Management of socio-ecological systems: the multi-agent approach

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Content

- **Eco-sociosystems as complex systems**
- Multi-agent approaches of complex systems
- Conclusion

Definition of complex systems

- Definition:
  - Complex system: set of components in non-linear interaction between themselves and with an outside :
    - Distinction between the set of components (the system) and the rest (the environment/outside): depends on the question ;
    - Importance of interactions : more than the sum of its parts.
- Other features:
  - Descriptions at multiple levels (a minima: environment/ component/system)
  - Structure formation
  - Emergence

Emergence

- A phenomenon is emergent if and only if we have:
  - A system of interacting entities whose states and dynamics is made using a theory D:
    - example: the cells and their transition rules
  - The production of a phenomenon (process, stable state, invariant) which is global relative to the previous system:
    - example: regularities in the cells dynamics
  - The observation of this phenomenon by an observer (weak sense) or by the entities themselves (strong sense), via an inscription mechanism, in another theory D':
    - example: the glider and its transition rules
  - The irreducibility of D' to D

Weak emergence

- The interpretation is done by the observer
- Example:
  - The gliders
  - The ants
    - deposits of pheromones while moving food
    - interpretation as the optimal path between the nest and the food source
- The « invisible hand »
  - Economic market: adjustment of prices by balancing offers and demands
  - Interpretation as an optimal allocation of resources

Strong emergence

- The interpretation is done by the entities themselves
- Examples
  - Auctions
    - Inscription of exchanges
  - Institutions
    - Inscription as myths, representatives
    - Inscription as legal texts

Eco-sociosystem management

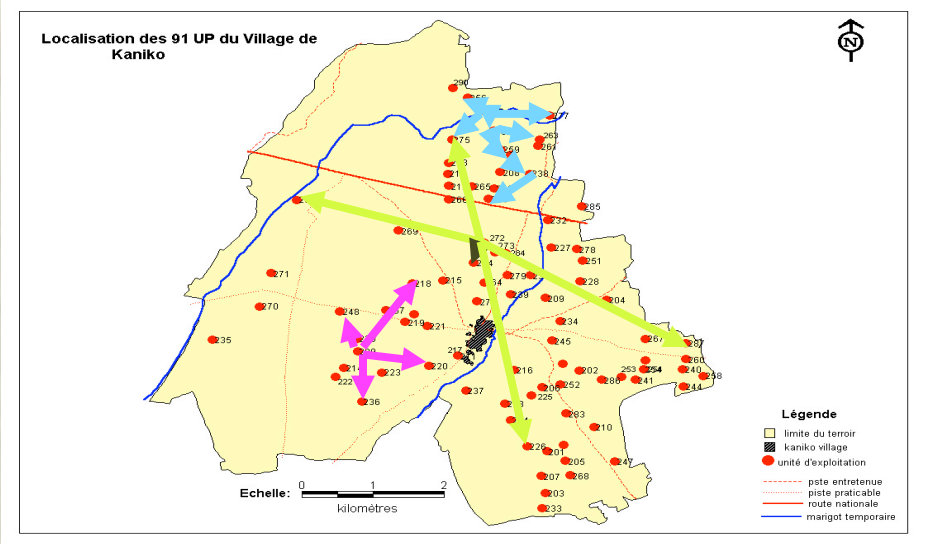
- Hypotheses:
  - No solution is either technical or organizational or economical but a combination of all that
  - Social dimension plays a central role
- Some example:
  - Farmer seed system
  - Erosion mitigation
  - Regional park
  - Watershed management

Farmer seed system (I)

- In Africa, 90% of the seed exchanges are informal
- Need for a diversity of cultivars for resilience to uncertain/contrasted situations (soil diversity, climate variability, market variability)
- Most farmers possess only one variety => the diversity comes from the social networks
- Farmers are continuously experimenting with new varieties

Farmer seed system (II)

- Questions:
  - Actual resilience of the system
  - In situ management of biodiversity (versus ex situ management: gene banks)
  - Impact of policies/introduction of « improved » varieties



Erosion mitigation (I)

- Erosion depends on:
  - Topography (slopes)
  - Climate
  - Farmer practices:
    - Link to markets, credits (formal and informal), manpower availability, etc.
  - Infrastructure

Erosion mitigation (II)

- Questions:
  - Which crop system changes can mitigate erosion
  - What are the social/economic impact/requirement of these changes
  - Communication with the provincial level

Regional park

- Biodiversity/landscape conservation
  - Landscape from interaction between human activities and ecological dynamics
    - Highly valued biodiversity
  - Conflicts between foresters, herders and farmers
- Questions:
  - Understanding how the interactions maintain biodiversity
  - Organize management between stakeholders and naturalists

Watershed management

- Sharing of water between a variety of users, producing different values from consumed water:
  - Domestic users
  - Industry
  - Mining
  - Agriculture
- Building a charter for equitable water distribution using licensing mechanisms:
  - Awareness on licensing and price negotiation
  - Impact of regulations

Common features (I)

- The global concern emerges from human interactions and interaction with the bio-physical dynamics:
  - Biodiversity and resilience through seed exchanges
  - Erosion mitigation through crop practices and their condition of possibility (similar for soil salinity)
  - Patrimonial conservation through coordination of a variety of activities
  - Equitable sharing through coordinated access to a common resource (similar for land security)

Common features (II)

- Lack of awareness of the relationships between the global concern(s) and the individual strategies and their coordination
  - Difficulty to value individual contributions to collective well-being
    - Weakness in negociations
  - Difficulties in assessing the real impact of global policies
    - Poor impact of policies and attention to local interests
- Need of combining expert knowledge (context insensitive) with local knowledge (where context is the key)

Common features (III)

- Importance of considering individual and collective aspects:
  - Social organization can make the difference under constant technical/biophysical conditions
- Requirements:
  - Understanding the biophysical and social aspects by the experts and the stakeholders
  - Understanding the impact of regulations and other conditions on global outcomes by articulating individual and collective strategies, and recognizing emerging issues

Content

- Eco-sociosystems as complex systems
- **Multi-agent approaches of complex systems**
- Conclusion

