Companion Modeling and Multi-Agent Systems for Integrated Natural Resource Management in Asia

Edited by F. Bousquet, G. Trébuil, and B. Hardy

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Foreword

For several years, agricultural research organizations such as the Consultative Group on International Agricultural Research (CGIAR) centers and Center for International Cooperation in Agricultural Research for Development (CIRAD) have been opening their portfolio of research methods to the sciences of complexity. The recognition of the importance of these methods is linked to the strategic decision to increase research on integrated natural resource management (INRM) on their agendas. The CGIAR organized a series of meetings on INRM research during the last five years: starting with the Bilderberg meeting, followed by the workshops in Penang, Cali, and Los Baños. Collaborative research activities in this field between IRRI and CIRAD started in 2001 and were based on the recognition of several principles that emerged from the earlier CGIAR meetings.

The founding Bilderberg consensus stated that INRM research requires that (1) stakeholders and national agricultural research and extension systems (NARES) partners should participate in all stages of the research process from conception to delivery of research results, and, (2) to help the poor, agricultural research must go beyond the traditional paradigm (…) rather than focusing narrowly on increasing and maintaining the productivity of commodities, and that, accordingly, CGIAR projects in the field of INRM should satisfy the following minimum set of criteria:

- Be defined in a collaborative and equitable manner with all relevant stakeholders and partners.
- Generate new knowledge as international/regional public goods based on both indigenous knowledge and modern science.
- Effectively communicate and disseminate results and conclusions to all stakeholders.
- Reform and strengthen institutions from local to policy levels.

It is in the mandate of both CGIAR centers and CIRAD to develop innovative methodologies based on new approaches and paradigm shifts. In the case of INRM, given its above-mentioned objectives, new research approaches originate from new scientific opportunities and recent breakthroughs, among which spatial modeling and adaptive management of renewable resources are key ones.

During 2001-04, joint efforts by IRRI and CIRAD led to the implementation of a Thailand-based companion modeling project with a regional mandate. Its complementary objectives were to create and train a regional network of NARES practitioners of companion modeling in Southeast Asia and to support them in the development of their own applications and case studies. Following an initial course on multi-agent systems for INRM offered at IRRI headquarters in late 2000, and thanks to a specific grant from the ASIA IT&C initiative of the European Community, a series of 11 short courses attended by some 80 trainees was organized in recent years. These were followed by the construction of some 15 applications dealing with concrete resource management problems in five different countries.

Upon completion of this three-year-long companion modeling project, the present volume is one of the first collective outputs and its various contributions show work in progress. Its production benefited from strong support from the NARES involved in the project activities, particularly in Thailand. A group of former trainees is now continuing the effort through the establishment of the Asia Pacific Social Simulation Association (www.apssa.net). They are also involved in a new series of projects, particularly under the Challenge Program on Water and Food.

We are very pleased to present the products of these successful collaborative training and research activities in the field of companion modeling and multi-agent systems for integrated natural resource management in Southeast Asia. We are also glad to see that this young regional network succeeded in finding ways to pursue this collective endeavor through new research and training projects funded by various donors during 2005-08. This illustrates convincingly that IRRI and CIRAD had a correct vision when they began this collaboration, and that they played their respective roles as strong partners of the NARES and other users in facilitating the dissemination of the companion modeling approach, methodology, and tools across Southeast Asia.

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

F. Bousquet and G. Trébuil

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

[1]In 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 under stand 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

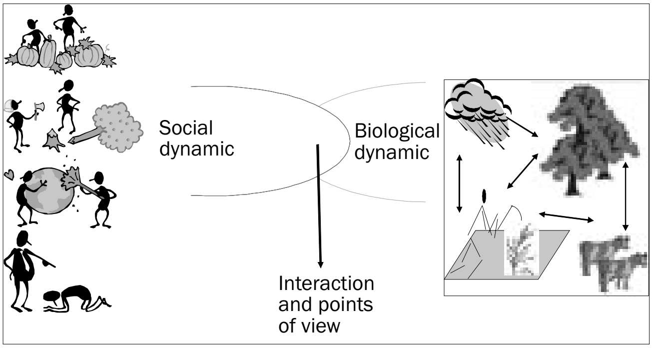

Fig. 1. Schematic representation of a socio-ecological system.

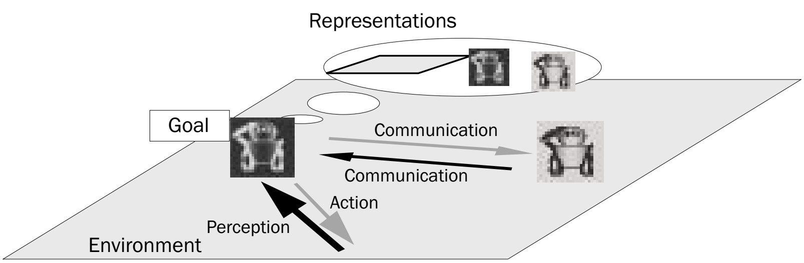

Fig. 2. Schematic representation of a MAS.

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.

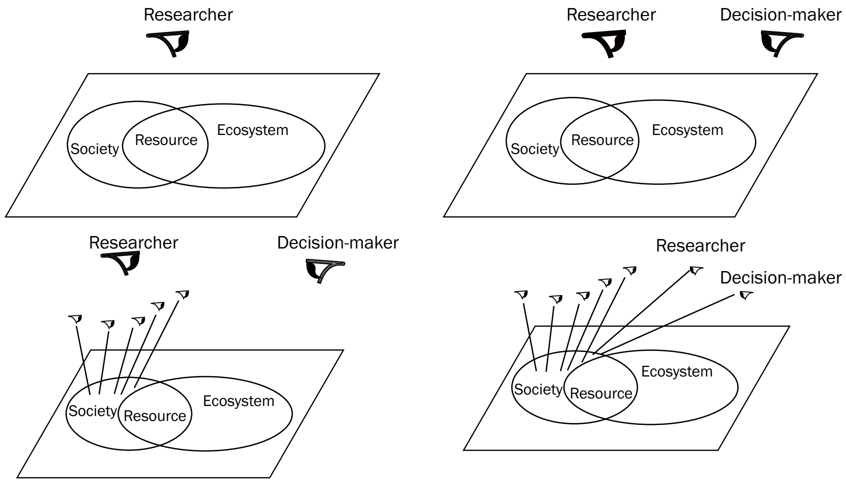

Fig. 3. Evolution of the scientist's role in the decision-making process. Top left: the scientist is perceived as having an objective point of view. Top right: the decision-maker is taken into account; the researcher is providing him with knowledge. Bottom left: with the introduction of social scientists, 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.

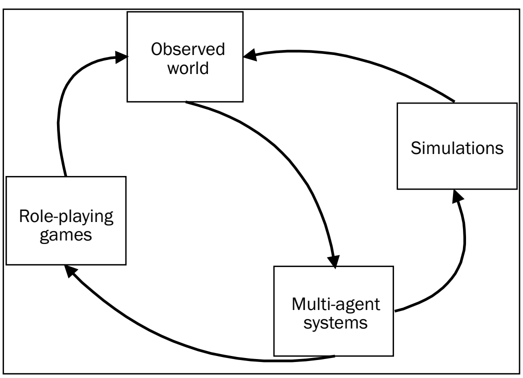

Fig. 4. The companion modeling cycle.

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	• The model supports the game • The model is included in the game • The game is a communication tool between the model and reality	• The game *is* the model
Model and game are used successively	• The game helps to learn how to use the model	• 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.

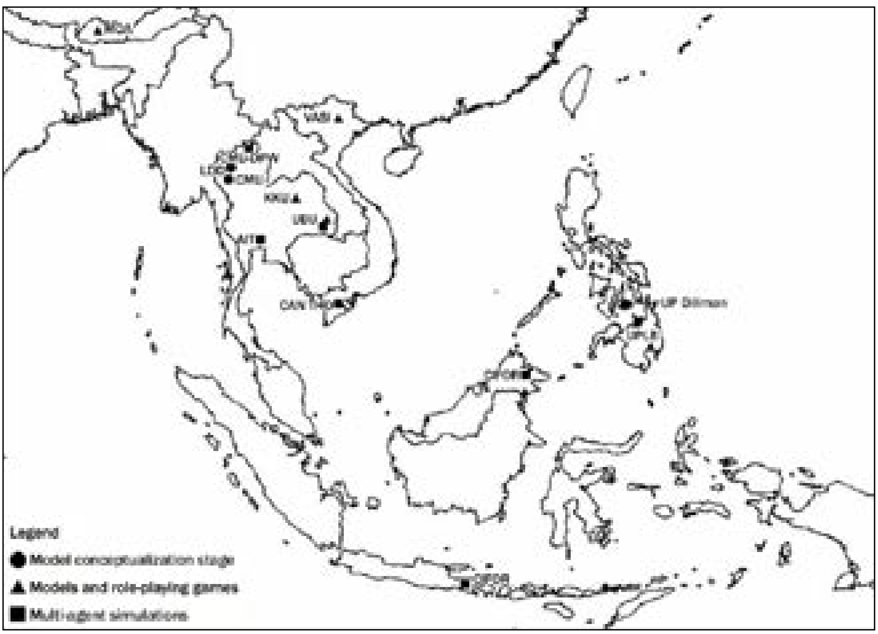

Fig. 5. Location of case studies (marked by symbol) and partners (denoted by acronym).

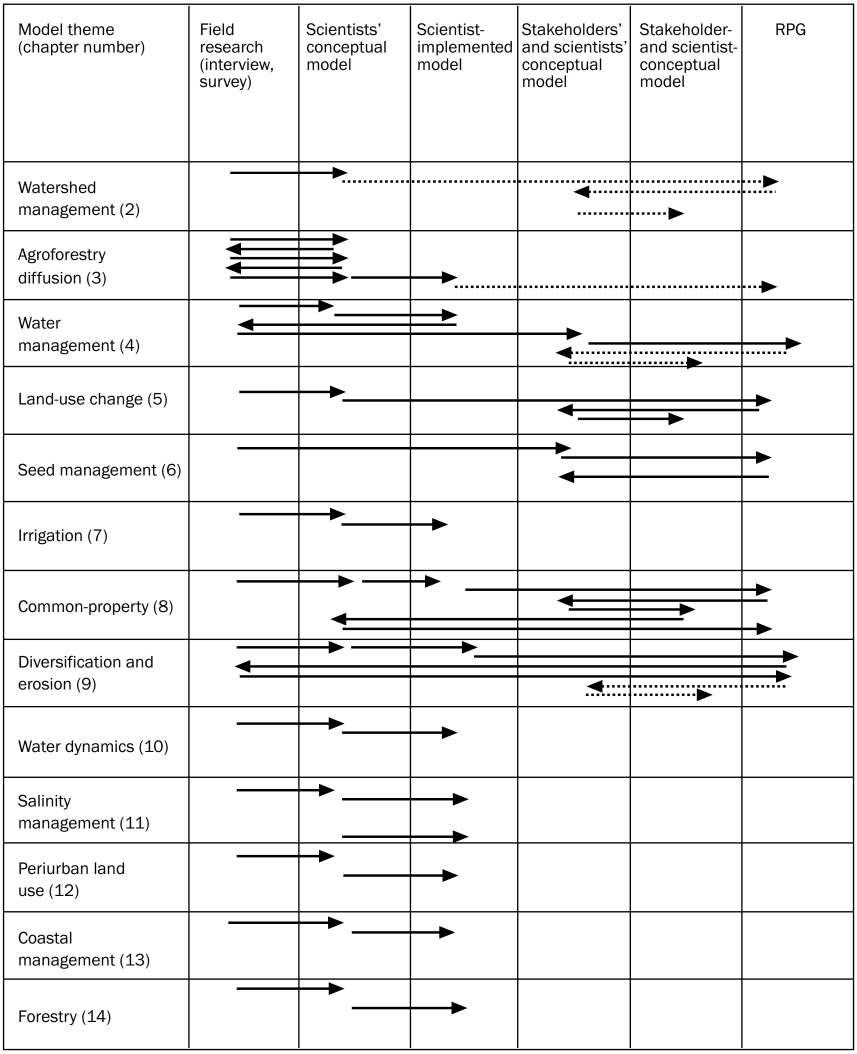

Fig. 6. The different methodological pathways and stage of advancement of the contributions presented in this book. Broken arrows represent activities not presented in this book.

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 northeastern 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.

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Notes

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The modeling process: from reality to conceptual model

Part 1

Multi-agent systems for collective management of a northern Thailand watershed: model abstraction and design

P. Promburom, M. Ekasingh, B. Ekasingh, and C. Saengchyoswat

Scarce farmland and water resources in the highland watersheds of northern Thailand coupled with multiple users and desires have led to conflicts among stakeholders who play important roles in the system dynamics. Integrating the participatory approach and multi-agent systems (MAS) modeling can facilitate adaptive learning processes to result in a collective management strategy that meets the balanced needs of all parties. However, this requires participation and cooperation from all stakeholders involved in the process.

This paper elaborates on the concept and processes of MAS model abstraction and design, which is the first study period of a research project. This project aims at developing an integrated participatory MAS model to support collective resource management in a watershed area of northern Thailand. A prototype MAS model was constructed using unified modeling language (UML) diagrams, and it consists of three major components: a biophysical module, a social module, and a political institution module. UML diagrams are used as an interface for discussing and sharing ideas among an interdisciplinary research team.

This prototype structure will be used as a guideline for further research steps, including stakeholder analysis, eliciting common representations for further model programming, and development. Finally and hopefully, the verified and validated MAS model could be applied in assessing natural resource management strategies agreed upon among all stakeholders and would result in the implementation of a desired intervention scheme for sustainable resource management in this watershed.

The idea of using multi-agent systems (MAS) modeling to understand the complexity of a watershed system with multiple users exploiting fragile natural resources in the northern Thailand highlands stems from the authors' participation in a training course on an introduction to MAS and integrated natural resource management (INRM) in late 1999 and 2000. This training provided knowledge on the concept of agents, software, and tools for developing simple MAS models. This introductory course was followed by a series of MAS for INRM training sessions during 2001-03. Knowledge representation and integration, technologies, and relevant concepts regarding MAS for studying dynamic interactions between societies and the environment were gained gradually and progress was satisfactory throughout recent courses. Meanwhile, the idea of applying MAS for INRM in northern Thailand emerged in early 2001, and system components and possible key interactions and consequences were roughly sketched out. Until late 2002, the initial conception and design of a MAS model was framed and constructed with colleagues from different disciplines.

Existing and recent research dealing with integrated MAS and NRM has been exploring several techniques, tools, and methods to provide a better understanding of complex and dynamic phenomena that may lead to improved collective decision-making. However, the context of human interactions and their effects on agroecosystems, including policy interventions and institutions, are rarely explored and modeled.

Therefore, this study focuses on resource-use planning and potential management intervention at the watershed level that can balance the needs of local people and government efforts to mitigate environmental degradation in the northern Thailand highlands. MAS modeling and a participatory approach are the main tools and concepts to be applied. Key stakeholders, particularly government agencies and local institutions that potentially play important roles in watershed management, will be involved in the study. This study targets the following objectives:

- To develop a MAS model that integrates a spatially explicit model and social systems model, and interconnect dynamics occurring at different scales in space and time.
- To incorporate political and local institutions in the MAS model.
- To apply participatory MAS modeling as a tool to facilitate collective learning and watershed management.

This paper presents results of the first-phase study. It aims at illustrating the concepts and processes used for MAS model design. The design represents our knowledge and understanding of the context of the study area. Thus, this predesign model reflects researchers' perceptions, which are mostly based on a literature review and our experience gained from previous research work in the same area. In further research steps, this will be modified using other stakeholders' perceptions and participation in the model-developing process. In this way, the model will better represent and reflect the real system of the study area.

The first part of this paper discusses the common concerns about natural resources and their management in upper watershed areas of northern Thailand. The paper assesses multiparty causes and consequences resulting in the complexity of the current highland agricultural system, approaches, and efforts that have been applied to tackle this problem. This is followed by the presentation of promising integrated approaches and tools that have been employed to achieve collective common-pool resource management with all stakeholders. Research results and applications of MAS for INRM in other regions and in northern Thailand are reviewed at the end of this section.

The second part of this article states the purpose of the study and hypotheses to be assessed. The following part provides the context of the study area and illustrates preliminary work in progress to analyze and design the prototype of a MAS model using unified modeling language (UML) diagrams. The model simply represents all key stakeholders, their interrelation, and other environmental components in a highland watershed system. This prototype will be further used as a conceptual framework to be developed and implemented into an integrated MAS model. We hope that it will be applied to improve collective natural resource management in the highland watersheds of northern Thailand.

Since these are the preliminary results of the initial period of the study, further research plans and specific objectives, concepts, and methods that can be used are discussed in the last part. In conclusion, the paper states the key concepts and concerns that we have experienced during this first study period, and the challenge in using the participatory modeling process and using the model directly with stakeholders to bring top-down and bottom-up approaches together to achieve desired collective resource management.

Natural resources and their management in the highlands of northern Thailand

The human-/agroecosystem of upper northern Thailand is characterized by its geographical structure, mountainous tropical forest ecosystem, and various ethnic groups scattered over the highland area that practice agriculture for staple food and cash crops. Since the 1950s, drastic changes have occurred in land-use patterns resulting from the adaptation of agricultural systems brought about by the imposition of new cash crop cultivation. This cash crop cultivation was a consequence of opium replacement programs and lowland marketing expansion, coupled with an increase in population density. This resulted in a change from traditional swidden agricultural practices to extensive clearance of forest and shortening of the fallow period, which have had a substantial effect on natural resource viability and the integrity of watershed systems. This led to the Thai government imposing land-use constraint policies to preserve forest area in the highlands, such as the watershed classification system that has produced conflict among land and water users. During the 1990s, public environmental awareness grew rapidly. This brought conflict between lowland and urban communities associated with the situation of natural resources in the highland and watershed areas. Instances of conflict about water use among upland and lowland communities occurred in Chiang Mai in the late '90s. Lowland communities blamed that scarcity and chemical contamination of water downstream on agricultural activities in the upland. They demonstrated and obstructed transportation between the upland and the city.

This rapid change and impacts on social, economic, and natural resources are complex and unpredictable. This has driven development and research efforts from many sectors and several policies and projects with various development strategies have been proposed and implemented to tackle the problem, especially in highland watershed areas (Enters 1995, Rerkasem and Rerkasem 1994). Some of these projects involved local people in the process but still focused on small target areas and rarely incorporated all local government agencies. Eventually, there was not much influence on national policy formulation for natural resource management. The processes of policy-making and implementation continue to rely mostly on a top-down approach.

Since development agencies experienced failure in managing natural resources because of their complexity and dynamic context, they turned to emphasis on a participatory development approach that opened the door for local involvement in resource management decisions (Missingham 2001). This approach was officially endorsed in both the Eighth and Ninth National Economic and Social Development Plan (1992-96 and 1997-2001, respectively). In 1997, Thailand adopted a new national constitution, which strengthened the role of local government institutions. Later on, this resulted in a range of new policies aiming at empowering stakeholders and institutions to participate in managing their own local resources in a sustainable way. However, neither suitable practical tools nor a clear mandate to achieve the goal was made available. Thus, roles and actions taking place in watershed areas appear to result in unpredictable changes in the land-use practices, productivity, and food security situation of highland communities.

Integrated participatory NRM in the northern Thailand highlands

From the late 1980s to the mid-1990s, an impressive number of influential highland development projects were implemented in the northern Thailand highlands. These projects aimed to suppress narcotics production and promote sustainable-cropping practices that could also contribute to improving the tribal people's well-being and ameliorating natural resources. In the beginning phases of implementation, most of these projects focused on introducing technological packages. However, they experienced failure with this top-down development approach. The United Nations-Sam Mun Highland Development Project (UN-SMHDP) was one that adopted and integrated a participatory development approach followed by the Thai-Australia Highland Agricultural and Social Development (TA-HASD) project, Thai-German Highland Development Programme (TG-HDP), and many other projects. Various participatory techniques and tools were applied to accompany problem analysis, plan alternative resource management, and finally establish collective rules and actions for watershed management. Examples are group seminars, three-dimensional topographical models (3-D model), the rapid rural appraisal (RRA), the rural system analysis (RSA), and the participatory rural appraisal. All the projects aimed at seeking cooperation and collaboration among key stakeholders through participatory approaches. At the same time, nongovernment organization (NGO) groups implemented development projects to encourage local people to collectively organize, analyze their situation and problems, make plans, and take action. However, they experienced difficulty because of insufficient cooperation from government agencies, and there was no law to support the right of local people to manage their local natural resources (Missingham 2001, Puginier 2002).

Integrated water resource assessment and management (IWRAM) has been conducted in five subcatchments in northern Thailand since late 1997. The project tried to involve all three keys government agencies in a process of adaptive decision-making (ADMP). However, only the Land Development Department (LDD) was incorporated within the project. The project developed an integrated decision-support system (DSS) by linking a biophysical module (hydrology, crop growth, soil losses) with a socioeconomic decision module to allow land managers (for example, LDD and the Royal Forestry Department, RFD) to assess the implications of alternative water resource management scenarios. However, this was not a fully decentralized dynamic model since individual household decisions were aggregated at each subwatershed level. Most of the model conceptualization, design, development, and validation phases were implemented by the researcher (Letcher et al 2002, Lal et al 2002).

Becu et al (2003b) developed CATCHSCAPE, a MAS model using the CORMAS (common-pool resources for multi-agent systems) platform, to simulate scenarios of resource management processes of land-use and hydrological dynamics of a catchment in northern Thailand. They used stakeholder elicitation techniques in digesting key perceptions of farmers toward agricultural practices related to water use to be used in model design and development (Becu, this volume). This model emphasized farmers' individual decision-making based on different viewpoints regarding household resources and land and water management without interventions from local and government institutions.

Trébuil et al (2002) conducted participatory research to test the companion modeling approach (Bousquet et al 1999) by associating MAS, geographic information systems (GIS), and role-playing games to enhance collective learning processes among stakeholders whose activities and interactions affect resource dynamics in a highland and market-integrated watershed of upper northern Thailand. The initial prototype model developed by the research group evolved iteratively between researchers and stakeholders through role-playing game sessions simulating a simplified version of the computer model, followed by individual interviews and group discussions (Trébuil et al, this volume). Thus, the model provides an acceptable common representation of current agricultural dynamics in this watershed system, and it allows stakeholders to experiment and assess land management scenarios. This kind of work is seen as being very useful for facilitating negotiation, mitigating conflicts, and enhancing collective land resource management. This promising approach and tool can be adapted to incorporate other key government agencies and local institutions to participate in desired decentralized natural resource management.

Puginier (2002) illustrated and assessed local land-use planning for natural resource management at the village level in Mae Hong Son Province. GIS and remote-sensing tools combined with participatory tools were used to collectively delineate a mutually agreed-upon land-use boundary and land-use plan among local people, key government agencies, and the Tambon (subdistrict) Administrative Office (TAO). The result of this study revealed that the tambon level is a suitable scale for creating a communication platform for stakeholders to collectively participate in desired land resource planning. However, government agency cooperation and the right of local people to manage their natural resources are needed to carry out these tasks.

Table 1 summarizes the various levels of the key stakeholders involved and tools and methods used in different research and development projects that deal with highland development and natural resource management in northern Thailand.

Most recent research and development projects concerning natural resource management in northern Thailand have been moving toward decentralization and adoption of integrated participatory approaches while government reform efforts have led to a new national constitution and strengthening of local governance institutions. There is now a stimulating challenge to step forward and integrate new tools and approaches to support and encourage participatory and collective management of natural resources at the watershed level in northern Thailand. MAS is one of the promising concepts that has been adopted and applied to deal with natural resource management in many aspects.

Table 1. Projects and research projects with different stakeholders, area scale, and methods and tools.

Project/research[a]	Stakeholder[b]	Implementation level	Methods/tools[c]
UN-SMHDP, TA-HASD, TG-HDP, NGO	Local organization	Watershed	3D model, RRA, RSA, group meeting, networking
IWRAM	LDD, RFD	Watershed	Biophysical and socio-economic model
Becu et al (2003b)	Local people	Watershed	Stakeholder elicitation technique, knowledge engineering, MAS
Trebuil et al (2002)	Local people	Watershed	GIS, MAS, role-playing games
Puginier (2002)	Local people, TAO	Village	GIS

[a]UN-SMHDP = United Nations-Sam Mun Highland Development Project, TA-HASD = Thai-Australia Highland Agricultural and Social Development, TG-HDP = Thai-German Highland Development Programme, NGO = nongovernment organization. [b]LDD = Land Development Department, RFD = Royal Forestry Department, TAO = Tambon Administrative Office. [c]RRA = rapid rural appraisal, RSA = rural system analysis, MAS = multi-agent system, GIS = geographic information systems.

Multi-agent systems and natural resource management

The MAS approach and computational modeling techniques have been progressively developed to explore and understand individual behavior and interaction among agents and the environment that represent the complexity of the whole system (Gilbert and Troitzsch 1999). They have been increasingly used to deal with ecological and socio-economic issues arising from the management of scarce resources by multiple users. Integrating MAS with other biophysical or economic models and spatial database tools can enhance the adaptive learning capability of all stakeholders regarding their role and effects on ecological system dynamics. This has tremendous potential for assisting decision-makers in understanding and managing landscapes (Gimblett 2002, Parker et al 2003, Le Page et al 2001).

In the field of common-pool resource management, many studies have focused on adaptive management to deal with complex situations, with the assumption that better mutual understanding brings about better coordination and greater collective ability, thus strengthening the adaptive capacity of stakeholders who take part in resource management (Lansing and Kremer 1993, Trébuil and Bousquet 2003).

The ideal MAS model that may be applicable to watershed resource management problems should include and dynamically link social and biophysical subsystems at multiple levels, and provide sufficient precise intervention scenarios to support the experimental discovery of possible intervention strategies that appear to be effective to achieve cooperative management by watershed stakeholders (Doran 2001). Several studies provide promising methods to integrate MAS and other tools to enhance decentralized and adaptive resource management. Stakeholders were included and allowed to participate in a research process called "companion modeling" (Bousquet et al 1999). This approach aims at empowering grass-roots stakeholders through the acquisition of a clear understanding and a long-term vision of their system dynamics, allowing them to cooperate and manage their natural resources collectively (Barreteau

2003, D'Aquino et al 2002). This enhances and facilitates research to understand complex phenomena and to develop, modify, and validate models through stakeholder participation. Moreover, this also changes the traditional relationship between the researcher and other stakeholders.

The unified modeling language (UML) is commonly used in conjunction with object-based models because it has mechanisms to communicate the structure, processes, and rules that drive model outcomes. UML has now become the standard for object-oriented modeling and design, as it is in the MAS model (Fowler and Scott 1999). The static class diagram in UML is widely used to enhance the process of identifying agents and their behavioral characteristics, functions, and relations to other agents. UML can be extended to develop events and sequences of models, which thus supports processes of programming, verifying, and redesigning models (Liang 2003).

Recent MAS applications have employed UML as a means of facilitating communication among model designers and programmers. This seamlessly becomes a standard protocol among researchers belonging to different disciplines and having various experience in developing computerized MAS models, and also among the participants in MAS training courses held in Thailand during 2001-03 (Parker et al 2003, Trébuil and Bousquet 2003).

Area under study

The Maehae watershed is situated in two subwatershed areas in northern Thailand. It is located 80 km southwest of Chiang Mai City, in a province that is one of the major forest-covered areas in the upper Chao Phraya River system in Thailand (Fig. 1). It consists of 14 villages, scattered in Mae-Wang, Mae-Chaem, and Sa-Moeng districts. This highland community has 550 households. Two major ethnic groups, the Karen and Hmong, practice agricultural activities in both traditional and new-technology-oriented ways, which have been actively introduced and supported by the Royal Project Foundation (RPF) development center (Ekasingh et al 2001b).

The study area is a slope complex with forest-covered areas of about 70%. The forest cover consists of pine mixed with evergreen and dry-dipterocarp forests. The land-use practice has changed from swidden agriculture to high-value cash crops and fruit orchards introduced by the RPF (Ekasingh et al 2001a). The LDD and RFD are government agencies working in the area. They are responsible for natural resource conservation. The LDD promotes soil conservation practices to reduce soil erosion. The RFD promotes forest resource rehabilitation. The conflict over land and water resource use within the community and also with government agencies in this area was observed during the most recent field visits, when some farmers encroached and cultivated in a restricted forest area.

As in other communities in this region, the heterogeneity of highland people arises from ethnicity, in which social and cultural institutions, goals, attitudes toward doing agriculture, household resource availability, and views of their relationship toward the environment are different (Ganjanapan 1996). In addition, political intervention also significantly influences the diversity of co-dynamic processes between social and environmental systems that make natural resource management situations

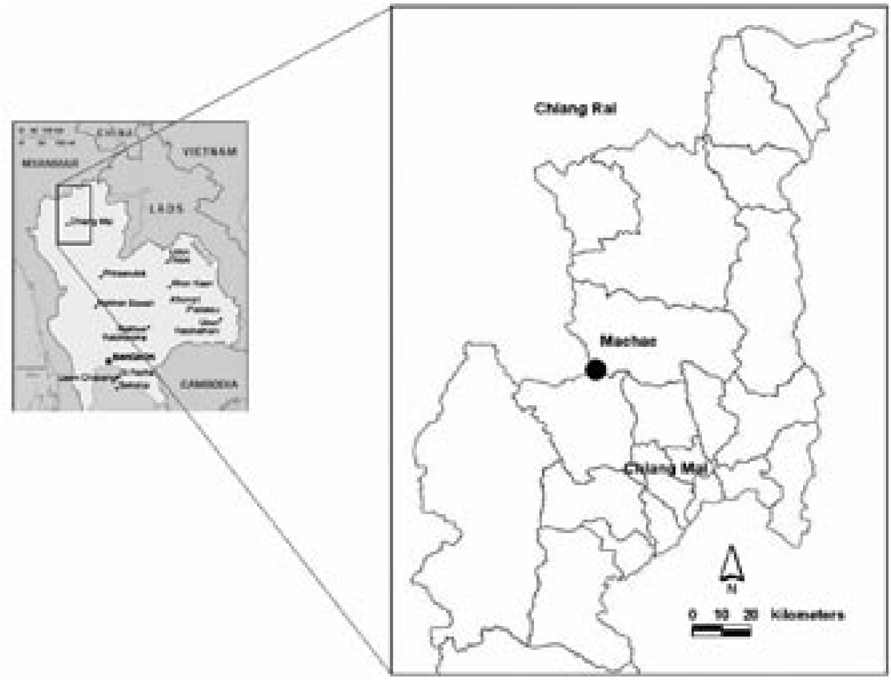

Fig. 1. Maehae watershed area, northern Thailand.

more complex and uncertain. It is not easy to perceive and understand the effect of government agencies' roles and their interactions with social and environmental systems on the overall catchment system.

Thus, environmental components and key stakeholders with their differing perceptions should be analyzed to bring about a better understanding of how individuals behave and interact with the environment and how this may affect the dynamics of the system.

Model abstraction and design

This study employs the concept of multi-agent systems through agent-based modeling to understand and to simulate the social interactions among stakeholders, decision-making regarding land management, and their effects on human and land-resource dynamics. The research started with a preliminary analysis of the Maehae watershed system to define entities that represent both actors and key environmental elements. The model consists of the following three major components:

1. A biophysical module to account for biophysical processes, particularly erosion. This module integrates the main environmental properties that will affect these natural processes, such as soil conditions, climate, and vegetation types.
2. A social module in which the stakeholders that play important roles in the dynamics of the study area were defined and abstracted using information obtained from field visits and secondary data (Ekasingh et al 2001a,b).

3. A policy and institution module representing the local institutions and government agencies whose interventions affect agents' decision-making regarding land use.

A UML class diagram was used to build and represent the fundamental properties, a set of common foreseen processes, relations, and interactions among entities. This UML static structure is a powerful tool to represent the components, structure, and possible dynamics of the system. It can also be used as a common tool for discussion among researchers with differing disciplinary backgrounds to criticize, modify, improve, and agree upon the structure of the model. Then, the system dynamics were defined and represented using a UML sequence diagram. Later on, an activity diagram will be built to demonstrate rules, function, and flow of particular subprocesses and mechanisms. The next step of this research consists of programming this predesigned model to verify the key functions of the prototype model before focusing in more detail on each component and its function.

From the Maehae watershed to a prototype MAS model

Model conceptualization

To transform the context of the study area into a conceptual model, we conducted a group meeting and discussion to digest and analyze the available literature, secondary data, and information obtained from research conducted in this area during 2001-02. The entities representing key stakeholders, environmental components, and a predefined relationship were identified and designed. Then a prototype MAS model was constructed using a UML static class diagram (Bommel and Le Page, this volume).

The preliminary design of the "world" representing the Maehae watershed system consists of three major components, corresponding to the stakeholders, their ecological environment, and the local institutions. Stakeholders share and intervene in common resources with different objectives and perceptions, whereas local institutions represent formal and informal groups or organizations representing stakeholders who share similar interests.

Model entities and their characteristics

In the first step in the model construction, stakeholders, biophysical components, and institutions were designed as class objects in a UML static class diagram. The stakeholders and environmental components are shown in Table 2.

Figure 2 shows the prototype model structure and illustrates the possible characteristics attributed to each entity and the linkage among these key components in this watershed system. Each agent and component object is represented using a graphical box as class and subclass entities. In each box, the top row gives the agent's name, the second subbox displays the agent's attributes, and the bottom subbox shows the processes of agent evolution or the method names. Lines connecting two objects correspond to either a relationship or an association, which determines possible inheritance, communication, and interactions among agents. The processes and methods are mechanisms that will be activated during the simulation to drive the system dynamics. These mechanisms may result in interaction among stakeholders and biophysical components, or between these two kinds of objects based on the relationship lines.

Table 2. The stakeholders and environmental components in Maehae watershed.

Class name	System component
Stakeholder and institution	
Farmer	The farmer practices agriculture in this highland environment and represents the household unit level.
RPFWorker	The Royal Project Foundation (RPF) worker's task is to promote high-value cash cropping to raise farmers' incomes and promote natural resource conservation.
LandManager	The Land Development Department (LDD) officer is in charge of promoting and facilitating soil conservation practices and other soil erosion controls.
ForestOfficer	The Royal Forestry Department (RFD) officer's duty is to protect the local forest cover, especially in upper watersheds defined by slope characteristics.
Trader	The trader acts as a middleman buying agricultural products from farmers for sale in town.
SocialGroup	Social institutions represent official and potential social organizations such as a village or forest conservation network.
Environmental entities	
LandUnit	This is the smallest land unit with homogeneous environmental characteristics, for example, soil, slope, elevation, climate, and vegetation.
LandusePlot	The aggregation of LandUnit is used for specific purposes or is occupied by a single type of natural vegetation and landscape.
LandFarm	This is a collection of all LandusePlot owned by a Farmer.
SubWatershed	This is a subwatershed within the Maehae watershed area and is delineated according to topographical characteristics.
WatershedClass	This is the official subwatershed classified by the National Environment Board (NEB) in 1983; each class corresponds to a specific permitted use type and management (Tangtham 1992).
Watershed	This is the entire watershed area.
LandCover	This represents different land-use types, including crops, natural vegetation, and physical infrastructure.
Climate	This is climatic variables and factors affecting crop productivity and soil erosion.

To better understand how real-world entities have been represented as entities (namely class) in computer models, the *Farmer* abstraction will be described in detail depicting the UML static diagram in Figure 2 as an example. The *Farmer* class object is associated with *AgentComm* (communicating agents) as a subclass (*Farmer* is a kind of *AgentComm*); thus, it inherits communication capability from *AgentComm*, which means that farmers can communicate with each other in general. Each *Farmer* is characterized by age, ethnicity, goal, and possibly membership in one or more *SocialGroup*. This social dynamics is linked to spatial dynamics through association between a *Farmer* and his or her *LandFarm*. The *Farmer* can perform an action or procedure to manage *LandFarm*, for example, choosing and growing a crop (+manageFarm), selling agricultural products (+saleProduct), and so on.

The dynamics

Based on a literature review and personal discussions with resource persons in Maehae, the agricultural practices and actions of each stakeholder involved in the system dynamics were transformed into a simple set of successive actions and decisions

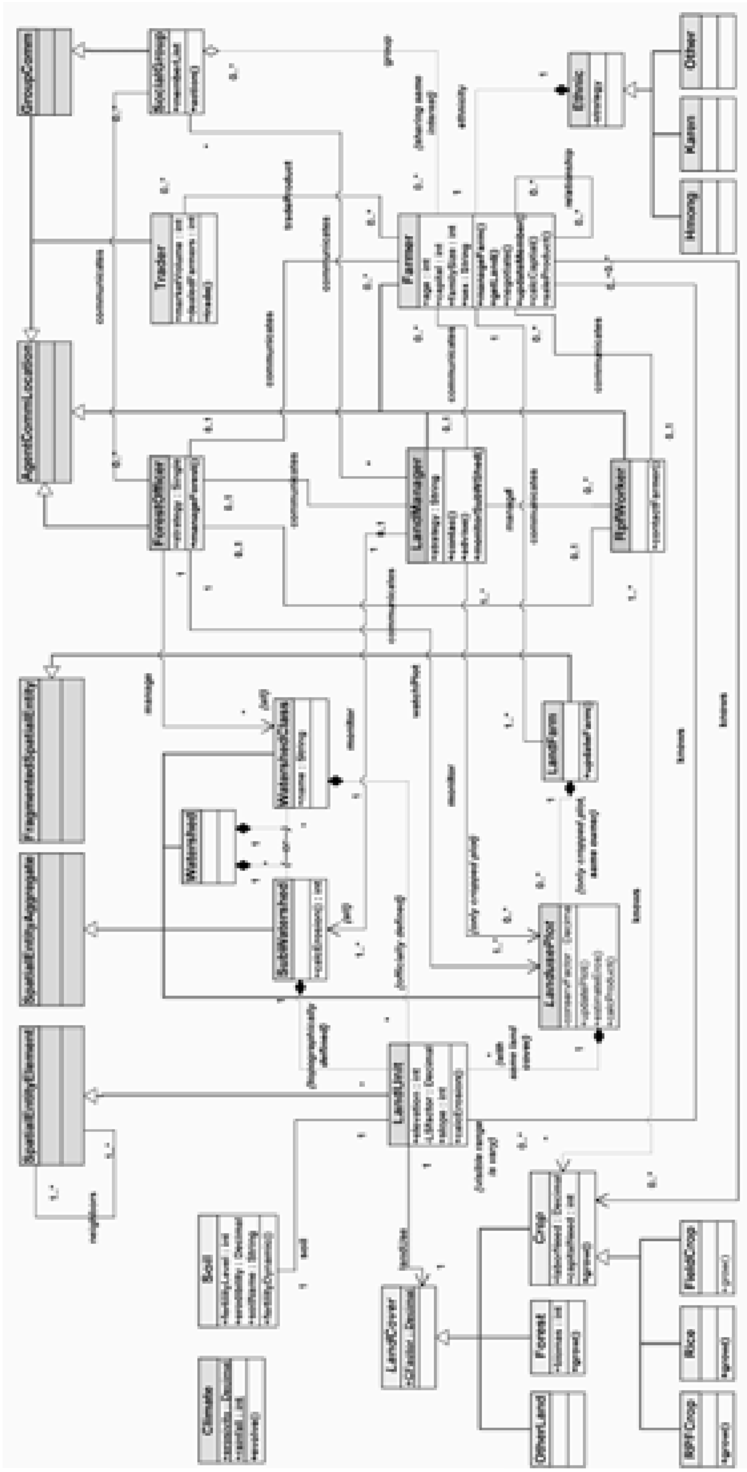

Fig. 2. UML class diagram of Maehae human-/agroecosystem.

illustrated by the UML sequence diagram shown in Figure 3. The time-step of the model operation is one cropping season. Therefore, within one year there will be two successive cropping seasons corresponding to the wet- and dry-season cycles. The main crops in the wet season are paddy rice, upland rice, and other field crops, whereas vegetables and flowers are planted in irrigated areas during the dry season.

At the beginning of this sequence of watershed dynamics, several *Farmers*, his/her household members, and a range of population growth rate are given. The dynamic starts before the beginning of the cropping season. Some *Farmers*' households may have a new member because of the natural growth rate and random occurrence. Some may be contacted by the *LandManager* according to historical records on levels of soil erosion that took place in his/her *LandusePlot* in the previous cropping season to provide advice on soil conservation practices. Thus, the *LandManager* will keep a record of whose *LandusePlot* is prone to soil erosion, and discuss a soil conservation practice that should be applied. The *RPFWorker* will use this information as one criterion in choosing a *Farmer* to become a member of the RPF. In each crop year, the *RPFWorker* will be given the types of crops and quotas to be produced. Then, the *RPFWorker* will look for *Farmers* who are interested and have the potential to produce particular crops. One particular criterion that the *RPFWorker* takes into consideration is to not choose a *Farmer* who cultivated a plot on a steep slope and prone to soil erosion in the previous cropping season unless soil conservation practices were adopted.

Before the cropping season starts, *Farmers* who are members of the RPF will decide what kind of crops they want to grow. The list of crops is not limited only to the types suggested by the *RPFWorker* but also includes other crops according to the *Farmers'* preferences and goals. Criteria and rules involved in how *Farmers* choose their crops have not yet been clearly defined, but will be made precise later. Available land resources and their suitability determined by soil characteristics and location, cost for cultivating a particular crop, and consumption and additional needs will be part of the major factors that determine *Farmers'* decision-making in choosing a crop and looking for new land. Once crops are selected, the *Farmer* will allocate *LandusePlot* for cultivation; this is the start of the interactions with the biophysical dynamics that also involve the *Crop, LandUnit*, *Soil*, and *Climate* entities. Crop yields will vary according to soil properties, climatic conditions, and cultivation practices. *Climate, Soil, Landcover*, and *Farmers*' practices are major factors influencing soil erosion, which is determined by soil physical structure, slope characteristics, crop cover type, and rainfall intensity. For each main crop, the attainable crop yield will be predetermined using empirical data, then a certain amount will be deducted based on soil fertility, rainfall function, and *Farmers*' management level. Thus, at the end of the cropping season, each cultivated plot will yield a certain volume of production.

As soon as a *Farmer* allocates crops to plots and starts cultivating, the *LandManager* will start to monitor the *Farmer's LandusePlot* to assess the severity of soil erosion that may occur along the cropping season, and these records will be used for action in the next time-step. Thus, at the dry-season time-step, the *LandManager* will not be active but will still hold records from the previous step to be applied in the next step. Likewise, the *ForestOfficer* will be monitoring the fragile forest area (determined by slope class and watershed class). At the watershed level, erosion oc-

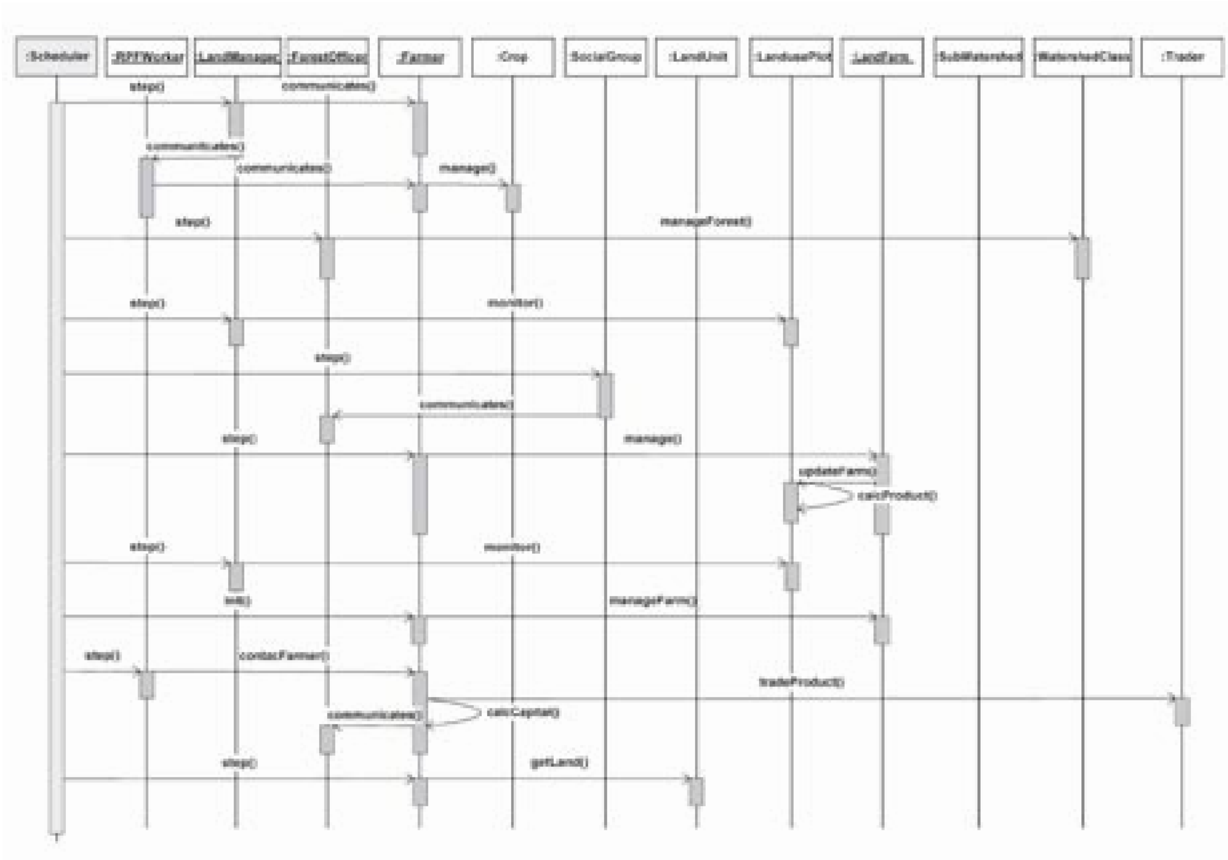

Fig. 3. A UML sequence diagram.

curring in cultivated plots and other erodable area will be aggregated and the result in total runoff and sediments of the whole system estimated at the watershed outlet. If these amounts of runoff and sediments exceed the acceptable level (given by LDD), both the *LandManager* and *ForestOfficer* will need to investigate and look at their monitoring records to find *LandusePlots* and owners (*Farmers*) that contributed to this situation. Then, communication and negotiation among these three agents and the *SocialGroup* will take place in the next step.

After the harvesting period, *Farmers* who are members of the RPF will sell their products as an amount of the given quota. Surplus products and/or non-RPF extension crops will be sold later on to a *Trader*. *Farmers* who are not RPF members will have two options for selling products. More than one *Trader* may come and trade for products and a negotiation mechanism between *Traders* and *Farmers* will be based on offered price, prices of previous cropping seasons, information about current common farm-gate prices, and a chance factor. The process and rules for this interaction and negotiation function will be further explored and analyzed based on *Farmer* and *Trader* perceptions to formulate a simplified decision-making process to be applied in the model. *Farmers* may decide to manage products to be used for household consumption, depending on their objectives and needs.

As soon as a deal can be made, *Farmers* will receive a certain amount of income. Both income and surplus products will be converted and compared to household consumption needs from the present until the next harvesting season. In the case of a consumption deficit, *Farmers* have to seek alternative ways to survive. At this moment, *Farmers* will look for a *LandUnit* to make a new *LandusePlot* to produce more in the next crop season. If a new *LandusePlot* happens to be located within the restricted area (according to the subwatershed classification scheme), which is prone to soil erosion and mostly assigned as a reserved watershed class, the *LandManager* and *ForestOfficer* will take action to either forbid cultivation or allow it under strict soil conservation practices advised by the *LandManager*. This is another communication and negotiation process that may occur. Relevant rules, actions, and mechanisms concerning this process need to be explored in the next research step. Since the government policy on environmental conservation, which is locally enforced by the *LandManager* and *ForestOfficer* to conserve soil and forest resources in upper watershed areas, provides only a broad concept and strategy of what should be done, this can create several implementation methods because of differences in personal attitudes and experiences among these agents. This will result in very diverse and dynamic situations. The UML activity diagram in Figure 4 shows an example of possible rules used in the decision-making process of the *ForestOfficer* in allowing the *Farmer* to open a new plot in a forest area.

In a future revision of the model, the mechanisms of communication and negotiation will not be limited only to individual *Farmers* and these two government agencies but they will try to take into account the local organizations (*SocialGroup*). This requires a participatory approach and companion modeling tools, such as role-playing games, to derive precise information to facilitate further model design and development.

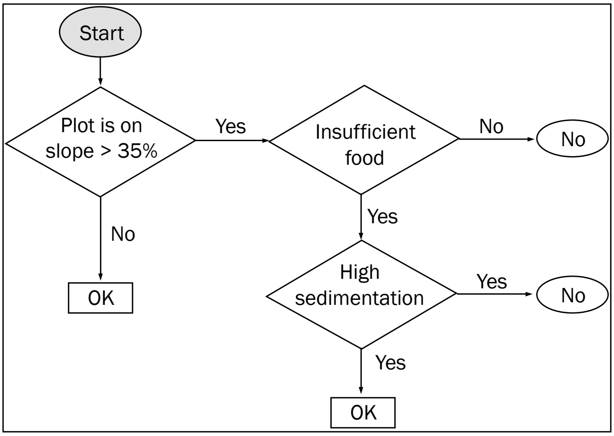

Fig. 4. Activity diagram showing the decision-making of a *ForestOfficer* in allowing a *Farmer* to cultivate a new plot in a forest area.

Future plans and perspectives

A prototype model of the Maehae watershed system composed of major stakeholders and a set of basic behavior and rules has been built. This model will be developed using the CORMAS platform (Bousquet et al 1998) because of its capabilities in modeling and simulating agent behaviors at both the individual and aggregate levels. Furthermore, it has ability to link MAS with a GIS database and software used to enhance spatial data import and export, spatial analysis, and visualization of simulation results. Then, simple scenarios will be simulated to verify the proper functioning of their various key components. Later, this prototype model will be used as a conceptual framework for further development.

For the model development, three major tasks will need to be accomplished: (1) evaluate and analyze stakeholders and their representations, (2) formulate rules and functions of the individual decision-making process, and (3) assess existing ecological dynamics models to be used in the model. Each task requires specific processes, steps, and tools for investigation and data inquiry.

The social dynamic is one factor that creates complexity, particularly because of the heterogeneity among the various agents involved in managing this system and the variability of their respective behavior and decision-making processes. As mentioned above, in the present model, agents, attributes, and processes were designed based on our past field experience and available data. This process did not take into account stakeholders' points of view. This may not be enough to represent correctly the stakeholders' behavior and actions during simulations. Thus, further participatory field surveys with stakeholders need to be carried out, coupled with stakeholder analysis and elicitation techniques as used in the field of collective INRM (Allen 2001, Becu et al 2003a, Becu et al, this volume). Apart from this, the model also provides insights into the decision mechanisms of such processes. This allows us to formulate a rule-based decision function to be applied in the model, for example, how *Farmers* choose a *LandUnit* to create a *LandusePlot* and allocate a *Crop* and what are alternative off-farm activities *Farmers* could choose to cope with insufficient goods for household use. However, defining agents and elicitating their representations is an iterative process, and, since it has been predefined and structured, it can be evaluated to modify the attributes and verify the functioning of the model through participatory approaches and tools (Bousquet et al 2002, Trébuil et al 2002).

The elements involved in the representation of the watershed biophysical subsystem are soils, climate, crops, and forest cover. Before building a spatially explicit model, data requirements and availability and scaling and integration of spatial heterogeneity are key aspects to be examined. The different perceptions of stakeholders toward their environment and its dynamics will determine the type of ecological dynamics model and data needed. The *LandManager* and *ForestOfficer*, whose perceptions may focus on soil, water, and plant dynamic processes, may request that the model represent their perceptions, whereas *Farmers*' perceptions formulated from empirical monitoring and observations accumulated over many years may be represented using simple cause-and-effect rules.

Several research teams have already attempted to develop spatially explicit biophysical models to represent and simulate human-environment dynamics employing various approaches and tools. These applications cover diverse kinds of environments and scales (Parker et al 2003, Le Page et al 2001). In the next step, some of these methods, including recent GIS technology, will be employed to develop an integrated and spatially explicit module appropriate for representing the biophysical subsystem of the Maehae watershed and which will be well adapted to match common stakeholders' representations.

Along with the research process, we try to involve stakeholders in the model development, validation, and simulation. With these participatory processes, stakeholders can help shape their representations and decision-making rules and processes. These iterative procedures between field work and modeling activities will result in an increase in stakeholders' cognitive ability and a better understanding of phenomena and consequences that may occur following actors' decisions, actions, and interactions.

Now, we are designing a role-playing game to be played by stakeholders in the Maehae watershed. This is a method used to clarify our point of view toward the context and dynamic of this area. It can also enhance the collective learning processes of stakeholders (Trébuil et al 2002). Furthermore, criteria and rules the players used in the game will be applied in the MAS model-developing process.

The challenge of this study is how to integrate the different perceptions of various stakeholders toward the environment and its dynamics to result in a common agreed-upon MAS model for all. Once the model structure and function are completed and accepted by stakeholders, this should allow us to simulate scenarios under alternative sets of indicators and rules proposed by stakeholders. This will lead to the suggestion of diverse discussion topics regarding each individual perception, decision-making process, and negotiation on rules and regulations for resource management. Therefore, this participatory and collective learning process should result in the identification of alternative watershed management schemes that are jointly acceptable to all key stakeholders.

Conclusions

We found that abstracting and designing real-world phenomena represent a crucial initial step for developing a MAS model for NRM. UML is a useful tool to bring together differing viewpoints regarding the area under study to transform the Maehae human-/agroecosystem into a conceptual framework representing a holistic view of the system. We can use this common framework to guide further research activities. This kind of research and action-oriented work needs to employ a participatory approach since stakeholders, their behavior, and the consequences resulting from their decision-making and interactions are key driving factors for system dynamics.

In the field of NRM, MAS and companion modeling tools, such as the role-playing game, the CORMAS platform, and GIS software, can be integrated to construct MAS models incorporating key components, functions, and mechanisms to represent dynamic phenomena occurring in complex agricultural systems such as a watershed. This innovative integrated participatory approach also provides an interdisciplinary environment and involves stakeholders in the research process itself.

This work tries to extend previous and current research efforts to bring together actors in different hierarchies who are involved in watershed resource intervention, accompanied by the MAS model as an interface and negotiation tool for the stakeholders. This is one of the recent applications using participatory MAS modeling for NRM in Southeast Asia that tries to fill the gap for stakeholders and move closer to a real collective effort to manage natural resources in the highland watershed system.

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A methodology for identifying and formalizing farmers' representations of watershed management: a case study from northern Thailand

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Linking modeling tools and the participatory approach for development is not a common combination. Participatory multi-agent system modeling (PMASM) is a tool for sharing viewpoints among stakeholders and facilitating the negotiation process. A key question of this approach is the acquisition and the modeling of the various stakeholders' representations. Our research team, whose Asian branch is represented in this book, tries to formalize the passage from fieldwork to the model by defining a methodology that can be implemented in the field. This methodology adapts knowledge engineering acquisition techniques to in-field stakeholders' representations for PMASM. In a northern Thailand watershed, we pursued implementation tests of this methodology. We first explored two ways to tackle fieldwork (ethnographic and project surveys), both showing weaknesses and strengths. We then built a first-version diagram syntax used for representing individual farmers' representations, and we considered options for analyzing those diagrams. Finally, we tested the elicited representations by leading farmers, through game-like sessions, to rebuild a model of their system structured by elements and links. Results reveal a great heterogeneity of farmers' representations, which we intend to manage by establishing farmers' synthetic profiles based on their orientations toward specific elements and aspects of their social and natural environment. Orientations of those profiles convey different conceptions of the functioning of the system with which farmers interact. This also results in decisions and reactions to issues that are different from one profile to another. The identification and formalization will contribute to the implementation of a computer model of farmers' representations. Perspectives are drawn on two ways to integrate representations into the modeling.

During the last ten years, researchers have been working on natural resource management (NRM) and ecosystem modeling using multi-agent systems (MAS) (Carpenter et al 1999, Lansing 1991, Rouchier and Bousquet 1998). This research has focused mainly on the interactions between biophysical and social dynamics as a means to understand the emergent behaviors of a system. A subset of experimental studies resulted in the combination of MAS modeling and participatory approaches and demonstrated the ability of participatory MAS modeling (PMASM) to promote discussions among stakeholders involved in the participatory process and lead them to defining negotiated scenarios (Bousquet et al 2002, Barreteau 2003, D'Aquino et al 2003, Etienne et al 2003). A key element of this approach is the construction of a shared representation of the system among participants. It consists of taking into account stakeholders' representations, emphasizing the differences among those representations, showing some participants the differences and similarities of the others' viewpoints, and facilitating a better understanding of the diverse views of the world. Thus, identifying and integrating stakeholders' representations is a necessary step of PMASM and the question emerging is how to formalize this step. This is the aim of this paper, which describes the setting up and application of methods for identifying and formalizing how farmers represent watershed management. This formalization will enable us to implement stakeholders' representations into a model in a next phase.

The field site of this research is a catchment located in northern Thailand. A great diversity of stakeholders intervenes in northern Thailand catchment management. There are cultural differences among stakeholders (northern Thai villages in the lowlands and various minority group settlers in the highlands), but also diversity in terms of stakeholders' involvement (farmers using resources, local extension and development offices, state intervention). Those various stakeholders are all involved at different levels in NRM and have recently been encouraged to interact more intensively together. Stakeholders' interactions in relation to NRM are not always smooth, and have sometimes led to tensions and conflicts. We tackle the analysis of those interactions from the angle of the representations that stakeholders have of catchment NRM. Indeed, in northern Thailand, we found that stakeholders have various views about the functioning of the social and natural system, about the issues to face, and the way to handle them. Identifying stakeholders' representations helps in understanding the functioning of stakeholders' interactions and the implications of their heterogeneous points of view.

In an early stage of our research, we laid out the elements of a methodology for identifying stakeholders' representations (Becu et al 2003). This methodology is based on the mutual use of knowledge engineering techniques (Gaines and Shaw 1993, Menzies 2002) and PMASM. The application of this methodology to the northern Thailand case study enabled us to identify and formalize a set of individual farmers' representations. Classifications of farmers' representations resulted in sets of farmers' profiles that demonstrate the heterogeneity of farmers' points of view. In this paper, we focus on the construction, application, and preliminary assessment of this methodology tested with local farmers. In the first part, we describe the field context and the modeling background. Then, we present our methodology, its application, and the results obtained. Finally, we assess the methods used and discuss the heterogeneity of the individual representations.

Natural resource issues in northern Thailand

Three decades of agricultural transformation in northern Thailand have witnessed increasing tension in relation to NRM. Permanent settlement of upland community groups, farmers' adaptations to market demand, and the increasing degree of state intervention in the highlands have resulted in increasing interdependencies among stakeholders. The 1997 National Constitution provides members of local communities the right to *"use and preserve their local natural resources and environment"* (section 46). It also requires the state to *"promote and encourage public participation in the preservation, maintenance, and balanced exploitation of natural resources* [...] *in accordance with sustainable development principles"* (section 79). These obligations are reinforced by the Eighth National Economic and Social Development Plan (1997-2001), which calls for a *"greater participation of local people and community organizations in the management of natural resources"* (Missingham 2000). Hence, various local stakeholders are now strongly encouraged to interact and collaborate on water management issues.

Meanwhile, tensions among stakeholders in relation to NRM are increasing and open conflicts are sometimes erupting (Vorapien 1994, Kanwanich 1997). In particular, several governmental and nongovernmental organizations in northern Thailand claimed that deforestation resulted in a dramatic decrease in water availability during the dry season. This assumption was repeatedly mentioned by lowland farmers to accuse upland settlers of reducing downstream flow. However, issues as fundamental as the relationship between upland agriculture and forest destruction or the impact of upstream agricultural intensification on downstream agricultural viability are contested by several experts (Alford 1992, Enters 1995, Schmidt-Vogt 1998). They argue that the expansion of irrigated schemes and horticulture in the lowlands are responsible for an increasing water demand. Supporters argue that these evolutions have increased the demand for water during the dry season, which now has to face a fluctuating water supply (Walker 2003, Waranoot and Bengtsson 1993). If deforestation and catchment hydrological equilibrium are often driving social tensions, related issues such as soil conservation, erosion, or irrigation infrastructure management are also sometimes leading to highly contentious management options.

Recent literature on environmental management, and catchment management in particular, places a strong emphasis on achieving negotiated settlements to such conflicts (Brown et al 1995, Crowfoot and Wondolleck 1990). In northern Thailand, such approaches are often seen as an appropriate way forward in a social and political climate that places increasing emphasis on participation. Understanding the interactions among stakeholders having different interests and viewpoints is one step in such an arrangement. In this perspective, multi-agent-based modeling used together with knowledge engineering techniques may help explain these interactions.

Modeling representations with multi-agent systems

MAS focus on interactions between agents as a means to understand the emergent behavior of a system (Ferber 1995). That is how a multi-agent model can simulate the interactions between two agents gathering a resource, with each having a different view about that resource (Epstein and Axtell 1996). The implicit assumption is that individual behaviors are driven by their specific objectives and perceptions of the system. Therefore, researchers working with MAS have become increasingly interested in modeling individual representations.

Still, modeling the specific nature of representations is not an easy task as the concept of representation itself is subject to several contrasting theories (Lauriol 1994, Descola 1996, Hutchins 1999). Two main trends can be identified. The first approach, known as cognitivist, states that representations are stabilized knowledge structures that are mentally built using a set of symbols and logical inferences, and that they can be stored in a long-term memory and reused (Craik 1943, Johnson-Laird 1983). On the other hand, the constructivist approach states that individual representations are temporary constructs elaborated through social interactions and communication and they are highly context-dependent (Piaget 1971). In both cases, knowledge and decision-making are not fully conscious in the mind, either because some of the elements and processes that constitute knowledge and representation are said to be unconscious (Newell 1982) or because the nature of representation is said to be socially constructed and continuously evolving (Röling 1996).

Hence, the modeling issue comes down to a choice between theoretically designed knowledge or empirically elicited knowledge.

Modeling from theories

So far, there is no unified theory in the field of MAS. Coming from artificial intelligence, the belief-desire-intention architecture has long been the most popular theoretical framework (Conte and Castelfranchi 1995). More recently, social scientists have challenged this view and proposed alternative frameworks (Gilbert 1995). Some of these models, such as the Consumat theory, have been tested against experimental data (Jager and Janssen 2003).

Companion modeling approach

Companion modeling is a trend of PMASM dedicated to NRM[1] (Bousquet et al 1999). It involves stakeholders in various phases of the modeling process. Stakeholders provide feedback about the model structure and the simulations produced thanks to iterative interactions with the designers. Several versions of the model might be discussed as its construction evolves (Barreteau and Bousquet 2000). This approach may also use workshops in which models are created in complete interaction with stakeholders. During those working sessions, stakeholders design the model using different model artifacts (computer model, role game) and researchers act as facilitators in this process (Bousquet et al 2002). Two applications of companion modeling are ongoing in northern Thailand, focusing on issues of deforestation (Promburom et al, this volume) or soil erosion (Trébuil et al, this volume).

By building models of stakeholders' representations in a participatory way, this work serves to create a shared representation and to simulate scenarios. This process is especially appropriate for taking into account the social construction of representations and for giving a relevant validation of the model. Now, when looking at previous experiences, a variety of ways have been used for identifying and integrating stakeholders' representations in the models. They may present individual representations either separately from each other or in an aggregated way. Moreover, and depending

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[1] http://cormas.cirad.fr/en/reseaux/ComMod/index.htm.

on the goal aimed for, the emphasis is given either to the individuals' representation of their biophysical and social environment or, when individuals' behaviors are highly driven by others' behaviors, to their representation of the others' representations of the environment. Nevertheless, in the community of PMASM users, a common trend is the use of conceptual models (one may use a single model or a set of models) to express the shared representation and therefore the individual representations. But, how do we ensure that the conceptual model holds the individual representations? In some cases, the identification and integration of individual representations are reached through the researcher's understanding of the system dynamics. In other cases, these are ensured through participatory methods such as role-playing games or group discussions. But, the identification and integration of individual representations are often not a formal procedure. Now that PMASM has proven its usefulness in promoting discussions and negotiated scenarios among stakeholders, we felt the need to reinforce the ways to reach the creation of a shared representation.

Methodological assumptions

We adapted knowledge engineering techniques to our specific working context, which deals with NRM and actors often performing ill-defined tasks. A methodology based on seven elements that constitute its fundamentals was elaborated during a study in the Orb Valley in southern France on wine farmers' perceptions of runoff and erosion processes (Becu et al 2003). The fundamentals of this methodology are summarized below.

A constructivist perspective

We acknowledge the constructivist perspective and believe that the nature of representation is socially constructed through people's interactions with their physical environment and their social relations. We assume also that representations have a psychological existence in people's minds and thus may be elicited. But, we recognize that these representations may evolve due to the elicitation process itself. Therefore, any elicited representation should be used as a basis for discussion rather than decision.

The use of elicitation

Our methodology uses elicitation techniques coming from knowledge engineering as a way to access individual representations. Elicitation consists of asking experts to describe and give information about a system and to model that information. Typically in knowledge engineering, experts are humans possessing special skill or knowledge, derived from training or experience, in some particular field (Gaines 2000). Experts should show abilities in answering questions, explaining results, and identifying issues. Elicitation focuses on the expert's knowledge about a domain and on the way he or she makes decisions. The implicit viewpoint on representation is thus the cognitive approach.

In the field of knowledge engineering, there are different approaches. Within the transfer view that we follow, elicitation and modeling of representations are treated as two successive and independent phases. The eliciting process is composed of a direct acquisition of information, followed by the interpretation of the collected information.

Acquisition may be achieved through semistructured interviews, process monitoring, or ethnographic surveys. These tools are highly complementary as behavioral observation may help in solving communication shortcomings or misunderstandings (Trimble 2000). Although it is severely criticized by knowledge engineers, we consider that individual semistructured interviewing is the most appropriate elicitation technique in the context of our application. When dealing with stakeholders in the context of NRM, interviews and meetings are common and well accepted by local actors. Moreover, we believe that the weaknesses of interviews (interpretation biases and inability to extract tacit knowledge) can be corrected by parallel techniques such as joint field observations, anthropological surveys, or stakeholders' zoning.

Associated with semistructured interviews, the interpretation is often made using the protocol analysis technique, based on the knowledge-level theory (Newell 1982). The principle consists of identifying in the transcript of an interview all the words and semantic expressions related to the elements and concepts that are relevant to the project. The experience of knowledge engineers using protocol analysis has refined and adapted Newell's knowledge-type classification. Knowledge engineers have identified different types of what they call knowledge objects and associated typical words and semantic expressions for each of them (Ehret et al 2000, Gray and Kirschenbaum 2000). That is how, using those classifications, we can extract the knowledge objects of a transcript containing a stakeholder's views on whatever topic and, by combining those pieces of information, we can obtain a conceptual model of the stakeholder's representation. To integrate representations in a running MAS model, we also adapted the knowledge objects classification to the unified modeling language (UML) formalism often used in MAS (Le Page and Bommel, this volume) and that greatly facilitates the implementation phase (Grady et al 1998, Graham 2001).

Taking situated cognition into account

Situated cognition theory considers that representations are context-dependent (Gigerenzer and Todd 1999, Menzies 1996). Thus, we try to place the interviewees in a context that makes sense for the topic of the representation that is examined. In their transect method, Ross and Abel (2000) make it possible to extract information concerning spatially distributed processes by interviewing stakeholders during a walk across the case study area. Similarly, in our methodology, (1) interviews should be done in the field, at a location relevant to the interviewee's actions, and (2) the interviewer's first question should be related to the interviewee's main actions at this location.

Use of multi-agent systems

Our main reason for choosing MAS is that it is especially appropriate for taking into account the heterogeneous social representations of a system and has been proven to be highly useful in simulating agents with different viewpoints and behavior (Ferber 1995, Etienne et al 2003). Moreover, it can be used to explore stakeholders' representations in a dynamic way, which is useful for our methodology in two ways. On the one hand, it allows us to check the model consistency according to the stakeholders' authentication of its different components. On the other hand, simulations developed with MAS are very efficient communication media as the model presented on a computer screen displays the environment in a simple and synthetic way. One of the best pieces of evidence of this is the selfCormas application, for which Senegalese farmers were able to discuss MAS results displayed on the screen of a laptop (Bousquet et al 2002, D'Aquino et al 2003).

Northern Thailand application

The northern Thailand application aims at modeling resource management for a small catchment, with the integration of stakeholders' representations using the above methodology. Research work was divided into three phases: data collection, data analysis, and validation. We will first describe the fieldwork context and then the three phases. As this research is still ongoing, this paper will focus on the elicitation process. Perspectives about the modeling process will be presented in the next section.

The context in village highlands and lowlands

Within the framework of a broader collaboration with the Land Development Department of Thailand, we have selected the Pang Da catchment, which occupies 15 km^2 and is located about 30 km northwest of Chiang Mai City. As we were also interested in lowland irrigated water management systems, we extended the study area to the portion of the Samoeng River located downstream from its confluence with the Pang Da River. Thus, this area is hydrologically dependent on the Pang Da catchment. A rapid rural appraisal was carried out and two main case studies were selected for the elicitation and modeling of farmers' representations. Each of these case studies, an upstream and a downstream village, has specific social, agricultural, and economic contexts (Fig. 1).

The upstream case study (1,250 m) is a Hmong ethnic group village of 103 households and a population of approximately 700 individuals, called Buak Jan. Agriculture is characterized by vegetable and flower production. There are two water sources for irrigation: small streams and a spring in the middle of the village. Streams are often private property and water sharing occurs principally among relatives, but the spring is an open-access water source and no collective management rules are defined at this level. The local issue of this case study is the lack of water for irrigation during the dry and warm season (March to May). Indeed, by February, streams are usually dry and farmers can count only on the spring from which they have to pump water to irrigate. In addition to consuming electricity and money, this spring dries up during average hydrological years at the beginning of May, resulting in an

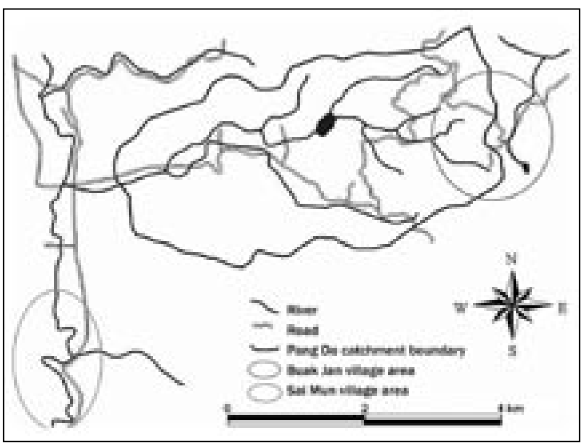

Fig. 1. Map of the study area.

incapacity to irrigate for about 2 weeks. For flower production, which is dominant at this time of the year, this drought results in a decrease in flower plant production and sometimes in the death of a part of the flower plants. During dry years, drought can last for 1 month or more. Free water access to the spring results in a heterogeneous pattern of individual satisfaction, leading to indifference toward the global water scarcity problem for farmers who always have water and to irritation for those who are less successful than others in getting water first.

The downstream case study (540 m) is a northern Thai village of 102 households and a population of approximately 500 individuals, called Sai Mun. Agriculture, which is the activity of most villagers, relies mainly on paddy field cultivation. Those paddy fields are irrigated areas belonging to three irrigated schemes with similar individual and collective water management. Farmers grow rice for home consumption during the rainy season and cash crops during the dry season (November to May). Contrary to what we thought at first, the cropping pattern is not driven by water management but highly depends on soil fertility. Most farmers had continuously grown garlic for about 20 years during the cold season as a high-value cash crop. This factor, together with others, has resulted in a decrease in soil fertility (decrease in soil nutrients, organic matter, and pH; soil structure disintegration), which has affected garlic and other cash crop yields for about three years. Farmers react to this problem in heterogeneous ways: for example, some try new cropping patterns, other than garlic, that are supposed to improve soil fertility, and others apparently ignore the problem and keep on cropping as they always did.

As farmers act on their system and react to local issues in different ways, we assume that these heterogeneous behaviors depend on each farmer's representations of the biophysical and social environment. Describing and modeling those representations should then lead to a better understanding of farmers' actions and therefore of the system dynamics. To do this, we conducted an elicitation process in both case studies that was divided into three phases. Data produced at each phase were used as inputs for the next phase (Fig. 2).

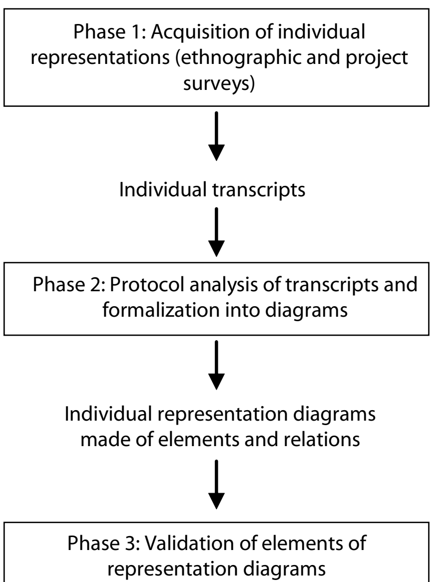

Fig. 2. Phases of the methodology and information transferred between each step.

Ethnographic and project surveys

Two different interviewing approaches were used in two separate villages: individual semistructured interviews and individual discussions (some would call them open interviews) combined with observations.

In Buak Jan, 12 individual semistructured interviews were conducted within the framework of a formal research project about water management established with the village headman. Each interview was done in the farmer's field after having met him previously two or three times to ensure a good relationship between the interviewee and interviewer. We tried to diminish Thai-English interpretation biases by training the translator on the semistructured interviewing techniques and by conducting the interviews as much as possible in Thai and recording them. The recorded interviews were translated verbatim afterward, resulting in an English transcript. However, this necessary translation phase definitely resulted in obvious losses or misinterpretations of the farmers' words and even more, considering that Thai is not the native language of the Hmong people. Topics tackled in the interviews were defined in collaboration with the headman's village but more important than the topics themselves for the focus of this paper is the type of questions asked of the farmers. As our interest was in collecting the interviewee's representation of his environment, topics were introduced through "How does this operate?" type questions when talking about an environmental state, through "Why is this so?" type questions when talking about an environmental dynamics, and through "What do you do about X and why?" type questions when talking about an action. Prompting questions were then used within each topic, either to invite the interviewee to develop his argument or to talk about a predefined subtopic. After interviewing, we reread the transcripts and prepared additional questions that we asked of the same farmers approximately 1 month after the first interview.

The Sai Mun study was conducted with a different fieldwork approach, which has more to do with ethnographic work than an interviewing approach. As no formal framework was defined for our presence in the village, the research team developed a relationship with the villagers through a continuous presence among them for 7 months, joining them in agricultural activities and discussing various topics about their lives. As contact with farmers became closer, discussions were refined and more explicit questions were asked. The types of questions asked were of the same nature as in Buak Jan ("Why is this so?", "What is happening here?"). When our understanding of the system issues became more accurate, we used the soil fertility issue as a way to structure a discussion guideline about farmers' representations of their environment. Fourteen individual discussions following this guideline were conducted in the field with the help of a translator. As we didn't want to use the tape-recorder because of the informal relation of the research with the village, we developed with the translator a note-taking technique to ensure a minimum loss of information during the process: (1) during the interview, rapid note-taking; (2) just at the end of the interview, quickly completing the missing parts of the notes; (3) in the following hours after the interview, chronological rereading of notes to complete missing parts and, as far as we could recall, rewriting the conversation in the way that the interviewee expressed it.

