

Introduction to companion modeling and multi-agent systems for integrated natural resource management in Asia

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This introductory chapter recalls the origins of this publication at the interface between the personal interest of several colleagues from different Southeast Asian countries and a growing interest in methodological innovation in the field of integrated natural resource management (INRM) in the Consultative Group on International Agricultural Research. The historical development of the so-called “companion modeling” (ComMod) approach relying on the use of multi-agent systems (MAS) for INRM is also described, and its main principles and objectives are defined: to develop simulation models integrating various stakeholders’ points of view and to use them within the context of platforms for collective learning. The ComMod methodology used to facilitate such a process in INRM is presented, with an emphasis on the combination of key tools used with stakeholders, such as conceptual models, MAS, and role-playing games. A final section introduces the diversity of the Asian experiences presented in this book and its content.

In late 1998, Dr. Benchaphun Ekasingh and her colleagues from the Multiple Cropping Center at the Faculty of Agriculture, Chiang Mai University (MCC-CMU), began organizing the first training course in Asia on multi-agent systems (MAS) and integrated natural resource management (INRM). Based on Dr. Ekasingh’s strong experience in the field of systems approaches in agriculture, she perceived the need to introduce innovative approaches belonging to the emerging sciences of complexity and new tools developed by researchers working in this field. This perception was confirmed a few years later when the Consultative Group on International Agricultural Research (CGIAR) organized several scientific workshops focusing on INRM. An important point was made at the Penang meeting in 2000 with the mention of the adaptive management concept, together with social learning and action research. Adaptive management was seen as a way to “...ensure that functional integrity of the system can increase the adaptive capacity. Adaptive capacity is dependent on knowledge (...) the ability to recognize points of intervention and to construct a bank of options for resource management.” Then, a new role for modeling was formulated in this context: “Modeling proceeds iteratively by successive approximations usually from simple to more complex representations of system dynamics. This iterative modeling is done in close interaction with stakeholders, who, along with the modelers, use the

models for scenario planning.” Thus, Dr. Ekasingh invited members of the GREEN (French acronym for “Renewable resource management and the environment”) team of CIRAD to hold a two-week course at MCC-CMU in late 1999.

Since the creation of the GREEN research team by J. Weber in 1993, several researchers have been developing modeling activities to better understand the interactions between social and ecological dynamics. A basic principle was to go beyond disciplinary approaches tackling the problem exclusively either from the angle of “an ecological system subject to anthropologic disturbance” or from the angle of “a social system subject to natural constraints.” In the first case, scientists carefully describe the dynamics of the resource and management is considered as the various forms of anthropologic exploitation of the ecosystem that can be sustained over the long term. Social dynamics are represented in terms of the type of resource exploitation they entail. In the second case, researchers generally focus on the problem of resource usage and position themselves as isolated economic agents who wish to maximize the benefits obtained from a limited resource and place the collective use of common resources within a framework of competitive exploitation. Unlike the ecological approach or the economic approach, both of which postulate hypotheses of equilibrium and optimization to formalize situations of competition or interaction, GREEN researchers look at renewable resource management in a different light by integrating the dynamics of the ecological and social dimensions and eliciting their interactions. Their main research theme is the decision-making process. Unlike the conventional decision-making process, which defines a decision as a rational calculation on the part of a more or less fully informed decision-maker, GREEN researchers consider the decision-making process as a series of interactions among stakeholders having various objectives, different perceptions, levels, or kinds of information, and varying degrees of importance and influence. Figure 1 illustrates such a frame of mind. The objective of the researcher working on such a system is to try to understand the interactions between key processes, the social ones being driven by various interacting points of view.

In the field of modeling, a choice was made to use and develop tools called multi-agent systems.¹ The aim of multi-agent systems is to understand how different processes in direct competition are coordinated. Woolridge (1999) defines an agent as “a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives.” An agent can be described as autonomous because it has the capacity to adapt when its environment changes. For Ferber (1995), an agent is a physical or virtual entity, which operates in an environment, is able to perceive it and act on it, which can communicate with other agents, and which exhibits an autonomous behavior that can be seen as a consequence of its knowledge, its interactions with other agents, and the goals it is pursuing. A multi-agent system (MAS) is made up of a set of computer processes

¹In computer science, this kind of model is called a multi-agent system. In ecology, they were called individual-based models. While other disciplines introduce multi-agent systems in their research field, one observes the emergence of new terms such as agent-based modeling (ABM). Some people, such as our group, think that ABM reflects the use of agents but does not emphasize interactions, which is the main innovation in our approach. This is why some researchers, most of them in social sciences, use multi-agent-based simulation (MABS). For the sake of simplicity, we use the MAS acronym in this introduction.

that occur at the same time, that is, several agents that exist at the same time, share common resources, and communicate with each other. Figure 2 shows a schematic representation of a MAS. It illustrates the conceptual relationship between a MAS and the definition of our research object shown in Figure 1.

In the field of MAS modeling for INRM, complementary activities were developed by GREEN researchers, PhD students, or associated researchers.