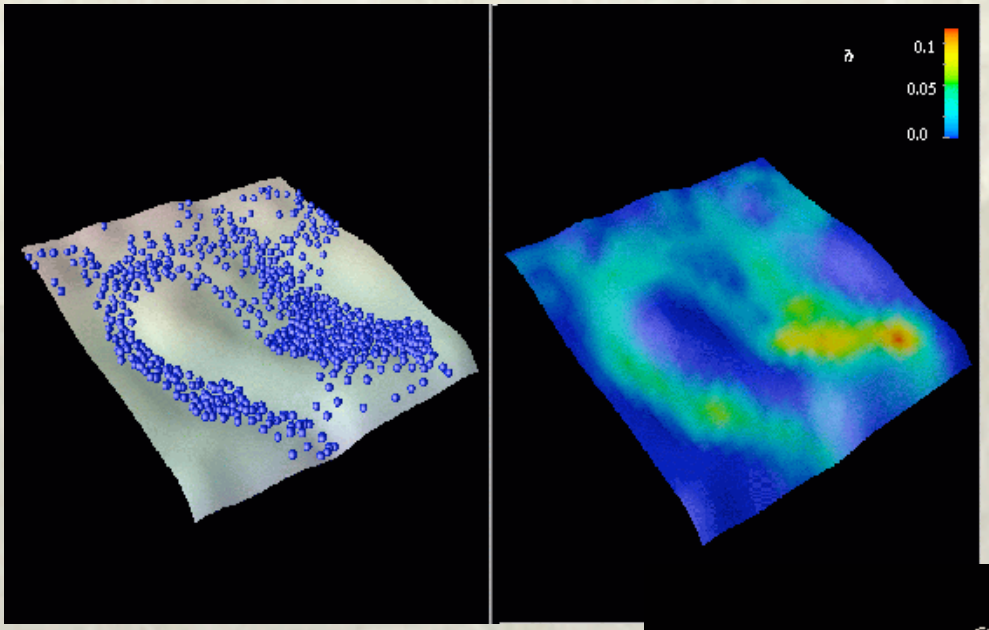
Approaches to complex systems

- Approaches :
  - Analytical : component by component (neo-classical economy, parcels, individuals, etc.) ;
  - Holistic or systemic : global behaviour of the system (macro-economy, compartment models, statistical models) ;
  - Constructivist : articulation between the individual behaviours of the components (local) and the global behaviour of the system (global).

Complex system : example

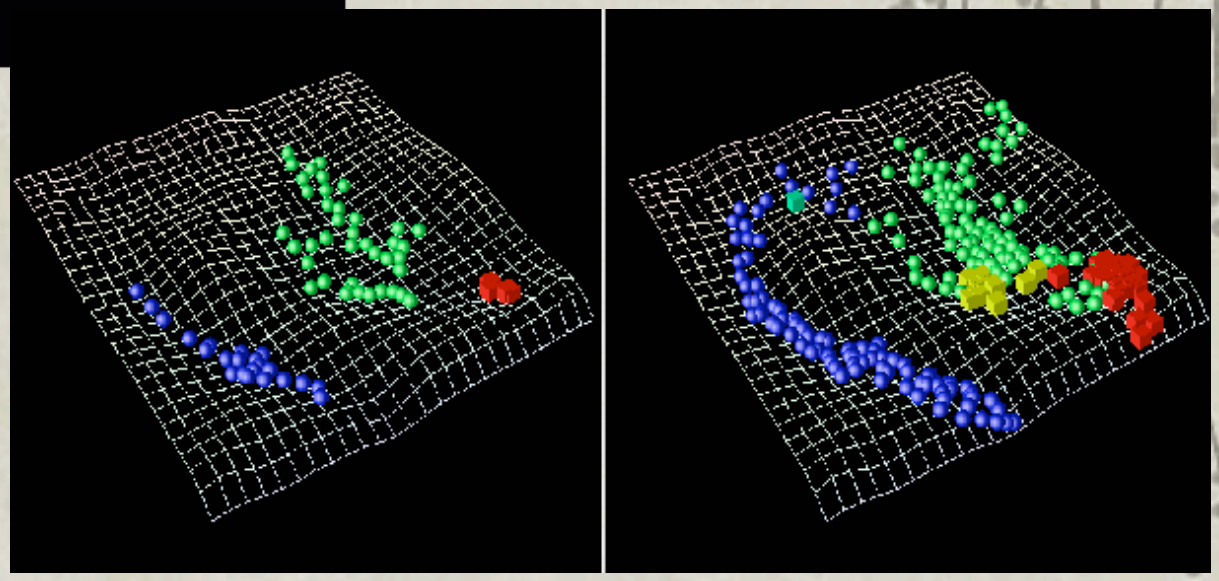
- Example: fluid dynamics
  - Analytical:
    - Behaviour of a water molecule
  - Holistic:
    - Navier-Stockes equations
  - Constructivist:
    - Interaction among water droplets or vortices => structures of fluid dynamics

Example : hydrology



LIP6/IRD: D.Servat

Identification of structures from local behaviours



Why the constructivist approach ?

- One knows the individual behaviour and we want to explore the resulting global dynamics :
  - Social engineering, negotiation support, simulation
- One knows the global behaviour and one seeks an explanation from the local behaviours :
  - Articulation local-global, decision support
- Understandability:
  - Intuitive description on terms of objects and actors rather than variables and equations
- Challenge of complexity: behaviours far from equilibrium
- Pertinence for modelling eco- and socio-systems

Models of complex systems

- Category of models :
  - Holistic or systemic :
    - Differential equations
    - Compartment models (Forrester)
    - Cellular automata: spatialization
  - Constructivist :
    - Micro-simulation
    - Individual-based systems : homogeneous entities
    - Multi-agent systems: heterogeneous entities

