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Collective creation of artificial worlds can help govern concrete natural resource management problems: a northern Thailand experience

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Keywords: Integrated natural resource management, multi-agent systems, soil erosion, farmers' practices, market integration, northern Thailand.

Introduction

When working to promote sustainable agricultural development, the problems of access to the land and the productive use of natural resources are key ones. Scientists working on such problems at the agricultural systems level need to understand the interactions among diverse ecological and social factors and the dynamics in complex systems. Natural dynamics are composed of numerous interwoven biophysical processes, involving different resources at different spatial and temporal scales. Social processes involve different stakeholders at various levels of organization, ranging from individuals or local communities occupying the land and exploiting its resources to large development-oriented or policy-making institutions. Based on a prior understanding of the natural and agronomic dynamics, finding a way to generate acceptable rules for an improved regulation of collective uses of land resources (through the application of economic, legal, or institutional management tools) is a major question. This constitutes the focus of this paper, which is illustrated by an ongoing case study about steep land management in diversified farming systems in the highlands of upper northern Thailand.

Multiple stakeholders, integrated management of natural resources, and models

In many case studies on natural resource management, the core problems to be addressed refer to the collective management of the land in which ecological dynamics need to be reconciled with social processes to use resources in a more sustainable and equitable way. Public administration agencies, private companies, non-government organizations, researchers, sedentary farmers, and migrants have different representations of the local agricultural system. Therefore, integrated natural resource management (INRM) by these different stakeholders needs to be seen also as a collective learning process. To deal with the increased complexity and the rapidity of changes in agriculture, models can be used to focus and to facilitate discussions and collective learning on the relationships between causes and effects and between agent behavioral and interaction rules and the agroecological dynamics. But what kinds of models should be used for such a purpose? And how can we use them with multiple stakeholders? These are key questions to be addressed. This contribution describes the current development of such a "companion modeling approach" (Bousquet *et al.* 1999).

For several years, significant progress has been made in the field of research on simulating societies in interaction with their environment (Epstein and Axtell 1996, Gilbert and Troitzsch 1999). Innovative approaches, such as multi-agent systems (MAS), can create virtual societies (Weiss 1999). MAS are computational systems in which various autonomous agents interact in a given environment. MAS originate from the computer science field of distributed artificial intelligence (DAI) and rely on the technology of cellular automata. They are based on the principles of distribution and interaction (Ferber 1999). Agent-based modeling and simulation are being increasingly used to deal with ecological and socioeconomic issues arising from the management of scarce environmental resources with multiple uses by multiple users. When such approaches are applied to NRM issues, as in modeling situations of conflict between stakeholders, the effects on the resource dynamics of the interactions among different agent behaviors and the associated feedback effects can be simulated and tested. Modelers use these methods to create computer representations of dynamics observed in the field. Therefore, in a companion modeling approach for addressing practical NRM problems, field work and system modeling are two complementary activities that are closely interlinked in an iterative way.

Recent examples have demonstrated the effectiveness of the use of such types of models in supporting interdisciplinary research. They are also powerful tools to facilitate dialogue, shared learning, negotiation, and collective decision-making about NRM issues among multiple stakeholders (Barreteau and Bousquet 2000, Lynam *et al.* 2002). In a companion modeling approach, the collective construction of a common artificial world leads to the emergence of a shared representation of the complex system and of the concrete problem to be addressed. Later on, this common vision can be used to facilitate stakeholders' coordination and negotiation mechanisms. In the process, simulation tools can be used to develop and assess scenarios of possible futures with all concerned stakeholders. In this way, various options can be rapidly and interactively defined, simulated, and discussed to facilitate the emergence of socially and ecologically acceptable courses of action through improved stakeholder interactions (Röling 1996).