1. Developing abstract models, also called artificial societies, that help to understand the generic properties of interacting processes: models on nonmerchant exchanges and reputation, models on economic tools for the regulation of economic exchanges, and models on spatial dynamics.
2. Developing models applied to concrete and local problems to understand the dynamics of natural and renewable resources and their management. Applications were developed in irrigation, wildlife management, and pasture management.
3. Developing a simulation platform (CORMAS, common-pool resources and multi-agent systems). This platform was developed in an inductive way by trying to select generic aspects while working on concrete applications and by integrating them into this tool.
4. Developing a companion modeling (ComMod) methodology for the use of these MAS tools within the community of approaches dealing with participatory modeling for collective learning and action. The ComMod method uses

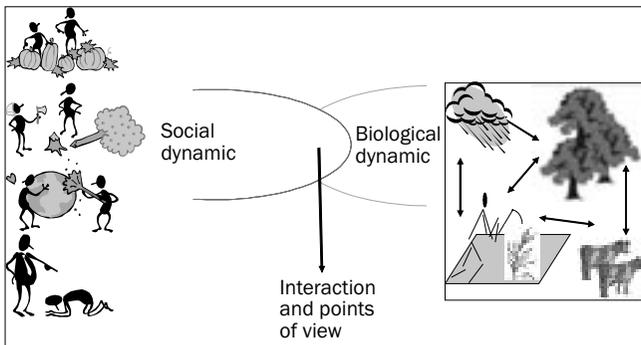


Fig. 1. Schematic representation of a socio-ecological system.

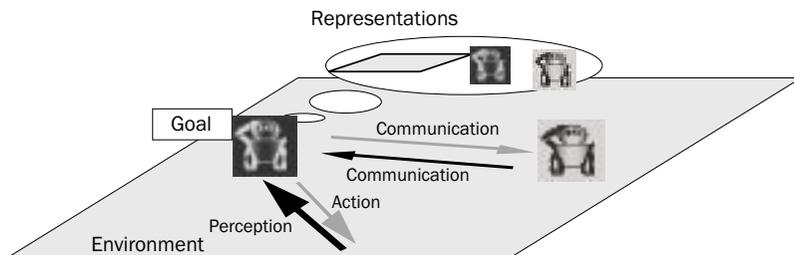


Fig. 2. Schematic representation of a MAS.

role games to acquire knowledge, build a MAS model and validate it, and use it in the decision-making process dealing with collective resource management. This will be discussed in more detail below.

In 1995, F. Bousquet and C. Le Page started to propose training courses on MAS modeling for INRM. The session organized in 1999 at Chiang Mai University in northern Thailand by Dr. Ekasingh was the starting point of a very rich set of interactions with many Asian institutions (mainly universities) and researchers working in the field of INRM. Because of the interest of the participants, a similar training course was offered at the International Rice Research Institute (IRRI) headquarters in Los Baños, Philippines, in late 2000 and a joint IRRI-CIRAD collaborative research project based in Bangkok was designed. The collaborative project was able to reinforce its training activities thanks to a three-year grant from the Asia IT&C initiative of the European Union (EU). The objective of this EU project was to train Asian lecturers and researchers on MAS for social sciences and INRM by inviting 12 internationally renowned European researchers to deliver one-week courses in Thailand on different specific aspects of this subject. This training process took advantage of the respective expertise available at three collaborating public universities in Thailand (Chulalongkorn University, Chiang Mai University, and Khon Kaen University) to organize each of the successive short courses. More on this training process and its effects will be found in Trébuil and Bousquet's article in the fourth part of this volume.

During this training process, several participants declared their interest in applying these approaches and tools to concrete case studies focusing on different real-world issues. This volume constitutes a collection of the applications initiated between 2001 and 2003. In October 2003, following a training session held at MCC-CMU, a technical workshop was organized near Chiang Mai for all the participants who had already started an application. Papers presenting these applications at different stages of advancement were presented and collectively discussed by the group, with the objective of further improving the contributions and publishing them in a collective book. Before introducing its detailed outlines, we shall briefly present the main principles and concepts of the ComMod approach.

Principles and objective of the companion modeling approach

Researchers in the field of postnormal science distinguish two main paradigms. Schematically, on the one hand, researchers following a positivist paradigm try to discover the objective truth and to unravel the natural laws driving the system. This knowledge is used to develop and deliver new technologies or new management rules. In such a context, definitions of sustainability emphasize biophysical attributes of ecosystems and often focus on calculable thresholds below which land use, for example, becomes unsustainable. On the other hand, soft systems are based on the assumption that people construct their own realities through learning along social processes. Hard sciences can show that an ecosystem is endangered but sustainable land use is defined as the outcome of human interaction and agreement, learning, conflict resolution, and collective action. As a consequence, the role of interdisciplinary teams including natural and social scientists is to understand and strengthen the collective decision-making

process through platforms of interactions. The different stakeholders, including scientists, should work out a common vision on resource management in an interactive fashion that would lead to the identification of new collectively agreed upon indicators, shared monitoring procedures, information systems, and concrete alternatives for action. The scientist's role (as displayed in Fig. 3) is partly to feed this platform with "objectively true" knowledge on the biophysical subsystem, and find ways to collectively compare, assess, and implement concrete alternatives.

Several approaches for supporting the collective management of ecosystems were developed in the recent past and they inspired the design of the ComMod methodology.

- Adaptive management is an approach recognizing that ecosystem management requires flexible, diverse, and redundant regulation and monitoring that lead to corrective responses and experimental probing of ever-changing reality. Although the adaptive management approach was conceived by ecologists, they recognize that adaptive capacity is dependent on knowledge—its generation and free exchange—and the ability to recognize points of intervention and to construct a bank of options for resource management. Thus, interactions with stakeholders for the generation and exchange of knowledge are required. This social process of generation and free exchange of knowledge may lead to new kinds of interactions and to the issue of devolving power over resource management.
- Co-management is defined as a partnership in which local communities, resource users, government agencies, nongovernment organizations, and other stakeholders share, as appropriate to each context, authority and responsibility over the management of a specific territory or set of resources.