Multi-agent systems: the agent

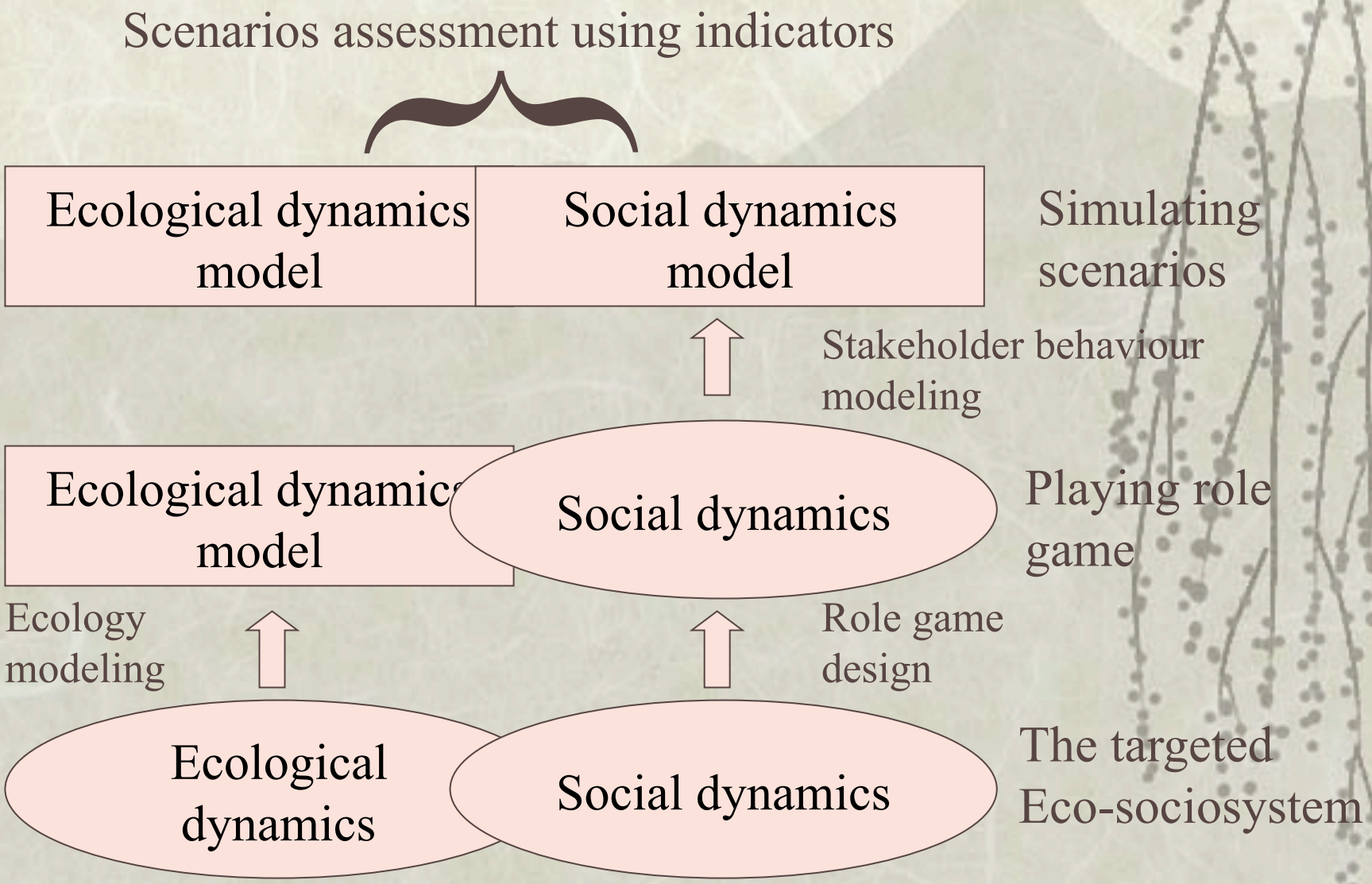
A physical or virtual entity

- Interaction with the environment:
  - able to act in its environment;
  - able to perceive (partially);
  - use of resources;
- Interaction with other agents:
  - able to communicate (social);
  - Offer and request services;
- With specific objectives;
- Able to reproduce.

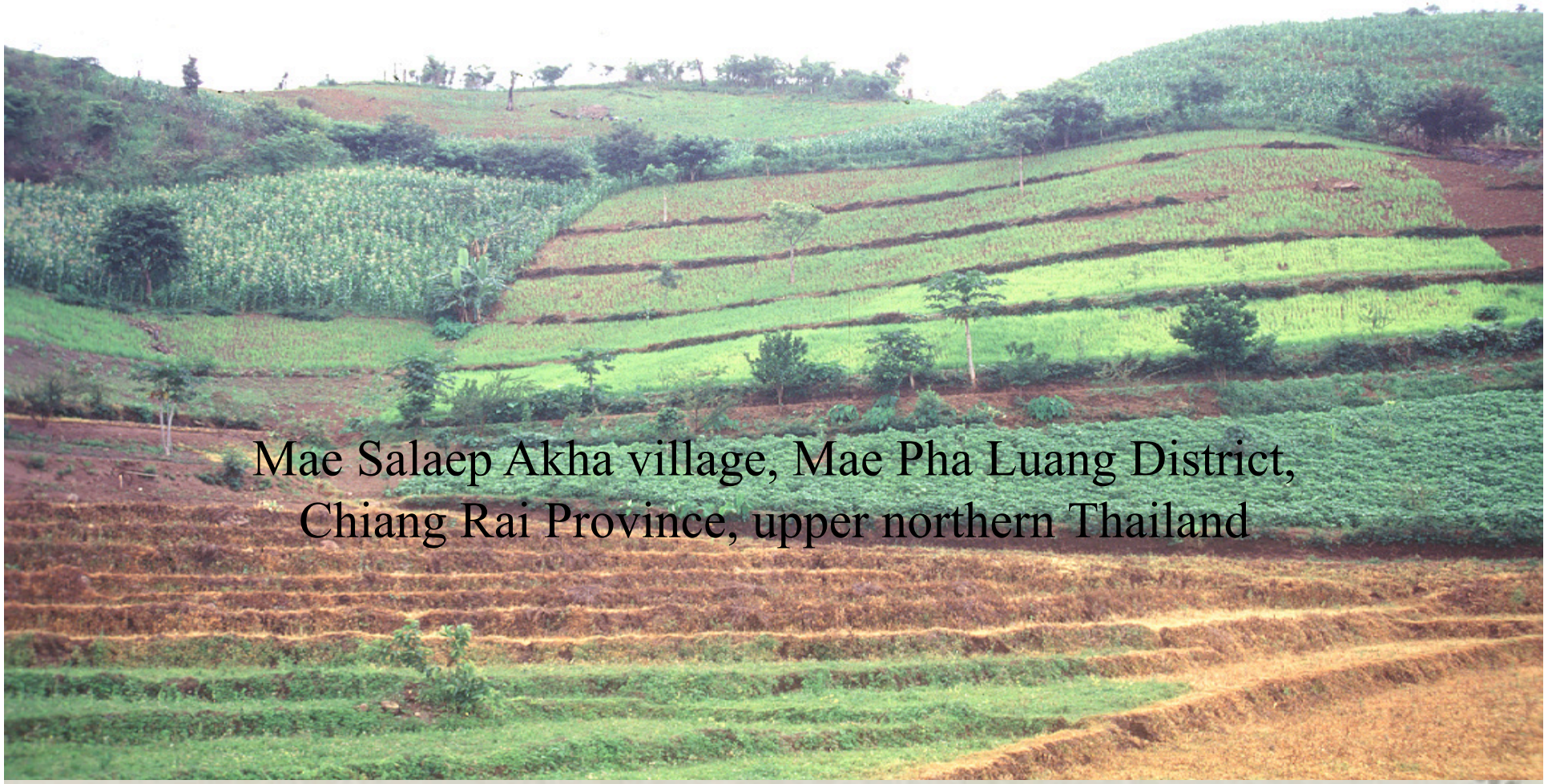
Multi-agent systems: the system

- A set of agents acting and communicating
  - Operators to perceive, to communicate, to produce, to consume, and to transform objects;
- An environment
  - Operators of reaction of the environment;
- Passive objects
  - A set of relationships;
- An organization or coordination mode;
- An observer's viewpoint.