As ethnographic or project surveys may be considered as a method on their own for identifying farmers' representations, it was important to keep track of the representations identified at this stage before starting the next research phase. By doing so, we were able to compare the results of ethnographic and project surveys with those of transcript analysis (which is another method for identifying representations) and thus discuss the representations' elicitation aspects of these two approaches. The results were presented in the format of classifications of farmers' representations. In this paper, we present only the classification of Sai Mun farmers built from an ethno-

Table 1. Classification of farmers in Sai Mun: classification 1 in columns and classification 2 in rows.

Classification 1 / Classification 2	Work alone: Open-minded	Work alone: Not open-minded	Work with agricultural partners	Not classified
Wide representations (initiator)	F11, F5		F12, F9, F3	F1
Narrow representations (follower)				
Focus on profit maximization	F4, F10	F8, F13		F14
Not self-confident	F2	F7		
In between				F6

graphic-type fieldwork approach. The comparison with the transcript analysis results will be presented later in this paper.

For Sai Mun, two classifications of farmers' representations were produced separately by different members of the research team (Table 1). In classification 1, farmers are classified according to their behavior toward agricultural partners: work alone or in contract with companies or institutions. Within the first group, farmers are divided according to their open-mindedness (open-minded or not). In classification 2, farmers are classified according to the "wideness" of their representations. The "wide representations" category corresponds to farmers taking many elements into account when making decisions about cropping or about resource management, whereas farmers within the "narrow representations" category are analyzing the system in a simple way (taking few elements into account for decision-making). We also found a parallel with an initiator/follower classification assuming that initiators need many elements when making decisions, whereas followers don't because they base their decisions on what others have experienced already. For the second group, we distinguish between farmers who are followers because (1) they focus only on profit maximization and they don't want to spend time thinking about biophysical dynamics, and (2) they are not self-confident for various reasons, mainly social reasons.

Transcript analysis

This phase aimed at extracting through a protocol analysis of the individual transcripts the elements and relations that would form the individual representations of the farmers. As a matter of fact, even if knowledge objects used in protocol analysis can all be classified in terms of elements and relations, their definition can be more precise than two categories only. However, we chose this classification for simplification as we intended to use the resulting conceptual model for further discussions with the farmers. The classification used for the protocol analysis is shown in the last column of Table 2.

The protocol analysis started with the preparatory phase of the transcripts. When multiple interviews had been done with the same farmer (as in the case of Sai Mun), transcripts were merged. The transcripts were then reread farmer per farmer to split each transcript into various themes. Themes were chosen both according to the themes

Table 2. Correspondences among knowledge objects, UML formalism, semantic expressions, and the classification used for protocol analysis in the northern Thailand case study.

Knowledge object	UML[a] formalism	Semantic expression	Classification used
Concept (object, person, etc.)	Class	Usually equivalent to nouns	Element
Instance	Instance	Ex.: "my car" is an instance of "car"	Element
Process (task, activity)	Operations	Ex.: "build a house," "design the engine"	Relation
Attribute and value	Class attribute and instance of attribute's value	Attribute: ex.: "cost," "age" Value: ex.: "120 kg," "heavy"	Attribute
Rule	Methods	Ex.: "If…, then…", "Do… until…"	Relation
Relationship	Association, aggregation, or inheritance	Usually equivalent to passive verbs; ex.: "…is a…", "…is part of…"	Relation

[a]UML = unified modeling language.

defined before the interviews and discussions and the actual themes discussed by the farmers (e.g., no specific theme for cropping was predefined before the interviews and discussions but this theme appeared explicitly during the discussions). Themes were identical for each farmer in each case study; however, when the information in a transcript was quite limited, we didn't feel the need to do the thematic classification. It appeared to us that the thematic classification was rather more a way to organize the protocol analysis when information was very rich than an analysis by itself. Moreover, after their identification with protocol analysis, elements and relations extracted from each farmer were combined in an individual diagram by whatever themes they were belonging to at first. The exception to this aggregation of the different themes is the case of Buak Jan, whose diagrams appeared to be very "wide" (numerous elements and relations), and which we split into four individual thematic diagrams to make them easier to understand. Examples of the resulting individual diagrams are given in Figures 3 and 4.

As shown in these figures, the diagrams resulting from the elicitation process are not easily readable at first. However, distinctions can be made. Figure 3 shows a soil-oriented representation of a Sai Mun farmer, whereas other farmers' diagrams from the same village show a market- and selling-oriented representation. These orientations are shown by the type of elements found in the diagrams as well as by the great number of converging relations going to the element "soil" in Figure 3, for example. Figure 4 is an example of the higher quantity of information elicited in Buak Jan, as we already stated above. Thus, the total number of elements for Buak Jan farmer 4 is 41, whereas there is a maximum of 19 elements per individual representation in Sai Mun village.

Although the diagrams' first reading could give information about their orientation, we conducted a qualitative analysis of them to extract more accurate results and establish a farmers' classification. Within the literature on qualitative data analysis, the concept of grounded theory is used when talking about theories formulated from

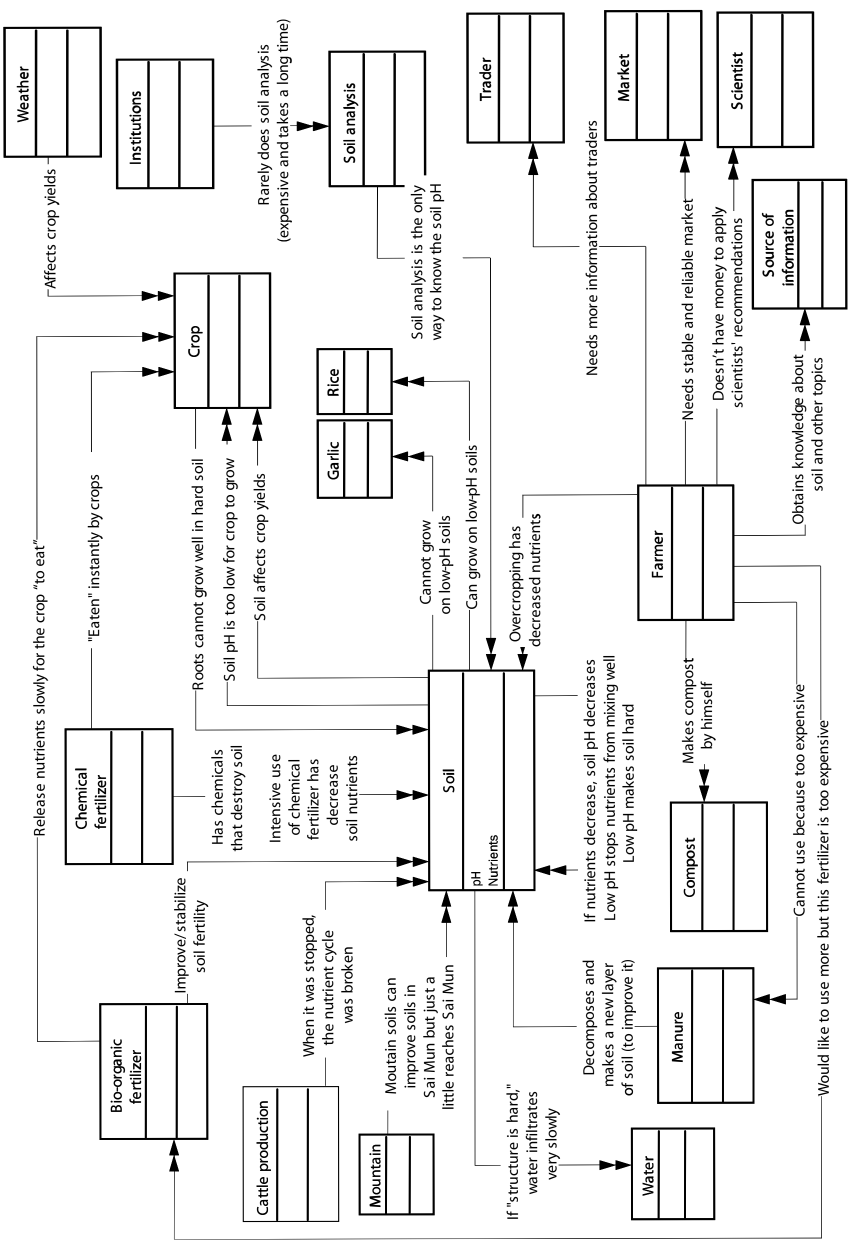

Fig. 3. Farmer 11 representation: example of soil-oriented representation in Sai Mun village.

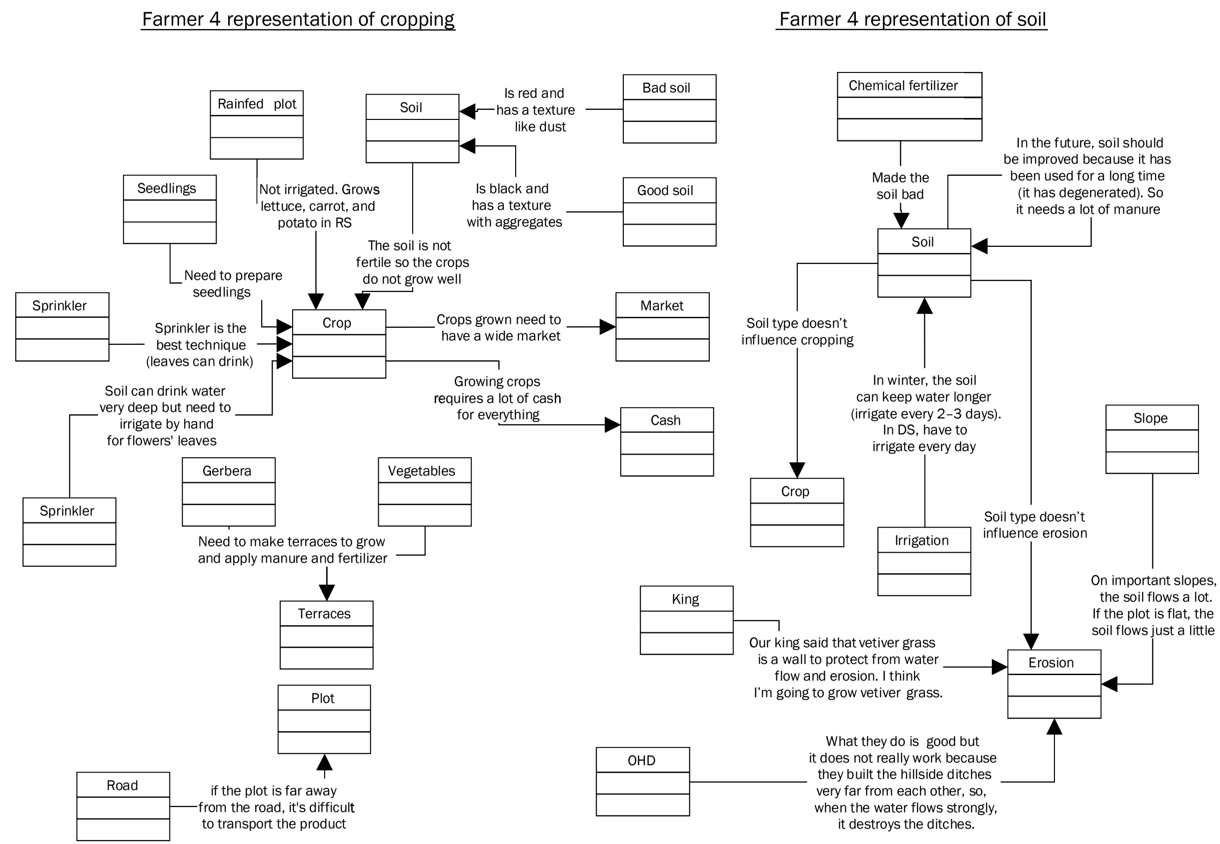

Fig. 4. Parts of farmer 4 representation: representation of cropping and of soil in Buak Jan village. RS = rainy season, DS = dry season, OHD = Office of Highland Development.

empirical observations. Practitioners develop theories through induction based on observation of a phenomenon (Glaser and Strauss 1967). This bottom-up approach uses some techniques that are especially relevant for our purpose. The formulation of a new theory begins by coding the data and formulating relationships among the coded objects, just as we have done with the elements of the farmers' representations.

Then we define two criteria—groundedness and density—that refer to the code frequency and to the relation frequency, respectively (Strauss and Corbin 1990). For the analysis of the individual representation diagrams, we adapt the two previous criteria to our data set. We defined two main indicators: the number of elements and the number of relations within an individual representation. For Sai Mun village, we have also calculated the number of relations with the element "crop" and the number of relations with the element "soil." Crop and soil are chosen because they are among the main elements used by Sai Mun farmers. Those indicators were then used to establish classifications of Sai Mun and Buak Jan farmers. In Table 3, for Sai Mun farmers, the numbers of elements and relations have been expressed in terms of relative quantity ranges. The same kind of table was made for Buak Jan farmers.

A comparison with the ethnographic approach classification shows that the extreme groups correspond in both classifications (group 1 corresponds to the "wide" representations group; groups 5 and 6 correspond to the "narrow" representations and not self-confident group, except F3). However, the "narrow" representations focusing on the profit maximization subgroup are distributed among very different groups of the postanalysis classification. A main reason for this inconsistency is the preanalysis classification inclination toward cropping and soil issues rather than toward economic issues. That kind of comparison is interesting as it reveals weaknesses and strengths of each type of classification. Indeed, the general convergence of the two classifications for Sai Mun village confirms in some way the relevance of the fieldwork approach adopted in Sai Mun village, as our preanalysis understanding of the system seemed quite accurate. However, incoherence such as with the profit-oriented subgroup demonstrates that a preanalysis classification is very dependent on our personal orientation toward the topic studied. Moreover, when comparing the preanalysis and postanalysis classifications for Buak Jan, many more mismatches were found and we are tempted

Table 3. Classification of Sai Mun farmers according to number of elements and range of relations.

Group	Farmer	No. of elements[a]	No. of relations		
			Total	With crop	With soil
1	1,9,12	+	++	++	++
2	13,14	+	++	++	+
3	11	++	++	+	++
4	5,6	0	0	+	+
5	2,8	+	–	+	–
6	3,4,7,10	–	– –	–	–

[a]++ = very numerous, + = numerous, 0 = medium, – = few, – – = very few.

to attribute this to the Buak Jan fieldwork approach, which resulted in a less accurate understanding of the system than in Sai Mun.

If the use of groundedness and density criteria resulted in a first interesting classification, it was unable to convey the orientations of the representations, such as soil- or market-oriented. Therefore, we worked on a second classification based on the type of elements embedded in each representation. This will be discussed later on in this paper.

Uncovering elements of the individual's representation through "playable stories"

Establishing a methodology. When it came to the phase of validation of our findings in terms of the actual individual representations of farmers in both case studies, it appeared clearly that validating both elements and interactions of our diagrams was too much to do all at once. Indeed, the total amount of different elements found in Sai Mun, for example, was more than 90 for all farmers. When we started to count the number of different relations, we quickly arrived at more than 100 types of interactions, after which we stopped counting. For the Buak Jan case study, the numbers were even larger. Validating such great diversity, element by element and relation by relation, was unrealistic; thus, we decided to focus on validating the important elements of the individual representations. Therefore, we identified around 60 main elements for each case study from the analysis of the individual representation diagrams and used them during individual sessions we conducted with each farmer of the sample. Those sessions are halfway between gaming sessions and story telling; we thus called them "playable stories."

Playable stories aimed to lead farmers to rebuild their world by selecting and organizing the elements of their world that were dominant in their representational system. The elements selected by each farmer during those sessions were then compared with the ones in their representation diagram as a means of validation. Each of the 60 elements mentioned above was therefore transcribed onto a card on which the name of the element was written in Thai and English (e.g., one card for weir, one card for trader, one card for rice, etc.). The 60 resulting cards were then placed on a panel in such a way that farmers could have an overview of the different elements at a glance (see Fig. 5).

Fig. 5. Cards for each element are placed on a panel for farmers to see them all at a glance.

To invite farmers to choose cards, as well as with regard to the situated cognition assumption, a story giving broad elements of the surrounding environment was recounted during the session so that farmers could locate themselves in a real-world context. The story told was the same for each farmer of a village and included different periods in which one topic at a time was emphasized. For example, for the Sai Mun case study, the first period focused on water management and the second and third focused on soil and market, respectively. Within this virtual world, farmers were invited to act, make decisions, choose cards that they thought were important for their way of life, and organize them if they wanted to.

To make those sessions a bit more entertaining, we added features such as virtual bank notes, which were used to pay and earn money, and meetings within the story with different stakeholders of the system with which the farmer was invited to converse (such as a soil scientist, a canal manager, a banker, a trader). Our story became a kind of gaming session and it was presented to farmers as one.

As a way to combine different approaches for identifying the important elements of the farmers' representations with this methodology, we organized the sessions in three separate and consecutive phases. In phase 1, we presented the board on which the cards were placed and asked the player to pick the one that he thought was important for his occupation. During phase 2, we recounted our story, step by step and year by year (one year is divided into six steps), and asked the farmer to "act" within this story as explained above. During this phase, the panel with the cards was hidden from the farmer and, while he was explaining what he was doing within the story, one of the interviewers was choosing the cards corresponding to the elements mentioned. When an element mentioned wasn't already available in the panel, a new card was added. All cards chosen, in all phases, were placed on a central board visible to all. During phase 3, we presented the panel to the farmer a second time with all the cards that he didn't mention or choose yet and we asked him to pick some new elements if he wanted to. Then, we discussed the different cards or groups of cards that were placed on the central board as a way to enrich the discussion. We also used cords to represent the interactions mentioned by the farmers (see Fig. 6).

Fig. 6. Cards of the board are linked with cords corresponding to interactions between elements.

Assessing the interest of "playable stories" for revealing elements. The research on and use of those playable stories to validate the elements of farmers' representations is still ongoing and only preliminary outputs can be mentioned. One primary output is that those sessions were able to reveal tendencies of the farmers' behavior in the game; for example, some farmers focused more on the market and earning aspects whereas others were oriented toward soil management. Identification of those main farmer representation orientations first came from our general impression at the end of each session; for example, some farmers spoke much more about elements related to the soil, whereas others were always arguing about prices, incomes, and markets. But, much more important than these subjective impressions, we were able to identify and describe those orientations by analyzing the set of cards that were chosen during the session. Indeed, as we recorded all the cards picked during the session, we could quantify and analyze objectively what happened during the sessions and this analysis confirmed the ability of the playable story to reveal the orientations of farmers' representations. In more details, with some cards being used or mentioned by the players more than other cards, we could weight the relative importance of the different cards. To do so, during the game we recorded players' reactions about the cards by arguing, giving comments, or asking information about a card. We then summed the number of times a farmer used, mentioned, or reacted to a card and assimilated the sum total to the weight of the element. We are currently combining these quantitative results with qualitative data extracted from the game (the verbatim transcriptions of farmers' reactions about cards) and preliminary results show that they contribute well to the definition of farmers' orientations toward specific interests.

Discussion

This paper focuses on the test of various methods for identifying and formalizing farmers' representations. We therefore presented the construction, application, and some preliminary results of those methods. Although this research is still ongoing, it is possible at this stage to assess the methodology from our experience. Moreover, an interesting specificity of this methodology is that it was applied at an individual level. This enabled us to demonstrate the heterogeneity of farmers' points of view, which we discuss in the second part of this section.

Methodology assessment

During the course of this research, we have tried diverse approaches for collecting information. Our aim was to find methodological elements that would tend to more accurately reflect the stakeholders' representations collected. An important source of bias when collecting this kind of information is the relationship between the interviewer and the interviewee (Portmann and Easterbrook 1992). Factors such as mistrust between the two persons may lead the interviewee to distort his answers. Knowledge engineers practicing elicitation techniques also demonstrate that meeting each interviewee several times is useful for creating a trustful relationship (Lépy 1997). The ethnographic and project survey approach used in Sai Mun and Buak Jan villages, respectively, resulted in a different nature of the relationship between the interviewer and interviewees. Although it is difficult to assess this relationship objectively, we believe that the ethnographic approach enabled a more trustful relationship that resulted in more accurate responses from the interviewees. In contrast, the project survey approach was much less time-consuming. Moreover, as audio-recording was used with this approach, it resulted in more information per transcript than with the ethnographic approach.

The representation diagrams completed in phase 2 (Figs. 3, 4) show interesting results as they show the elements of the system and the relations among those elements, but they also carry in their structure the orientations of the person's representation and his strategies (that may intervene in the decision-making process). Thus, when looking at a single individual diagram, one can follow the train of thought that demonstrates some logic of thinking or strategies. Still, those diagrams have limitations when one tries to analyze them collectively. We were able to use the different types of elements and relations to define classes of representations among the individual diagrams, but we were lacking methods to compare them according to elements such as train of thought or strategies. This difficulty may also partly be explained by the fact that each strategy or logic of thinking also contains series of elements and relations. This also demonstrates that tendencies and similarities can be found among several individuals in terms of elements referring to a specific topic, but that these individuals organize those similar elements in different ways.

Preliminary results of playable stories show some elements of interest regarding the nature of the representation extracted with this method. When compared with the elements of the representation diagrams, the type of elements extracted with playable stories are much more oriented toward actions and decision-making. Elements such as forest, mountain, or underground are never mentioned by the farmers during the playable stories. Once again, situated cognition theory contains elements of discussion that can explain these differences. Indeed, the context in which the interviewees are placed during the interviewing phase and the playable story is different. During the interviews, farmers were asked to discuss their environment in a general way, explaining processes of various elements and reasons for their thoughts and actions. In contrast, during the playable stories, interviewees were asked to act in their environment and eventually to comment on it as well as the reasons for acting in such a way. Therefore, farmers expressed their representation of the environment oriented toward action within the playable stories, whereas they had revealed their representation of the environment in a generic way during the interviews. Thus, current results tend to show that farmers use some parts of their representation of the environment when making decisions and performing tasks. Reasons for such behavior may be arising from simplifications, which are often made during a decision-making process, made to restrict a choice to its core (Gigerenzer and Todd 1999).

Importance of heterogeneity of representations and modeling perspectives

All the way through the identification process of our methodology, we found specific perspectives that farmers have for different aspects of their system. Elements and relations of the diagrams reveal that some farmers are more oriented toward soil, some toward market and selling aspects, and some toward partnership with private companies or institutions. Orientations revealed by playable stories complement the previous and help refine the profile of each farmer. These results are very demonstrative of the heterogeneity of farmers' perceptions of their social and natural environment and how they react to specific issues. In the case of Sai Mun, for example, farmers whose representation is oriented to soil aspects perceive the decrease in soil fertility as the result of the intensive use of chemical fertilizer associated with garlic production. They developed a thinking process about the relations among chemical fertilizer (as well as other inputs), soil, and plant. This process is based on their own experience, on comparisons with other farmers' practices, and on technical information they acquired from the radio or from technicians from local institutions. The conceptions that resulted from their thinking process as well as the source of information used are reflected in the diagrams. For example, Figure 3 shows the conception that the farmer has of the benefit of manure for soil fertility and how he perceives the pH as being dependent on soil nutrients. These conceptions result in specific decisions. That is why the farmer of Figure 3 will not grow garlic on a plot in which he thinks the soil is acidic but will grow soybean instead, or will use manure. Now, in the same village, the representation diagrams oriented toward profit aspects reveal a completely different view and reaction to the soil fertility issue. Those farmers explicitly refer to the soil as a resource used for production that can be managed. Investment is then the means to improve soil fertility. Here, the use of chemical fertilizer is not reappraised and should be completed by additional inputs such as bioorganic fertilizer. Similarly, those farmers will stop growing garlic if they consider that it is not profitable given the additional inputs required.

Throughout this example about farmers' conceptions and reactions to soil fertility, we showed that the representation diagrams can explain farmers' way of thinking and how different conceptions of a system result in different decision-making. The next step of this research now consists of integrating those different representations into the modeling. The coauthors of this paper foresee two main possibilities for integrating representations into the modeling. On the one hand, the model is a direct transcription of the stakeholder's representation and all objects of the model correspond to an element elicited within at least one farmer's transcript. On the other hand, agents introduced in the model use the representation and those agents interact with other objects that are coming from scientific knowledge and not from elicited elements. Figure 7 gives a schematic representation of these two forms of stakeholders' representation models.

Our aim is now to apply our reflections on the integration of individual representations into the modeling to the northern Thailand data set and to submit the resulting models to the stakeholders. Even if the representations elicited were only the ones of the farmers of the catchment, after the playable story phase, most farmers spontaneously asked us to organize meetings with this type of playable stories grouping together diverse types of stakeholders (government institutions, the Land Development Department, the Royal Project Foundation, etc.). Our perspective is thus to organize feedback working sessions with all stakeholders' groups, present our models, and use them as a way to discuss the diverse representations and ways of thinking present in the catchment.

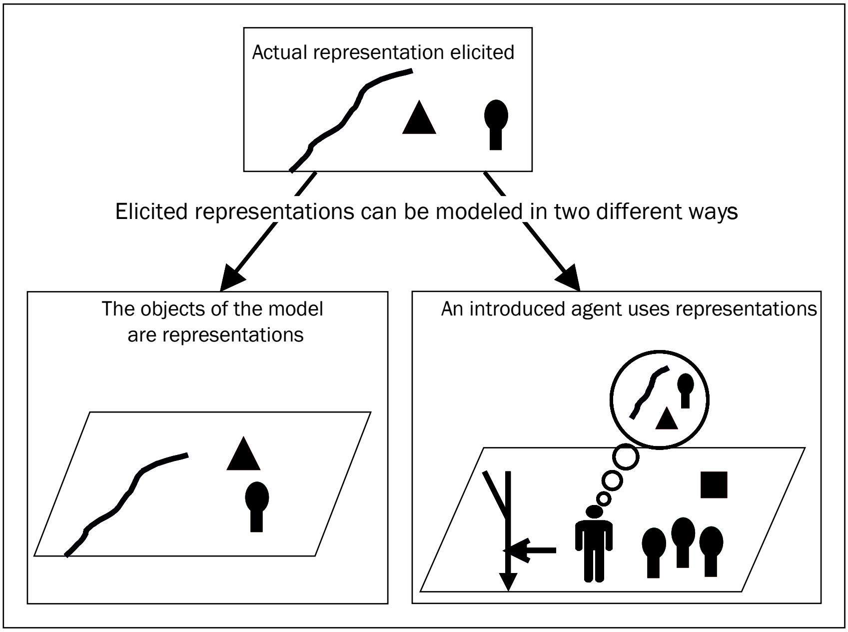

Fig. 7. Two types of stakeholders' representation models.

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Notes

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Developing a multi-agent systems model of agroforestry adoption on smallholder farms in the Philippine uplands

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The SAFODS-MAS (Smallholder Agroforestry Options for Degraded Soils–Multi-Agent Systems) model was developed following an iterative process based on repetitive back-and-forth steps between the model and field activities. Gradual changes in the model were introduced as new ideas from fieldwork were collected. Ideas, information, and knowledge about the study area were gathered and accumulated using a combination of participatory rural approaches (PRA), household surveys, and case studies. The model was developed to understand the adoption of agroforestry technologies by smallholder farmers in the sloping uplands in Claveria, southern Philippines.

Two versions of the model are presented here. The initial version of the SAFODS-MAS model is composed of the Crop-Tree Choice module and Timber Harvesting and Marketing module. The main features of this version are that (1) farmers' choice of crop to plant is greatly influenced by elevation and financial capital, (2) planting of trees is largely dictated by land tenure, and (3) harvesting and marketing of mature timber trees are influenced by timber price. Modifications in the second version of the model included farmer typologies (agroforestry adopter and nonadopter), fruit traders, choice of agroforestry system as affected by available capital and slope, and the social network effect.

The second version of the model was used to simulate and observe the different scenarios: cumulative income of agroforestry adopters and nonadopters, impact of market information on farm income, neighbor effects on the spread of agroforestry adoption, and impacts of the establishment of a tree seedling nursery on tree planting and income from trees.

The model scenario simulations can serve as a decision support for policymakers, farmers, and other stakeholders toward sustainable management of resources. It is envisioned to produce information useful for the design and dissemination of agroforestry technologies to other sites.

The sloping uplands are geographically the most extensive ecosystem in Southeast Asia, constituting from 60% to more than 90% of the total land area of the respective countries. These areas are likewise the most threatened ecosystem in the region because of increasing populations of subsistence farm families cultivating the infertile soils, land degradation, soil erosion, and deforestation (Garrity 1993). A large and rapidly expanding portion of the upland landscape is being converted to permanent annual cropping. These cultivation systems are usually found in the relatively accessible sloping areas, close to lowlands and roads.

Many factors limit the stability, productivity, and sustainability of upland farms, including inappropriate land use considering land topography, soil fertility, vulnerability to soil erosion, lack of planting materials, climatic variation and lack of irrigation systems, biological stresses, insecure land tenure, and social and economic uncertainty. New technologies will be essential in sustaining the stability and productivity of upland farms.

Agroforestry is a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms, diversifies and sustains smallholder production for increased social, economic, and environmental benefits (Leakey 1996). Trees and crops in agroforestry systems interact in relation to total nutrient and water cycles as well as light capture. Several positive interactions take place. Nutrient and water recycling occurs. Tree roots act as a "safety net" for nutrients that have leached down the soil profile below the crop roots and as a "nutrient pump" for weathered minerals in deep soil layers. Old tree root channels improve water infiltration and can reduce soil erosion. Nitrogen is supplied by tree roots due to root decay or by nitrogen fixation. Mycorrhizal associations enhance phosphorus availability, litter production, and maintenance of soil organic matter. Mulching conserves soil moisture and enhances soil microbial activity. Shading and microclimate improvements render temperature and humidity favorable for understorey species, and maintain carbon stock and belowground biodiversity. Negative interactions that may be involved between trees and crops are aboveground competition for light, belowground competition for water and nutrients, pests and diseases, and the allelopathic effect (Rudebjer et al 2001).

In the past three decades, a stream of government programs and externally funded projects were introduced and implemented in Claveria, southern Philippines. Among these were Sustainable Agriculture, SALT (Sloping Agricultural Land Technology), community-based forest management (CBFM), reforestation, agroforestry systems, and Landcare. However, most of these projects had low rates of adoption and success and were not sustained after project termination. The adoption of agroforestry systems was found to be concentrated at specific locus points and lacked widespread adoption in the municipality.

A model to understand the adoption of agroforestry technologies in Claveria was developed using a combination of participatory approaches, household surveys, and agent-based modeling. Understanding the decision-making strategies of farmers with regard to agroforestry adoption is essential to the success of efforts to address the sustainability of upland areas in the Philippines and Southeast Asia. In developing the model, we follow the "companion modeling approach," in which we start with a preliminary model with initial ideas about the system that is eventually revised and rebuilt. The model evolves as a result of the addition of new information from actual observations and experiences in the field. This process leads to the construction of a new model and, as this cycle is repeated, a family of models representing the successive interactions between the researcher and the field is developed (Barreteau et al 2003). The SAFODS-MAS (Smallholder Agroforestry Options for Degraded Soils–Multi-Agent Systems) model is a work in progress resulting in a genuine knowledge-based system that allows interactions between researchers and stakeholders (Berkes and Folke 1998, as cited in Barreteau et al 2003).

Land-use change involves interactions between ecological and socioeconomic systems (Polhill et al 2002). The FEARLUS (Framework for the Evaluation and Assessment of Regional Land-Use Scenarios) project applied agent-based modeling techniques to explore possible land-use outcomes under different scenarios such as the introduction of new legislation, globalization of markets for farm produce, or climate change (Polhill et al 2003). In our study, the SAFODS-MAS model will be used to simulate and predict land-use change in Claveria as a result of agroforestry system adoption by the different farmer types.

The SAFODS-MAS model aims at supporting discussion and coordination among stakeholders at the study site to better manage their resources by simulating the decision-making strategies of upland farmers in adopting crops and trees.

The study site

Claveria is a municipality of Misamis Oriental, Mindanao, about 40 km southeast of Cagayan de Oro City. Claveria is the biggest municipality in the province of Misamis Oriental, with a total land area of about 82,500 hectares, which is 30.5% of the province. In 1999, the population was estimated at 46,745 and it is scattered sparsely at 61 people per km^2, with an annual growth rate of 4.62% (CCLUP 2000).

The municipality is on a volcanic plateau ascending abruptly from the west from about 350 m to about 1,200 m in the east. Its topography is generally rugged, characterized by gently rolling hills and mountains with cliffs and escarpments. It sits on six major watersheds. The area is divided into two topographic regimes: Upper Claveria with an elevation of 650–915 m and Lower Claveria with an elevation of 390–650 m. Upper Claveria is located in the north and northeast areas of the town while Lower Claveria lies in the west and northwest section of the municipality.

Soils from Claveria are derived from pyroclastic materials and classified as acidic-upland (fine-mixed, isohyperthermic, Ultic Haplorthox) with a depth of more than 1 m (Garrity and Agustin 1995). The soils are usually characterized by high organic matter content, low pH (4.2–5.2), and low CEC and anion activity (Hafner 1996, CCLUP 2000).

According to the Philippine climatic system, the area belongs to Type 2 climate, with pronounced dry and wet seasons. The wet season is from June to December (>200 mm rainfall mo^{-1}) and the dry season (<100 mm rainfall mo^{-1}) from January to May (CCLUP 2000). The average annual rainfall in the area is 2,000 mm (Garrity and Agustin 1995). However, rainfall patterns throughout the municipality vary with elevation, with the upper areas of Claveria having relatively more rainfall than the lower areas (CCLUP 2000). The rainfall pattern is one factor that determines cropping patterns and land use across Claveria's landscape.

The municipality of Claveria has a total estimated open cultivated/agricultural land area of 26,055 ha. The dominant crop in Claveria is maize, with 51% of the arable land devoted to maize production. In Upper Claveria, 1,837 ha are planted to tomato. Cassava is a widely grown root crop in Lower Claveria (CCLUP 2000). Selected permanent crops are orchards, coffee, cacao, coconut, banana, and others. Banana occupies a larger area (641.5 ha). It is followed by coffee (497 ha) and coconut (172 ha). The presence of promising high-value permanent crops such as durian, rambutan, mango, lanzones, and mangosteen is thriving in the area.

Soil erosion occurs frequently in sloping areas cultivated to annual crops (Beniest and Franzel 1999). Increased pressure from rapid population growth has resulted in the clearing of remaining forests and grasslands, causing watershed degradation. Several NGO-assisted projects advocating agroforestry technologies to minimize soil erosion, restore soil fertility, and improve crop production have been introduced to farmers at the site (Mercado et al 1999). Although positive results of agroforestation have been observed at several experimental and demonstration sites, farmer adoption of the technology has been poor. This low adoption is associated with the constraints of high labor requirements for establishing and managing agroforestry systems, the longer time for a return to investment, above- and belowground competition of crops and trees causing poor crop yield, and a lack of marketing knowledge of farmers for timber and other tree products (SAFODS 2003).

Methodology

The SAFODS-MAS model was developed using a stepwise approach. A series of participatory rural appraisal (PRA) activities, case studies, and household interviews were conducted to gather information and accumulate knowledge on the study area. Particular consideration was given to the farmers' and stakeholders' perceptions, motivations, and actions. Two versions of the model were developed representing the evolution of knowledge resulting from the interactions between the researchers and the actual conditions in the field (Barreteau et al 2003).

Participatory rural appraisal (PRA)

PRA is a growing family of approaches and methods to enable local people to express, enhance, share, and analyze their knowledge of life and conditions, to plan and to act (Chambers 1994). A four-day PRA with key informants from different *barangays* (smallest political unit) in Claveria was conducted to obtain an initial biophysical characterization of the study site and a socioeconomic profile of the farmers in the area.

A reconnaisance survey and transect line were conducted on the first day to have an overview of the area's landscape, biophysical conditions, and existing agroforestry and cropping systems. These activities were done to assess the strengths, potentials, constraints, and opportunities for agroforestry adoption. One-on-one interviews were conducted with selected key informants, including farmers, barangay officials, elders, and extensionists in the area. Key informants (KI) were selected on the basis of their perceived level of knowledge and experience on the different topics that were tackled. General topics discussed in the KI interviews were agroforestry systems, soil erosion, soil fertility management, marketing, and farm production.

On the third day, farmers were grouped into two: Upper Claveria and Lower Claveria farmers, based on the general elevation of their local community (barangay). The mind-mapping activity was done separately for the two groups of farmers. Farmers' ideas and knowledge on soil degradation, strategies to examine soil degradation and rationale, local ecological knowledge on trees, tree-crop preferences, perceived improvement needs in the marketing of farm products, and the relevance of different institutions in the locality were probed. The two groups of farmers were also asked to recall significant events pertaining to land-use change and the introduction of trees in the area for the time-line activity.

These activities were carried out to come up with a stratification scheme or typology of farmers based on resource endowment, ratio of land to family labor, farmers' motivations to plant trees, and farmers' local ecological knowledge on soil conservation and tree-crop interactions.

Results of the PRA showed that farmers practiced four types of agroforestry system based on spatial arrangement of trees, hedgerow planting, parkland or scattered planting, block planting, and border planting. This facilitated the stratified random sampling in selecting the respondents for the subsequent activity, the household survey.

Household survey

The study area covers 17 barangays in the municipality with a total of 6,918 households, of which about 89% of the households are engaged in farming. Interviews of 300 households were conducted to collect primary data on farmers' demography, farm biophysical resources, household socioeconomic data, motivations for planting trees, and ecological knowledge.

Verification of information

Verification of the information gathered from the household survey was carried out through case studies, traders' interviews, and consultations with farmers and government agencies.

Model development

The SAFODS-MAS model was implemented using the CORMAS (common-pool resources and multi-agent systems) software. Two versions of the model have been developed as data and knowledge on the field accumulate through the conduct of the different research activities.

The initial version of the model was conceptualized from the results of the conduct of the PRA activities. These activities lead to exposure of the researchers to the field and interaction with farmers in the area. Farmers' adoption of crops and trees is mainly affected by elevation and land tenure.

The model was further developed into its second version as more information was gathered from the subsequent household survey and case studies. Changes made in the second version of the model included the addition of farmer typologies, crop and timber traders, and choice of agroforestry system to adopt depending on available capital and slope. The landowner entity was deleted in the second version of the model based on the household survey results that the majority of the farmers hold land tenurial instruments. Thus, the farmers themselves are the ones making the decisions on tree planting on the farms.

General structure of the models

Diagrams constructed in unified modeling language (UML) (Le Page and Bommel, this volume) show the model structure, which was illustrated by a class diagram (Figs. 1 and 3) and flow or activity diagrams (Figs. 2, 4, and 5). The class diagram describes the model's structure, associations, and links. It displays the features of the different model entities: the passive objects and the communicating agents. Each box features the set of attributes or characteristics of each entity and the various methods characterizing the main behaviors of each entity. Passive objects such as the market, crops (tomato and maize), and timber tree (gmelina) are the entities that the agents can perceive, create, remove, and modify (Ferber 1999). The evolution of these objects is basically based on the methods or actions of the social agents. On the other hand, social agents such as the farmers and traders are entities that can communicate and can form an association. The flow or activity diagram represents the model's set of actions and their sequences and describes the behavior of the agents and their interactions.

Initial version of the SAFODS-MAS model. The initial version of the model is made up of two modules: the Tree-Crop Choice module and the Timber Harvesting and Marketing module. In the Tree-Crop Choice module (Fig. 2A), farmer agents can choose the type of tree or crop they want to plant on their farms. Most farmers plant maize in the area because it is their staple food. Farmers in high-elevation areas have the opportunity to plant tomato, a high-value crop because of the lower temperature

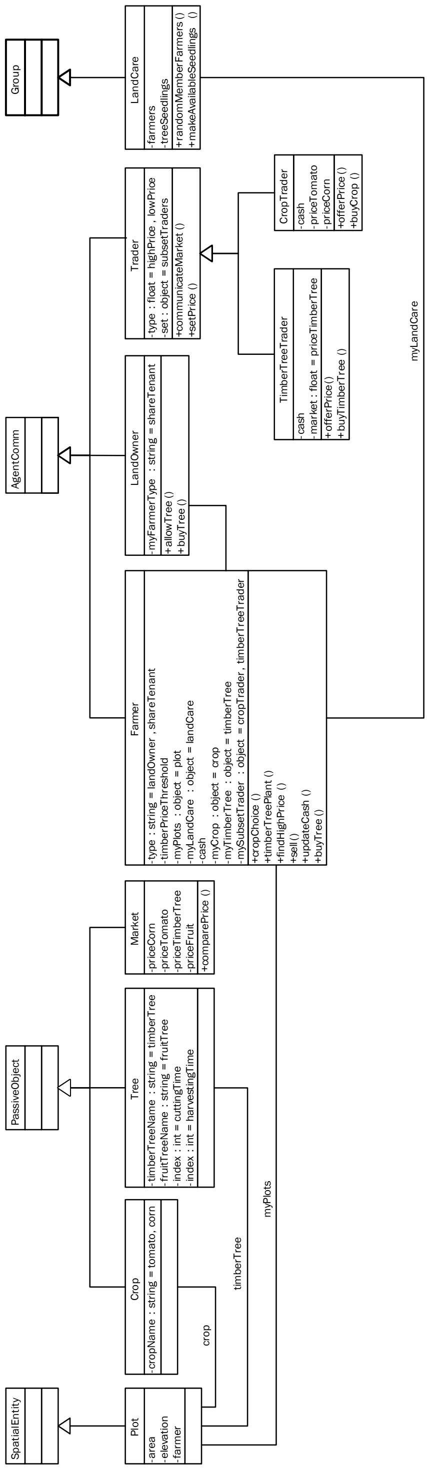

Fig. 1. Class diagram of the initial version of the SAFODS-MAS model.

in high-elevation areas. The main constraint to Upper Claveria farmers in planting tomato is the availability of cash for the inputs used in planting, as this crop requires high inputs for fertilizer, insecticides, and labor. Farmers may decide to integrate trees on their farms if they have space available for the trees. If they are tenant farmers, they have to ask permission first from the landowner to plant trees on the farm.

Farmers were classified into two groups: the landowners and the share tenants. They were categorized according to tenure and capacity to plant trees on their farm.

- Landowners—have permanent land tenure, directly influence the decision of the share tenant to adopt trees on the farm, have a relatively greater financial and natural capital, and can be a member of Landcare.
- Share tenants—have no land tenure security since they do not own the land, have lower financial and natural capital, and can be a member of Landcare.

Another social agent is the timber trader (Fig. 1). The timber trader is capable of manipulating prices and is the sole buyer of trees. Landcare is a program composed of extensionists and farmer-led organizations in each barangay in Claveria, with a primary objective of raising a tree seedling nursery to make it available to its members for planting on their respective farms. Landcare has a large impact on the adoption of agroforestry by farmers as this program provides seedling materials for trees (Fig. 2A).

In the initial version of the model, the inclusion of trees in the plots depends on the farmers' resources in terms of natural capital (land area), financial capital, and social capital (access to institutional support).

In the Marketing module, farmers decide on when and to whom to market their products. The price of timber is the major determining factor for the farmer to harvest the mature timber trees (Fig. 2B).

SAFODS-MAS Model version 2. As more information and knowledge about the farmers and the field accumulated arising from our interactions with the farmers and extensionists through the household survey and case studies, the SAFODS-MAS model was further developed, leading to the creation of its second version.

The factors that affect a farmer's decision to adopt a certain type of agroforestry system are multidimensional. The decision-making process of the farmer on whether to adopt agroforestry is influenced by the complex interplay of physical, biological, demographic, institutional, and socioeconomic factors (Garcia 2000, Lapar and Pandey 2000).

In this model, we consider the following factors affecting agroforestry adoption: (1) the availability of planting materials, from one's own farm and the barangay nursery; (2) the effects of the farmers' network or linkages on the adoption of agroforestry; (3) the farmers' market information; and (4) total area of the farm, as farmers with larger farms are more likely to adopt new technologies than farmers with smaller farms (more land to spare) (Fig. 3).

In this version, farmers must perform four groups of methods. They are allowed to finish the set of methods in the group before moving on to the next set of methods (Fig. 4). The set of methods are (1) collection and giving of seeds to the barangay nursery, (2) agroforestry system adoption and/or crop planting, (3) harvesting and selling, and (4) checking of adopter neighbors by the nonadopters. Also, the extent

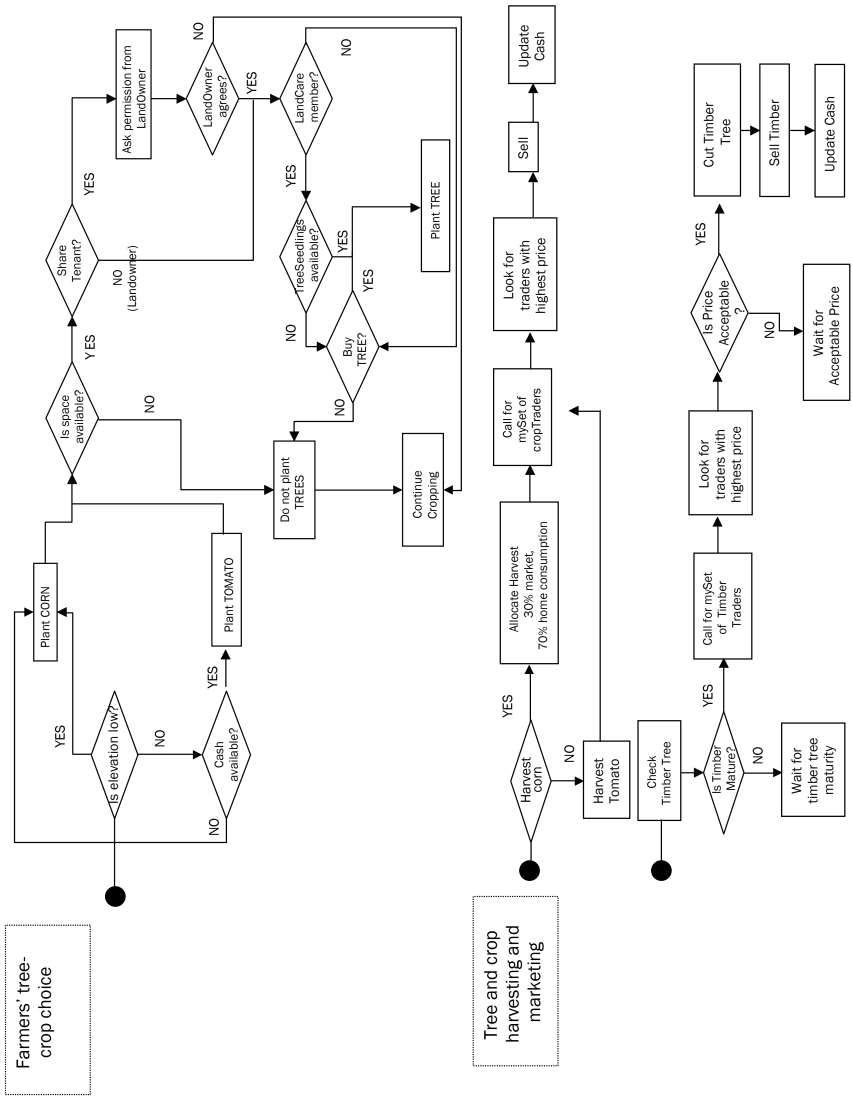

Fig. 2. Activity diagram of the initial version of the SAFODS-MAS model.

of farmers' knowledge on the crop, timber, and fruit market affects their decision to sell their tree products (Fig. 5).

Adoption of the agroforestry system in the second version of the model was influenced by the farmers' motivation and availability of resources. Additional attributes were featured in the revised version. Slope was added to the plot's attributes and banana fruit was added to the crop's attributes (Fig. 3). The farmers' neighbor network was also introduced. Farms close to each other composed a network. They can observe the activity and methods of each farmer member. The model featured farmer typologies based on their motivation to adopt the agroforestry system on their farm and their financial capital: block planting, parkland system, border planting, and hedgerow farmers (Fig. 3). About 70% of the farmers in the model adopt a particular agroforestry system.

- *Block planting*. Farmers implement this system if they have three or more plots. Farmers can have only one plot that is using a block system. Initially, they must also have the financial resources to afford the high-cost inputs needed in practicing this system. Crops may be planted on the same plot for the first three years or six time steps and/or after the tree-stumps (left after harvest of timber) have decayed. Most of these farmers are motivated by an increase in income and they have the greatest financial capital.
- *Hedgerow system*. Farmers adopting this system are usually motivated by soil and water conservation. This is implemented when plots have slope greater than 18 degrees. The decision to adopt is made before cropping. Initially, farmers must at least have the funds to plant maize. Effective area devoted for crops is 70% of the plot, and trees can occupy at least 30% of the area. Initially, about 33% of the total number of trees planted are fruit-bearing perennial (banana), whereas 67% are timber trees (gmelina).

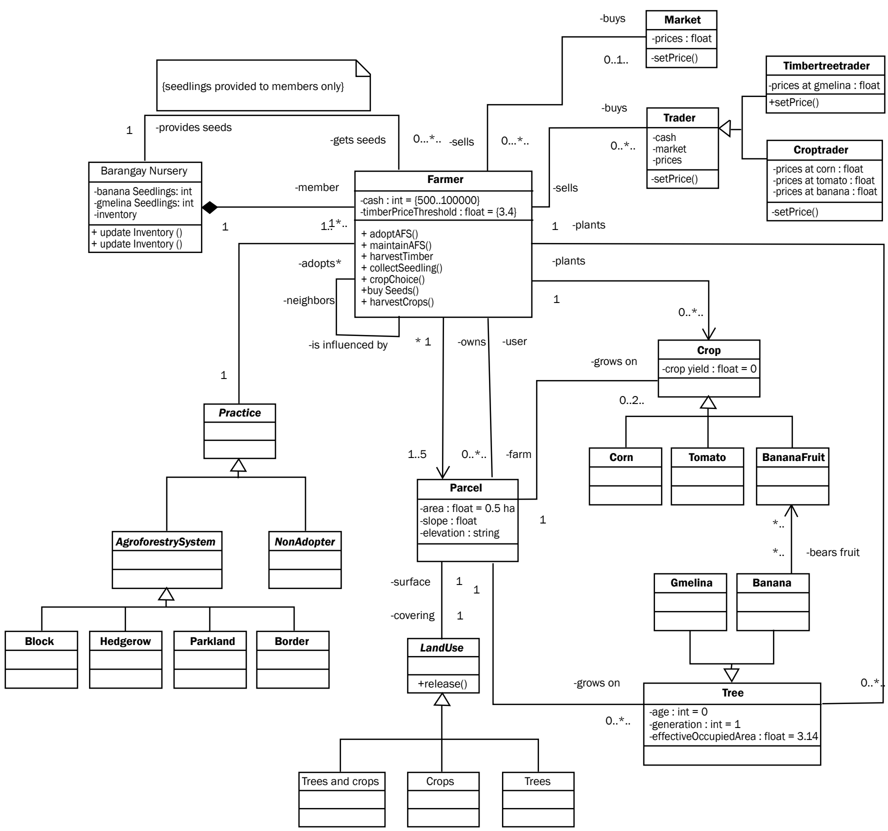

Fig. 3. Class diagram of the second version of the SAFODS-MAS model.

- *Border planting*. This system is adopted when farmers can cover the effective area for cropping. The decision to adopt is made after cropping. Trees are usually planted on the buffer areas to mark the farm boundaries.
- *Parkland system or scattered planting of trees*. This system is adopted if the farmers cannot meet the requirements of starting a block, hedgerow, or border system. The decision to adopt is made after cropping. Initial trees planted are banana, whereas gmelina is incorporated depending on the remaining area after crops and banana have been planted.

Thirty percent of the farmers are nonadopters of agroforestry. They plant tomato and maize only on their plots. Each cropping season, farmers will plant a crop whether they have enough money or not to secure the need for food of the household.

Other communicating agents included in the second version are the timber and crop traders. Association among farmers was introduced; thus, a farmer knows a set of farmers in his network. Farmers' decisions to cut and sell trees depend on both the selling price and actions of neighboring farmers, as they may tend to imitate what the neighbors are practicing.

Decision-making processes and activities in the model

Farmers were classified into agroforestry adopters and nonadopters (Fig. 4). Nonadopters need to perform three methods: (1) the choice of crops, (2) harvesting and selling of crops, and (3) checking or observing their neighbor agroforestry adopter. After each harvest, farmers updated their cash. Because of the farmers' neighbor network, they can observe and compare their income with that of the agroforestry adopters. The chance of shifting from nonagroforestry adopter to agroforestry adopter is highly associated with the level of income received.

Adopters, on the other hand, performed four methods: (1) crop choice, (2) agroforestry adoption, (3) collecting and giving of seeds to the barangay nursery, and (4) harvesting and selling of crops and trees. Adopters have to assess the availability and sufficiency of planting materials. If the adopter farmer is a member of the barangay nursery, he has to give it excess tree seedlings from his collection of planting materials. These planting materials are pooled together by the barangay nursery, and are distributed equally to members.

Farmer adopters then assess the availability of space to adopt block planting, as this system requires at least 1.5 ha of farm area. If the farm area is limited, farmers need to determine whether they can adopt border planting or the parkland system instead. Hedgerow planting is limited to areas with a slope of more than 18 degrees (Fig. 4). Initially, farmers have to buy the planting materials for timber and banana. Later on, these initial trees and banana plants will be sources of planting materials for the farm and the barangay nursery.

In marketing the crops and trees, farmers have the option to sell them to the market or to the set of traders they are acquainted with. Farmers will sell their harvested crops (maize and tomato) to the crop traders with the highest buying price. They allocate a portion of their maize harvest (30%) and banana harvest (20%) for home consumption. The rest of the maize harvest will be sold to the crop trader with the highest buying price. Banana is sold in the local market (Fig. 4).

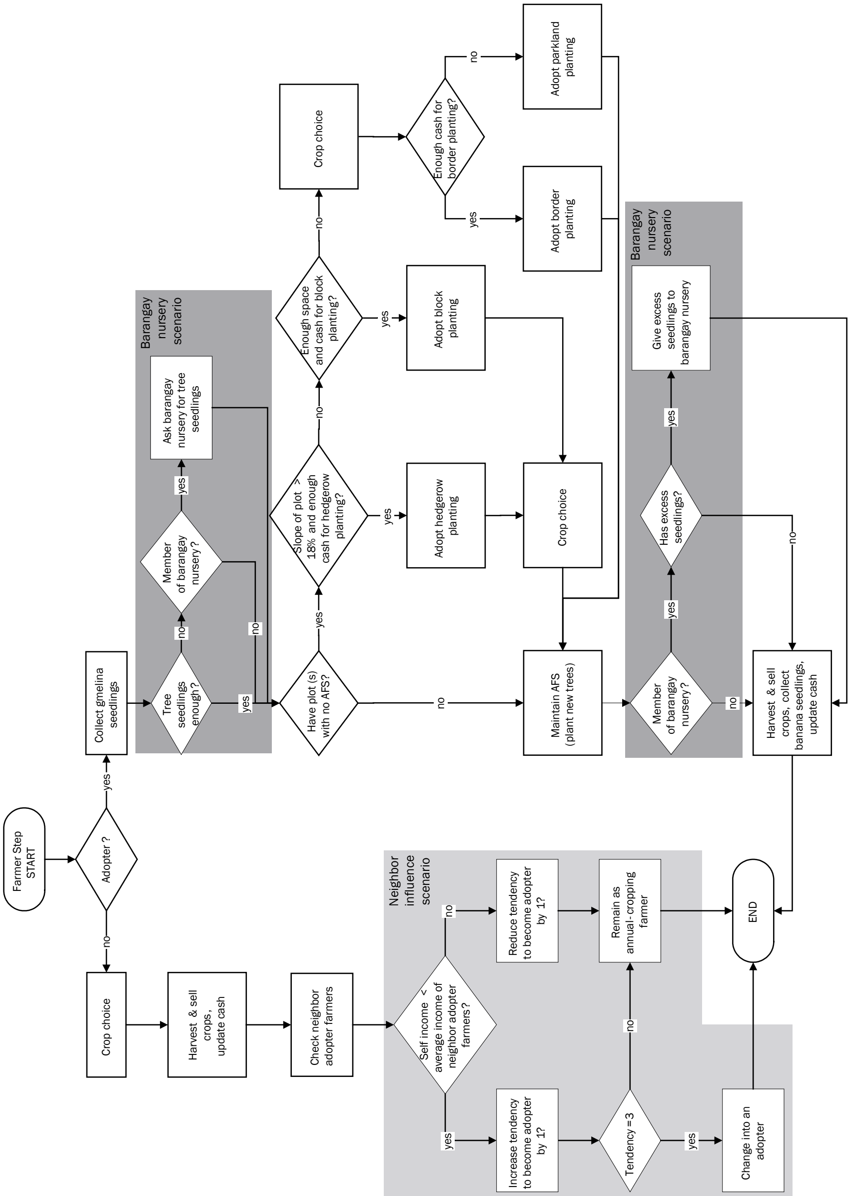

Fig. 4. Activity diagram of farmers' adoption of agroforestry and the neighbors' influence, second version of the SAFODS-MAS model.

In selling timber, the farmers may decide to imitate other farmers within their network of farmers who are selling timber trees (Fig. 5), reflecting the social network effect (Janssen and Jager 2001). The observations from the farmers' network and the timber traders' network on the selling price will determine the decision to harvest the trees. If the price is acceptable to farmers, they will sell the timber. However, in cases where the selling price in the farmers' network and traders' network both is not acceptable, farmers' knowledge of the market price is an advantage.

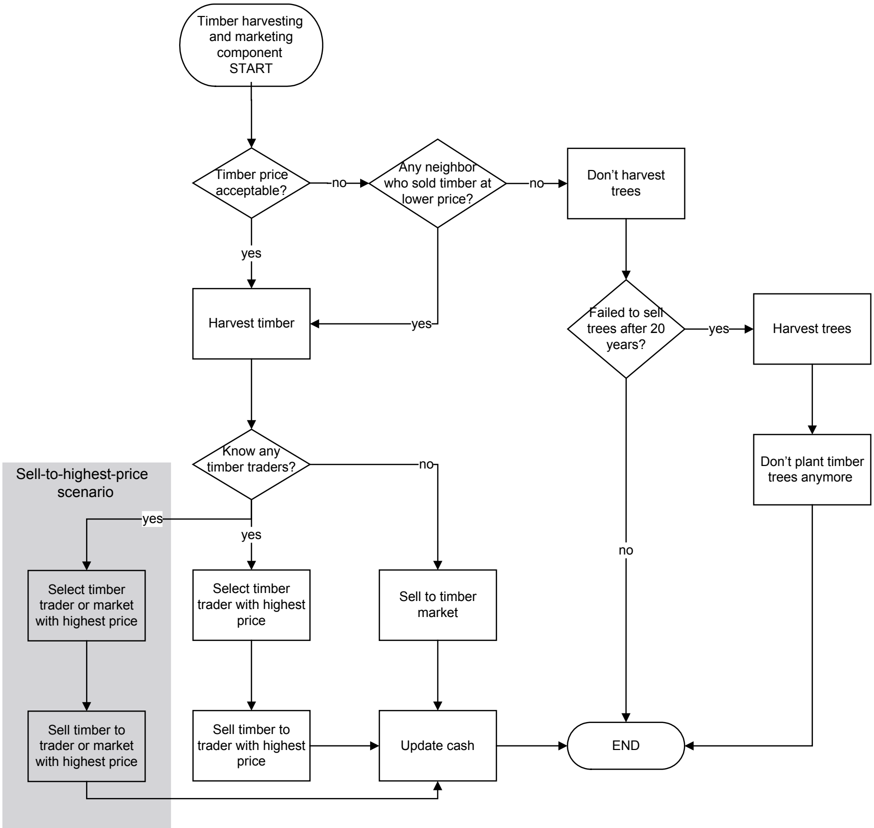

Fig. 5. Activity diagram of marketing timber, second version of the SAFODS-MAS model.

Visualization and initialization of the model

To represent the spatial entity of the model, a 10 × 10 grid space amounting to 100 spatial units (equally sized polygons) representing farm plots was created in the CORMAS platform. The plots were randomly allocated to 20 farmers. The number of plots varied according to the size of the farm. A farmer can own 1–5 farm plots with each plot equal to 0.5 ha.

These plots may contain a single crop type and may be planted with trees. Each crop and tree are represented as a single object and can both occur at the same instance. Each time step of the model is equal to one cropping cycle or 6 months. Crops and trees have a different maturity period. Two cycles of annual crops are grown within one year and they are to be harvested at the end of each crop cycle. Trees are grown for 7 years, and are to be cut after 14 crop cycles.

At the initialization stage of running the model, the space is divided diagonally into three portions to represent the three elevation classes of the landscape: lower, middle, and upper.

Scenario simulations

The second version of the model was used to simulate different scenarios to observe the cumulative income from agroforestry, neighbor influences on agroforestry adoption, the effect of marketing information on income, and the impact of tree seedling nursery establishment on tree planting and income from trees.

At the end of the simulation, the model displayed the spatial distribution of crops and trees in the landscape as well as the distribution of the different agroforestry systems (Fig. 6). The figure showed the variation of agroforestry systems as well as the crops and trees planted in each plot. All the results presented are an average of 10 simulations, with each simulation run for 100 time-steps.

Results of the model simulations showed the effects of the interactions among farmers in the diffusion of agroforestry systems in the area. The indices of income from crops and tree products over time allowed comparisons of economic benefits gained in the adoption of agroforestry systems and annual cropping. They also served as an important indicator to illustrate the socioeconomic status of farmers. Important results of the simulations also allowed the evaluation of the consequences of farmers' knowledge on marketing their crops and tree products. This displayed the effects of establishing a common nursery for the barangay and the influence of farmers' neighbors.

Cumulative income of agroforestry adopters and nonadopters

The cumulative income of adopters and nonadopters is presented in Figure 7. In the initial time-steps, the cumulative income of agroforestry adopters is lower than the cumulative income of nonadopters. This can be accounted for by the initial costs of establishing trees. However, at time-step 45 or 23 years, agroforestry adopters started to gain higher income than nonadopters. Although farmers received positive income from trees after 100 time-steps, the increase in income from adopting agroforestry is relatively small compared with the income contributed by the production of high-

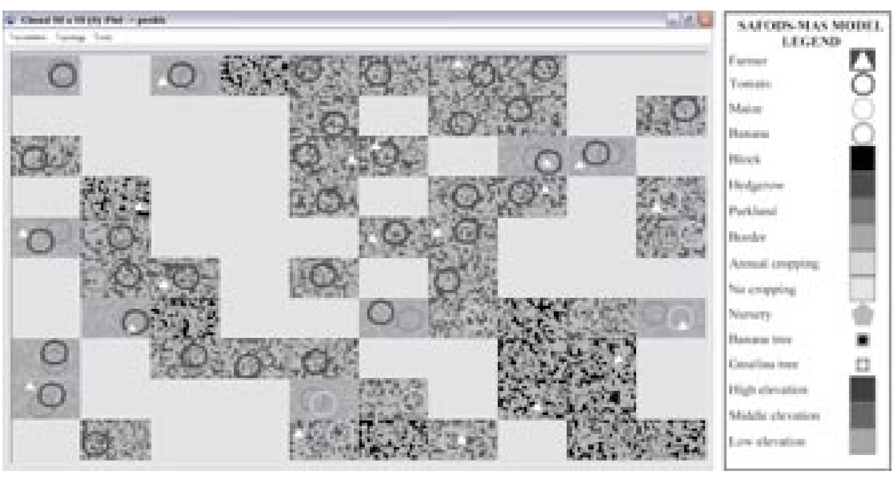

Fig. 6. Distribution of agroforestry systems in Claveria, Misamis Oriental.

value annual crops such as tomato (Fig. 8). The long gestation period from planting to marketing tree products is an important factor that constrains farmers from planting trees on their farms.

Neighbor effects

To determine the extent of neighbors' influence in agroforestry adoption, two scenarios were simulated using the model. In these scenarios, each plot has four neighboring plots following a cardinal direction. Farmers may have adjacent plots, in which case they will not include themselves in their neighbors' plots. Farmers observe unique occurrences of farmers; thus, a certain neighbor farmer is considered only once.

In the first scenario, 35% of the population (7 out of 20 farmers) is annual-cropping farmers or those who are not adopting a certain agroforestry system, while the

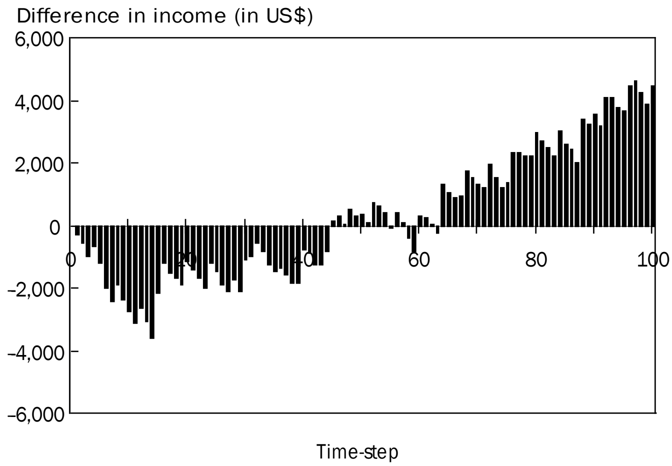

Fig. 7. Seasonal farm income of agroforestry adopters relative to nonadopters.

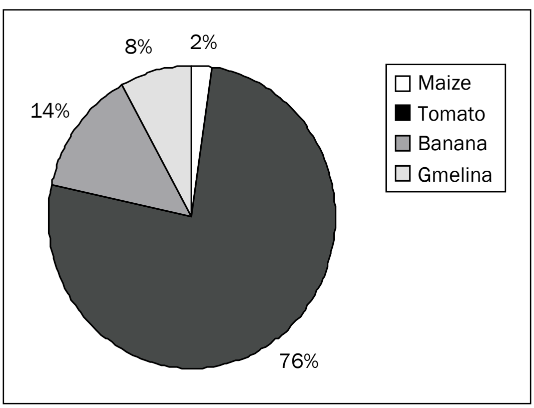

Fig. 8. Contribution of each commodity to the farmers' total gross income after 100 time-steps.

other 70% are agroforestry farmers. In the second scenario, 95% are annual-cropping farmers and only 5% of the population (1 out of 20 farmers) is an agroforestry adopter (Fig. 9).

Simulation results of the first scenario showed that, at time-step 4 or at the second year, about 15% of the nonadopters adopted a certain agroforestry system. On the other hand, simulation results of the second scenario showed a gradual or slower rate of agroforestry adoption up to the 30th time-step compared with the first scenario. In both scenarios, a plateau was reached. In the first scenario, a plateau was reached at time-step 14, whereas, in the second scenario, a plateau was reached at time-step 30 (Fig. 9).

Results showed that farmer neighbors have a great influence on the spread of agroforestry in Claveria. The more farmers adopting an agroforestry system in the neighbor network, the greater is its influence to motivate the nonagroforestry farmers to practice a certain agroforestry system. Farmers shifted because of the increased income from harvesting and selling banana fruits. Adoption of agroforestry by non-adopters was observed even at the 14th time-step or the seventh year when gmelina trees are already mature and ready for harvest (Fig. 9).

A plateau was attained at an earlier stage in scenario 1 because shifting from nonadopter to adopter ceased at an earlier time. The remaining nonadopter farmers are those with 3 to 5 parcels who are able to plant tomato. They have gained a much higher income than those farmers adopting agroforestry. In the second scenario, the plateau is reached at a later time because of the spatial distribution of adopter farmers in the environment. The likelihood of agroforestry adopter occurrence in the neighbor network is less; thus, it will take several time-steps for a nonadopter to shift to agroforestry. The spread of agroforestry is slow across the environment in the second scenario.

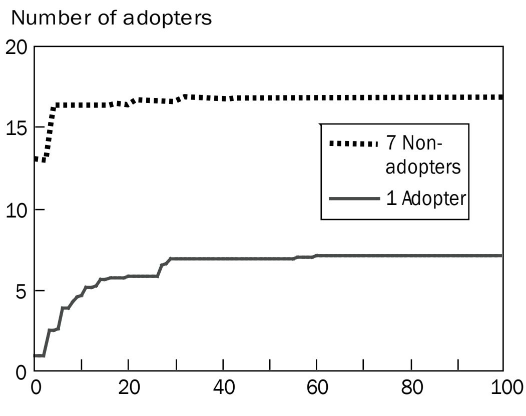

Fig. 9. Effects of neighbors on the adoption of agroforestry systems.

Market information

The market is one of the major factors that contribute to sustainable agroforestry. Farmer adoption of agroforestry technologies is highly affected by the availability of a market for crop and tree products. In this scenario, market information is implemented by allowing farmers to compare prices between the market and traders, which is not done in the base model. In the base model, farmers who know traders would automatically sell their produce to the trader with the highest price without going to the market, which may have a higher price than the trader. If farmers have limited access to information on market prices, they cannot optimize the opportunity to sell at the highest price offered in the market. Figure 10 shows the increase in income by allowing farmers to compare prices between traders and the market and being able to sell at the highest price.

Establishment of a tree seedling nursery

The establishment of a barangay tree seedling nursery increased the availability of planting materials for gmelina tree and banana. Nursery establishment has two major effects: (1) income from banana increased dramatically (Fig. 11) and (2) less gmelina is planted because farmers prefer planting banana. Farmers are motivated to propagate banana because it is a relatively short-term perennial with a shorter gestation period than gmelina. Banana starts to bear fruit after about 18 months and the income from selling banana contributes greatly to farmers' household income (Fig. 12).

Future activities

Another tool that will be employed to further understand the decision-making process of farmers in adopting agroforestry systems and to verify the decision-making process model is role-playing games (RPG). RPG will be conducted with farmers and extensionists in the area. An actual model of the Claveria landscape will be constructed and different plots will be assigned to participating farmers. Each plot will

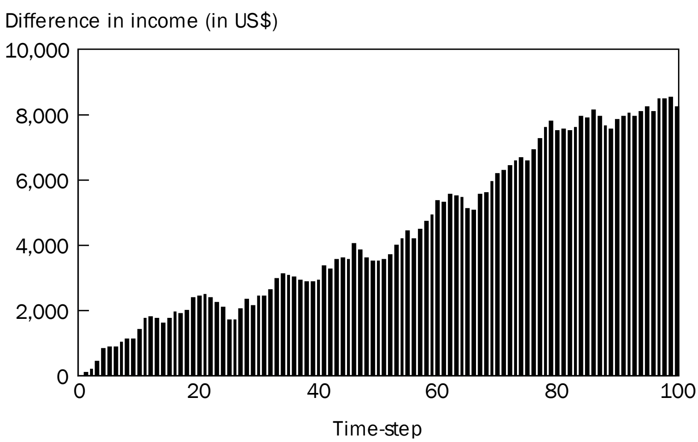

Fig. 10. Cumulative difference in income of farmers with market information relative to farmers with limited market information.

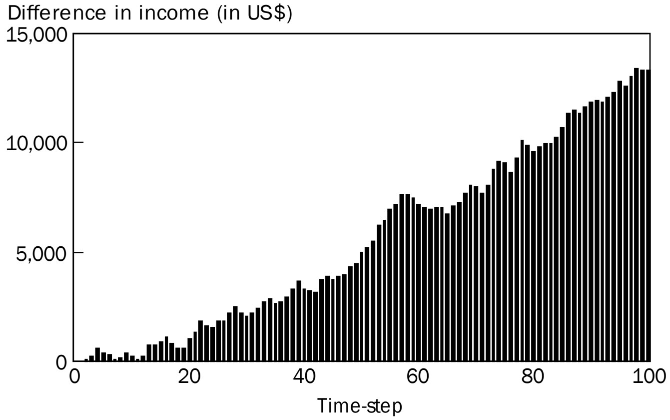

Fig. 11. Cumulative difference in income of farmers with access to seedlings from barangay nursery relative to farmers without access to seedlings.

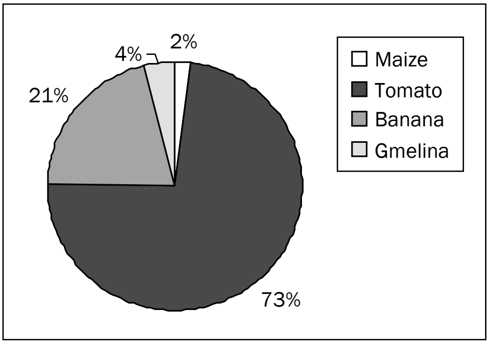

Fig. 12. Influence of the establishment of barangay nursery on the contribution of each commodity to farmers' gross income.

have a characteristic elevation and slope. Farmers will be assigned different farmer typologies with their characteristic plots and farm size. During the role game, different scenarios will be presented to the farmers and these will let the farmers decide on adopting agroforestry or nonagroforestry systems on their plots; harvesting their crops, timber, and fruits; marketing their products; or selecting timber or fruit trees for the next cycle. The frequency of agroforestry adoption and the available cash of the farmer agents will be noted during the RPG.

Conclusions

The SAFODS-MAS model is a work in progress, being revised and improved through repetitive confrontations with real situations in the field. The iterative process with the model is useful in probing deeper into the decision-making process of farmers in adopting an agroforestry system.

The model scenario simulations can serve as a tool to facilitate interactions between stakeholders and scientists and in the future as a decision support for policy-makers, farmers, and other stakeholders toward sustainable management of resources. It is envisioned to produce information useful for the design of agroforestry technologies and their dissemination to other sites.

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Notes

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Models and role-playing games

Part 2

Co-evolution of a research question and methodological development: an example of companion modeling in northern Vietnam

S. Boissau

In this paper, I present the itinerary of my research examining the emergence of local rules for access to land in the mountainous areas of northern Vietnam. To do this, I mobilize a set of tools ranging from interviews and participative observation to gaming-simulation and multi-agent systems. I show how this exploratory research is an iterative process going through different phases of field work, modeling, and theoretical development. This process is known as companion modeling.

Scientific methodology is often presented as a process that starts from a well-defined a priori hypothesis, goes through experiments (and/or modeling, surveys, etc.) to test the hypothesis, and eventually leads to (theoretical) results in terms of rejecting or confirming the hypothesis. Such a presentation may be somewhat caricatural but it reflects what can still be read in many scientific publications.

In this paper, I would like to describe an alternative methodological process that I followed in my (still ongoing) PhD research. More precisely, I try to show how my research question, and the methodology I developed to try to answer it, (co-)evolved over time, following a companion modeling approach (Barreteau et al 2003). The process started from a rather fuzzy research question inspired by a first field experience: How do collective rules for access to a resource emerge out of individual actions when the resource becomes scarce? This first question, which is also linked to my theoretical interest, may be called a first representation of the reality. I elaborated my first methodology to confront this representation with reality. I present this methodology and the outcomes of this experience. I then analyze the problems encountered but also how this experience made the question evolve and become more precise. This led to a new phase of methodological development, whose results I present. Once again, the experience led to the evolution of the research question. In conclusion, I present a preliminary synthesis of my approach and its still-ongoing development.

The original question

My original research objective, as noted in the first version of my research proposal, was to understand the (emergent) links between individual and collective levels in the evolution of land-use systems facing increasing land scarcity in the mountainous areas of northern Vietnam. My idea was that, when pressure on the land increases, new collective rules (institutions) may emerge out of individual actions, and these rules may in turn affect individual actions through a second-order emergence process (Gilbert 1995).

This objective was first formulated after more than one year of work on the allocation of forest land to individuals (Castella et al 2002) in the framework of the SAM-Regional Program.[1] My impression was that, in spite of an apparently very strong top-down political system, there was enough room inside the village for the adaptation of the official rules or even for the emergence of informal ones. Actually, this impression is reflected in the popular Vietnamese saying: "The law of the king stops at the entrance of the village." The literature that describes very different land management systems, in spite of a common national law on land tenure, was also consistent with this impression (see, for example, Castella and Dang Dinh Quang 2002, Sikor and Dao Minh Truong 2001).

