Integrated Modelling Approaches to Land Use Change in the Thai and Vietnamese Uplands

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Over exploitation of natural resources

Northern-Thailand: Chiang Mai Province

Northern-Vietnam: Son La Province
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Land degradation through intensified maize production
Upland Thai

Upland Hmong
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Research problems

- Land-use change/intensification
- Water scarcity
- Pesticide contamination of water flows
- Soil erosion
- Socio-economic inequality
- Market pressure
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Research Fields in Phase III of The Uplands Program

Subprojects in Thailand
- B1.3 Resource conservation
- B2.3 Agrochemical transports
- B3.2 Strategic fertilization
- D1.3 Off-season fruits
- E1.2 Optimizing fruit drying
- E2.3 Fruit quality/processing

Subprojects in Vietnam
- B4.1 Land suitability analysis
- B5.1 Water quality analysis
- D2.3 Livestock efficiency
- D6.1 Fruit set and standards
- F2.3 Impact evaluation

Cross-country projects
- A1.3 Participatory research
- C4.1 Land use modelling
- E4.1 Product marketing
- F1.3 Environmental valuation
- G1.2 Sustainability strategies
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**Integrated modelling: Goals**

- **Analysis of potential impact and feedback mechanisms by introduction of new technologies**
  - Off-season fruit production
  - Greenhouse vegetable production

- **Exploring possible adaptation strategies and improving land use planning**
  - Better understanding of human-environment interactions
  - Capturing decision making at land user level

- **Identifying ‚sustainable‘ (biophysical-socio-economic-market) land-use options**

- **What are the trade-offs (environmental services) and vulnerabilities towards climate change?**
  - Water quality/willingness to pay
Why Integrative Modelling?

- "Value Added" when integrating and communicating across knowledge domains
  - Feedback loops, thresholds, irreversibility

- Unexploited data sets, both biophysical/socioeconomic aspects
  - Merging possible through spatial data models

- Participatory planning tools, new governance concepts
  - Integrated river basin management
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Challenges for Land System Models

• Linking various biophysical and socioeconomic process models at high resolution
  – Results from subsystem models cannot simply be matched or aggregated
  – Interpretation difficult because boundary conditions under which results were generated are too restrictive

• Model integration must be achieved at several levels
  – Conceptualization, modelling, programming
  – Experimental frame to ensure transparency and traceability in execution of simulation scenarios
Integrated model = \[ \Sigma (\text{best models (discipline)}) \] ?

Integration = Process crossing boundaries
Choice of model integration approaches depends on:

- Goals
- Prediction/scenarios
- Precision/resolution required
- Level of interaction
- Data availability
- End user
Model coupling approaches

- Representation of integrated model through meta-model approach
  - transfer- or production functions

- Reprogramming and implementing in one code (Brute Force Merger)
  - MAS & Edic-Cedec & CropWat (Berger, 2001)
  - MAS & TSPC (Berger/Schreinemachers, 2006)

- Component-oriented implementation framework (.NET or J2EE)
  - Re-usable model components, connected with Plug-And-Play
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Model integration and interdisciplinary co-operation

G1.2
MAS
(Multi Agent System)

A1.3
Participation

C4.1
LUCIA
(Land Use Change Impact Assessment)

E subprojects

B1.3, B4.1, B3.2
Land use

B2.3, 5.1
Soil+ Water+ Pesticides

D1.3, D6.1
Off-season Fruit

D2.3
Livestock

E4.1
Markets

F2.3
Poverty

D1.3, D6.1
Off-season Fruit

A1.3
Participation

C4.1
LUCIA
(Land Use Change Impact Assessment)
## Challenges to model integration (1)

<table>
<thead>
<tr>
<th>Code</th>
<th>Model</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4</td>
<td>WaNuLCAS</td>
<td>Plot-level model of soil-crop interactions in agro-forestry systems</td>
</tr>
<tr>
<td>B2</td>
<td>SWAT</td>
<td>Watershed-level model simulating water flows and pesticide runoff</td>
</tr>
<tr>
<td>C4</td>
<td>LUCIA</td>
<td>Ecosystem-level model - Land use change impact assessment tool (developed out of FALLOW, GENRIVER, WaNuLCAS)</td>
</tr>
<tr>
<td>G1</td>
<td>MP-MAS</td>
<td>Farm-level model simulating farm household decision-making</td>
</tr>
</tbody>
</table>
## Challenges to model integration (2)

<table>
<thead>
<tr>
<th></th>
<th>Economics</th>
<th>Agro-ecology</th>
<th>Hydrology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spatial scales</strong></td>
<td>Farm household</td>
<td>Plot</td>
<td>Watershed</td>
</tr>
<tr>
<td><strong>Temporal scales</strong></td>
<td>Yearly</td>
<td>Daily-yearly</td>
<td>10 minutes</td>
</tr>
</tbody>
</table>
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1st part of the approach taken in SFB Uplands project
Use complex models and transfer functions to calibrate simpler models applied in MP-MAS

SWAT → Water Bucket model
(Edic-Cedec)
Interaction of hydrological flows is considered in multidimensional directions above and below ground in drain directions.