Companion Modeling: the process



Mae Salaep case study



ComMod: the process

Ecological dynamics

Social dynamics

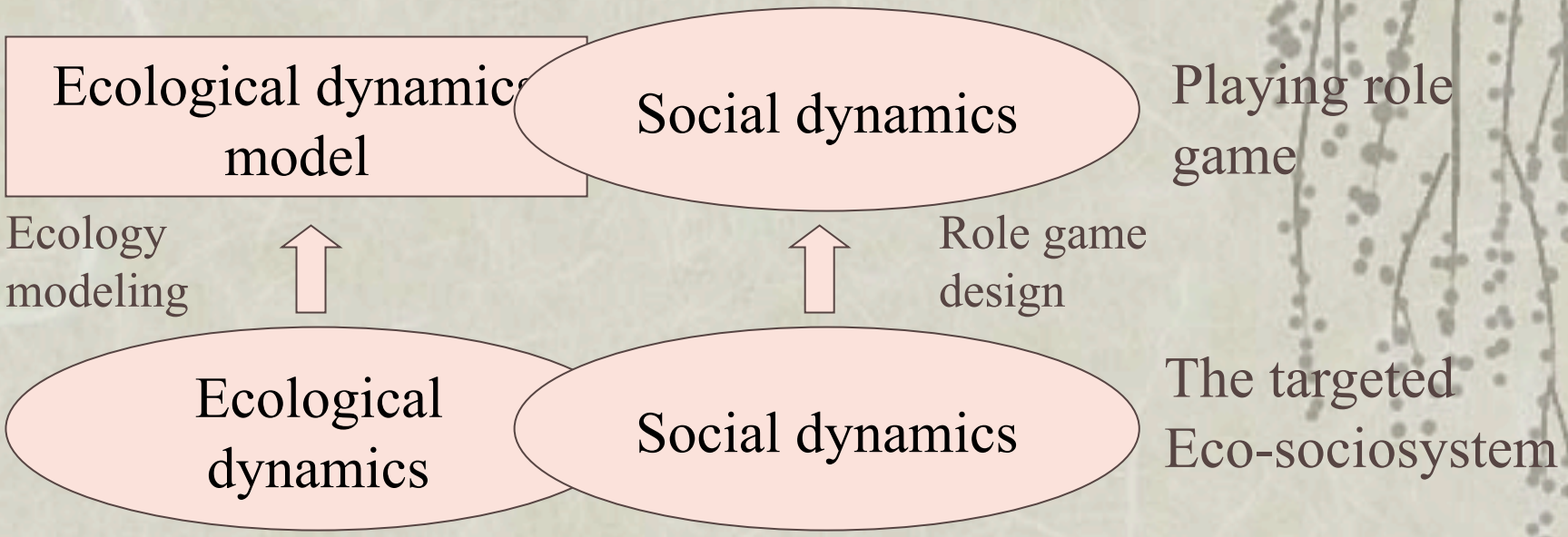
The targeted Eco-sociosystem

Watershed dynamics

The context & NRM problem

- Montane highlands of northern Thailand
  - Highland – lowland conflict re. land use
  - **Agricultural diversification vs soil & water conservation: is land degradation accelerating with market integration?**
- Rapid changes in:
  - Population (immigration, migration, citizenship)
  - Agricultural practices (intensification, external inputs)
  - Access to markets (regional, national, international)
  - Institutions (numerous agencies, new constitution, decentralization, civil society movements)

ComMod: the process

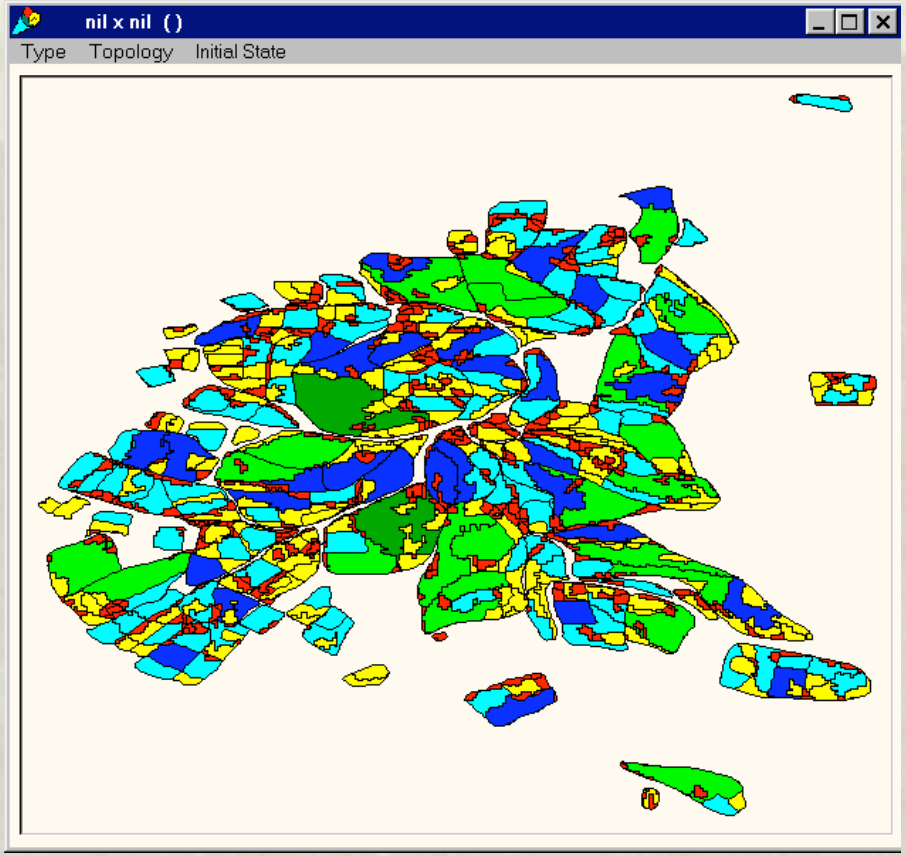


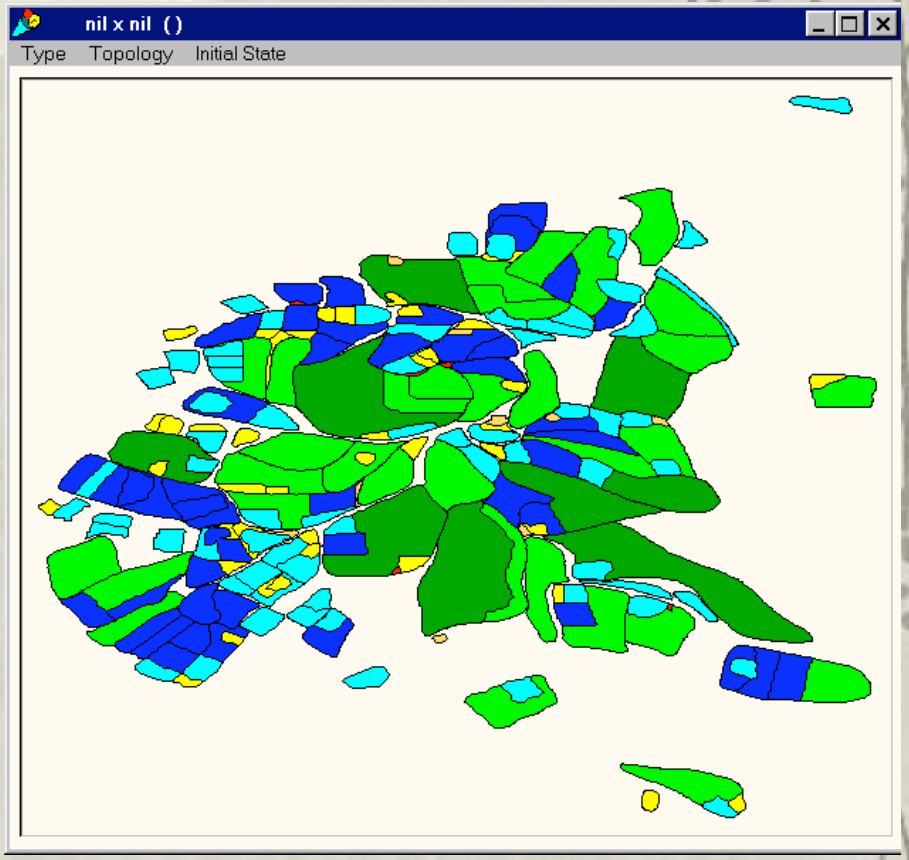
Acquiring information as usual

- **Surveys, measurements at field/farm levels:**
  - Field level: on-farm erosion dynamics (type of processes, key thresholds for management)
  - Crop patterns: practices, labor requirements
  - Farm level: livelihood systems, farmers' typology/strategies, plot allocation to farmers
- **GIS at village/watershed level:**
  - DNM: slope+orientation --> homogeneous unit
  - Land use changes: 1990, 1994, 1998WS