Nevertheless, in spite of an extensive period of field work in four villages using a methodology based on participative observation and interviews, no real clue was found to gain the understanding sought in my original research objective and what remained as an impression. But the apparent emergence of diverse systems, in spite of centralized rules, only made the original objective more challenging. I had to find another methodology to tackle this question.

At the same time, in the framework of the SAM-Regional Program, and following previous work by researchers at CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement) (D'Aquino et al 2002, 2003, Barreteau et al 2001, Bousquet et al 1999, 2003, Etienne 2003, Etienne et al 2003), a multi-agent model called "SAMBA" had been developed to understand the dynamics of households' differentiation at the end of the collectivist period (Castella et al 2001a). This model offered a good description of land-use dynamics at the time of the land redistribution to individual households, but was too simple to capture the complexity of the current dynamics. Also, building on previous work (Barreteau et al 2001, D'Aquino et al 2002), the SAMBA multi-agent model had been transformed into a gaming-simulation (Greenblat 1981). The grid of the multi-agent simulation environment was represented by a game board composed of cubes painted with six different colors (each color representing a type of land use or land cover). Farmers were invited to use the game board and simulate the management of the land (Boissau et al 2001).

This game has been played twice and the experience has been very rich. Simulation-gaming proved to be a very powerful tool to observe the actions of the player-farmers and the land use resulting from their actions. However, it appeared that the observation of the game alone was not enough to understand what was happening in it. Especially during the second game we organized, we could observe the emergence of a collective pasture management system. Unfortunately, the observation and the

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[1]SAM-Regional is a joint research program of the Vietnam Agricultural Science Institute (VASI, Vietnam), the Institut de Recherche pour le Développement (IRD, France), and the International Rice Research Institute (IRRI, Philippines).

analysis of the game did not provide enough information to really understand how such a system emerged. That is why the methodology has subsequently been extended to a 5-day process called "SAMBA-Week."

The SAMBA-Week methodology[2]

The SAMBA-Week methodology was a 5-day process organized as follows:

- The first day was dedicated to a gaming-simulation similar to SAMBA. About ten farmers were invited to participate as players. They were given a virtual family and some paddy fields and buffaloes. They then had to manage their production in order to feed their family. Through these actions, farmers changed the land use and the land cover represented through different colors on the game board (Fig. 1). About six years could be simulated through the game and the session ended with a collective debriefing.
- During the next three days, two processes were followed in parallel:
    1. Individual interviews were carried out with the players to understand the rationale of their actions during the game. Round after round, they were asked to justify their actions, for example, with regard to their economic

Fig. 1. Picture taken during SAMBA-week experiment.

[2]The evolution from SAMBA to SAMBA-Week took place in cooperation with the SAM-Regional Program and, apart from the objective cited here, the methodology also pursued other objectives within the framework of this program. Consequently, all comments presented here about SAMBA or SAMBA-Week methodologies refer only to the objectives pursued in my PhD research, and involve only me. For a more detailed description of the SAMBA-Week process and the different objectives it pursued, one can refer to Boissau and Castella (2003).

situation, their past actions, the actions of the other players, their actions and situation in reality, etc. Through these questions, we intended to better understand what happened during the game. The interviews also tackled the question of the comparison between the game and reality on both a general and a more individual point of view. Lastly, the interview ended with an assessment of the game by the interviewee.

2. A computerized multi-agent simulation of the game was implemented. The model, and especially the behavior of the agents, was based on the observation of the game and information drawn from individual interviews. This first model intended to replicate as faithfully as possible the sequence of the game, by specifying only general rules for individual behaviors and land-cover dynamics. These rules were then used to simulate potential scenarios identified by the participants (for example, scenarios with demographic growth or with additional rules governing land and/or livestock management).

- On the fifth day, a collective meeting was organized with the game participants to present them with the computer simulation. The session typically started with the presentation of the simulation that replicated the game session the players had a few days before. Through this presentation, the players could become familiar with the computer model and "learn to follow" a simulation on the screen. For example, they were able to describe the evolution of the landscape and were inferring the behaviors of the agents. Afterward, other scenarios were presented to the participants and then discussed. Computer-simulated scenarios allowed us to simulate, in a shorter time, longer periods than in the game and therefore showed farmers the implications of their choices in the long term. The discussion focused in particular on the similarity between the simulated scenario and reality (past, present, or future), its likelihood of happening, the problems that would result, and possible ways of solving them.

The whole SAMBA-Week process has been followed five times in five diffe ent communes of Bac Kan Province. In the following section, I will assess this experience.

Assessment of the SAMBA-Week experience

Regarding the methodology itself, the first point to mention is that participants accept playing. Even if the players may be surprised initially when the facilitator asks them to participate in a game, they realize very quickly that the game is not as trivial as it may first appear and they take it very seriously. Actually, the situation in the game is close to their reality: players (who are themselves farmers) play the role of farmers, the virtual landscape created on the game board is close to the landscape of the village, etc. These elements make the players quickly understand the connection between the game and reality and they typically feel very comfortable after only one round of the game. Very often, players incorporate by themselves features of reality into the game. We encountered many examples of this during the different sessions: players imagining a river running through the game board, players not intensifying their rice fields because there was not enough water for irrigation, whereas the availability of water was not included in the game, and players imagining the slopes around the village and including this factor in their decisions. These examples show that, at least to some extent, the players "import" their reality into the game.[3] At the same time, since it is a game, players may feel more freedom to engage in different actions than they would in real life. For instance, one player tested a new production system during the game session, thus really using the game as a simulator.

This leads to the broad question of the model, the way it is constructed through the gaming-simulation, and the computer simulations in which it results. Actually, the gaming session on the first day is a way to make people construct their own model of the system.[4] The only framework that is imposed on the players is the game board composed of cubes. The session typically starts by asking the players to draw the landscape around their village and this landscape is then represented on the game board. During the game session, players are free to propose new actions (for example, introducing new crops). The production levels of the different crops are determined after a discussion with the participants. Thus, to some extent, the model is constructed by the participants themselves. Also, on the fifth day, when the computer simulation was presented to the participants, we observed that they could easily understand it and comment on it. As mentioned, the first simulation presented to the participants reproduces the game they played a few days before and the grid of the computer simulation looks like the game board (same structure, same colors). A collective discussion on the evolution of the simulations can be held, even with people who are not familiar with computers or who may even be illiterate.

Another important aspect of the methodology is the high quality of the interaction we were able to have with farmers.[5] This is especially important in a country such as Vietnam, which is characterized by a very hierarchical political system and where decisions are often made before the meetings occur. The Vietnamese also tend to avoid conflict.[6] In such a context, it is very difficult to engage in a "real" discussion during a collective meeting. Another element to take into account is that one may easily encounter wariness toward strangers/foreigners. It may thus be difficult to gather accurate information. Through the game session of the first day, we were able to create a very different atmosphere without a dominance relationship but based on a players-facilitators relationship. Also, the fun aspect of the game helped to reduce wariness. In the context of the game, we could therefore substantially improve the quality of the information we obtained.

The game session, complemented with the individual interviews afterward, offered an overview of the agro-socioeconomic system. What is more, the overview was dynamic, because about six years could be simulated during the game. This was particularly interesting as actual field research allows one to observe only the present time. Observing the dynamics would only be possible through extensive field

[3]In our experience, these observations were quite anecdotal. A detailed study of the question and a methodology to test how reality is brought into the game can be found in Daré and Barreteau (2003).
[4]Another example of the self-design of a model can be found in D'Aquino et al (2002).
[5]Some of these aspects are described in more detail in Castella et al (2001b) and Boissau and Castella (2003).
[6]Cultural aspects may have a strong influence on the gaming-simulations as shown in Patamadit and Bousquet (this volume).

work over several years. Through gaming-simulation, the evolution of individual decision-making and the resulting evolution of the whole system could be explored in a few days' time. But, even if both the individual rationale underlying farmers' actions and the collective rules could be quite well observed and understood through this methodology, the precise mechanisms linking them, that is, the very process of emergence, could not be characterized.

Limitations of the SAMBA-Week methodology and evolution of the research question

The SAMBA-Week methodology aimed to examine the link between individual and collective levels, that is, how individual farmers through their actions collectively create a landscape or a land-use pattern. For example, farmers may practice shifting cultivation while the forest is abundant and then slowly shift to another agricultural system when the forest becomes scarce. However, the process by which individual decision-making evolves and gives rise to collective rules, and the way collective rules constrain individual actions, was difficult to observe.

I now try to explain why this process of emergence was difficult to capture through the SAMBA-Week methodology. The different games we played had a kind of common structure. They typically started with a period of "exploration" (about three rounds of playing corresponding to three years), during which the players were trying different options and observing each other. After that phase, the players would usually repeat their actions with minimal changes. Emergence, in the sense of a collective decision appearing during the game, could be observed in only one game as already mentioned above. In other games, players often tried to limit interactions that would possibly lead to conflict, even when we limited the size of the game board to try to provoke more interactions, because we believe that increased interdependencies may be one of the elements leading to change (Röling 2002). Because many elements were already included in the game and as players were free to introduce new features themselves, it seems that they could almost always find a way to avoid potential conflict.

Although the process of emergence could therefore not be fully captured through the SAMBA-Week methodology, it suggested some new elements that helped me to refine the research question. Subsequently, I decided to limit the study to the emergence of rules for access to the land, as this issue appeared to be crucial throughout the different games. By rules, I mean the local rules at the village level that may be different from the official ones. These rules (formalized or not) are seen as the basis for decision-making (North 1990). At the village level, they constitute an institution that regulates access to the land for the different uses. To put it another way, I was looking for the evolution of rules, in the sense of a system of representations shared by a community, which may also be called institutional change (Aoki 2002). The idea behind this is that institutional change may occur when the institution as a collective representation does not reflect anymore the reality stakeholders experience, that is, a decreasing correspondence between the cognitive system of the actors and their domain of existence (Röling 2002). A case study based on this question would focus on the process of evolution of rules for access to land when the pressure on land increases.

Building on the lessons from the SAMBA-Week methodology, a new methodology had to be developed to focus on this question.

Development of a new methodology

To develop a new methodology, we had three sources of inspiration: gaming-simulation, game theory, and behavioral/experimental economics.

From a methodological point of view, the main lessons I drew from the SAMBA-Week were that (1) gaming was an efficient approach for working with stakeholders, (2) I had to try to keep the process as simple as possible, and (3) I had to focus the game on my particular problem.

Game theory provides interesting inputs. Game theory is a theoretical and analytical framework to describe and understand interactions among players. However, game theory often hypothesizes rational economic agents and focuses on equilibrium conditions reached under fixed conditions given by the payment matrix that is not subject to change during the course of the game. Attempts have been made to introduce dynamics into game theory in seeking to avoid these shortcomings and evolutionary game theory studies how boundedly rational agents attain an equilibrium through evolutionary processes (Young 1998). Behavioral economics uses economic experiments to show that human players do not behave as economically rational agents (Tversky et al 1982). These approaches have been applied to common resource dilemmas by Ostrom et al (1994), who studied the conditions of success or failure of collective institutions. However, they do not give an account of how these institutions may change.

Economic experiments have been transferred from the laboratory to the field (e.g., Cardenas 2000, Henrich et al, n.d.) and show that stakeholders can easily understand such abstract experiments and relate them to their own local experience. However, these experiments start from economic theory, generally show that individual behavior does not conform to the *homo economicus* hypothesis, and then try to link results from the experiments to ethnographic observation in order to explain observed behavior. My approach is different in the sense that I start from actual behavior observed in the field and afterward try to relate this behavior to existing theories, amending them if necessary. Instead of starting from the hypothesis to confirm or reject it, I try to reproduce a phenomenon through an experiment in order to better capture it.

From these different sources of inspiration, I tried to design new games having the abstract nature of experimental economics but the openness and degree of freedom to act in gaming-simulation. These games have to be adapted to the particular problem of the concrete situation in which they are implemented but still share some common features. They are organized around a whiteboard divided in cells representing the (renewable) resource. During the game, the pressure on the resource increases and players who are harvesting from the resource may change the rules of the game, that is, the rules for access to this resource. Two games were developed at two different locations, previously identified through the SAMBA-Week experiences, to try to capture the very process of emergence. The gaming-simulations carried out for these two case studies are described below.

Presentation of on-field experiments

The "EPP?" (Emergence of Private Property) game

This gaming-simulation has been conducted in Nghien Loan commune, Ba Be District, Bac Kan Province. The aim of this gaming-simulation was to understand how an open-access resource could be transformed into a common-pool resource or a private-property resource when the pressure on the resource increases, especially because of immigration.

To examine this question, the game was designed as follows: a game board consisting of a 49 (7 × 7)-cell grid was supporting the forest resource with levels from 0 to 3 (at the beginning, all the cells have three points of resource). Twenty farmers from one village had been invited to participate in the game but, at the beginning, only 6 had access to the resource; the other 14 were sitting in another part of the house. Players could harvest the resource (up to 4 cells each round) and received points according to the amount of the resource they harvested, corresponding to the harvest of upland rice fields. In each round, whenever a cell was not harvested, the resource regenerated and the level increased by 1 point (up to a maximum of 3).

At the beginning of the game, the rules regulating access to the resource were as follows:

- The resource was accessible by anyone but a cell might only be appropriated as long as the appropriator was not harvesting the resource on it, that is, from the time a cell was left "fallow," it could be harvested again by anyone else.
- At the beginning of each round, a new player was asked to enter the game.

This set of two rules is characteristic of an open-access resource and reflects the situation of the commune where the role-play took place. Until 1991, the forest was an open-access resource and an important immigration rapidly increased the pressure on the resource.

In the gaming-simulation, at the end of each round, the players were given time to discuss the possibility of changing either of these two rules. If the first rule was changed, that is, the resource could not be appropriated by another player while one of the players left it fallow, the resource would become a private property. If the second rule was changed, new players (i.e., outsiders, people coming from outside the existing community of users) were not allowed to enter the game anymore, and the resource would become a common-property resource.[7]

The first (and only) experience with this gaming-simulation encountered several problems but some lessons could still be drawn from it. The main problem encountered was that the active participants never changed the rules! Even, as the end of the game was approaching,[8] they wanted new players to enter the game two by two!! The debriefing at the end of the game shed some light on this unexpected behavior. It appeared that the participants would have liked to stop the entrance of new players

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[7]Actually, the ability to exclude outsiders from appropriating the resource is only one of the characteristics of a common-pool resource (see, for example, Ostrom 1990 for a description of the set of rules defining a common-pool resource). To keep the focus of this paper on the research process and the methodological development, this issue may be discussed in forthcoming papers.

[8]No precise time was given for the end of the game but participants knew I had arranged lunch!

but they were afraid that inactive players would become bored just waiting without playing.[9] It also appeared in the debriefing that at no time during the game did the participants want to change the rules of the game and establish private property even if, in reality, private property was governing access to the uplands for about ten years while the land was still officially property of the state. The question was then: Why did private property emerge in the actual situation but could not emerge in the game and was even categorically refused?

Subsequent interviews showed that private property in the villages did not emerge in a "natural" way but was in some way "imposed" on the villagers by another ethnic group. Before the collectivization of agriculture, the Tay ethnic group occupied the bottom of the valley. Their agricultural system was mainly based on the cultivation of irrigated rice complemented by swidden cultivation of rainfed rice and cassava in the uplands. Irrigated paddy fields were privately owned based on a system of inheritance, sharing the fields among sons. Swidden cultivation was taking place in the surrounding forest governed by open access and temporary appropriation by clearing until the field was fallowed.

Villages of the Dao ethnic group were located a few kilometers away, up in the mountains. These villages did not have any irrigated fields (or had only very marginal ones) and their agricultural system was based exclusively on swidden cultivation and regular migration. Swidden cultivation was governed by the same type of rules as in the Tay ethnic village—open access and temporary appropriation.

After the collectivization of agriculture and the establishment of the cooperative system, a sedentarization program was launched by the state. Dao people were encouraged to "go down the mountain" to join the cooperatives. The irrigated land belonging to the Tay villagers was shared between two cooperatives, one with the Tay people, the other one with the Dao people. At the termination of the cooperative system, the Central Committee of the Communist Party issued a directive for the redistribution of land. But, following a movement originating in Cao Bang Province, the Tay people from Cao Bang and Bac Kan provinces claimed the land of their ancestors, each family taking back the land they or their parents had contributed to the cooperatives.[10] Through this movement, the Dao and Hmong people, who had worked on this land during the cooperative, were excluded from access to the irrigated land and had to rely exclusively on the forest for swidden cultivation.

However, something happened in the commune studied that did not happen in other places. The Tay also claimed the uplands that they had previously cleared, that is, almost all the area surrounding the irrigated paddies. Consequently, they asked the Dao people to buy land the Dao wanted to exploit for shifting cultivation or even land on which their houses were located, just so they could sell irrigated paddies. The Dao people had the choice between moving to another place, opening swidden far from their houses, or buying the land at a reasonable price. Many of them chose

[9]The design of the game had been revised within the perspective of a repetition of the game and incorporated another game board located in another room to keep players who were not active busy.

[10]The precise means for the redistribution of land to households were under the responsibility of the province. This may explain why in Cao Bang and Bac Kan provinces, populated by a majority of Tay providing the provincial leadership, this movement occurred and also why the state did not intervene.

this last option. By entering the monetary sphere and being sold from one individual to another, the individual property was institutionalized in the uplands and the Dao people kept on buying land from the Tay people and selling it to newcomers, either Dao or Hmong households.

Even if this experiment may be considered as a failure (nothing emerged!), some lessons can be drawn from it. Through this process, and in only a few days, I got insights into some historical processes that could not be made clear through individual interviews conducted before the game. One of the reasons is that, beyond human relationships created by the game, the players and I had shared a common experience through the game and this common experience could be used as a reference point in subsequent discussions. Also, in my study of the emergence of rules, the process of nonemergence may have as much importance as the process of emergence in determining the conditions for the emergence of these rules. I may come back to this last point later.

The "PAT" (pasture) game

The second gaming-simulation session was conducted four times in two villages of Duc Van commune, Ngan Son District, Bac Kan Province. This aimed at understanding how a common-property resource may become private when pressure on the resource increases.

The game board was a 5 × 5-cell grid representing a grazing land. Each cell had a level of resource ranging from 0 to 3, starting at 3. Five players took part in the game and they were initially allocated from 1 to 6 buffaloes randomly.

Each round of playing was organized as follows. Players located their buffaloes on one or more cells of the grid (Fig. 2), knowing that each buffalo needed to

Fig. 2. Picture of the "PAT" gaming-simulation.

"graze" one unit of resource, that is, a cell with a resource level of 3 might be enough for 3 buffaloes, a cell with a resource level of 2 could support 2 buffaloes, etc. If on a specific cell there were more buffaloes than the resource level, the facilitator drew randomly which buffaloes would "eat" the resource and which ones would not. "Starving" buffaloes were identified and any buffalo starving 3 rounds would "die." Also, the resource level of each cell was reduced according to the number of buffaloes on the cell. For example, a cell with a resource level of 3 and 2 buffaloes resulted in a resource level equal to 1.

The facilitator gave to each player the number of points corresponding to the number of nonstarving buffaloes the player had (1 point for each nonstarving buffalo).

Additional points (from 1 to 4) were "drawn" randomly by the players and these corresponded to the income from other activities (agriculture, hunting, etc.).

Players could buy or sell buffaloes at the price of 10 points per head.

The resource level was renewed and was increased by 1 point, with a maximum level of 3.

At the beginning of the 4th, 6th, and 8th rounds, 5 cells from the resource randomly chosen were declared unsuitable for pasture and could not be accessed anymore, so that, in the 8th round, only 10 cells remained accessible to the players. This decrease in the amount of resource in the game corresponded in reality to the planting of pine trees that occurred a few years ago in the villages where the game has been played. As the pine trees grew up, the grass underneath disappeared, thus reducing the grazing land available for buffaloes. Another cause of the shrinking of grazing land was the gradual decrease in the number of swidden fields: they were extensively used as grazing land during both wintertime and when the fields were fallowed.

A preliminary analysis of the games showed that, in any case, participants did not want to change the rules for access to the land to establish private property. They more or less adapted to the evolving situation of the game. If during the first rounds they tried to accumulate as many buffaloes as they could, starving buffaloes appeared soon after the resource area started decreasing. The players thus gradually sold some of their buffaloes to the facilitator (the players having the most buffaloes usually sold their buffaloes first). During the following rounds, if the players observed that the resource was sufficient, they might buy more buffaloes. The game invariably ended with 10 buffaloes as only 10 units of resource were still available, each player having from 1 to 3 head, and in most cases the game ended with each player owning 2 buffaloes.

During the game, two behavioral norms could be observed:

1. Avoid possible conflict: for example, having 2 or more buffaloes, belonging to different players, on the same cell.
2. The more buffaloes you have, the earlier you will be selling them when the resource becomes scarcer.

Elaboration of a new hypothesis

In this section, I propose the idea and hypothesis I want to test, which are suggested by the outcomes of the gaming-simulations presented above.

It appears that the evolution from an open-access resource (OAR) to a common-pool resource (CPR) is a "natural" and "logical" evolution of institutions to protect a community when its survival may be endangered, for example, by the overexploitation of critical resources as a result of immigration. The evolution from an open-access resource or a common-pool resource to an individual private-property resource (IPPR) seems to be a different process that may be neither necessary for the survival of the community nor a "natural" evolution.

The underlying idea is that evolution from OAR to CPR is a process involving the whole community in devising rules to restrict access to the resource from outsiders.[11] It implies interaction between the whole community and the outside world to protect the community.

On the contrary, evolution from OAR or CPR to IPPR involves interactions inside the community or new institutions imposed from outside the community, for example, by the state or a more powerful group. This is what we observed in the first case study, and also what happened with the allocation of forest land to households decided by the state in its effort to protect the forest resources. Another example of such an "emergence" of private property is described in Angelsen (1995) regarding indigenous communities in Sumatra as a consequence of state projects (migration, logging, etc.) and the nonrecognition of customary laws by the state.

For these reasons, I propose to focus on the evolution from OAR to CPR as this process appears to be a more endogenous and general one, that is, it may not imply power relationships such as the evolution to IPPR, with these relationships being more context-specific and more difficult to capture.

The next step of my research will consist of developing a multi-agent model to be used as a virtual laboratory to explore the process of emergence of common-property regimes, as well as the conditions under which emergence takes place.

Conclusions

The itinerary of the research presented in this paper is still ongoing, so these conclusions can only be preliminary. By presenting the process of co-evolution between my research question and the methodology to examine it, I tried to show that this is a construction process. First of all, it is the construction of a research question that is linked to the representation of the reality one may have. It is also the construction of a methodology to examine this question. It is based on existing tools and methodologies that are used as building blocks. This methodology is used as a tool to confront the reality with our representation of it. Out of this confrontation, our representation may be modified and the research question refined or clarified, leading to an (endless) iterative process.

The other point I would like to make is how such research starts in the field and evolves toward more theoretical questions. Starting from a real-world situation and an open question, the research progressed gradually toward a more precise but

[11]Here, we deal only with the evolution from an open access to a common pool as an autonomous process and not as the establishment of a common-pool institution imposed from outside the community, which is much more likely not to succeed (Ostrom 1990). In this latter case, there is no institutionalization in the sense of Aoki (2002).

also more abstract and theoretical question (see Fig. 3). The first model (SAMBA) was very close to the reality and was examining a local problem, a particular land-use system in the mountainous areas of northern Vietnam. The research evolved toward more abstract models examining a theoretical question, the evolution from an open-access resource to a common-pool resource management system. Subsequently, such a research process may provide a better foundation for theoretical questions because real-world situations are not illustrations of a theory but they constitute the very basis on which the theory is built.

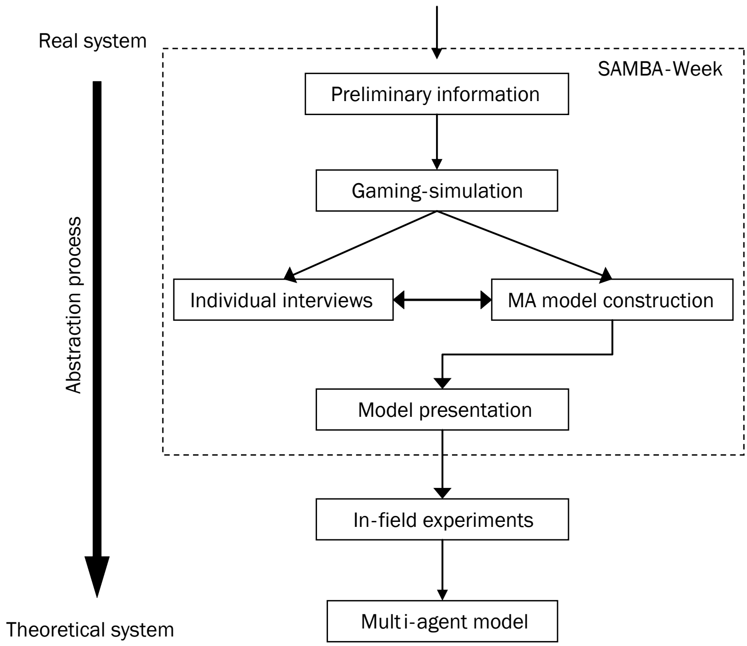

Fig. 3. The overall methodology.

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Notes

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Companion modeling to examine water-sharing arrangements among rice-growing villages in west-central Bhutan: preliminary results

Tayan Raj Gurung

Age-old traditions and interactions among users constituted a broadly respected customary regime of natural resource management that achieved social and environmental objectives. However, with the increased pressure of commercialization, the role and efficiency of local arrangements/institutions have weakened. During the past decade, a major policy drift of devolving control over natural resources from government agencies to user groups was observed.

Economic development has brought changes to environmental, social, and economic conditions and such changes are known to cause conflict. Consequently, this conflict can threaten to weaken the fabric of society. To understand these changes emerging from human learning, interactions, and institutions, an integrated approach is needed. Companion modeling in natural resource management is considered as an interactive approach for creating a shared perspective on a complex ecosystem and for generating scenarios as future options. These scenarios also seem to be relevant for negotiation or collective decision issues.

This study used role-playing games (RPG) and simple simulations on spreadsheets to collectively learn the current state of affairs and explore possible mitigation strategies. The study revealed that RPG can be used effectively as a learning tool to bring together two villages that are in a conflict situation so that they can discuss their problem and relate it to a broader perspective. Ultimately, this was seen as an approach for examining the emergence of complex macro phenomena from relatively simple micro activities to enhance people's perceptions of resource sharing and collective management, especially through knowledge sharing and learning.

There is ample scope to improve RPG and to build associated simulation tools that can be used in different situations to explore and assist in improving natural resource management situations. With the success of the present exercise, scaling-up of the games has been planned for 2004 to organize the community as a user group at the watershed level.

Bhutan is predominantly an agrarian nation, with some 80% of the population dependent on small-scale mountain agriculture and livestock rearing for their livelihood. Despite numerous hurdles, Bhutan has successfully maintained its 72% forest cover, rich biodiversity, and plentiful water resources (RGOB 2003a). In Bhutan, age-old traditions and well-established relationships among users constituted a broadly respected customary regime of natural resource management (NRM), which has resulted from the blending of appreciation for the dependence of people on natural resources and the value of these resources (NEC 1998). However, over the years, the role and efficiency of these local norms and arrangements have weakened because of the influence of development and commercialization (Turkelboom et al 2001).

One of the natural resources that has been principally managed by traditional institutions and norms is water (Litmus Consult 2002). Access to water and management is still governed by traditional rules that evolved during times when water demand was limited (MoA 2002a). A nationwide renewable natural resources census indicated that 21% of 60,000 farmers interviewed reported a lack of irrigation water as a major constraint to agricultural production, second only to crop predation by wild animals (42%) (MoA 2002b). Inequitable access to water is a major cause of conflict in many communities. With increasing demand and competition for water, frequent violent confrontations and abuse of resources have become a major concern (RNRRC 1998). Such conflicts can become severe and debilitating, resulting in violence, resource degradation, the undermining of livelihoods, and the uprooting of communities. If such conflicts are left unattended, they may become causes for a breakdown in social institutions and even threaten society itself (Castro and Nielsen 2001).

The ratification of the Forest Act 1969 showed that Bhutan was already concerned about NRM problems. However, Gurung and Turkelboom (2000), Messerschmidt et al (2001), and Tshering (2001) suggest that, since the centralization of forest resource management in 1969, many of the indigenous knowledge systems and community-based regimes for natural resource management disappeared, as communities lost their customary rights and control over local forest resources. This has brought about an "open-access" regime, as adequate resources were not in place to effectively and efficiently implement the forest regulations (MoA 2002a). Many natural resources are considered to be under the purview of the Forest Act. However, the specificity of the rules varies among the resources. For instance, there is no specific policy and law for water resources; the MoA is currently drafting the Water Act. This act will address the policy, legal, and organizational framework for the fair sharing of resources, for property rights (including water rights), and for effective participation, partnerships, and cooperation of stakeholders, as well as conflict avoidance (Bhutan Water Partnership 2003).

According to the decentralization policy, beneficiary participation is the primary driving force for development (PCS 1993). Further, with the ratification of *Dzongkhag Yargey Tshogtshung* (DYT) (District Development Committee) and *Geog Yargey Tshogtshung* (GYT) (Block Development Committee) governance acts, the responsibility for managing natural resources has been passed on to communities and local institutions (PCS 2002, MoHA 2002, RGOB 2003b). This is specifically a devolution of decision-making to the lowest appropriate level (Röling 1999). To complement the devolution of NRM responsibilities, the Ministry of Agriculture formulated and released a community-based natural resource management (CBNRM) framework in 2002 (MoA 2002a).

The complexity of resource management, coordination, networking, and negotiation raises methodological questions, such as how to facilitate understanding and learning processes, mediation, and the development of management regimes that fulfill the aspirations of the majority of the stakeholders and yet ensure sustainability of the resource base. It is expected that enhancing knowledge and understanding through collective learning on the NRM regime can contribute to developing equitable and sustainable resource-sharing strategies.

As changes in resource use are supposed to emerge from human learning, interactions, and institutions, these changes often require considerable attention to create a common perspective on problems, diagnosis, and possible solutions (Röling 1999). Therefore, an integrated approach is needed to understand resource-use dynamics as this often involves multiple stakeholders and a series of decisions emerging from different behavioral patterns. Efforts in evolving multi-agent systems (MAS) for natural resource management are of recent development, and such an approach is gradually catching up as a versatile tool (Barreteau et al 2003, Etienne et al 2003, Trébuil et al 2002). MAS allow the examination of the emergence of complex macro phenomena from relatively simple micro activities. MAS are also considered efficient in expanding one's perceptions and ability to negotiate and collectively make decisions to manage a scarce resource in a conflict situation.

Role-playing games (RPG) and MAS have been used extensively to understand the management of irrigation water. The support process, involving both RPG and MAS simultaneously, is as follows:

1. Stakeholders are identified, as well as their perceptions of the environment.
2. Hypotheses are validated, and this is done by involving stakeholders in RPG.
3. Finally, simulations are run to show the systems dynamics generated by interactions between agents and the environment.

The three steps together can be termed "companion modeling" (Bousquet et al 2003). Considering that RPG and MAS simulations can integrate knowledge in a collective learning process on integrated natural resource management (Barreteau et al 2001, Bousquet et al 2003, D'Aquino et al 2002), this research proposes to use the companion modeling approach based on the association of RPG and simple MAS simulations to collectively learn the state of affairs of irrigation water sharing in Lingmuteychu, Bhutan. Accordingly, research questions can be formulated as follows:

1. Can companion modeling based on the combination of RPG and simple MAS simulations facilitate the emergence of a new set of rules, agreed upon by different parties in conflict?
2. Can it play a mitigation and mediation function in a context of conflict among common-pool resource (CPR) users in Bhutan?

The above research questions have been included in an M.Sc. student research activity, which is currently being conducted in Lingmuteychu. As a part of the fieldwork, RPG were conducted in April-May 2003 with two communities in Lingmuteychu.

This paper attempts to present the preliminary findings from the RPG conducted at the study site in April 2003 and draw certain conclusions to assess their usefulness as a tool to examine the research questions. The paper provides a general description of the study site, formulates the RPG, and discusses the results.

Irrigation water sharing in Lingmuteychu

Lingmuteychu is a small watershed located at 27°33′N and 89°55′E on the east bank in Punatshang Chu in west-central Bhutan, occupying an area of 34 km2 (Fig. 1). It is drained by the 11-km-long Limti Chu stream that originates as a spring from a rock face at an altitude of 2,400 m north of Limbukha village (Fig. 1). It is a rainfed stream since the ranges that confine the watershed are below the snow line. The stream serves five irrigation systems supporting 11 irrigation canals that irrigate about 179 ha of terraced wetland belonging to 121 households of six villages (RNRRC 1998). These six villages share irrigation water within a broadly respected customary regime that evolved during times when water demand was lower.

The base flow during the dry months of April and May fluctuates at about 40 to 50 L s^{-1}. The flow produced by a widespread rain in the watershed can be more than 500 L s^{-1}. The rainfall-runoff response is quick and the stream returns to its base flow within a couple of days after the rainfall. The fluctuating nature of the stream mainly results from the steep gradient of the watershed. The watershed receives an average annual rainfall of 700 mm (RNRRC 1998). Regulations in terms of water diversion by different irrigation canals from the Limti Chu are based on two broad principles. The rule "first come, first served" applies, which means that existing schemes have an established water right and can prevent newcomers from using it. For instance, Nabche (one of the villages within the watershed) is a resettled community and it does not have water rights, which prevents it from constructing an irrigation canal. The second rule can be interpreted as "more water for upper-catchment communities." Conflicts arise particularly from these two rules. Under such a water-use regime, the community in the uppermost catchment (Limbukha), close to the intake point, has absolute control over the headwater.

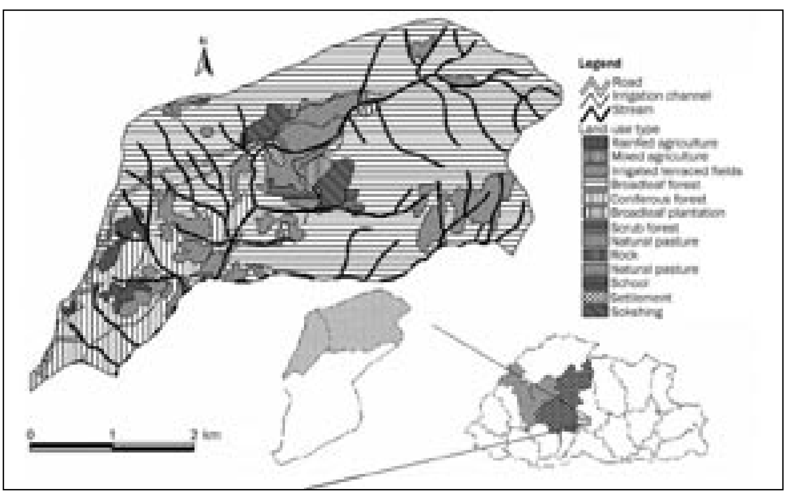

Fig. 1. Map of study area (LUPP, 1997). Sokshing = forest for collecting litter.

Dompola, a second village in the upper catchment located approximately 4 km downstream from the intake point, does not have direct access to the stream. As such, Dompola has to share water with Limbukha and the rules are stringently adhered to. As per the traditional arrangement, Dompola gets half of the stream flow only from the tenth day of the fifth Bhutanese month every year. As such, Dompola farmers really struggle to get their field transplanted. This indiscriminate use of water in the upper catchment produces conflicts and a chain of reactions from farmers in the lower catchment.

Within a village, water is shared on the basis of a rotation system locally known as "chukor." The rotation interval among different communities in the watershed varies from 3 to 13 days. In both communities, water is shared on the basis of three "relative" categories: "Thruelpa," Chhep," and "Chatho." The fourth category, "Lhangchu," has no entitlement to water.

- Thruelpa: entitled to half the flow in the canal (½ of canal flow)
- Chhep: entitled to half of Thruelpa (¼ of canal flow)
- Chatho: entitled to half of Chhep (⅛ of canal flow)
- Lhangchu: no entitlement (has to beg)

As shown above, existing water rights are not equitable. As the water resource becomes scarce, the current system has deficiencies. With differences in water rights, conflict can crop up within and between communities. It has also been shown that farmers use excessive water (MoA 2002a). This is aggravated by the introduction of multiple-cropping practices in upper villages, which have strong negative effects on water supply and rice productivity in the lower communities.

Within the present context of decentralization, whereby local institutions are given responsibilities over the management of natural resources (MoHA 2002), conflict could arise over boundaries. In particular, the Lingmuteychu catchment, occupying only 34 km^2, in extent falls within the administrative jurisdiction of the three districts of Thimphu, Punakha, and Wangdue, which invariably need to collaborate to sustain the resources and livelihoods of the people in the target area.

Materials and methods

Conception of the RPG

The problem was initially analyzed and existing knowledge synthesized through a review of the available secondary data on the Lingmuteychu watershed (RNRRC 1997, Duba and Swinkles 2001). Discussions with researchers and extension staff also helped in situational analysis and identification of a knowledge gap. To fill the information gap, a household survey using a structured questionnaire was conducted in two villages. Survey data helped in triangulating the information gathered from other sources. The study followed the conceptual framework shown in Figure 2.

Considering the problem of conflict in irrigation water sharing between two villages (Limbukha, upstream village, and Dompola, downstream village), the RPG method was conceived as a potential tool to initiate and facilitate dialogue between the two villages and for the research-extension team to enhance its understanding of the problem. With the onset of the transplanting season from the fourth Bhutanese month (end of May), Limbukha farmers started transplanting in the watershed. The game

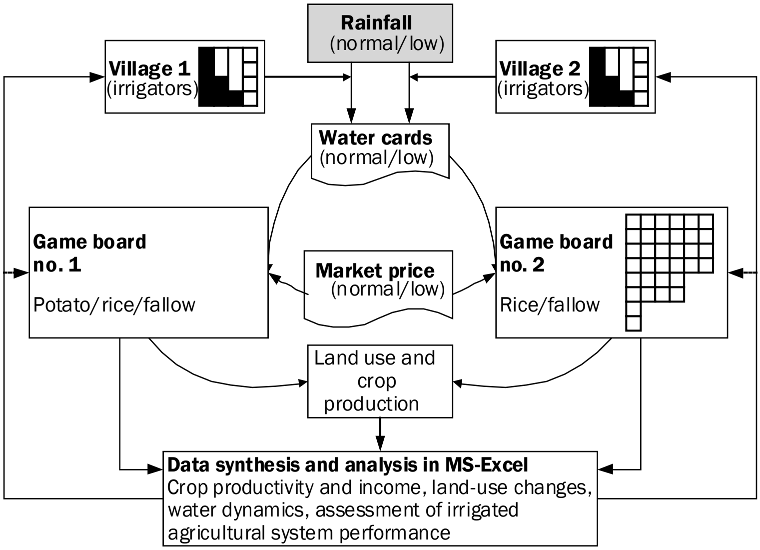

Fig. 2. Conceptual framework for the RPG process.

starts on the tenth day of the fifth month as Limbukha farmers will release 50% of the water to the Dompola canal. Six farmers of Limbukha village have yet to transplant rice, which means that what they do will still have an effect (on the quantity of water available for the next village, hence on the actions of the farmers in the next village). There will be two major chance factors: rainfall (normal and low) and market price (high and low). Rainfall will be declared after drawing a card at the start of the game, whereas the market price is declared after each game.

Six farmers each from two villages were categorized according to their water-right categories for the game. The game was played in three decision modes: village, collective, and swapped role. The first mode was played for 7 years (crop seasons); the second mode was played for 5 crop seasons with only 2 years for the swapped role (the third mode). Each crop year was divided into two cycles (first week of June to October and third week of June to October). Therefore, each successive time-step in a given season covered roughly two water-share cycles (12 days each) from the tenth day of the fifth month to the fourth day of the sixth month (= end of the rice transplanting season).

The game board

Two simple game boards (one for Limbukha and the other for Dompola) were drawn on a 0.5 m × 1 m poster paper representing the farmers in columns and their plots in rows (Fig. 3). On the game board, columns represented six farmers. For Limbukha, each column was divided into two subcolumns to represent potato (grown from March to June) and rice (grown from June to October). The game board for Dompola displayed just one column, implying that its farmers can grow only rice (June-October) and then fallow their fields (November-May).

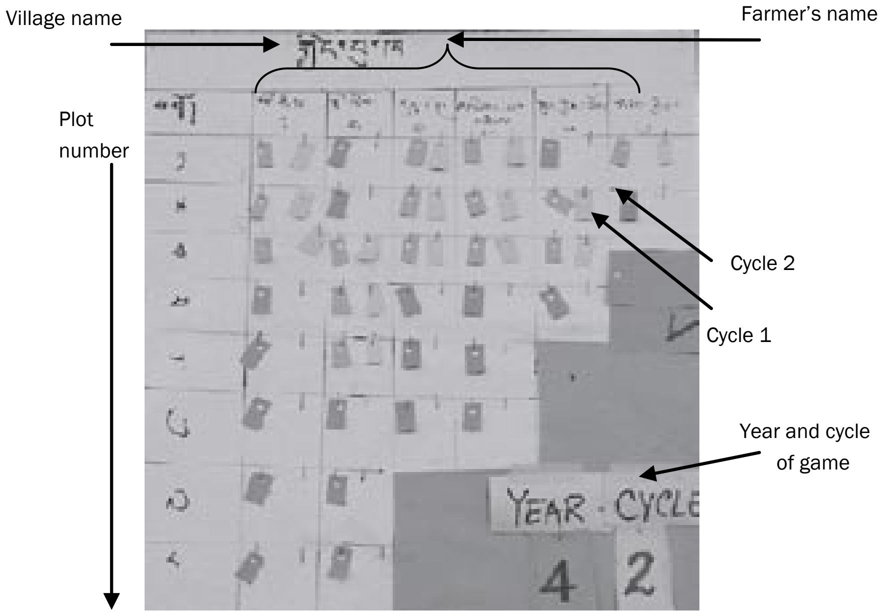

Fig. 3. RPG game board.

Rows represent plots that ranged from 1 to 8 (depending on the category of the farmer). Each plot is equivalent to 0.1 ha of paddy field. Only one crop can be grown at a time. However, in the actual game, players proposed that Limbukha villagers could grow a crop of potato before any rice field. The year and cycle of the game (e.g., 4/2: implying year 4 and cycle 2) were indicated in the lower left corner of the board.

The playing cards

Six types of cards were used as a medium in the game:

- *Name tag*. Each player was given a badge, which identified the bearer's social status and water-sharing category. The card carries the name of the type of farmer and a four-square box representing that person's share of irrigation water (Fig. 4A).
- *Cash.* Different denominations of local currency were used as cash to start farming and settle accounts after each cropping season (Fig. 4D). As the players introduced an exchange of labor, cash was also used for labor transactions. One could borrow and lend. The card was used as an indicator of performance in terms of income. Each player received initial cash to start farming at the following rates: Thruelpa = Nu. 20,000 (US$1 = Nu. 47.50), Chhep = Nu. 15,000, Chatho = Nu. 10,000, and Lhangchu = Nu. 5,000.
- *Rainfall.* Two cards, normal (N) and low (L) rainfall for each cycle, were used as chance cards to determine the volume of water available for sharing (Fig. 4B). Depending on the rainfall pattern, the units of water received by each player were regulated to induce dynamism. Before each cropping cycle, the card was randomly drawn and declared.

- *Potato card*. Limbukha farmers received yellow cards representing potato fields. One card was equivalent to 0.1 ha of potato grown before rice. Each player could use a maximum of three cards, and could also skip a season without growing potato.
- *Water cards*. Pink and light blue cards were used to represent water. One pink card was used as the equivalent to the volume of enough water to transplant and irrigate 0.1 ha of rice. Pink cards represented water used in the first cycle (first week of June to October) and light blue cards represented water used in the second cycle (third week of June to October). This means that farmers could place only one water card in one plot to indicate that that plot has been planted to rice. This card could be sold, exchanged, or used for transaction among villagers in a community or between farmers of the two communities. The game facilitator issued water cards in correspondence to the rainfall type. In the normal-rainfall season, Thruelpa received 5 water cards, Chhep 3 cards, Chatho 2 cards, and Lhangchu 1 card. During the low-rainfall pattern, the water provision was reduced by one unit, that is, 1 card less.
- *Market price*. Two cards representing a high and low price were used to indicate potato and rice prices. One of these cards was drawn randomly and declared after each cycle (Fig. 4C).

The spreadsheet

A spreadsheet program (Microsoft Excel) was used to record all the data produced from the RPG and to run simulations. The data from the game board were transferred into a data-capturing spreadsheet (Fig. 5A) in codes (1 = rice, 2 = potato, and 3 = fallow). The data were linked to a simulation spreadsheet (Fig. 5B) on which gross margin is analyzed. This spreadsheet was used to calculate income from land-use

Fig. 4. Cards used in the game.

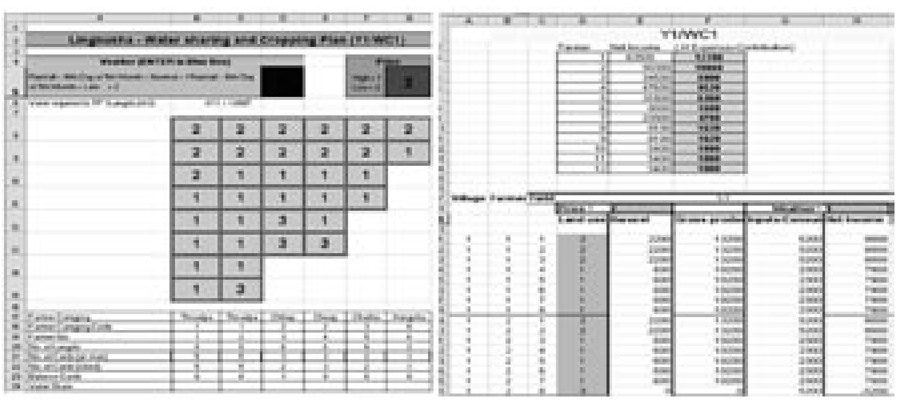

Fig. 5. MS Excel Spreadsheet used in the RPG.

decisions. Based on the simulated results, each player was paid an income at the end of each game. Other data such as water dynamics and land-use changes were analyzed after all the game sessions concluded. This actually facilitated the game session, thus enabling rapid calculations and year-wise comparisons if required.

Pretest of RPG

The game was pretested at the RNR Research Center, Bajo, with researchers and trainees playing the role of farmers. Subsequent to the test, a few changes such as the number of plots and options for sharing water were incorporated into the actual game. This also helped to schedule the game in terms of time taken for each step. The game also served the purpose of training of the selected facilitators and assistants for the RPG in the field.

Game sessions with villagers

In Dompola, RPG were used for 3 days. Six farmers from each of the two villages representing four water-share categories (Thruelpa, Chhep, Chatho, and Lhangchu) were selected to play the game. Players were given predefined numbers of rice fields (each field size was 1 langdo = 0.1 ha): Thruelpa got 8 plots, Chhep got 6, Chatho got 4, and Lhangchu only 2.

The first day was assigned for game (or RPG) sessions, which started with a briefing about the game, the purpose, the role of the players, and the expected outputs (Fig. 6A, B). The game sessions corresponded to three different modes of communication among villages: intravillage, intervillage (collective), and swapping roles. The first session represented the existing situation in which each village discussed water sharing independently at the village level and accordingly decided to grow different crops. Even the game boards were kept in distant places such that one village could not

Fig. 6. (A) Linbukha farmers playing the game and (B) settling their accounts after each cycle of the game.

see the actions of the other village. The game was played for seven cropping seasons. During the second session, farmers from both villages formed one group to discuss collectively water sharing between the two villages. The game boards were placed together side-by-side to allow the farmers to see and discuss them. This was necessary to demonstrate that two villages can freely discuss and share water to grow crops for five crop cycles in a collective decision mode. During the third session, roles were swapped between the two villages. We anticipated that this would provide a better understanding of other village situations, identify any unique decisions, and bring about new understanding from the swapping of the roles.

The second day was devoted to analyzing the RPG outputs and discussing them among the facilitators. On the third day, based on the preliminary analysis and observations, semistructured individual interviews with each player were conducted to collect views on the game and evaluate it. Following the individual interviews, a plenary session was organized to present the preliminary results of each RPG session to the players and to get their response to the proposed analysis in the form of simple graphs of land-use dynamics, water exchanges, and income.

Results and discussion

Despite the concerns of many researchers about the simplicity of the game and the newness of the approach in the research field, the players adapted well to the game environment. After some initial confusion during the first time-step, which took almost 45 minutes to complete, subsequent time-steps took less than 20 minutes. The first game also generated new ideas and suggested that some rules needed to be changed. In view of the three RPG sessions in Dompola, a comparative analysis of the three modes of communication is presented in the following sections.

Land-use dynamics

Game 1: intravillage mode of communication. The most critical effects of decisions on water use and sharing are land-use changes over the years. These changes are further influenced by the amount of rainfall, which in turn determines the stream discharge. For Limbukha farmers, when the rainfall pattern was low-low, 29% of the plots were left fallow (Fig. 7A). The number of fields planted with potato was highest (57%) when the rainfall pattern was low-low. Similarly, all the plots were planted with rice when both cycles received normal rainfall, thereby leaving no field fallow. In contrast, an average of 16% of the plots were left fallow in Dompola. Fallow plots existed in all rainfall patterns except in the normal-normal pattern. The highest rate (31%) of fallow plots was recorded during the low-low rainfall pattern (Fig. 7B). The fluctuation in number of plots transplanted with rice depended on the rainfall pattern and was higher than for Limbukha.

This indicates that rainfall amount and pattern strongly influence farmers' decisions to alter the cropping system. On average, 46% of the plots were planted with potato.

Game 2: intervillage mode of communication (collective). When both villages were grouped for collective discussion and decision-making on water use, farmers initially congregated to their individual village cluster and showed a passive expres-

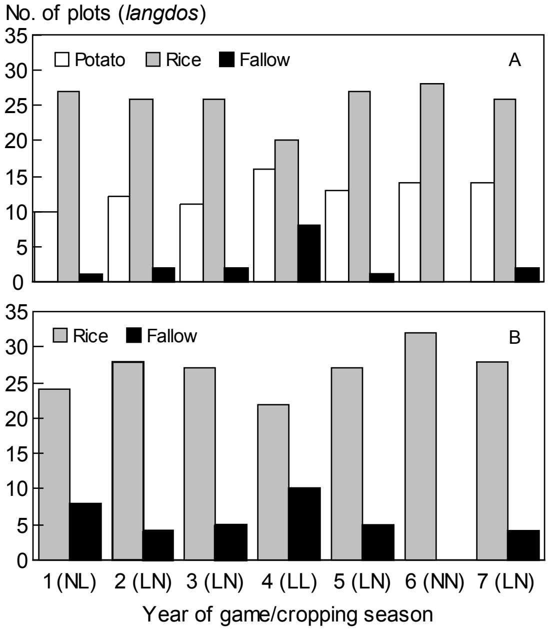

Fig. 7. Land-use changes in (A) Limbukha and (B) Dompola over cropping seasons during the first gaming session. 1–7 on X-axis indicate year; letters in parentheses indicate rainfall pattern in two cycles, i.e., N = normal rainfall and L = low rainfall (e.g., NL means rainfall was normal in the first cycle and it was low in the second cycle).

sion. This was the initial response, but it gradually turned into a very congenial environment featured by lots of exchange of views, water sharing, and discussions on cropping and other aspects of livelihood between the villages. There is no influence of communication mode on land use in Limbukha (Fig. 8). The percentage of plots planted to rice and fallowed was 91% and 9%, respectively, in both communication modes. However, in Dompola, there was a 4% increase in plots planted to rice and a decrease of 4% in fallow plots with the collective communication mode. This implies that, when farmers communicate collectively, the Dompola farmers seem to share water more efficiently. During the RPG session, players introduced water sharing between the two villages, which benefited Dompola farmers.

Water management dynamics

Intravillage mode of communication. Water sharing is more prominent and systematic in Limbukha village, except when rainfall is low in both cycles. Sharing of water was a consistent feature among the villagers. It was interesting to note that 26% of the paddies are left fallow during the low-rainfall season, indicating a shortage of water. Throughout the years, Limbukha farmers shared on average 5% of the total water allocated, leaving behind 6% as excess water and 5% of the plots fallowed (Fig. 9A). Dompola farmers operate in a water-scarce situation, which can be seen from

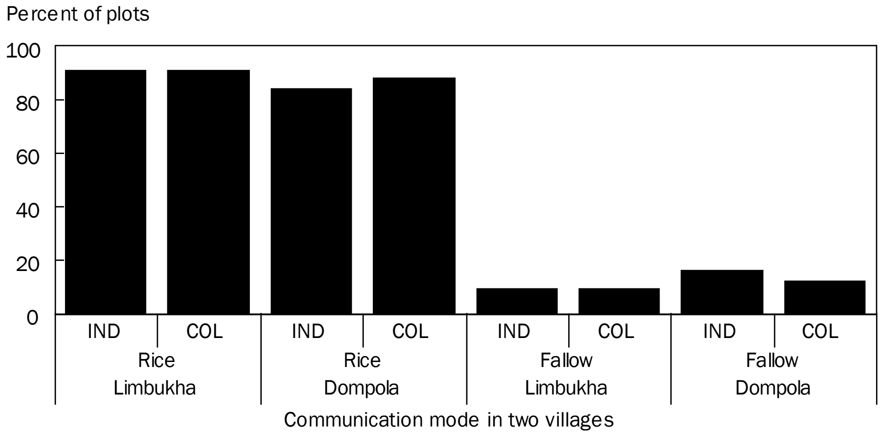

Fig. 8. Comparison of land-use changes in two villages because of different modes of communication. IND = intravillage and COL = intervillage mode of communication.

annual average fallow plots of 16%. Although Dompola farmers shared 2% of their water, they were left with 4% of the water share as excess water (Fig. 9B). Whenever there was excess water, it was shared within the village. Sharing was in the form of an exchange of water for labor. One water turn (12 hours of discharge) equates to 1 person-day of labor during the rice transplanting season.

In the game, the players introduced a charge of Nu. 100 per unit of water (equivalent to one day's wage). As this rule was not clearly documented, it was not included in the RPG rules initially. With the increasing competition and demand for water, the value was raised to Nu. 200 per unit of water. Figure 10B clearly indicates that Dompola farmers often have fallow plots because of a shortage of water. Fallow plots ranged from 1 to 10 (maximum of 31% of plots) except in the year of normal rainfall in both cycles. Players reiterated that exactly the same happens in reality.

Intervillage mode of communication (collective). The collective communication mode seems to ease the pressure on water management, as players exchanged water between the villages, thus introducing the collaborative approach in resource management. For Limbukha, farmers found that in the collaborative mode they could sell or exchange the excess water with Dompola farmers and earn more income. It can be seen that, on an annual average basis, while Limbukha farmers shared 5% of the water (the same as in the intravillage mode), they had 9% of the plots fallowed (4% higher than in the intravillage mode) (Fig. 9C). One player from Limbukha remarked, "If I did not share (exchange) excess water from my allocation with neighbors, it goes to waste as it will flow downstream without anyone making use of it." This statement highlights the satisfaction of Limbukha farmers when sharing water with Dompola farmers. This is valid as Dompola is located far from the stream and has neither provisions nor permission to construct a new channel to divert stream water. There was no difference whatsoever in water use between the two communication modes in Limbukha (Fig. 9C).

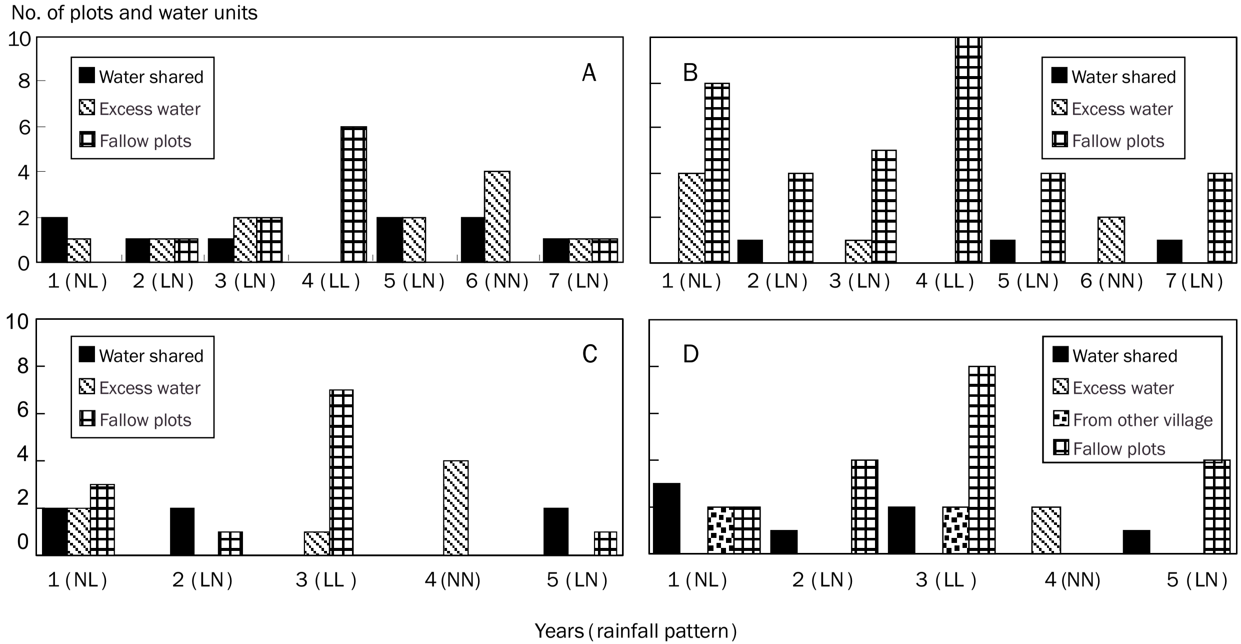

Fig. 9. Water dynamics in two villages following two modes of communication. (A) Limbukha intravillage communication mode, (B) Dompola intravillage communication mode, (C) Linbukha intervillage communication mode, and (D) Dompola intervillage communication mode. 1–7 on X-axis indicate year; letters in parentheses indicate rainfall pattern in two cycles, i.e., N = normal rainfall and L = low rainfall (e.g., NL means rainfall was normal in the first cycle and low in the second cycle; "from other village" in D means water shared between villages.

In the collective mode, Dompola farmers seem to benefit the most in terms of access to water. Throughout the years, the percentage of fallow plots declined from 16% in the intravillage mode to 11% in the intervillage mode in Dompola. In year 1 (NL) and year 3 (LL), Dompola farmers even received water from Limbukha farmers, an example of intervillage exchange. On an annual basis, this accounts for 3% of the water used coming from intervillage exchange (Fig. 9D). Particularly in the low-low rainfall pattern, the number of fallow plots decreased from 10 in the intravillage communication mode to 8 in the intervillage mode. It is evident that the number of fallow plots declines substantially in the collective mode. One of the reasons for this reduction is water sharing between the two villages.

Income

All the players considered income as the immediate indicator of their actions in deciding water and land-use features and as a measurement of success. This was evident as all players, after each gaming session, took some time to assess the amount of cash accumulated (Fig. 10).

Income analysis showed that, overall, farmers' income was higher by 9% in the collective communication mode. Importantly, it can be seen that income is more stable in the collective communication mode than in the intravillage mode. When assessing the performance of different farmer categories, all categories except Lhangchu have more stable income over the years (rainfall types). For instance, the annual income of Thruelpa, Chhep, and Chatho was 4%, 13%, and 18% higher in the village-based communication mode than in the collective mode of communication (Fig. 11).

This implies that collective communication produces a more uniform distribution of income, based on the effective sharing of resources. It also indicates that sharing of water beyond the village boundary with other villagers provides an opportunity for the villagers to sustain their production and income. It also helped Dompola farmers

Fig. 10. Players receiving their income and some players counting their cash accumulation.

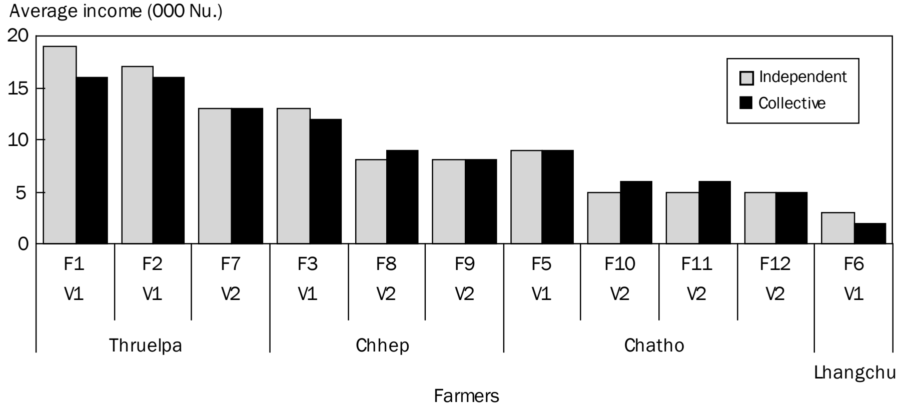

Fig. 11. Income variation among farmer categories according to two modes of communication. F1–F12 imply farmers coded as 1–12; V1 = Limbukha; V2 = Dompola; and Thruelpa, Chhep, Chatho, and Lhangchu indicate farmer category based on water share.

to become aware that income generation between two villages varies only because of potato cultivation in Limbukha. Consequently, this encouraged ideas such as trying out potato cultivation in Dompola and leasing land from Limbukha farmers to cultivate potato.

Swapped role between two villages

As a third scenario, the role of each player was swapped with that of another village. It was swapped in the order of 1 taking the role of 7, 2 that of 8, 3 that of 9, and so on. Farmers easily swapped roles as they considered this a discovery, experiencing the condition of the other village. A comparison of annual income produced from three modes of communication clearly indicates the superiority of the collective mode for all categories of players. Income in the swapped mode was much lower for Dompola farmers playing the role of Limbukha farmers (Fig. 12). This further confirms that Dompola farmers were very cautious and that their perception of water resource scarcity dominated their actions.

Analogous to Barreteau et al (2003), the pertinent benefit of the swapped game was the learning experience for both teams (Table 1). One of the Limbukha players (Thruelpa) did not want to play the role of the Dompola farmer, as his major concern was low income. We presumed that his demotion in role from Thruelpa to Chhep made him discontented. The rest of the players considered the session as an opportunity to learn about the problem of Dompola farmers and the potentials of Limbukha farmers.

Individual interviews

A majority of the farmers considered that the gaming parameters were precisely selected and laid out and they opined that all looked similar to reality. One farmer remarked, “It appeared like playing a game but recalling in the evening all appeared precisely real and stimulating.”

Table 1. Farmers' response on swapping the role between two villages. Farmer 4 was not interviewed.

Response[a]	Percentage of respondents (n = 11)
Did not like swapping the role (2)	9
Comparison of income between two villages (1, 3, 8)	27
Understood the potential of potato in Limbukha and are motivated to try it out in Dompola (9 and 11)	18
Resource advantage of Limbukha farmers (10)	9
Understood the problems of Dompola farmers (12)	9
Possibility to grow potato in Limbukha (5, 6, 7)	27

[a]Numbers in parentheses represent the number of the farmer, i.e., 2 = farmer 2.

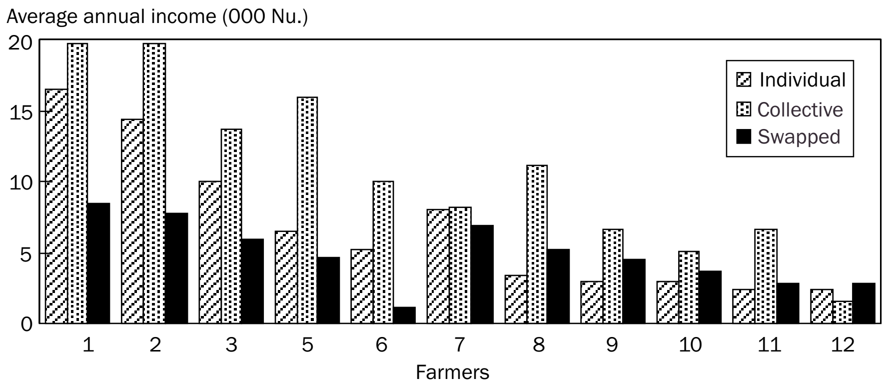

Fig. 12. Annual income produced from three different modes of communication.

As the game board was a poster paper with rows and columns representing plots, 82% of the respondents believed that the plots represented the actual spatial distribution. During the first game session, in which two villages played independently, definite patterns existed in choosing the crops and the plots in the first cycle. This revealed that, in the first cycle, potato is planted in central plots to facilitate protecting the crop from wild boar damage. However, the rest of the participants thought that the plots are more scattered and numerous in reality. All accepted the categorization of farmers in terms of access to water, number of field plots, and cash allocation: 27% (one each from Thruelpa, Chhep, and Chatho) of them thought that the cash allocation was too high, as farmers may not be in a position to gain access to that amount to start farming.

Initially, it was assumed that potato cultivation in Limbukha would have some effect on Dompola farmers in terms of access to irrigation water, but the interview revealed just the opposite. It was later clarified that potato is harvested before the rice-transplanting season in Dompola and its occupancy of the terraces will not influence the water-sharing system. Overall, all the players believed that the game results depicted the real-life situation.

Among the three gaming sessions, farmers preferred the second one as it allowed them to collectively share resources and work together. One participating member stated that "it is more fun and interesting to work together in a community, helping each other to pull along." This implies that both the villages would, given the opportunity, operate in a collective mode.

RPG actual circumstances/reality linkages. The components and rules used in the RPG were considered to represent the real-life situation. Water share, water units, and the influence of rainfall on water availability were the main features that players related to reality. Although water exchange depended on the demand from those who needed it, kinship played a dominating role in the exchange of water. Whenever there is excess water, it is given free of charge to relatives who need water. It was stated that it is shared on the mutual basis of helping each other in times of need. Only after satisfying the relatives' requirements would the players exchange water with whoever wants it for labor.

Although exchange of water between the two villages does not exist, 45% of the respondents answered that a water exchange could take place between the two villages. Further, they suggested that, when there is plenty of water at the source, it should be shared. With the increased dependence of Limbukha on farm labor from Dompola and other socioeconomic dependence, this should provide a platform for cooperation and the collective decision-making process in natural resource management, primarily for water.

Possible improvements suggested. It was evident from the game and individual interviews that the inclusion of labor in the game as a means for water exchange would improve the results of the RPG. As farm labor is the most limiting resource for Limbukha farmers, the inclusion of labor as one variable in the game could produce unique reactions. It was also suggested that the number of plots per farmer category and the initial capital provided to each player might have to be revised. Prior to the start of the gaming session, more elaborate briefings and discussions with the farmers (stakeholders) will help in enhancing the efficiency of the gaming process.

Learning experiences. As a learning experience from the game, 36% of the farmers reported that it helped them to understand the benefits of sharing water with a neighboring village, which enhanced their land-use system, productivity, and income. This was evident from the discussions they had on the preliminary results before the plenary session (Fig. 13). The game also helped in understanding the valuation of water share for 27% of the respondents and the facilitators. This implied that, given the opportunity, a water market will emerge in the system. Apart from the economic valuation of water, the game helped to open up new understanding of the social dependence between villages, particularly in terms of labor exchange and other services. The players also believed that the RPG helped them to understand the value of maintaining farm accounts, the problems of a neighboring village, and the importance of completing farm work on time. For Dompola farmers, the game gave them the idea to attempt potato cultivation either in Dompola or by leasing land in Limbukha to grow the crop.

Possible use of RPG. The responses of the players in the Dompola RPG on the possible use of RPG indicated that 36% would consider their use for crop production

Fig. 13. Preliminary results and players discusssing the results.

problems, followed by use in collective actions (27%). Others thought that RPG could be used for awareness and learning, and for weed management.

Conclusions

The most important realization was the awareness of the ability of the RPG to bring two communities in conflict together to discuss and collectively develop options. RPG enabled two villages to cooperate for the betterment of both. The RPG also prompted a "sense of oneness" and interdependence that can expand the scope to look for alternative strategies to overcome water-sharing problems.

Since the RPG carried out in May 2003 began the process of discussion to seek a better management of resources, certain changes in resource-use decisions can be expected. One piece of vital information to substantiate the research findings will be to monitor behavioral patterns during the current cropping season. Even if sequential observation is not possible, interviewing the same players at the end of the 2003 paddy season could produce useful information to evaluate the influence of RPG. Accordingly, any changes in the rules of the game could be incorporated in a new version and the game could be played once again to see any pattern of change. In addition to the above use, RPG can also be used as a communication tool for awareness building by motivating stakeholders to participate in management actions.

In a situation in which irrigated agriculture is dominated by a small-farmer-managed irrigation scheme built on the traditional institutional platform passed down through generations, critical learning and understanding of the context and issues are the most important step in entering into the problem-solving phase.

We can conclude that Dompola RPG have helped in facilitating the emergence of new rules in resource sharing that could possibly be further tested and adapted in a situation of conflict. These games also have the potential to serve as a tool for a common platform for stakeholders in conflict, to initiate collective learning and negotiations.

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Notes

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Role-playing games to understand farmers' land-use decisions in the context of cash-crop price reduction in upper northeast Thailand

N. Suphanchaimart, C. Wongsamun, and P. Panthong

The undulating landscape of upper northeast Thailand forms a succession of adjacent mini-watersheds occupied by lower and upper paddy fields and upland cash crops. The last decade has seen the expansion of small-scale sugarcane plantations into the upper and even lower paddy areas as farmers responded to market demand and the government sugar price support policy. How extensive is this expansion and how will farmers adjust if the sugarcane price decreases are key questions in order to better understand the effects of this recent change in land use on the agroecosystem and household livelihoods. Moreover, the collection of sugarcane requires coordination among various stakeholders: different types of farmers and quota leaders, and sugar mills. Field research was carried out to better understand farmer decision-making regarding land use and the interactions among key stakeholders involved in the sugarcane production and marketing system.

Following the construction of a conceptual model based on existing knowledge representing farmer decision-making as seen by the research team, role-playing games (RPG) and focus-group discussions backed by individual interviews were the main investigation tools used in this study. A three-dimensional playing board and game rules were conceived based on actual circumstances and the preliminary findings of three gaming sessions undertaken with multiple stakeholders are presented. Under a scenario simulating a drop in the market price of sugarcane, the study found that glutinous rice remained dominant in lowland paddies while sugarcane plantations occupying the upper paddy area were replaced by other crops, except rice. In general, rice is doing poorly in such a drought-prone landscape position and farmers decided to experiment with alternatives such as integrated farming and an increase in cattle rearing. The collection of sugarcane at harvest required an active role by small-scale quota leaders at the village level since not all cane growers can look after their plantations and harvest sugarcane by themselves. This last operation requires important cash expenses and an ability to manage hired labor. Large sugarcane quota leaders from outside the village who hold more capital acted as a second type of sugarcane collector but did not take part in any price competition with local collectors to get access to the product.

This RPG enabled researchers to observe the local pattern and dynamics of land use and the interactions among stakeholders since players imported many

aspects of their real circumstances into the game. However, because this RPG focused on individual choices based on one's actual situation, the players suggested few new rules. Ultimately, the new knowledge and decision-making rules gained from the RPG should be inserted into an associated multi-agent computer model. Following its validation with users, this model could be used to run time-efficient simulations of different scenarios of land use and price movements. This endeavor requires ample investment in building an interdisciplinary team.

In the upper part of northeast Thailand, the undulating land forms a succession of adjacent mini-watersheds. The low terrace is occupied by lower paddies usually planted to the staple glutinous rice. The uplands are planted to industrial cash crops, mainly cassava and sugarcane, and the transition zone, sometimes referred to as the upper paddies, is traditionally planted to nonglutinous rice in wet years and to drought-tolerant cassava or left idle in dry years (Limpinuntana 2001). In this region, farmers face infertile sandy soils and an erratic distribution of rainfall. Rainfed lowland rice is the main subsistence crop, whereas cash earnings come mainly from industrial crops and nonfarm employment (Thomas 1988). The last decade has seen a gradual expansion of sugarcane into areas occupied by upper and even lower paddies. This expansion of area planted to sugarcane is raising concern among scientists about its ecological effects, especially soil erosion and soil losses in upland fields and a possible decline in rice production and local household food security. A recent study on land use in upper northeast Thailand found that farmers have been applying a high level of chemical fertilizers in their upland fields (an average of 625 kg ha^{-1}) to compensate for nutrient loss. Soil loss from upland fields is a problem commonly found in areas where monocropping is practiced in the upper land unit connecting the paddies with the upland subecosystem (Vityakorn et al 2004).

The expansion of sugarcane in this region is directly related to government policy for the sugar industry. Unlike rice or cassava, sugarcane production and price have been managed by the Sugarcane Board since 1984. The production, collection, and processing of this industrial crop involve multiple stakeholders: farmers, different types of quota leaders, sugar mills, etc. Annually, Thailand exports a total of about 2.1 million tons of sugar, while another 1.7 million tons of white sugar covers domestic consumption. Sugar production is an important economic activity as more than 700,000 farmers are engaged in mostly small-scale sugarcane planting, and a total of 1.4 million people are taking part in some kind of sugar-related activity (Thailand Development Research Institute 1994). The commodity board also helps to manage the profit-sharing system. At the end of the production cycle, the annual profit from the sugar industry is shared between cane growers and sugar mills on a 70:30 basis. Under this system, cane growers have to register with a sugar mill and be a member of the Cane Grower Association to be able to participate in this end-of-the-season profit-sharing system. The official price of sugarcane is negotiated and must be approved by the cabinet before its official announcement to the public prior to the harvesting season. Consequently, the primary price of cane can be negotiated and stabilized, the volume of sugarcane production is controlled, and cane producers are divided among registered and independent growers.

In 1989, the government allowed existing sugar mills in search of raw material from the western region to relocate to the northeastern part of the country to stimulate the local economy of this poorest part of the kingdom. As a consequence, the total area planted to sugarcane in the northeastern region jumped from 40,000 hectares in 1973 to more than 300,000 ha in 2002, and the number of sugar mills in the region increased from 7 to 13 during the same period. More than 50,000 farmers registered with these mills and supplied them annually with more than 20 million tons of cane (Office of the Cane and Sugar Board 1999). Confidence in the price negotiation system is a powerful incentive for farmers to remove bunds and convert upper paddies into more drought-tolerant sugarcane plantations.

Is this trend going to continue? Will the expansion reach a critical stage at which lowland rice production would be significantly affected? And, if the cane price cannot be supported anymore because of changes in the context of international trade, can local farmers adapt their production system by integrating new alternatives? In addition, because the collection of sugarcane is organized through quota leaders, how do farmers manage this phase of the production cycle that involves multiple actors? These questions require a better understanding of land-use dynamics and interactions among the concerned stakeholders: independent small-scale growers, different kinds of quota leaders, and sugar mills. Within this context, the authors attempted to understand farmers' decision-making regarding land use when facing a reduction in the farm-gate price of sugarcane. The innovative modeling concept of multi-agent systems and an associated role-playing game (RPG) were used to represent the interactions among multiple stakeholders under a given set of rules and for researchers to observe the exchanges and gain new knowledge on the systems under various circumstances.

This article presents the construction of the initial conceptual model and its related RPG, as well as its use with stakeholders. First, the study method and site are described. The RPG features and rules are introduced and three successive gaming sessions are presented. The results of this experiment are analyzed and a final discussion deals with the lessons learned and comments on the methodology.