In various regions of the world, while focusing on different concrete NRM problems, an increasing number of research teams are developing methodologies relying on the MAS approach, models, and associated tools to facilitate collective decision-making. Closely articulated with MAS models, role games generate new knowledge and can be used to help building the models. They also play a role in the validation of these models and in using them in stakeholders' coordination and negotiation processes. Therefore, the complementary roles of the MAS model and its associated role game are an original methodological feature of the companion modeling approach. This approach facilitates the communication of agent-based simulation results to stakeholders and helps empower them to use such tools when looking for "solutions" to a concrete NRM problem. Because of their potential for improving interactions among local stakeholders and for elucidating the effects of their respective decisions on the resource base, these methodologies could use INRM for conflict resolution about scarce resources with multiple uses and users. They can also help to identify and to assess suitable scenarios and innovations leading to desirable future situations.

A multi-agent system model to understand and to manage the interaction between crop diversification and the risk of land degradation in upper northern Thailand

As small highland farming is being rapidly integrated into the market economy, the risk of increased land degradation is becoming a major social issue in this fragile and very heterogeneous environment. An increasing number and types of individual or collective stakeholders are presently (inter)acting in sloping land agriculture with different land-use strategies. Over the past two decades, intensive efforts focusing on the introduction of soil and water conservation techniques generally had little impact in farmers' fields. This underlines the need for improving researchers' knowledge and understanding of farmers' existing practices and diverse farming strategies. It also calls for new coordination mechanisms among stakeholders to facilitate the emergence of an ecologically sustainable and socially equitable type of highland agricultural development.

The experiment presented here is being developed by different collaborative research and development partners with complementary comparative advantages. These partners also represent successive links along the research-development continuum: KU-Leuven University, Cirad and IRRI, the Multiple Cropping Center of the Faculty of Agriculture of Chiang Mai University (MCC-CMU), the Department of Public Welfare of Thailand (DPW), and the farming communities in Pakasukjai and Mae Salaep villages of Mae Chan and Mae Fah Luang districts in Chiang Rai Province. A MAS modeling approach is being developed to explore ways for better collective resource management at the watershed level in the diversifying high and steep lands of Chiang Rai Province. The local agricultural system displays a very rapid diversification of agricultural practices and an extensive socioeconomic differentiation among farming households at the village level. These profound rural transformations are powered by strong driving forces, such as the integration of the local economy into commodity and labor markets, the expansion of communication infrastructure, population migrations, and national policies on environmental protection (Trébuil *et al.* 2000).

Purpose of the model and potential users

Based on earlier in-depth on-farm surveys at the field, household, and watershed levels that were carried out during two years in the two villages of the Akhas ethnic minority (Trébuil *et al.* 1997, Turkelboom and Trébuil 1998), a prototype MAS model was initially built to integrate relevant knowledge on crop diversification versus land degradation interaction across sources, that is, indigenous and from different scientific disciplines (soil science, agronomy, microeconomics, and geography). This first agent-based simulation model is being improved to explore the observed system behavior at different scale levels: from the small homogeneous units in cultivated fields with complex slopes to the whole village watershed, through farmer-managed fields planted to a given crop, and the functioning of the main different types of households. This simulation model is now providing a spatial representation of the effects of farmers' actual practices and decision-making related to crop selection and allocation to their various fields on the risk of land degradation at different scales. This first version can be used in teaching and training activities.

In Thailand, as in other neighboring countries, however, the general policy-making framework regarding the land is characterized by a decentralization of the management of natural resources toward local communities and institutions. In this context, beyond its present development stage, we would like to use this multi-agent systems model to facilitate dialogue and coordination mechanisms on land-use changes among local stakeholders in highland watersheds. Possible future scenarios for upland-highland agricultural situations similar to the one observed in the villages where intensive field data collection was conducted could be jointly defined and assessed with them. In the process, we also aim at exploring the influence of social behavior and farmers' practices on the effects of the government environmental policy in the upper watersheds of the region. We also assume that this experiment will contribute to the methodological development of the companion modeling approach for agroecosystem management. It is forecast that the outputs of this research will be used for training students and local resource managers at different administrative levels (regional and provincial planning specialists, staff of subdistrict "Tambon administrative organizations" and village-based non-government organizations, etc.).