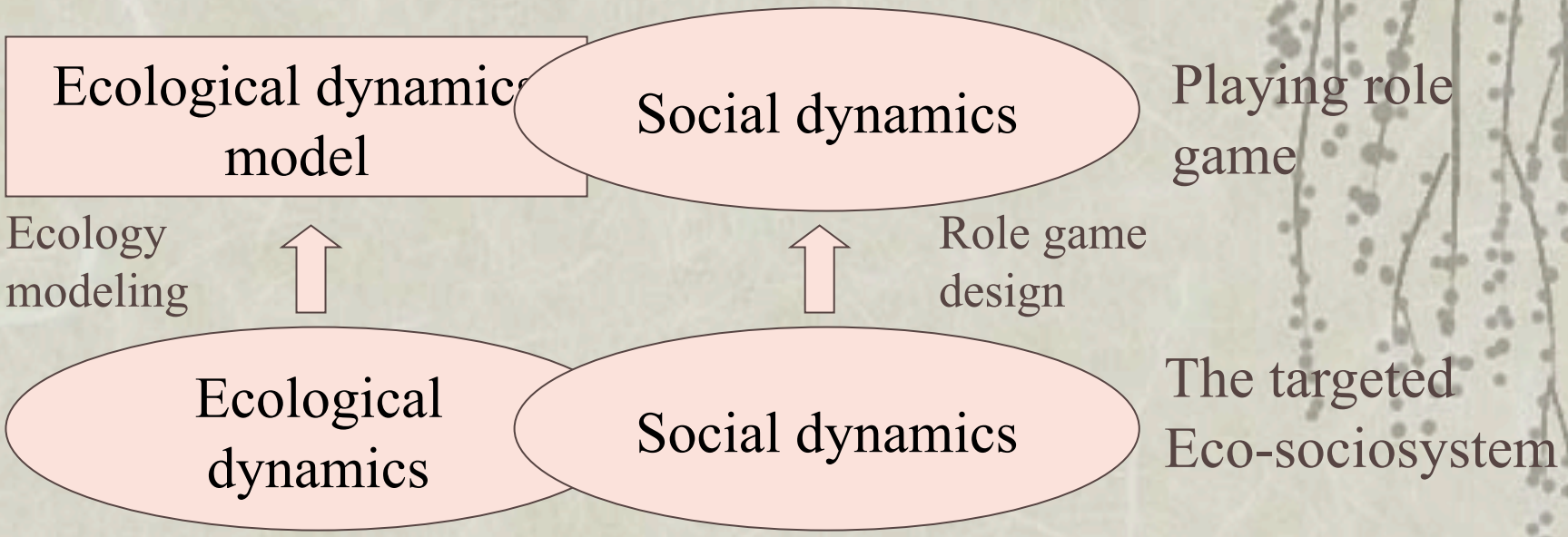
Mae Salaep village land use in 1994

Homogeneous units & Farmers ' fields





The approach



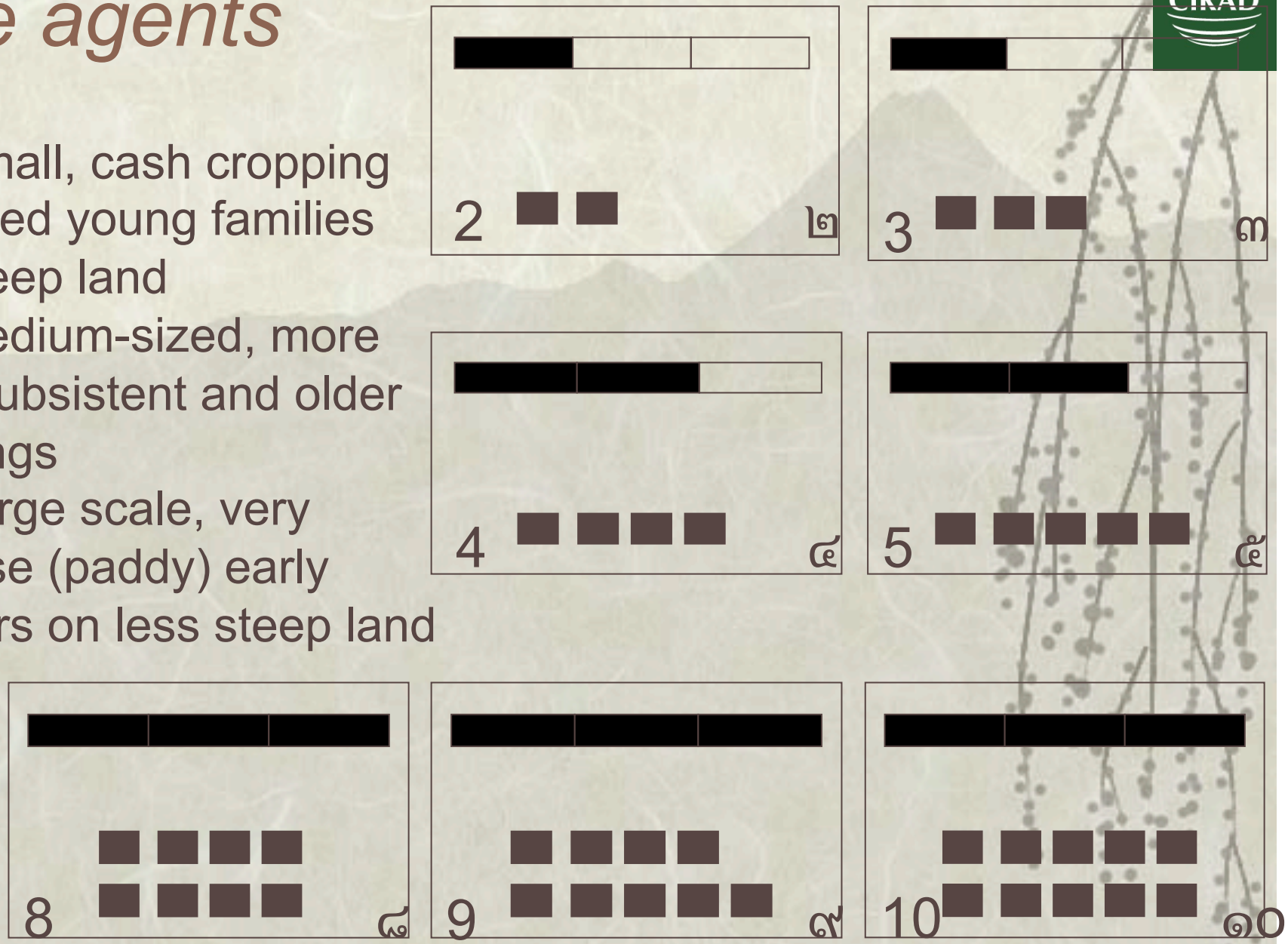
The environment

The agents

A: Small, cash cropping oriented young families on steep land

B: Medium-sized, more self-subsistent and older holdings

C: Large scale, very diverse (paddy) early settlers on less steep land



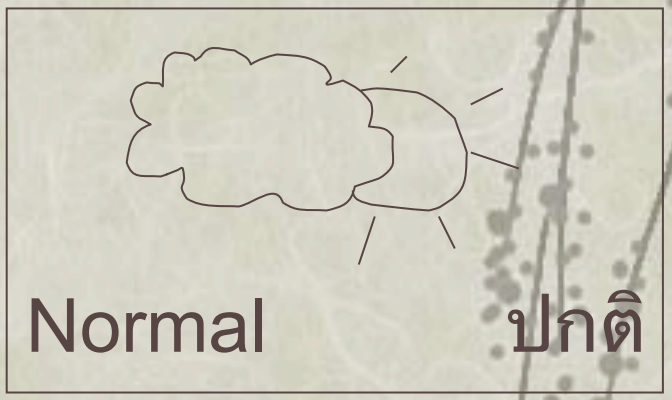
Scenario factor 1

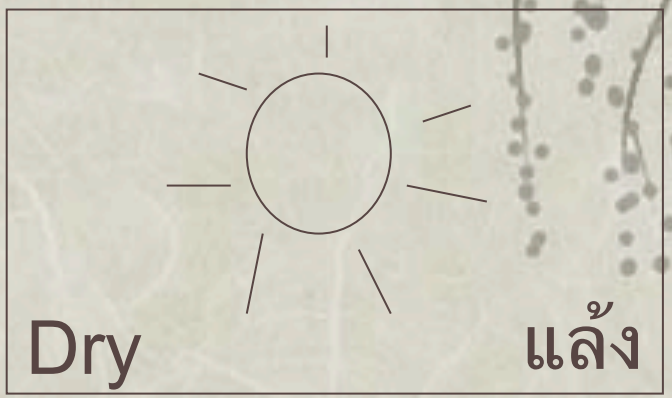
Market dynamics:
-3 types of years
-Price fluctuates for horticultural crops only (high inputs, high commercial value, short duration crops)

Scenario factor 2

Variable climatic conditions:

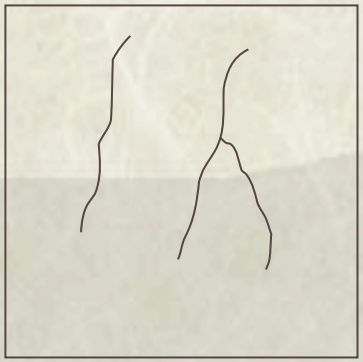
- 3 kinds of years
- Climatic conditions known AFTER crop allocation to fields (card drawn randomly each year)
- Affecting the risk of soil erosion for a given year