The study method

Resource management is complex and is constrained by both biophysical and socioeconomic conditions. Human interaction is an important determining factor of patterns of resource use. This involves multiple stakeholders with different needs, objectives, strategies to achieve them, and perceptions. The integration of diverse stakeholders' perceptions and behaviors in the study process is essential to gain a collective understanding of the problem to be examined. Conventional methods of study such as individual interviews and group discussion, rural appraisal, and goal-seeking modeling are not adequate to conceptualize the interactions among stakeholders and the integration of resource management in space and time. We need a tool that helps to capture stakeholders' decision-making, and, moreover, their coordination at the same time. Multi-agent systems (MAS) modeling could be seen as a state-of-the-art approach to do just that. MAS is suitable for analyzing complex systems since it represents an environment of autonomous agents that can act locally in response to stimuli or communicate with other agents. Based on the observation of the effects of changes in the system, one can examine the relationships among agents under various circumstances. To make the process more iterative, one can implement these relationships in a computerized MAS model. For more information on this step, readers can refer to other articles on MAS simulations presented elsewhere in this volume.

The use of MAS with stakeholders can also be supported by other tools. Recent experiences in various parts of the world have shown that the joint use of RPG, individual interviews, and MAS facilitates communication among stakeholders facing a common natural resource management problem, and helps to empower them when looking for "solutions" (Bousquet et al 2003, D'Aquino et al 2003, Dare and Barreteau 2003). The study method used in our case involves a review of secondary data, a rural assessment, stakeholder interviews, role-playing sessions, and MAS modeling. In this way, the model is gradually developed in a participatory and iterative way, and the whole methodology is also referred to as "companion modeling" (Bousquet et al 2003).

In Senegal, scientists used RPG and MAS to help multiple stakeholders (farmers, herders, fishermen, hunters, and national park officers) to reach collective decision-making in land use. The study process started with a stakeholder-designed RPG followed by MAS modeling. A game was organized after several workshops involving stakeholders. The RPG facilitated dialogue among stakeholders and led to collective decision-making. Afterward, a real situation was modeled. The RPG was used to support computer modeling and a geographic information system (GIS). It is important to note that this methodology does not aim directly at the selection of a solution to the problem under study, but at stimulating the joint identification of alternatives to the current situation and their discussion to facilitate collective decision-making (D'Aquino et al 2003).

By using an RPG to study negotiation processes in irrigated systems of the Senegal River Valley, Dare and Barreteau (2003) found that the RPG was accepted among stakeholders as a good representation of their reality. They also found that the social background of the players interfered with role-playing during the sessions. However, the RPG could be used to investigate social relations among people in combination with sociological interviews and analysis of videos and other materials used to record information during gaming sessions, and to facilitate a negotiation process (Dare and Barreteau 2003).

The methodology adopted in our case study follows the experiments of collective modeling in which the model is created from existing knowledge and additional information can be gathered during the RPG and individual interviews with the players. Before interactive experiments can take place, researchers integrated knowledge from various sources to obtain an understanding and first representation of the agents' behavior within the system. The players taking parts in gaming sessions were selected in collaboration with local institutions. We looked for farmers who grow rice and sugarcane but without a quota, farmers having a sugarcane production quota, quota leaders who do not grow sugarcane in the village, and leaders in the local farming community.

The whole methodological process can be divided into three main phases:

1. *The role-playing game.* The objective is to assess whether the features and rules of the game proposed by the researchers constitute a fair representation of farm-

ers' actual circumstances, and whether the same kind of event emerges from the interactions among players. The RPG is also used to gather new knowledge by encouraging the players to modify the game during successive sessions. Problems are identified and scenarios can be simulated and their results collectively discussed.

2. *Individual interviews with the players*. The objective is to better understand how they played during the gaming sessions, and to what extent the RPG is related to their real circumstances.
3. *MAS modeling*. A simple computer model with features and rules similar to the RPG and integrating the knowledge gathered during the interviews could be developed and presented to the players to stimulate the identification of scenarios of land-use change, simulate them, and collectively assess their results. The common-pool resources and multi-agent systems platform (CORMAS, for more details, see the article describing this MAS simulation tool in the last section of this volume) was used by an external modeler to build a preliminary version of the computer game simulating the first and second gaming sessions, but it is not presented in this article.

Conception of the role-playing game

Knowledge synthesis and development of a conceptual model

Prior to game development, an interdisciplinary group of researchers gathered secondary information and conducted a series of interviews with several key stakeholders to improve their understanding of farmer decision-making processes regarding the allocation of different crops to different landscape units and marketing of sugarcane production. Data on resource exchange patterns, minimum land areas for rice or sugarcane production, and returns for the main crops were collected to be used in the conception and calibration of the game. For example, the minimum sugarcane price reported by small-scale growers could be as low as US$10 per ton. It is important to note that this price level is about 45% lower than the price negotiated at the commodity board level for the 2003 crop year.

Diagrams were used to assemble, display, and verify the consistency of knowledge acquired on these decision-making mechanisms. The unified modeling language (UML) was used to allow interdisciplinary exchanges on agent identification, farmers' decision-making rules, and conditions for them to become quota leaders. Examples of possible land-use patterns were also prepared. In the lowlands, although glutinous rice production is dominant, sugarcane may encroach if the family is self-sufficient in rice and the price for sugarcane is high. In the upper paddies, farmers make cropping decisions between nonglutinous rice and two major commercial crops, cassava or sugarcane. In the uplands, only sugarcane or cassava is a possible choice. Figure 1 displays a UML activity diagram representing the general farmer decision-making process for the allocation of crops to different landscape units.

Farmers' decision-making to become a quota leader or not depends on two main determining factors: access to capital (cash and transportation equipment) and marketing networks that usually originate from social networks made up of relatives or friends. Some sugarcane growers who are able to shoulder the harvesting costs

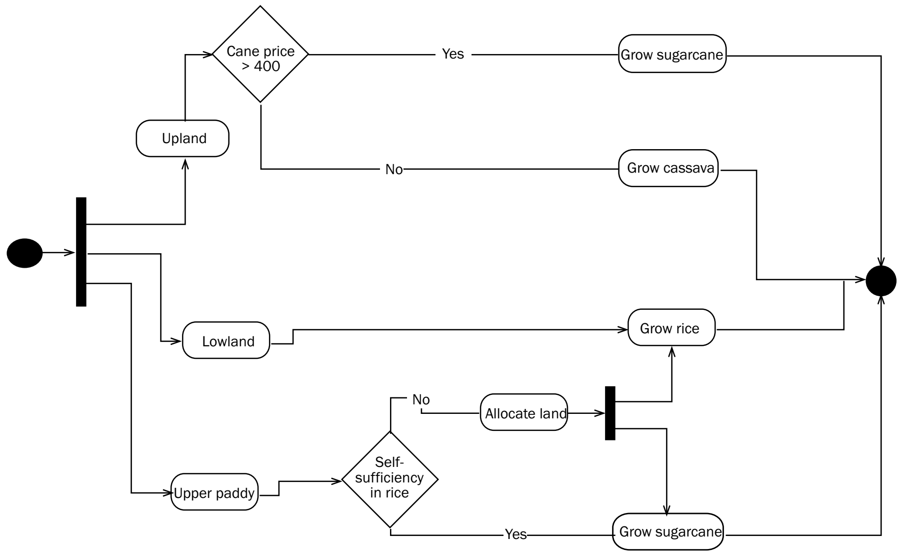

Fig. 1. UML diagram displaying a decision-making tree regarding crop allocation to land by farmers in Nam Phong District of Khon Kaen Province, upper northeast Thailand.

and have good connections with a quota leader may sell their crop under the leader's name and thus benefit from the end-of-season profit-sharing arrangement. Figure 2 represents the relationships between cane growers and the two main kinds of quota leaders and the conditions to be met to be able to obtain a sugarcane quota from a given mill.

It is also important to identify the possible interactions among different agents and to represent them in the RPG, for example, the interactions between quota leaders and small growers after the sugarcane planting season. The agents deal with the purchase and sale of sugarcane crops before harvest when the small farmer does not have sufficient resources (cash for fertilizer, labor for weeding, etc.) to look after the plantation. Price negotiations for these plots of sugarcane purchased as "green" start soon after the crop is planted. After the deal is concluded, crop maintenance and harvesting are the buyer's responsibility.

Site selection and description

Located some 50 km north of Khon Kaen City, the village of Ban Pung Tui in Nam Phong District of Khon Kaen Province was chosen for this experiment because its landscape has the common combination of lowlands and uplands separated by a transition zone. The conversion of paddy fields into small sugarcane plantations has been extensive and key information on the households' farming activities was available. Out of a total area of about 770 ha, the lowlands, uplands, and transition zone occupy 25%, 40%, and 35% of the village territory, respectively. Key informants indicated that more than 25% of the land exploited by the 259 local farming households had already been converted from paddy land into sugarcane fields. The average farm size is 4 ha, but it varies within a range of 1 to 15 ha. A large sugar mill and two cassava

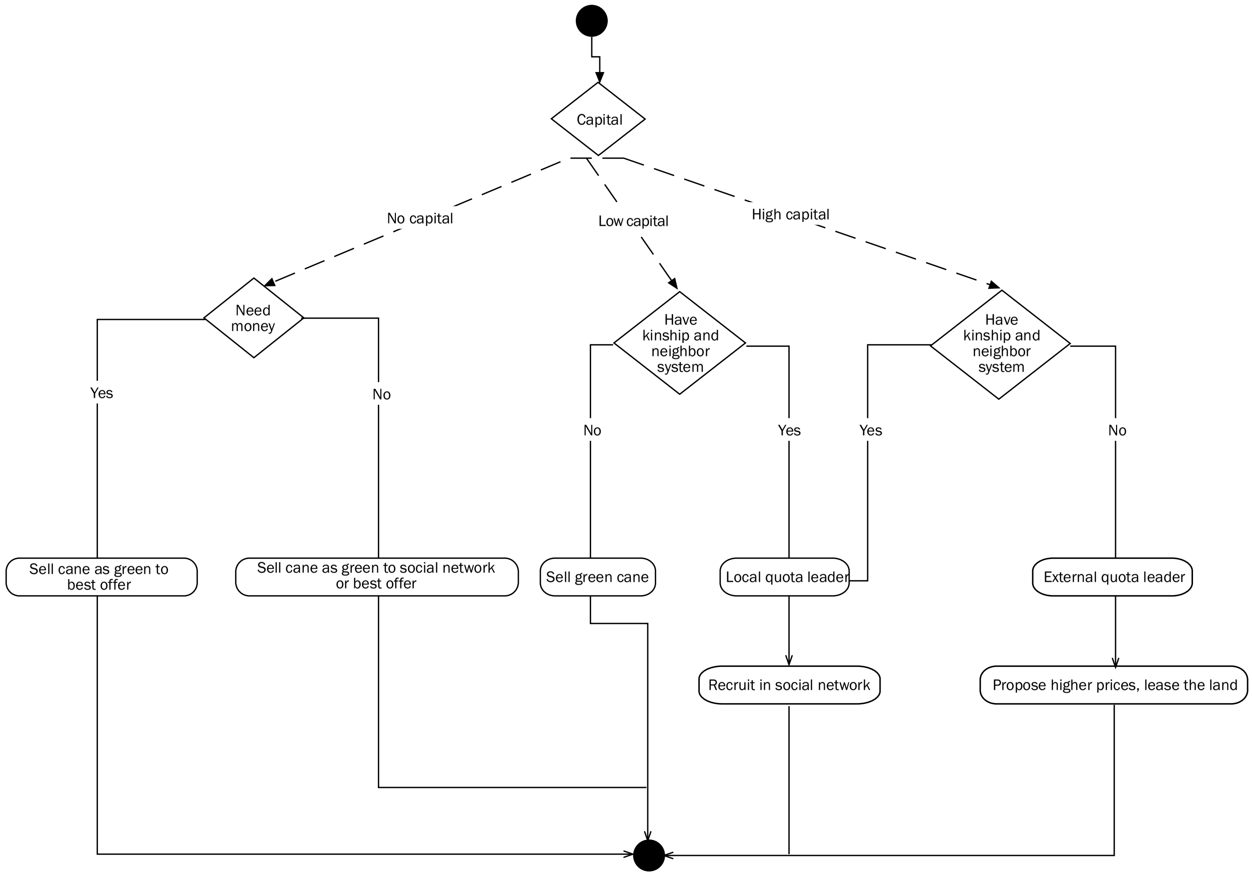

Fig. 2. UML diagram for the identification of sugarcane quota leaders in Nam Phong District of Khon Kaen Province, upper northeast Thailand.

processing plants operate nearby. Each year, more than 60% of the farming households grow sugarcane, but only 10 to 15 farmers register as quota holders with the mill. Focused interviews were carried out to record farmers' perspectives on the land conversion issue. Farmers' decision-making regarding land use is related to perceptions on rice self-sufficiency, the expected price of sugarcane, and farmer interactions with quota leaders.

Role-game preparation

The playing environment of the agents is a 3-dimensional board model that represents a typical local landscape with its main heterogeneities (3 levels of land units). Preparation highlighted that one important factor influencing agents' decisions is the topographical position of the plots (Fig. 3). This is supposed to be similar to the real landscape experienced by the players, but is not an exact representation of any particular site. The purpose is to capture the main land-use processes and such a board is supposed to be used in other villages.

Design accessories of the game are farm plots, crop yields and price lists, and sticky colored papers (Post-Its) predefined for each crop and medium of exchange. For instance, strips of white paper represent the farmers' plots of different land areas. Each block of fields is divided into subplots or "cells" corresponding to 0.8 ha each. The size of a cell is based on the minimum plot size for rice production that is sufficient to support an average household made up of five people. Different colored Post-Its represent different types of crops. When the land allocation to players is predefined, it mimics the actual heterogeneity in size among the local landholdings.

The game is designed for 10–15 players taking part in each gaming session. It can be played with more people but then time management could become a problem. Only three players can gather around the board at one time to make decisions and three assistants are needed to help them. Each time a farmer chooses a crop for a given cell, the assistant writes the cell number and time-step of the game on the Post-It. At

Fig. 3. General view of the 3-dimensional board used in the role-playing game.

the initialization of the game, the role of sugarcane quota leaders is allocated to a few players and the others are independent growers. In some cases, players are allowed to choose their own roles.

In this study, each player allocated different crops to his/her plots. After all players planted their crops, those who planted sugarcane started informal discussions with quota leaders and bargained the cane price at which they were willing to sell some of their crop as "green" cane (Fig. 4). When an agreement was reached, the exchange price was written on the Post-It to be collected later by the buyer. This procedure resembles reality in that buyers are the ones who harvest the fields so in the game they removed the cane represented by the Post-It to sell it at the sugar mill at the end of the cropping season.

Two organizers played the role of the sugarcane mill and of the market (to buy or store other crops). At the end of each time-step, players collected their Post-Its and sold their production to the mill or on the market. Information provided on Post-Its was recorded on spreadsheets for further detailed analysis of the full set of decisions made during a given gaming session. At each time-step, all crop yields were dependent on the weather randomly defined by the game organizer after all the crops were planted. Toward the end of each simulated "crop year," the sugarcane price was announced shortly before harvesting. Prices for other crops were determined on the market. If a player wanted to store rice, the market would keep its corresponding Post-It but would not return any cash to this player.

Organization of the gaming sessions

Before the interactive experiment, this RPG was tested with students to calibrate each successive step of the game and to verify the effects of the game rules and the duration of a gaming session corresponding to a minimum of 4–5 "crop years." Several game assistants were also trained at that time. One week before each gaming session, 12

Fig. 4. Price negotiation among players during the purchase of sugarcane fields sold as "green" cane.

farmers (including a few quota leaders) were invited to participate. This experiment consisted of three successive gaming sessions conducted in the same village. The first and second ones were implemented on the same day in May 2002, whereas the third one occurred in September 2002. The preparation of these experiments followed the following schedule:

- Day 1. Confirm the invitation of players representing farmers with small and large landholdings, and farmers with and without sugarcane quotas at the mill.
- Day 2. Role-game implementation in the village: one game session simulating 3–5 crop years lasts about 2–3 hours.
- Day 3–4. Synthesis of the game results, and individual interviews with the players. When possible, a companion MAS model simulating the RPG is developed.
- Day 5. Plenary meeting with the players: presentation of the game results and the model, and discussion about scenarios.

All three gaming sessions were conducted at the office of the subdistrict administrative organization near the selected village. The first session aimed at testing the representation of the system proposed by the research team and farmers' decision-making processes regarding their crop choice for different landscape units. Therefore, plot location, game rules, and lists of crops were provided. This first session is called the "researcher-controlled" game. In the second gaming session, we allowed the players to select the location of their farmland on the gaming board and to add more crop variety and other enterprises (such as pasture and livestock rearing) among the possible activities carried out on their cells. The players were also able to choose their role, so any one could register as a quota leader during this second game. This was done to allow players to create new rules and to experiment with some of their projects, such as becoming a quota leader. This game is referred to as the "farmer-controlled" game. The third gaming session was implemented with a new combination of stakeholders, including a large quota leader who is not a resident of this village. Some of the players who joined in the previous games played again in this one. The rules of this last game were more flexible and coordination among multiple stakeholders could be observed. This game is called the "multistakeholder" game. A comparison among the three gaming sessions is shown in Table 1.

Results from the role-playing game

The researcher-controlled game

In this game, players were farmers in the study village, of whom a few were local quota leaders. They played their own roles in the game. There were 12 players, of which six were defined as quota leaders (100–200 tons of cane each). Each player was given farmland of 2.5 to 9.5 ha on the board. The allocation of farmland across the three different zones materialized on the board was 20% in the lowlands, 50% in the uplands, and the rest in the transition zone. The position of each player's farmland, the list of possible crops, and all crop yields and prices were all predefined based on secondary data. For example, rice yield was 2.5 t ha^{-1} and sugarcane was 62.5 t ha^{-1} in a normal climatic year. In a dry year or for ratoon crops, all sugarcane yields were assumed to be one-half lower. Three rounds of play, corresponding to as many crop years, were played over 2.5 hours. The game started with the land allocation to crops.

Table 1. Comparison among the three games played in Nam Phong District of Khon Kaen Province, upper northern Thailand.

Game name	Researcher-controlled	Farmer-controlled	Multistakeholder
Players	- 12 farmers, - 3 local sugarcane quota leaders	Same as in the previous game - 1 large quota leader	- 8 farmers - 3 local quota leaders from outside the village
Land allocation to players	Predefined	Players defined	Predefined
Set of crops	Predefined	Players added more choices	Players added more choices
Registration as quota leaders during the game	No	Yes	Yes
No. of rounds of game ("crop years") played	3	3	5
Scenario	Drop in sugarcane price	Drop in sugarcane price	Drop in sugarcane price

Trading of "green" sugarcane fields began after all crops were planted. During the game, an announcement about good or bad rainfall conditions was made. The rainfall conditions were used to determine crop yields and prices provided at the market. When the harvest of all crops, sales on the market or at the sugar mill, and the payment of gross income to the players were completed, the round of play was finished. A drop in the price of sugarcane was the main scenario simulated in this game. The cane price started at US$15 per ton; after two time-steps, it was announced that the price of sugarcane dropped to the critically low level of $12.50 per ton. The main game results were as follows:

1. All players kept glutinous rice in their cropping systems. Rice was still planted in the lower paddies and kept for home consumption, while cash crops were planted in other zones. A few players planted and sold nonglutinous rice.
2. After the fall of the sugarcane price, players planted short-duration field crops, such as maize and watermelon, in the transition zone, but they did not grow more rice.
3. All sugarcane growers sold their crops as "green" cane to predefined quota leaders. They did not have to look for buyers since quota leaders came to growers to seek their production.
4. Bargaining for higher prices occurred among players. Some players sold to those offering the highest price, others decided to stick to the same quota leader as they do in their real circumstances.
5. Quota leaders planted sugarcane to fulfill their quota and earned more from the purchase of "green" sugarcane from other growers since they could supply the mill with an amount of cane exceeding their given quota.

These observations confirmed the farmers' strong preference for seeking maximum cash income from sugarcane production while preserving the glutinous rice production for family needs. When the sugarcane price dropped, farmers turned to other annual cash crops rather than switching back to rice because rice was less productive in the transition zone or because it was already sufficient to meet family needs. In addition, players without quotas who planted sugarcane could earn a substantial income because of the high demand for sugarcane. A price competition for "green" sugarcane fields occurs since quota leaders could supply sugarcane to the mills in excess of their predefined quota.

The farmer-controlled game

In this game, players were allowed to choose the location of their fields on the 3-D block model. They allocated their given amount of land and number of plots to capture different topographical positions on the board. Players were also given a wider choice of crops and the possibility to establish farm ponds. Players could also request new sugarcane production quotas. The sequence of successive steps in the game was the same as in the previous one.

We found that players located a smaller proportion of their farmland in the lowlands compared with that provided by the research team in the first game. This is because they wanted to earn a higher income from sugarcane. They also tried to experiment with new activities on their land, such as initiating beef-cattle rearing on pastures or intensive fish production. Except for small landholders having only 1.6 ha, most players selected farm ponds on their plots. In each time-step, all players retained sugarcane in their crop combinations. Three more players registered as new quota leaders in addition to the predefined ones. Interestingly, they requested the lowest possible quota of 100 t since they had no problem supplying more than this amount, but would have to pay a penalty if they could not meet their quota.

As the price of sugarcane dropped, the land-use pattern became more diverse than in the previous game. Players inserted "integrated farming" activities around small farm ponds, livestock grazing fields, orchards, and cassava plots. In this gaming session, sugarcane planting was not as extensive as in the previous one. Selling sugarcane as a "green" crop was less frequent than in the researcher-controlled game since most players looked after and harvested their own crops to meet their own quotas. As suggested by the players, quota leaders could reduce the size of their registered quota before the harvesting season. Most of them did this as they proceeded to the following round of play because they anticipated a fall in the price of sugarcane. In the final time-step, the sugarcane price dropped to $10 per ton. Sugarcane growers obtained less cash and quota leaders lost money since some of them purchased part of their amounts as "green" crops at a higher price. The interactions among the players were less frequent in this game because of the increased number of quota leaders.

The multistakeholder game

Thanks to the previous games, we had gained a good understanding of farmers' decision-making regarding crop choice and of the nature of their interactions with local quota leaders. In this third gaming session played in September 2002, the presence of other stakeholders, such as a large quota leader who is not a villager, was introduced. A large quota leader is an investor who can obtain much more production quota than he/she can plant on his/her own land. These leaders usually reside in town and invest their money in buying "green" sugarcane fields to complement their own production.

The large quota leader from outside the village who played in this game obtained a 10,000-t production quota and is producing only 10% of that amount on her own land. She came with her son, who is a member of the sugarcane growers association. We also invited an extension worker from the sugar mill, and a member of the Bangkok-based Cane and Sugar Fund, an organization that is instrumental in determining the official price of sugarcane. While the large quota leader played the game, these last two new stakeholders were observers.

The farmers who already played in May 2002 were visited to learn whether they were interested in playing again or not, and whether they thought that modifications to the game were necessary. Four players decided to join in this new RPG session. Those who did not come back said they were not available at that time. One said that it was better to allow new people to come and to learn how we use this RPG in the study.

The game procedures were similar to the farmer-controlled game except for land location, which was predefined. Among the 12 players, the large quota leader did not hold any land in the game. The results of this multistakeholder gaming session can be summarized as follows.

Regarding cropping decisions, we found that the farmer-players planted 45% more sugarcane than in the previous games possibly for the following two reasons. First, they could have been influenced by the presence of observers linked to the promotion of sugarcane production. The second reason was that, with a large-scale external quota leader taking part in the game, all the players knew that she would look for sugarcane to purchase. But the cropping decisions were also as flexible as in the second game. Glutinous rice and a small proportion of nonglutinous rice were planted, mostly for family consumption and in the lower paddies, while cash income was sought through sugarcane plantations in the uplands and upper paddies. When the price of sugarcane fell, most of the players switched to cassava, livestock and pastures, or integrated farming around an on-farm reservoir, but not to an increase in rice production.

For the exchange of sugarcane, we observed that one of the players who helped invite farmers to participate in this game was an influential person at the village level. He also acted as the first-level collector of sugarcane for the large-scale external quota leader. As a consequence, the players were already familiar with the network of this invited large quota leader. She also purchased "green" sugarcane from her agent in the game. The external quota leader did not try to compete with the price offered by the local quota leaders. She let the local network of quota leaders function, and bought sugarcane when she was interested or when people came to her offering a good price. She also did not want to buy ratoon crops because of their lower yields. By using the same strategy as in reality, she ended up buying less in the game than local quota leaders. She had to pay for "green" sugarcane in cash, whereas a local quota leader could pay only half of the cost during the crop cycle and settled the remaining part of the payment after selling the crop to the sugar mill.

Aggregated results

To analyze the results of land use, areas planted to different crops and for each land unit in each game were entered on a spreadsheet. The proportion of each crop grown in each land unit was compared from one time-step to another. The results from the three games displayed a similar land-use pattern, with rice in the lowlands and field crops prevailing in the uplands. More land-use dynamics were found in the upper paddy area corresponding to the transition zone. Based on the results of the multi-stakeholder game, we found that, at the beginning of the game, sugarcane was planted in all landscape units and in particular in the higher ones. Figure 5 shows that, as the game proceeded and the sugarcane price dropped, the land-use pattern became more diverse, with more orchards, livestock and grazing land, and integrated farming systems, but not more rice. In general, the decision to convert a sugarcane field into another type of crop was delayed by one year because farmers waited after the harvest of the ratoon fields in the second year.

The pooled data of all crops regardless of location differences indicate that the land-use pattern based on the farmers' point of view was more diversified than the aggregated data on land use provided by the District Agricultural Office (Fig. 6). The average planted area of glutinous rice during 1998-2002 in Nam Phong District covered about 30% of the farmland and smaller shares were found for sugarcane and cassava. In spite of the main scenario simulating a drop in the price of sugarcane, the aggregated data from the three games showed a larger proportion of sugarcane than the district statistics. However, the proportions of the total farmland under rice were found to be similar in the games and according to these statistics. This may be because the current rice areas in this district have already dropped to subsistence levels as shown in the game when most players planted rice mostly for home consumption as soon as the sessions began.

Discussion of the game results

All players expressed positive opinions on the 3-D board, the game accessories, and the rules of this RPG. They said that the gaming conditions were close to reality. For example, the heterogeneity of the gaming landscape was similar to that of their village territory. They also had to make crop choices before knowing the rainfall conditions during the cropping season, and could sell sugarcane as a "green" crop before the announcement of the official price of sugarcane for a given year. As in reality, sugarcane quota leaders were important actors in the exchange system that was used during the gaming sessions.

Most of the players acted individually when choosing crops to be allocated to their fields without any prior collective discussion. As in reality, the players considered all the different factors (physical, biological, household needs, and crop prices) related to such a choice, and decided by themselves so that in the game they did not need to request detailed information and could make their crop choices without hesitation and based on their actual circumstances and way to do things without being forced or influenced to do so. For example, at the beginning of the second session, they selected the location of their plots on the 3-D board similar to their actual locations in the village territory and so that they could gain access to at least two different landscape units. But some players used the RPG to test their personal projects, such as the creation of a fish-raising option that was not originally specified at the start of the game.

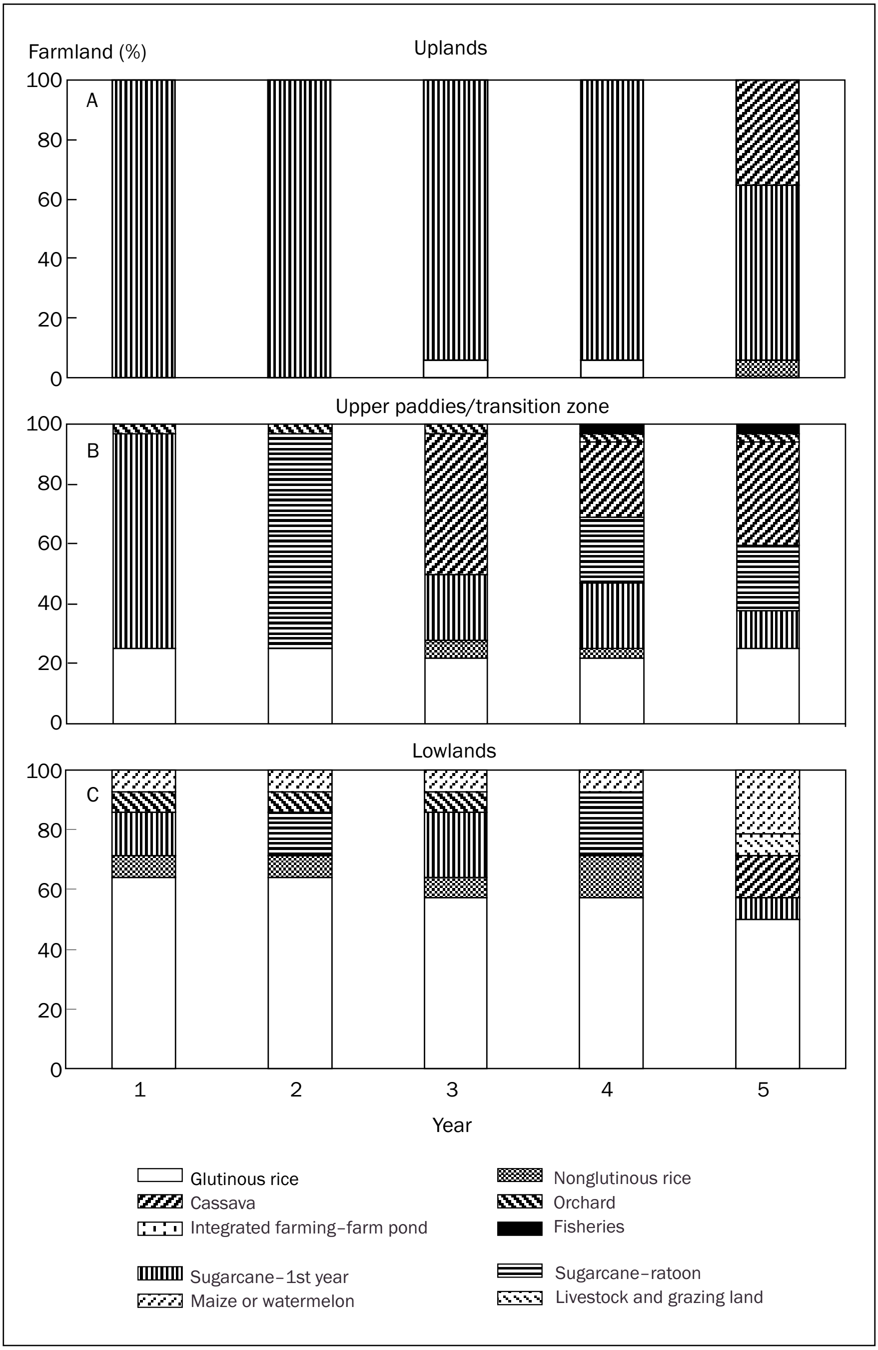

Fig. 5. Dynamics of land-use patterns for each landscape unit during the multistakeholder game.

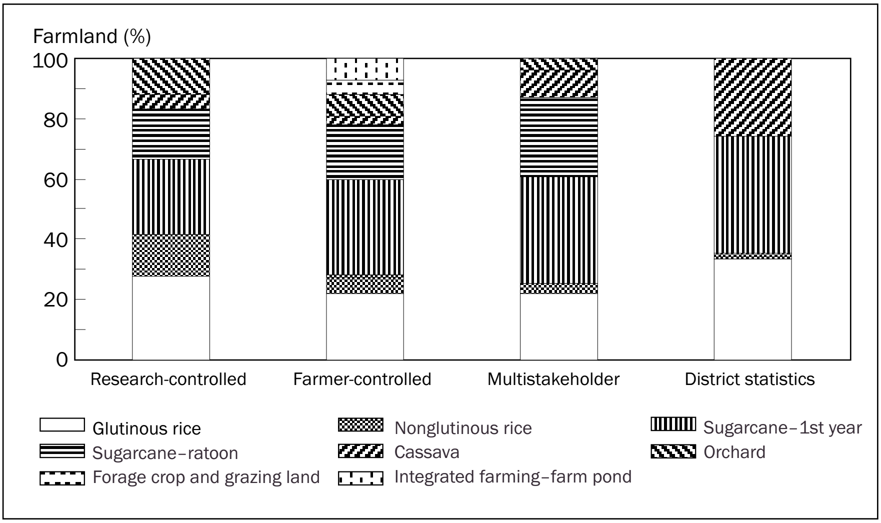

Fig. 6. Respective shares of the total farmland occupied by each main crop in the three games (pooled data) and according to the statistics of the District Agricultural Office.

At the beginning of each game, the land-use pattern was very much dominated by sugarcane plantations (Fig. 5). It was quite obvious that assured yields and expected returns from sugarcane were the main incentives. One farmer said, "I could plant 1 rai (equivalent to 0.16 ha) of sugarcane and earn enough to buy enough rice for one year, an amount of paddy that is equivalent to the production of about 4 rai of rice." Another farmer stated that "planting rice in the upper paddies is risky. If there is a dry spell, I may not get any yield, but by growing sugarcane at least I see the plants." Prior to the game, we got the impression that rice could be abandoned for more profitable cash crops such as sugarcane, but the results of the different gaming sessions showed that the extent of the paddy area could be reduced, but not beyond the level guaranteeing enough rice production to satisfy local needs for the staple crop. At the start of the games, players could be seen "planting" enough rice to be sure to meet their household needs. Thus, the proportion of rice land in the whole catchment did not change much as the game proceeded. This finding is also supported by the experimental observation indicating an increase in lowland rice yields in fields located below sugarcane fields receiving significant amounts of chemical fertilizers, part of them being carried by runoff from uplands fields to lowland paddies (Vityakorn et al 2004).

During the plenary discussion that followed the gaming sessions carried out in May 2002, we realized that it was difficult for farmers to envision a drop in the government-supported price of sugarcane. Farmers believed that large quota leaders would not let the cane price drop thanks to their strong bargaining power. As one farmer put it, "If the quota leader gets a good price, we will also get a good price for our 'green' cane." But, in September 2002, when our team came back to implement the third gaming session, the farmers said that, after learning about the ongoing negotiations on international trade, now they were aware of a possible drop in cane price. They reacted to such a scenario by producing a more dynamic and diverse pattern of land use over that third game showing that a drop in the price of sugarcane could lead to diversification, especially in the transition zone.

Although the marketing risk for sugarcane growers was limited by the existing quota and benefit-sharing system, a wider exchange system was brought about when the sugar mill allowed the participation of small-scale quota leaders, which seemed to benefit small-scale growers. This can be seen from the multistakeholder game in which the large external quota leader, using the old marketing network and strategy, earned less because more small-scale quota leaders were competing for the purchase of "green" sugarcane and bought the ratoon crop. This is possible because, at present, sugar mills allow quota leaders to supply more than their registered amounts. In real circumstances, the large quota leader gets many more sellers from other villages since she is well equipped with capital and transportation equipment to buy from her network or from walk-in sellers. The follow-up interview found that she was also well aware of the likely future price fluctuation for sugarcane and was also considering the planting of alternative crops on her own land.

In the RPG, farmers were able to try out their own projects without consultation with others. This is because they are knowledgeable about physical conditions and crop choice is individual. The UML diagrams prepared before the game were also validated during these gaming sessions, while decision-making processes regarding land use were confirmed by the game results: the price negotiation process for "green" fields of cane was verified and the RPG showed clearly that rice subsistence is still a small farmer's top priority despite higher returns from sugarcane. Regarding the sugarcane exchange system, the characteristics of the marketing network could be observed thanks to the interactions among actors in the last multistakeholder gaming session. When some rules were changed during the game, such as allowing players to register as small quota leaders, at least half of the players did not request a quota from the factory even though they did not have to invest any money or change their crop choices in the game. From the follow-up interview, those who did not become quota growers in the game said they had never done that in reality and expressed their concerns about labor management difficulties at harvest and transportation costs. Players were afraid to assume roles in the RPG that they thought they could not have access to in reality. This is a further indication of the very strong linkages established by the players between their behavior in the game and their actual circumstances and way to manage their productive resources. This observation could lead to useful information for future sugarcane quota policies at the mills willing to limit the number of growers to those who can register a production quota. However, modification of this game is needed if we want to involve new stakeholders such as sugar mill managers for the purpose of sharing knowledge and learning about the sugarcane supply chain.

The role games were found to be effective for stimulating discussion and exchange of views as they allow multistakeholders to interact in the study process at the same time. Besides being entertaining, the games helped farmers to reflect on their (and their neighbors') decision-making on land use in a timely manner. After realizing that the price of sugarcane could drop someday, farmers said that this made them think and heightened awareness of that possibility. Players also said that in the

RPG they learned about what others were thinking and planning to do. However, collective discussion about land-use pattern did not occur. One reason is that the game is based on real situations and focused on individual players' choices so players could apply their actual way of doing things in their own situation. This also indicates that in northeast Thailand farmers have been producing their crops individually and they are price takers. The latter point is based on the observation that players did not argue about the determination of crop prices made by the sugar mill or the market.

Conclusions

This RPG experiment was a preliminary step toward the development of a related MAS model. Beyond the confirmation that rice remains a key subsistence crop in this region despite high economic incentives to expand area under industrial crops such as sugarcane, the gaming sessions showed that a reduction in the price of sugarcane could lead to diversification in upper paddy area.

By using the RPG tool, particularly in the multistakeholder game, researchers were able to observe the pattern of coordination among actors of the sugarcane supply chain and this knowledge could be used in the subsequent phase of MAS modeling. A key observation from the game is that small quotas of sugarcane benefit small-scale growers and make the local market more competitive.

The farmer-players validated the features and rules of this RPG and imported their reality into the game. However, this RPG is too focused on individual crop selection and did not enhance collective discussions on land-use issues at the community level. Nevertheless, the RPG was flexible enough to allow several players to experiment with their different projects, especially during the second more open session. These gaming sessions were not designed to promote the active participation of higher-level stakeholders such as sugar mill or government officers; their presence in the third game was influential but not participatory. Beyond this first experiment, it would be interesting to explore how the game could be adjusted to focus on the sugarcane exchange system with a more active involvement of key stakeholders, particularly sugar mill managers.

Although role-playing games are useful for observing interactions, representing reality, gathering data, and sharing knowledge, this tool requires ample preparation, the availability of an interdisciplinary team and assistants made up of some half a dozen people, and careful management of this tool in the field to be able to record what happens and, later on, be able to carry out a detailed analysis of each gaming session. Follow-up interviews were found to be essential to confirm players' strategies, to obtain more explanations of the game results, and for researchers to improve their understanding of the system under study. Ultimately, knowledge and rules gained from the RPG should be built into associated computational modeling in order to allow more time-efficient simulations of possible land-use scenarios. Such a model could also be applicable to multiple locations across this subregion. For this, the reinforcement of the interdisciplinary team with a computer scientist will be required.

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Notes

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Participatory modeling for managing rainfed lowland rice variety and seed systems in lower northeast Thailand: methodology and preliminary findings

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Rainfed lowland rice varietal and seed management involves a complex system dealing with problems such as variety adoption, biodiversity, and the supply of good-quality seed. Participatory modeling of rainfed lowland rice varietal and seed management in lower northeast Thailand has been carried out to better understand the seed system and identify problems. Conceptual modeling was done through interinstitutional research team meetings, stakeholder analysis, surveying stratified random sampling of farmers and seed supply agents in Ubon Ratchathani Province, and conducting role-playing games (RPGs). The seed system was divided into three subsystems: farmers' decision-making related to rice varieties, farmers' management of seeds, and the whole existing seed supply system. A first RPG representing the first two subsystems was used at two different locations with 25 farmers. The initial findings from the RPG helped to validate and improve the conceptual model and provide a common understanding of farmers' rice varietal and seed management. Problems of limited access to or sharing of information about varieties and seed, the need for early-maturing varieties, and the scarcity of good-quality seeds were identified. A second RPG will deal with the whole seed supply system. A more comprehensive analysis of the RPG results with those of the farm survey will be done to improve the conceptual models, together with developing a multi-agent model representing the whole rainfed lowland rice seed system.

This paper aims to present and discuss the research framework, research methods, and initial results of investigating the systems for rice varietal and seed management through systems modeling with a participatory approach under a collaborative research project between IRRI-CIRAD and the Office of Agricultural Research and Development (OARD) IV and Rice Research Institute (RRI) under the Thai Department of Agriculture (DOA) and Ubon Ratchathani University (UBU) that started in November 2002 within a selected region of lower northeast Thailand, a major rainfed lowland rice (RLR) area in Thailand.

The lower northeast Thailand subregion contains nine provinces covering 8.4 million ha, with 17,357 villages and 11.5 million people. About 70% of the agricultural land belongs to the rainfed lowland rice ecosystem (DOA 2001). According to a survey done by the Rice Research Institute during 1982-86, more than 1,500 rice varieties were grown in northeast Thailand (Chaidee and Thongpitak 1992). The government has been making a high investment for a long time to release better varieties (according to rice scientists' criteria) as recommended varieties and produce and supply seeds to farmers. Fourteen recommended varieties have been distributed by the DOA to farmers in northeast Thailand since 1956 (Pantuwan and Jongdee 2003). Rice varieties in this region can be separated into glutinous and nonglutinous ones. Glutinous rice is mainly for family consumption in the majority of households in the region and the nonglutinous paddy is mainly for sale. Recent surveys reported that the glutinous rice varieties were more diverse than the nonglutinous ones (OAE 2000, Polthani et al 2002). RD6, the glutinous variety released in 1977, is the dominant one in this group. The nonglutinous one mainly grown for sale is "Hom Mali rice," which officially includes the two recommended RLR varieties, KDML105 and RD15 (Ministry of Commerce 1997). KDML105 was released in 1959 and is much more dominant than RD15, an early-maturing mutant of KDML105 released in 1978. About 77% of the farmers in the northeast have adopted these three recommended varieties (OAE 2000). In Thailand, Shinawatra and Woottikarn (1994), CBDC (2002), and Gypmantasiri et al (2003) have studied farmers' adoption and preference of rice varieties. The DOA has tried to find out why farmers have not adopted the most recently released varieties (Pantuwan and Jongdee 2003). Little work has been done to comprehensively analyze farmers' variety adoption and especially to study the linkage between farmers' requirements for varieties and seeds and the government and commercial seed service systems.

It has been reported that most farmers in the northeast are still using their own rice seed, but more farmers tend to buy seeds and also to change seeds more frequently (OAE 2000). However, the production capacity of the government for rice seed is only 3–5% of the demand (DOCP 2001). Meanwhile, more and more organizations and projects are becoming involved in the rice seed supply system nationally besides the Seed Centers (SCs) under the Department of Agricultural Extension (DOAE), which used to be the only ones responsible for this task in the country since 1976. These emerging agents are supported by either the government or the private sector. The deficiency in rice seeds required by farmers is a problem that also occurs in countries such as Indonesia, Vietnam, and Malaysia (CBDC 2001a,b). In Thailand, few technical documents have explained the rice seed production and supply system, except for some statistical reports and comments in the annual reports of each institute, such as the DOA, DOAE, or Department of Cooperative Promotion (DOCP). A need to improve rice seed production systems of the DOAE has been recently documented in Siriwattananukul et al (2003), studying the adoption of the DOAE's rice seed production program in the southern region. No comprehensive information on rice seed supply systems of different agents and their linkage with the varietal and seed management system at the farm level has been reported. The situation of seed systems in Thailand agrees with what Tripp (2001) had identified as the three main generic problems of seed systems: problems with variety release procedures, which were a monopoly of the public sector subject to bureaucratic delays; the inadequacy of information available to farmers; and weaknesses in commercial seed markets.

Similar to what occurs in many other rice-growing countries, the impact of the adoption of a few dominant recommended varieties has led to genetic erosion concerns

(IRRI 1998), resulting in more attempts to establish rice biodiversity conservation projects (Bellon et al 1998, DOA 2002, CBDC 2002, Zhu et al 2003), with research and development trends turning to the farmer participatory approach (CBDC 2002). Bellon (2004) has argued that the crop diversity maintained by farming households results from the interplay between a demand of farmers and a supply of seed. Now, there is no common platform for stakeholders to communicate about this topic, particularly for farmers, who should have their required varieties match their consumption needs and field conditions and should have good-quality seed for agronomic and marketing aspects, while the public institutions conserve rice biodiversity as valuable genetic sources and as alternative varieties.

To understand the complexity of the system, an interactive participatory modeling approach is proposed for better knowledge integration and communication of different perceptions. The rice varietal and seed management system is modeled to encompass farmers' behavior regarding RLR variety and seed source selection in such a heterogeneous ecosystem in relation to seed supply systems. The modeling process requires the participation of farmers and other stakeholders to share their actual needs and roles in the common communication platform. A main purpose is to provide a better understanding of the system's behavior, to identify its key constraints and current weaknesses, and to help find acceptable ways to improve its current functioning to better meet farmers' seed requirements. This can lead to establishing a coordination and negotiation support system for serving farmers' needs in RLR production and to harmonize stakeholders' roles and objectives as well as conserving biodiversity under dynamic and multilevel circumstances.

This paper explains the research problems, the model conceptualization, its theoretical background, and methodology used. The participatory research procedure starting from establishment of the interinstitutional research team with information and concept sharing is emphasized. The paper also presents the preliminary major activities of conceptual modeling and an analysis of stakeholder and farm surveys together with the conducting of a role-playing game (RPG) as a part of participatory modeling. Also mentioned are some proposed aspects for the next phase.

Assumptions and hypotheses

The study of a system is dynamic and complex, spatially diverse, and multilevel and concerns many stakeholders. A system is based on several assumptions drawn from existing knowledge about it. Rice biodiversity in the region tends to decrease because of the high adoption of major rice varieties under market demand and their fitting with farmers' preferences. Also, farmers are more commercially dependent on a seed supply from different external sources with seed scarcity and quality concerns. However, many farmers (more than a third of them in our study area) are still using other varieties beyond the recommended ones. Those varieties fit their needs, resources, and environments, but are not looked after by government agencies involved in the seed system. One assumption examined in this research is the contrast in objectives among the government or international agencies themselves—promoting a few recommended varieties, but also willing to conserve biodiversity for global sustainability.

Hence, our central hypothesis to be examined with the mentioned assumptions is that, in the system of rice varietal and seed management, what the farmers decide and need does not match with what policymakers decide and implement because of the lack of system understanding, and improper connections and poor communication from farmers to policymakers and researchers. In addition, some significant weak points in the existing system need to be identified and improved.

The participatory modeling approach we selected should provide a clear and holistic explanation of the system and can be applied to other similar problems related to the management of scarce renewable resources. Consequently, the model and knowledge produced should be able to produce a best-bet alternative for farmers and other stakeholders to put in place a sustainable seed supply system for suitable varieties while conserving rice biodiversity.

Theoretical background and state of the art

The management of RLR varieties and the seed system deals with various varieties having different purposes of use, different sources and suppliers, different farmers with different resources, and different institutes and agents, with systems changing over time and location, depending on many levels of decision-making—from the plot level to international concerns. Understanding this complexity can be attempted by a systems approach and simulation modeling. Several methods of simulation modeling have been developed for social sciences for decades. For example, system dynamics based on differential equations with the stock-and-flow concept describes the system under study as a single entity or object and aims to use simulation for prediction. Forrester (1972) illustrated some examples of system dynamics models for simulating the supply of products from a factory to its customers. Low (1980) applied this system dynamics modeling principle to improve the Samuelson-Hicks multiplier-accelerator model of a business cycle that can identify causal structures that underlie actual decision-making and clarify the direction of causality. However, these types of model also depend heavily on quantitative assumptions that are weak points of simulation based on social science that we are more concerned with understanding and explaining (Gilbert and Troitzsch 1999).

Multi-agent models able to simulate autonomous individuals and their interactions developed from nonlinear dynamics and artificial intelligence research could be applied to the simulation of human societies. They rely on computer programs to facilitate an increase in knowledge and procedural skills by learning from experience. Models with the ability to learn are very useful both for simulating cognitive processes of individuals and for modeling the society adapting to circumstances over time.

The participatory modeling approach based on multi-agent systems (MAS) associated with RPGs is proposed as our chosen method. In this approach, field work and system modeling are two complementary activities that are closely linked in an iterative way to produce a shared representation of the system. Recent field experiences have demonstrated the effectiveness of the use of such models to support on-farm, interdisciplinary, and action-oriented research in various contexts (D'Aquino et al 2002). MAS are the computational systems originated from distributed artificial intelligence (DAI) and they rely on the technology of cellular automata (Bousquet et al 2004, Trébuil et al 2002a) that are increasingly used in various fields of natural resource management research. This MAS modeling process can be associated with RPGs, another interactive tool frequently used in the companion modeling approach. The use of RPGs derived from more complex models through simplifications is a dialogue-facilitating tool for the collective and interactive learning process among multiple stakeholders (Bousquet et al 2004). RPGs are used to validate and criticize the preliminary conceptual model and our existing knowledge of the system, and to enrich it through an interactive process among players. Another advantage of RPGs over interviews is that people may feel more comfortable in answering "what if" questions because these are closer to the reality than thinking of a way to answer a more difficult and abstract question. Moreover, the game playing is orderly when played in a sequence reflecting the step of decision-making actually used in real circumstances. Working on the 3-D model board helps the players visualize together and make decisions under the spatial arrangement (Bousquet et al 2004, Trébuil et al 2002b).

Since this study involves both the decision-making of individual farmers and the management of the seed supply system of institutions, several economic theories can be employed. The theory of decision-making in product choice explained by the conceptual model of consumer behavior called the Consumat approach using MAS proposed by Jager and Janssen (2003) is aimed for inclusion in modeling. This interesting approach integrates several decision-making theories and explains the different behaviors in choosing products as repetition, imitation, social comparison, and deliberation regarding the two dimensions of uncertainty and need satisfaction level. These can be applied to the selection behaviors for rice varieties and seed sources of farmers, which seem to be diverse and influenced by the uncertainty of physical and social variables of the RLR production system.

The analysis and modeling of a seed production and supply system at the institutional level can be done under the approach of supply chain modeling that crystallizes the concepts of integrated business planning with the functional integration of purchasing inputs, manufacturing, transporting, and warehousing, and the spatial integration of these activities across vendors, facilities, and markets, with support from a geographic information system (GIS) to become a decision support system (Hoffman 1997). Moreover, modeling the process of seed distribution from different institutions to farmers can be compared and shared with model-based analysis and simulating the diffusion of "green" (organic) products with co-evolution between firms and consumers under the abovementioned Consumat approach (Janssen and Jager 2002).

Construction of a conceptual model and data gathering

At the initial stage of the research project, the system was first analyzed within the boundary of RLR in Ubon Ratchathani Province, a major province in the region with key agricultural research and extension institutes. The participatory approach was employed to carry out several meetings of different relevant institutes in Ubon Ratchathani to gradually establish the research team and develop a conceptual model of RLR varietal and seed management. The interdisciplinary team is composed of an agricultural systems specialist and a MAS modeler from IRRI-CIRAD, a breeder and a seed production specialist from the Ubon Ratchathani Rice Research Center (URRC), a farming systems research and development team from the OARD-IV, and a systems agronomist, as well as a landscape agronomist and a rural sociologist from Ubon Ratchathani University.

The unified modeling language (UML) for building the conceptual model has been introduced to provide a diagrammatic representation of the research team's understanding of the rice varietal and seed management system before looking for more information from farmers and other stakeholders. The whole system was initially split into two models: farmers' varietal management model and seed supply model.

The first model was formed as a decision flow diagram explaining farmers' decision-making on varieties. The farmer decision-making model was initially based on relevant secondary data and experiences from the team. The other model was constructed to represent the structure of seed supply systems concerning the relevant institutes or agents. Stakeholders were defined by the research team and questions were asked concerning their objectives, roles, and functions in the system (Table 1). These have been done with iterative processes from simple to more complex models during several meetings, along with information gathered from field work and available data. Successive half-day-long meetings gradually improved the models by sharing experiences, information, and perceptions of each researcher, especially the ones from OARD-IV and URRC, who have much experience working with rice farmers and agricultural institutes in this region. This helped to create a common picture of the system to be managed and generated follow-up questions. Then, information was gathered for improving our understanding for the next meeting, meaning more updating of information and a better conceptual model each time a meeting took place.

Another model about farmers' choice of seed sources was added to a link between the first two models mentioned above. This model is another decision flow diagram that explains how farmers manage their seeds and decide to buy new ones from a certain supplier. Data from the farm survey and the RPG helped to construct this model.

Relevant documents were reviewed and secondary data were analyzed in parallel with the field survey. The complementary field work included interviews with key informants from different stakeholders such as the DOA, DOAE, DOCP, agricultural cooperatives (ACs), seed traders, and contract farmers (Table 1). A survey of farmers' use of rice varieties in the 2002 wet season was carried out by stratified sampling of 258 farmers from all 25 districts in Ubon Ratchathani from December 2002 to May 2003. This aimed to collect, analyze, and integrate current information to document farmers' decision-making rules regarding rice varieties and seed supply. Results were also compared with previous rice variety studies in northeast Thailand by Chaidee and Thongpitak (1992) and Gypmantasiri et al (2003) to assess rice biodiversity dynamics as well as its spatial distribution. These gradually improved conceptual models are presented below.

Construction of the role-playing games (RPGs)

We decided to build two separate RPGs on the basis of different focused objectives based on the knowledge acquired during the model conceptualization phase and the

Table 1. Stakeholders of the RLR rice seed system in northeast Thailand, 2002.

Stakeholder	Role/function/linkage in the system
Farmers	Producing paddy rice for home consumption and sale. Using variety and seeds as inputs, collect own seed if not changing, exchange seed with other farmers.
Seed production contract farmers of each agency (SC, cooperatives, or CP)	Doing as other farmers do, and also producing stock or certified seed to sell to their contract agencies.
Rice Research Centers (RRCs)/ Rice Research Institute (RRI)/under the Dept. of Agriculture (DOA)	Breeding for new varieties. Maintaining quality of the recommended cultivars. Producing foundation seed for the requested seed multiplication agents and selling the surplus. Conserving rice genetic pool.
Seed Centers (SCs)/under the Dept. of Agricultural Extension (DOAE)	Managing contract farmer system to produce stock and certified seed, seed improvement and selling seed at the center or through agents and DAO, or providing seed for special projects. Certifying seed. Certifying seed traders.
Agricultural Cooperatives (ACs) (supported by Dept. of Cooperative Promotion, DOCP)	Seed-producing cooperatives (5 in Ubon Ratchathani) producing stock or certified seed through contract farmers and implementing other AC activities such as seed trading, paddy trading, and providing loans to members.
District Agricultural Office (DAO, under the Dept. of Agricultural Extension, DOAE)	Assisting community rice Seed Centers and distributing seed to farmers at the district level. Collecting data on farmers, providing seed and technical information. Getting stock seed from SC through DAO to produce certified seed through members and distributing seed for the community by exchanging or selling.
Charoen Phokpand (CP) Seed Company	Running seed production business. Multiplying foundation seed to produce stock seed and sell seed.
Bank for Agriculture and Cooperatives (BAC)	Giving loans to farmer members, including distributing seed from the ACM.
Agricultural Cooperative for Marketing (ACM)	Trading seed and other agricultural inputs and products.
Rice mills	Trading rough rice and producing milled rice, grading rice production quality when buying. Sometimes selling seed.
Agricultural store/traders	Trading seed and paddy. Distributing stock or certified seed to farmers.

results of the farm survey. The first RPG simulates farmers' decision-making on rice varieties and seed sources and the second one simulates the decision-making of different stakeholders in the seed supply system. Each game is used in sessions organized at different geographical locations (an area close to seed production agencies and a more remote one) to avoid the management of too many players and activities at the same time.

Before designing these RPGs, the research team from Ubon Ratchathani had visited two other teams and projects using this tool with MAS modeling in other regions of Thailand. One was about understanding the interaction between agricultural diversification and the risk of soil erosion in a highland watershed of Chiang Rai Province (Trébuil et al 2002b) and the other one was about the dynamics of the transition from paddy land to sugarcane plantations in Khon Kaen Province (see Suphanchaimart et al, this volume). At these two sites, our team learned how to design an RPG and to implement a gaming session followed by individual farmer interviews and collective discussions.

In the first game, the room is spatially arranged into two zones according to different factors such as distance to major seed suppliers and degree of rice biodiversity found during the farm survey. The 3-D board (60 cm × 60 cm) representing the paddy landscape made up of three main types of fields is prepared to represent the lower, middle, and upper paddy terraces (Fig. 1). The selection of RLR varieties or seed sources is represented by sticker tapes of different colors and patterns applied by players to each field with the help of several assistants. For practical convenience, two boards representing two different areas are played simultaneously in the same room. Six farmers play at each board, with two players representing each main type of farm (small, medium, and large ones) in the same zone. The number of paddy fields assigned to each player changes with his/her farm size, as shown in Figure 1.

Farmers are selected from the surveyed villages but not among the ones we interviewed. The selection of farmers aims at a diversity in farm size, rice variety, and seed suppliers, with a balance between the number of male and female players. At the beginning of the game, the suitable types and number of rice fields are allocated to each farmer on the 3-D board according to the actual characteristics of their own farms. Each farmer receives a certain amount of money for buying seeds. Each "year," farmers are asked to select the varieties grown on each plot, the planting method (transplanting or direct seeding), and the source of seeds for each selected variety. Then, farmers pay for the purchase of their seeds if applicable. After all players complete these activities, they are asked to harvest their rice crops and to decide, for each variety, how much paddy they want to retain for seeds, family consumption, and sale. They

Fig. 1. Players allocating their rice varieties to their different types of paddy fields on the RPG board.

receive payment for the sale of their paddy and wait to play the following "year" of the gaming session. Farmers are reminded not to be too much concerned about cash flow and earnings in the game but to decide according to their actual practices under the given conditions.

This first game explores the decision-making behaviors that include the choice of rice variety and the choice of seed source, the allocation of each variety to different types of paddy fields, and the decision to collect or discard RLR seed from their own fields. The feedback of players' decisions that may affect the decision of the next step can be shown as the quality and/or price of rice sold depending on seed quality, variety grown, and amount of money left after buying seed. A key concept is to keep the game interactive and flexible. Some game conditions or rules may be modified according to the players, for example, changing the landholding size, number of family members, farm labor, seed price, and rough rice price, or a new variety can be introduced to see its contribution to the next decision-making.

After playing for two simulated "years," we discussed with farmers their feelings and opinions about the game in relation to reality. Farmers were asked whether they wanted to change the rules or resources allocated; however, no farmer suggested significant changes. We discussed rice practices, such as planting methods, variety choice, seed prices, and seed supplier availability across villages and zones. Farmer-players were interviewed the day after the gaming session about their decision-making during the game, their real circumstances, and their opinions about the usefulness of the RPG tool. Analysis through the game gave us some more details on what farmers do and how they decide at each step of a round of play. The farmers are observed to see how they relate their actions in the RPG to reality, and how they experiment and imagine new things during the game. We also try to study the different kinds of reasoning behind farmers' decision-making processes on varietal management according to the abovementioned Consumat approach of Jager and Janssen (2003).

The first gaming session was played on 29 September 2003 at the Ubon Ratchathani Agricultural and Technology College with 12 farmer-players from three specific zones: one close to the RRC, another one close to the city, and a last one in a partially irrigated area. The second session was played on 26 January 2004 in the more remote areas of Ban Bua Ngarm village of Det Udom District, 80 km south of Ubon Ratchathani. This time, 13 farmer-players took part. They belonged to different ethnic groups: Khmer farmers from a village near the Cambodian border growing only nonglutinous rice, Lao farmers from Ban Bua Ngarm growing diverse glutinous rice varieties, and Lao villagers engaged in a special rice production for a niche market in Pibun Mungsaharn District. Seed-producing farmers from the Community Seed Centers (CSCs) in each village also took part in this second session. The initial results of these first gaming sessions are presented below.

The second RPG deals with the whole seed supply system and is designed according to the conceptual model on seed supply. Players will mainly belong to the seed production and supply institutes or will be contract farmers producing seeds (Table 1). This time, each player can use different system boundaries or scales according to their respective mandates and responsibilities. The CSC may play at the village scale, while the cooperatives could play at the District scale, and the RRC or SC at the provincial scale. This setup should assist in the collective learning of each stakeholders' objectives, functions, and interactions, or lack of them, in different RLR-growing areas. The decision-making, planning, and implementing process of each seed-producing agent to get and supply the amount of seed of each variety required by seed purchasers each year and at different locations could be learned from this second RPG.

Preliminary results and discussion

Farmers' choices and management of varieties

Modeling the farmers' choices of varieties was based on our initial understanding that ethnicity is a determinant of the type of rice to grow for home consumption as reported by Chaidee and Thongpitak (1992) and Polthani et al (2002). Lao farmers, who are the majority of people in the northeast, usually eat glutinous rice, whereas the Khmers, living in the lower part of the region, as well as other Thais, eat mainly nonglutinous rice. The decision flow model shown in Figure 1 simply states that Lao farmers have to grow glutinous rice for food security and they grow nonglutinous rice (Hom Mali rice) for cash income since it usually fetches a higher farm-gate price. However, we found that some nonglutinous rice is also consumed (around one in ten meals) by most Lao households. In our survey, the 3.5% who did not grow glutinous rice are Khmers, living in the southernmost part of the province along the Cambodian border. However, several Khmer households included in our survey in Ubon Ratchathani Province and who took part in the first RPG also grow and consume glutinous rice, probably because of the proximity and influence of the majority of Lao ethnic farmers.

The survey and the first RPG indicated that Lao farmers prioritize growing glutinous rice in agroecological zones and fields to be able to produce enough yield to ensure food security (Fig. 2). From our survey data, we found that the average glutinous rice area required per family member is about 0.16–0.32 ha, or 1.6 ha per household. Some 11.5% of the households grow only glutinous rice, with an average farm size of 2 ha and average family of five members, with not much variation (Table 2). In the RPG, when increases in household members and labor units were announced, most farmers then grew more glutinous rice. This confirms the priority of glutinous rice for food security and as a preference. One farmer who grew only glutinous rice asked us to sell some, though breaking our initial game rule. We found that few farmers grow glutinous rice for sale except when they have a surplus.

KDML105, RD15, and RD6 are the major RLR varieties confirmed by our field survey (Table 3) and the first RPG. Many different reasons for choosing glutinous varieties are found, such as taste preference, maturity, yield, etc. Growing only RD6 for glutinous rice is most popular (61%), but other glutinous varieties are still used by 17.4% of the farmers, while 18.1% grow a combination of RD6 and other glutinous varieties (Table 3). All the farmers seem to be familiar with RD6, but some have rejected it for different reasons. Many claim that RD6 has a hard cooking texture if its seeds are not changed frequently (1–3 years). Some prefer to grow early-maturing or nonphotoperiod-sensitive glutinous varieties to avoid drought or to be able to grow postrice crops earlier, especially for upper paddy conditions.

Choosing early-maturing glutinous varieties can be related to the decision to grow nonglutinous KDML105 or RD15 rice because of the mutual help practice still

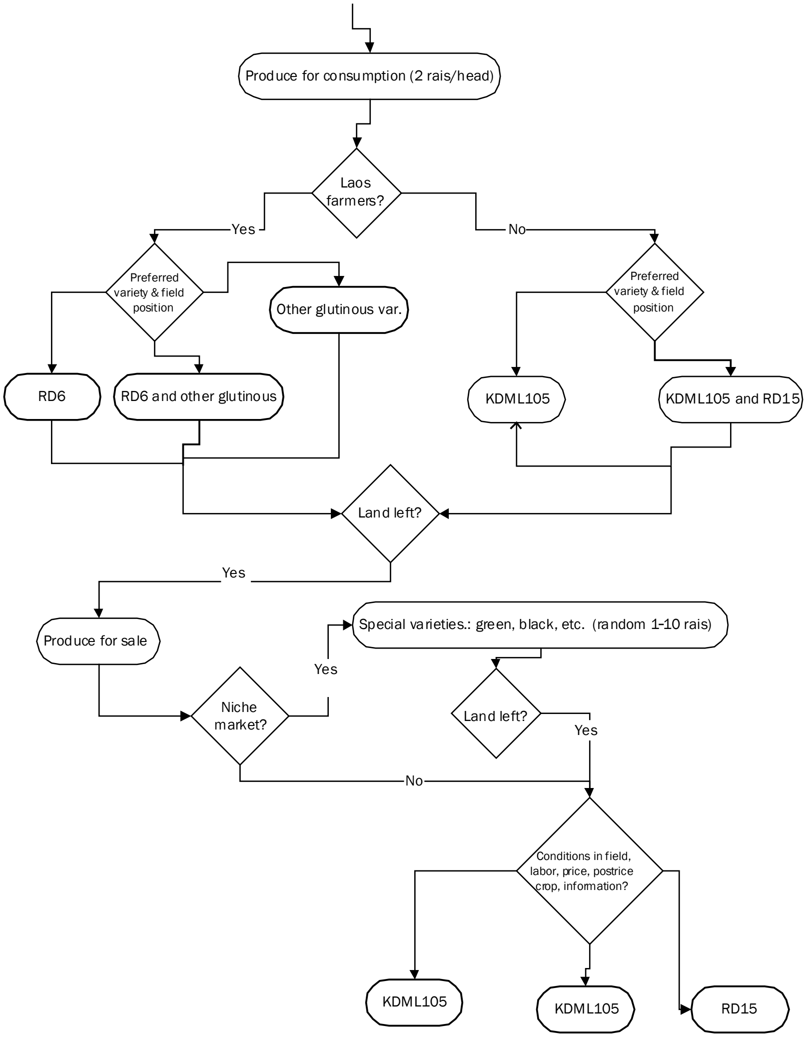

Fig. 2. Decision model for a farmer's choice of rice varieties, focusing on main varieties, lower northeast Thailand, 2002. Percentages are the proportion of farmers found in the survey in Ubon Ratchathani, 2002.

in use at harvesting. Some farmers who grow KDML105 prefer to grow early-maturing glutinous rice to be harvested first. Farmers also grow more than one glutinous variety when they want to stagger the rice harvest. A labor constraint at rice harvest is common as the average farm labor is only 2–3 persons (Table 2). Some 35 variety names of glutinous rice were found in this survey and almost all of them seem to be early-maturing varieties bearing the same names as local varieties listed in Chaidee and Thongpitak (1992) such as Daw Boonma, Daw Khao, Daw Ko Diew, etc. Some of them used to be recommended, such as Niew Sanpatong, RD8, and Hang Yi cultivars. Some surveyed farmers grow RD10, a nonphotoperiod-sensitive variety that

Table 2. Rice type grown by farmers with different ethnic groups and main purposes and frequency (%), with average farm household and amount of farm labor and mean, standard deviation, and range of farm size (surveyed in Ubon Ratchathani, 2002 wet season).

Farmer group by rice type grown	Farmer ethnic group	Rice production type	% of farmers growing	Mean no. of household members	Mean household labor	Rice-growing area (rai) (1 rai = 0.16 ha)			
						Mean	Standard deviation	Min.	Max.
Only glutinous	Lao	Subsistence	11.5	5	3	12	8	4	33
Only nonglutinous	Khmer, Thai	Partly commercial	3.5	5	2	22	11	10	46
Both glutinous and nonglutinous	Lao	Partly commercial	85.0	5	2	20	16	3	130

is currently recommended for irrigated rice during the dry season. It is considered as an early-maturing variety because it is usually planted early in the season and then harvested first. The E-norn glutinous upland rice variety is also planted by a farmer who took part in the RPG. Frequent changes in these glutinous rice varieties are observed but access to information about them is sometimes limited, even in the same community. New varieties may be introduced from other provinces, often thanks to relatives living there. Variety names used by farmers are sometimes confusing, as reported by Bellon (2004).

Growing rice for cash as a second priority can have two alternatives (Fig. 2). If farmers have potential access (skill and a market) to produce special types of rice or rice for a niche market such as glutinous green rice (immature rice), black glutinous rice, or yellow nonglutinous rice for dessert and red Mali rice that seems to earn more income than Hom Mali rice, they should grow those varieties, but on a small area of 0.16 to 1.6 ha because of the limited production capacity and limited market. Only 2.7% of the farmers represent this case from our survey. A late harvest of RD6 or any glutinous rice can be used to make green rice.

The nonglutinous rice varieties such as Khao Chao Daeng used for producing Thai noodle starch existed 10 years ago in many areas of Ubon Ratchathani Province as reported by Chaidee and Thongpitak (1992) but they were not found at all in our recent survey. The Thai noodle factories buy milled nonglutinous rice from other provinces, such as Nakhon Ratchasima, for this purpose instead. One farmer selected to play in the second gaming session grew a deepwater nonglutinous rice variety called Leb Mue Nang to avoid flooding damage and could sell it to the local rice mill.

Generally, growing nonglutinous rice is limited to KDML105 or RD15 since they are the only varieties accepted as Hom Mali rice and are accepted on most of the non-glutinous rice markets in the region, where they are 10% to 50% more expensive than the other common rice varieties. According to our survey, 65% of the local farmers are planting only KDML105, 12% grow only RD15, and 15% produce both cultivars (Table 3 and Fig. 2). This kind of choice depends on several factors. RD15 matures in late October or early November, 2–3 weeks earlier than KDML105, and this early harvest leads to a higher farm-gate price. RD15 is suitable for well-drained fields that tend to be more extended. RD15 also provides more time for labor sharing at harvest if farmers also grow RD6. However, limitations of RD15 are its early harvesting period, sometimes in wet conditions, which damage the quality of the paddy; the scarcity of good-quality seeds; and the lack of information about this cultivar. However, our survey found that RD15 is becoming more popular in many areas of the province.

The need for early-maturing varieties was confirmed in the RPG. When a new glutinous nonphotoperiod-sensitive variety with 120 days' maturity was introduced, some farmers selected it, especially those from areas with a higher diversity of cultivars. This also indicates different characteristics among farmers and areas regarding variety adoption. The preliminary findings from both the field survey and RPG indicated that the extent of rice biodiversity or number of varieties found is related to spatial patterns in the province. In the districts close to URRC and the SC and near Ubon Ratchathani City, only three recommended varieties were found. Areas with high rice biodiversity (9–16 varieties) were found in the southern and eastern districts, with influence from irrigated rice varieties and border exchanges with Laos and Cambodia.

The allocation of certain varieties to specific types of fields is decided for various reasons. For example, priority staple glutinous rice is grown in more favorable conditions, mostly in the well-watered lower paddies, whereas early-maturing rice is grown in the upper paddies for water-regime reasons or close to the farm hut or the road for convenient rice threshing and paddy transportation. These familiar choices are well represented on the playing board of our RPG (Fig. 1).

In summary, many factors have been claimed by farmers to influence the choice of variety, such as yield, landscape, market demand, price, seed availability and accessibility, information accessibility, labor availability at harvest, farm size, cooking quality, aroma, preference, maturity, disease or pest susceptibility, degree of lodging, flood or drought tolerance, grain fitting the milling machine, or use for specific rice products, or even health problems.

Farmers' management of seed sources

Our initial understanding regarding farmers' choice of seed sources is shown in Figure 3. This conceptual model has been developed from the survey information and was validated and improved through the RPGs. This model is linked to the previous one presented in Figure 2 displaying how farmers select the RLR varieties to be used. If farmers do not plan to change a variety, the decision they have to make is between collecting seeds from their fields or changing to new seeds from outside their farm. Our survey found that 50–60% of the farmers changed the seed of the three recommended varieties every 1–3 years, whereas 10% never changed it (Table 4). A similar picture emerged from the game results.

Table 3. Choice of varieties used and frequency (%) of farmers growing them, with average farm household and amount of farm labor and mean, standard deviation, and range of farm size (surveyed in Ubon Ratchathani, 2002 wet season).

Choice of rice varieties	% of farmers growing (n = 258)	Mean no. of household members	Mean household labor	Rice-growing area (rai) (1 rai = 0.16 ha)			
				Mean	Standard deviation	Min.	Max.
Glutinous							
RD6 and other glutinous	18.1	5	3	28	23	8	130
RD6 but not other glutinous	61.0	5	3	20	12	3	65
Other glutinous but not RD6	17.4	5	3	20	17	4	94
Nonglutinous							
KDML105 and RD15	14.8	5	3	27	22	5	130
KDML105 but not RD15	64.7	5	3	22	15	3	94
RD15 but not KDML105	12.4	5	3	22	11	4	50
Special varieties for niche market	2.7	6	3	26	18	11	58

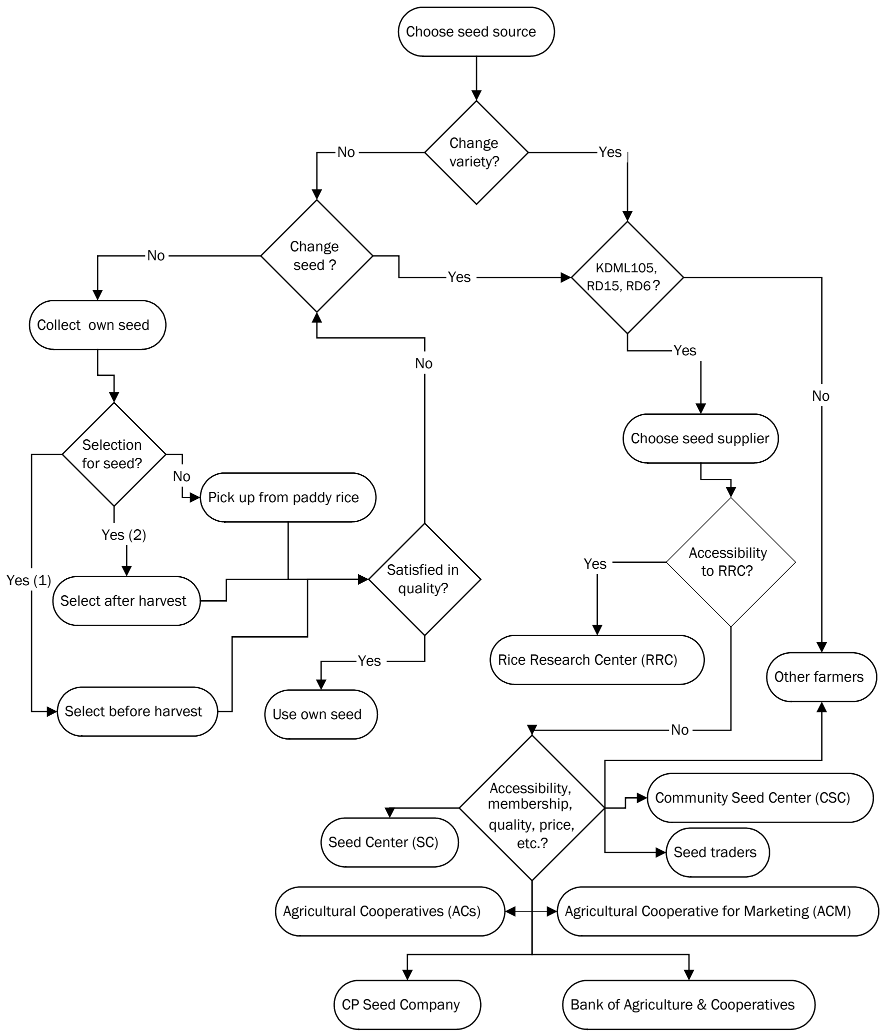

Fig. 3. Decision model for a farmer's choice of seed sources and suppliers, Ubon Ratchathani, lower northeast Thailand, 2002.

A major reason for changing glutinous rice seed is cooking quality, as the grain becomes harder with time. For nonglutinous KDML105 and RD15, a change of seed is necessary when more off-type plants appear, resulting in a lower paddy price. The seed suppliers of the above three recommended varieties could be several agencies: URRC, Seed Center (SC), Community Seed Centers (CSCs), the Agricultural Cooperatives (ACs), and the Charoen Pokphand Seed Company (CP). The SC's seed can be obtained through the District Agricultural Offices (DAOs) or from their network of certified stores and rice mills, whereas CP seeds are sold by the Agricultural Cooperative for Marketing (ACM) organization with support from the Bank for Agriculture and Cooperatives (BAC), or at several stores (Fig. 3 and Table 4).