Conception and development stage of the model

The MAS modeling approach has been used to integrate local and scientific knowledge on land management obtained at complementary spatial and social levels of organization, as well as time scales (single rain event, crop cycle, crop succession, long-term trends in land-use changes). Intensive on-farm surveys and dialogue with stakeholders provided the information to understand the key mechanisms, processes, systems, and subsystems taken into account in the MAS model. The principal ones are

- Detailed knowledge on the climatic conditions in these highland agroecosystems,
- An understanding of the actual process of soil erosion caused by concentrated runoff in farmers' fields on steep land: identification of key thresholds for slope angle, slope length, soil coverage, etc. (Turkelboom 1999),
- The diversity of cropping systems: analysis of farmers' practices and their influence on soil erosion risk (Turkelboom and Trébuil 1998),
- The degree of differentiation among household-based production systems: characterization of the different types of farms based on their socioeconomic objectives, resource availability, and strategies (Trébuil *et al.* 1997), and
- The long-term dynamics of the local agricultural system: analysis of changes in the farm environment, including policies: construction of a small geographic information system (GIS) for analyzing trends of land-use changes and to be linked with the MAS model (Trébuil *et al.* 2000).

Modeling formalism

In a MAS model, an agent is a computerized autonomous entity that is able to act locally in response to stimuli from its environment or to communication with other agents (Bousquet *et al.* 1999). The whole model provides an agent-based representation of the village watershed, in which different interacting entities with specific behavioral patterns perceive (partially and differently) their common environment and act on it. The focus is on the interaction between the resource dynamics and its exploitation by different agents pursuing various objectives and strategies. Their actions and collective behavior toward their common environment are assessed through a bottom-up aggregation of their effects on the resource base.

The CORMAS ("common-pool resources and multi-agent systems", Bousquet *et al.* 1998) simulation platform has been specifically tailored by Cirad for applying the MAS approach to INRM issues, and has therefore been used to construct this model. This platform provides sets of programs

- To model agent attributes, behavior, and interactions, with these interactions being mediated via a spatial display of land resources at the watershed level,
- To control the dynamics of the simulation, and
- To define different viewpoints for observing the simulated system through either maps or graphs.

Four types of agents were modeled under the CORMAS environment:

- Situated agents having spatial references on the map (fields, etc.),
- Passive objects (crops, crop successions, farmers' practices, rainfall),
- Communicating agents being able to receive messages from the environment (different types of farmers, the village), and
- Spatial entities located on the grid: an original characteristic of this MAS model is its built-in linkage with GIS maps of a surveyed watershed. This MAS-GIS link allows the model to handle

dynamically two complementary spatial entities: small intrafield homogeneous units, with regular slopes, and farmers' entire fields.

Model structure

The model structure is shown in Figure 1 as a simplified class diagram constructed in universal modeling language (UML). It displays the different model entities and agents, as well as their hierarchy and relationships. Under the name of each model entity, a box indicates its own set of attributes while, just below, another one lists the various methods associated with it to make it evolve.

The model has two main spatial entities: (1) the farmer's field homogeneously managed by its owner and (2) intrafield homogeneous units that are small polygons characterized by identical (relative to several key thresholds identified by on-farm field surveys) slope characteristics (angle, orientation, length). The first spatial entity is the essential one for managing agronomic information (crop allocation, crop calendars, activation of successive farmers' practices for a given crop, etc.) and the second one is used by the MAS model to assess the risk of soil erosion after each significant rain event (R > 10 mm). For this, the GIS data files, representing actual maps of the watershed at different scales, were transferred into the CORMAS environment. This linkage allows users to run simulations taking into account multiple spatial levels of organization and several specific spatial functions. In this way, the right layer of information at the most relevant scale is used for each important process to be simulated.

Based on the farmer typology built through on-farm surveys, the communicating agents are made up of three different types of farmers with contrasting resource availability and agricultural production strategies:

- Type A: small holdings on steep slopes managed by relatively young farmers, who are very much involved in cash cropping (maize, soybean, and vegetables),
- Type B: medium-sized farms with a rather conservative management strategy (domination of upland rice and maize crop production),
- Type C: larger, very diversified and relatively well-off farming units managed by early settlers on prime, less steep land with access to water for paddy rice production and capital for establishing perennial plantations (Trébuil *et al.* 1997).