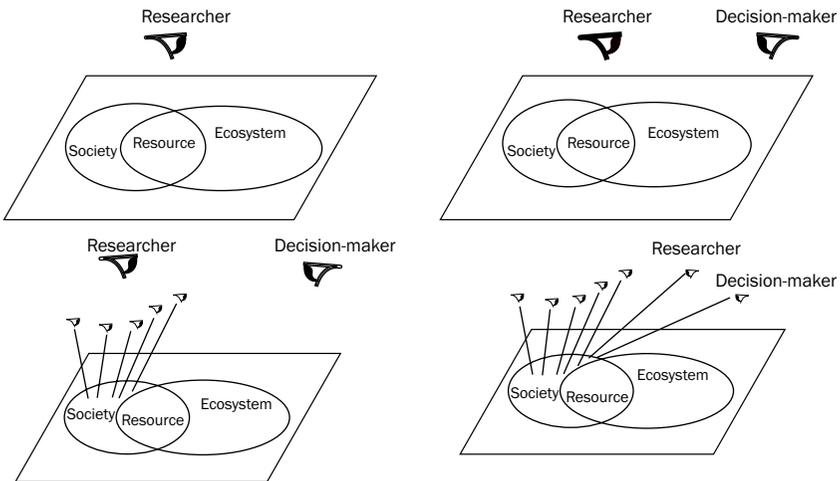


Fig. 3. Evolution of the scientist's role in the decision-making process. Top left: the scientist is perceived as having an objective point of view. Top right: the decision-maker is taken into account; the researcher is providing him with knowledge. Bottom left: with the introduction of social scientists, society is no longer considered as being composed of homogeneous mechanistic entities but as a set of interacting actors having various points of view. Bottom right: the researcher and the decision-maker are considered as stakeholders among others and they interact for a better management of the ecosystem.

- Patrimonial mediation is an approach that contributes to the understanding and practice of co-management. “Patrimonial” is defined by Ollagnon (1991) as “all the material and nonmaterial elements that work together to maintain and develop the identity and autonomy of their holder in time and space through adaptation in a changing environment.” A patrimonial representation of a territory, an area, or a set of resources links past, present, and future generations of managers, focuses on the owner’s obligations more than on the owner’s rights, and promotes a common vision of sustainability that reconciles the needs and opinions of various actors. Mediation is a negotiating method that brings in a third, neutral party in order to facilitate agreement among the different parties involved in the process; it is an approach in which each party’s views on the issue or problem are translated for the others to understand.

Management consists not only of increasing the adaptability of the ecosystem; it also deals with the social process leading to this ecological state. In other words, what is important are the solutions emerging from interaction. And with them comes a different portfolio of interventions, including mediation to resolve conflicts, facilitation of learning, and participatory approaches that involve people in negotiating collective action.

In this context, computer-enhanced modeling becomes a tool for interactive learning instead of a tool to pilot the system. A classic use of simulation is prediction, but this is not the option we have chosen. The very long term of complex systems, such as the ones we have to deal with in INRM, cannot be predicted in the economic and social fields, though it is partially decidable. As Weber and Bailly (1993) said, “Because the very long term is beyond the scope of prediction, if we wish to take it into account in the analysis of environmental problems, we must give ourselves very long-term reference points or objectives to guide the possible or impossible pathways of development. The long-term approach must inevitably be based on a scenario.” Because rules result from interactions among stakeholders, they are legitimized in the eyes of all stakeholders and they incorporate particular perceptions. It is on the basis of a shared conception of how the present situation should evolve that stakeholders are able to “decide” on very long-term objectives. On that basis, scenarios enabling these objectives to be reached can be discussed. The entire mediation approach presupposes making explicit the initial situation. At this stage, stakeholders are clearly informed about the issues dividing them and about their common dependence upon a solution to the problem at the origin of the mediation process. The challenge of the initialization phase is to enable stakeholders to express their perceptions of the present situation and of its evolution. When a “map of perceptions,” all equally legitimate and equally subjective, has been established and discussed, the stakeholders are asked to discuss the acceptability of the continuation of existing trends.

MAS models, like any other kind of representation of a system to be managed, can be used to increase scientific knowledge about the ecological and social processes at stake. The collective creation of a common artificial world serves to create a shared representation that is a prerequisite to simulating various scenarios identified by the stakeholders, the scientist being one of them. Within this frame of mind, any decision, particularly if collective, is context-dependent and should be seen as a stage at a given “time t” in the continuous process of management of a complex issue. As

Roling (1996) said, “Based on their intentions and experience, people construct reality creatively with their language, labor, and technology. Different groups do this in different ways, even if they live in the same environment. The same people change their reality during the course of time in order to adjust to changing circumstances.”

In brief, the main principle of the ComMod approach is to develop simulation models integrating various stakeholders’ points of view and to use them within the context of platforms for collective learning. This is a modeling approach in which stakeholders participate fully in the construction of models to improve their relevance and increase their use for the collective assessment of scenarios. The general objective of ComMod is to facilitate dialogue, shared learning, and collective decision-making through interdisciplinary and “implicated” action-oriented research to strengthen the adaptive management capacity of local communities.

By using such an approach, we expect to be in a better position to deal with the increased complexity of INRM problems, their evolving and continuous characteristics, and the increased rapidity of changes and changes in number of stakeholders.

Companion modeling methodology: the use of MAS and role-playing games

MAS simulation tools were selected because their principles are very much in line with GREEN scientists’ representation of their research object. This can be seen when comparing Figure 1 and Figure 2, which focus on interactions among agents having different representations of the system to be managed and diverse status in the interaction process. These agents act and transform their common environment, which will be modified for other agents. By doing this, economists would say that they generate “externalities” while this environment also has its own ecological dynamics of change.