Based on information from both the farm survey and the RPG, many farmers are very unclear and confused about seed sources. Most farmers may know a direct supplier but not the actual original source of the seed. Some suppliers sell seed from more than one source. The diversity of places from which farmers buy seed is high (Fig. 3 and Table 4). However, the survey findings show that seed of the three dominating recommended varieties is mainly purchased from two sources—the SC through DAOs and traders (14–20%) and ACs (18–21%). The price of seed from ACs was lower (260–320 baht 25 kg^{-1}) and varied more than at the SC (320 baht 25 kg^{-1} or 12 baht kg^{-1}). CSCs had a small share probably because of poor quality, poor packaging, and limited distribution to the local community. A higher proportion of CP rice seed was observed in 2003 though its high price (360 baht 20 kg^{-1} or 18 baht kg^{-1}) limited access, but it had the best packaging and good quality.

Most farmers cannot explain clearly why they choose such seed suppliers or do not choose any at all. Poor accessibility to seed information was confirmed in the survey and RPG. Most farmers had not realized that so many suppliers were available. However, several reasons for their choice of suppliers can be listed, such as distance to selling places, access to relevant information, seed quality, brand name, community influence, membership in an organization, seed price, etc. URRC seems to be the first choice because of its production of high-quality foundation seed and its reputation for a relatively cheap price (10 baht kg^{-1}) thanks to government subsidies. But seed availability and access limit its role as a first-choice supplier. In the seed supply model (Fig. 3), we considered that seed quality should be the first priority when making a choice among suppliers and concluded that URRC is the most preferred, if it is accessible. Proximity or accessibility—physical or social—to seed suppliers was found to be a major determinant of supplier choice. Seed price does not seem to trouble most farmers compared with fertilizer or labor costs. In the RPG, when we let every supplier sell the major recommended varieties at the same low price (10 baht kg^{-1}), this did not change farmers' decision-making. For some farmers, seed investment in the game was somewhat higher than in reality. In fact, some farmers did not purchase enough seed for all their fields, especially farmers using the broadcasting method with a higher seeding rate.

For other RLR varieties that are not currently recommended, farmers have to exchange seed among themselves. Seed of the recommended varieties is also being exchanged among farmers (14–20% of the total) and some seed trading among farmers is observed. Switching to other glutinous rice varieties seems to be common in areas with a higher diversity of varieties. The model shown in Figure 3 illustrates the different ways farmers manage to collect seed: selection from the part of the field with the best crop stand, selection of bunches of panicles during threshing, or random selection from the rice grain pool. This behavior and the seed quality seem to be related to the choice of threshing technique—manual or mechanized. Farmers may finally decide whether to grow a variety by using the seed they collected only after seeing the aspect of the milled rice or after tasting cooked rice from that field. This part of the model was improved by information obtained from the RPG and the follow-up interviews. We were able to specify how farmers collect seed, how they decide to exchange seed with certain farmers, how they buy seed, or how much they keep from their harvests before selling rice. This improved understanding of the farmers' decision-making

Table 4. Frequency of farmers (%) choosing rice seed suppliers of each variety from the survey of 258 farmers in Ubon Ratchathani, 2002 wet season.

Seed supplier	Seed production source[a]	Seed quality class[a]	% of farmers			
			KDML105	RD15	RD6	Other varieties
Ubon Rice Research Center (URRC)	RRC	FS	4	3	4	3
Seed Center (SC)	SC	SS	2	2	0	0
District Agricultural Office (DAO)	SC	SS	19	13	14	9
Seed traders	SC, RRC	SS, FS	5	5	2	0
Rice mills	SC, RRC	SS, FS	2	2	1	1
Agricultural Cooperative (AC)	AC, RRC, SC	SS	25	23	22	7
Bank for Agriculture & Cooperatives	CP Company, SC	SS	4	2	3	1
Community Seed Center (CSC)	CSC	CS	1	2	1	0
Others organizations/projects, e.g., NGOs	na	na	2	0	1	0
Farmers (exchange)	Farmers	–	18	27	28	47
Farmers' self-production	Farmers	–	17	22	25	32
Total			100	100	100	100

[a]FS = foundation seed (produced from breeder seed inside URRC), SS = stock seed (produced from foundation seed), CS = certified seed (produced from stock seed). na = not available.

processes led to improved conceptual models and a better design of the second RPG focusing on the seed supply model.

Seed supply system

The UML diagram shown in Figure 3 displays the structure of the existing seed supply system as understood by our interinstitutional research group and based on the survey results. This conceptual model and other relevant information were used for designing the second RPG.

Officially, every year, the URRC is the only producer of foundation seed of the main recommended varieties (KDML105, RD15, and RD6) on its station. The foundation seed is then distributed annually to other seed production agencies to produce the stock seed to be sold commercially. URRC tries to produce the amount of seed of certain varieties requested in advance (before the growing season, one year before the seed is needed) by the key seed stock producers (SC) and other entities. Any remaining amount can be sold to farmers.

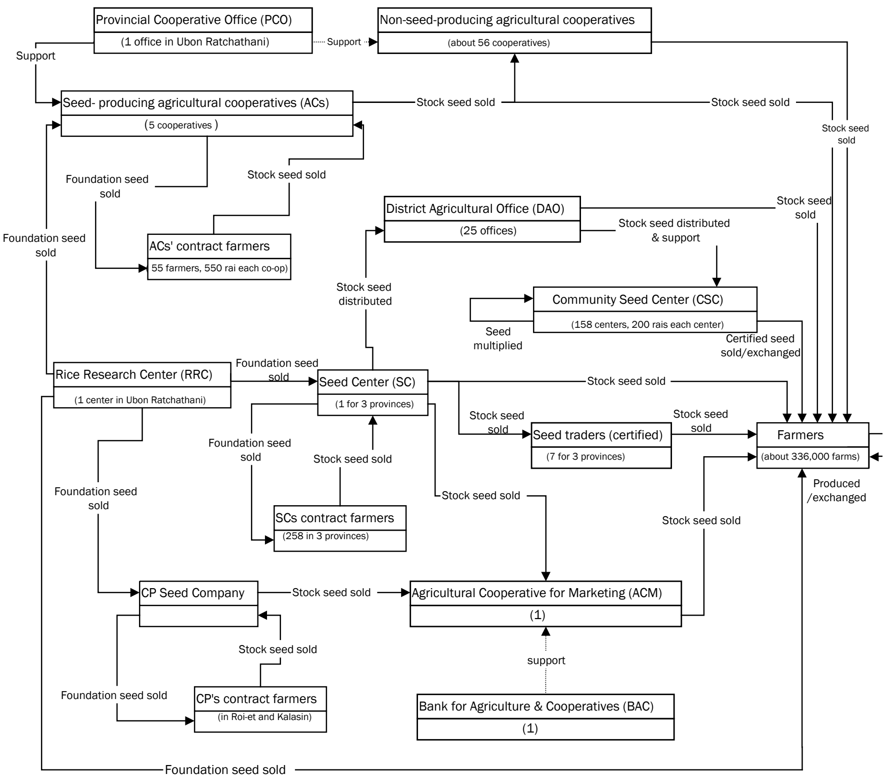

Fig. 4. Structural diagram of the seed supply system in Ubon Ratchathani, lower northeast Thailand, 2002. Seed flow among institutions is mainly KDML105, RD6, and RD15; the others mostly belong to farmer-to-farmer systems only. Numbers below each agent indicate number of places or persons of each agent in Ubon Ratchathani, except for SC and CP seed company subsystems.

The SCs have been the major rice seed producer for as long as their mandate has existed to produce stock seed at the amount planned at the national level for selling to farmers and for special projects. The total combined amount of seed production of RD6, KDML105, and RD15 was about 1,500 t in 2001.

The ACs—privatized agencies with technical and institutional assistance from the Provincial Office of Cooperatives (POC) under the DOCP—have run their rice seed project since 1998 and they also use a system of contract farmers. In 2002, five ACs were producing seed in five districts of Ubon Ratchathani Province. Each AC manages its seed production separately. The ACs producing seed, or those that don't produce seed, can be seed, paddy, or milled rice traders. The amount of stock seed (mostly KDML105) produced by these five cooperatives amounted to about 700 t in 2002 from 16 t of foundation seed.

We also investigated the contract farmers with seed production agencies. The basic seed production systems used by ACs and the SCs are similar. These institutions select farmers, sign a contract, purchase foundation seed from URRC, and sell it to the contract farmers at no profit. Contract farmers produce seed that will be certified and sold back to the contracting agency at a price about 10–20% above the paddy price, depending on the quality of the seed and sometimes on the institutional budget and rules. Some contract farmers become unhappy with the system because of the lower selling price of the seed compared with their expectations, labor limitations, and lack of technical support. This is in agreement with the observations reported by Siriwattananukul et al (2003). Informally, some contract farmers sell some seeds to other farmers. In 2002, 258 contract farmers were under SCs in seven districts belonging to three provinces, including Ubon Ratchathani. In the same year, about 250 contract farmers worked under the five seed-producing ACs in Ubon Ratchathani.

The only rice seed company, CP, locally established in 2001, also purchases foundation seed from URRC under the DOA and produces seed through its own network of contract farmers. The seed factory and contract farmers are located in neighboring Roi-et and Kalasin provinces, about 200 km northwest of Ubon Ratchathani. The contract system used by CP has not yet been investigated. In Ubon Ratchathani, CP seed is sold at the Agricultural Cooperative for Marketing (ACM) and at some agricultural stores.

The CSCs, established in 2000, are part of a nationwide project supported by the DOAE to distribute seed at the tambon (subdistrict) level. Some 158 CSCs existed in Ubon Ratchathani Province in 2002 and they use a different system for producing seed. Each center is made up of a group of 20 farmers. They obtain stock seed from the SC through the DOAE office at the district level to produce certified seed to be exchanged or sold in their community. During our farm survey, labor limitations for field checks, poor seed processing, and the lack of adequate government support were mentioned by some farmers belonging to CSCs. DOAE officials emphasized problems of quality control.

Formal seed traders need to be certified each year for selling seed purchased from the SC. They can receive a price deduction of 20% if the seed is sold at the price usually used for SC seed (320 baht 25 kg^{-1}). Seven seed traders (four of them located in Ubon Ratchathani Province) were registered under the Ubon Ratchathani SC in 2000. Some millers who buy rough rice also sell rice seed purchased from the

URRC or the SC to the farmers. Many informal seed traders are observed, including seed-producing contract farmers or unregistered farmers.

It should be noted that the rice seed supply system of URRC (under the DOA), the SC (under the DOAE), and CP is actually operating at the national level. The recommended varieties and their seeds can also be supplied to other parts of the country. Decisions concerning variety release, recommendations, and seed supply are being made at their headquarters in Bangkok. Therefore, this research project's initial regional boundary, lower northeast Thailand, can be used for modeling farmer decision-making, but it is not broad enough for the whole seed supply system. This problem is strongly related to the centralized phase of planning for the seed supply system at each seed-producing agency. Moreover, recent administrative changes concerning DOA, OARD, RRI, and RRC make things unclear. This aspect will be further investigated in the coming gaming sessions using the second RPG representing the RLR seed supply system, to be followed by MAS modeling of the RLR seed system for Ubon Ratchathani Province.

Conclusions and perspectives

Participatory modeling of this RLR varietal and seed management system using UML diagrams and role-playing games, associated with a farm survey, revealed the complexity of its different facets. Diversity of varietal uses, farmers' choices of seed sources, and linkage or competition of seed suppliers and producers are interrelated with several social (household differentiation) and physical (types of paddy fields) factors among rice-growing farms and communities. Integration of various research tools and activities is needed to well understand this complexity.

Forming the interinstitutional research team with several successive meetings was essential to this research project, while the UML diagram of conceptual modeling is effective for interactive construction by integrating and sharing information among our research team, as a basic framework for stakeholder analysis, survey activities, and RPG, and also for the presentation of such a complex system.

Interviews of selected representatives of each stakeholder and of a stratified sample of farmers during the farm survey, combined with observations on the farm environment and activities related to RLR varieties and the seed system, provided a lot of updated quantitative and qualitative data for helping to improve the conceptual models and RPG design.

The first RPG with a 3-D board improved communication among researchers and farmers toward a common understanding of the system to model. The first gaming sessions elucidated the successive decision-making steps related to the allocation of a combination of RLR varieties to different types of paddy fields, the procedures for seed collection, exchanges across farms, or acquisition from seed-producing agencies. This created an artificial community to observe the pattern and intensity (or lack) of information exchange among players. Testing the farmers' behavior responses to given conditions (such as the introduction of a new variety) was also possible with the RPG. A second RPG focusing on interactions among seed production and supply agencies and growers is being conceived to model the regional RLR seed production and supply system.

Preliminary findings generally confirm our previous understanding of farmers' choice of RLR variety, such as the high rate of adoption of three recommended cultivars in relation to the decreasing regional biodiversity in rice. A better understanding of the whole system and particularly of the roles of each stakeholder was reached. Problems of farmers' limited access to information about seed suppliers, the need for early-maturing varieties, the scarcity of good-quality seed, on-farm seed production constraints, and the difficult adoption of CSC's seeds were identified as key entry points for improving the current situation. These findings also confirm that more dynamic and interactive information sharing about the RLR seed system should be encouraged as part of the new official or community-based seed projects. To be more useful, both agronomic and economic studies on rice varietal and seed management should also take institutional aspects into account. Particularly, the contradiction between the biodiversity conservation goal and the promotion of only a few varieties deserves a more in-depth analysis of the current situation and possible future scenarios. GIS (geographic information systems) can be applied to integrate and analyze spatial information on RLR varieties and seed suppliers across agroecosystems, administrative units, and society.

The current understanding of the seed system proposed in the UML diagrams is being tested and validated with all key concerned stakeholders through the second RPG. After this step, MAS modeling will be used to build a single agent-based model of the whole RLR seed system. It will be verified and validated with the stakeholders who took part in the RPGs because they will be able to recognize the system's features and be in a better position for following what computer simulations are doing in a few minutes (compared with half a day for a gaming session). Finally, we intend to use the MAS model to simulate different scenarios of changes proposed by the stakeholders and to discuss the simulation results collectively to facilitate a common agreement on acceptable ways to improve the current seed system.

By studying such complex systems, we have confirmed that appropriate approaches and tools need to be developed for making use of the information to obtain a better understanding and to correctly identify the problems before implementing any strategies. This suggests the prospect of applying participatory modeling to the evaluation methods for such development-oriented research activities. Obtaining participation of various stakeholders may need much effort, skill, and time but should be worthwhile for providing a common and collective understanding of reality and more acceptable and practical policies.

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Notes

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Multi-agent simulations

Part 3

A multi-agent model linked to a GIS to explore the relationship between crop diversification and the risk of land degradation in northern Thailand highlands

G. Trébuil, F. Bousquet, B. Ekasingh, C. Baron, C. Le Page

Integrated watershed management implies a collective management of the land reconciling ecological dynamics and social processes to ensure a viable and equitable use of renewable resources and to mitigate conflicts. Based on the integration of existing knowledge from different sources and disciplines, this chapter describes the construction of a spatially explicit multi-agent model to analyze the poorly understood interaction between the risk of land degradation and crop diversification and agricultural commercialization of heterogeneous household-based farming systems in a highland Akha village catchment of upper northern Thailand. In this region, cash cropping on sloping land is commonly blamed by lowlanders for aggravating land degradation. But on-farm agronomic surveys led to the hypothesis that this interaction is far more complex and could be further examined by using an integrative model to explore simultaneously the interaction between the agronomic and socioeconomic components of the system. The simulated behavior of the different model entities is based on previous field observations and measurements. This agronomic simulator represents actual farmers' cropping practices at the field level under different slope and climatic conditions. The social dynamics are taken into account through the representation of three main types of households identified through a farm survey. They have contrasting historical backgrounds, are managing different amounts of resources, and correspond to a gradient of integration into commercial agriculture. Because key agroecological and socioeconomic processes need to be simulated at different pertinent scales, this multi-agent model is loosely linked to a geographic information system (GIS) displaying the distribution of three complementary spatial entities in the catchment. Following a presentation of the selected integrative modeling approach, the model conceptualization, its architecture, and modeling sequences are described. An analysis of the results of several sets of simulations is also presented. They were performed to explore the relationships between soil erosion and the variability of rainfall distribution, farmers' crop production practices, and different types of farms. Finally, the use of such a multi-agent model with stakeholders for collective learning and improved communication purposes is discussed.

Scientists working in the field of integrated watershed management (IWM) with local communities need to understand and represent the interactions among ecological, social, and economic dynamics in such complex agroecosystems. Such a representation can be used to identify more viable and equitable use of renewable resources, and to mitigate resource-use conflicts among different groups of stakeholders. In such a context, complexity is created by the heterogeneity (over space) and variability (over time) of landscapes and society. It is also generated by the diversity of interacting processes that are taking place among different natural and human entities. In the field of integrated natural resource management (INRM), understanding the effects of interactions between natural and social dynamics is of paramount importance. Ecological dynamics are made of interwoven biophysical processes, involving different renewable resources, such as soil, water, and vegetative cover, at various spatial and temporal scales. The set of socioeconomic processes to be considered involves an array of individual or collective stakeholders. These range from different types of individual farming households displaying specific socioeconomic objectives, strategies, and related agronomic practices to local communities managing the collective exploitation of land resources at the catchment level, and development-oriented or policy-making institutions operating at higher regional or national levels of organization. A prior understanding of these interacting dynamics, their co-viability, and their effects on both the state of the renewable resources and the status of heterogeneous farming communities is a prerequisite for researchers to assist stakeholders in mitigating conflicts and facilitating negotiated settlements over the use of renewable resources. Doran (2001) explained that descriptive and integrative models are useful tools to stimulate cooperative ecosystem management. Models proposing representations of the complex system to be managed collectively can be used to stimulate communication among stakeholders (the on-farm researcher being one of these) and the creation of acceptable rules for regulating land use through the application of resource management tools selected by local users (D'Aquino et al 2002, Etienne et al 2003).

The current land-use dynamics of montane northern Thailand are characterized by a rapid diversification of cropping systems. Horticultural production for different markets is playing a key role in these agricultural dynamics. This crop diversification accompanies the integration of highland farming households into commercial production and the market economy for goods, labor, and capital. These profound rural transformations are powered by strong driving forces such as the ramification of the communication infrastructure, population migrations, a stronger presence of state institutions in the highlands, and national policies dealing with access to land resources and environmental protection of headwaters in the context of a closing land frontier (Trébuil et al 2000).

Because most highlanders' fields are located on steep slopes, with angles reaching up to 60%, the risk of severe land degradation, particularly through soil erosion by concentrated runoff, is strong during the wet season, from May to October, in such highly heterogeneous and variable catchments (Turkelboom 1999). An overall understanding and representation of farmers' diverse production practices and decision-making processes regarding land use is needed to elucidate the much debated relationship between crop diversification-commercialization and the risk of land degradation on sloping lands. This can be based on the integration of existing knowledge from different sources and disciplines obtained over several years of on-farm research. Such an understanding is a prerequisite to the identification and assessment with the concerned stakeholders of various possible land-use scenarios to mitigate the risk of land degradation problems. It is urgent to find ways to make progress in this area with all concerned highlanders to improve their relations with the lowlanders who are blaming them for environmental destruction in a socially tense atmosphere.

The risk of increased land degradation is becoming a major issue in this ecologically and socially fragile montane environment. An increasing number and types of individual or collective stakeholders are presently (inter)acting in sloping land agriculture with different land-use strategies. The local agricultural system already displays an extensive socioeconomic differentiation among farming households at the village level. Over the past two decades, intensive efforts focusing on the introduction of soil and water conservation techniques had little impact in farmers' fields. This underlines the need for improving researchers' understanding of farmers' actual circumstances, practices, and diverse farming strategies (Turkelboom et al 1996). It also calls for new coordination mechanisms among stakeholders (including researchers) to facilitate the emergence of a more ecologically sustainable and socially equitable type of highland agricultural development.

To move forward in this direction, this article describes the use of a multi-agent modeling approach to examine the poorly understood interaction between crop diversification and the risk of soil erosion at the catchment level in diversifying smallholdings of Chiang Rai Province in upper northern Thailand. The objective is to use this model to better assess how far soil erosion in steep-land agricultural production is influenced by climatic variability, current farmers' practices, the increased differentiation among local farming households observed during previous field surveys, and the recent evolution toward a more market-oriented and horticultural crop-based agricultural system.

The specific objectives of this case study were threefold:

1. To integrate existing agroecological and socioeconomic knowledge on crop diversification and commercialization and the risk of soil erosion gathered at the field, farm, and catchment levels into a spatially explicit model;
2. To represent the diversity of the farming community and farmers' decision-making processes driving land-use changes at the village catchment level; and
3. To achieve this by adopting a methodological approach based on the construction and testing of a multi-agent system (MAS) linked to a GIS to provide a dynamic representation of diverse cropping and farming systems in a highly heterogeneous and variable biophysical environment.

Following a presentation of the study site and of the characteristics of the selected integrative modeling approach, the model conceptualization and its architecture are described. The modeling sequences, agents, and methods are introduced before presenting the results of simulations performed to explore the relationships between soil erosion and the variability of rainfall distribution, farmers' crop production practices, and different types of farms in this catchment. Finally, the proposed use of such a model with stakeholders for collective learning and improved communication and coordination purposes is discussed.

The study site and field surveys

For the past two decades, crop diversification and commercialization have been going on in the highland Akha village of Mae Salaep in Mae Fah Luang District of Chiang Rai Province in upper northern Thailand. Over time, the expansion of farmland on sloping land was more and more limited by the environmental protection measures enforced in this area. Fallow periods are presently very short (generally 1 or 2 years long) and, every year, more fields become permanently cultivated. While the area under upland rice, the traditional zero-input subsistence crop, is already very limited, maize is a very popular low-input, low-commercial-value cash crop. Rice terraces are limited to the valley bottoms, which are mainly owned by a minority of early settlers. For the past 15 years, horticultural production has been expanding in this former opium-growing area. In the early 1990s, ginger was the most important high-input, high-value vegetable crop, while lychee orchards and, more recently, small plantations of Assam tea are expanding on the farmland surrounding the village.

Mae Salaep village was previously a pilot site under an important Thai-Australian highland agricultural development project. This project provided detailed information on land allocation in the village catchment in 1990 to support an analysis of recent trends in land-use changes between 1990 and 1998, and the construction of a small GIS (Trébuil et al 2000). A field office of the Department of Public Welfare (DPW, now an agency under the new Ministry of Social Development and Human Security), the main Royal Thai government development organization in charge of highlanders, was also established in Mae Salaep. A DPW officer participated in a farm survey carried out in the mid-1990s to characterize the differentiation among local farming households based on their socioeconomic objectives, amount of resources available, and related agricultural production strategies. The construction of a simple farmer typology displayed the respective combination of different cropping systems in each main category of household-based production systems (Trébuil et al 1997).

In the neighboring Akha village of Pakasukchai, which presents biophysical, agronomic, and socioeconomic conditions similar to those observed in Mae Salaep, data were intensively collected over a period of two years (that is to say, four cropping seasons) to assess the risk of soil erosion by concentrated runoff under very diverse conditions in farmers' fields. A very extensive range of slope, climatic, and actual farmer cropping circumstances was observed intensively in this on-farm soil erosion survey and its results are reported elsewhere (Turkelboom and Trébuil 1998, Turkelboom 1999). In particular, this on-farm erosion survey produced precise knowledge on the relationship between climatic conditions and soil erosion processes on steep land. In particular, a series of key thresholds for erosion risk according to cropping history, slope angle and length, and soil coverage were identified.

This comprehensive body of knowledge was gathered from different sources (indigenous farmer practices and scientific analyses) and disciplines (agronomy, soil science, agroclimatology, agricultural economics, geography). It was also acquired at complementary scales ranging from small intrafield observation stations displaying homogeneous slopes to entire farmer fields, different types of farms (seen as sets of cropped fields and fallows managed by a single decision-making unit for crop production), and the entire village catchment. The selected modeling approach aimed at integrating this knowledge into a spatially explicit MAS model.

Design of an integrative modeling approach

At the initial meeting, a group of CGIAR researchers working in the field of INRM said that the models used in such research needed an increased capacity to integrate social and bioeconomic information beyond the common representations of biophysical and agroecological dynamics (CGIAR 1999). At their following meeting in Penang, they added that modeling activities "should proceed iteratively by successive approximations (…) of system dynamics (… and) in close interaction with stakeholders, who, along with the modelers, use the models for scenario planning" (CGIAR 2000). Izac and Sanchez (2000) stated that the understanding of a complex agroecological system implies the understanding of interactions among different hierarchical levels of organization. To put these recommendations into practice, we decided to use an agent-based modeling approach for land use in a village catchment considered as a complex system. Therefore, the emphasis will be on its entities and hierarchical relationships, its multilevel organization, its behavior, and the interactions among its agents and their common environment (Bousquet et al 2001). Because, later on, we plan to use the model in a participatory way with stakeholders, it was important to construct a dynamic, open, and adaptive tool having the flexibility to be modified according to the content of the feedback received from users. Because of the topic of this application, we also wanted to be able to run simulations based on different temporal scales, that is, on a day-to-day basis to analyze the effects of a given allocation of various crops in the catchment fields (as shown in an example below), or on a year-to-year basis to explore and assess longer-term scenarios (this is not illustrated in this article).

Choice of a multi-agent systems approach for knowledge integration

Models are commonly used to deal with the increased complexity and rapidity of changes in agricultural systems. Quite often, they also constitute a tool to facilitate and focus discussions among stakeholders on the relationships between causes and effects of their practices on the ecological and social dynamics of their common agroecosystems. In this case study, an integrative and dynamic approach is needed to understand the distribution of the risk of soil erosion at the catchment level because different cropping systems present different susceptibilities to land degradation (Turkelboom 1999). Meanwhile, the choice of a given crop combination by a farming household depends on its economic orientation and its recent history (Trébuil et al 1997). Therefore, the model should be able to represent the individual behavior of the heterogeneous set of Akha farming units exploiting the catchment, and their respective or aggregated impacts on soil erosion at this level.

In the recent past, significant progress has been made in the field of modeling and simulating societies in interaction with their environments (Epstein and Axtell 1996, Gilbert and Troitzsch 1999). Many research teams are now relying on agent-based modeling (ABM) for the representation and analysis of land-use and land-cover change (Parker et al 2002). ABM approaches such as multi-agent systems (MAS), which are based on the principles of distribution and interaction, can be used to create virtual societies and their relationships with a given environment (Ferber 1999). MAS and simulations are being increasingly used to represent complex distributed systems and explore interactions between ecological and socioeconomic dynamics arising from multiple uses of the land by multiple users (Bousquet et al 1999, Bousquet et al 2001). Modelers use these methods and tools to create computer representations of dynamics observed in the field. Therefore, field work and systems modeling need to be seen as two mutually supporting activities that are closely interlinked in an iterative way.

Recent examples have demonstrated the effectiveness of these models to support interdisciplinary research and to provide dynamic, spatial, and temporal representations of the system under study. In the Senegal valley, Barreteau and Bousquet (2000) built the SHADOC model to simulate the management of irrigation based on the individual behavior of a heterogeneous society of water users having contrasting socioeconomic objectives and strategies regarding agricultural production. More recently, Bécu et al (2003) conceived the CATCHSCAPE model to simulate water management based on farmers' individual decisions at the small catchment scale in northern Thailand. Other similar case studies recently developed in Southeast Asia are presented in this volume. When used with stakeholders, very dynamic and open MAS modeling and simulation tools seem particularly useful to facilitate the emergence of a common agreement on a shared representation of the system to be managed. Subsequently, they also facilitate the identification and assessment of possible future scenarios with all concerned parties. In such a context, they can be useful to support the selection of socially and ecologically acceptable courses of action regarding land management by facilitating stakeholders' interactions (Röling 1996).

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 Mae Salaep model needs to provide an agent-based representation of the village catchment in which different interacting entities with specific behavior perceive, partially and differently according to their respective amount of resources, 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 socioeconomic objectives and adopting different crop production strategies to achieve them. The consequences of their agricultural production practices and collective behavior for the risk of land degradation in their common environment are assessed through a bottom-up aggregation of their effects on the resource base from the field to the farm, and then the village catchment level.

The Mae Salaep MAS model was built by using the CORMAS (common-pool resources and multi-agent systems) platform under the VISUALWORKS environment. This simulation platform has been specifically conceived to apply the MAS approach in the field of collective management of renewable resources (for more details about this simulation tool, see Le Page and Bommel's contribution in this volume). CORMAS provides users with a choice of different types of entities to create situated and/or communicating agents with their specific sets of attributes, methods, and interactions. It also facilitates implementation of the control of simulation dynamics and proposes several kinds of visual interfaces (spatial grids, graphs, communication diagrams) to observe simulations and analyze their results. Particularly, its spatial grid allows users to display different viewpoints regarding the resource management problem under consideration. Technical procedures are also available for linking the CORMAS environment with a GIS to make use of its data files.

Linking multi-agent systems with GIS to represent multi-scale land management dynamics

There is an increasing body of literature on spatially explicit simulation models using GIS in connection with ABM techniques to dynamically simulate evolutionary, ecological, and social phenomena in complex systems (Gimblett 2002). An original characteristic of the Mae Salaep MAS model is its built-in linkage with GIS maps in a vector mode providing a spatially explicit representation of land resources in the catchment. This MAS model is an importing input variable and data from several layers of the GIS are used to manage multiple spatial entities and to characterize the initial states of these different spatial components before running the model. This MAS-GIS linkage allows the model to handle dynamically three interconnected spatial entities: small intrafield homogeneous units, which are portions of fields showing regular slope angle and orientation delimited in the GIS, full farmers' fields usually displaying complex slopes, especially in the case of large ones, and the whole catchment (Fig. 1).

GIS data files created with the Arc Info software package and corresponding to actual maps of the catchment at different scales were transferred into the CORMAS environment. These GIS data files are used by the model in the following ways:

- To allocate fields to farms (field location, number of fields, and field size),
- To delimit small intrafield homogeneous units, and
- To provide the spatial distribution of data regarding slope angle and length at the catchment level.

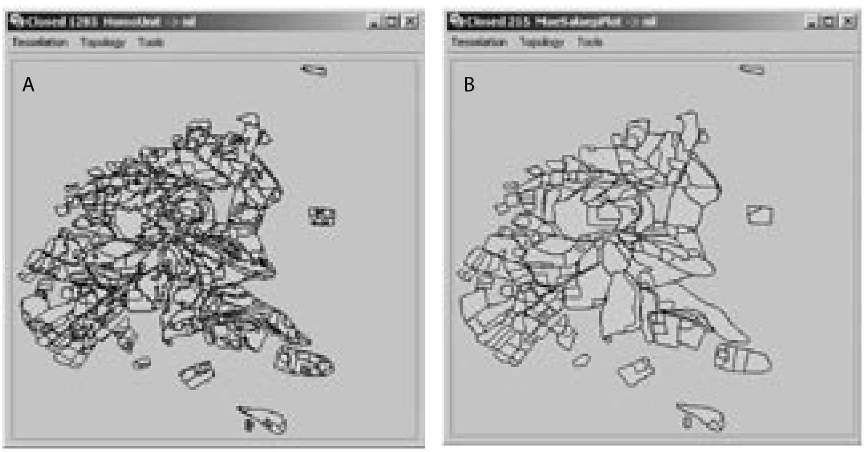


Fig. 1. Spatial levels of organization in Mae Salaep catchment: (A) homogeneous units to assess soil erosion and (B) farmers' fields to simulate cultivation practices and to represent the different crop combinations selected by the main types of farms.

This procedure allows the use of the most relevant layer of information and scale for each important process to be simulated, as shown in Table 1. For example, following each storm exceeding 10 mm (this being the minimum volume of a storm to create new erosion symptoms according to field observations), the risk of soil erosion by concentrated runoff is first assessed at the most relevant micro level of the small homogeneous units before being aggregated to the level of the whole farmer field made up of several of such units.

This integrative MAS-GIS modeling approach was used to represent into a single model farmer 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).

Model description

This model proposes a dynamic representation of the catchment as a complex totality characterized by a biophysical setting exploited by different types of farmers.

Modeling assumptions

The Mae Salaep model is based on the following main assumptions made to simplify the modeling of agronomic and socioeconomic processes linked to the interaction between soil erosion risk and agricultural diversification:

- Field position in the landscape: the model locates paddy fields in the valley bottom and takes into account the fact that they usually belong to the families of early settlers who are presently managing the largest and most diverse types of agricultural production systems. Young families and recent settlers have access only to steeper fields located on the upper slopes.

Table 1. Relationships between simulated dynamics and GIS layers in the Mae Salaep model.

Simulated dynamics	Pertinent scale for simulation	Number of objects in the GIS map	Agent/object name in model	Category of entity/ agent in the model
Soil erosion risk	Homogeneous unit	1,500	Homo unit	Spatial entity
Crop successions and cultivation practices ("inventories of techniques")	Field	220	PlotWS	Spatial entity
Farmer strategy and selection of crop combinations	Farm	48 (3 types)	FarmerWS	Communicating agent
Land-use changes and erosion risk at village level	Catchment	1	VillageWS	Communicating agent

- Crop choice in relation to farm types: in the model, farmers can choose among the whole range of main annual crops being grown in this village such as upland or wetland rice, maize, beans, or vegetables. But each type of farm manages a crop combination corresponding to its specific strategic orientation and corresponding amount of (land and financial) resources available. Small farms generally managed by young villagers (type A) grow mainly short-duration cash crops, while the large ones (type C) display a diverse selection of crops, including wetland rice. Medium-sized and more conservative holdings (type B) tend to focus on staple crops, such as upland rice and maize, and low-input, low-risk ones.
- Crop successions: bunded and terraced paddies located at lower elevation can be double-cropped with rice in the wet season, followed by soybean in the early and cool part of the dry season, while a single crop of upland rice, maize, beans, or vegetables is grown on sloping fields during the wet season if they are not fallowed.
- Farmer typology and farm dynamics: the ability of a given holding to switch to another category of farm following a series of good or bad economic results, or the retirement of the family head at 55, is not activated in the version of the model used to illustrate this article. Similarly, interactions with markets, especially farmers' reaction to price fluctuations for high-value cash crops, are not displayed in this mainly agronomic version.
- Climatic data: simulations use the rainfall distribution provided by the chronological series of daily pluviometric data recorded in neighboring Mae Chan District for 1976-2002. Turkelboom (1999) has shown that this data set can be used to represent rainfall in the local highlands if small storms, which are more frequent at higher elevation, can be ignored. This is the case in our study because the same author also showed that, under the local soil conditions, a storm of more than 10 mm is needed to create new erosion symptoms in sloping fields.
- No cumulative effect of soil erosion from field to field along the slope is taken into account by the model. This is because the catchment is made up of a patchwork of small fields usually separated by fallows or hedges. Turkelboom (1999) showed that, in some three-quarters of the actual field situations, the plots could be considered as hydrologically isolated. As a consequence, for each storm of more than 10 mm, the model estimates a level of soil erosion for each homogeneous unit in a given field and then aggregates these erosion indices at the whole-field level based on the respective size of each homogeneous unit.
- A single succession of well-ordered cultivation practices (or "itinerary of techniques") is associated with a given crop and is applied across all the farms. This is because only slight differences among farmers were observed during the preliminary on-farm surveys. A given duration of the critical period during which the field is susceptible to soil erosion by concentrated runoff is associated with each main kind of cropping system (kind of crop and its associated itinerary of techniques). This varies from 120 days for upland rice, the most susceptible crop, to 38 days for beans and cabbage, and 44 days for maize (Turkelboom 1999).
- Fallow effect on the risk of soil erosion: in this version of the model, fields are cultivated for 2 years and then fallowed for 1 year. Turkelboom (1999) found that fields cropped just after a fallow displayed strong aggregates that are more

resistant to soil erosion than second-year fields. This effect of fallowing on the risk of soil erosion is taken into account in the model, with newly cleared fields eroding less than the second-year ones (see below in Table 2).

Model entities

The selection of research objects and their corresponding entities represented in the model denotes the degree of system complexity taken into account. These entities and their linkages are displayed in Figure 2. Four different categories of agents were modeled under the CORMAS environment:

1. Situated agents having spatial references in the watershed such as homogeneous units, farmers' fields, etc.
2. Passive objects such as crops, crop successions, successions of farmers' practices for a given crop, series of daily rainfall distribution, etc.
3. Communicating agents being able to receive messages: these are the village entity and three main types of farmers displaying contrasting socioeconomic objectives and cropping strategies, amounts of available resources, and degrees of integration into the market economy. The farm-level agents are autonomous and the results of their agricultural practices in their respective fields are pooled at the village catchment level. There is some communication among the different types of farmers through access to land.
4. Spatial entities located on the grid: an original characteristic of this MAS model is its built-in linkage with GIS maps of the catchment. This MAS-GIS link allows the model to handle dynamically two complementary spatial entities: farmer fields subjected to a homogeneous type of crop management are split into smaller homogeneous units regarding their slope conditions and are characterized by their size, slope angle, and length.

Spatial representation and entities. The representation of the Mae Salaep catchment takes into account the different levels of organization and relevant spatial units needed to simulate the land management dynamics. They constitute classes in object-oriented language (see below in Fig. 2). Spatial units are characterized by their actual boundaries. Agricultural land use is represented by the allocation of a given crop to each of the farmers' fields delineated in the catchment.

- Whole farmers' fields are used by the model to manage farmers' crop production practices and crop population dynamics, especially the duration from sowing to

Table 2. Thresholds for slope angle and length, soil coverage, and cropping history and corresponding range of soil loss (in t ha^{-1}) used by the model to assess the risk of soil erosion in the Mae Salaep catchment and their effects on the severity of land degradation.

		Slope characteristics			
		< 47%		> 47%	
Soil cover	Field history	< 25 m	> 25 m	< 25 m	> 25 m
< Critical cover	Fallow clearing in	2–20	2–20	21–100	101–350
	2nd-year field	21–100	21–100	101–350	101–350

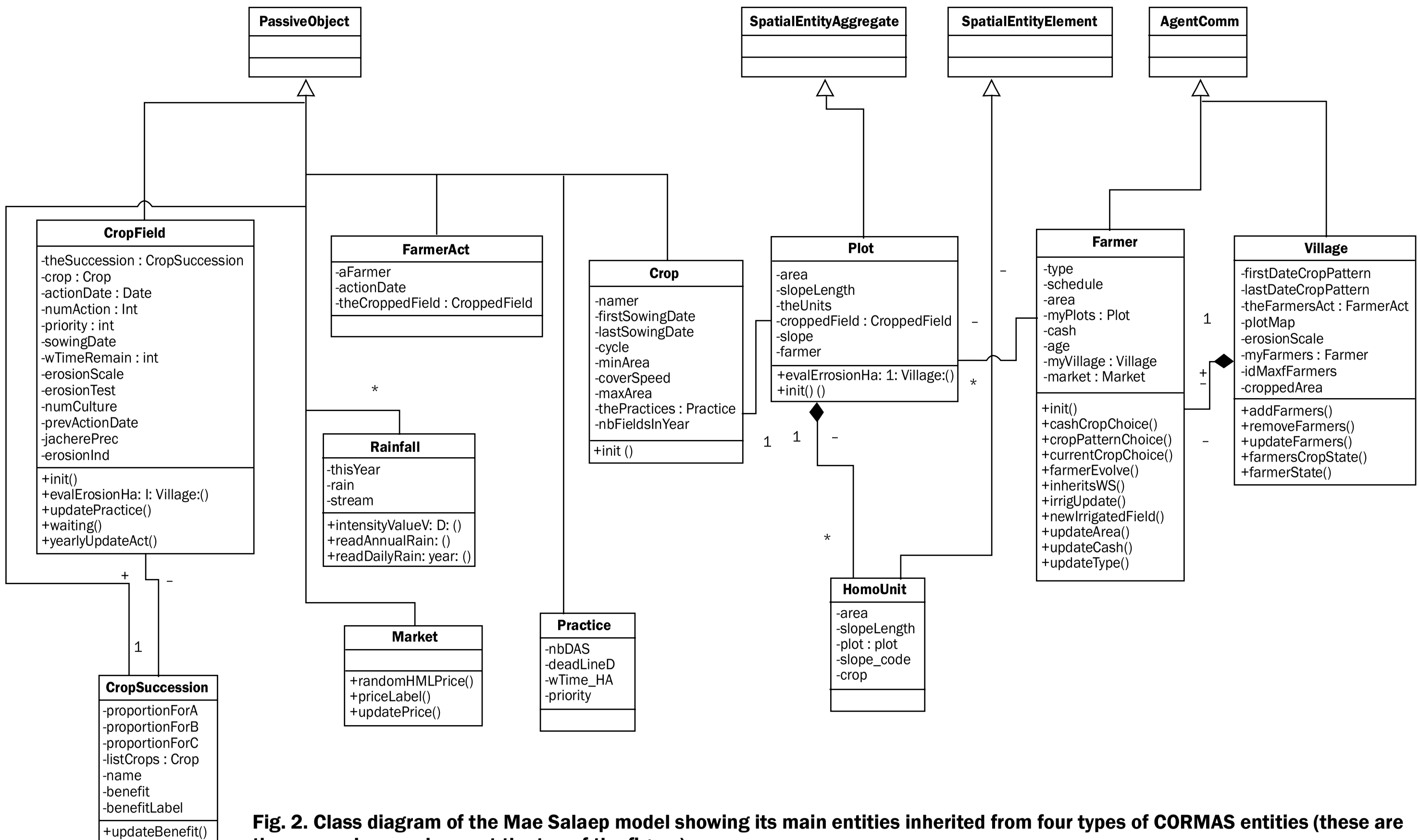


Fig. 2. Class diagram of the Mae Salaep model showing its main entities inherited from four types of CORMAS entities (these are the upper classes shown at the top of the figure).

a soil coverage of 50% beyond which no more erosion symptoms were observed in the on-farm survey. The farmers' fields are homogeneously cropped by their owners and constitute the essential spatial entity for managing agronomic information and decisions such as crop allocation, cropping calendars, crop population dynamics, activation of successive farmers' practices for a given crop, etc.

- Small intrafield homogeneous units with regular slopes are used by the model to assess the effects of farmers' practices on the risk of soil erosion over the cropping season, according to various rainfall distributions and a series of slope angle and length thresholds identified during the previous on-farm erosion survey (see below in Table 2). The homogeneous unit is used by the MAS model to assess the risk of soil erosion after each significant rain (rainfall > 10 mm).
- As in reality, the village entity main role is to regulate the beginning and end of the crop year and consequently the timing of farmers' cultivation practices. It is also at the village catchment level that the daily results of the assessment of soil erosion in each homogeneous unit and field are pooled.

This linkage among complementary spatial entities allows researchers to run simulations taking into account multiple levels of organization and several specific spatial functions. In this way, the most pertinent layer of information at the most relevant scale is used for each important biophysical or socio-agronomic process to be simulated.

Social agents. The preliminary farm survey showed that farmers' objectives and cropping strategies are contrasted. Therefore, the social heterogeneity among the local farming community is represented by three different main types of households with contrasting resource availability (particularly quantity and quality of land) and agricultural production strategies (Trébuil et al 1997):

- Type A: small holdings on upper steep slopes, managed by relatively young farmers who are very much involved in the production of annual cash crops such as maize, vegetables, beans, etc.
- Type B: medium-sized farms characterized by a rather conservative management strategy; upland rice and maize production dominate in these fields.
- 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 (lychee, tea).

In the agronomic version of the model presented in this article, interactions are limited to access to farmland. The model allocates annual crops to the available fields at the whole-farm level depending on the farmer's strategy and related choice of a combination of crops.

Passive entities. These are made of various elements in the farm environment that are needed to simulate land-use and soil degradation dynamics: the fields, the various crops and their successions, the inventories of techniques associated with each crop, and the historical series of daily rainfall data for Mae Chan District. Specific attributes, procedures, and interacting rules are also programmed for these passive agents.

Model structure

The model structure is shown in Figure 2 as a simplified class diagram using the unified modeling language (UML). It displays the different model entities and agents, as well as their hierarchy and relationships. For example, each plot instance is attributed to a given farmer managing several of them. Just under the name of each model entity, a box indicates its own set of attributes while, just below, another box lists the various methods associated with this entity and linked to its evolution during simulations.

Sequential flow of information during simulation

Soil erosion dynamics. The model relies on a series of thresholds for slope angle and length, soil coverage, and cropping history to assess the level and severity of soil erosion risk after each rain with a total volume of more than 10 mm, the minimum amount of rain needed to generate new erosion symptoms in local fields. They are shown in Table 2 and detailed information on these thresholds can be found in Turkelboom and Trébuil (1998) and Turkelboom (1999). In particular, the thresholds dealing with slope angle and length take into account the nonlinear characteristics of soil losses at the site depending on the dominating type of soil erosion process (gully erosion, plow layer erosion, rill networks, etc.) occurring in different slope conditions.

The village decides the start of the crop year in March, at the end of the dry season, by allowing farmers to allocate their crops to their different fields and to begin their land preparation practices according to the itinerary of techniques programmed for each kind of selected crop. As soon as the wet season begins, if a potentially damaging rain event occurs, the soil coverage (which is modified by the timing of farmers' practices such as plowing and weeding) and slope conditions of each homogeneous unit in each field are checked on a daily basis according to the recent crop management practices performed by farmers. If the model finds that soil erosion occurred during this storm, it estimates a level of damage severity and a given amount of soil loss based on the thresholds shown in Table 2. Then, the amount of erosion damage for this field is updated. This procedure repeats itself until the end of the wet season.

Farmer decision-making processes. The simplified UML sequence diagram presented in Figure 3 displays the chronology of the model operations when it reads the instructions. This sequence diagram shows the objectives of the successive sets of instructions and procedures. For each key step, it displays the interactions between various objects and agents of the system, their activities, and changing states. At the initialization stage, the model reads a set of GIS files to create the spatial units (small homogeneous units and whole fields), passive objects, and social entities (number of farmers per main type and the village made up of 48 households). Afterward, it allocates the fields to the different farmer categories according to their number in each category. Then, for each field, the erosion counter registering the amount and the frequency of erosion damage is initialized and set at nil. Next, farmers are asked to allocate their crop combinations among their different fields in agreement with their respective strategies. The village agent decides to start the cropping year and "sends" the farmers to their fields at the beginning of the wet season. The control of the simulation can be set up according to a daily or a yearly time scale.

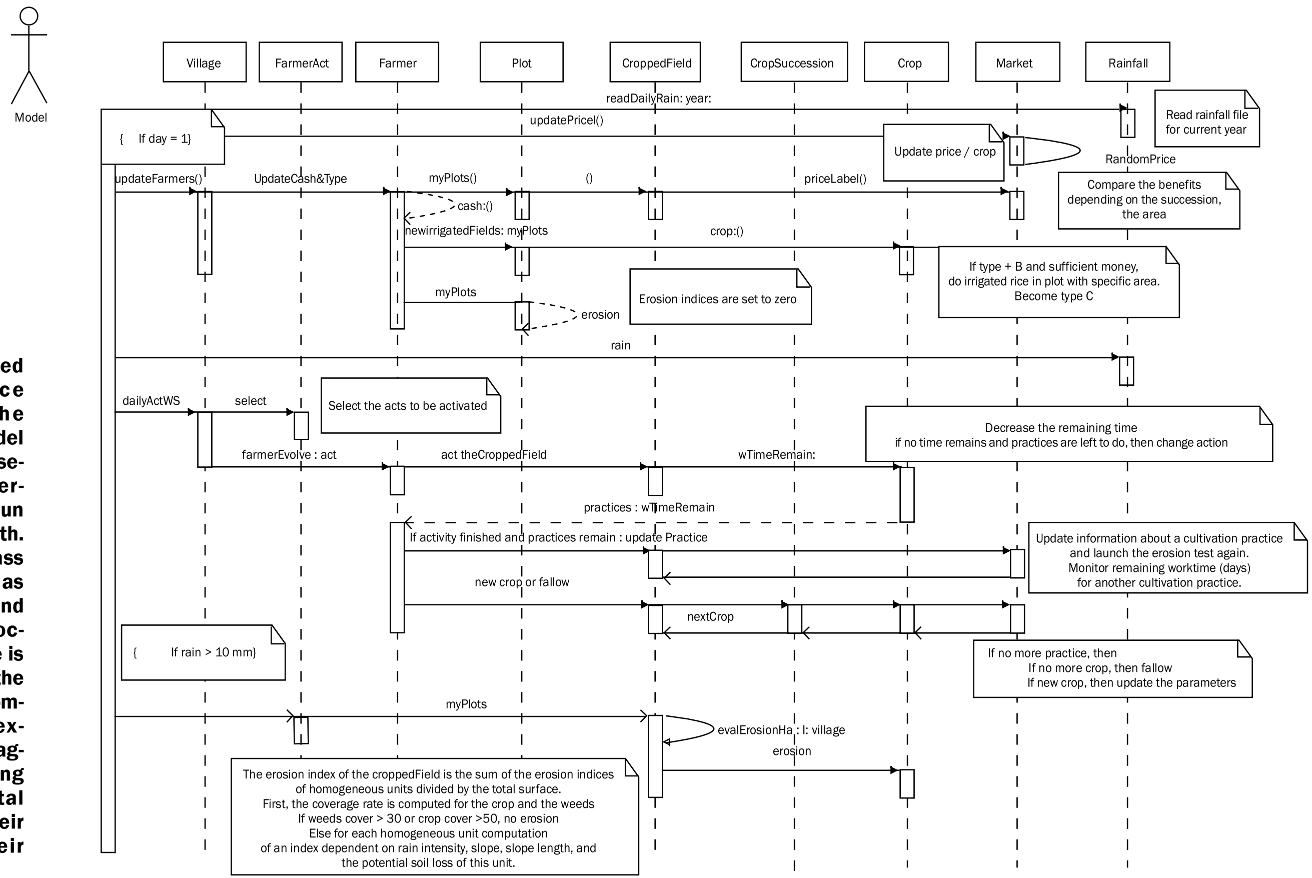


Fig. 3. Simplified UML sequence diagram of the Mae Salaep model displaying the sequence of different procedures run during a time path. Each model class is represented as a vertical line and its activation occurs when there is a rectangle on the line. Objects communicate by exchanging messages corresponding to the horizontal arrows from their senders to their receivers.

Outputs and indicators

The dynamics of the simulated system can be visualized and analyzed thanks to a selection of indicators. In this chapter, we will focus on the risk of soil erosion quantified by the cumulative assessment made for each spatial unit after every eroding storm. At the end of a simulation, the model can display the spatial distribution of erosion damage for each field or each farming unit in the village watershed. Based on given distributions of the village's 48 farming units among the three main types and crop allocations to their respective fields, this indicator allows us to assess the effects of climatic variability on soil erosion damage due to unpredictable rainfall distribution. Later on, it could be used to assess the environmental effects of new land-use scenarios proposed by stakeholders. The same indicator can also be used to compare the impact of different types of crop allocations on the risk of soil erosion and total soil loss during the wet season, for example, after the introduction of more perennial crops in this catchment. The respective contribution of the different types of farming units to the total erosion damage can also be evaluated through this indicator.

Beyond this environmental indicator, the outputs of the complete version of the model will also be able to display graphs to observe changes over time in the social distribution of the farming community and the related economic status of the household types. Such changes depend on the local rules for inheriting the land from old farmers and on the economic results of farmers' cash-cropping activities. This kind of socioeconomic indicator could be very useful to answer the question "Who benefits?" when assessing alternative land-use scenarios proposed by local actors.

Model verification and calibration

A verification of the coded modules was performed to ensure their coherence with the conceptual model represented in UML diagrams (Figs. 2, 3). For several of these modules, the simulations were stopped during execution and the modeler used the CORMAS debugger to check those lines of code and to verify that they operated in agreement with his expectations.

Several simple tests were performed to verify that the model was behaving logically and realistically according to experts. For example, the module dealing with farmer decision-making was followed step-by-step under different conditions.

The actions of several key agents, such as farmers' practices and their effects on soil erosion dynamics under given rainfall conditions, were observed during simulations to check the coherence between their behavior and the modeler's expectations.

Most of the model calibration relied on expert knowledge and the published results of previous on-farm experiments and surveys.

Model validation: respective roles of experts and stakeholders to assess the simulated behavior of the system

A general two-step approach is being 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 potential users among the local stakeholders (Bousquet et al 2001).

Expert validation. An internal and formal validation of the model was done by the project modeler to check the relationships among variables. Sensitivity tests were performed on selected key variables such as rainfall distribution, farmer actions, and soil erosion and analysis to assess the reactions of the modeled system when its values vary. Because of the large number of parameters included in the model, a full exploration was not feasible. Analyses of the simulation results under a variety of input parameter settings were carried out to verify that the outputs were reasonable in comparison with the system dynamics understanding based on field studies. Several examples are provided below.

Participatory validation. In agreement with our INRM approach, it is essential that the model be found acceptable by the stakeholders so that it can be used to facilitate communication among them. It is necessary to verify that, in the eyes of its potential users, the model is transparent enough, and that its key assumptions and hypotheses can be accepted. Therefore, suitable procedures for model validation to be put in place must make its contents explicit, and users must be able to verify the coherence between the observation and the simulation of dynamic events. To do so, this MAS model needs to be simplified, by retaining only key interactions, and transformed into a less complex tool, such as a role-playing game to be tested with stakeholders. To limit the "black box" effect, such a simpler gaming tool can help local actors to 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 (Trébuil et al 2002).

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, while increasing its credibility and legitimacy. Because the role-playing game has a dual role (validation of the proposed representation of the system and production of new knowledge to improve it), a back-and-forth process between this interactive tool and the MAS model is an original feature of the companion modeling approach. As soon as the stakeholders become familiar with the rules and the outputs of the role-playing game, a similar version of the MAS model incorporating their contribution on the representation of the system could be used with them. Their knowledge of the functioning rules of the model will allow them to criticize the simulation results and, later on, to use a modified version of this tool to explore the effects of various scenarios of land-use changes.

Exploration of simulated scenarios

In this article, each scenario is run for a period of 1 year only. Because random functions are included in the program (for example, to determine the amount of soil loss corresponding to the three levels of severity of erosion displayed in Table 2), it is necessary to repeat the simulation of each scenario to assess the variability of the results. At the end of each simulation, the dynamics of total erosion at the catchment level is plotted on graphs for further analysis. The final amount of soil loss can also be displayed on maps to study its spatial distribution.

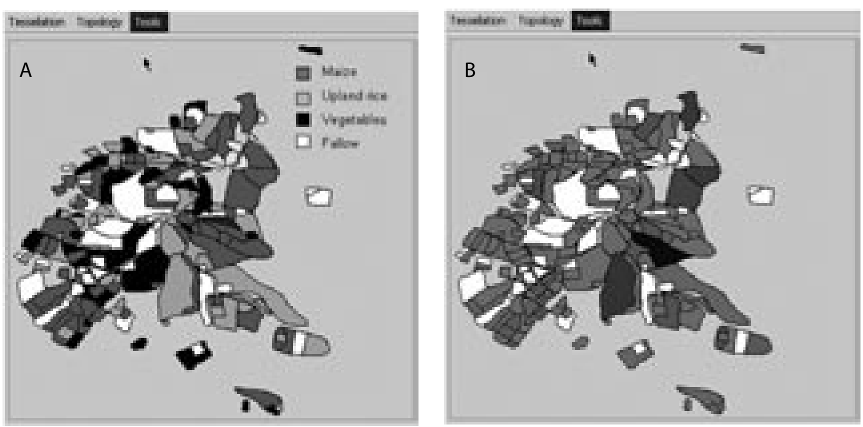
Simulation of a baseline scenario and soil erosion dynamics

The baseline scenario simulates the farming conditions regarding the production of annual crops in the Mae Salaep catchment as observed during field research in the mid- and late 1990s. Figure 4 displays the allocation of various annual crops to farmers' fields at the beginning of the wet season (A) and the spatial distribution of the simulated total soil loss at the end of the year. Such an output allows the identification of "hot spots" for the risk of soil erosion in the catchment and their characterization (slope conditions, crop grown, and type of farmer managing these susceptible fields).

For a given year, Figure 5 displays the dynamics of soil erosion in relation to rainfall distribution in 1987, soil coverage by weeds and crop canopies, and farmers' practices. Soil loss increases very significantly at land preparation and at first and second weeding stages at around 100, 140, and 185 days, respectively. After that, the total soil cover remains above the critical threshold of 50% in most of the fields and, consequently, total soil loss increases only marginally until the end of the crop year.

Effect of variable rainfall distribution on soil loss

The soil erosion created by the same baseline scenario of crop allocation was simulated for each of the 27 successive years of the 1976-2002 period. Figure 6 shows that the important variability of rainfall distribution across years (the annual total of rainfall varied from 1,097 to 2,257 mm in 1992 and 2001, respectively) and its interaction with the timing of farmers' practices in their fields led to a very extensive range of total soil loss at the catchment level at the end of the cropping season. This total amount of soil loss varied between 12.1 and 51.1 t ha^{-1} in 1995 and 1993, respectively. Such variability explains the limited success of classic input-output and small plot-based agronomic research procedures to understand the effects of various factors and field conditions on soil loss. A detailed monitoring of soil surface states in relation to rainfall distribution is necessary to be able to explain the total amount of soil loss observed at the end of the crop year.



Relative index: the darker the plot, the higher the soil erosion

Fig. 4. Simulated allocation of farmers' fields to annual crops at the beginning of the baseline scenario (A) and simulated distribution of soil erosion (t ha^{-1}, B) in Mae Salaep catchment.

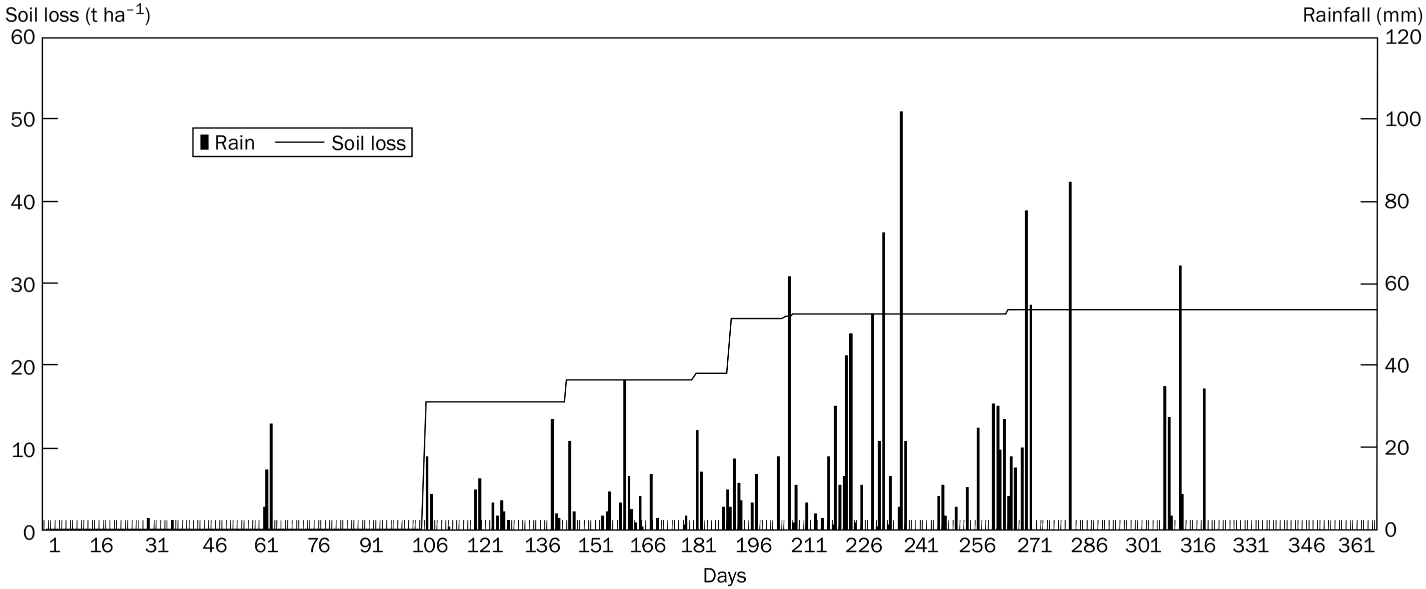


Fig. 5. Dynamics of soil erosion at the catchment level for rainfall distribution in 1987.

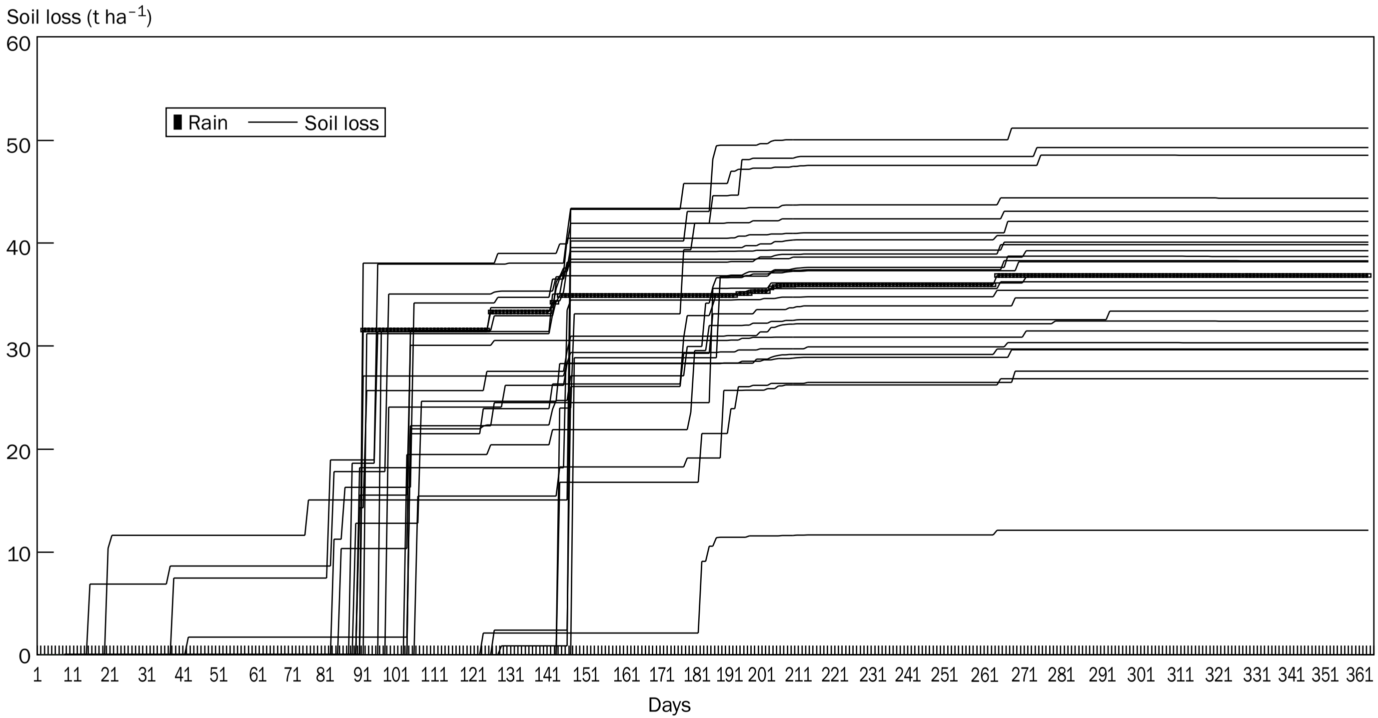


Fig. 6. Simulated results of the effects of rainfall variability (1976-2002) on soil erosion for a baseline scenario of land allocation to annual crops in Mae Salaep catchment.

Effect of different crop allocations to fields on total soil loss

For a given climatic year, we run simulations with 30 different kinds of crop allocation to farmers' fields to assess the effect of crop choice on the total amount of soil loss in the catchment. Figure 7 shows the results of these simulations for the 1987 crop year. The total amount of soil loss at the end of the year varies from 23.9 to 40.8 t ha^{-1}. This confirms the importance of the spatial allocation of the different annual crops in the landscape to mitigate the risk of soil erosion. For example, in Mae Salaep village, most of the farmers say that, when they can, they try to avoid growing upland rice (the crop most susceptible to soil erosion) on very steep slopes.

Effect of farm type on soil loss

Based on the simulation of the baseline scenario of crop allocation for 27 years (1976-2002), Figure 8 shows the respective mean and standard deviation values of total soil loss per cultivated hectare for the three main types of farming households identified in Mae Salaep. With a mean soil loss of 66.8 t ha^{-1}, which is almost twice as large as the estimations for type B and C farms, the very small-scale type A farms show their higher ecological vulnerability. But with only two or three fields, usually located on steep upper slopes, the total amount of soil loss created at the whole-farm level by these smallholdings is less than in the case of larger type B and C farms.

This result shows that, later on, much attention will have to be given to the already extensive social differentiation among the farming households when identifying and assessing alternative land-use scenarios with Mae Salaep villagers. In particular, it will be essential to ensure that the most resource-poor smallholdings will also be able to meet the necessary conditions to implement the most promising practices if they wish to do so.

Conclusions and perspectives on model use

This simulation model provides a spatial representation of the effects on the risk of land degradation of farmers' actual practices and decision-making related to the selection of annual crops and their allocation to their various fields. We found that the selected MAS-GIS modeling approach has the capacity and flexibility to represent and integrate different kinds of (qualitative as well as quantitative) knowledge across sources (indigenous and scientific ones) and to display interconnected dynamics operating at multiple levels of organization. We do not plan to use this model to predict changes or to better control the simulated agroecosystem. Our aim is to focus on understanding key interactions and on using this tool in a communication and negotiation support approach with local stakeholders.

Such a representation helps to understand dynamically the functioning of a complex agricultural system such as a highland village watershed. If this holistic representation of the system can be validated and shared in a participatory companion modeling process, it could be used as a coordination and negotiation support tool among stakeholders to assess scenarios of possible futures and to support collective learning and management of their common environment. Such a common representation of the system to be collectively managed can also be used with stakeholders to define appropriate indicators and monitoring procedures or information systems.

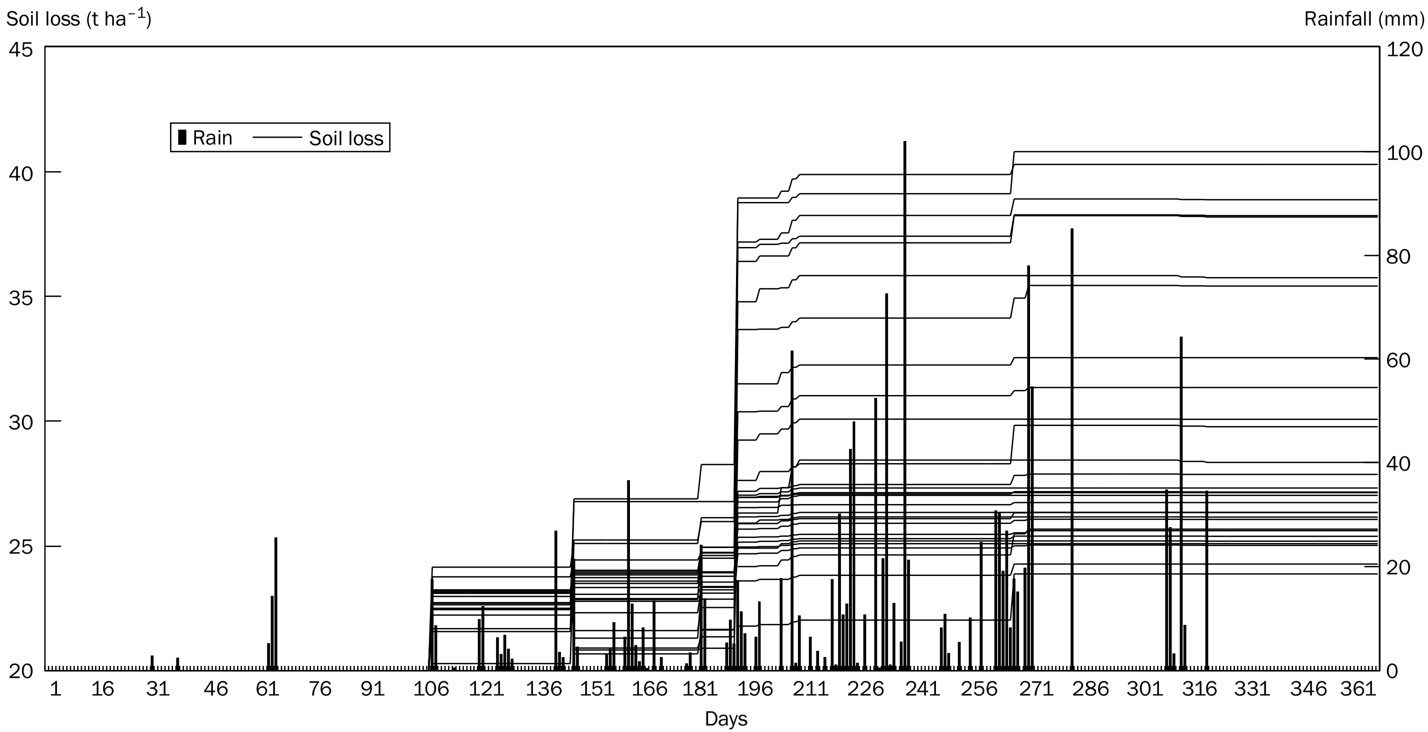


Fig. 7. Effect of 30 different kinds of crop allocations to farmers' fields on total soil erosion at the catchment level for the 1987 crop

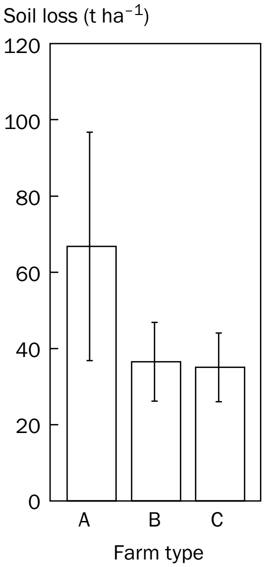


Fig. 8. Simulation results of 27 years (1976-2002) displaying the respective contributions of the three main types of farming households to soil erosion per land unit in Mae Salaep catchment.

Further work is needed to allow a more dynamic management of the model spatial entities by the farmers. In particular, they should be able to change the size of the cropped field when they switch from a traditional and self-subsistence crop to a market-oriented and more labor-intensive one. The latter type of crop is usually grown in smaller fields, with shorter slope lengths and, as a consequence, a lower susceptibility to soil erosion. This could be done by introducing the possibility to split large fields into their homogeneous units, for example. More work is also needed to take key economic processes into account, such as price fluctuations for horticultural crops and the more and more common articulation between on-farm and off-farm employment.

Following further validation of this model by experts and Mae Salaep villagers, we plan to use this model to simulate possible future scenarios for highland agriculture in the villages where intensive field data collection was conducted. To be useful, these scenarios should be jointly defined and assessed with the concerned players. Based on recent interactions with them, they could deal with the expansion of perennial crops (mainly lychee and green tea) in this catchment to improve soil coverage during the wet season. Before being able to do so, there is a need to go back to the field to update the list of crops managed by the model to include perennial ones and to collect information on farmers' decision-making procedures regarding market price fluctuations of horticultural crops and labor management between on-farm and off-farm opportunities. This will create a reciprocal learning process between stakeholders and researchers, which is a key characteristic of companion modeling. We think that this "learning by modeling" approach provides an operational way for INRM researchers to closely articulate their field and modeling activities. In many situations characterized by a general policy framework encouraging the decentralization of resource management, it can help to prioritize, plan, implement, and assess research work with diverse stakeholders to accompany and support their projects.

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Modeling a biophysical environment to better understand the decision-making rules for water use in the rainfed lowland rice ecosystem

G. Lacombe and W. Naivinit

Growing rainfed lowland rice (RLR) is the main activity in northeast Thailand. Unpredictable droughts and coarse-textured soil are the principal constraints usually cited to explain the low yields and economic poverty of this region. Past studies tried to improve the drought tolerance of rice varieties and hydrological functioning at the field level. How water is used at the farm level remains largely unknown. Consequently, it is relevant to understand the interactions between the water-resource and water-use dynamics in the RLR ecosystem. This article proposes to develop a simulation tool based on multi-agent systems to explore adaptations of the rice cropping pattern to rainfall variability. An environment containing the main biophysical entities involved in decision-making rules for water use is modeled and its hydrological functioning is verified. Preliminary simulations are run to illustrate the model capacities. These simulations aim at evaluating farm pond capacity to alleviate early drought at the vegetative stage. Simulations comparing scenarios with and without ponds show that ponds are less efficient at the beginning of the RLR cycle, when rains are still light. Pond efficiency is stable when the period separating two seedbed sowings is longer than 2 months. Below this threshold, it is possible that the ponds are not completely refilled. The next step in the model development will consist of adding autonomous agents to simulate scenarios in which farmer agents may cooperate to use water.

Fischer (1996) projected that total rice production must increase by 25% by 2025 to meet the increasing human population needs. Worldwide, 28% of the total rice-growing area is planted with rainfed lowland rice (RLR). Mackill et al (1996) define the rainfed lowland ecosystem as areas where rice is grown in unirrigated, leveled, and bunded fields that have shallow flooding with rainwater. The northeast Thailand region is mainly a large plateau on sandstone, which is usually characterized by poor soils and erratic rainfall. It covers one-third of the Kingdom area and also corresponds to a third of its total population. This region is the poorest of the country and is still a major rainfed lowland rice-growing area. Farmers practice rice monocropping mostly in the wet season. A common feature across the rainfed production environment, which is clearly distinguished from the irrigated system, is uncertain water supply. Past efforts to alleviate water stress in RLR (varietal improvement, irrigation, soil compaction, etc.) had limited effect. For some years, the construction of farm ponds that began and was subsidized by the King's patronage seemed to be successful in mitigating drought at the farm level (Hungspreug 2001). Although water availability has been improved, farmers do not seem to take this opportunity to intensify their rice production. They still grow traditional types of RLR cultivars, which provide low yield but high grain quality.

New research is needed to identify actual water needs in local farming systems based on the use of traditional RLR cultivars and to determine appropriate improvement pathways as farmers will probably continue to grow this type of RLR. An understanding of existing patterns of water use and water users' needs is required to improve the current situation. This article proposes to develop a simulation tool based on multi-agent systems to explore adaptations of the rice cropping pattern to rainfall variability. To do this, we propose three complementary steps: (1) identifying hydrological dynamics, (2) understanding farmers' decision-making rules regarding water use, and (3) integrating both components into a multi-agent simulation. This model should help in analyzing the system's functioning and evaluating its sensibility to parameters such as the date of seeding and transplanting, which vary according to rainfall variability. Our article presents the different stages of the modeling process, from data collection and field studies to computer simulations of scenario assessment by means of model implementation and verification.

Water resources and rainfed lowland rice in northeast Thailand

More than 80% of the farmed area in northeast Thailand (NET) is used to grow RLR (Office of Agricultural Economics 2001). The cropping cycle usually starts with the beginning of the rainy season, in late April, when fields are still unflooded. Rice is first seeded in nurseries near water sources so that complementary irrigation can be applied in case of drought. Approximately 1 month later, rice seedlings are transplanted in flooded fields after the water table has moved up and the rivers spread out in flooded plains. Paddy fields are usually harvested after rains have stopped and the land has drained. Therefore, this agroecosystem is characterized by a low water control and farmers have to adapt the crop calendar to the rainfall pattern. Their room to maneuver for water management is very limited and they often face unavoidable dry spells.

In northeast Thailand, this situation is made worse by disadvantageous natural conditions. The high rainfall variability causes successions of dry spells even during the rainy season (Fukui 1993). Water stress is aggravated by very coarse-textured soils with low water retention and salinity problems (Trébuil et al 1998). This unfavorable natural environment is usually cited to explain the low rice yields (1.8 t ha^{-1}) and the relative economic poverty of this region (Somrith 1997). Past agronomic research focused on improving rice varieties to increase their tolerance of drought (Singh et al 1996). At the same time, government agencies implemented water development projects to increase irrigated area and the availability of water resources at the farm and community levels. The results are not very satisfactory as most irrigation schemes have been underused and improperly maintained. An important reason is that farmers did not actually participate in all stages of project development (Patamatamkul 2001).

