 + 1.008 X \]
\[ R^2 = 0.615, \ p < 0.0001 \]

\[ Y = -1.853 + 0.323 X \]
\[ R^2 = 0.253, \ p < 0.005 \]

\[ Y = -2.012 + 0.530 X \]
\[ R^2 = 0.465, \ p < 0.0001 \]
Results of case study 1

- Results were qualitatively similar for all seven groups
- Clear linear correlation of NPP_t and species richness supports species-energy hypothesis and indirectly supports HANPP/bio-diversity hypothesis.
- Negative correlation of HANPP% and species diversity supports HANPP/biodiversity hypothesis ($S_t$ could be a proxy of $\Delta S$ here).
- Focused on cultural landscapes (intensive agricultural use) with „high“ HANPP (>45%)
Case study 2: HANPP and avifauna richness in Austria on 4 spatial scales

- Biodiversity components: total avifauna richness, percentage of endangered bird species

- Four nested spatial scales were studied (random sample): 250x250m, 1x1 km, 4x4 km, 16x16 km

- Possible direct effects of climate on avifauna richness were eliminated in a residual analysis
Results of case study 2, a)

0.25x0.25 km

\[ Y = 1.17963 + 0.65977 \times X - 0.27495 \times X^2 \]
Adj. \( R^2 = 0.48 \)

1x1 km

\[ Y = 1.32916 + 0.69916 \times X - 0.22962 \times X^2 \]
Adj. \( R^2 = 0.69 \)

4x4 km

\[ Y = 1.56346 + 0.62743 \times X - 0.24329 \times X^2 \]
Adj. \( R^2 = 0.67 \)

16x16 km

\[ Y = 1.86994 + 0.33894 \times X - 0.15837 \times X^2 \]
Adj. \( R^2 = 0.27 \)
Results of case study 2, b)

Elimination of Climate (elevation)

Landscape heterogeneity

Y = 0.00666 + 0.49388 X - 0.16142 X^2
Adj. R^2 = 0.39

Y = 0.01452 + 0.30084 X - 0.75448 X^2
Adj. R^2 = 0.42
Results of case study 2

- Good correlation between bird species richness and NPP$_t$ on all scales (best: 1x1km, 4x4km)
- NPP$_t$ retained its explanatory value after the effect of climate (elevation) was eliminated.
- Biodiversity was less correlated with landscape heterogeneity indicators than with NPP$_t$.
- No direct test of HANPP/biodiversity hypothesis possible (low $S_0$ in alpine systems $\Rightarrow S_t$ no proxy of $\Delta S$).
- The percentage of red list species was significantly higher in plots with low NPP$_t$. 
HANPP can be studied consistently across time ...
(e.g. HANPP Austria 1830-1995)
... and on any spatial scale

- **Global**
- **Regional**
- **National**
- **Local**
HANPP caused by land conversion ($\Delta NPP_{LC}$)

Global average: land conversion has reduced total NPP by $\approx 10\%$, aboveground NPP by $\approx 5\%$
Total HANPP (land conversion plus harvest)

Global average: human harvest is ≈11% of \( NPP_0 \), plus human-induced fires ≈2% of \( NPP_0 \), total HANPP ≈22% of \( NPP_0 \) (of which ≈2% are direct backflows, e.g. dung excreted by grazing animals, wood felled but not removed...).

Aboveground HANPP ≈29% of aboveground \( NPP_0 \)
### Global carbon flows related to HANPP around the year 2000

<table>
<thead>
<tr>
<th></th>
<th>Total NPP [Pg C/yr]</th>
<th>[%]</th>
<th>Aboveground NPP [Pg C/yr]</th>
<th>[%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential vegetation (NPP₀)</td>
<td>65.51</td>
<td>100.0%</td>
<td>35.38</td>
<td>100.0%</td>
</tr>
<tr>
<td>Actual vegetation (NPP_{act})</td>
<td>59.22</td>
<td>90.4%</td>
<td>33.54</td>
<td>94.8%</td>
</tr>
<tr>
<td>Alteration of NPP (ΔNPP_{LC})</td>
<td>6.29</td>
<td>9.6%</td>
<td>1.84</td>
<td>5.2%</td>
</tr>
<tr>
<td>Human harvest (NPPₜₕ)</td>
<td>7.23</td>
<td>11.0%</td>
<td>7.23</td>
<td>20.4%</td>
</tr>
<tr>
<td>Human-induced fires</td>
<td>1.14</td>
<td>1.7%</td>
<td>1.14</td>
<td>3.2%</td>
</tr>
<tr>
<td>Remaining in ecosystem (NPPₜ)</td>
<td>50.85</td>
<td>77.6%</td>
<td>25.17</td>
<td>71.2%</td>
</tr>
<tr>
<td>HANPP_{total}</td>
<td>14.66</td>
<td>22.4%</td>
<td>10.21</td>
<td>28.8%</td>
</tr>
<tr>
<td>Backflows to nature*</td>
<td>1.51</td>
<td>2.3%</td>
<td>1.51</td>
<td>4.3%</td>
</tr>
</tbody>
</table>