We used these MAS tools in a cyclic ComMod process displayed in Figure 4. It is made up of three stages that can be repeated as many times as needed:

1. Field investigations and a literature search supply information and help to generate explicit hypotheses for modeling by raising a set of initial key questions to be examined by using the model.

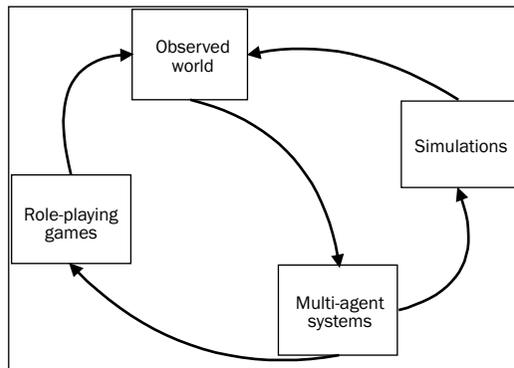


Fig. 4. The companion modeling cycle.

2. Modeling, that is, the conversion of existing knowledge into a formal tool to be used as a simulator.
3. Simulations, conducted according to an experimental protocol, to challenge the former understanding of the system and to identify new key questions for new focused investigations in the field.

We named this process “companion modeling” because it is used in the mediation process (the social dimension of the companion) and it co-evolves with this social process (temporal and adaptive dimensions). The next question was about how to use these models in an interactive way with stakeholders. In agreement with the above-mentioned principles, a model, which is a given kind of representation among other possible ones, should be presented in an explicit and transparent way to avoid the “black box effect” as much as possible when it is proposed to users. We were inspired by the work of several scientists working in the field of environmental management who developed and used role-playing games (RPGs) for collective learning or collective action. Intuitively, a MAS model could be seen as an RPG simulated by the computer. Consequently, we proposed to set up RPGs, similar to MAS models, with the objective of inviting real stakeholders to play the game in order for them

- to understand the model, and more precisely to understand the difference between the model and reality,
- to validate it by examining the individual behaviors of agents and the properties of the system emerging from their interactions, and by proposing modifications, and
- to be able to follow MAS simulations on the computer, and to propose scenarios to be assessed and discussed following their simulations.

We started different applications to assess whether models combined with RPGs could be used successfully to support collective decision-making and the design of concrete action plans, and to explore and evaluate different participatory uses of these associated tools. In 1998, Barreteau proposed a first application dealing with the viability of an irrigated scheme in Senegal. He simplified a complex MAS simulation model to build an RPG and used it with several stakeholders and subsequently proposed a new MAS model allowing researchers to explore scenarios with stakeholders. Several months later, D’Aquino also relied on an RPG linked to a MAS model in the Senegal River delta with a different perspective: his objective was to collectively prepare an RPG with stakeholders and later on translate it into a MAS model for scenario simulation. This was done during three day-long participatory workshops held with different resource users and local decision-makers. Boissau and Castella (2003) started similar applications for land-use changes in northern Vietnam uplands and designed their own “SAMBA” process. Aubert et al (2002) working on plant resource management in Madagascar and Etienne’s (2003) research in the field of sylvopastoral management planning also produced other applications using different kinds of associations between MAS simulation models and RPGs. As the number of case studies and researchers involved in this kind of work increased, a small community of users sharing this approach was born and two important ethical and methodological issues emerged at this juncture.

Very much like in the case of other participatory approaches for resource management, it appeared that the status and legitimacy of the researchers and of the

proposed process itself could be questionable. Following the development of this first set of applications, this group of researchers felt the need for a ComMod charter to clarify their stance and to guide users of this approach. Thanks to the circulation of several successive draft versions discussed among 12 authors, a first document was produced and published. This charter is available at <http://cormas.cirad.fr/en/reseaux/ComMod/charte.htm> and here we briefly summarize the main points examined in this short document.

The ComMod charter postulates that all the assumptions to be made and that are backing the modeling work should be voluntarily and directly subjected to refutation. Having no a priori implicit experimental hypothesis is also an objective implying the adoption of procedures to unveil such implicit hypotheses. The impact of the ComMod process in the field has to be taken into consideration as soon as the first steps of the approach are implemented in terms of research objectives, quality of the approach, quantified monitoring, and evaluation indicators. Particular attention should also be given to the process of validation of such a research approach, knowing that a general theory of model validation does not exist, and that procedures differing from those used in the case of physical, biological, and mathematical models need to be considered. The charter also proposes distinguishing between two specific contexts when using this approach: the production of knowledge on a given complex system and the support to collective decision-making processes. While the first context deals with systems research via a particular relationship to field work, the second one corresponds to methodological research to facilitate the concerted management of such systems.

- In the first case, the key ComMod challenge is to deliver an improved understanding of the interacting processes related to the resource management problem being examined rather than a “turn-key” itinerary for renewable resource management. This understanding relies on a special relationship between the field and the model: instead of proposing a simplification of stakeholders’ knowledge, the model seeks a mutual recognition of everyone’s representation of the problem under study. Such mutual recognition lies with indicators that are gradually and collectively built during the implementation of the case study, and constitutes the fundamentals of participatory modeling.
- In the latter case, even if it is not covering the whole process of mediation by itself, ComMod is contributing significantly to it. This approach intervenes upstream of any technical decision to support the deliberation of concerned actors, to produce a shared representation of the problem at stake, and to identify possible ways toward collective management and alleviation of the problem. Meanwhile, ComMod does not include the other possible steps of the mediation process, particularly those dealing with more quantified expertise (type and size of a new infrastructure, estimation of production and costs, etc.).