Several models have already been built to represent the biophysical environment of the RLR ecosystem. The RLRice, Rainfed Lowland Rice model (Fukai et al 2000), simulates the growth of many rice varieties according to the amount of water available. The ORYZA model (Bouman et al 2001) is made up of different modules that calculate water deficiency according to soil, climate, and plant physiology. Other models propose spatial representations (Suzuki et al 2001, Kam et al 2001) that take into account hydrological conditions according to field position along the toposequence, or depend on the soil type and climatic conditions at the regional level. All these models have the same aim: to calculate the terms of a water balance to predict a level of water stress and related RLR yield loss. They were helpful in conceiving the structure of our own model. Particularly, they provided representations of the main water transfers to be considered in the RLR ecosystem. Nevertheless, the "water use" component was rarely considered in these past studies. The formalization of interactions between the water-resource and water-use dynamics requires a model allowing the representation of the diversity of water uses and water access, as well as their determining parameters. Several models have been developed to represent such interactions in other regions and toward the world.

As multi-agent systems (MAS) have proved to be particularly adapted to represent such dynamics (Ferber 1999), we present hereunder some of their applications, with a focus on their hydrological structure and functioning. CATCHSCAPE (Becu et al 2001) is a MAS designed to comprehend the interactions of conflicts between upstream and downstream activities in an irrigated rice ecosystem in northern Thailand. At the field level, crop yield is calculated using a two-reservoir water balance model already validated and calibrated in northern Thailand catchments. SHADOC (Barreteau and Bousquet 2000) is a MAS designed to explore the viability of irrigated systems in Senegal. A pump controls the water discharge entering the irrigated network. At the field level, a water balance model calculates the water deficiency from which a yield loss is estimated. Rainwater is absent. Ducrot et al (2003) articulate land and water dynamics with urbanization in a MAS that combines to examine the connections among the hydrological process (water cycle, pollution), land-use changes, and urbanization. The hydrological process is mainly used to monitor the pollution process, which transfers into the catchments (surface runoff and river flow). Although all the research mentioned above used the MAS approach to build hydrological models, it did not strongly emphasize the precision of water balance or water transfer.

The SINUSE model (Feuillette 2003) based on MAS was built to explore groundwater management in the Merguellil watershed of Tunisia. It emphasized simulations of water-table and user interactions with a special focus on economic and social interactions. The main physical criterion that farmers take into account when they use water is water-table depth. To restitute its spatial heterogeneity, the water table is modeled with five tanks having their own hydrodynamic parameters and connected to each other. Although rainfall data series are used in the simulations, the aquifer recharge is calculated using a hydrogeological model disconnected from these series. All these MAS models favored social dynamics in their development. Hydrological processes were extremely simplified as they are comparatively less relevant regarding the research question. The surveys conducted in the RLR ecosystem revealed that farmers' adaptations to rainfall variability closely depend on the water availability in the natural or artificial sources (ponded water in paddy field, soil moisture, river, ponds, water table). The water dynamics of these entities are closely interconnected in step with the hydrological process at the subwatershed scale. Consequently, the representation of water transfers from the rainfall to the subwatershed outfall was considered of paramount importance to initiate the model conceptualization.

Materials and methods

This research was carried out in the Land Reform Area of the Lam Dom Yai watershed in southern Ubon Ratchathani Province. Considering that northeast Thailand is divided into micro-watersheds with similar socioeconomic and biophysical organizations (Khon Kaen University-Ford Cropping Systems Project 1982), the Huay Bua subwatershed was selected for this study as its farming systems and hydrological conditions were found to be representative of the regional diversity in hydrological processes, water access, and water use (Fig. 1). To assess this diversity, 32 semi-structured interviews were conducted with farmers in early March 2003, during the

Fig. 1. Location of the study area in the Lam Dom Yai watershed of Ubon Ratchathani Province.

dry season, in seven villages distributed across the study area. These villages were chosen according to their location along the toposequence and the selected sample of villagers aimed at covering the diversity of farm types. In late May, a new series of surveys was conducted to fill some knowledge gaps, particularly to determine the dimensions of farm ponds and their spatial density, useful for the model conceptualization. A frequency analysis of rainfall (data not shown) based on data from several meteorological stations in Ubon Ratchathani Province was carried out to quantify the spatial and temporal variability of rainfall, to assess its possible consequences for water management, and to guide the implementation of the pattern of rainfall distribution in the model. The CORMAS (common-pool resources and multi-agent systems) platform was used to implement the model because its entities could be spatialized and represented on a metered grid, and because of the possibility it allows to model farmers' decision-making rules regarding water use.

Conceptualization of the model

Three main water uses were identified: the phase of land preparation for rice production (April-May), the supplementary irrigation of rice fields during the early vegetative phase (June-July), and the irrigation of vegetable crops during the first half of the dry season (December-February). The water volumes corresponding to domestic uses were considered as negligible compared with agricultural uses. The major factors involved in farmers' decision-making processes concerning water use were as follows: rice varieties (early or late-maturing types, for self-consumption or for sale, more or less tolerant of drought); the position of fields and ponds along the toposequence, which determines the accessibility to water resources and the amount available; soil moisture; and customs and religious events such as the Royal plowing ceremony and the Thai New Year that may influence the cropping calendar. All these factors determine the date, frequency, and location of water uses. The two main RLR varieties grown in this region are KDML105 and RD6; both are photosensitive varieties. KDML105, a nonglutinous variety, is usually seeded in nurseries in late April near a source of water to compensate for the lack of rain because rain is still light at this time. As this variety is more tolerant of water stress, it is usually transplanted in the upper paddies (Fig. 2). RD6, a glutinous and late-maturing variety, is mainly grown for family consumption. This variety is usually seeded in June, when labor is available after KDML105 transplanting, and is preferably transplanted in lower paddies where water is more abundant. In this way, farmers prioritize their family food security by growing RD6 in a safer area regarding water source as RD6 is harvested after the drainage of these lowlands. Figure 3 illustrates the synchronism between the rice cropping pattern and seasonal variability. Such an understanding of the spatial and temporal distribution of RLR helps when selecting the biophysical factors involved in decision-making that should be included in the model. Some of them vary (1) in space: accessibility to water resources, soil hydraulic properties, the position of fields, and sources of water along the toposequence; (2) in time: rainfall, the quantity of water available, and soil moisture; and (3) in both time and space: rice varieties. A map displaying elevation, soil series, and the hydrographic network was used to determine the slope, the pattern of soil distribution, and the streams to be represented in the model.

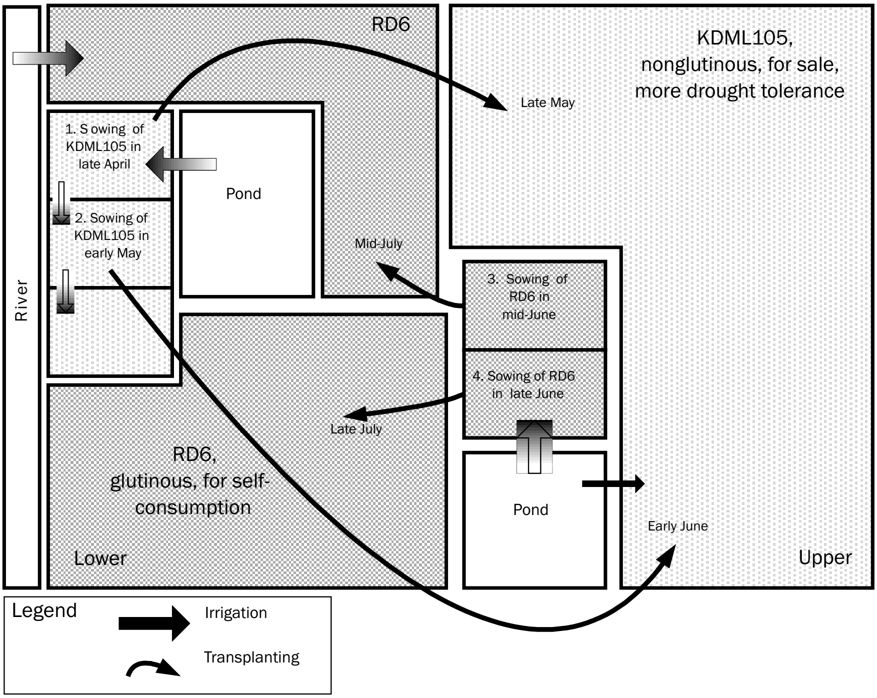

Fig. 2. Main water uses and rice cropping pattern at the farm level in the Lam Dom Yai area of Ubon Ratchathani Province.

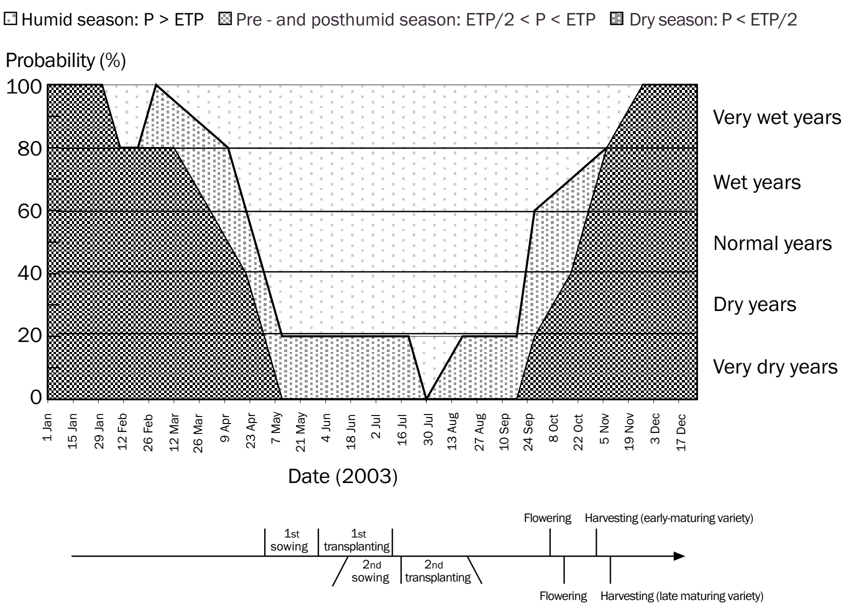

Fig. 3. Seasonal variability (adapted from Franquin 1985) and synchronism with the crop calendar.

Suitable time steps and spatial units had to be defined. The time steps should be compatible with the length of the simulated periods and with the time base of input data, such as rainfall and evapotranspiration. Decisions on water use usually consist of choosing a date and a frequency of the use. This date can vary from one day to another according to daily rainfall distribution or habits. Consequently, a single-day time step was chosen. Because farmers' decision-making criteria linked to water uses may vary among fields according to their location, soil characteristics, and distance from a source of water, the RLR field was selected as the key spatial unit in the model. The size of the area represented in the model was defined according to the total number of fields to be represented. According to field observations and measurements, the average field size was 800 m^2 and varied from 100 to 1,600 m^2. As the surface of the entire Huay Bua watershed is 11,250 ha, corresponding to some 140,625 fields, it was not possible to represent all these fields in the model because such a large number of fields will unnecessarily slow down the simulations. The area represented in the model corresponds to 50 ha made up of 625 fields. We believe that the real diversity of the fields' spatial organization is retained in this scale change.

As several decisions concerning water use depend on distances between fields and reservoirs, attention had to be paid to this scale transfer. Following a second series of field surveys, average dimensions and standard deviation were calculated to determine the size and the spatial density of entities to be represented in the model to create a realistic environment. As the modeled area represents the Huay Bua River, the average distance between the fields and the river is artificially minimized. In some cases, this distortion may affect the decision-making rules linked to distance and it will have to be taken into account during model simulations. Another scale-transfer problem concerns the water-table level, which is normally correlated to the total volume of rainwater received in the watershed. In the model, the surface receiving rain is smaller than the whole watershed. To take into account the groundwater coming from the whole watershed and to determine the level of the water table, a correction coefficient had to be used during the model calibration to artificially increase the amount of rainwater percolating into the water table.

Structure of the model

The hydrological process represented in the model should involve all water entities (ponded water in paddy field, soil moisture, water table, ponds and rivers) that may interact with water uses and whose water volume may vary according to the rainfall pattern.

The model structure relies on hydrological entities. These entities are divided into two categories: the ones supplying water (such as the pond, the river, the water table) and the entities consuming water (such as the RLR fields). All these entities are organized into two layers: a first layer is made up of the water table and river entities (Fig. 4). To represent the natural slope of the watershed, these entities are terraced at three elevations (130, 131, and 132 m) as shown in Figure 4. The main horizontal water transfers (except for surface runoff) occur at this layer level: the Huay Bua River is made up of three tanks, and each tank has a threshold. If the water level exceeds this threshold, the excess water flows into the downstream tank. Each of the three river tanks receives water from the two neighboring water-table tanks (Fig. 5). The

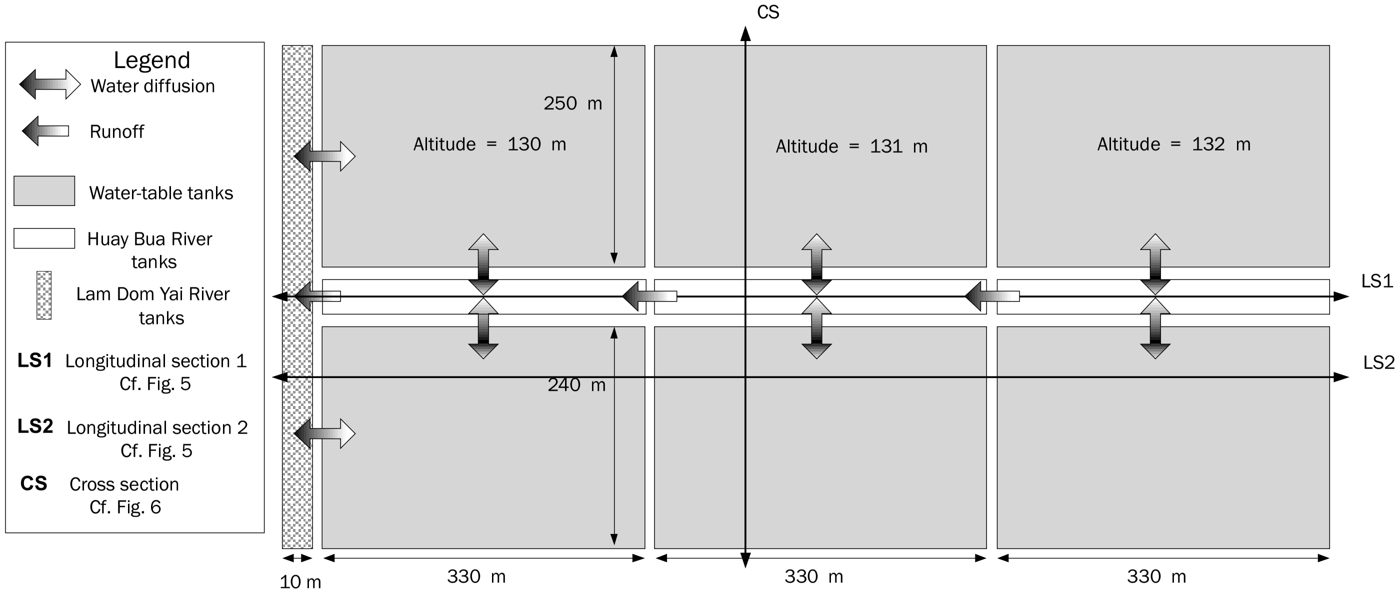

Fig. 4. First layer of the model spatial entities representing the water table and rivers.

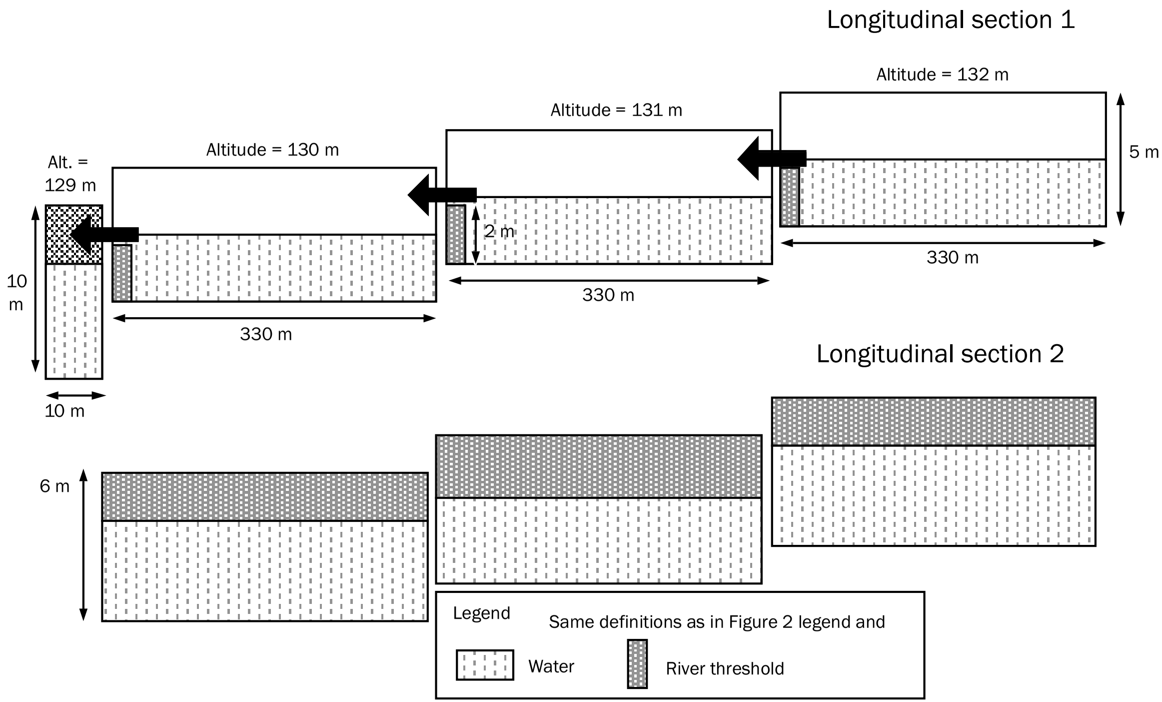

Fig. 5. The three-level terraced entities of the first layer in the model.

lack of precise data concerning soil hydrodynamic parameters forced us to simplify the representation of these transfers: in this way, water transfers between water-table tanks were neglected. This first layer is overlaid by a second layer made up of the RLR fields and the pond entities (Fig. 6). Each field is made up of a root-zone tank and a ponded-water tank. Ponds are made up of a single tank. The vertical water transfers occur at this layer level: rain falls into the ponds, the ponded-water tank, and the river tanks. The rain collected in the ponded-water tanks seeps into the root-zone tanks and water in the root-zone tanks percolates into the water-table tanks. These model entities are represented on the CORMAS grid by an aggregate of cells.

The spatial soil variability in northeast Thailand has been identified as an important factor that may interact with farmers' decision-making regarding cropping patterns and water uses (Oberthür and Kam 2000). To represent this variability, a map of the soil series was used. Six soil series were identified in the Huay Bua watershed and one of these series is attributed to each cell of the grid (Fig. 7). For each soil series, three kinds of hydraulic parameters were estimated or calculated using textural class equations and experimental measurements (Akatanakul 1985): the total porosity was used to determine the soil moisture of the rooting zone using the volume of water in the tank. The soil moisture at field capacity was used to calculate the rates of percolation and evapotranspiration on a cultivated soil. Percolation stops when soil moisture of the root zone is below the field capacity. Evapotranspiration is maximal when the root-zone soil moisture is superior to the field capacity. Saturated hydraulic

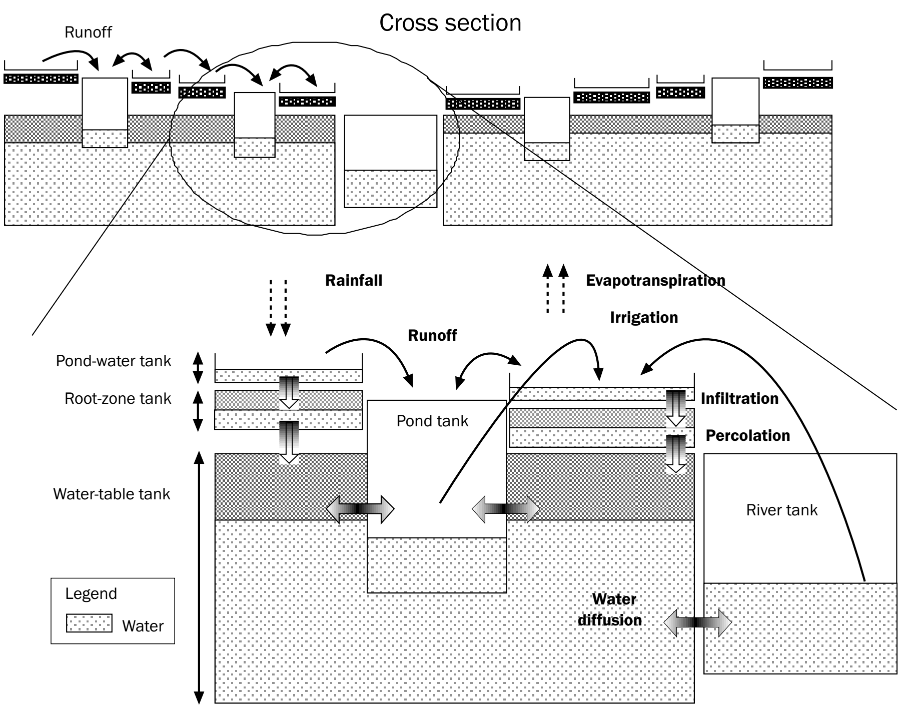

Fig. 6. Structure and hydraulic functioning of the multi-agent model.

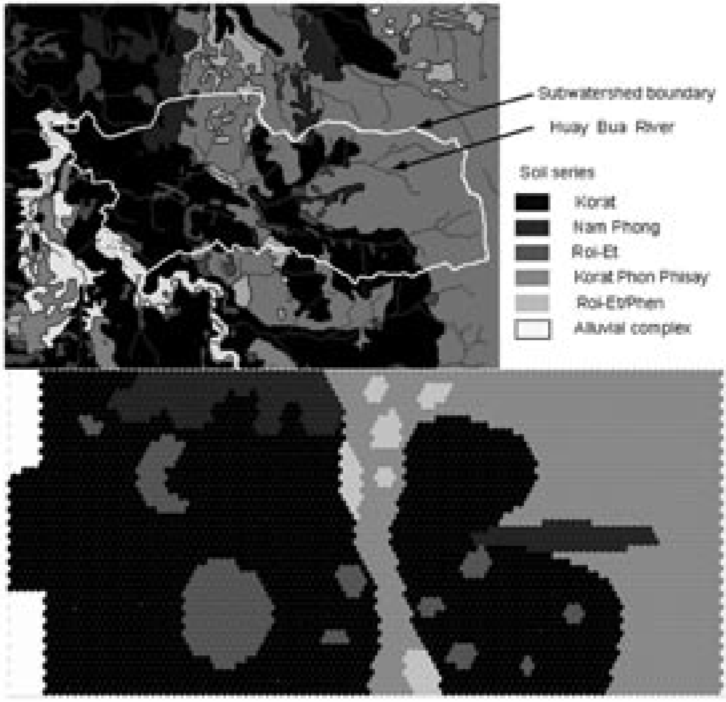

Fig. 7. Distribution of the soil series (A) on the soil map and (B) on their representation on the CORMAS grid.

conductivity was used to determine the maximum transfer for infiltration, percolation, and diffusion (Table 1) (Lacombe 2003).

Several decisions concerning the use of pond water depend on the volume available and the distance from the field to the reservoir. The diversity of possible situations regarding the location and size of fields and ponds is realistically represented in the model. For each aggregate, the number of cells is determined to represent the actual relative variability in size of each entity. The grid representing an area of 50 ha and 625 fields is made up of 5,000 cells and each cell is equivalent to 100 m^2. Each aggregate corresponding to a field consists of several cells varying from 1 to 16. According to our field surveys, there is an average of three ponds for 10 ha of paddy, and so 15 ponds are shown on the grid. Each pond is made up of 2 to 8 cells, as shown in Figure 8. The Huay Bua River is made up of a linear aggregate crossing the grid from east to west, whereas the Lam Dom Yai River is represented by the same kind of aggregate following the west side of the grid. The Lam Dom Yai River is wider (2 cells) than the Huay Bua River (1 cell) in accordance with the field observations. Each pond tank is partially submerged in the water-table tank as displayed in Figure 6 and this structure determines the water level in the ponds after a hydrostatic equilibrium has been reached. This water level may vary between ponds according to their respective locations along the virtual toposequence, as is also the case in reality.

Table 1. Model parameter values for different soils.

Tanks of each soil series	Soil total porosity ($cm^3\ cm^{-3}$)	Soil moisture at field capacity ($cm^3\ cm^{-3}$)	Saturated hydraulic conductivity ($mm\ d^{-1}$)
Korat			
Root-zone tank	0.36	0.19	5,387
Water-table tank	0.40		1,379
Roi-Et			
Root-zone tank	0.39	0.27	1,891
Water-table tank	0.39		1,830
Korat/Phon Phisai association			
Root-zone tank	0.36	0.18	5,233
Water-table tank	0.43		509
Roi-Et/Phen			
Root-zone tank	0.37	0.24	1,762
Water-table tank	0.37		1,714
Nam Phong			
Root-zone tank	0.34	0.21	1,250
Water-table tank	0.38		1,250
Alluvial complex			
Root-zone tank	0.36	0.22	3,104
Water-table tank	0.39		1,336

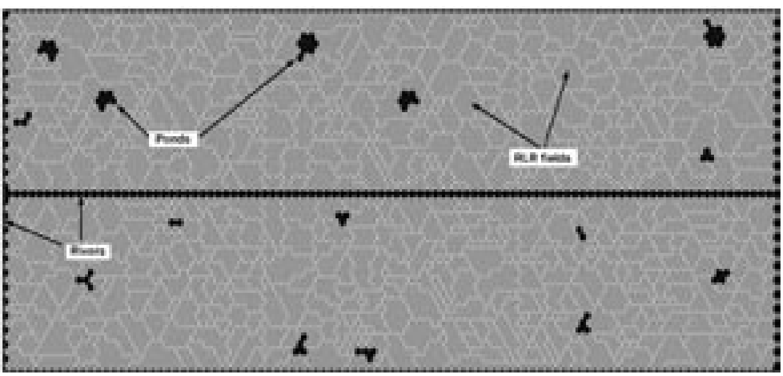

Fig. 8. The model spatial entities as represented on the CORMAS grid (the water-table entities are not represented).

Verification and calibration of the model

Model verification aims to control that each of the model entities is performing its functions properly. By choosing simple initial conditions, it is possible to observe the variation in water level and water transfer, inside and between tanks, and then to compare the model evolution with predictable behaviors. The verification is repeated for each entity and each associated parameter. As an example, one simple model consists of verifying the functioning of water transfer between a ponded-water tank, initially full of water, and its root-zone tank, initially set as being dry. Figure

9 displays the initial drop in the ponded-water level. This decrease is first rapid and constant and then slows down when the root-zone tank reaches saturation. When the root-zone humidity exceeds the field capacity, the percolation function is activated (as soon as time-step 3) and starts draining the root zone. As soil moisture decreases, the infiltration function is slowly reactivated. At time step 9, infiltration increases again because of the root-zone soil moisture drop. When there is no more ponded water, the root-zone tank continues to drain out until it reaches field capacity. Another scenario was run to verify the evapotranspiration function in the model. The ponded-water and root-zone tanks were initially set as full and the percolation and rainfall transfers were inactivated. The two tanks had losses only by evapotranspiration (Fig. 10). Initially, the evapotranspiration function affected only the ponded-water tank for nearly 40 days. Even if RLR roots absorb water from the root-zone tank, evapotranspiration is

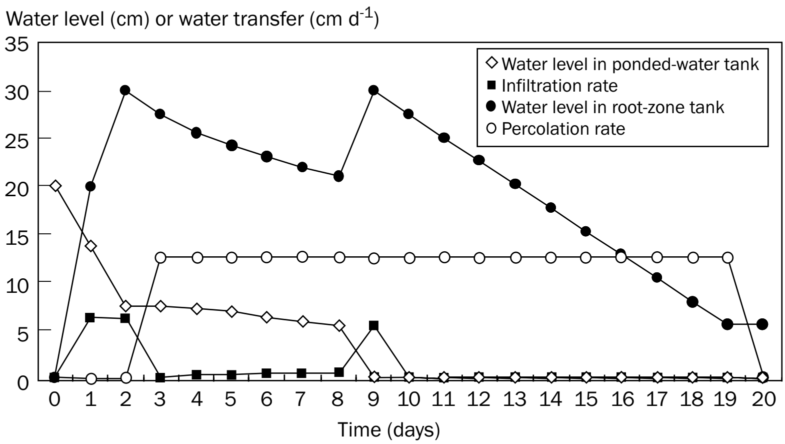

Fig. 9. Verification of infiltration and percolation functions in a simulated field.

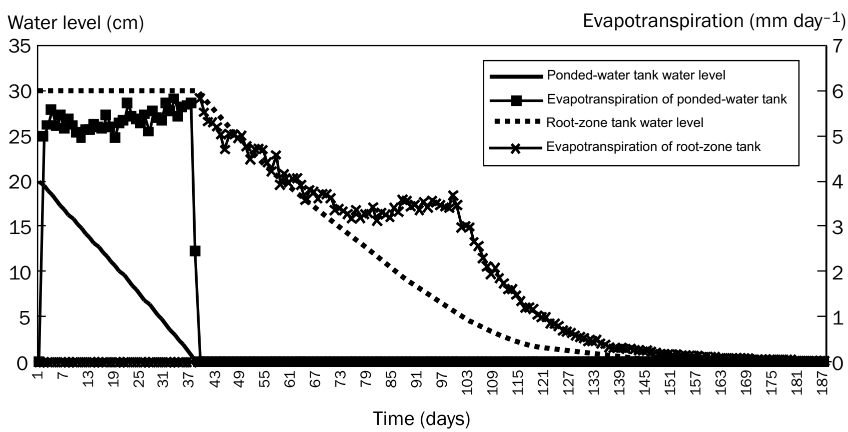

Fig. 10. Verification of the evapotranspiration function at the simulated field level.

set to zero since the climatic demand is mainly satisfied by the physical evaporation from the ponded-water tank. As soon as ponded water disappears, evapotranspiration from the root-zone tank starts. It is maximal at the beginning and then it decreases because of the decline in soil moisture content. Thresholds appear at time-steps 75 and 100. The first threshold is due to the roots' absorption moderating the decline in evapotranspiration, even if the soil moisture continues to decrease. The second threshold appears as the soil moisture content drops below field capacity: beyond this threshold, the roots do not affect the evapotranspiration rate anymore. These two examples illustrate the methods that were used to verify the functioning of each tank and its associated water transfer functions.

After its verification, the model was calibrated. The model parameters such as water levels or water transfers should display realistic variations in time and space. The water table is the model entity for which the water-level variations are well known. Piezometric measurements made by Torii and Minami (1985) helped in calibrating this parameter by defining coefficients to adjust the variations in the water table calculated by the model. By modifying the percolation rate (water transfer from root zone to water table) and the diffusion rate (water transfer from the water table to the river), it was possible to correct the water-table level variations to make the water-table level more coherent with the available empirical data. According to surveys, ponded water appears in RLR fields at the beginning of August and usually disappears in late October when rains stop. Infiltration and percolation transfers had to be calibrated so that the water level in the ponded-water tanks would follow these yearly variations with some spatial variability according to the field position along the toposequence and the soil type (different permeability). Figure 11 shows the variations in water levels in the six water-table tanks of the model along the year. An initialization artifact consists of setting the water level at the same value for the six tanks at the beginning of each year. We assume that there is no hydrological linkage between years.

Exploring scenarios with simulations

Although we have chosen the multi-agent systems approach to create our model, it doesn't include any autonomous agent able to make decisions yet. Consequently, at

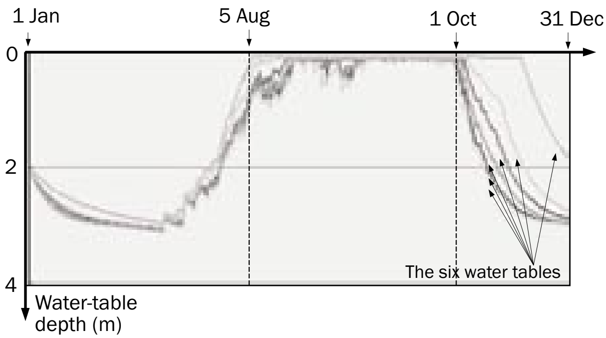

Fig. 11. Calibration of the water levels in the six water-table tanks of the model.

the present stage of development of this model, the decision-making rules we wish to simulate need to be decided at the initialization of the model and they cannot evolve during the simulation. For this, two functions were created. The “irrigation” function takes water from the ponds or the rivers and transfers it to the RLR fields or nurseries when their root-zone moisture content has dropped below a value corresponding to the water-stress threshold. As precise information on RLR wilting point in the Huay Bua watershed is not available, this value is arbitrarily set to the moisture level at field capacity. At each time-step, a second “evaluate water stress” function calculates the proportion of water-stressed fields that couldn’t be watered because of insufficient water volume in the ponds or in the rivers or because they are located too far from the water sources. This function is based on a hydrological point of view and should be readjusted through validations.

An important question concerns the assessment of the efficiency of these ponds to decrease the proportion of water-stressed fields during dry spells. This efficiency can be estimated by comparing the proportion of water-stressed fields after running simulations with and without ponds. Scenarios were defined to analyze the sensitivity of pond efficiency to parameters that farmers can manipulate according to their objectives related to rice sales or family consumption and cost and availability of the labor force. Such parameters could be the dates for early and late seeding of their seedbeds or the number of days between these two sowing periods. It is possible to observe the variations in pond efficiency and their correlations with these sowing dates (Fig. 12A). Pond efficiency increases with the proportion of late-seeded nurseries because the ponds have a limited capacity to store rainwater at the beginning of the rainy season, which is characterized by light rain showers, and they are more efficient later in the year. Figure 12B shows the effects of the duration of the period between the two seeding dates on pond efficiency. For a period longer than 2 months, pond efficiency is maximum and stable. Below this threshold, the efficiency is limited by a too short period between sowings.

Discussion

These simulations illustrate the dilemma that farmers have to face: early sowing of RLR nurseries may be important for farmers who wish to sell their rice crop as early transplanting maximizes the length of the vegetative phase during which the plant accumulates dry matter. At the same time, early sowing increases the risk of drought, which occurs frequently in the early part of the wet season. Although these results should be further discussed with farmers to validate the model, these first simulations aim at showing the possible uses of the simulator. This model contains the main biophysical entities involved in the decision-making rules regarding water use. It offers an environment predisposed to receive autonomous farmer-agents, which could help us to better understand the interactions between water supply and demand. Introducing such farmer-agents would allow us to model irrigation processes depending on individual decisions based on the perceptions of the water-resources dynamics rather than using irrigation functions (used in this model) whose criteria are fixed by the modeler.

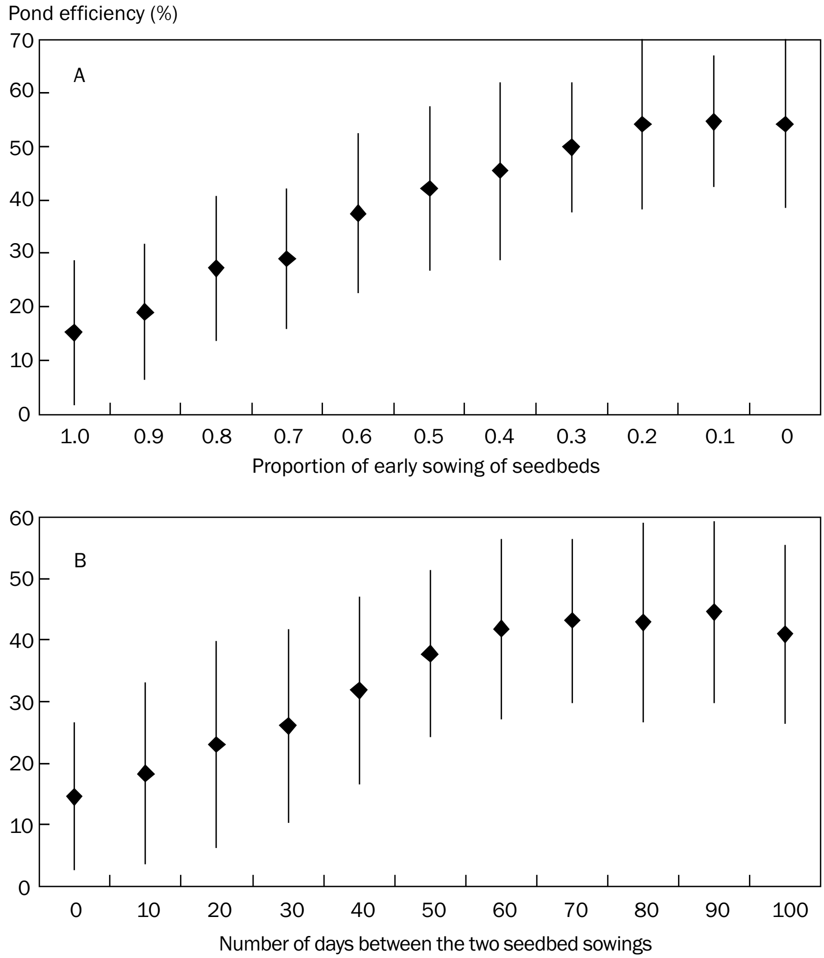

Fig. 12. Sensitivity analysis of pond efficiency according to variations in the proportion of early sowing of seedbeds (A) and the duration between the two nursery seeding periods (B).

Conclusions

The initial simulation results depend on the parameters that were chosen during the model conceptualization and their respective values implemented in the model and then corrected during the verification and calibration steps based on the "expert" knowledge of the modeler. These simulation results should be interpreted with care and must be further validated by transmitting them to the farmers to assess their degree of correspondence with actual circumstances based on the farmers' empirical experience.

An increasing number of wells used for the irrigation of rice and vegetables was observed during the field surveys. This simulator could help to explore scenarios of change in the use of water tables to evaluate the possible consequences of this emerging pattern of increased well irrigation. Compared to the ponds, the water table may be a more suitable source of water for irrigation, particularly at the beginning of the RLR cycle when rains are still light and the need for water is already important. The next step in the model implementation could also consist of adding autonomous agents making decisions regarding water use. These developments of the model would allow the simulation of new scenarios in which farmer-agents could cooperate. One relevant topic to be explored with them would be the possibility of exploiting common water resources such as the several large collective ponds that are clearly underexploited now.

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Notes

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Economic differentiation of rice and shrimp farming systems and riskiness: a case of Bac Lieu, Mekong Delta, Vietnam

Le Canh Dung, Nguyen Nhi Gia Vinh, Le Anh Tuan, and F. Bousquet

In production terms, Bac Lieu Province in the Mekong Delta of Vietnam is characterized by rice and saline-water shrimp farming. This paper presents two simulation models of economic differentiation of those farming systems.

The first model simulates observed farmers' behavior in six different farming subzones of the province. After simulating 5 years for each farming system corresponding to each subzone, the results showed that economic differentiation has occurred in every subzone at the study site in terms of both household average accumulation of income and number of households in the rich and poor class. The household average accumulation of income of the rich household class in those subzones where physical conditions allowed shrimp farming has a high value, while that of the medium and poor households remains at a low value, and is even negative for two subzones. The household average accumulation of income of the rich household class in those subzones where physical conditions (freshwater zone) allowed only rice farming reaches a high value after 5 years of simulation, but this value is still less than that in shrimp-culture subzones. The poor households in these subzones of rice-based farming also face a negative income after some years.

The second model aims at simulating changes in cropping system under various conditions. The individual decision-making process is based on a theoretical model, the Consumat. Scenarios based on alternative values of prices, yields, risk, and size of networks are compared. It is shown that prices and shrimp yields make the difference in terms of both wealth and economic differentiation.

Bac Lieu, in Ca Mau Peninsula, is one of 12 provinces of the Mekong Delta in Vietnam (Fig. 1), where about 85% of the population is engaged in agricultural and fishery activities, with rice cultivation being the most important (Hoanh et al 2001). The combination of farming and livelihood as well as the interactions between biophysical and social factors are complex. Therefore, we want to clearly understand them, especially over time. Different farming systems and thereby income are major issues being taken into account. This is because the evidence showed that monoculture of shrimp has a high return but also a high element of risk (Hossain et al 2002), whereas rice farming has a low benefit but is much more stable. The questions raised over time are (1) Is there a differentiation in income distribution at the household level because of the biophysical conditions and market factor? (2) Is there a differentiation in household income within the subzone because of biophysical conditions and hetero-

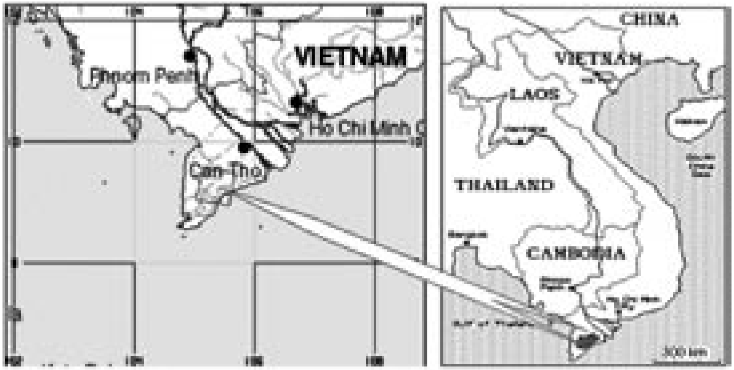

Fig. 1. Location of the study site in the Mekong Delta of Vietnam.

geneity in farm management knowledge? (3) How will the differentiation evolve if the farmers change their behavior? In this research, the first two questions are discussed by running a simulation model based on the observations of farmers' decisions for six different zones and the third question is discussed by running a simulation model using a theoretical model of the decision-making process, the Consumat approach (Jager 2000).

A multi-agent systems (MAS) model supported by the CORMAS (common-pool resources and multi-agent systems) program helps us to answer those questions. It allows us to visualize the scenarios after linking several biophysical and socioeconomic factors. Consequently, given the complexity of this subject, the spatial characteristics, and, above all, the noneconomic and interactive behavior of farmers, we use the MAS model to simulate the scenarios. This paper presents first the background of the study and a brief review of applications of MAS for water management and economic differentiation. Then, a first model is conceptualized and simulated to explore the consequences of the actual behavior of stakeholders. A second model, more abstract, explores the consequences of the changes in behavior and the relative effects of various driving forces.

Background

This coastal province has recently experienced a large conversion in land use. The original objective was to shift from the natural exploitation of fisheries and a single traditional rice crop to modern double and triple rice crops. The conversion relied upon changes in water resource-use strategy. In the early 1990s, in response to the country's high demand for rice, the government constructed a series of embankments and sluices along the coast of Ca Mau Peninsula. The purpose was to (1) build a series of sluices that could be closed at flood tide to protect rice lands from saline intrusion and (2) improve the canal networks to increase the supply of fresh water from the Mekong River. The total area that the project could protect was 250,000 ha, of which approximately 160,000 ha belonged to Bac Lieu Province. This resulted, as intended, in the rapid expansion of intensified rice cultivation and a sharp decline in shrimp farming in the project area.

An intervention such as that does not always have a positive environmental and socioeconomic impact because of the rapid change in hydrological conditions. The impact varies with farmers' production conditions and their environment. The farmers on nonacid sulfate soil in the east of the project area benefited from the saline protection scheme, which allowed them to increase rice intensification. In contrast, farmers in the acid sulfate soil in the western part found themselves having to abandon their shrimp farming, which in some cases meant a sharp decline in household income. The change in environment also caused a decline in income earned from capture fisheries, which were not only an important income source for poor households but also their major protein source (Hoanh et al 2001).

Recently, the high profit of shrimp and low profit of rice production have had a strong economic impact on those who had converted from shrimp to rice cultivation. Moreover, unproductive rice production in the acid sulfate soil area, especially in the western part belonging to the project area, led to a great loss of both farmers' income and government revenue. This prompted the government to re-examine the original development objective. Since 2000, the policy had to change to two distinct water-control schemes. In the eastern part of the project area, the first scheme is preventing saline-water intrusion while supplying more fresh water to develop rice-based farming. The second scheme, applying to the western part, is alternatively allowing saline water in the dry season and keeping fresh water in the rainy season for shrimp and rice culture, respectively. The project area can now be separated into six subzones, in which subzones 1, 2, and 3 follow the first water scheme and subzones 4, 5, and 6 follow the second water scheme (Hoanh et al 2001; Fig. 2). Over five years, farmers in the project area have faced great difficulty in coping with variation in environment and their strategy of resource use. This brought about a strong requirement of technical and socioeconomic assessment and research from government and research institutions. The integration of knowledge on biophysical and socioeconomic factors is being taken into account as a prerequisite in this context. In 2000-03, a DFID project carried out a study on research knowledge, technologies, and recommendations on natural resource use at both the farm household and commune level. The study confirmed that the environment and resource use in coastal lands are very sensitive to external intervention (Hossain et al 2002).

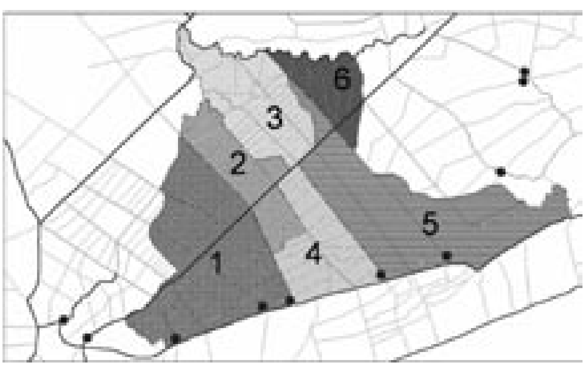

Fig. 2. Six subzones at the study site in Bac Lieu, Mekong Delta, Vietnam. The dots represents the sluices.

Literature review

MAS and water management

Multi-agent systems are increasingly used in the field of environment and natural resource management (Doran 2001). MAS combine the advantages of cellular automata and multilevel modeling since these are able to represent both interactions between individuals and between different levels of organizations (Gilbert and Troitzsch 1999). MAS have proved to be very useful for taking into account several kinds of anomalies that cannot be explained with other models (Bousquet et al 1999). MAS are used to show the observed dynamics of the system to stakeholders (including noneconomic interactions and long-term strategies of users). Multi-agent systems have proved to fit very well with these kinds of goals (Barreteau and Bousquet 2000, Deadman et al 2000, Ferber 1999, Janssen 2003, Rouchier et al 2001). For water management, several attempts have been made to model the interactions between resource dynamics and societies.

MAS were useful for the integrated management of the use of the water table of the Kairouan region in Tunisia. They were useful in representing a complex and distributed system of the water table. They can explore the interactions between the physical and socioeconomic components of the system (Feuillette et al 2003). Recently, multi-agent modeling has enabled horizontal relationships (spatial configurations) and vertical relationships (socioeconomic organization) to be integrated for predicting not only the duck population but also the economic conditions under an exchange between decision-making of farmers and hunting rights in the Camargue, in the South of France (Mathevet et al 2003). The multi-agent approach is applied to model and simulate hydraulic management in the Camargue (Franchesquin et al 2003). In this model, hydrologic and human decisions are integrated and two models are defined. The first one computes the hydro-saline state of the Vacarres region according to natural factors (rain and evaporation) and human factors (irrigation, drainage, and management of the dike). The second one formalizes decisions on hydraulic management in the two phases of the life cycle of a contract. For the Tisza River in Hungary, a simulation model using the Consumat approach (Jager 2000) to evaluate alternative flood management policies is used. This is because one cannot predict the time, location, and magnitude of floods in the case of limited historical data (Brouwers and Verhagen 2003). In the model, the behavior of the river and the financial consequences are simulated on a year-by-year basis. The extension of the model has been successful as results are more in line with the real world. So, MAS are very useful for integrating several aspects that one wants to take into account.

MAS and economic differentiation

It is evident that MAS can integrate socioeconomic, ecological, and spatial dynamics into one single model. In a diffusion process, the agent-based model is explored as a bottom-up approach to make a good prediction of the dissemination of a good in the market, for which the outcome is consistent with results produced by the top-down approach using the Bass model (Holanda et al 2003). The economic behavior of human beings is much more closely related to cognitive science, in which the emotions of a human being are more flexible and decision-making is more rational. Under this concept, four styles of decision making come from the combination of two reasons and autonomous dimensions followed by individual and social dimensions of cognitive processing. These are repetition, deliberation, imitation, and social comparison behaviors. Repetition behavior occurs when consumers have a high level of need satisfaction and certainty; deliberation behavior occurs when consumers have a low level of need satisfaction but have high certainty; imitation behavior occurs when consumers have a high level of need satisfaction but have uncertainty; and social comparison behavior occurs when consumers have a low level of need satisfaction and low certainty (Jager 2000). This model assumes that an agent has four kinds of decision-making process:

- *Repetition*. The agent just keeps on making the same decision.
- *Imitation*. The agent imitates the decision of other agents he is connected with.
- *Deliberation*. The agent will compare the potential options and select one of those.
- *Social comparison*. This is the same procedure as the imitation, but, before adopting a new activity, the agent checks whether the new activity has a better expected output than the current one.

As in Bac Lieu, decisions are closely linked to risk. In this case, the Consumat approach is useful for modeling the changes in behavior.

First model: simulating actual dynamics and consequences on economic differentiation

Methodology and approach

A companion modeling approach is applied for this model. The research questions came from field observations and discussions among scientists that took place at an interdisciplinary meeting in Ho Chi Minh City in late 2000 and from information gathered from the baseline survey, participatory rural appraisal (PRA), and full household socioeconomic survey in previous research projects implemented in Bac Lieu Province. Bac Lieu was the site for investigation, especially after the saline protection project went into operation. A baseline sampling survey of 350 households took place in early 2000 (Gallop et al 2002). A PRA and a full household socioeconomic survey in five hamlets of the project area were conducted in mid-2000 (Hossain et al 2002). A key informant interview was done in late 2002 and a final survey and PRA were made in early 2003 to assess livelihood dynamics under 3 years of readjusted land-use strategy. After building the model for the simulation for 260 time-steps, in which one step is equivalent to 1 week, the model is run. An important aspect of our model is that the simulation results are validated by revisiting the six communes to verify the results with local people (Fig. 3).

Available knowledge and data

From the baseline sampling survey, we learned that in 350 households interviewed the family size averaged 5.23 persons, and ranged from 1 to 13. Rice production is the dominant cropping system, and it occupies 75.8% of the total parcels in the survey, followed by aquaculture and fisheries. Average rice yield surveyed was 3.29 t

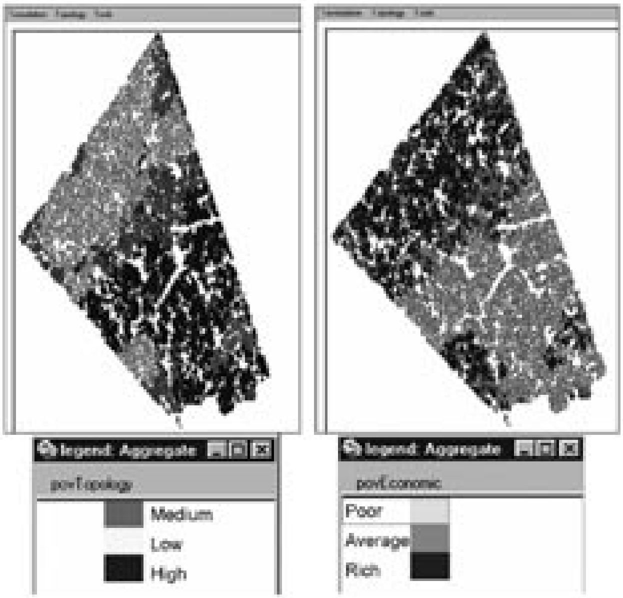

Fig. 3. The companion modeling approach.

ha^{-1}, which could be seen as a reasonable yield in acid sulfate soil conditions under controlled irrigation. A double rice crop is the major pattern among rice production systems; this type of crop represented 64.3% of the total parcels in the survey. Rice could be sold at an average price of 1,602 Vietnamese dong[1] (vnd) kg^{-1}, and ranged from 800 to 3,200 vnd kg^{-1}. Therefore, the profit that could be obtained from rice production was 885 vnd kg^{-1} of paddy; consequently, rice farmers could earn a profit of 6 million vnd per household per year. However, because of uncertainty and farm size, the profit differed markedly, from –12 million to +67 million vnd per year per household. Some 42.9% of the total households surveyed engaged in aquaculture and fisheries, but only 22.5% of the households practiced shrimp/fish production. Profit from this sector varied widely, from –15 million to +216 million vnd per household per year. The semistructured interviews done in six communes also showed that, among the vast number of farmers doing extensive farming of shrimp, some advanced farmers have improved their shrimp production by changing from extensive to semi-intensive shrimp ponds, which they expected would earn a higher profit. One advanced farmer interviewed could harvest 500 kg of shrimp ha^{-1} under the semi-intensive raising method. This key informant interview also showed a variation in rice and shrimp production and their prices, as well as among the subzone after readjustment of the land-use strategy (Table 1). At the prevailing price of rice and shrimp and with the low yield under extensive shrimp cultivation, fish production is about five times more profitable than rice production. As a result, the socioeconomic survey estimates the negative effect at 39% of household income during the transitional period, and 17% at full development.

[1]US$1 = 15,000 vnd.

Table 1a. Parameters of rice and shrimp production by subzone in the study area.

Subzone	Rice yield (t crop^{-1} ha^{-1})			Rice price (vnd kg^{-1})	Rice cost (million vnd crop^{-1} ha^{-1})
	Highland	Medium land	Lowland		
1	3.5–4.0	No rice	No rice	1,500	3.5
2	1st: 2.5–3.5	1st: 2.5–3.0	3.0	1st: 1,300	1st: 3.5
	2nd: 3.0–4.0	2nd: 3.0–3.5		2nd: 1,200	2nd: 3.4
3	1st: 4.0	1st: 3.5	4.0	1st: 1,700	1st: 4.0
	2nd: 3.0	2nd: 3.0		2nd: 1,700	2nd: 4.0
4	1st: 5.4	1st: 4.6	1st: 3.8	1st: 1,750	1st: 3.5
	2nd: 4.6	2nd: 3.8	2nd: 3.0	2nd: 1,600	2nd: 3.5
5	1st: 6.2	1st: 4.6	1st: 4.2	1st: 1,800	1st: 2.0
	2nd: 5.4	2nd: 4.6	2nd: 4.2	2nd: 1,700	2nd: 1.5
	3rd: 4.6	3rd: 4.2	3rd: 3.0	3rd: 1,700	3rd: 1.5
6	1st: 4.5	1st: 4.0	1st: 3.5	1st: 1,600	1st: 3.2
	2nd: 5.0	2nd: 4.5	2nd: 4.0	2nd: 1,500	2nd: 3.5
	3rd: 3.5	3rd: 3.0	3rd: 3.0	3rd: 1,500	3rd: 3.5

Table 1b. Parameters of shrimp production by subzone in the study area.

Subzone	Shrimp yield (kg crop^{-1} ha^{-1})			Shrimp price (vnd kg^{-1})	Shrimp cost (million vnd crop^{-1} ha^{-1})
	Highland	Medium land	Lowland		
1	1st: 0	1st: 50	1st: 60	1st: 100,000	
	2nd: 20	2nd: 50	2nd: 80	2nd: 100,000	15.0
	3rd: 80	3rd: 80	3rd: 100	3rd: 100,000	
	4th: 80	4th: 80	4th: 120	4th: 100,000	
2	No shrimp	No shrimp	300	100,000	5.0
3	No shrimp	No shrimp	100	100,000	5.0
4	No shrimp	No shrimp	No shrimp	–	–
5	No shrimp	No shrimp	No shrimp	–	–
6	No shrimp	No shrimp	70	80,000	5.0

Source: Key informant interviews in study area carried out in December 2002.

So, thanks to the available knowledge and the typical biophysical conditions, especially in the different farming systems in the six different subzones of the research area, the six communes corresponding to each subzone were chosen for incorporation into the model.

Conceptualization of the model

The model was based on a series of assumptions, as follows. There are six communes with different topology and number of households. Farmers that live in the six communes plant different crops and have different knowledge. Almost all of them have land for planting rice or raising shrimp; the rest are landless people that have different characteristics and experience, who can choose different job opportunities for earning money, such as fishermen, hired laborers, seasonal migration, and sellers. In this model, farmers' living costs are already taken into account. The number of households and their distribution in three economic categories (poor, average, and rich) were given by the data of the baseline sampling survey, BSS (Table 2). Poor farmers receive a plot of 0.5 ha, average ones a plot of 1.5 ha, and rich ones a plot of 3.5 ha. The plots are randomly placed on the map. The farmers also receive various amounts of money at initialization (Fig. 4).

Table 2. Number of households by economic class in six selected communes.

Class	Number of households by commune					
	1	2	3	4	5	6
Poor	996	552	728	830	803	735
Medium	1,546	1,540	1,943	1,106	987	1,648
Rich	961	995	508	585	283	734

Source: Baseline sampling survey carried out in 2000.

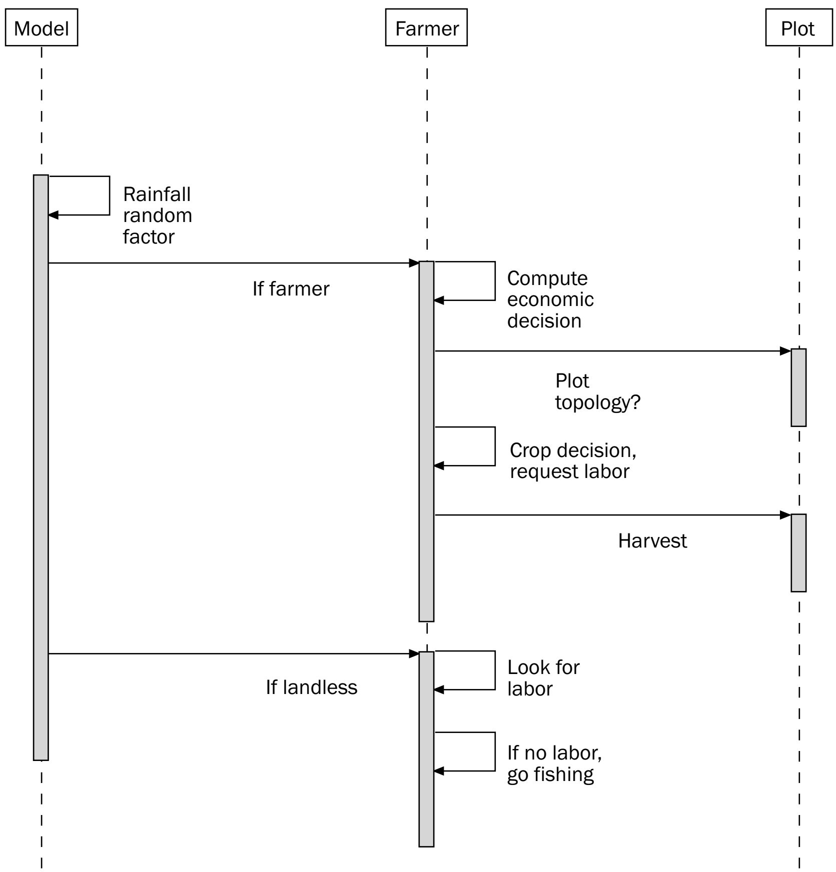

Fig. 4. Topology and economic conditions of commune 1.

The following factors are taken into account:

- The climate is separated mostly into two seasons: dry and wet. The status of sluices is determined by the wet season. When the wet season arrives, the sluice is closed and vice versa. The climate factor can be a random factor in this model.
- Choosing farmers' crops (rice, shrimp) depends mainly on the economic conditions, type of land (high, medium, or low), and the status of sluices in the region (open or closed). The decision-making process schedule appears in Figure 5. In some regions, farmers plant a rice crop in rotation with a shrimp crop to improve biological conditions and increase shrimp quality for later crops.
- The appropriate time scale to represent the changes in the model is the week because, after several weeks, farmers harvest a crop and prepare for the next crop. Therefore, in one year, they can have more than two rice or shrimp crops.

Harvest time can be a random factor. Farmers harvest at a time from the 15th to 17th week for the rice crop and 14th to 16th week for the shrimp crop before the end of the crop because other environmental factors can affect the growing of rice or shrimp; this means that the harvest time cannot be fixed from year to year.

Implementation of the model

We use CORMAS as a tool to simulate the BACLIEU model. This tool is based on the platform VisualWorks®, a programming environment software used for programming in Smalltalk® object-oriented language (Bousquet et al 1998). In CORMAS, an agent or entity can be described as autonomous because it has the capacity to adapt when the environment changes. In addition, CORMAS helps us create relationships in communication and situations between entities or agents. The BACLIEU model has three main entities: (1) the spatial unit, "cell," which can be regarded as the smallest land area of 1 ha; the other is the "plot," which aggregates cells together to form bigger land areas and to separate one land area from others; (2) "farmer" is the social entity; each farmer can exchange messages with others; and (3) the passive entities "rice" and "shrimp" are specified as crops. Each plot instance is assigned to a farmer instance. Each farmer instance can have no plot or only one plot. A landless farmer can be a hired laborer or choose another job to do. Farmers can perceive what happens

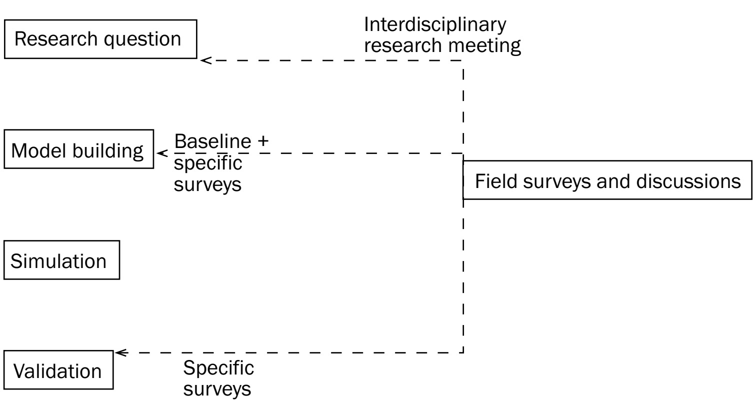

Fig. 5. The sequence diagram of the BACLIEU model.

in the environment so that they can decide which crop they want to plant. Each farmer instance receives a status of sluice and rainfall; harvest time of shrimp and rice come from passive objects, including shrimp, rice, sluice, and rainfall.

Results and discussion

Farming systems, average accumulated household income, and the number of different household classes are visualized in this model. Average accumulated household income is a return above the variable production cost plus family living cost. Results are presented for different classes of agents: class A stands for rich farmers who have more than 250,000 vnd, class B stands for those who have from 100,000 to 250,000 vnd, class C for those who have less than 100,000 vnd, and class D for the landless agents. In this scenario, the model is run for 260 time-steps (1 week = one time-step) equivalent to 5 years. The simulation results from six communes are summarized. We can state that the two important research questions are economic differentiation (1) among subzones and (2) within subzones. The results are presented in Figure 6. Line A represents the rich households, line B the medium households, line C the poor households, and line D the landless households.

In commune 1, there is a large economic differentiation after 5 years of the simulation, reflected in the average accumulated household income among household types and the variation of those households. Income and number of rich households are increasing yearly, reaching 80 million vnd and 2,101 households, respectively, at the end of the fifth year (Fig. 6A,B). Another household type, such as the medium one, has its income stable at around 10 million vnd, while the household number increases by 155% after 5 years. The income of poor households is low and varies around zero. However, it is interesting that the number of poor households declines sharply to 740 from 3,500 households after 5 years. We can state that the farming system in which shrimp is dominant has strongly influenced the increase in rich households and the decline in poor households in commune 1. This balance in income distribution leads to an acceptable Gini value of 0.61 in this commune.

The number of rich and medium households increased rapidly in commune 2 after 5 years. It reached 1,384 and 109 households, whereas poor households declined sharply to 1,595 from 3,087 in the beginning (Fig. 7A,B). One special thing that happened in this commune was that the income of rich households reached a high of 226 million vnd, while that of the poor and landless was declining annually. This situation reflects an economic polarization, which is indicated by the value of the Gini coefficient (0.66) at the end of the fifth year.

Economic differentiation in both income and household number in commune 3 still occurs. However, the magnitude of income of the rich household is not much higher than that for the other household types (Fig. 8A,B). It reaches about 36 million vnd after 5 years. The number of poor households varies slightly in the early years, but remains at a high level afterward. Rich and medium households are a small number and they are stable in the commune. This commune's land has already been converted for both rice and shrimp farming; however, rice is the dominant crop because of the high proportion of high and medium land. In contrast, this area is far from a saline-water supply and shrimp is not favorable. A high proportion of the poor remained and the number of medium and rich households was unchanged. This was associated

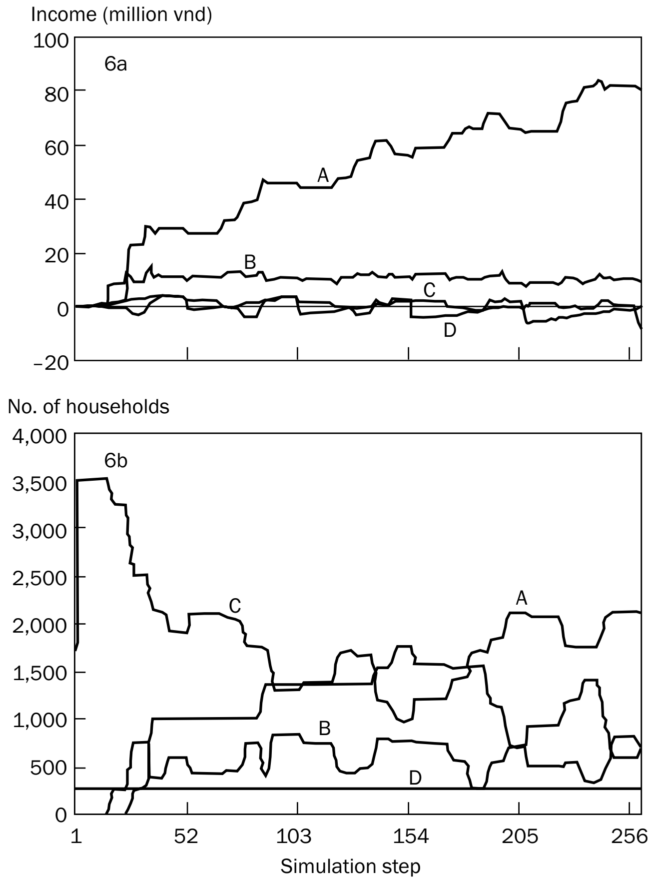

Fig. 6. Accumulated household income and number of households by class in commune 1 for 260 simulation steps. Panel a shows the averaged-accumulated income of rich households (A), medium households (B), poor households (C), and landless households (D). Panel b shows the total number of rich households (A), medium households (B), poor households (C), and landless households (D).

with their economic polarization, which led to a high Gini coefficient of 0.96 after 5 years of simulation.

Rice production is a dominant crop in commune 4, as was planned by the province. High and medium lands are occupied in a large proportion in this commune. A serious economic polarization is also found in this area. Rich households increase their income annually, reaching 40 million vnd, while that of medium and poor, together with landless households, declines yearly, to 12 million and –26 million vnd, respectively (Fig. 9A,B). More riskiness occurs for the poor and landless in this area. These poor and landless people have economic returns lower than their living costs. Because much economic differentiation occurred, the Gini value was 0.88.

A similar economic situation also occurs in commune 5; however, its variation in magnitude is much more obvious. Rich and medium households have incomes of 58 million and 14 million vnd in the fifth year, respectively. There is a similar trend

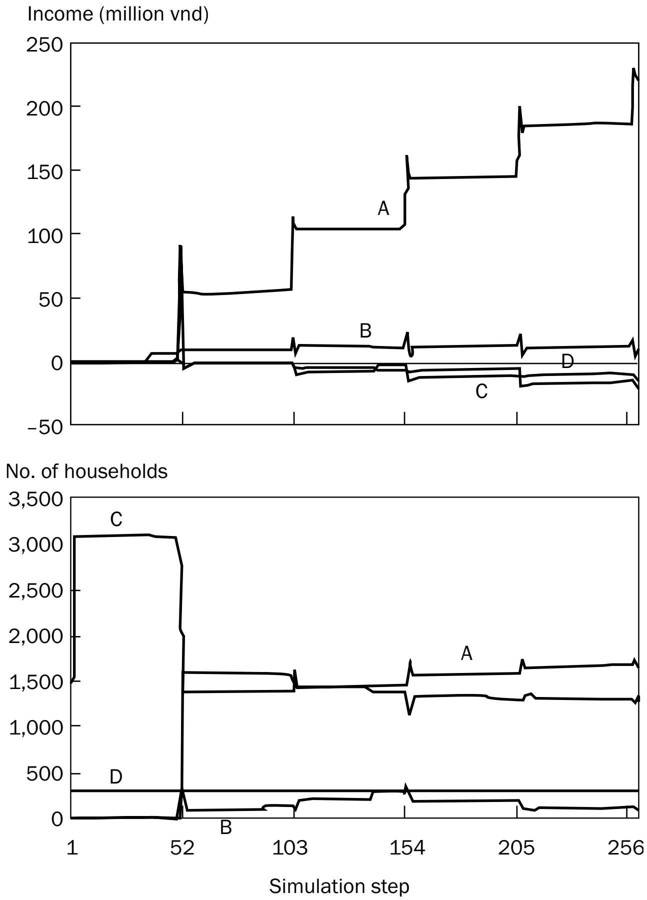

Fig. 7. Accumulated household income and number of households by class in commune 2 for 260 simulation steps. Panel a shows the averaged-accumulated income of rich households (A), medium households (B), poor households (C), and landless households (D). Panel b shows the total number of rich households (A), medium households (B), poor households (C), and landless households (D).

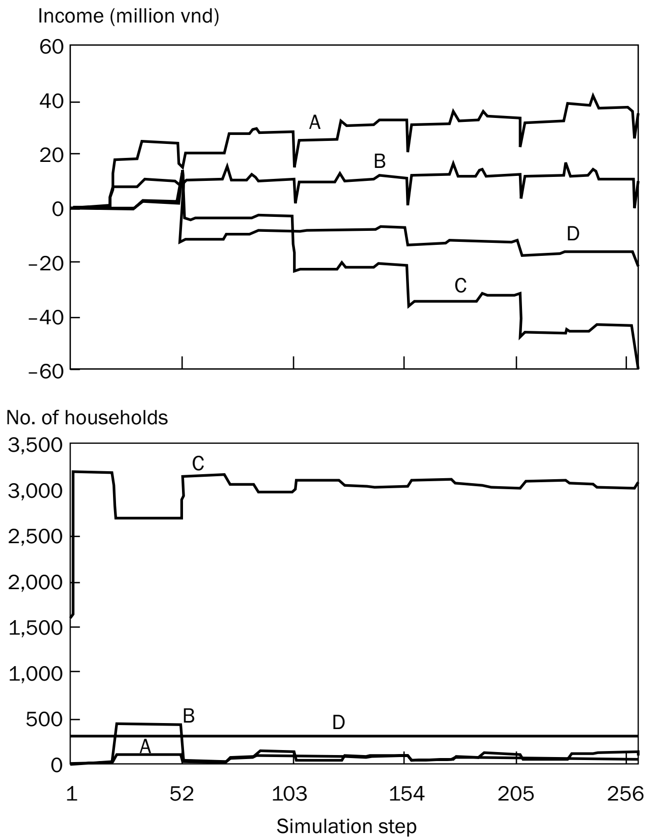

Fig. 8. Accumulated household income and number of households by class in commune 3 for 260 simulation steps. Panel a shows the averaged-accumulated income of rich households (A), medium households (B), poor households (C), and landless households (D). Panel b shows the total number of rich households (A), medium households (B), poor households (C), and landless households (D).

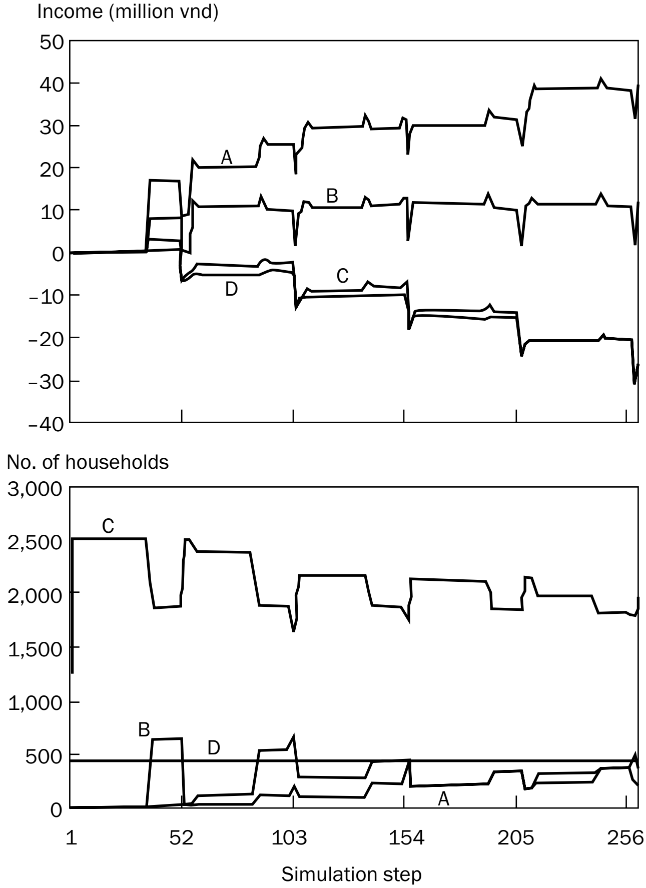

Fig. 9. Accumulated household income and number of households by class in commune 4 for 260 simulation steps. Panel a shows the averaged-accumulated income of rich households (A), medium households (B), poor households (C), and landless households (D). Panel b shows the total number of rich households (A), medium households (B), poor households (C), and landless households (D).

in variation in household income and number of households vis-à-vis commune 4; however, this took place much more clearly (Fig. 10A,B). Commune 5 is being noted as a favorable area for rice cultivation. A high economic differentiation is also recorded in this commune, reflected in the high value of the Gini coefficient (0.81).

Economic polarization is also found in commune 6; however, it is much milder than in communes 4 and 5. Income of rich households is 39 million vnd, while that of medium households is 11 million vnd. Poor households are less poor than in the other communes, only –7 million vnd in the fifth year (Fig. 11A,B). In addition, the number of poor households declines sharply and that of rich households increases rapidly. This leads to a Gini value of 0.65 at the end of the fifth year.