* On-site backflows of harvested biomass to ecosystems, i.e. unused residues, harvest losses and feces of grazing animals.
Breakdown of global HANPP* in the year 2000 to land use classes

<table>
<thead>
<tr>
<th>Land Use Category</th>
<th>NPP₀ [gC/m²/yr]</th>
<th>NPP_{act} [gC/m²/yr]</th>
<th>NPPₕ [gC/m²/yr]</th>
<th>NPPₜ [gC/m²/yr]</th>
<th>HANPP* on this area [%]</th>
<th>ΔNPP_{LC} [%]</th>
<th>Contribution to total HANPP [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropping</td>
<td>611</td>
<td>397</td>
<td>258</td>
<td>139</td>
<td>77.2%</td>
<td>35.0%</td>
<td>51.6%</td>
</tr>
<tr>
<td>Grazing land</td>
<td>486</td>
<td>433</td>
<td>41</td>
<td>392</td>
<td>19.4%</td>
<td>11.0%</td>
<td>21.8%</td>
</tr>
<tr>
<td>Forestry</td>
<td>720</td>
<td>720</td>
<td>37</td>
<td>683</td>
<td>5.2%</td>
<td>0.0%</td>
<td>10.2%</td>
</tr>
<tr>
<td>Infrastructure areas</td>
<td>586</td>
<td>221</td>
<td>63</td>
<td>158</td>
<td>73.0%</td>
<td>62.3%</td>
<td>8.7%</td>
</tr>
<tr>
<td>Wilderness</td>
<td>229</td>
<td>229</td>
<td>None</td>
<td>229</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Global average / total</td>
<td>502</td>
<td>454</td>
<td>55</td>
<td>399</td>
<td>20.6%</td>
<td>9.6%</td>
<td>92.2%**</td>
</tr>
</tbody>
</table>

* Excluding human-induced fires.
** The remaining 7.8% are caused by human-induced fires.
Tentative conclusions I
Requirements of LTSER

LTSER should help evaluating progress towards (or deviation from) sustainability

⇒ Long-term, i.e. inclusion of pre-fossil-fuel baseline data
⇒ Balance of site-specific and generic knowledge
⇒ Balance monitoring and predictive/explanative modelling
⇒ Support stakeholders
Tentative conclusions II

- Transition to LTSER considerably raises complexity, but has a high potential to yield innovative insights, above all with respect to biodiversity.
- LTSER requires a different kind of research infrastructure as LTER: LTSER platforms (that include LTER sites).
- LTSER links global change research with local-scale socio-economic research and environmental history.
Challenges

- Integration between social/natural sciences has begun, but what about the humanities?
- Scale mismatches between social and ecological systems
- How to appropriately link findings/models/data from different scales?
- How to integrate data from measurements and observation with geographical data, statistical data, survey data, etc.?
- How to appropriately balance generalization with the need for rich, descriptive studies of local peculiarities?
Thank you for your attention

Further information:
http://www.iff.ac.at/socec
http://www.umweltbundesamt.at
## Data and methods

<table>
<thead>
<tr>
<th>political units (Nation, supra &amp; sub-units)</th>
<th>Material flow data-models</th>
<th>Land cover / land use data-models</th>
</tr>
</thead>
<tbody>
<tr>
<td>• FAOstat (land use)</td>
<td>• LPJ-DGVM:</td>
<td>• GLC2000 (JRC-GVM)</td>
</tr>
<tr>
<td></td>
<td>– NPP of the potential vegetation</td>
<td>• Cropland %Gridcell, (Ramankutty &amp; Foley 1998)</td>
</tr>
<tr>
<td></td>
<td>– NPP of actual land cover (e.g. grassland, savanna)</td>
<td>• FRA2000 (GIS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Irrigation Data (Siebert, Döll, Hoogeveen 2002)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Glasod (soil degradation)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• „Human Footprint“, Sanderson et al. 2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• FRA2000 (forest area, area change)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• TBFRA2000 (forest area)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• FAOstat (agricultural products, livestock, roundwood production)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Biomass harvest factors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• alternative woodfuel statistics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• UN, IEA statistics on biofuels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• FRA2000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• TBFRA2000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Livestock feed balance model</td>
</tr>
</tbody>
</table>
Data integration: the land use model

GLC2000

Potential grazing area