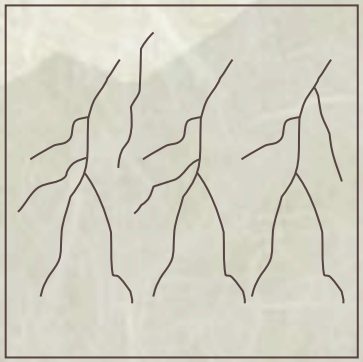
Observation: soil erosion symptoms

Low



Medium

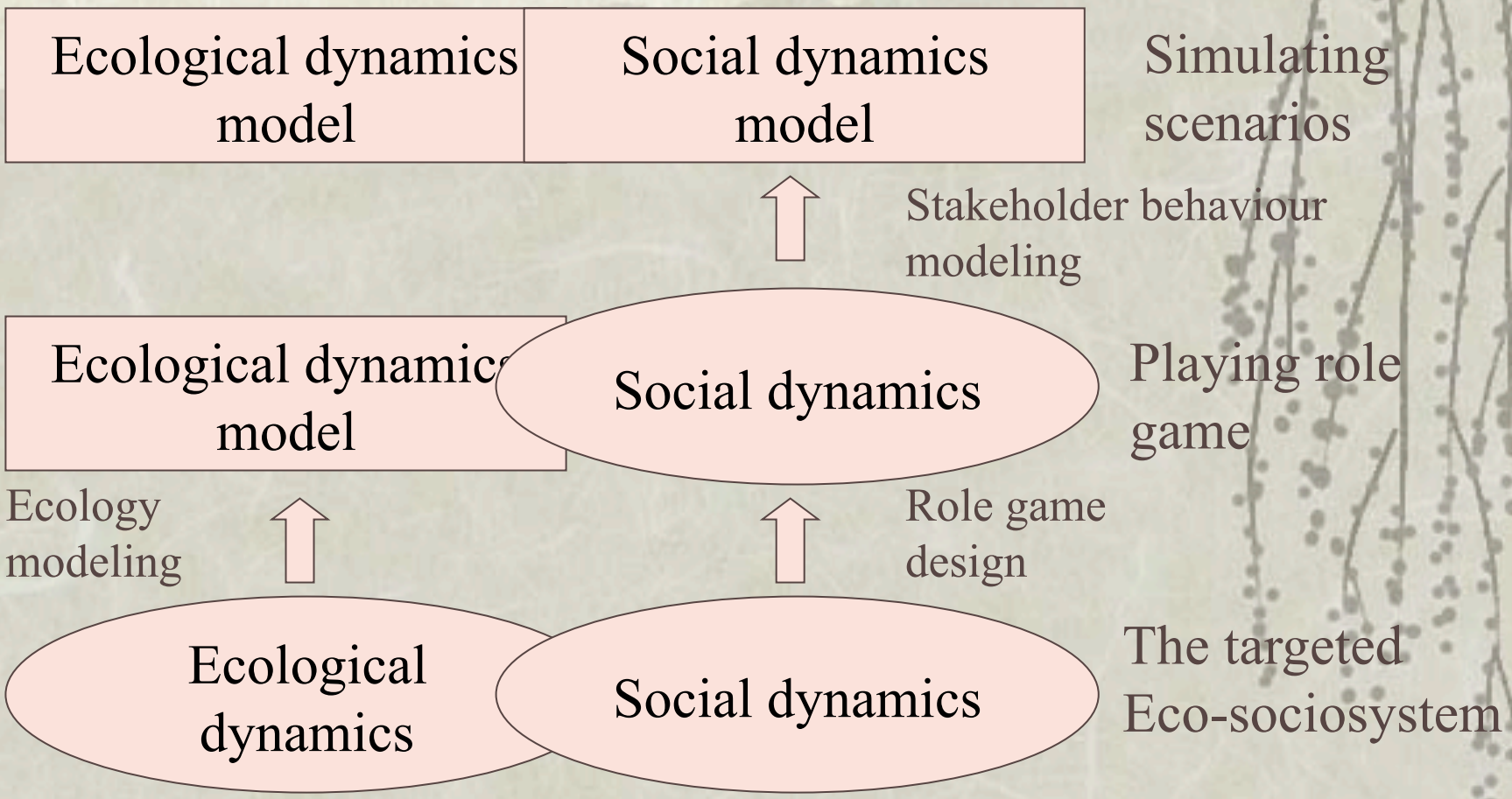
Severe



Very severe

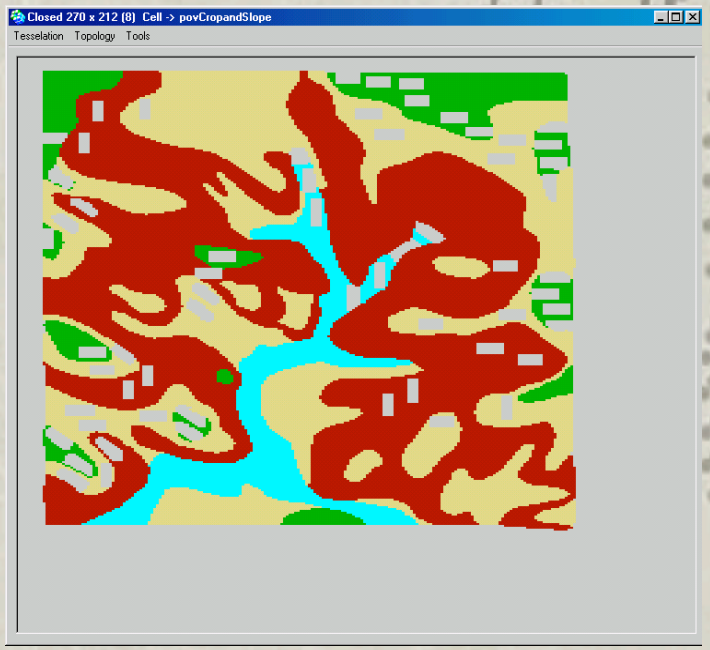
But if land is fallowed => soil improvement

The approach