The model allocates the crops among the available fields at the whole-farm level depending on the farmer's strategy and related choice of a combination of crop production. Over time, depending on the farmer's age and the economic results of cash-cropping activities, a given household can evolve into another type as observed during field surveys. Specific attributes, procedures, and interacting rules are also programmed for several passive agents such as fields, crops and crop successions, cropping calendars, successions of elementary cultivation practices for each main annual crop (the most frequent itinerary of techniques recorded in farmers' fields is used by the model), rainfall distribution (a 1976-95 series of daily rainfall for Mae Chan district is used), etc.

Model functioning: flow of information during the simulation

The UML sequential diagram presented in Figure 2 displays the chronology of the model operations when it reads the instructions. This sequential diagram shows the objectives of these successive sets of instructions and, for each key step, elucidates the interactions between the various entities and agents. At the initialization stage, the model reads files to create the spatial units (small homogeneous units and whole fields), passive objects, and social entities (farmer types, the village made up of 48 households). Afterward, it allocates the fields to different farmers according to their category and numbers in each category. Then, for each field, an erosion index registering the severity and the frequency of erosion damage is initialized and set at nil. Next, farmers are asked to allocate their combinations of crops to their different fields in accordance with their respective strategies. The village agent decides the start of the cropping year and "sends" the farmers to their fields. As soon as the wet season begins, if a potentially damaging rain event occurs (daily intensity > 10 mm), the soil coverage and slope conditions of each homogeneous unit in each field are checked on a daily basis according to the recent management practices performed by the farmers. If the model finds that soil erosion occurred following this rain event, it calculates a level of severity of the damage and updates the erosion index for this field. This procedure repeats itself until the end of the wet season.

Outputs and indicators

At the end of a simulation, for each field in the village watershed, the model can display the spatial distribution of erosion indices. These indices are aggregated over time during the whole cropping season, going from the small homogeneous unit to the field, the farm, and finally the whole village catchment. This allows comparisons among various crop allocations or distributions of farmers among household types, and the resulting risk of land degradation across different climatic years to be analyzed. This indicator can be used to assess the environmental effects of a given land-use scenario discussed and proposed by stakeholders. Beyond this environmental indicator, simple graphs can also be prepared to observe changes over time in the social distribution and the related economic status of the household types, for example. Such changes depend on the local rules for inheriting the land from old farmers (above age 55) and on the economic results of farmers' cash-cropping activities. Again, this kind of socioeconomic indicator can be very useful to help answer the question "Who benefits?" when assessing a given land-use scenario with local actors.

Procedure for model validation: the key role of stakeholders

A general two-step approach is used for validating this model. Following expert assessments of the results of simulations, further improvements and validation of the model will be carried out with its potential users, that is, the local stakeholders themselves (Bousquet *et al*. 2001). To do so, the MAS model needs to be first simplified (but retain all key interactions) and translated into a less complex tool, such as a role game, to be tested with stakeholders. To limit the "black box" effect, such a simpler tool or game can help local actors familiarize themselves with the way the MAS model is working. It can also show them how it relates to the real world in which they act. We anticipate that this step will generate new knowledge on actors' strategies and decision-making processes that will imply modifications of the original MAS-GIS model. This approach is used to stimulate a collective production of knowledge of the system. As soon as the stakeholders become familiar and at ease with the rules and the outputs of the role game, for example, an improved version of the MAS model, incorporating the shared representation of the system, could be used with them. Their knowledge of the functioning rules of the model will allow them to criticize the results of the simulations and to use this tool to explore the effects of various scenarios of land-use changes on both the natural environment and the socioeconomic status of the local farming community.

Conclusions: strengths and limitations of the approach

This recent ongoing experiment is part of a current set of similar field experiences applying the MAS approach for knowledge integration and collective INRM in situations characterized by multiple uses of the land by multiple (individual and collective) users. In northern Thailand, it was first used to help assess the relationship between the diversity of actual farmers' production practices and changes in the risk of land degradation on sloping land. We found that the adopted MAS-GIS-based modeling approach has the capacity and the flexibility to represent and integrate different kinds of (qualitative as well as quantitative) knowledge, across sources (indigenous and scientific ones) and at multiple levels of organization, to better understand the functioning of complex agricultural systems in transition. The key output of this "learning by modeling" approach is a holistic type of representation of knowledge of a complex system seen as a set of dynamic and interconnected hierarchies. MAS modeling also allows the visualization of the results of simulations at various scales. The display of results facilitates their communication to local stakeholders. This approach can also lead to the construction of simple generic models to move beyond the site specificity of NRM research.