“Bucket approach” - drain directions are simplified and aggregated over one month.
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1st part of the approach taken in SFB Uplands project
Use complex models and transfer functions to calibrate simpler models applied in MP-MAS

- SWAT
- WaNuLCAS
- LUCIA

Transfer functions

→ Water Bucket model (Edic-Cedec)
→ Crop response (CropWat)
→ Nutrient balance (TSPC)
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WaNuLCAS

MP-MAS CropWat

Exemplified response function of crop yield to water deficit:

\[ f(y) = e^{-2x} \]
2nd part of the approach

Compromise on the scales

- **Spatial scale:** watershed level divided into grid cells of about 40x40 m

- **Temporal scale:** months with an annual decision-making cycle
3rd part of the approach

Use agent-based modelling to integrate models at a gridcell level
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Exteded MP-MAS

Layer 1
Human actors/
Communication networks

Layer 2
Land and
water markets

Layer 3
Landuse/
cover

Layer 4
Farmsteads

Layer 5
Ownership

Layer 6
Soil quality

Layer 7
Water flow

Layer: Human actors/
Communication networks

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MP-MAS Decision making

Hydrology model
simulates the water supply

Economic model
Crop choice, inputs, water demand (irrigation) based on expected yields

Crop model
simulates crop yields

Environment Services

Economic model
simulates farm income

Updating of yield expectations

Berger/Schreinemacher, UoH
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Upland Hmong
Mae Sa Noi: Seasonal water availability vs demand by off-season fruit production

Lychee:
Main season
Off-season

River discharge (m$^3$ day$^{-1}$)

Month

Flowering
Harvest
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Mae Sa Noi parameterization:
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Sensitivity analysis

of land use change vs water availability

Preliminary results

Schreinemacher et al., 2007
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Farmers adoption attitude to alternative management options

(292 obs.)

% Household knowing this technology

% Household using this technology

All SCT 74.7% 57.9%
Terrace 20.9% 2.7%
Contour ploughing 20.2% 19.2%
Mulching 3.4% 1.0%
Hedgerows 36.6% 8.9%
Agroforestry 20.5% 6.5%
Vegetative strips 5.8% 0.7%
Cover crop 12.7% 1.0%
Ditches or channel 56.2% 35.6%
Other SCT 5.1% 4.1%

If you know the technology why didn't you apply it?

(% of answers)

0.0% 5.0% 10.0% 15.0% 20.0% 25.0% 30.0%

No erosion
Too expensive to establish
Too expensive to maintain
Lack of labour
Lack of Equipment
Lack of access to seedlings
Lack of land
Fear negative effect
Not effective
Fear to affect neighbouring lands
Other

Saint-Macary et al. (2008)
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Linkage between upland-lowland

Erosion

Vegetative filter zone

Wetland-Rice: a major sediment filter

How much really goes downstream?
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Linkage between upland-lowland

Land use intensification

Adopted from Dung et al., 2008
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Nutrient Balance (kg/ha)

Dung et al., 2008
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Impact of upland derived sediment inputs on paddy rice yields

Grain yield (kg/m²)

Schmitter et al., 2008
Climate change: Vulnerable linkages
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4th part of the approach

Challenges to the extended MP-MAS

Limited capability to represent:

- Landscape specific interactions
- Not spatially explicit in several components
- Feedback interactions

LUCIA
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Extende MAS grid cell maps (GIS)

Layer 1
Human actors/
Communication networks

Layer 2
Land and water markets

Layer 3
Landuse/cover

Layer 4
Farmsteads

Layer 5
Ownership

Layer 6
Soil quality

Layer 7
Water flow

Dynamic scale in PCRaster
→ Voxel approach

→ LUCIA approach
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Where are we now?

- **July 2006**: Start of phase III
- **July 2007**: Sub-catchment model in Thailand
- **July 2008**: Scale up/calibrate using SWAT WaNuLCAS
- **July 2009**: Model for Mae Sa Watershed in Thailand

Full integration of improved models

Phase IV
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Integrated modelling

Challenges ahead:

• Improve multi-disciplinary approach
• Out-scaling
• Data availability/accessibility
• Model validation
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Challenges ahead: Out-scaling vs data availability (I)

<table>
<thead>
<tr>
<th></th>
<th>Black Soil</th>
<th>Hard Red Soil</th>
<th>Soft Red Soil</th>
<th>Orange Soil</th>
<th>Yellow Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated Infiltration</td>
<td>high</td>
<td>low</td>
<td>very high</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>$K_s \text{ [cm h}^{-1}]$</td>
<td>11</td>
<td>10</td>
<td>$&gt;200$</td>
<td>6</td>
<td>$&lt;1$</td>
</tr>
</tbody>
</table>

Schuler et al., 2008
Challenges ahead:

• Improve multi-disciplinary approach
• Out-scaling
• Data availability/accessibility
• Model validation
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Integrated modelling: Validation

Validation: a model is acceptable for its intended use because it has met a certain performance criteria (Rykiel, 1996)

What if your model or your model output is intended to be used by farmers or natural resource managers for decision making?
Integrated modelling: Integration of knowledge domains

- **Public/Policy Ecological Knowledge**
  - Based on categories
  - Based on ‘processes’

- **Local Ecological Knowledge**
  - Direct observable

- **Modellers’ Ecological Knowledge**
  - Includes balance sheets

Van Noordwijk, Cadisch and Ong, 2007
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Participatory modelling
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Model Criteria

1. Salience: relevance of model output to stakeholders

2. Credibility: model perceived by users as valid, dependable and of high quality

3. Legitimacy: model scenarios are free from bias and were developed transparently

Model users/ Natural resource managers

Model developers/ Research community

Louisiana, 2008
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Why is Integration so Difficult?

• Demanding process in terms of communication
  – Institutional integration: involving resource users and managers
  – Knowledge integration: scientific conceptualization and discourse of stakeholders
  – Technical integration: coupling of computer models
Conclusions:

• There are few alternatives to integrated modelling to test interactions between human behaviour and ecological dynamics

• Integrative modelling is a challenge
  – Team building
  – Time consuming
  – Negotiation process/compromise
  – Involvement of all stakeholders

• Added value
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