An original characteristic of the ComMod methodology is the flexible association of key tools such as RPGs and MAS simulation models, and also geographic information systems (GIS), surveys and interviews, etc. Table 1 shows a classification of these associations as proposed by Barreteau (2003).

This table emphasizes the importance of the preliminary conceptual model. In some cases, the RPG is used as a tool for collective conceptualization, but usually a

Table 1. Classification of the categories of joint use of a computerized model and a role-playing game based on the similarities of conceptual models and time of use.

	Underlying conceptual models are different	Same conceptual model
Model and game are used at the same time	<ul style="list-style-type: none"> • The model supports the game • The model is included in the game • The game is a communication tool between the model and reality 	<ul style="list-style-type: none"> • The game <i>is</i> the model
Model and game are used successively	<ul style="list-style-type: none"> • The game helps to learn how to use the model 	<ul style="list-style-type: none"> • The model is used to repeat the game rapidly • The game is used to validate the model • The model is used to support game design • The game is used to support model design • Co-construction of the model and game • The model is a benchmark

phase of conceptualization precedes the construction of an RPG, a MAS simulation model, or both. Very often, this conceptualization phase is an interdisciplinary endeavor carried out through discussions, literature reviews, and field surveys or experiments. The use of the graphical unified modeling language (UML) has proved to be very useful at this stage because it obliges the participants in the conceptualization process to be precise and provides gradually successive concrete outcomes of the agreed-upon model. It is then easier to implement it and these diagrammatic outcomes also facilitate very much the verification process to check that the implemented model is a true representation of the conceptual model.

The classification also relies on similarities among the conceptual model, the RPG, and the MAS simulation model. When the conceptual model is not the same, one tool is usually used to support another tool. This is the case when MAS models provide a dynamic environment to the players of a game or, conversely, when an RPG is used to explain what the MAS model is actually doing. When the conceptual models for the RPG and the MAS are different, they are mutually supportive during the phase of design and problem analysis: the RPG facilitates the sharing and modification of the conceptual model with stakeholders, whereas the MAS model allows fast simulations of various scenarios proposed by the actors. In the iterative ComMod cycle, a co-construction of the model and of the game occurs, each one allowing the analysis and improvement of the other.

Although the ComMod approach proposes methodological principles and tools, it does not impose any rigid set of procedures to be strictly followed when using these tools. For example, D’Aquino et al (2002) present a comparison among five different ComMod experiments. This key characteristic is in agreement with the principle of adaptive management seen as a social process that needs to take into account the specificities of a given set of stakeholders (the scientist being one among them) in a given ecological environment at a given period of time. Given the context and the constraints, researchers mobilize the set of tools in different ways.

Asian experiences and book outline

This book presents a choice of various Asian case studies using the ComMod approach. Some of these applications, located in Figure 5, are still at a preliminary phase of their development, and some are at a more advanced stage.

Although all of them relied on the ComMod approach, Figure 6 shows that each case study followed its own pathway when putting the set of proposed tools to use.

All the case studies developed from a real-world key question identified in the field and the problems to be investigated were generally chosen for their relevance to users and decision-makers with whom the authors worked, or else for a methodology development purpose. We classified these contributions into four groups.

The first group deals with the model conceptualization stage based on an observed reality.

- P. Promburom and co-authors present their case study on watershed management in northern Thailand and a first conceptual model that corresponds to the analysis of actors and processes to be taken into account for the simulation of land-use dynamics at the watershed level. Further steps of their work such as the development and use of RPGs were also published during the preparation of this book.
- D. Macandog and others illustrate the iterative process leading to the design of different conceptual models for the study of the diffusion of agroforestry systems in Mindanao, Philippines.
- N. Bécu and others deal with the methodological problem of eliciting and modeling stakeholders' representations in a northern Thailand watershed, and the authors propose a method for that.

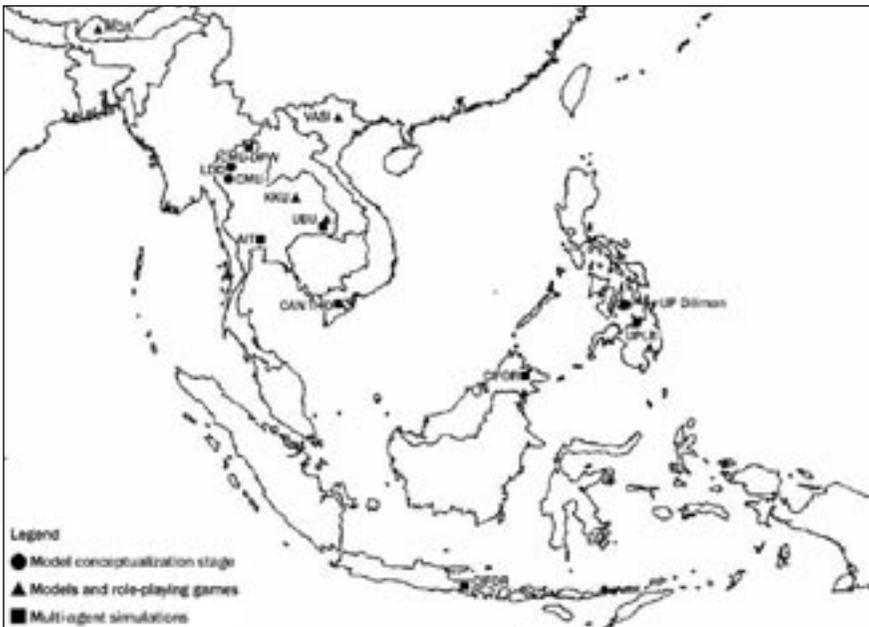


Fig. 5. Location of case studies (marked by symbol) and partners (denoted by acronym).