If, in most situations, existing and relatively easily accessible information is available to get started when the practical problem to be addressed is well defined, such an approach to INRM research implies setting up functional interdisciplinary teams willing to adopt a collective learning attitude with stakeholders. To work on a given problem, in addition to NRM and social scientists, a modeler and computer scientist are often required to transfer field knowledge into a MAS simulation tool. Project training activities now aim at removing such a limitation by providing degree and on-the-job training opportunities, on freely available software, to colleagues interested in both the simulation tools and this whole approach to INRM research.

We think that the proposed companion modeling approach provides an operational way for INRM researchers to closely articulate their field and modeling activities. This approach has a strong potential for helping to fill the current gap between "hi-tech" modeling and essential on-farm research. In many situations characterized by a general policy framework encouraging the decentralization of NRM, we think that it can help to prioritize, plan, implement, and assess research work with diverse stakeholders to accompany and support their projects. An important research activity in our future work plan will be the analysis of the use of such a companion modeling approach and methodology to facilitate stakeholders' collective decision-making processes for key local INRM problems in different agricultural contexts.

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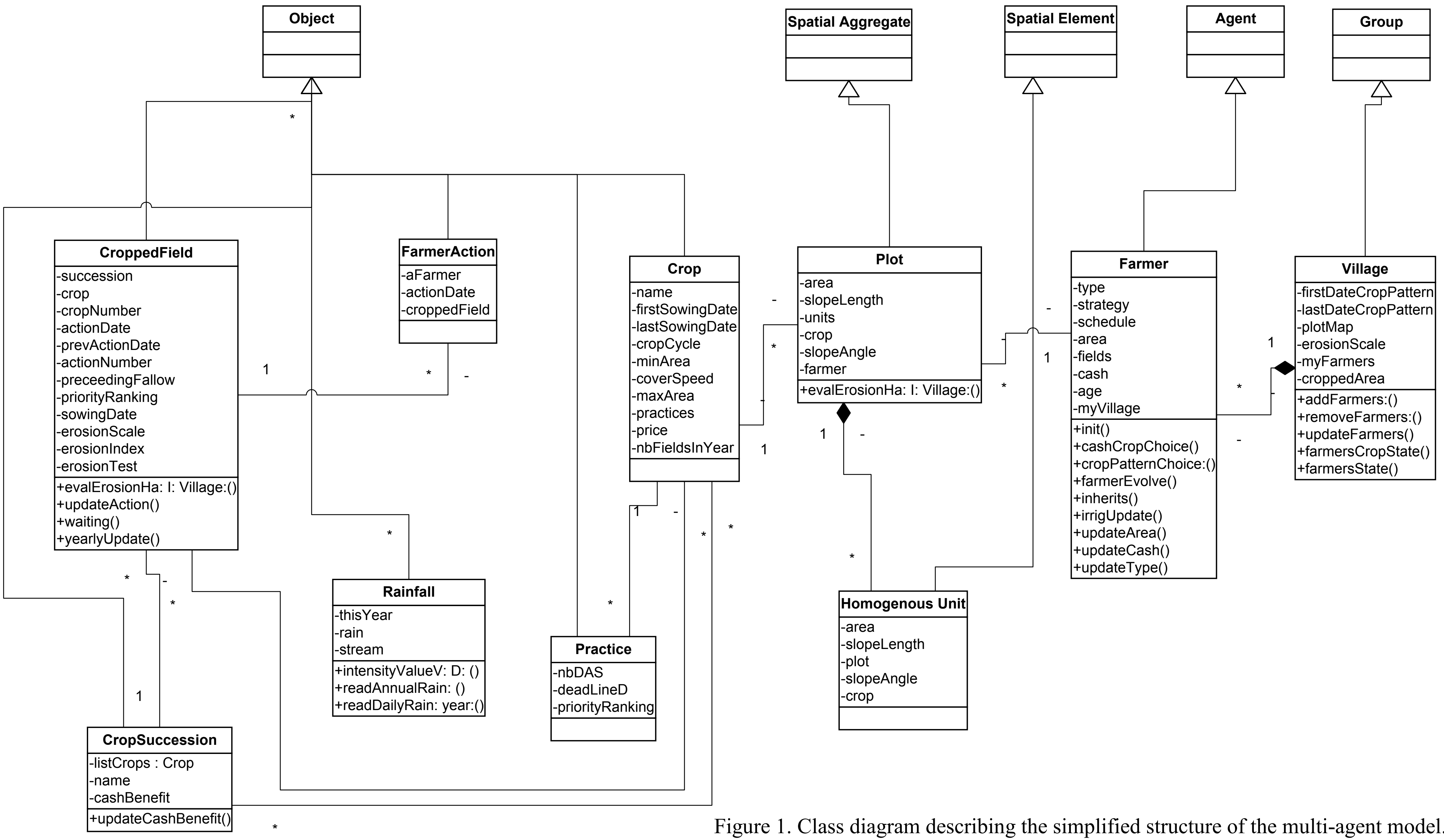
Figure 2. Sequential diagram describing the functioning of the multi-agent model.