So, economic differentiation has occurred in every subzone. The number of rich households increased in all subzones except for subzones 3 and 4. The number of poor households declined in all subzones except for subzone 3. The gap in absolute household income in the subzone where shrimp farming is dominant is higher than that in the subzone where rice is dominant. The largest gap is found in subzone 2, which recorded 247.6 million vnd, and the smallest one is 30.8 million vnd in subzone 5. For economic differentiation, much more took place in subzones 3, 4, and 5, where the Gini coefficient surpassed 0.8. Although rice production dominated in these subzones, a high proportion of the poor remained, and a high Gini value was recorded. We can state that rice farming as the dominant crop would increase slightly the number of rich and medium households, but would barely reduce the poor in the community. In contrast, the number of rich households and their income would increase and the

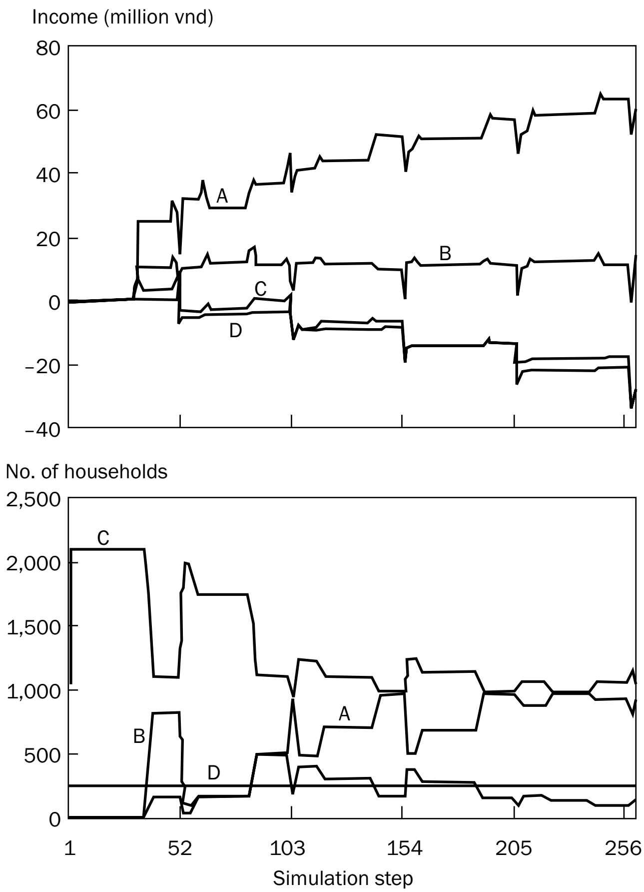

Fig. 10. Accumulated household income and number of households by class in commune 5 for 260 simulation steps. Panel a shows the averaged-accumulated income of rich households (A), medium households (B), poor households (C), and landless households (D). Panel b shows the total number of rich households (A), medium households (B), poor households (C), and landless households (D).

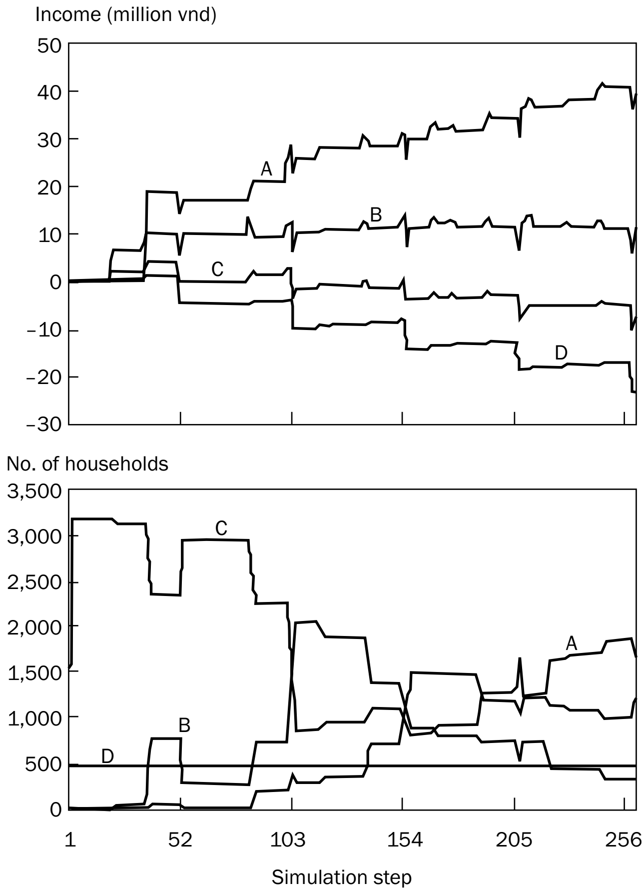

Fig. 11. Accumulated household income and number of households by class in commune 6 for 260 simulation steps. Panel a shows the averaged-accumulated income of rich households (A), medium households (B), poor households (C), and landless households (D). Panel b shows the total number of rich households (A), medium households (B), poor households (C), and landless households (D).

number and income of the poor would decline in the subzones where shrimp farming is dominant, such as in subzones 1 and 2.

In this step, we found that the simulation results are quite consistent with what happened in reality in terms of economic tendencies and a reduction in poor households while rich households increased in number in several communes.

Second model: dynamics of change and external driving forces

What has been run in the first model came from a static model. The model figured out the economic differentiation among and within subzones in the research area. The main weakness of the first model is that it simulates the present behavior of the stakeholders but does not take into account their potential decisions to change crops. The purpose of this second model is to simulate such capacity to change and to explore the reaction of farmers to contextual changes. Thus, the model that we propose here is more abstract than the previous one. It corresponds to stylized facts, although we introduce realistic data. In this model, the agent can choose three kinds of production: shrimp (2 crops per year), rice (2 crops per year), and shrimp and rice (1 crop of each). With this model, we will explore the influence of five kinds of factors: the price of the commodities, rice yield, shrimp yield, variation in prices, and network size.

Conceptualization of the model

The environment. The environment is composed of 300 plots of variable size (from 0.5 to 5 ha). There are three classes of soil (low, medium, and high) (see Fig. 12A). The environment is divided into two zones of equal size: one zone with fresh water (only rice can be grown) and one zone with brackish water (both shrimp and rice can be grown) (see Fig. 12B).

The farmer. We do not know in reality how farmers make their decision when they change crops. Thus, we have selected and adapted a theoretical model of choice, the Consumat model (Jager 2000). Developed by Jager and Janssen (Janssen and Jager 2001), this model is generic and seems relevant for the case study. This model assumes that an agent has four kinds of decision-making process:

- *Repetition.* The agent just keeps on rasing the same crop at time t + 1.
- *Imitation.* The agent imitates the decision of other agents he is connected with. In this model, the agent will adopt the decision made by the majority of his acquaintances (the agents he is connected with).
- *Deliberation.* The agent will compare the potential options and select one of those. In this model, the agent will choose the activity that has the best expected output. These expected outputs are given parameters that depend on the topology of the parcel. For rice, the expected yield is 5.5 t ha^{-1} for the high field, 4.5 t ha^{-1} for the medium-altitude field, and 3.5 t ha^{-1} for the low field. For shrimp, the expected output is, respectively, 100, 150, and 200 kg ha^{-1}.
- *Social comparison.* This is the same procedure as the imitation, but, before adopting a new activity, the agent checks whether the new activity has a better expected output than the current one.

In the Consumat model, these different modes of decisions are activated under different conditions. This depends mainly on two factors: the satisfaction of the agent (S) and his uncertainty (U). Each agent has a satisfaction threshold (St) and an uncertainty threshold (Ut). These thresholds are individual parameters. In the simulation, the St is randomly generated in the range of 0.6 to 1 and Ut is generated in the range of 0.5 to 0.95. The decision-making process depends on the value of the satisfaction and the uncertainty compared to the thresholds.

- If $S \geq St$ and $U < Ut$, repetition
- If $S < St$ and $U < Ut$, deliberation
- If $S \geq St$ and $U \geq Ut$, imitation
- If $S < St$ and $U \geq Ut$, social comparison

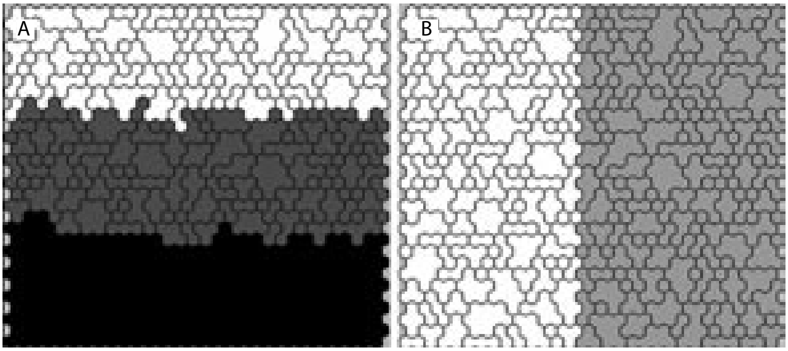

Fig. 12. (A, left) Three types of soils: low (black), medium (gray), high (white). (B, right) Two zones of water management: brackish water (white) and fresh water (gray).

For the Bac Lieu model, we decided to express the satisfaction of the agent as the ratio between the benefit and the cost:

Satisfaction = net income/costs.

Uncertainty depends on the difference between net income and expected net income:

Uncertainty = Min ((abs(net income – expected income)/expected income), 1).

In these simulations, the agents that are in the freshwater area cannot raise anything other than rice. What we measure is thus their willingness to change, their frustration. The agents in the brackish-water zone cannot raise two crops of rice.

Other objects. Two other objects are used in the simulation:

- *The market*. It stores the price of shrimp and price of rice, as well as the previous prices of shrimp and rice (which are used to compute expected income), and an attribute whose value is the variability range of the price. With each time-step, a new price is drawn in the range (price – variation, price + variation).
- *The crop*. It can be shrimp or rice. It has two attributes: yield and risk of failure. For shrimp cultivation, the risk of damage (probability that damage will occur) to the crops is set at 15% for lowland plots and at 30% for medium and highland plots. For rice cultivation, the risk of damage is set at 20% for lowland soil and at 5% for medium and highland plots. In case of damage, the quantity lost is variable and various scenarios will be simulated (see below).

The sequence diagram of this model is in Figure 13.

Scenarios

In these preliminary simulations, we test several scenarios to see the relative effects of different parameters. This corresponds to "what if?" simulations, leading to discussions on what would be the most sensitive factors to improve. Our observations are still on economic differentiation and net income. In these simulations, we explore the effects of various parameters that we grouped into four types of influences. For each scenario, we compare different values of parameters (low, medium, and high).

- *Influence of price*. We fix three different prices for rice (1,200, 1,500, and 1,800 vnd) and three different prices for shrimp (80,000, 100,000, and 120,000 vnd).

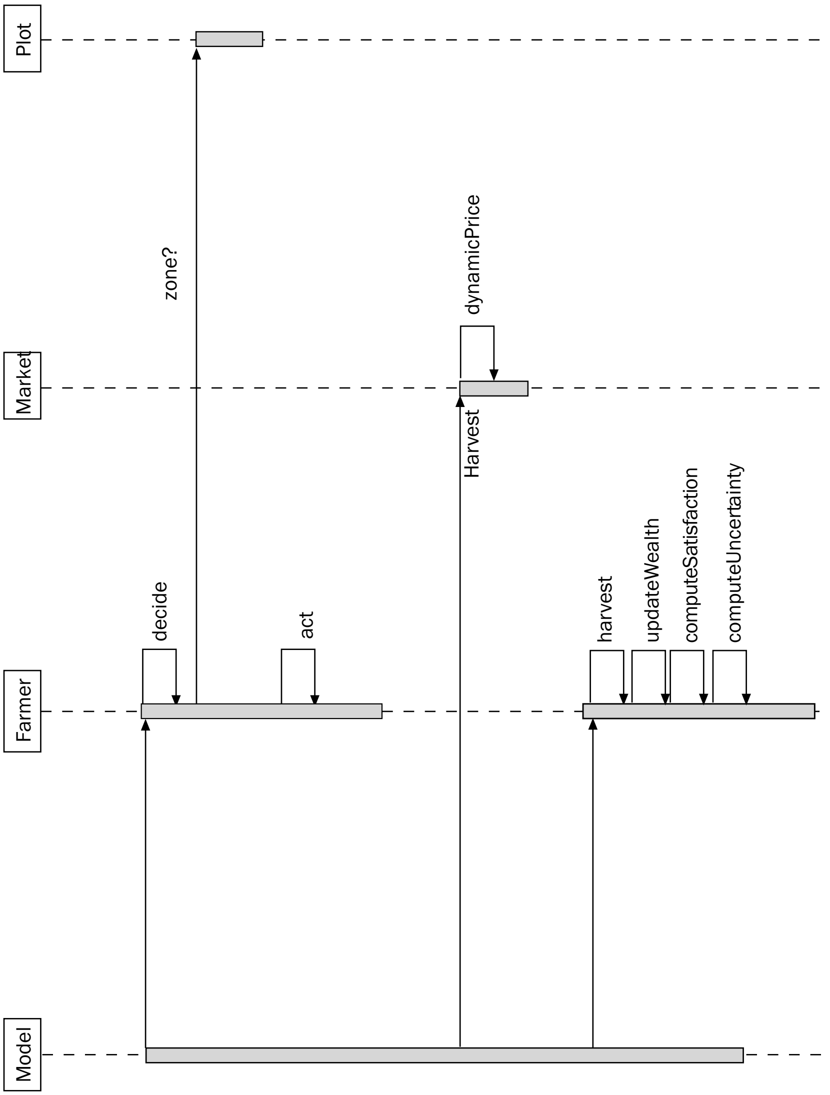

Fig. 13. The sequence diagram of the Consumat model.

- *Influence of rice yield.* Depending on the topology, yield is fixed at three alternative values: 3.5, 4.0, or 4.5 t ha^{-1} for lowland; 4.5, 5.0, or 5.5 t ha^{-1} for medium land; and 5.5, 6.0, or 6.5 t ha^{-1} for highland.
- *Influence of shrimp yield.* Depending on the topology, yield is fixed at three alternatives values: 200, 250, or 300 kg ha^{-1} for lowland; 150, 200, or 250 kg ha^{-1} for medium land; and 100, 150, or 200 kg ha^{-1} for highland.
- *Influence of risk.* Two dimensions are associated with risk: the variation in market prices (giving an interval around the average prices), which can have three values (0, 0.2, 0.4), and the amount of harvest lost in case of failure, which can also have three values for rice (0.2, 0.1, 0) and for shrimp (0.4, 0.2, 0).
- *Influence of the network.* The set of acquaintances of the agent is fixed as the neighbors of his plot, the agents in his hydraulic zone, or the full set of agents.

For a first exploration of the model, we have tested the influence of each of these parameters. The remaining parameters were set at their low value. For each simulation, the model is run in 30 time-steps representing 30 years. Each scenario is simulated 30 times and the values presented below are average values.

Results and discussion

For this preliminary exploration of the model, we have compared the different scenarios for economic differentiation, using the Gini coefficient, and the total wealth of the agents in the simulation. The results appear in Figures 14, 15, and 16.

Figure 14 presents the proportion of decision mode during the simulation. An interesting result is the fact that very few decisions are based on repetition, which means that the agents are not satisfied and certain. This illustrates the strength of this second model compared with the first one, which was based on the repetition of decisions every year.

The best results in Figures 15 and 16, in terms of aggregated wealth, correspond to the high and medium values of prices and high and medium values of shrimp yields. However, it appears also that these parameters also increase the economic differentiation among agents. The different rice yields do not affect the results of the simulations very much relative to the influence of prices and shrimp yields.

Another remarkable result is the effect of risk. The simulations with high risk give very bad results in terms of total wealth, even though prices can be good. More than the loss of harvest, high risk provokes frequent changes in activity linked to frequent failures. As agents are unsatisfied and uncertain, they engage in social comparison and deliberation. Thus, their choices are based on expected incomes that are highly dependent on market prices. These market prices fluctuate a lot among two time-steps. The simulation with high risks also shows a very small economic differentiation: most of the agents are poor.

In terms of economic differentiation, the best situation occurs with high risk because high risk makes everybody poor. The better scenarios are observed when agents are inserted into networks, from medium to large in size. The total wealth for these scenarios is not very good but we have to keep in mind that all parameters such as prices and yields were set at "low."

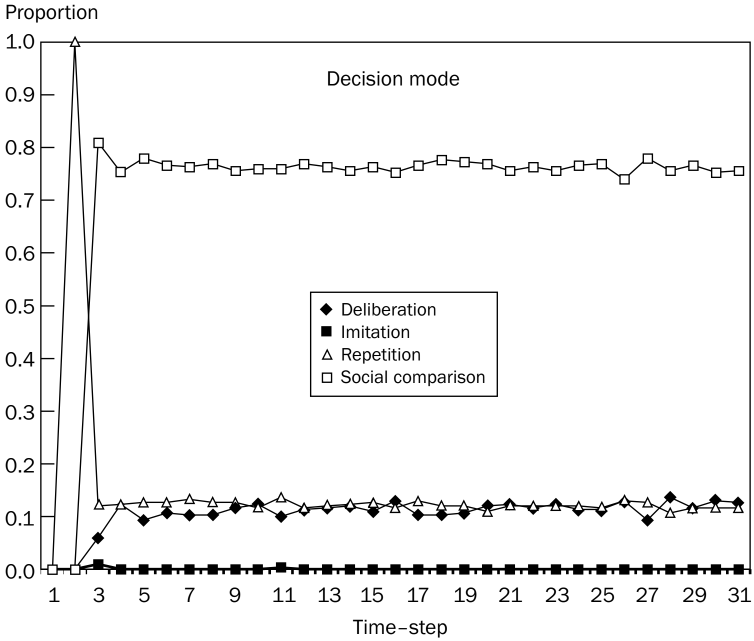

Fig. 14. The decision mode of the agents for one simulation.

These simulations correspond to a first exploration of the model. The first results can be presented, which lead to simple observations:

- The most efficient way to improve the wealth of the agents is to increase prices or increase the yield of shrimp production. But this also increases the economic differentiation. The increase in rice yield does not make a big difference in terms of wealth or economic differentiation.
- The reduction in risk of failure and variability of prices is very important to secure the decision of agents and avoid poverty.
- The exchange of information plays a role in reducing economic differentiation.

This second model gives interesting preliminary results. It shows how simulations can indicate to researchers and decision makers which factors make a difference and thus orient their research. The perspectives are twofold. First, we have introduced the Consumat decision-making model, which assumes a decision process of farmers. This has to be checked through some experiments. Second, the set of choices is very small (although realistic). The model could serve to study the introduction of innovations characterized by parameters such as price, yield, and riskiness and evaluate their chances of dissemination.

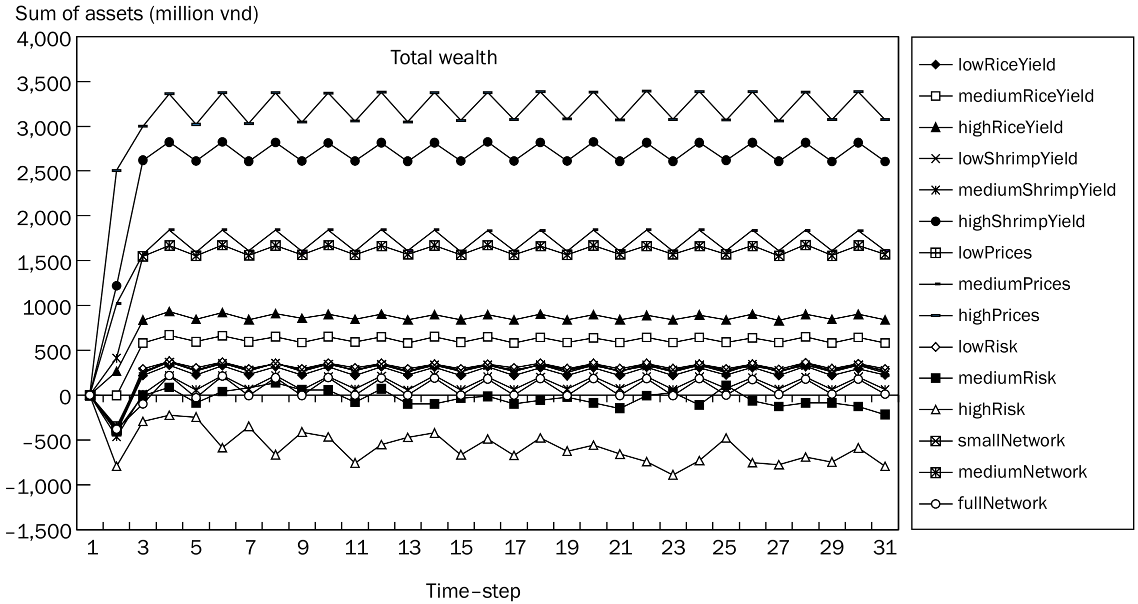

Fig. 15. The sum of individual wealth for various scenarios. The values correspond to the average value of 30 simulation runs.

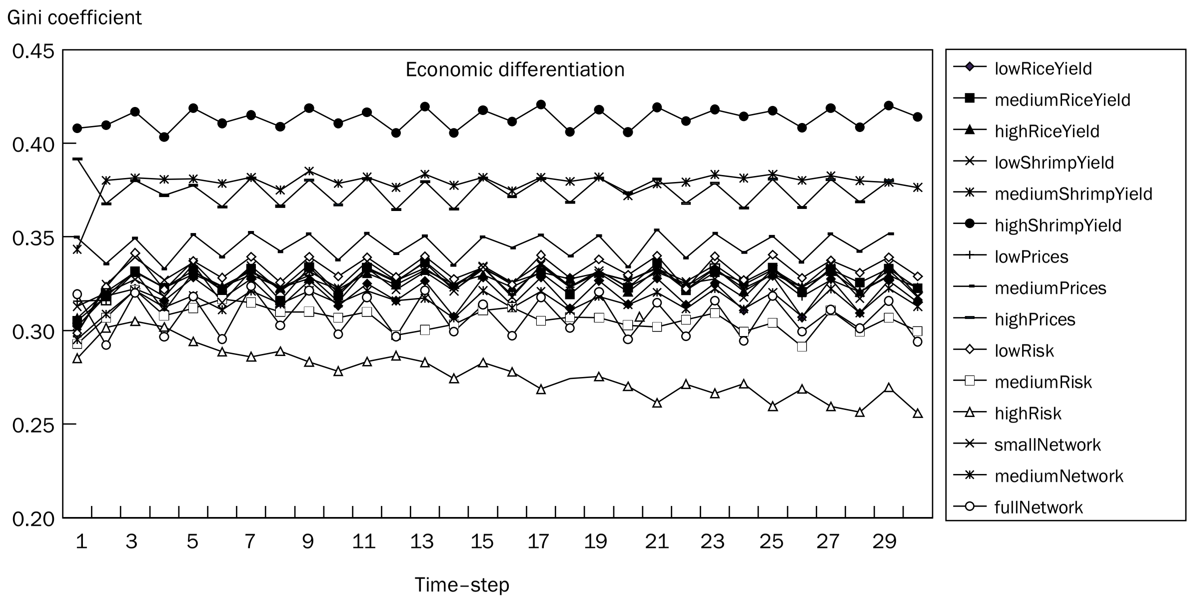

Fig. 16. Economic differentiation for various scenarios. The values correspond to the average value of 30 simulation runs.

Conclusions

We can draw several conclusions from the two models developed. From the first model, we conclude that

- The MAS concept associated with the CORMAS program has proved its usefulness in visualizing the diversified and complex farming systems at the study site of Bac Lieu in the Mekong Delta of Vietnam.
- Economic differentiation has occurred in every subzone at the study site in terms of both household average accumulation of income and number of households in the rich and poor class. As the best indicator of economic differentiation, the Gini coefficient had a low value in the first year. It increased, however, and became stable and had a high value from the second year onward in some subzones in either rice- or shrimp-based farming systems, especially in subzones 3, 4, and 5.
- The household average accumulation of income of the rich household class in those subzones where physical conditions allowed shrimp farming reaches a high value, while that of the medium and poor households remains at a low value, and is even negative for the poor in subzones 2 and 3.
- The household average accumulation of income of the rich household class in those subzones where physical conditions (freshwater zone) allowed only rice farming reaches a high value after 5 years of simulation, but this value is still less than that in shrimp-culture subzones. The poor households in these subzones of rice-based farming also face a negative income after some years.
- The number of rich households tends to increase over the years, whereas the number of poor households tends to decline from year to year of the simulation. However, the number of poor households remains high in subzones 3 and 4.

From the second model, which is more stylized, we can conclude that the economic wealth of the stakeholders mainly depends on the value of prices and yield of shrimp. These two factors are also responsible for economic differentiation. The exchange of information among stakeholders favors a reduction in economic differentiation.

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Notes

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Dynamic simulation of land-use changes in a periurban agricultural system

Sk. Morshed Anwar and F. Borne

Studying the driving forces of land-use change dynamics (LUCD) is important for understanding the change process. A spatially explicit simulation model helps to test hypotheses about landscape evolution under several scenarios. This paper presents a dynamic simulation model of land-use change (LUC) of the Nong Chok area in Central Thailand. Simulation of LUCD has been performed integrating remote sensing, geographic information systems (GIS), and the dynamic simulation toolkit. The model is a cellular automata model that has been developed on the basis of selected spatial and human driving forces. This study was conceived for the simulation of LUC, in particular, from paddy fields to fishponds. The model was run for 19 years from 1981 to 2000. Data describing present and historic land-use patterns were derived from aerial photographs. Transition functions were developed using the ID3 algorithm of the LUC data sets. The model uses as its input a land-use map (1981) and spatial and human variables: distance to canal and age, ownership, religion, education, and family size of the farmers. The results of the simulation showed substantial ability of the model to diffuse fishponds. To validate this spatial simulation model of LUCD, the simulated maps were compared with the reference land-use maps using a set of landscape indices: number of fishpond cells, patch density, mean patch size, edge density, fractal dimension, and mean nearest neighborhood.

Change is a continuous process, but learning is optional. Resources, ecosystem, biophysical environment, and land use/cover on the surface of Earth undergo changes over time. Land cover is the layer of soil and biomass, including natural vegetation, crops, and manmade infrastructure that cover the land surface, whereas land use is the purpose for which humans exploit the land cover. Land-use change is the modification in the purpose of the land, which is not necessarily only the change in land cover but also changes in intensity and management. Land-use and land-cover change are critical issues because of their large influence on agricultural diversification, land quality and productivity, nutrient use, soil/nutrient fluxes, water resources, labor allocation, and impact on human life. Because of their enormous impact and implications, the International Geosphere-Biosphere Program (IGBP) and the International Human Dimension Program (IHDP) started a joint international program of study on land use/cover change (LUCC) (Geoghegan et al 2001). They recognized the need to improve understanding, modeling, and projections of land-use dynamics from the global to regional scale and focusing particularly on the spatial explicitness of the processes and outcomes.

The spatial setting of landscape elements is characterized by the combination of both biophysical and human forces (Fernandez et al 1992). In temporal scales of decades, human activities are basic factors in shaping land-use change. Some of these changes are due to specific management practices and the rest are due to social, political, and economic forces that control land uses (Medley et al 1995). Spatial simulation of land-use change is very important for monitoring and understanding the composition and configuration of the change process, and for observing the behavior of the actors and the interaction between system dynamics and actors and bio-geographical phenomena of the area under investigation. The purpose of LUC simulation modeling is to describe, explain, predict, assess impact, and evaluate hypotheses (Briassoulis 2000). To have a better understanding of landscape evolution, researchers have focused on developing dynamic simulation models (Wang and Zhang 2001, Britaldo et al 2002, Veldkamp and Fresco 1996, Gilruth et al 1995, Wu 1998, Verburg et al 2000, Soepboer 2001). In the arena of simulation modeling, one of the promising approaches to simulate and analyze LUCC is the multi-agent systems (MAS) model of land-use and land-cover change (Parker et al 2003).

During the last few decades, Thailand has undergone rapid urbanization and tremendous economic boom. These changes have rapidly transformed Thailand from a subsistence agrarian economy into a rapidly industrializing country. Most of the economic development activities are concentrated in and around the Bangkok metropolitan area. The growing urbanization in the urban fringe of Bangkok has created pressure for changes in land-use pattern. Nong Chok is on the outskirts of Bangkok. This area has experienced sharp changes in land use during recent years. Farmers have changed their land use from rice production to shrimp and other aquaculture because of the large demand for fish in the market. It is reported that the Department of Fisheries first promoted fish culture in rice fields in the 1950s in the Central Plain of Thailand (Surintaraseree 1988). Infrastructure development (e.g., road networks, electricity) has further enhanced the land-use change process in the area (Ahmad and Isvilanonda 2003). The process of intensification and diversification of agricultural production in irrigated, especially periurban, areas is a very widespread one. And this meets a rapidly growing demand for animal proteins for expanding middle-class urban consumers. This is a generic issue across the cities of developing economies such as Jakarta, Manila, Ho Chi Minh City, and southern China.

Declining profitability from rice production had led to efforts at sector-level agricultural diversification in Thailand. This diversification stimulated the production of high-value-added products such as fisheries, fruits, livestock, etc. During the 1980s and 1990s, Thai agriculture has moved to a more diversified cropping pattern with a variety of cash crops (e.g., aquaculture) (Ahmad and Isvilanonda 2003). Paddy fields are generally physically suitable for building fishponds. In terms of economic returns, fish culture often gives a higher return than rice culture. However, the decision to convert paddy fields to fishponds is often related to food security and social aspects. Moreover, labor availability, market locations, and technology also play an important role in the conversion process.

This paper attempts to develop a methodological framework on the dynamic simulation of land-use changes and a characterization of the spatial setting of the landscape through landscape indices. Simulation is considered to be an important tool for scientists because it is an excellent way to model and understand the social process. This paper first describes land-use changes over the Nong Chok area. Then it discusses the development of multi-agent systems modeling, the decision rules derived from the ID3 algorithm for the model, and the simulations. The most important issue is to validate the simulation model. This paper outlines some state-of-the-art landscape indices as an approach to characterizing the simulated maps and to validating the model. The simulated maps were compared with the observed land-use maps using the landscape pattern indices.

Profile of the study area

Nong Chok is an *amphoe* (district) of Bangkok Province and is situated around 30 km northeast of the Bangkok metropolitan area (Fig. 1). The study area comprises around 3.2 km^2 under Lam Toy Ting *tambon* (subdistrict) and is geographically distributed between latitudes 13°45′ to 13°50′ N and longitudes 100°50′ to 100°55′ E. Nong Chok enjoys a tropical monsoon climate. The mean annual temperature is 27.9 °C, the mean annual rainfall is 409.9 mm, and the mean relative humidity is 73% (TMD 2002).

Fig. 1. Location map of the study area (polygon), Nong Chok, Thailand.

The topography of the study area is flat, without any significant variation in elevation. The soil characteristics are homogeneous (as expressed by farmers during the interview). Thus, soil does not affect the land-use pattern in the area. There are canals on all sides of the study area, which provide a water source for fishponds and irrigation for paddy fields.

The landscape of Nong Chok is characterized by agricultural lands, orchards, urban areas (residential areas), roads, industrial areas, and fallow lands. The main activity of the area is agriculture, which produces income for the farmers. Agricultural activities include paddy cultivation, fish production, orchards, vegetables, poultry, and others. However, most of the farmers produce rice while some of them have fishponds, which support their income fully or partially.

Excellent harmony exists among the villagers, who follow different religions. Most of the people practice Buddhism, which is followed by Islam. There is a golf course in the northwestern part of the study area. A lot of people had moved into the study area during the establishment of the golf course.

Landscape pattern indices

The most effective manner for landscape planners to understand, plan, and manage change is by developing a basic understanding of the dynamic interactions of the structure and function of the landscape. Landscape ecology deals with the patterning of ecosystems in space. The importance of spatial effects for ecological processes has led to the development of state-of-the-art landscape indices for quantifying landscape pattern.

Landscape structure has two basic components: (1) *composition*, a nonlocation-explicit characteristic that refers to the variety and relative abundance of patch types represented on the landscape; (2) *configuration or structure*, which implies the spatial arrangement, position, orientation, or shape complexity of patches on the landscape.

Quantitative methods are necessary to compare spatial patterns and to evaluate the performance of spatial simulation models (Turner 1989). One of the important questions in simulation modeling is how to compare model outputs and validate the model. Several indices are used in landscape pattern analysis to measure landscape fragmentation (Wu et al 2000) and in the validation of spatially dynamic models (Britaldo et al 2002, Gilruth et al 1995).

Since the study area is very small (covering around 3.2 km^2) and this research considered only land-use change from paddy field to fishpond, all the widely used indices are not applicable in this study. However, after screening, *number of patches, patch density, mean patch size, edge density, fractal dimension*, and *mean nearest neighborhood* indices were found to have good potential for this study. Landscape pattern indices are discussed in detail in the section on indicators for validation of the model.

Materials and methodology

Simulation of land-use change has been performed integrating remote sensing, geographic information systems (GIS), and a dynamic simulation toolkit. The study has the following three main components (Fig. 2): (1) land-use change analysis, (2) development of the model, and (3) validation of the model. This paper focuses on only the simulation of land-use change dynamics and validation of the model.

Data set used for the study

A series of aerial photographs was used to prepare a land-use change map of different dates (1981, 1990, 1995, and 2000) for the study. The aerial photographs are of different scales (i.e., 1981: 1:50,000; 1990: 1:15,000; 1995: 1:20,000; 2000: 1:15,000). The resolution of the aerial photographs used for the photo interpretation is 65 cm. Different thematic layers, such as a house map, road map, and canal map, were developed using these aerial photographs. A topographic map was used for georectification purposes. Demographic and socioeconomic data about the farmers were collected by a field survey to assess the decision variables/underlying factors of

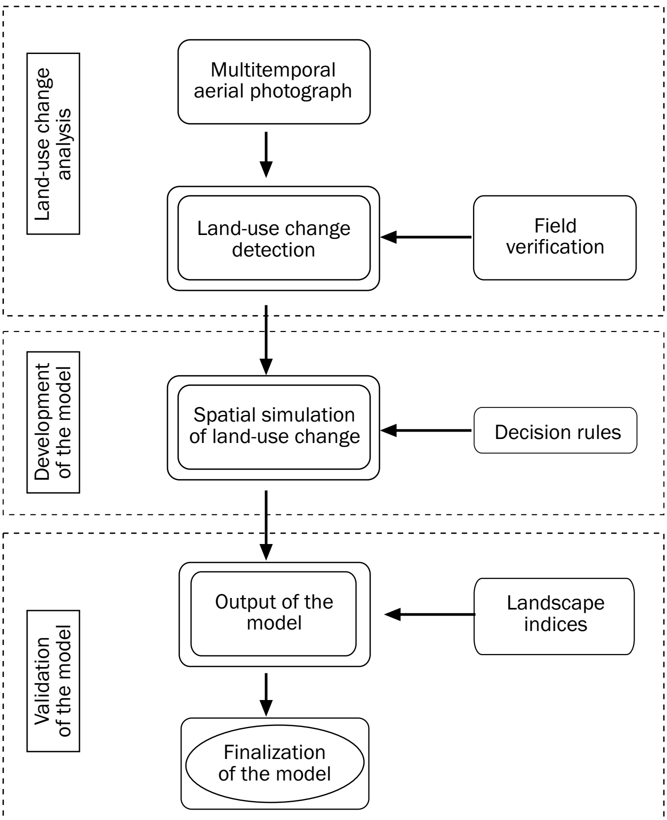

Fig. 2. Methodological framework of the study.

the land-use change process. Because of the limitation of available data, this study attempted to develop the model with a limited number of variables. Land ownership, education, age, religion, and number of family members of the farmers were used as decision variables. A spatial factor, distance to canal, was calculated from the land-use and canal maps.

Land-use change analysis

The photographs were georectified using image-processing software following standard procedures (Anwar 2002). Land-use maps and other associated thematic layers of 1981, 1990, 1995, and 2000 were extracted from aerial photographs using GIS software (Anwar 2002). Land use was classified into five categories: paddy field, fishpond, resident and orchard, waterbody, and others. Paddy fields are only paddy-producing lands. Fishponds include shrimp and all kinds of fishponds. Resident and orchard are homestead areas of the farmers with surrounding orchard. Waterbody refers to only a canal that flows within and around the study area. Others includes land that is currently unused, such as fallow land. In 1981, only paddy field (2.78 km^2), resident and orchard (0.29 km^2), and waterbody (0.11 km^2) were represented throughout the study area, whereas, in 2000, it was observed that a certain amount of land use has been turned into fishpond (0.46 km^2) and others (0.16 km^2) (Table 1).

Multi-agent modeling

Multi-agent systems (MAS), often denoted as agent-based (computational) modeling (Epstein and Axtell 1996), consist of a number of interacting autonomous agents (Gilbert and Troitzsch 1999, Weiss 1999, Ferber 1999). MAS has generated substantial attention in recent years as an important tool, technique, and metaphor for conceptualizing, designing, implementing, analyzing, and exploring the understanding of complex adaptive systems and can be modeled as bottom-up. MAS can be used to set up spatial models that integrate social and ecological dimensions (Janssen et al 2000). A detailed overview on MAS and land-use and land-cover change can be found in Parker et al (2003).

The conceptual model. The model is a cellular automata (CA) model that presents vicinity-based transitional functions such as DINAMICA (Britaldo et al 2002). CA are simple models for the simulation of complex systems, which successfully replicate aspects of ecological and biogeographical phenomena (Parker et al 2003). The model

Table 1. Areas of different land-use types from 1981 to 2000.

Land-use type[a]	Land use, 2000 area (km^2)	Land use, 1995 area (km^2)	Land use, 1990 area (km^2)	Land use, 1981 area (km^2)
Paddy field	2.15	2.26	2.62	2.78
Fishpond	0.46	0.35	0.15	–
Resident and orchard	0.30	0.32	0.26	0.29
Waterbody	0.11	0.11	0.11	0.11
Others	0.16	0.12	0.02	–

[a]Explanation of different land-use types is given in the section on land-use change analysis.

on the biophysical environment consists of initial land use (1981) and a canal map. It is a two-dimensional space. For each time-step, it calculates the transition probability of the cells based on decision rules. Among the cells having a probability of change, the spatial distribution of changed cells was calculated and the model changed the cells from paddy field to fishpond. The study was conceived for the simulation of land-use dynamics, in particular, from paddy fields to fishponds. This process operates for one time-step. The simulation iterates for 19 steps. It is assumed that each year represents one step. Figure 3 shows the workflow of the simulation of the model.

Decision tree using ID3 algorithm. Transition function of the model was developed based on the ID3 algorithm (Quinlan 1986), which has been widely used in several application domains. Selected demographic and socioeconomic factors of the farmer (i.e., age, ownership, religion, education, and family size) were categorized into three classes based on statistical analysis between percentage of land-use change and decision variables (Anwar 2002).

A decision tree is developed following the ID3 algorithm with change index[1] data sets. This ID3 algorithm was used to characterize the decision variables of the land-use change process over the Nong Chok area. The ID3 algorithm tries to find out the root of the decision tree based on the highest information gain using entropy calculation (Anwar 2002). The process continued through the decision space to find out change and no-change decisions.

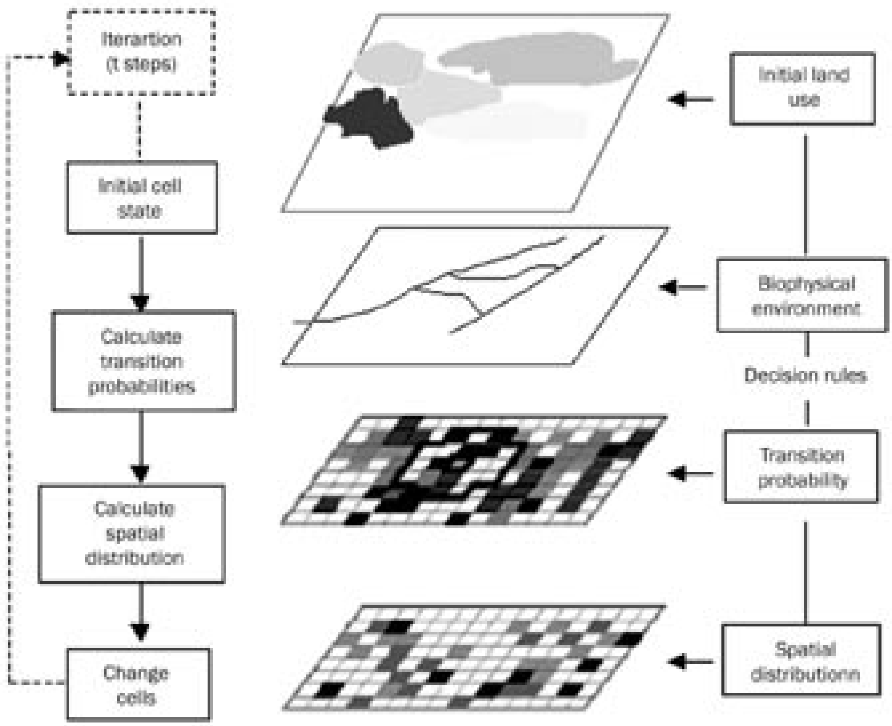

Fig. 3. Dynamic spatial simulation modeling diagram.

[1]A changed parcel was assigned a value of 1 and a parcel without change was assigned 0.

The heuristic decision-making methodology for changing land use from paddy field to fishpond shows the relationship among all the decision variables and change attributes (parcel whether changed or not changed). The decision tree was converted into an equivalent set of decision rules. The decision rules are based on an "if … and … , then … else…" statement. These decision rules were applied in CORMAS (common-pool resources and multi-agent systems) to develop the simulation model. For example,

If myOwner ownership = "owner + tenant" and myOwner familySize = <4, then land use = #paddy (no change).

Else If myOwner ownership = "owner + tenant" and myOwner familySize = (4–6) and myOwner age = (36–55), then land use = $\#\text{fishpond}_{P0.813}$ (change probability = 0.813, calculated from statistical analysis).

The structure of the model. The unified modeling language (UML) (see Le Page and Bommel, this volume) class diagram of the model consisting of spatial entity, spatial aggregate, and agents is shown in Figure 4. The spatial entity is composed of four levels of spatial units: farm, block, parcel, and cell. "Cell" is the basic spatial unit for the development and application of transition rules. Cell has several attributes: OwnerID, landUse, parcel, and distanceFromCanal. "Parcel" is composed of cells, which have the same owner and same land use (e.g., paddy field). "Block" is composed of parcels of the same owner with the same land use. "Farm" is represented as an aggregate of blocks of the same owner with different blocks with different land use (e.g., paddy field and fishpond). The farmer is denoted as an agent named FishRice-Farmer in the model, who has a spatial entity farm composed of block, parcel, and FishRiceCells. FishRiceFarmer has attributes such as owner, age, religion, education, and familySize.

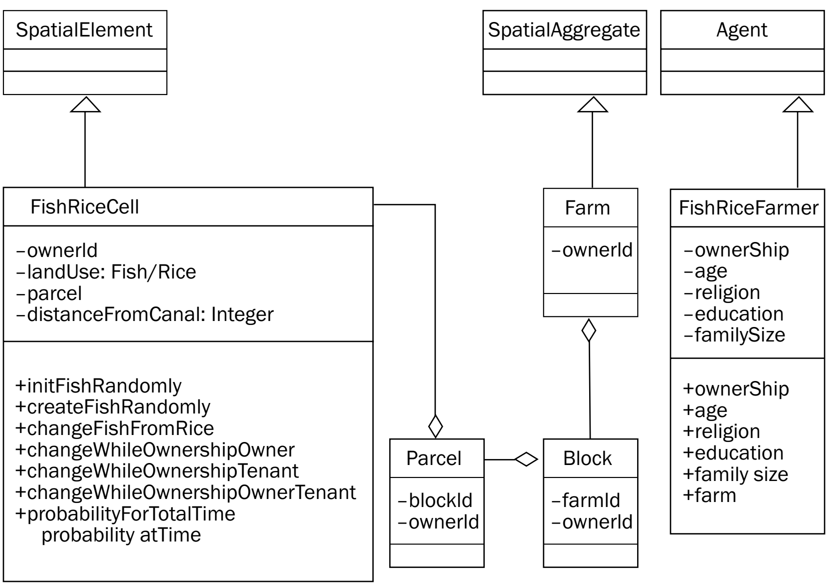

Fig. 4. UML (unified modeling language) class diagram of the Nong Chok model.

The model was implemented in CORMAS, an agent-based simulation toolkit (Le Page and Bommel, this volume). To be compatible with CORMAS, a land-use map of 1981, which represents initial land use, was exported in ASCII format from ArcView. The maps (distance to canal map, ownerId map, parcelId map, blockId map, and farmId map) were also exported. Before doing so, the survey database of farmers with ownerId was integrated with the maps through GIS. These maps were imported into CORMAS to build the environment of the model. Grid size of the model is 30 × 30 m, which means that the GIS data sets for 1981, 1990, 1995, and 2000 were resampled into 30-m resolution and exported to CORMAS. All simulations and subsequent analysis (calculation of the landscape pattern indices value) are accomplished on 30 × 30-m cell resolution. Figure 5 shows the initial state of the Nong Chok model in CORMAS. The environment has three types of land use: paddy field, resident and orchard, and waterbody, as was observed in the 1981 land-use map.

Simulation. There were no fishponds in the study area in 1981 (Table 1). So, the model was initialized with fishpond based on randomization. The rules imply that, if the land use of the cell is paddy and the neighborhood contains a fishpond, the model applies decision rules; otherwise, if the neighborhood contains no fishpond, if the cell is within 150 m of a canal, and if the neighborhood contains residentOrchard, then CORMAS draws a random number and, if the number is below 0.1, the land use of the cell is changed to fishpond. If the random number is above 0.1, the land-use state is kept the same. The fishpond is created stochastically. Water is needed to develop and maintain the fishpond. Thus, distance from the canal is important and it was observed that farmers used to keep their fishponds close to their residence to take care of them. In the light of the above information, fishponds were initialized in the model.

Fig. 5. Initial state of the Nong Chok model (1981 data) in CORMAS.

The model simulates for 19 time-steps. For each time-step, it creates new fishponds randomly and simultaneously extends the fishponds following decision rules. Thus, the extension of fishponds is stochastic in this model.

Indicators for validation of the model

Validation deals with comparing the model outputs with the real-world observation. The process answers how well the model outcomes represent the real-world system (Parker et al 2003). Several criteria exist to evaluate the model: correctness, consistency, universality, simplicity, and novelty (Manson 2002). The model in this study is validated using the following landscape pattern indices in terms of quantitative correspondence between the model's behavior and the reference map. Thus, it is more a model assessment than a rigorous validation that is proposed in this paper.

Description of the indices. The following landscape pattern indices were scrutinized from the literature. These indices are used only for fishpond class diffusion over the landscape. Thus, the indices calculated values for fishpond class of the simulated maps such as $NP_{fishpond}$, $PD_{fishpond}$, $MPS_{fishpond}$, $ED_{fishpond}$, $FD_{fishpond}$, and $MNN_{fishpond}$. Simultaneously, the indices were applied to a reference map (1981, 1990, 1995, and 2000). They were programmed into the CORMAS toolkit. The implementation of these indicators is facilitated by the existence of CORMAS primitives that allow the creation of spatial composite objects and allow the primitives to calculate the edge of composite objects or distance between composite objects.

Number of patches (NP). A patch represents an area that is covered by a single land-cover class. This is an indication of the diversity or richness of the landscape. This index can be calculated and interpreted easily. However, like other richness measures, this interpretation might give misleading results because the size of the area covered by each class is not considered here. Even if a certain class covers only the smallest possible area, it is counted. The index is calculated as $\mathrm{NP} \sum_{j=1}^{N} = Pi$, where Pi is the number of patches for land-use class i and N is the number of land-use classes.

Patch density (PD). The patch density expresses the number of patches within the entire reference unit on a per area basis. It is calculated as $\mathrm{PD} = \frac{NP}{A}$, where NP and A represent the number of patches and area, respectively.

Mean patch size (MPS). Mean patch size is a measure of the composition of the landscape. The formula is $\mathrm{MPS} = \frac{\sum PS}{NP}$, where PS and NP denote patch size and number of patches, respectively.

Edge density (ED). An edge is the border between two different classes. In contrast to patch density, edge density considers the shape and complexity of the patches. The index is calculated as $\mathrm{ED} = \frac{E}{A}$, where E and A denote total edge (in m) and total area, respectively.

Fractal dimension (FD). A perimeter to area relationship can be used to calculate the fractal dimension of patch perimeters using grid data. Using all patches of a single cover type (or all cover types) in a landscape, a regression is calculated between log (perimeter/4), the length scale used in measuring the perimeter, and log (size) of each patch (Turner et al 1989). Fractal dimension is related to the slope of the regression, by the relationship D = 2*S*, where *S* is the slope.

The dimension can range between 1.0 and 2.0. If the landscape is composed of simple geometric shapes such as squares and rectangles, the FD will be small. If the landscape contains many patches with complex and convoluted shapes, the FD will be large (Krummel et al 1987).

Mean nearest neighborhood (MNN). Some ecological processes are strongly influenced by the distance separating patches of the same class. Various nearest neighborhood metrics attempt to encapsulate in a single number the characteristic of the degree of separation. One of the more common is the mean nearest neighborhood distance, $\text{MNN} = \frac{\sum_{i=1}^{m} \sum_{i=1}^{m} h_{ij}}{NP}$, where h_{ij} is the edge-to-edge (or centroid-to-centroid) distance from patch *ij* to the nearest neighboring patch of the same class and *NP* is the number of patches in the landscape having nearest neighbors.

Results

Simulation of land-use change

Dynamic simulation with stochastic components produces one of the possible scenarios of the model. This helps us to understand the underlying process of the system. Simulation outputs of three different runs are presented in Figure 6. On the simulated maps, most of the fishponds were distributed into four clusters, which is similar to the land-use change map (Fig. 6). There was no fishpond in the western part of the area near the golf course because of insufficient water flow into the nearby canal. Moreover, water in the canal becomes polluted from pesticides from the agricultural fields. Although the simulation created a small fishpond (one pixel) in both the western part (Fig. 6, white circles) and along the "resident and orchard," the reference map does not show any fishpond in that part. This happened because of the stochastic distribution of the fishpond of the model at each time-step.

The middle part of the study area had no fishpond on the simulated map (Fig. 6, black circle). Since the neighborhood of the resident of the cell was taken into account during initialization of the simulation and there was no resident around that area in 1981, the model could not initialize and diffuse the fishpond over that area.

Spatial characteristics of model output

Various researchers used landscape pattern indices to validate their simulation models (e.g., fractal dimension, contagion index, and number of patches, Britaldo et al 2002). Number of fishpond cells, mean patch size, edge density, patch density, fractal dimension, and mean nearest neighborhood indices were calculated from the simulated map and compared with the reference maps to validate the Nong Chok model.

Area of fishpond. Simulated fishponds have shown an area of 0.29 km^2, whereas, on the reference map (land-use map 2000), the fishpond area was 0.46 km^2 (Fig. 7A). Thus, the overall agreement of the simulated fishpond is 62% of the reference map.

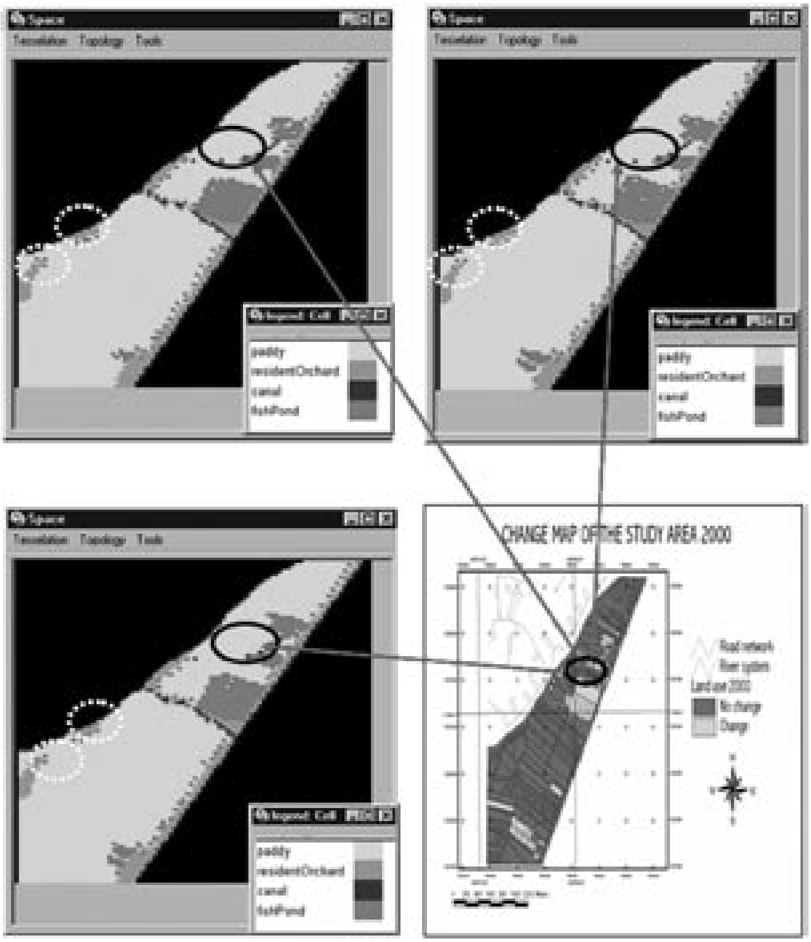

Fig. 6. Outputs of three different runs of the simulation (final map).

As the study area is around 3.2 km^2, the model produced a fishpond in simulation that was 9%, while the actual fishpond on the reference map was 14%. This index considers only total area of fishponds, not their spatial composition. Both the simulated and reference maps show a similar pattern of fishpond diffusion over the years.

Patch density (PD). PD of the simulated map was calculated based on the entire study area (i.e., number of patches in the entire area). The PDs of the simulated map and the reference map (2000) are 0.017 and 0.0017 (Fig. 7B), respectively. In the simulation, the density increases very fast and a plateau is reached earlier.

The landscape is very small and the model simulates random fishponds based on the createRandomFishpond method and diffuses new fishponds simultaneously, following decision rules for each time-step. Consequently, there are several small fishponds (one pixel) along the resident on the simulated map. Several researchers used the patch density index to validate a simulated map for regional-scale landscape.

This index may not be suitable for a small-scale study area because of its initial randomization effect.

Mean patch size (MPS). MPS is the mean area of the patches in the landscape. MPS of the simulated map is 5, whereas MPS of the reference map (2000) is 32 (Fig. 7C). The MPS value of the patches increased during the simulation from 1 to 5. This index gives information on fragmentation of the landscape. The mean patch size index also suffers from the same drawbacks as mentioned with patch density.

Edge density (ED). ED of the simulated map is 0.112 (Fig. 7D, left). Following the same procedure for patch density, ED of the simulated map was calculated based on the entire study area. Edge density of the reference change map (2000) is 0.059 (Fig. 7D, right). Edge density measures the total edge of patches in the landscape. Although the simulation could not simulate properly in the middle part of the landscape, it showed a high value in the simulation because it counts all tiny fishponds along the resident, which were not found on the reference map.

Fractal dimension (FD). FD of the simulated map is 1.17 (Fig. 7E, left). In the first half of the simulation, FD increases, but in the last half it decreases. To validate the simulated landscape, researchers try to find correlation of the complexity of the patches between the simulated and reference landscape (Britaldo et al 2002). FD of the reference change map (2000) is found to be 1.31 (Fig. 7E, right). This index characterizes the complexity of the landscape. Interestingly, FD of the simulation showed a decreasing trend because of the tiny fish cells, whereas, on the reference map, FD is increasing.

Mean nearest neighborhood (MNN). MNN of the simulated map is 5.83, while MNN of the reference change map (2000) is 23.32 (Fig. 7F). This reveals that the simulated map is less fragmented than the reference map. MNN decreases on the reference map because of the rapid diffusion of fishponds (Fig. 7F, right). This index indicates the isolation and distribution of patches.

Fishpond areas, patch density, mean patch size, edge density, and fractal dimension indices consider only the composition of the patches in the landscape. Conversely, mean nearest neighborhood considers the configuration of the patches. Most of the landscape pattern indices have redundancy among them and consider diversity or composition of the landscape only.

Discussion and conclusions

This is a preliminary model of diffusion from paddy field to fishpond based on selected spatial and human driving forces. The model uses as its input a land-use map (1981) and spatial and human variables: distance to canal, age, ownership, religion, education, and family size of the farmers. Land ownership was found to be the most sensitive among all the driving factors. Education and religion could not significantly influence the transition function. Young farmers are more courageous in adopting new land use despite the risk factor. The topography and soil characteristics of the study area are uniform and thus do not influence the land-use change process. Other important driving forces affecting land-use change are comparative economic return from alternative crops from the same land, market dynamics, various policies, and wage levels, etc., that are operating at a higher level and are modeled as factors exogenous

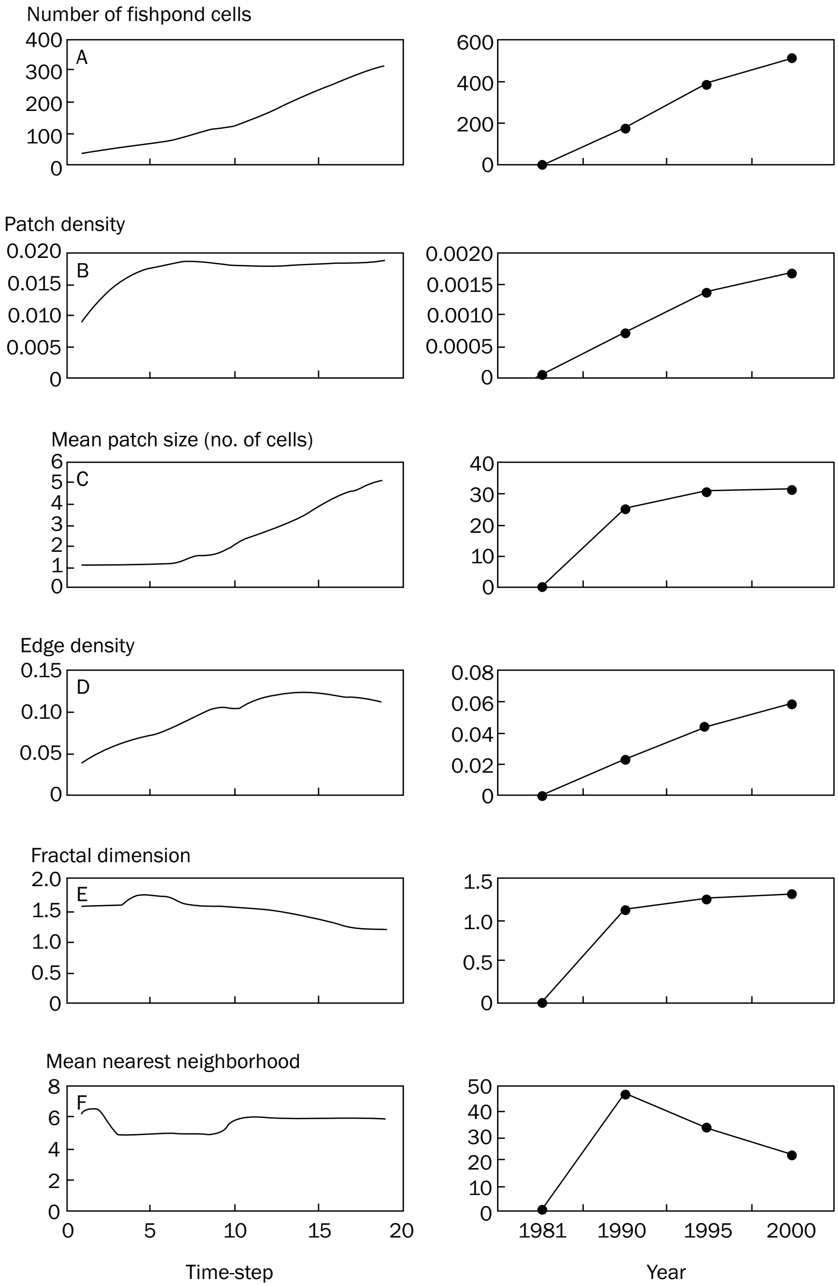

Fig. 7. (A) Fishpond areas, (B) patch density, (C) mean patch size, (D) edge density, (E) fractal dimension, and (F) mean nearest neighborhood of the simulated map (left side) and reference map (right side).

to the system. The model, however, focused on the available data collected from the farmers as decision variables. More work in the field should be done.

The model was able to diffuse the fishpond substantially from 1981 to 2000. To validate this spatial simulation model of land-use change dynamics, the simulated maps were compared with the reference land-use maps using a set of landscape indices: number of fishpond cells, patch density, mean patch size, edge density, fractal dimension, and mean nearest neighborhood. The indices do not exhibit a similar pattern on the reference and simulated maps because of two factors. First, the indices suffered considerably from the random effects. The randomized creation of fishponds during the initialization process generated a number of fishpond cells (single pixel), which raised the index value to 0.017 for PD and 0.112 for ED on the simulated maps vis-à-vis the reference map (Table 2). Future research should carefully focus on this aspect. The number of fishponds between the simulated and reference maps showed 62% overall agreement. Farmers who are early adopters of the new land use got information about fishponds from fishery extension workers. Once one farmer converts land use from paddy to fishpond, this diffuses among his neighboring farmers if fish cultivation produces a higher profit. So, the diffusion is spatially clustered as it is seen on both the simulated and reference maps. An index such as the mean nearest neighborhood measures this spatial clustering. Even though MNN did not show a close agreement, it could be an important index for validating the simulation of land-use change dynamics. Second, the dynamics of the model should rest more with agents' decisions. In this version of the model, a diffusion dynamics is simulated based on rules applied to the spatial entities. In reality, the land-use change decision is made by agents.

Comparing the results of simulation with an existing land-use map is always risky. The issue of validation raises here a crucial question whether a good fit of index validates the model or a bad fit does not, as some indices revealed in this study. A system is modeled with a certain number of variables as essential to represent the process of investigation. These variables might not be the most appropriate ones. Moreover, the model could show some possible scenarios of land-use change instead of many others. The two scenarios produced by the reference map and the model might both be different and both be true in terms of what could happen in the study area. Thus, the focus of the simulation should be to study the overall dynamics of the systems and understand what drives the process and leads to understanding the process and creation of the spatial pattern of land-use change, not a direct pixel-by-pixel comparison between the simulated and real map.

Table 2. Analysis of landscape indices of the simulated and reference change map.

Item	Landscape indices[a]					
	NFC	PD	MPS	ED	FD	MNN
Simulated map	320	0.017	5	0.112	1.17	5.83
Reference map (2000)	513	0.0017	32	0.059	1.31	23.32

[a]NFC = number of fishpond cells, PD = patch density, ED = edge density, MPS = mean patch size (number of cells), FD = fractal dimension, MNN = mean nearest neighborhood.

The model, however, fails to incorporate some aspects of the dynamic behavior of the variables. All variables in this study were static. The model starts working on certain hypotheses and in each time-step it calculates the transition probability based on fixed parameters of the variables. The sensitivity of driving forces operating at a higher scale should be measured. Further investigation may lead to other factors to test their sensitivity. The model could also simulate fishpond diffusion on the 1990 data set as initial land use to see the behavior of the model. Farmers were sometimes found to stop fish cultivation during the study period (1981-2000), but the model did not integrate that behavior.

Another important feature of the model is its cellular automata cell size, which was 30 × 30 m. This cell size was chosen to boost the simulation. However, the model could be tested with a different cell size to observe its impact on the diffusion process.

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Notes

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Integrating multi-agent systems and geographic information systems modeling with remote-sensing data for participatory natural resource management in coastal Bohol, Philippines

P.C. Campo

This exploratory research tried to develop a methodology for building a multi-agent systems (MAS) simulation model, following the companion modeling approach, while integrating geographic information systems (GIS) and remote-sensing (RS) for data collection, processing, and analyses. One of the main outputs of this research was a prototype MAS simulation model for the municipality of Loon in Bohol, Philippines. Using the model, the researcher attempted to demonstrate how individual actions of stakeholders collectively affect the environment, thus providing the stakeholders with a new way to view their natural resources and environment. In this way, stakeholders in an NRM situation would be more involved in effectively managing their own environment and resources. Also, scenarios based on the initial findings of the fieldwork were developed for the model, whose results were analyzed using GIS techniques.

Although the Philippine government is promoting natural resource management (NRM) using a decentralized approach, such that the local government would be responsible for managing its resources, most of the management of natural resources has remained top-down. Usually, little or no participation occurs among the stakeholders in NRM policy formulation and implementation (Boquiren and Cabalfin 1995).

The top-down approach of resource management limits knowledge about the system for both the policymakers and stakeholders who are directly affected by these policies. This may lead to badly formulated NRM policies that could drastically affect stakeholders in terms of decreased financial opportunities, or could be detrimental to the environment by making its exploitation unsustainable. To help avoid these problems, a better knowledge and understanding of natural resources and their management are necessary. In this way, NRM policies can be designed more appropriately for the NRM system they were intended to help. Modeling the NRM situation may provide a solution to this end.

Geographic information systems (GIS) and remote-sensing (RS) have been used in natural resource management for gathering, integrating, and analyzing data gathered from various sources (Rajan 1991). The rapid development of GIS and RS applications together with advancements in computing has made obtaining, managing, manipulating, and analyzing data faster, easier, and more cost-efficient (Davis 1995, Korte 2001).

Despite the advantages of GIS/RS, most applications developed using these technologies are static because GIS doesn't have an inherent capability of handling time (Gimblett 2002), and this may not be enough to model the complexity and behavior of systems, and to explain their emerging patterns. Ecosystems are not static and the conditions of these systems, both local and global, change over time, and, therefore, must be considered in order to model ecological phenomena (Gimblett 2002, Biswas 1990). There is also a difficulty of relating macro-spatial patterns with decision-making activities and behavior occurring at the micro-level (Griffith and Mackemon 1981). An integrated approach to modeling, for example, coupling multi-agent systems (MAS) and GIS such as in the case of this research, may be able to overcome these obstacles.

MAS can be used as a learning tool for a better understanding of a system through simulation modeling (Barreteau et al 2001, Parker et al 2002). By focusing on key elements of a system, a better view of how these elements affect the system can be attained (U.S. EPA 2000). For example, by incorporating human activities together with biophysical processes in the model, which would have been difficult in conventional GIS/RS modeling, stakeholders can gain more knowledge of how they affect the environment and vice-versa, and, as a result, provide more focused ideas on how to manage their resources. Furthermore, by developing strategies or scenarios for NRM, these scenarios could be tested in a MAS simulation model before applying them to the real system, thus minimizing money, time, and other costs of policy implementation.

The goals of this research are to develop a methodology following the companion modeling approach (Bousquet and Trébuil, this volume) for developing a MAS model integrating GIS/RS techniques that could be used as a tool for NRM, and build a prototype MAS model based on these methods following Barreteau et al (2001), Etienne (2003), and Etienne et al (2003). This model could be used to support the process leading to a decision by facilitating communication related to negotiation. By discussing the model and its outcomes (by running different scenarios or strategies), stakeholders could reach a collective decision as to how their natural resources could be managed. This paper presents the first steps of the research that is the development of the model.

The research area is the municipality of Loon. Loon is located in the northwestern portion of Bohol Province, in the Central Visayas region of the Philippines, roughly at 123°50′E and 9°55′N (Fig. 1). Loon is around 11,200 ha and is composed of 67 *barangays* (the smallest political unit in the Philippines), 18 of which are coastal barangays. On the basis of the workshops, focus-group discussions, and interviews conducted with the local people and the local government unit (LGU) of Loon, several problems were identified (Campo 2003). The fishermen, most of which fish on a small scale, are having problems with the constant decline in the fish catch caused by overfishing by large-scale fishermen from outside Loon. The LGU, recognizing the dwindling fish stock within its municipal waters, passed a policy declaring mangrove areas as sanctuaries, prohibiting any form of human activity in these areas. Since most of the fishermen use only small paddleboats, limiting their fishing activities to shallow waters, the implementation of the policy has resulted in a reduction of the available fishing grounds. Furthermore, since a large portion of the coastline of Loon is sur-

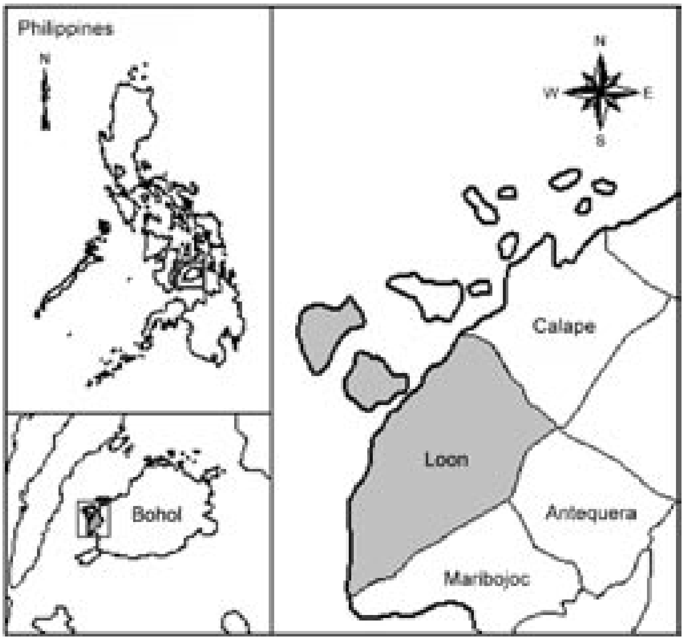

Fig. 1. Location map of municipality of Loon in Bohol, Philippines.

rounded by mangrove, and the fishermen are not allowed to cross these areas, they face the dilemma of how to go from the shore to the fishing grounds to fish. Another problem the LGU and the fishermen face is the growing number of fishponds in the municipality. Since the LGU is not the approving body of fishpond business applications, it cannot prevent the conversion of land to fishponds. Chemicals used to clean and prepare the fishponds for the next cycle of harvest are eventually drained into the sea, killing the organisms living there, including mangrove and fish. Moreover, the bottoms of the fishponds are replaced every four harvests with limestone material quarried from the mountainsides. For now, the only solution for the LGU is to set a limit on the maximum income that fishponds could generate. Severe soil erosion and river siltation during the wet season are attributed to unsuitable farming practices in the uplands, such as slash-and-burn farming, which, in turn, contributes to the continued forest denudation. Collection of wood for firewood in mangrove and forest areas has also been observed, thus increasing the loss of trees in those areas. Many problems may yet be identified. But, for this exploratory research, the initial findings give researchers preliminary ideas as to where to begin building the MAS model.

With these problems in mind, the MAS model was developed to try to show how the individual activities of the stakeholders affect the environment and other stakeholders. This research also tried to introduce a simple collective decision-making activity by a group to recognize the significance of the decisions of organized groups in an NRM system, such as a group of fishermen. Furthermore, scenarios were developed to show the potential of this MAS model as a tool for enhancing a greater awareness of the current state of the environment and natural resources of the municipality, and the current trends.

In the succeeding section, the methods for the MAS modeling process developed for this research are discussed, its basis, and implementation into an actual fieldwork, including the kinds and sources of data used to develop the prototype model. After that, the Bohol model is presented. Analyses of the simulation results follow and then conclusions are drawn to synthesize the lessons learned from fieldwork and simulation results.

Materials and methods

Methodology

The processes involved in building a MAS simulation model come from and feed into different activities. Physical and biophysical processes (domain expert knowledge) are elicited from local experts for information on the various human/nonhuman processes occurring in the system. The stakeholders provide information on their activities and decision-making processes for resource management. This information is elicited by using participatory approaches, such as interviews or role-playing games (RPGs). The database will contain spatial and nonspatial data that are acquired and integrated using GIS and RS techniques. This would represent the initial state or condition of the system. The role of the experts and stakeholders in the modeling process does not end in merely providing information. Through participatory processes, they may also be given the task of verifying the contents of the database, both the spatial and nonspatial, whether they are correct, complete, or necessary, before the data are incorporated into the MAS model. After the initial MAS model is built, it has to be verified by the sources of data it uses. This can be done by asking the experts and stakeholders whether the model is close to reality or if it could be used to represent their reality. After validation, the MAS model simulation and its results could be used to foster discussion or negotiations in participatory NRM. The spatial information from the simulation could be processed and analyzed by using GIS/RS techniques, the results of which could be used to support the MAS simulation in the negotiation process. The outcome of the discussions or negotiations between the stakeholders and policymakers may be strategies or scenarios that are thought to foster sustainable exploitation of the natural resources. However, before these strategies can be applied in reality, they could be first tested in the MAS simulation model already created. Again, the process of data collection, verification, and validation would be repeated, and the results could again be used for further negotiations. Figure 2 shows the interrelationships of these processes and the basis of the methods of this research.

The steps for the MAS modeling process (as shown in Fig. 3), which follows the companion modeling approach, would have two stages, the initial stage and the continuing stage. The steps outlined in Figure 3 are performed in the initial stage, with the assumption that the NRM problem has yet to be defined and the model has yet to be conceptualized. For the continuing stage, the same steps are repeated, with the assumption that there is already a model from which scenarios or new strategies would be built upon. The stakeholders of the NRM system identify problems. Because different stakeholders would have their own perspectives about their NRM system, they may identify problems in different ways (Etienne et al 2003). These problems should be analyzed based on their similarities and differences, and later synthesized into a

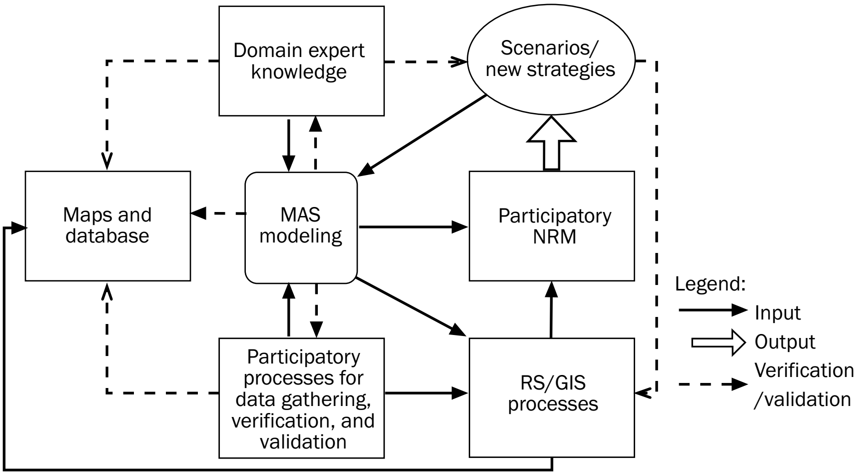

Fig. 2. MAS modeling integrating GIS and RS for participatory NRM (after Pahl-Wostl 2002).

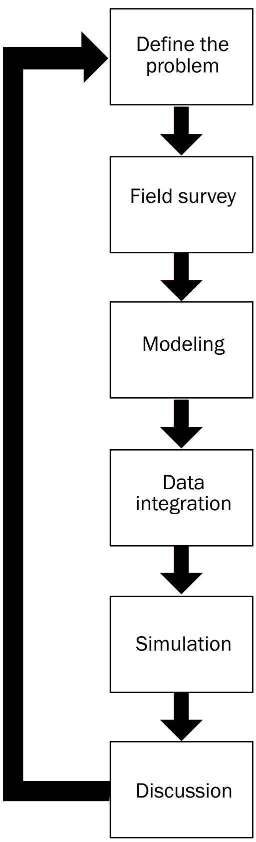

Fig. 3. Steps of the MAS modeling process.

cross-cutting encompassing problem or problems that should have been agreed upon by the stakeholders. An initial model may be an outcome of this step and would guide the collection of data during the field survey. MAS modeling involves the synthesis of various submodels, such as the activities of the stakeholders and the spatial dynamics of the environment, with the structure of the environment designed such that the submodels would function within this environment. Data integration would involve spatial data integration and file format conversion using GIS software and putting all the data and submodels together into one encompassing model, and translating it into a computer program. Simulations would be performed and the results discussed afterward with the stakeholders to validate the consistency of the model as compared to reality. The presentation of results may include change detection maps, charts, and cross-tables. A joint evaluation of the simulation results among stakeholders may result in a remodeling of the MAS or the identification of scenarios or strategies. The steps of the MAS modeling process are repeated for the continuing stage as the need arises, such as the identification of new problems and development of new strategies or scenarios.