Model theme (chapter number)	Field research (interview, survey)	Scientists' conceptual model	Scientist-implemented model	Stakeholders' and scientists' conceptual model	Stakeholder- and scientist- conceptual model	RPG
Watershed management (2)	→	→	→	←	→	→
Agroforestry diffusion (3)	→	→	→	→	→	→
Water management (4)	→	→	→	→	→	→
Land-use change (5)	→	→	→	→	→	→
Seed management (6)	→	→	→	→	→	→
Irrigation (7)	→	→	→	→	→	→
Common-property (8)	→	→	→	→	→	→
Diversification and erosion (9)	→	→	→	→	→	→
Water dynamics (10)	→	→	→	→	→	→
Salinity management (11)	→	→	→	→	→	→
Periurban land use (12)	→	→	→	→	→	→
Coastal management (13)	→	→	→	→	→	→
Forestry (14)	→	→	→	→	→	→

Fig. 6. The different methodological pathways and stage of advancement of the contributions presented in this book. Broken arrows represent activities not presented in this book.

The second group of papers describes applications characterized by an association between models and role-playing games.

- N. Suphanchaimart and others present a case study on land-use change in north-eastern Thailand. An interdisciplinary group of researchers conceptualized a model that was used to build an RPG. Once the game was played with stakeholders, the conceptual model was updated and a simple MAS model was created to simulate and discuss scenarios with the stakeholders.
- C. Vejpas and others organized a similar process on the topic of rice seed management in lower northeast Thailand, but with the participation of government agencies in the model conceptualization phase. The process led to the creation of

two complementary role-playing games played at different (village and provincial) scales.

- T. Raj Gurung and others prepared an RPG on the problem of sharing irrigation water between two villages at rice transplanting in a Bhutanese watershed. This game was played two times in a negotiation process. Two villages were in conflict for the use of water and the ComMod process was used to bring people together and discuss the issues at stake. The RPG is presented in this volume; later on, a MAS model was also produced.
- S. Boissau presents his experience on alternating the use of MAS and RPG to collectively assess the driving forces of land-use changes in the uplands of northern Vietnam. After a first MAS model was built, an RPG was conceived and played several times. Simple MAS models were used to simulate scenarios with stakeholders. Then this author worked on simpler and more generic models and developed a new RPG to be associated with these new models.

The third group of papers presents MAS models with an emphasis on technical aspects or simulation results.

- G. Trébuil and others developed a case study to understand the interaction between soil degradation and agricultural diversification in a highland watershed of northern Thailand. The initial phase of the modeling process was based on several years of on-farm research. The first model developed was a MAS loosely linked to a GIS to assemble scientists' knowledge on erosion processes and crop allocation in this mountainous area. Later, this model was used to conceive an RPG that was played twice with stakeholders and led to the construction of a second, simpler MAS model simulating the RPG. In this volume, more details are given on the technical aspects of the initial scientist model while information on the subsequent RPG can be found elsewhere.
- G. Lacombe and W. Naivinit present a MAS model that simulates water dynamics at the subwatershed level in lower northeast Thailand. Its objective is to study how stakeholders cope with the highly variable hydrological pattern in this rainfed region. The model is described and preliminary simulations are run to assess different farmer strategies regarding the use of stored water resources for irrigating rice nurseries.
- L. Dung and others produced two models dealing with water management in the lower part of the Mekong Delta in southern Vietnam. Water management and the associated geographical zoning of fresh and brackish water led to a conflict among different users. These models were developed to examine economic differentiation among households. The first one is based on realistic maps and simulates the actual behavior of farmers and the consequences for economic differentiation. The second one is a more abstract version that focuses on the dynamics of change by using the Consumat theoretical model.
- Sk. Morshed Anwar and F. Borne worked on a model of land-use changes in a periurban area of Bangkok. They focused on the identification and assessment of spatial criteria allowing a comparison between spatial simulation outputs and GIS maps.

- P. Campo presents a model for simulating the coastal management of an island in the Philippines. His model integrates GIS maps and interactions between stakeholders and policies.
- H. Purnomo and P. Guizol developed a simulation model focusing on the spatial configuration of land leading to better co-existence between smallholders and industrial tree plantations in Indonesia.
The fourth and last group of papers deals with different learning issues.
- C. Le Page and P. Bommel present a methodology for the conception of MAS models in the field of INRM. They mainly focus on the use of the unified modeling language for model conceptualization and on the CORMAS platform for simulations. Most of the contributions in this book refer to this chapter by Le Page and Bommel.
- I. Patamadit and F. Bousquet analyze the relevance of the ComMod approach in the Thai cultural context. They tackle this question by exploring the cultural aspects that support the use of this approach as well as other aspects making it inadequate.
- G. Trébuil and F. Bousquet propose a critical evaluation of the learning process of their Asian partners who attended a series of short courses and workshops on multi-agent systems, social sciences, and INRM organized with the support of the Asia IT&C project between October 2001 and April 2004.

The discussions held during the Suan Bua technical workshop in October 2003 that led to the preparation of this book are also reported at the end of this volume.

Because of the recent development of all these case studies, no in-depth ex post evaluation of the effects and impact of using the ComMod approach with stakeholders has been made yet. In fact, a specific methodology to assess these effects and impact is needed. It will have to take into account the definition of the research objectives, the quality of the approach, the characterization of the initial state, the agreed-upon monitoring and evaluation indicators of the system resilience, and, last but not least, it will have to define how to assess the improvement in stakeholders' capacity for collective learning.