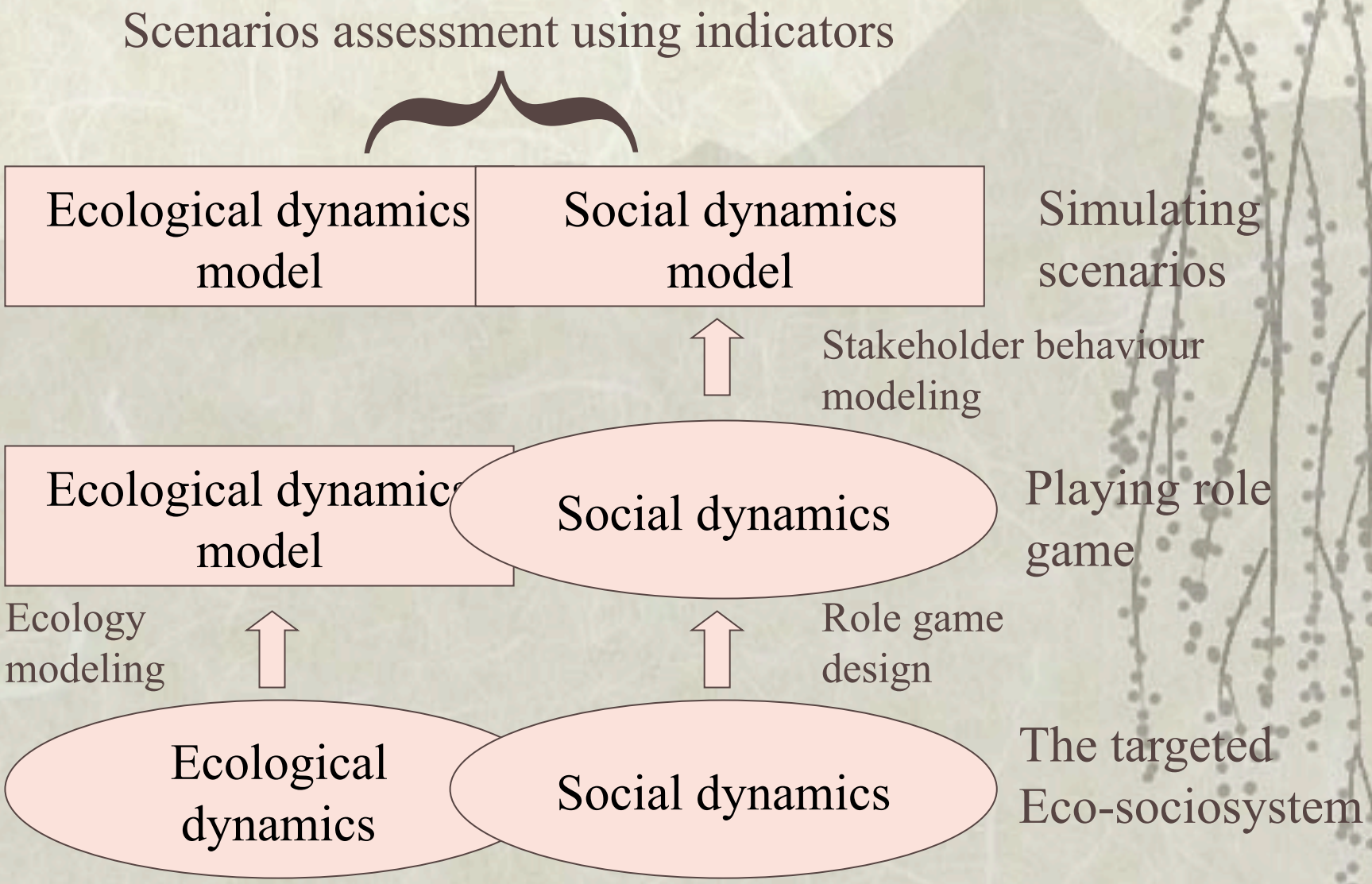


From the RPG to a MAS model

- The MAS (multi-agent system) model plays this first RPG: same interface, same rules, etc.
- MAS simulations could run for assessing scenarios of landuse & economic changes with stakeholders:



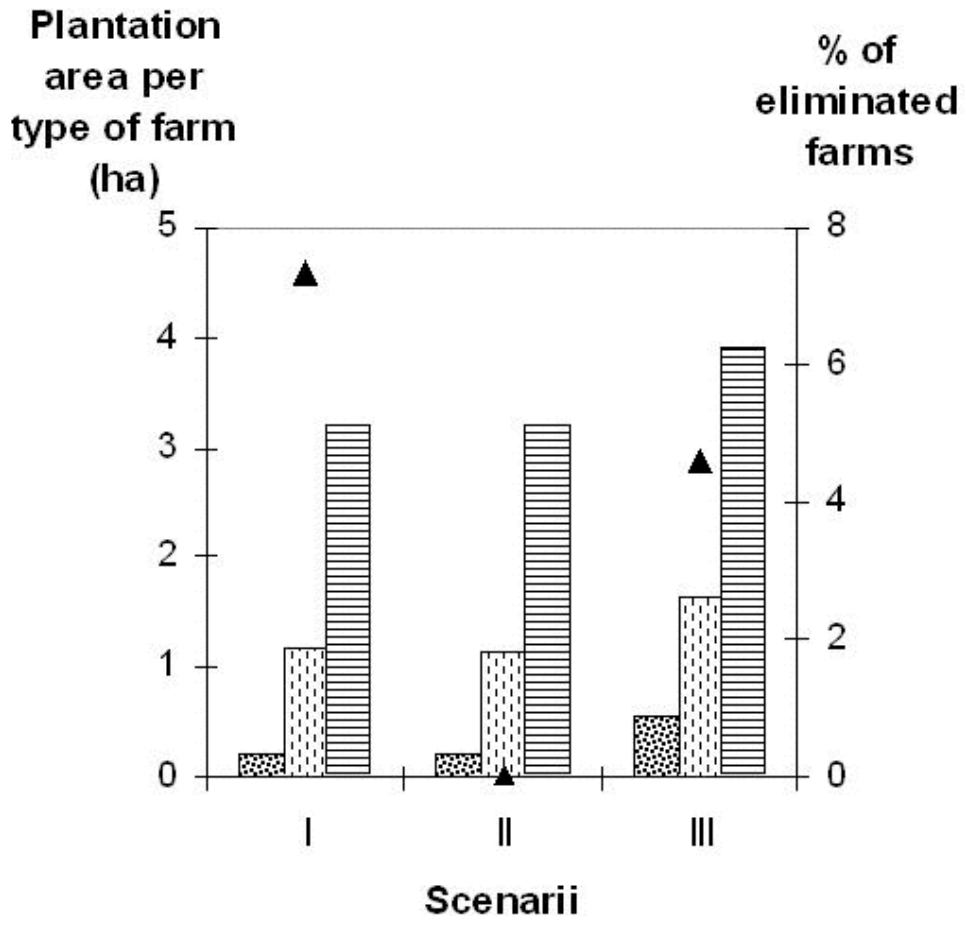
The approach



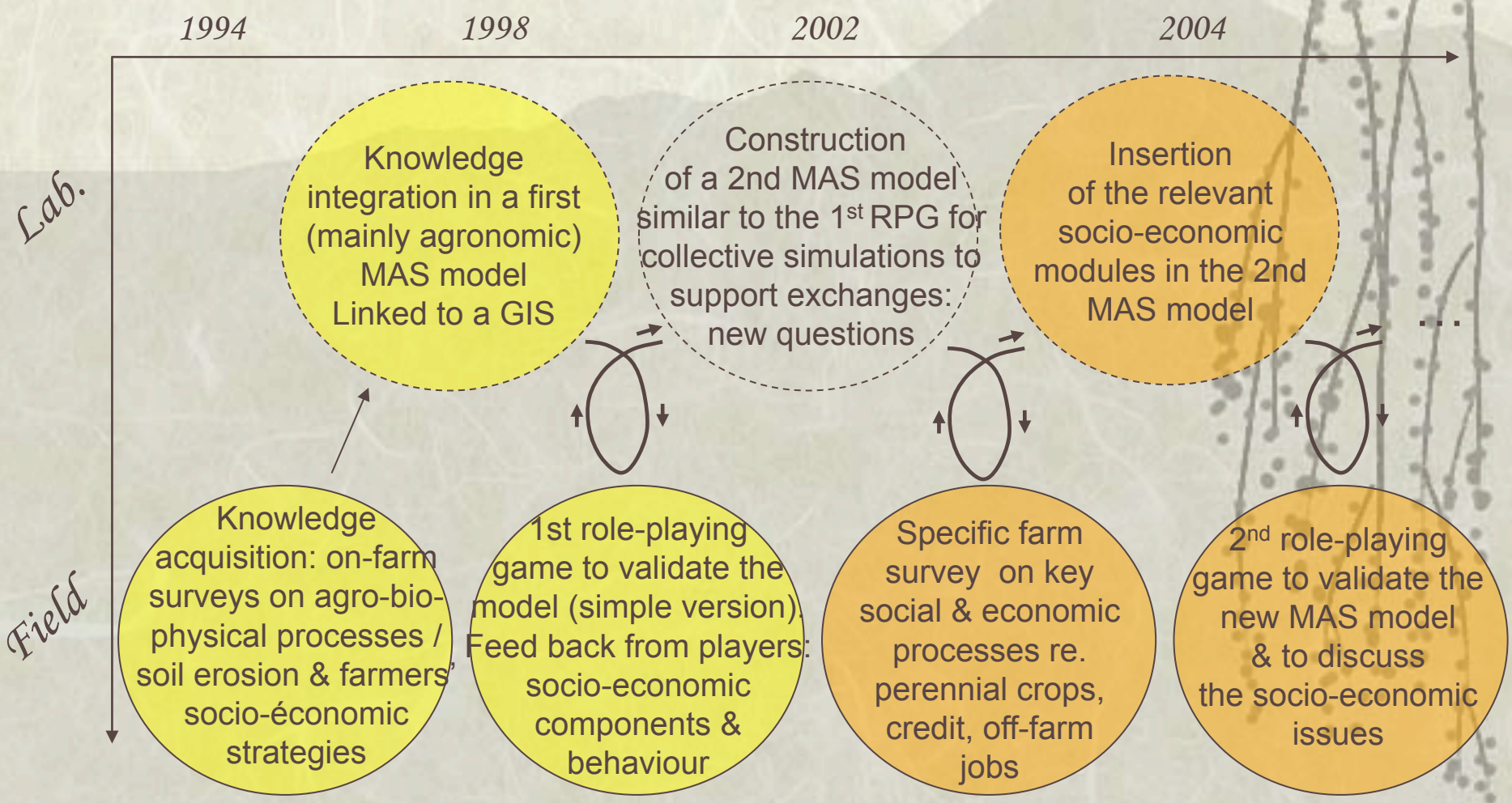
Exploring scenarios (I)

- Scenario I: simulation of the current situation and rules regarding the allocation of credit among villagers.
- Scenario II: simulation with modified rules for the allocation of informal credit through larger and mixed networks of villagers.
- Scenario III: simulation with modified rules for the allocation of formal credit, longer period for reimbursement and more equitable distribution.

Exploring scenarios (2)



Adaptive management



Content

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Conclusion (I)

- Use of multi-agent systems:
  - A constructivist approach to complex systems
  - The possibility to explore the emergence of collective effects from individual interactions
  - Various possible implementations
    - Through role playing games
    - Through computer simulation

Conclusion (II)

- Use of companion modelling:
  - Empowering stakeholders in negociation processes
  - Collective learning through the modelling process
  - Defining development issues
  - Exploring scenarios
  - Adaptive management
  - Linking various decision making levels

Conclusion (III)

Analogy of reality, RPG and MAS model -- to support stakeholder & expert interactions throughout the modelling process

From the reality…

…through the role games…

…to the computerized simulation models.

Thank you!