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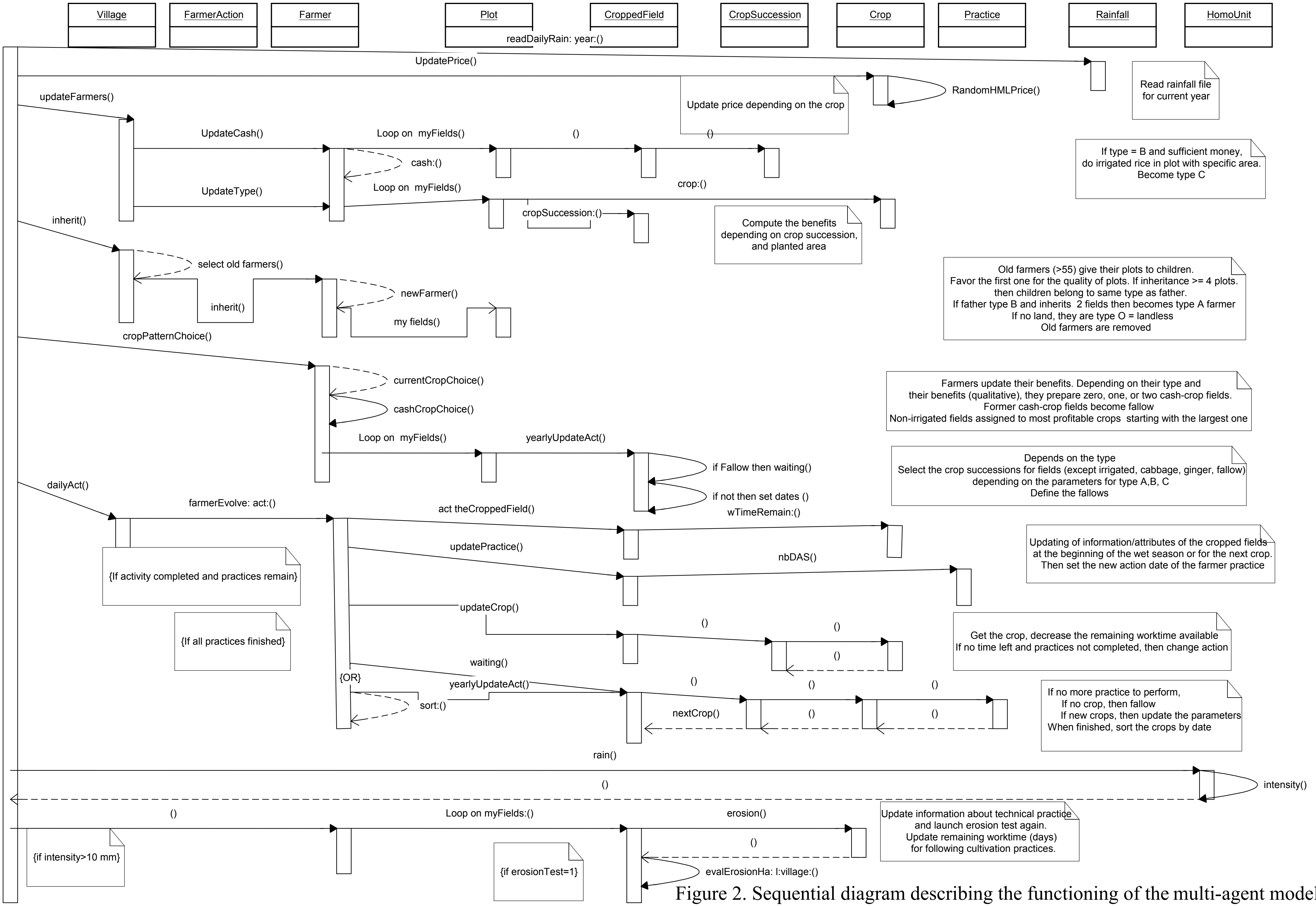