On another front, further methodological development of the ComMod approach is under way to better deal with the modeling of stakeholders' perceptions and spatial representations. The possibility to upscale the use of this approach will also be investigated in the near future, particularly by looking at the way it could be used to facilitate communication among heterogeneous agents, groups, and institutions/organizations at higher levels. Based on the ex post analysis of past case studies, characterization of the contexts in which ComMod can be used efficiently and how it should be used will also be documented.

Bibliography

- Antona M, Bousquet F, Le Page C, Weber J, Karsenty A, Guizol P. 1998. Economic theory of renewable resource management: a multi-agent systems approach. *Lecture Notes Artif. Intell.* 1534(1534):61-78.
- Aubert S, Le Page C, Joly H, Razafindraibe R, Ranaivoson J, Ralalaoherivony SB, N'Daye IC, Babin D. 2002. Conception, adaptation and diffusion of a computer-assisted role game

- about phylogenetic resources management at a rural level in Madagascar. In: Proceedings of the 7th biennial conference of the International Society for Ecological Economics, Sousse, Tunisia, 8-10 March.
- Babin D, Bertrand A. 1998. Managing pluralism: subsidiarity and patrimonial mediation. *Unasylva* 49(3):19-25.
- Barnaud C. 2004. Erosion des sols et systèmes agraires dans les hautes terres de la Thaïlande: une approche de la complexité par une modélisation d'accompagnement. Mémoire de DEA, Géographie et pratique du développement, Paris, Université de Paris X-Nanterre. 148 p.
- Barreteau O. 1998. Un système multi-agent pour explorer la viabilité des systèmes irrigués: dynamique des interactions et modes d'organisation. PhD thesis. Montpellier, Ecole Nationale du Génie Rural, des Eaux et des Forêts. 260 p.
- Barreteau O, Bousquet F. 2000. SHADOC: a multi-agent model to tackle viability of irrigated systems. *Ann. Oper. Res.* 94:139-162.
- Barreteau O, Bousquet F, Attonaty J-M. 2001. Role-playing games for opening the black box of multi-agent systems: method and lessons of its application to Senegal River Valley irrigated systems. *J. Artif. Soc. Social Simul.* 4(2). www.soc.surrey.ac.uk/JASSS/4/2/5.html.
- Berkes F. 1997. New and not-so-new directions in the use of the commons: co-management. *The Common Property Resource Digest. Quarterly Publication of the International Association for the Study of Common Property* 42:5-7.
- Boissau S, Anh HL, Castella J-C. 2004. The Samba role play game in northern Vietnam: an innovative approach to participatory natural resource management. *Mountain Res. Dev.* 24(2):101-105.
- Boissau S, Castella J-C. 2003. Constructing a common representation of local institutions and land-use systems through simulation gaming and multi-agent modeling in rural areas of northern Vietnam: the Samba-week methodology. *Simul. Gaming* 34(3):342-357.
- Bonnefoy JL, Le Page C, Rouchier J, Bousquet F. 2000. Modelling spatial practices and social representations of space using multi-agent systems. In: Ballot G, Weisbuch G, editors. *Applications of simulation to social sciences*. Hermes Science, Paris. p 155-168.
- Borrini-Feyerabend G, Farvar M, Nguiringuiri JC, Ndangang VA. 2000. Co-management of natural resources: organising, negotiating and learning by doing. GTZ and IUCN, Kasperek Verlag, Heidelberg (Germany).
- Bousquet F, Bakam I, Proton H, Le Page C. 1998. *Cormas: common-pool resources and multi-agent systems*. Lecture Notes in Computer Systems. Springer 1416:826-838.
- Bousquet F, Barreteau O, Le Page C, Mullon C, Weber J. 1999. An environmental modelling approach: the use of multi-agent simulations. In: Blasco F, Weill A, editors. *Advances in environmental and ecological modelling*. Paris (France): Elsevier. p 113-122.
- Bousquet F, Barreteau O, Mullon C, Weber J. 1996. Modélisation d'accompagnement: systèmes multi-agents et gestion des ressources renouvelables. Proceedings of *Quel environnement au XXIème siècle? Environnement, maîtrise du long terme et démocratie*, Ministère de l'Environnement et Association GERMES, 8-11 September, Abbaye de Fontevraud.
- Bousquet F, Cambier C, Morand P. 1994. Distributed artificial intelligence and object-oriented modelling of a fishery. *Math. Computer Modelling* 20:97-107.
- Bousquet F, Gautier D. 1998. Comparaison de deux approches de modélisation des dynamiques spatiales par simulation multi-agents: les approches spatiales et acteurs. *CyberGéo* 89. <http://193.55.107.45/modelis/bousquet/bousquet.htm>.
- Bousquet F, LePage C, Bakam I, Takforyan A. 2001. Multi-agent simulations of hunting wild meat in a village in eastern Cameroon. *Ecol. Modelling* 138:331-346.

- Burton M. 1994. The irrigation management game: a role playing exercise for training in irrigation management. *Irrig. Drainage Syst.* 7:305-348.
- Castella JC, Boissau S, Lan Anh H, Husson O. 2001. Enhancing communities' adaptability to a rapidly changing environment in Vietnam uplands: the SAMBA role-play. In: Suminguit J, Caidic J, editors. *Proceedings of Sustaining Upland Development in Southeast Asia: issues, tools & institutions for local natural resource management*, Makati, Philippines, 28-30 May 2001, SANREM CRSP/Southeast Asia.
- Checkland P. 1981. *Systems thinking, systems practice*. Chichester (UK): John Wiley.
- D'Aquino, Le Page C, Bousquet F, Bah A. 2002. A novel mediating participatory modelling: the 'self-design' process to accompany collective decision making. *Int. J. Agric. Resources Governance Ecol.* 2(1):59-74.
- D'Aquino, Le Page C, Bousquet F, Bah A. 2003. Using self-designed role-playing games and a multi-agent system to empower a local decision-making process for land use management: the SelfCormas experiment in Senegal. *J. Artif. Soc. Social Simul.* 6(3). <http://jasss.soc.surrey.ac.uk/6/3/5.html>.
- Etienne M. 2003. SYLVOPAST: a multiple target role-playing game to assess negotiation processes in sylvopastoral management planning. *J. Artif. Soc. Social Simul.* 6(2). <http://jasss.soc.surrey.ac.uk/6/2/5.html>.
- Etienne M, Le Page C, Cohen M. 2003. A step-by-step approach to building land management scenarios based on multiple viewpoints on multi-agent system simulations. *J. Artif. Soc. Social Simul.* 6(2). <http://jasss.soc.surrey.ac.uk/6/2/2.html>.
- Ferber J. 1995. *Les systèmes multi-agents: vers une intelligence collective*. Paris (France): InterEditions. 522 p.
- Ferber J. 1999. *Multi-agent systems: an introduction to distributed artificial intelligence*. Reading, Mass. (USA): Addison-Wesley. 509 p.
- Feuillette S, Bousquet F, Le Goulven P. 2003. SINUSE: a multi-agent model to negotiate water demand management on a free access water table. *Environ. Modelling Software* 18(5):413-427.
- Funtowicz SO, Ravetz JR. 1994. The worth of a songbird: ecological economics as a post normal science. *Ecol. Econ.* (10):197-207.
- Gurung TR. 2004. Use of multi-agent simulation to improve irrigation water-sharing in Lingmutyechu watershed (Bhutan). Thesis. Master of Science in Agricultural Systems, Chiang Mai University. 163 p.
- Holling CS. 1978. *Adaptive environmental assessment and management*. London (UK): John Wiley.
- Jager W. 2000. *Modelling consumer behaviour*. Groningen (The Netherlands): Universal Press. 225 p.
- Mathevet R, Bousquet F, Le Page C, Antona M. 2003. Agent-based simulations of interactions between duck population, farming decisions and leasing of hunting rights in the Camargue (Southern France). *Ecol. Modelling* 165(2/3):107-126.
- Meadows D, Meadows D. 1993. *Fish Banks News*. Durham, N.H., USA, Fish Banks Ltd. and Laboratory for Interactive Learning, University of New Hampshire.
- Mermet L. 1993. *La nature comme jeu de société*. L'Harmattan, Paris.
- Ollagnon H. 1991. Vers une gestion patrimoniale de la protection et de la qualité biologique des forêts. *Forest Trees & People Newsl.* 3:2-35.
- Penang. 2000. *Integrated natural resource management research in the CGIAR*. 50 p.
- Piveteau V. 1994. *L'avenir à long terme des zones rurales fragiles, approche par le jeu prospectif d'une question complexe*. Ph.D. dissertation. Université Paris 1. 355 p.
- Promburom P. 2004. Participatory multi-agent systems modelling for collective watershed management: the use of role-playing games. In: *Proceedings of International Envi-*

- ronmental Modelling and Software Society iEMSs 2004, International Conference: Complexity and integrated resources management, University of Osnabrück, Germany, 14-17 June 2004.
- Roling N. 1996. Towards an interactive agricultural science. *Eur. J. Agric. Educ. Ext.* 2(4):35-48.
- Rouchier J, Bousquet F. 1998. Non-merchant economy and multi-agent systems, an analysis of structuring exchanges. *Lecture Notes Artif. Intell.* 1534:111-124.
- Rouchier J, Bousquet F, Requier-Desjardins M, Antona M. 2001. A multi-agent model for transhumance in North Cameroon. *J. Econ. Dynam. Control* 25:527-559.
- Rouchier J, O'Connor M, Bousquet F. 2001. The creation of a reputation in an artificial society organised by a gift system. *J. Artif. Soc. Social Simul.* 4(2). www.soc.surrey.ac.uk/JASSS/4/2/8.html.
- Thébaud O, Locatelli B. 2001. Modelling the emergence of resource-sharing conventions: an agent-based approach. *J. Artif. Soc. Social Simul.* 4(2). www.soc.surrey.ac.uk/JASSS/4/2/3.html.
- Trébuil G, Baron C, Bousquet F, Shinawatra Ekasingh B. 2002. Collective creation of artificial worlds helps the governance of concrete natural resources management problems. International Symposium on Sustaining Food Security and Managing Natural Resources in SE Asia: Challenges for the 21st Century. Chiang Mai, Thailand.
- Trébuil G, Shinawatra-Ekasingh B, Bousquet F, Thong-Ngam C. 2002. Multi-Agent Systems Companion Modeling for Integrated Watershed Management: A Northern Thailand Experience. In: Jianchu X, Mikesell S, editors. *Landscapes of diversity*. Yunnan Science and Technology Press, China. p 349-358.
- Walters CJ, Hilborn R. 1978. Ecological optimization and adaptive management. *Annu. Rev. Ecol. Syst.* 9:157-188.
- Weber J, Bailly D. 1993. "Prévoir c'est gouverner". *Natures, sciences, sociétés* 1:59-64.
- Wooldridge M. 1999. Intelligent agents. In: Weiss G, editor. *Multiagent systems: a modern approach to distributed artificial intelligence*. Boston, Mass. (USA): MIT Press. p 27-78.

Notes

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