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International Symposium on Sustaining Food Security and Managing Natural Resources in Southeast Asia: Challenges for the 21st Century

Extended Abstract

Collective creation of artificial worlds helps govern concrete natural resource management problems: a northern Thailand experience

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Introduction

On the basis of an understanding of natural and agronomic dynamics, the way to generate acceptable rules for an improved regulation of collective uses of land resources by applying economic, legal, or institutional management tools is a major question. This constitutes the focus of this paper, which is illustrated by a case study on steep-land management in diversified farming systems in the highlands of upper northern Thailand.

Multiple stakeholders, integrated management of natural resources, and models

In many NRM case studies, the core problems to be addressed refer to the collective management of the land, in which ecological dynamics need to be reconciled with social processes to make resource use more sustainable and equitable. Public administration agencies, private companies, non-government organizations, researchers, sedentary farmers, and migrants have different representations of the local agricultural system. Therefore, the integrated management of natural resources (INRM) by these different stakeholders could be seen as a collective learning process. To deal with the increased complexity and the rapidity of changes, models can be used to focus and to facilitate discussions and collective learning on the relationships between causes and effects and between agent behavioral and interaction rules and agroecological dynamics. But what kinds of models should be used for such a purpose? And how can we use them with multiple stakeholders? These are key questions to be addressed. This contribution describes and illustrates the current development of such a "companion modeling approach" (Bousquet *et al.* 1999).

For several years already, significant progress has been made in the field of research on simulating societies in interaction with their environment. Innovative approaches, such as multi-agent systems (MAS), can create virtual societies (Ferber, 1999). Agent-based modeling and simulation are being increasingly used to deal with socioeconomic issues that arise from the management of scarce environmental resources. When these approaches are applied to NRM, as in the case of modeling of situations of conflict between stakeholders, the effects of the interactions among different agent behaviors on the resource dynamics and the associated feedback effects can be simulated and tested. Modelers use such methods to create computer representations of the dynamics observed in the field. Therefore, field work and modeling are seen as two complementary activities that are closely interlinked in an iterative way for addressing practical NRM problems.

Recent examples have demonstrated the effectiveness of the use of these models in supporting interdisciplinary research and facilitating dialogue, shared learning, negotiation, and collective decision-making about NRM among multiple stakeholders (Barreteau and Bousquet

2000, Lynam *et al.* 2002). In a companion modeling approach, the collective construction of a common artificial world leads to the emergence of a shared representation of the complex system and of the concrete problem to be addressed. Later on, it can be used as a coordination and negotiation support tool, for example, by developing and assessing scenarios of possible futures using simulation with all concerned stakeholders. Various options can be rapidly and interactively defined, simulated, and assessed to facilitate the emergence of socially and ecologically acceptable courses of action through improved stakeholder interactions (Röling 1996).

A multi-agent system model to help manage the interaction between crop diversification and risk of land degradation in northern Thailand

This case study is being developed by six main partners representing successive links along the research-development continuum. In cooperation with the KU-Leuven University, Cirad, IRRI, the Multiple Cropping Center of the Faculty of Agriculture of Chiang Mai University, the Department of Soils and Fertilizers at Maejo University in Chiang Mai, and the Department of Public Welfare of Thailand, a MAS modeling approach is being developed to explore ways for better collective resource management at the watershed level in the diversified high and steep lands of Chiang Rai Province. In this agricultural system, the rapid diversification of agricultural practices and the related socioeconomic differentiation among farming households are powered by strong driving forces such as the integration in commodity and labor markets, the availability of communication infrastructure, and national environmental protection policies.

In Thailand, as in other countries in the region, the general policy-making framework regarding the land is characterized by the decentralization of the local management of natural resources. In this context and beyond its present development stage, we would like to use this multi-agent systems approach to facilitate dialogue and coordination mechanisms on land-use changes among local stakeholders. In the process, possible future scenarios of upland-highland agricultural situations, similar to the one observed in the villages where intensive field data collection was conducted, could be jointly defined and assessed with the stakeholders. In this way, we also aim at exploring the influence of social behavior and farmers' practices on the effects of the government environmental policy in the upper watersheds of this region. It is also assumed that this experiment will contribute to the methodological development of the companion modeling approach for agroecosystem management. It is forecast that the outputs of this research will be used for training students and local resource managers at the subdistrict ("Tambon administrative organizations") or village levels (non-government organizations, etc.).

Based on earlier in-depth surveys, at the field, household, and watershed levels, that were carried out during two years of intensive on-farm research in two villages of the Akhas ethnic minority (Turkelboom and Trébuil 1998), a MAS model was first used to integrate relevant knowledge across sources, that is, indigenous as well as from different scientific disciplines, the main ones being soil science, agronomy, microeconomics, and geography. This agent-based simulation model is also being developed to explore the observed system behavior at different scale levels, from the small homogeneous units in cultivated fields with complex slopes to the whole village watershed, through farmers' fields planted to a given crop and different types of households. This simulation model is now providing a spatial representation of the effects of farmers' practices and decisions related to crop allocation on the risk of land degradation at different scales that can be used in teaching and training activities.

The MAS modeling approach has been used to integrate local and scientific knowledge on land management obtained at complementary spatial and social levels of organization, as well as time scales (single rain event, crop cycle, crop succession, long-term trends in land-use changes). Intensive on-farm surveys and dialogue with stakeholders provided the information to understand the key mechanisms, processes, systems, and subsystems taken into account in the MAS model. The principal ones are

- Detailed knowledge on the climatic conditions in these highland agroecosystems;
- An understanding of soil erosion caused by concentrated runoff on steep land: identification of key thresholds for slope angle, slope length, soil coverage, etc.;
- The diversity of cropping systems and farmers' production practices and their influence on soil erosion risk;
- The degree of differentiation among household-based production systems: characterization of the different types of farms based on their socioeconomic objectives, resource availability, and strategies (Trébuil *et al.* 1997); and
- The long-term dynamics of the agricultural system: analysis of changes in the farm environment, including policies: construction of a small geographic information system (GIS) for analyzing trends of land-use changes and to be linked with the MAS model.

This MAS model provides an agent-based representation of the village watershed. An original characteristic of this MAS model is its built-in linkage with GIS maps, thus making it able to handle multiple spatial entities. This MAS-GIS link allows us to use the right layer of information at the most relevant scale for each key process to be simulated.

While focusing on different concrete NRM problems, an increasing number of research teams are developing methodologies relying on the MAS approach, models, and role games to facilitate collective decision-making for more appropriate INRM. Closely articulated with MAS models, role games generate new knowledge on the system and can be used to build them. They also play a role in the validation of these MAS models and in putting them to use in stakeholders' coordination and negotiation processes. Therefore, in a companion modeling approach, the complementary roles of the MAS model and its associated role game are an original methodological feature for communicating the results of agent-based simulations to stakeholders and to empower them to use these tools to look for "solutions" to the problem being addressed. By facilitating interactions among local stakeholders and elucidating the effects of their respective decisions on the resource base, these methodologies offer a strong potential to use INRM for conflict resolution about scarce resources with multiple uses and users or to identify and assess suitable innovations and desirable scenarios for the future.

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