This research is currently in its first stage of implementation. The participatory process that has been applied is limited only to data gathering, that is, ground mapping and verification with the locals, and extraction of information on the current physical and social situation of the study area and the social dynamics of the stakeholders. Model validation has yet to be performed. The use of the model in an actual NRM negotiation process is expected to occur in the second stage of the MAS modeling process.

Data and sources of information

Workshops were conducted with the local people to understand how the inhabitants of Loon viewed their environment and natural resources, and what they thought were the problems related to these resources. Meetings with the mayor of Loon obtained his perspectives about NRM problems in the town, and introduced the possibilities of using geo-information technology. Individual and group interviews, as well as focus-group discussions, were also conducted with farmers, fishermen, fishpond operators, and the mayor to obtain information about their activities in terms of the use of natural resources.

A Landsat 2000 satellite image of Bohol Province was acquired from the Bureau of Fisheries and it was used as the primary source of land-cover/-use information. This is a significant aspect of this research because a land-use map of the municipality was not available at the time of data acquisition, and, without the satellite image, a land-use/-cover map couldn't have been constructed. It also provided land-cover/-use information beyond the boundaries of the municipality. The satellite image was classified using e-Cognition® image-processing software, a software for remote-sensing applications. Field verification was again performed for ground-truthing of the satellite image using a global-positioning system (GPS) to locate points on the ground. This image was also used during workshops to introduce the technology to the locals. The Participatory Coastal Resource Assessment (PCRA) maps of northern Bohol were obtained from the Coastal Environment Profile of Northern Bohol (Green et al 2000), which includes Loon. Topographic maps covering the study area were obtained and used as a source of bathymetric data, verification, and geometric correction of data. Digital data on the municipal and barangay boundary maps were acquired from the Haribon Foundation, an environmental nongovernmental organization, whose study areas include the province of Bohol. Mapping activities were also carried out—the quarry sites owned by large fishpond owners were mapped, as well as the location and extent of mangroves. The GPS surveys were conducted with the assistance of the local people.

The MAS model for this research was programmed using the common-pool resources and multi-agent systems (CORMAS) platform, which is specifically designed for natural resource management applications (Le Page and Bommel, this volume).

The process of spatial data integration and spatial data importation into CORMAS is discussed in the next section.

Spatial data integration and coupling of MAS and GIS/RS

Given that the spatial data for this research are of different scales, formats, and grid systems, there was a need to process these layers of information to make them useful. The paper maps, namely, the topographic maps and PCRA maps, were digitized. Points obtained from the GPS mapping activity were plotted and stored in ArcView 3.2®, the GIS software used in this research. After this, the satellite image and digital data obtained from the paper maps were geometrically corrected to properly orient and overlay them with the digital data for the political boundaries, quarry sites, and mangrove areas. This was done by using the topographic maps and having the Universal Transverse Mercator (UTM) as the base grid system of all spatial data. The classified satellite image was then converted from raster to vector data format to be consistent with the other layers of information. After geometrically processing the spatial data, they were then integrated within ArcView 3.2®. The classified satellite image and PCRA maps were combined, resulting in a land-use/-cover map of the study area, as shown in Figure 4. In the implementation of the model, 14 classes were used for land and sea cover. However, for visual clarity, the land-use/-cover map has been generalized into four categories, namely, water with vegetation composed of sea grass/weed, coral, and mangrove cells; normal water—water without any vegetation—composed of water and mud cells; forest and nonforest cells composed of beach, flats, farm, grassland, bare soil, fishpond, and built-up area; and quarry cells.

Since there is no direct linkage between the GIS software, ArcView 3.2®, and the MAS programming software, CORMAS, a loose coupling of the two software was used. Loose coupling of software involves the software "communicating" with each other using interchange files—a file format that could be read by both software (Bailey and Gatrell 1995). In this case, the ArcView data were converted to raster data format and then to ASCII (American Standard Code for Information Interchange) file format. The header information of the ASCII data files was edited so that it could be read by CORMAS. Then, the ASCII data files were imported into CORMAS. Further data-reduction activity was done within CORMAS to reduce the number of data, thus reducing the complexity of programming codes and speeding up the simulation.

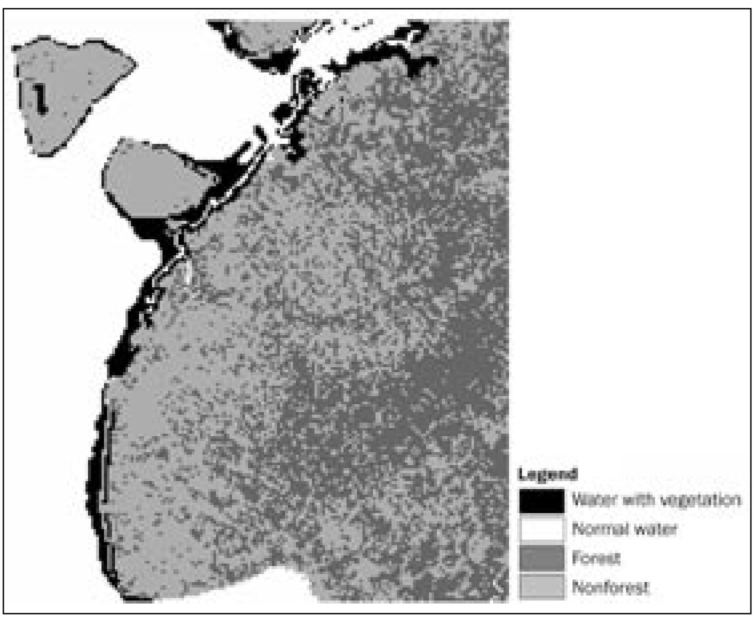

Fig. 4. Land-use/-cover map of Loon and adjacent municipalities.

Although this step could have been done within the GIS software, it was performed to demonstrate that it could also be done within CORMAS. The integration process to prepare the spatial data for use in the programming platform of the MAS model is summarized in Figure 5. The coupling process came into full circle when the resulting grid maps from the CORMAS simulations were exported back to ArcView, processed, and analyzed, the results of which are found in the simulation results.

Verification and validation of the model

As of now, this research is in its first phase and model validation has yet to be performed with scientists/experts and the stakeholders. The codes of the model were checked using built-in CORMAS tools such as the debugging tool and the "Communication's Observer Window." Because of the large size of the environment for the study area, making the simulation runs go slowly, the codes of the model were initially tested

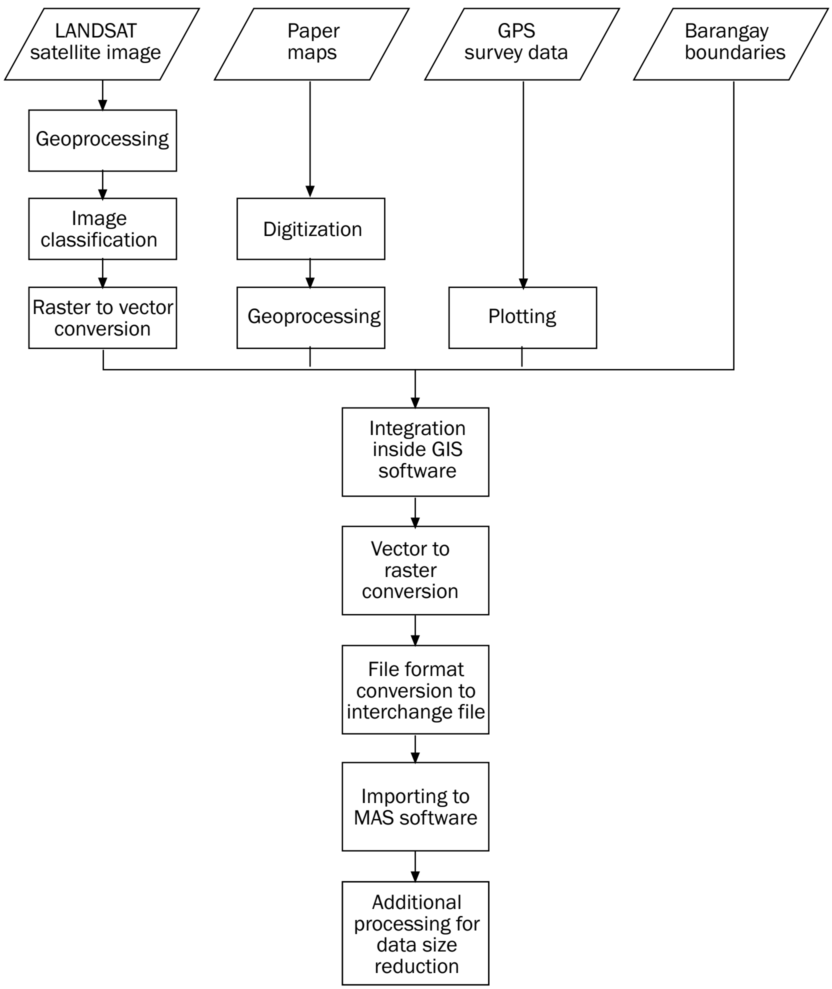

Fig. 5. Integration process to prepare the spatial data for use in the programming platform.

using a smaller environment—a 20 × 20-cell grid that was randomly produced. The consistency of the model with respect to reality will be discussed later in the discussion of results.

General presentation of the model

The different entities defining the static structure of the model are illustrated using a class diagram (Fig. 6). This was developed and, later, refined with the help of participants and trainers during the training conducted by CIRAD for its Asia IT&C Project on Multi-Agent Systems, Social Sciences, and Integrated Natural Resource Management, and through the advanced MAS course at the CIRAD-Ballairguet campus in Montpellier, France. This class diagram shows the entities inside the model, their attributes and procedures, and their interrelationships. More detailed explanations of the entities and their interrelationships follow.

Spatial entities

The study area was represented using a raster grid, having dimensions of 183 rows by 162 columns, with each cell being equivalent to 1 ha. Aside from having attributes built within CORMAS, four more attributes were added to the cell entity to accommodate different resources and/or characteristics that it may have. The spatial dynamics built for the environment were simple growth models for forests (which are applied to forest and bare soil cells) and fish stocks (which are applied to water, mud, coral, sea grass, and mangrove cells). In the case of a forest cell surrounded by other forest cells, at the next time-step, the amount of biomass of a forest cell is given by this equation:

$$b_t + 1 = bt + 0.0000337 * (b_t + \sum b't,i), \qquad i = 1 \text{ to } 8$$

where t = current time-step, $t + 1$ = next time-step, b = tree biomass of cell, and b' = tree biomass of neighbor cell.

In the case of a coral cell surrounded by other coral cells, its fish stock at the next time-step is given by this equation:

$$s_{t+1} = s_t + 0.0005 * \{[s_t * (1 + v_t/100)] + \sum [s'_{t,i} * (1 + v'_{t,i}/100)]\},$$
$$i = 1 \text{ to } 8$$

where t = current time-step, $t + 1$ = next time-step, s = fish biomass of cell, s' = fish biomass of neighbor cell, v = vegetation biomass of cell, and v' = vegetation biomass of neighbor cell.

Changes in the type and amount of resources remaining or existing in a cell would bring about a change in state of the cell. In general, cells containing vegetation less than 50% of its carrying capacity will change into a basic cell. For example, a forest cell with less than 50% vegetation will turn into bare soil, and a coral reef cell would turn into a basic water cell if the coral vegetation it contains drops to less than 50% of its carrying capacity. Farms abandoned by farmers revert back to bare soil.

The aggregates (Le Page and Bommel, this volume) created for the model were mainly for purposes of initialization and the creation of instances of new inhabitants, and were set up so that other processes could be added later. The aggregates, namely, "Barangay Boundary" and "Loon," represent political units within and around the municipality. These aggregates are important because the activities of the inhabitants are restricted within these political units.

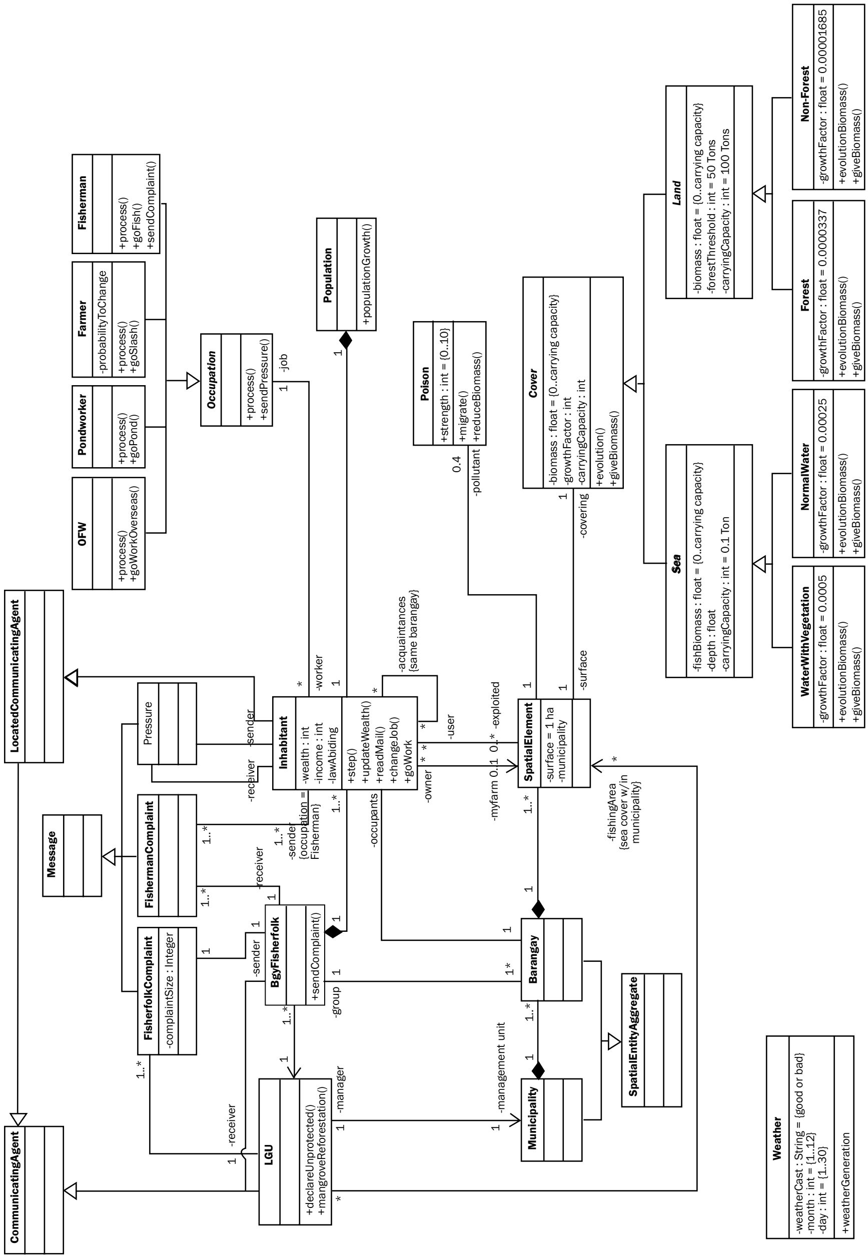

Fig. 6. Bohol model class diagram.

Social agents

The "Inhabitant" class represents the local people of Loon, at the household level. An inhabitant can be categorized as one of several types depending on occupation—fisherman, slash-and-burn farmer, fishpond worker, or overseas Filipino worker (OFW)—and it belongs to a barangay in the municipality. An inhabitant, depending on its occupation and related activities, affects a cell by reducing its resources or changing its state. A fisherman exploits the fish resources of water cells. A farmer may cut the trees contained in a cell and convert the cell to a farm. Other minor activities aside from its main occupation are quarrying, collecting firewood in mangroves and forests, and collecting shells to augment its income. These minor activities also reduce the resources contained in a cell. An inhabitant earns income from selling the products it is able to get or produce from its environment. In the case of a fishpond worker, it has a monthly wage with additional income proportional to the amount of fish it is able to harvest. Daily living expenses are deducted from the income of an inhabitant. An inhabitant also has the ability to change occupations. A farmer and fishpond worker may decide to change its occupation after every harvest. A fisherman can change its occupation every 30 steps or working days. An OFW no longer changes occupation. An inhabitant will change to a prospective occupation if its net income is less than zero or if its prospective occupation, determined by the "Pressure" messages (discussed in the next section) sent by its acquaintances—the other inhabitants of its barangay—offers better income. The process of changing occupation is described in the activity diagram shown in Figure 7.

The LGU class represents the local government unit in the area and it has the task of performing several activities depending on the scenario being run. Every year, it can perform mangrove reforestation (the number varies depending on the interactions among agents) and declare the reforested areas as sanctuaries in cells where the fish stock has been depleted. The cells are beside mangrove cells and are located in shallow waters. Also, the LGU can grant access to mangrove areas within barangays whose fishermen have a low fish catch.

Three classes of groups of agents were created depending on the occupation of an instance of an inhabitant. The groups are mainly used for initialization. However, future changes could be accommodated for the activities of the groups. A "BgyFisherfolk," a group composed of fishermen, is able to retrieve messages from its members and it sends a message to the LGU based on the messages received. Its role in the model, at this point, is to represent how the fishermen may communicate with the LGU.

Passive entities

Fishponds, after the harvesting process, are treated by the fishpond workers with chemicals to kill any remaining parasites. These chemicals are later drained into the sea. The chemicals are represented as a class of situated passive objects called "Poison" having an assumed "lifespan" of from 8 to 10 days. The movement of a "Poison" is based on a simple migration model, wherein, at every time-step, it would move to a neighboring cell with less than 4 other poison objects, and it affects sea grass, coral, mangrove, mud, or water cells by reducing the resources that the cell contains. After several time-steps corresponding to the lifespan, it "dies" and is removed from the simulation.

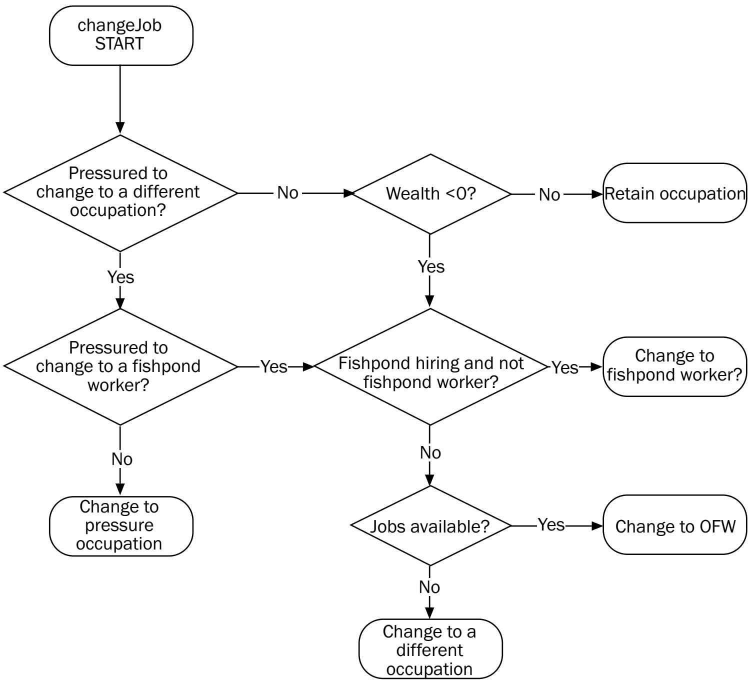

Fig. 7. Activity diagram for changing occupation.

A simple model of weather was made and it is dependent on the months of a year and is represented by the "Weather" class. The first half of the year, representing the dry season, would have less chance of having bad weather than the later months of the year.

Three kinds of messages are included in the model to facilitate communication between agents. An inhabitant sends a "Pressure" message, containing information about the sender's occupation and income, to its acquaintances if its daily income is greater than its daily living expenses and if its wealth is greater than or equal to zero. During the process of changing occupation, an inhabitant reads all the "Pressure" messages sent to it and then chooses the occupation with the highest average income and compares it to its own income. If the inhabitant's current income is less than that of the highest average income, it is pressured to take on that occupation with the highest average income. If a fisherman catches less than 1 kg of fish, a "FishermanComplaint" message is sent by the fisherman to its respective BgyFisherfolk group to inform it of a low fish catch. In turn, the BgyFisherfolk would send a "FisherfolkComplaint" message to the LGU to inform the LGU that the barangays have a low fish catch. The LGU, depending on the scenario, may grant access to mangrove cells equal to the number of "FisherfolkComplaint" messages received from the BgyFisherfolk groups.

Sequence of operations

For the Bohol model, a base sequence diagram was created and, for other scenarios, the sequence was modified to accommodate new tasks. One time-step is equivalent to one day. The sequence of operations is illustrated in Figure 8, which shows all the possible activities that could occur in a time-step. A time-step begins with generating weather, that is, whether the weather is good or bad, as this will govern the rest of the actions of the entities. Poison entities are then activated. The inhabitants are activated to perform their tasks according to their occupation. At the end of a month or after every 30 time-steps, jobs outside the municipality are made available to the inhabitants. Also, depending on the scenario, the LGU agent may give limited access to mangrove areas. At the end of a year, the population of inhabitants is made to grow and, depending on the scenario, the LGU may perform mangrove reforestation. Cellular automata processes are performed near the end of a time-step.

Results and discussion

Scenario selection

Though the stakeholders were not the ones who developed the scenarios, the researcher based the formulation of the scenarios on what could interest the stakeholders. Eight different scenarios were developed based on the combinations of the role of the LGU in NRM and the attitude of the people toward rules or policies. The LGU has the option of having or not having an NRM policy by actively performing mangrove reforestation, and listening to the fishermen and giving access to mangrove areas, or ignoring the fishermen. On the other hand, the inhabitants have three potential behaviors toward NRM rules: always obey them, always ignore them, or have varying tendencies of breaking the law on sanctuaries. This tendency of breaking the law is represented by an attribute of an inhabitant having values from 0 to 1, with 0 always being a law-breaker and 1 always being a law-abider.

Simulation results

Because many parameters could be analyzed in the model, the discussion of results here is limited to four indicators: number of mangrove cells, amount of fish stock, average daily income of fishermen, and the population of fishermen. To illustrate the effects of varying inhabitant attitudes, the results of the scenarios were grouped, keeping either the activities of the LGU constant, as shown in Figure 9, or the activities of the inhabitants constant, as shown in Figure 10.

For scenarios 1, 2, and 3, the LGU does not perform any NRM tasks, that is, no mangrove reforestation occurs, and it ignores the complaints of the fishermen. For scenario 1, all inhabitants are following the policy on mangroves, that is, fishermen do not fish in mangrove areas and farmers do not gather wood. For scenario 2, all inhabitants break the policy, and, for scenario 3, inhabitants randomly break the policy. In these scenarios, the number of mangrove cells decreased sharply at around time-step 70 because of the chemicals released in the water after the first harvest of fishponds. After this, the decrease in mangrove cells slows down for scenarios 1 and 3 as most of the mangroves around the fishponds have been destroyed. Firewood being collected by some inhabitants in scenario 3 resulted in a lower number of mangrove cells vis-à-vis

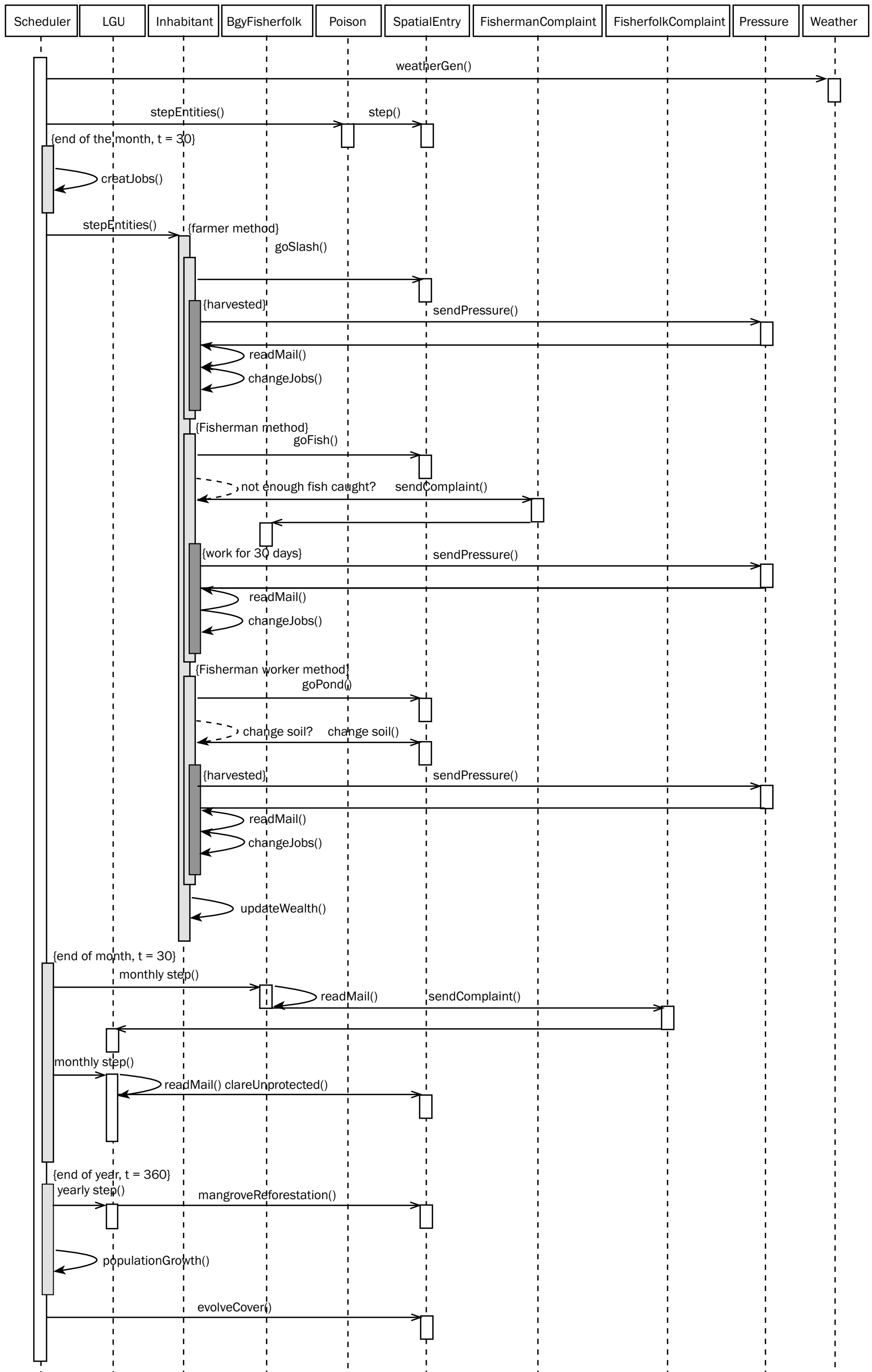

Fig. 8. Bohol model sequence diagram.

scenario 1. For scenario 2, the continuous high rate of decrease in mangrove cells is due not only to the chemicals being released but also to the continuous collection of firewood by farmers breaking the law. It could be said that the aggregation of small activities, such as firewood collection, has a big impact on the resources.

For scenarios 1, 4, and 7 presented in Figure 10, all the inhabitants follow the law. The LGU does not perform any tasks in scenario 1. For scenario 4, the LGU performs mangrove reforestation, and, for scenario 7, the LGU performs mangrove reforestation and gives access to mangrove areas. There is not much difference in the graphs of the number of mangrove cells as all inhabitants are following the policy. Surprisingly, although mangrove reforestation is being performed in scenarios 4 and 7, it hardly contributed to a higher number of mangrove cells. This may be because the LGU's mangrove reforestation efforts are insufficient to have a positive effect on the number of mangrove cells. However, giving limited access to the mangrove areas, as seen in the graphs of scenario 7, contributed to a higher fish stock and about \$0.20 more income per day for the fishermen than in the other scenarios. This higher amount of fish stock may have resulted from the fishermen fishing in different areas, therefore allowing other parts of the fishing grounds to replenish their fish stock and not be completely depleted.

As shown in the graphs of Figures 9 and 10, several relationships could be established. The increase in population of fishermen due to inhabitants changing occupations is a major cause of the depletion of fish stock vis-à-vis the effect of the chemicals. Obviously, less fish stock would mean less income for fishermen. Although

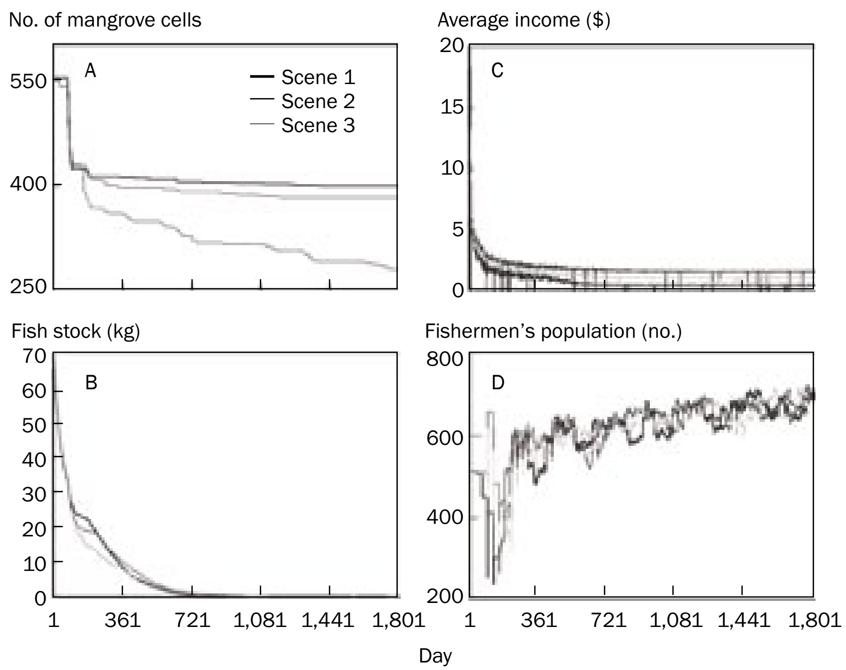

Fig. 9. Results of scenarios 1–3 after a 5-year run: (A) number of mangrove cells, (B) average fish biomass, (C) fishermen's average income, and (D) fishermen's population.

the population of fishermen would have sudden increases and decreases, the general trend is that more and more inhabitants are becoming fishermen, while there are fewer farmers and fishpond workers. The decrease in mangrove area is more affected by the poisonous chemicals than is the collection of firewood.

To observe the changes in land use/cover of the environment, a cross-tabulation of the initial state and the final state of scenario 7 was prepared. The values in the diagonal of the table, which are also the intersections of corresponding land use/cover in the initial and final states, show the number of cells that did not change per land use/cover. The intersection of the row for sea grass and the column for water yields a value of 89, which means that 89 cells have changed from sea grass to water after the 5-year run. The other nonzero values not on the diagonal indicate that 86 cells have changed from coral to water (cells covered by dead corals were assumed to be the same as water), 158 cells have changed from mangrove to mud, 28 cells have changed from forest to farm, and 1,240 cells have changed from forest to bare soil. The sea grass and coral cells that have changed into water, and the mangrove cells that have changed into mud, are found surrounding the fishponds, as shown in Figure 11, indicating that the change was caused mainly by the poisonous chemicals. The forest cells that have changed into farms are those converted by the slash-and-burn farmers. Most of the forest cells that have changed to bare soil used to be old slash-and-burn farms that have been abandoned. A total of 1,601 cells (or 5.4%) of the environment have changed in just 5 years. A change from bare soil to forest would not be observed in the 5-year run as the growth of forest cover is programmed to occur only after 10

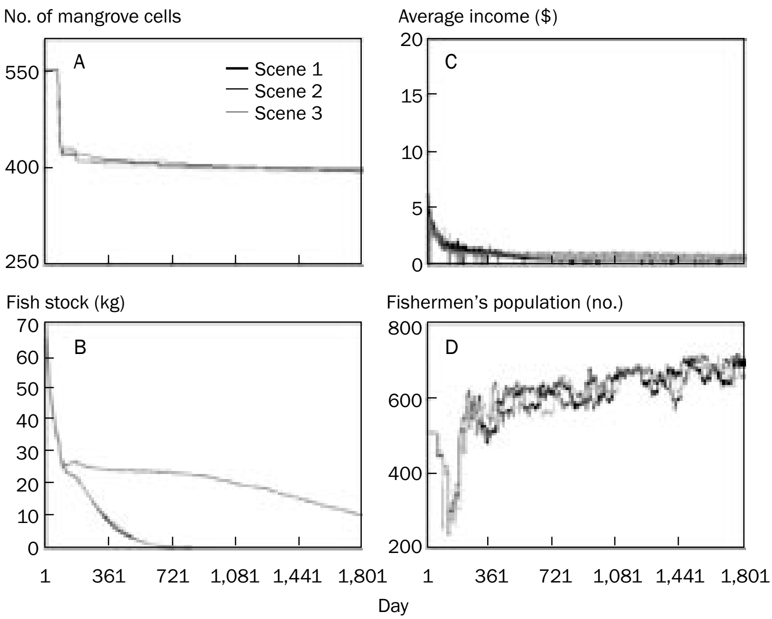

Fig. 10. Results of scenarios 1, 4, and 7 after a 5-year run: (A) number of mangrove cells, (B) average fish biomass, (C) fishermen's average income, and (D) fishermen's population.

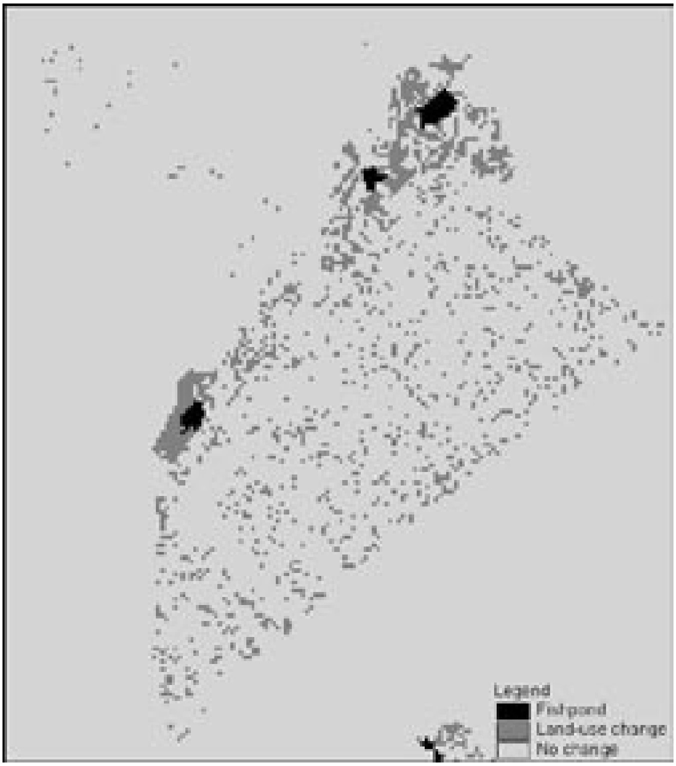

Fig. 11. Bohol environment land-use/-cover change map.

years. Although there is mangrove reforestation, it did not appear in the cross-tabulation as the reforested mangroves may have reverted to their previous states before the end of the simulation. The cross-tabulation cannot show the transitional states of the environment.

As this research is still in its first stage of implementation, some inconsistencies with the results emerged from the results of the simulations, as expected. For example, a decrease of up to 100 mangrove cells due to the chemicals released from fishponds in just a few days seems to be too great. The same reasoning could also be applied to the sea grass and coral covers. Also, fish stock going down to almost zero in just 2 years would be highly improbable as the average fish catch in the area at present is about 2 kg per day per fisherman and about 3.5 kg in the previous decade (Green et al 2002). By continuing the implementation of the methods and validating the model with scientists/experts and with the community, it is expected that these assumptions would be made more precise and the variables of the model would be further calibrated to produce more realistic results.

Conclusions

GIS and RS technologies have made it possible to perform resource inventory over a very large area for a short period of time. Maps produced using these technologies may give stakeholders a broader view of their area and some information regarding their current NRM situation. But, because they are just static pictures, the information provided by these maps may not be enough and we are left with questions such as "What is now happening to these resources, what could possibly happen to these resources in the future, and what can we do about it?" These questions may not be easily answered by just using GIS and RS techniques. By coupling GIS and MAS, these maps are given life. Similar to watching a home movie, the actors of the MAS simulation model (the stakeholders and policymakers) may see themselves moving in their environment. As the simulation progresses, they may observe and relate their activities to the changes in the supply of their natural resources and also observe and relate how their individual actions, when taken collectively, could change their environment. From what they may learn from watching a "movie" about themselves and their possible future, they may be able to develop new strategies or come up with scenarios that may lead to a sustainable use of natural resources; thus, MAS models could foster the development of scenarios or strategies for NRM. Moreover, these scenarios or strategies could be tested on the existing MAS model. By being able to test these strategies, the set of strategies could be filtered or sorted out depending on their viability; thus, the costs of implementation of new strategies could be minimized.

For now, the effectiveness of the Bohol model as being a "movie" cannot be ascertained because the model has not been validated with the stakeholders. To make this an effective tool that stakeholders would understand, there should be a consensus among them as to what indicators would be useful for them and how the model and indicators would be displayed so that the simulation model and its results could be more easily understood, as suggested by Etienne et al (2003). The prototype Bohol model itself was a bit ambitious to have included a lot of parameters, some of which don't have a major role in the simulation itself, and present a multitude of NRM problems while lacking data, leading to inconsistent and misleading results. Although these inconsistencies are expected, given that the model is exploratory in nature, it may be better in the future to start out with a model with a small scope, so that data gathering could focus on fewer, more specific areas to ensure that every aspect of the simulation model is necessary. Later, what seems to be lacking could be added.

During the fieldwork conducted for this research, several observations were made that may help facilitate a smoother and more efficient execution of tasks in the future. Linkages with NGOs based at the research site could provide not only logistics, such as organizing activities with the stakeholders, but could also provide information regarding the current socio-political situation of the area that may not be easily observed in the field. This information would guide the researchers in formulating activities with the stakeholders and help avoid antagonism. Linkages with organizations in the area may help improve the relationship between researchers and the stakeholders as these organizations may have already established a good reputation with them. This good rapport and trust may eventually carry over to future studies of a similar nature. Another important insight gained from the fieldwork is that the stakeholders' or the end-users' receptiveness to new methodologies and new technologies is an important factor in the amount of support and cooperation these people would give to the research. The research would be hard-pressed in gaining support and momentum if the stakeholders themselves were not convinced that technology could help them, as some people may believe, especially those who come from the poorest municipalities. And, finally, the MAS modeling process itself may be a good learning experience, which could increase awareness among the stakeholders of the NRM system and their existing and potential problems.

Further research may lead to refinement of the research questions and objectives, the methods used, and the model itself. The preliminary simulations presented in this paper show that an interesting aspect to focus on would be the mangrove-fishpond interaction or the impact of fishponds on their surroundings. It might be interesting for higher government to see how the growth and maintenance of fishponds, even the kind of animals being grown in the fishponds, actually affect their surroundings and vice-versa since it is a higher government unit that approves fishpond permits and not the local stakeholders. There is still a need to validate the model with the stakeholders. Role-playing games may be developed and played with the stakeholders to validate the model and also help the stakeholders relate better to the simulation model, and possibly even use it in the negotiation process. It would also be interesting to know if the same model could be used at different levels of the negotiation process, such as negotiations between the local stakeholders and the LGU, and negotiations between the LGU and government entities at the national level.

As a whole, research activities, such as this, have the ultimate goal of providing effective techniques and tools for learning and negotiation processes that may lead to a more sustainable management of natural resources and the environment. Improvement of methods and techniques used for MAS modeling must be fine-tuned for achieving this goal.

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Notes

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Modeling multi-stakeholder forest management: the case of forest plantations in Sabah

Ph. Guizol and H. Purnomo

The underlying decision theory of forest management changed from decisions made by the forest manager, a single stakeholder, to a decision-making process, which involves a variety of stakeholders with different goals. From concept to implementation, forest professionals are in trouble because, despite the potential of technological progress and the development of tools to support decision-making, tools to facilitate multi-stakeholder decisions are lacking.

This paper proposes a framework to link social, economic, and biophysical dynamics using multi-agent simulation to explore scenarios of collaboration for forest plantation management. The modeling is based on decision theories. This framework uses the concept of a value-added chain as a model of alliances. The added-value breakdown analysis is a tool, which is used at the forest-plot level as a means of anticipating benefit sharing among the stakeholders before they decide to harvest; this also highlights the added-value variation from plot to plot. The framework can also take into account noneconomic-based relationships. Each stakeholder has explicit communication capacities, behaviors, and rationales, and forest management emerges from their interactions.

The purpose of this modeling is to produce shared knowledge about dynamics to facilitate coordination among stakeholders; it is a learning tool about forest management. Our main hypothesis is that stakeholders, by creating a virtual world with researchers, will learn about the effects that their own decisions might have on themselves, others, and the environment. In the case of Sabah, we are at the stage of the first loop of learning, and scenarios need to be further tested with the stakeholders themselves. This forest plantation simulation suggests that the development of sawmills adapted to plantation wood might offer a promising pathway for increasing added value and the benefits of many stakeholders, including local communities.

Principle 22 of the Rio Declaration on Environment and Development (1992) highlights the importance of local people and their participation in sustainable development. In forest plantations, this should apply to local communities living in or near forest plantations.

Malaysia, the country where Sabah State is located, is situated right in the heart of Southeast Asia and is divided into two geographical sections: Peninsular Malaysia and the East Malaysian provinces of Sabah and Sarawak in North Borneo (Fig. 1).

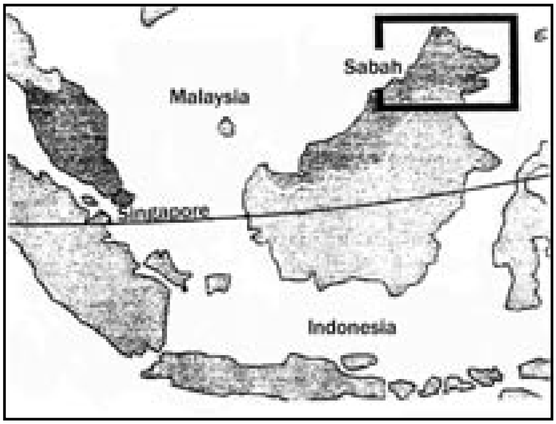

Fig. 1. Sabah location map.

The study area is located in northeastern Sabah, mostly in Bengkoka, Marudu, and Keningau districts. Grasslands, logged-over forest, and secondary forest cover most of the landscape.

Smallholders believe that many opportunities are provided for forest plantation development. A lot of logged-over land is available for plantations. Sabah natives have the possibility to obtain security over land and rural people have the will to invest in forest plantations to secure their ownership of land, to rehabilitate the landscape, to rehabilitate wildlife resources for hunting, and to invest for themselves and the coming generations.

The Sabah Legislative Assembly created SAFODA (Sabah Forestry Development Authority) in 1976. Its mission is to develop highly productive forest plantations for the long-term supply of wood resources and to improve the socioeconomic status of the state and country on a sustainable basis (SAFODA 2003). Currently, SAFODA manages about 100,000 ha of land.

The local government perceives the development of forest plantations in this part of Sabah as a means to improve the landscape and smallholder income. Today, most of the land, which has been logged over and is unused, is highly fire-prone (a lot of areas are covered with *Imperata cylindrica* and large stocks of remaining deadwood). The development of smallholder plantations could also produce a variety of plantation systems. These plantations will reduce the areas' fire proneness and would involve the local population in fire control.

The wood price is a major impediment to the development of all plantations. Sabah State has already invested a lot in smallholders' plantations and SAFODA estates. So far, SAFODA plantation area amounts to 31,000 ha. The planted species are *Acacia mangium* (28,000 ha) and rattan (2,100 ha). SAFODA encouraged small landowners, adjacent to their forest plantation areas, to grow trees. Currently, these smallholder plantations amount to 3,000 ha supervised by SAFODA.

However, this development is in crisis as SAFODA faces problems in self-financing its development in the current context of low wood prices. Currently, SAFODA has to export, at a low price, fast-growing wood produced on its own plantations as the existing paper mill in Sabah (Sabah Forest Industries, SFI) is too far away from the SAFODA plantations.

The local stakeholders are disappointed and don't want to invest as long as wood prices are too low. The domestic wood price would increase if domestic downstream industries existed to buy wood. Investors would consider investments in downstream industries for plantation wood if mature plantations were available but they might postpone such investments as long as faster returns from natural forest logging exist. The challenge is to create conditions for co-development of plantation forests and downstream industries using plantation wood.

It looks like more coordination and a more bottom-up approach to the problem are needed among the Sabah plantation policy, smallholders, and the development of wood-processing industries. The goal of our model is to observe the impact of wood-processing development on land use and income of different local stakeholders. This research explores scenarios of co-development of smallholder plantations and wood-processing enterprises.

This paper presents the theoretical background on which the selected methodology relies, followed by the method and its implementation, and then a first discussion about the preliminary results, the use of simulation, and the next steps of the research.

Theoretical background of the model

In this section, we present the theories and concepts we use in our model. Forest management planning used to be a process driven by the theory of individual decision focusing on forest dynamics. The new paradigm of sustainable forest management increases the scope of forest management by recognizing the environmental, social, and economic elements of forestry as well as the multi-stakeholder and institutional dimensions of the underlying decision process (Edmunds and Wollenberg 2003, Gibson et al 2000, Ostrom 1990, Weber et al 1990). This dramatic change requires new approaches.

Forest management planning and decision theories

The underlying decision theory of forest management planning came from substantive rationality (Simon 1976). This is a deeply rooted perception of decision-making, which assumes that an objective is clearly stated, solutions are in restricted number and known, and the decision-maker is free to find the optimal solution. The decision is rational as it is a coherent sequence of stages designed to reach this objective:

> Observation/intelligence activity > objective/design > deliberation/choice > review/assessment of choice.

The process of forest planning from classic forestry textbooks is very well structured and looks the same:

> Owner objective > data analysis > decision > action plan.

Of course in detail it is much more complex, but still linear, for instance:

Land right update > description of the forest and the forest plot characteristics (soil, species, topography, history, etc.) > definition of long-term production goals, choice of species > plot classification and silviculture choices at the plot level > productivity expectation, annual allowable cut (AAC), harvest design method > operational planning of activities (maintenance, thinning, pruning, harvest) > financial assessment.

This theory consists of matching the owners' will with the potential of the forest to guarantee forest sustainability. It is a tool that evolved with the development of new technologies for environmental observation (satellite imageries, description of ecosystems) and data management (such as geographic information systems, GIS). It is in use in many countries, such as in France by the state enterprise managing the national forests (Dubourdieu 1997).

The flaws might be that, despite the development of technologies, forest management planning is a process driven mostly by an understanding of the biological subsystem only, and the interaction between biological and social dynamics is not taken into account well. Other stakeholders' objectives are seen as the "social pressure" (Dubourdieu 1997). When the social pressure increases, some participatory approaches might be introduced without fundamentally changing the nature of the decision model. National forest planning in the United States starts with an inventory, followed by a participatory process, which designs the desirable future state of the forest. The forest service then makes the final decisions, while it elaborates an action plan (Risbrudt 1999).

Simon (1976) stated that economic analysis rests on two assumptions: that the agent has as a specific goal the maximization of its profit and that it is rational. Rationality, or hard rationality, also means that the agent has all the information and that solutions exist in a limited number. Under these conditions, Simon (1976) defined the rational agent as an agent who compares the different solutions to its goal and chooses rationally one with a method, such as cost-benefit analysis.

March and Simon (1974) identified limits to the rational decision theory. They observed that, in the real world, decision-makers make decisions with a subset of information, and do not try to find the optimal solution but a satisfactory one. Simon (1976) proposed the theory of bounded rationality in which decision-makers have multiple constraints: limited information, limited time, and limited processing and memory capacities. In the real world, decision-makers use simplified sets of rules, or heuristics, to make decisions. This theory does not consider situations with multi-stakeholders.

In uncertain situations, Simon (1978) proposed the theory of the decision-making process, in which a decision is the outcome of a complex system in which multiple stakeholders can interact.

The social network theory contemplates society as a complex structured system in which a stakeholder is a social entity, which can be a single person or a group with common resources and interests. The stakeholder behaves according to his/her interest but is constrained by a set of social norms (Crozier and Friedberg 1977). Social norms are a classification of the world, things, people, and people's relations with things (Weber et al 1990). In a social network, relations among stakeholders are critical as in all complex systems. In the following section, we describe how we model agents with some economic rationality.

The concept of value-added chain

We view the value-added chain as a short-lived alliance among a variety of stakeholders to produce goods from forests. This concept allows the integration of different decision levels and forces us to describe the communication patterns among stakeholders, and the perceptions and goals that govern each stakeholder's behavior. Usually, the value-added chain is reduced to the supply chain perspective of an industry trying to secure its supplies. Here, we look at it in the other way, from the forest side; the value chain concept helps to anticipate before harvest the use of the wood and benefits that wood products will generate. This is what stakeholders in the forestry sector are doing, consciously or intuitively, in real circumstances.

We assume that the decision to cut a forest plantation plot results from an agreement among key stakeholders. A piece of wood will be harvested and extracted from the plot if all key stakeholders along the value chain are satisfied with the system of alliances. If a key stakeholder, a woodcutter or a road haulage contractor, does not get what he/she really expects, wood will not be harvested and nobody will be paid. The common interest is to reach an agreement, but this is not always possible. Success or failure of the negotiation depends on the negotiation process but also on forest plantation physical conditions. For instance, if the forest is far away from the market or a factory, transportation costs might be so high that a satisfactory solution for all cannot be found.

This system of alliances is the result of negotiation among stakeholders who try to reach their own goals through such a process. It can change over space and, at any specific location, it is a snap alliance as it can change over time according to stakeholders' changing perceptions of the environment and their relationships. This allows us to represent the interaction between forest dynamics and social issues as it links these changing alliances directly to the rate of harvesting, which affects the forest dynamics.

The value-added breakdown analysis, which includes costs and added value at each stage, is a very simple and practical economic model that we use to analyze the contribution of each stakeholder to the final product price from wood standing value to the retail price of the final product. The coordination of the economic goals of diverse stakeholders through negotiation is the process used in this breakdown analysis.

Methodology

In this section, we propose a framework to represent the interactions between socio-economic dimensions and forest dynamics; this framework takes into account the critical role of communication patterns among stakeholders in the process of forest management. It uses the theory of decision-making process and the concept of value-added chain mentioned above.

Simulating for collective learning is the objective

The purpose of our model is to produce simulations. "Simulation" means making a simplified representation of a real-world situation, and animating it so that stakeholders can envision what the future situation might be. This simulation tool is not created to select a solution but rather to stimulate a discussion with the real-world stakeholders about whether a given solution might satisfy them.

A simulation tool is one tool to support a decision among a large family of decision support tools for sustainable development as described in Kersten et al (2000). These authors would class it in a subset of communication or teamwork support tools to be used when a decision involves more than one decision-maker. In practice, for instance, multi-criteria decision-making (MCDM) has been used to make decisions for forest management planning more effective (Tarp and Helles 1995). MCDM prioritizes criteria and uses them for assessing the specific performance of a system. Even though MCDM is not designed specifically as a teamwork support tool, it can be used within a participative process.

Simulation will be used within an action research process, which involves stakeholders in producing knowledge, assuming that collective action is more likely to occur based on a common representation of the environment. Interaction between simulation and stakeholders, including researchers, is also a learning process, which should influence long-term forest management. Researchers are already using scenarios generated by other participative tools in the field of forest management (Wollenberg et al 2000, 2001, Nemarundwe et al 2003).

The choice of a multi-agent systems approach

Multi-agent systems (MAS) offer a promising way to examine natural resource and environmental management issues (Bousquet et al 1999, Gilbert and Troitzsch 1999). The hallmark of MAS is the recognition of "agents," which are entities with defined goals, actions, and domain knowledge. Some degree of agent autonomy is central to the notion of multi-agent modeling (Weiss 1999). These interactions can be cooperative or selfish, with agents sharing a common goal or pursuing their own interests (Sycara 2000, Gilbert and Troitzsch 1999). Agents are entities within an environment, which they can sense, modify, and improve. This collection of agents in interaction is not a sum of isolated entities but it forms a society of agents.

Simulating the stakeholders' activities and interactions requires a tool that is able to represent the individual's knowledge, belief, and behavior. MAS have their roots in the field of artificial intelligence. Hence, most of the early theoretical development of MAS evolved from computer-related work (Weiss 1999). Recognizing the close analogy between distributed artificial intelligence and individual-based modeling, several authors saw the potential for adopting MAS in natural resource management, particularly in areas where several stakeholders share the control of renewable resources. In the field of renewable resource management, other researchers already use simulation with MAS and role-playing games to allow mutual feedback between the real world and stakeholders, and to promote communication (Barreteau et al 2001).

Modeling forest management

In our model, we recognize two different levels of decisions (Fig. 2). At the first level, each agent has an individual bounded rationality. The agent makes decisions according to its goals. It is constrained by its social norms, its limited knowledge of the

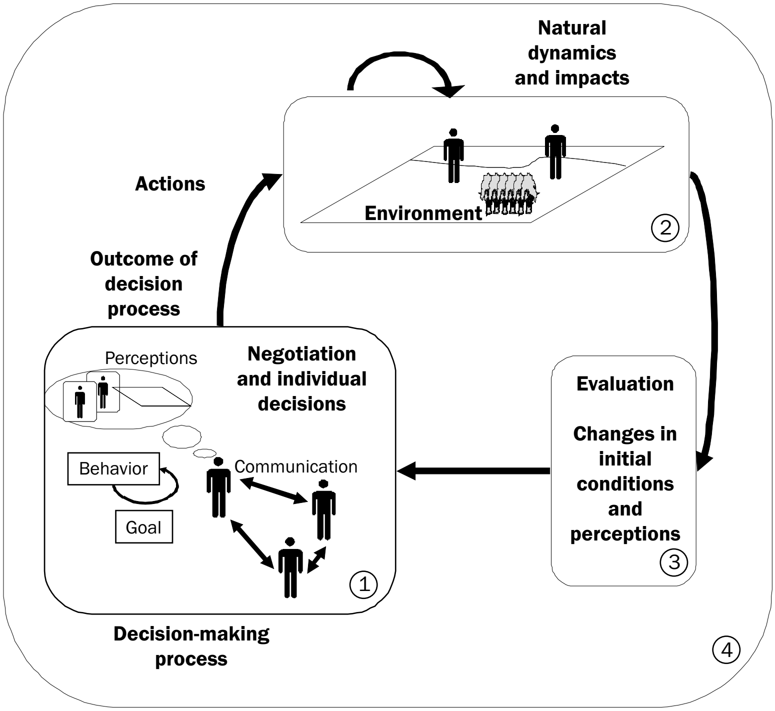

Fig. 2. Theoretical model of forest management. Block 1: Inside agents have goals and behavior, and they make individual decisions; from the whole block emerge decision processes produced by these agents in interaction. Block 2: The environment (space, forests as renewable resources, noncommunicating agents, objects as roads, etc.). Decision processes in block 1 affect environmental dynamics. Block 3: A phase of analysis and evaluation. Block 4: The level of emergence of forest management.

environment, and its relationship with other stakeholders. It also has some economic rationality, and we use the value chain to represent it (Fig. 3).

A second level of decision is the outcome of a set of agents' interactions that these agents are able to communicate. This set makes up a social network. At this level, agents are coordinating their decisions and some form of negotiation takes place. This decision has an effect on their environment. A phase of intelligence, review, and assessment allows stakeholders to modify some of their perceptions and behaviors before a second loop starts.

A type of artificial forest management emerges following a number of these loops—it is a third level or emergence level. We also want to assess the scenario occurring at this level.

From stakeholders to agents

We identify stakeholders according to the criteria of the "who count matrix," namely, proximity to the forest plantation, legal and traditional rights over the forest plantation, dependency on the forest plantation, and knowledge of forest plantation management (Colfer et al 1999). Stakeholder characteristics were recognized through field visits and discussions. Researchers facilitated the discussion to establish stakeholder identities,

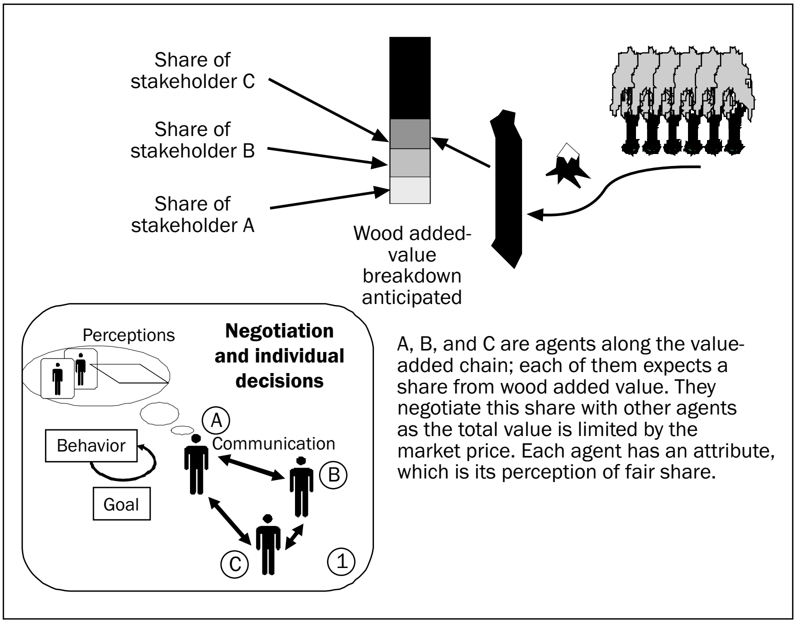

Fig. 3. Multi-stakeholder decisions and the value-added chain.

their rationale, and their behavior and actions. These characteristics formed the basis for the MAS model to be subsequently developed.

An agent, which is here a computed representation of a stakeholder, might have an economic behavior. To model this specific behavior, we use the added-value chain concept described above. Agents in the model are anticipating the outcome of their decisions during the decision process. The stakeholder evaluates the outcome of the process vis-à-vis his/her goals (Table 1).

The distinction between a communicating agent and a noncommunicating agent is key. In Figure 2, some agents are not communicating and are part of the environment. As Holling (1999) remarks, there is a difficult trade-off between keeping the model simple enough for sharing information with real-world stakeholders and complex enough for understanding. Stakeholders, with researchers, should reassess this distinction about agent communication capabilities because some agents can move from one condition to another.

Expected results

We expect that the structure of the added-value breakdown, although analyzed at each forest-plot level of a map, will differ according to the forest-plot location, and this would reflect potential benefit-sharing variation. This would link economic issues to spatial structure (Fig. 4). Negotiations will take place on each patch of the map, revealing linkages between economics and space.

A simulated forest plantation management will emerge from our model and we will be able to observe it on a spatial grid over a long simulated time on the spatial

Table 1. Respective goals and strategies of the selected stakeholders.

Stakeholder	Goal	Strategy
SAFODA	Improve its returns	By reducing its costs and increasing its revenue.
Smallholders	To improve their well-being	They have lands and can expand the plantations. If wood price is high enough, they expand their plantations for pulp or timber. If their pulpwood plantations are not commercially viable, they can convert them to timber-wood plantation or other uses.
Buyers	To improve their profits	They take care of logging and transportation costs. They need a margin of 20%.
Government	Forest sustainability	More smallholders, more wood resources, and forest landscapes.

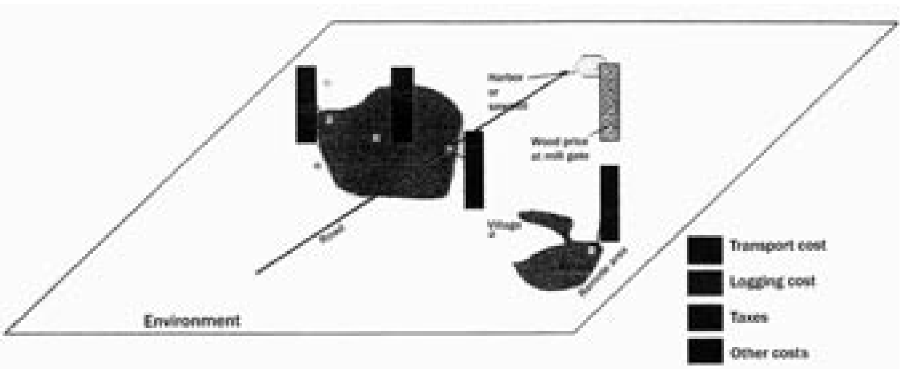

Fig. 4. Negotiations take place on each patch of the map, revealing links between economics and space.

grid. We will observe the impact of the simulated dynamics on each agent income that we can derive from added-value breakdowns. We expect that such simulations will help stakeholders to react and express themselves and will allow us to learn more about the processes and their needs (Fig. 5).

Model implementation

The choice of the CORMAS simulation platform

We use common-pool resources and multi-agent systems (CORMAS, Le Page and Bommel, this volume), a simulation platform specifically designed for renewable resource management systems. CORMAS provides a framework for developing simulation models and offers predefined elements, which users can customize to a wide range of specific applications (CIRAD 2001).

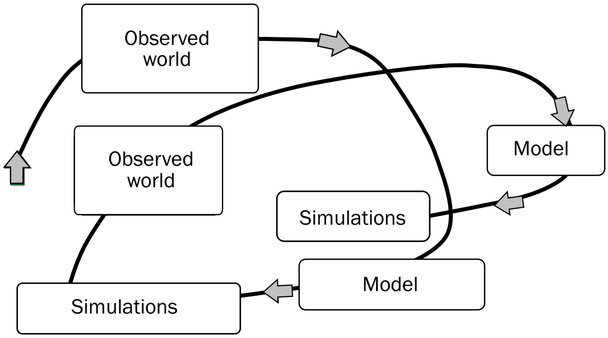

Fig. 5. Simulation as a research action tool for companion modeling (modified after Bousquet et al 1999).

We chose the CORMAS platform as it focuses on interactions between social and resource dynamics, based on spatially defined communication patterns. In CORMAS, communicating agents are already predefined with a set of attributes and processes used for sending a message, which makes it easy to simulate communication. Effects on forest resources can be visualized on a simulated grid or map.

Agents' attributes

The stakeholders we identified, based on the criteria mentioned previously, are SAFODA, smallholders, buyers (for pulp and sawmill), and the government. Table 1 describes the respective goals and strategies of those stakeholders.

We create agents from information we have about stakeholders. Basically, we define the initial conditions, the agents' attributes and their relationships with other agents and (forest) resources, the forest dynamics, as well as the way agents are able to adapt to change; agents are at least reactive to environmental change, but they can also learn. During a process of evaluation, they can change their perceptions about the environment and other agents and add addresses of new agents to their list of attributes (box 3 in Fig. 2). Among agent attributes are agent goals, their perceptions of the environment (resources and other agents), and their ability to communicate. Agents might also have a bank account as another attribute. We observe the effects on the forest resources and on agent changes in attributes (perceptions, bank account, and addresses of other agents, for example).

Biophysical and economic data

We obtained biophysical and economic data from SAFODA and the literature. At this stage, we have not incorporated real spatial data into the model. Presently, the model has used a map displaying a typical spatial configuration of forest plantations.

We analyze the growth volume model to represent plantation dynamics. Table 2 shows the dynamics of pulpwood growth volume that is used in the simulation. After 10 years, the mean annual incremental growth is 14 m^3 ha^{-1}.

Model overview

The conceptual model is presented in Figure 6. In this conceptual model, a sawmill that does not exist currently is added. Figure 6 shows that SAFODA and the smallholders grow *Acacia* on their plantations. Then they negotiate with a buyer to sell their timber. The buyer sends the wood he buys to mills. The wood for pulp is taken to the harbor for export if there is no pulp mill. The government observes the impacts of stakeholder interactions on the income of smallholders, pulp availability, and landscape.

If the sawmill exists, its primary goal is to maximize its profit. In the model, the sawmill can be set up anywhere on the map. It produces a demand for wood at a sawed-log price. The buyer takes into account the sawmill location to calculate the sawed-log price.

Spatial representation

The current study represents the forest landscape as pixels, including the explicit location of SAFODA and smallholders' plots, the sea, road network, pristine forest, agricultural land, and the harbor. Each pixel represents an area of 25 ha. Figure 7 shows an example of a virtual map of forest landscape where SAFODA, smallholders, and

Table 2. Wood growth for pulpwood plantations.

Item	Year									
	1	2	3	4	5	6	7	8	9	10
Volume (m^3 ha^{-1})	0	5	15	25	35	50	70	100	120	140
Annual volume increment	–	5		10	10	15	20	30	20	20

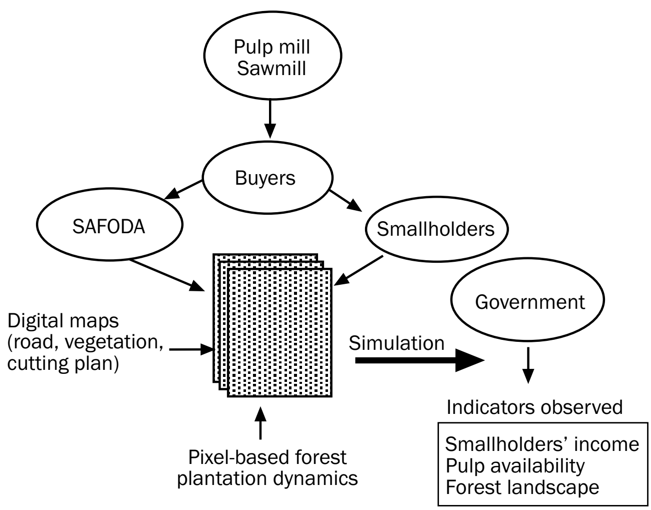

Fig. 6. An overview of the model.

1_n: SAFODA forest management plots (age 1 to 10)
2: Smallholder plots
3: Sea
4: Road network
5: Pristine forest
6: Agricultural land
7: Harbor
8: SAFODA field office

Fig. 7. Representation of forest landscape. Large plots marked 1 are SAFODA forest management plots. The different gray areas relate to the plot wood stock, while black illustrates that the plot is ready to be cut. The small triangles represent smallholders located in their forest plots at the beginning of the simulation (2). The black area at the bottom of the map represents the sea (3) and the harbor (7). In the top right of the large area marked 5 is the pristine forest. The white areas (6) represent land devoted to agriculture. The Y-shaped lines (4) are roads, with different gray colors relating to road quality and to different transportation costs.

the harbor are located. Small triangles represent smallholders. They can move during the simulation if they are not satisfied with their plot production at the beginning of the simulation.

We developed a spatially explicit algorithm to compute the transportation cost. The algorithm calculates the cost between the plots and mills by considering the existence of the roads and their quality. If there is a road, the distance cost is lower than if there is no road. Similarly, the better the road quality is, the lower the distance cost. The algorithm seeks the path providing the lowest distance cost. This is done by looking at the distance cost of the eight cells surrounding the one in which the wood is located. If the cells have exactly the same distance cost, then the algorithm looks at the next range of cells surrounding those eight cells, and so on.

Agent interactions

Figure 8 illustrates the interactions among agents as a sequence diagram in unified modeling language (UML). SAFODA has only pulp plantations, but smallholders might have small plots for pulpwood and also plots for sawed timber. When SAFODA has a plot ready to be cut, it sends a message to pulp buyers. If they are interested, negotiation between the buyers and SAFODA follows. The negotiation results between SAFODA and buyers will affect SAFODA's strategy to replant in the following years. If SAFODA implements a benefit-cost analysis for each plot, it will then have two options: to grow or not to grow trees. If it uses a plant-cut-replant approach, it will grow trees regardless of income produced from the plantation.

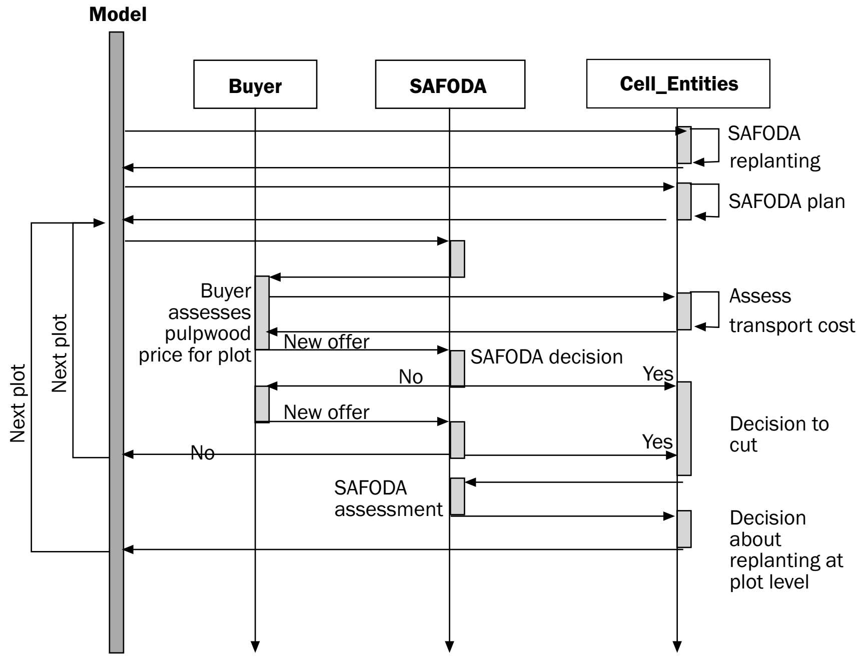

Fig. 8. Sequence diagram of agent interactions during negotiation.

At the same time, pulp and sawed-timber buyers are looking for wood from smallholders. If smallholders have plots ready to be cut, they send a message to buyers and negotiation follows. Negotiation about wood prices also occurs between buyers and mills. Smallholders also take into account outcomes of past decisions to decide about future activities. If they obtain a good income from the plantation, they expand it on new unproductive land. Buyers propose prices to tree growers, that is, SAFODA and the smallholders, based on the prices at which they can sell the wood to mills or at the harbor for export. The wood transportation cost from plots to roads is higher than from the road to the mill.

Simulation results

Initial conditions and scenarios

The structure of the initial condition is described in Figure 7. SAFODA manages its large plantation plots located nearby the road, while smallholders manage small plantation plots located far away from the road. The locations of small plantation plots used to be agricultural land. Natural forests still exist north of the plantations. There is no sawmill or pulp mill in the area and the wood is transported to the harbor.

Evaluation and observation

Model evaluation. A study was planned to develop and verify the model. The dynamic responses implicit in many natural resource management settings add to the challenge of interpretation and testing (Barreteau et al 2001). We evaluated the present model using two criteria: (1) the logic of the model and its outcomes and (2) the similarity between predictions and expectations. The model met these criteria. The assessment that the model was reasonable was based on a systematic checking of all the relationships within the model, from the simplest submodel (forest plantation growth) to the more complex submodels (e.g., the agents' communications). Finally, we assessed the outputs of the model. This assessment led to the conclusion that the model complied with the patterns we expected before.

Envisioning scenarios of forest plantations. Under the current scheme, after 10 years, the smallholders move to sites close to the road network to maximize their benefits in relation to transportation costs (Fig. 9). If existing plantations are not financially sustainable, smallholders just abandon them. They leave their plots and look for new accessible plots closer to the main road. This will decrease the available wood for pulp, degrade the forest landscape, and decrease their income.

Figure 10 presents a scenario with the establishment of a sawmill. Smallholders convert most of their pulpwood plots into sawed-timber plantations. These sawed-timber plots are commercially sustainable and give more income to smallholders. The smallholders leave several plots, which are far away from the road network. The forest landscape is larger vis-à-vis a scenario in which a sawmill does not exist.

Conclusions

Policymakers should be able to assess the very long-term effects of their decisions, such as the establishment of plantations or wood-processing industries. Simulations, which involve stakeholders' knowledge, are one way to examine this issue, as they

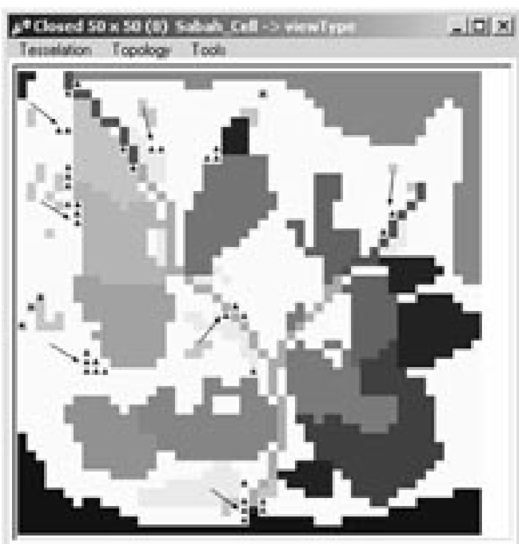

Fig. 9. Smallholders abandon their plantations and move to locations closer to the road as indicated by the arrows.

Fig. 10. Scenario of the impact of the establishment of a sawmill. A is a sawmill, L represents areas from which smallholders left, and C represents areas converted into sawed-timber plots.

allow the representation of complex coordination among multiple individual decisions through a negotiation process, and its effects on plantation resources and income generation.

In this article, we proposed a theoretical framework to design a model of multi-stakeholder forest management and its ongoing implementation under the CORMAS platform. It is a practical way to envision long-term scenarios of forest management involving multi-stakeholders. We have found the model to be useful for developing scenarios and observing the likely effects of each scenario on the forest landscape and on the well-being of stakeholders.

In the specific case of this Sabah plantation model, setting up a sawmill adapted for processing small logs from plantations might be a large incentive for smallholders to develop plantations, including in areas far from roads. The sawmills would increase the value of wood. The outcome, besides landscape management, is also better income for smallholders. Without a sawmill, smallholders move to sites close to roadsides and abandon their remote plots. Thus, the wood supply to enterprises, smallholder income, and forest areas decline. Nonetheless, this work in Sabah is in the very early stage of an action research process that we will continue.

In the next steps, we will involve the stakeholders more intensively in the modeling process to develop communication and reciprocal learning across stakeholders and researchers. Although we did our best in representing stakeholders' behavior, we did not make formal knowledge elicitation and representation during the process of building the simulation. We intend to improve the agents' learning process, coordination, and cooperation among them as well as the spatial representation of the area.

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Learning processes

Part 4

The Thai traditional learning process in folk culture: implications for the companion modeling approach

I. Patamadit and F. Bousquet

A group of researchers working in the field of renewable resource management tries to apply simulation tools when dealing with these complex systems in order to understand the institutions and norms that drive the interactions among actors, and consequently between actors and their environment. This method can be used in many cultural contexts and leads to generic outputs (collective learning process, good understanding of computer simulation by stakeholders). But the effectiveness of the method seems to be very dependent on the social and cultural context. We decided to do some research on the learning process in Thai traditional culture. It aims at identifying and understanding such villagers' worldview through religious texts, traditional literature and poetry, folk songs and music, ceremonies, and festivals. We try to understand how the Thais interpret their social environment and learn to act accordingly within it. It seems that the companion modeling approach is quite successful in the Thai learning context because the method is based on experience and fun derived from the game process, but the collective discussion aspect that is supposed to emerge from the use of this tool does not really occur, probably because of individualism, a strong cultural structure, a fundamental culture of conflict avoidance, and difficulty in distinguishing reality from virtual scenarios.

The scientific background of companion modeling is presented in the first chapter of this book. The inspirational sources of this approach come on the one hand from the community of researchers working on common property and co-management applied to the management of renewable and natural resources and on the other hand from the community of researchers working on multi-agent simulations, policy simulations, role-games, and participatory modeling. These communities are strongly influenced by results obtained in different cultural contexts, and they sometimes conduct anthropological studies to understand the institutions and norms that drive the interactions among actors, and consequently between actors and their environment. However, the companion modeling approach was conceptualized and then assembled by Europeans. Since the beginning and thanks to the CIRAD mandate, it has been tested in various cultural contexts, in Senegal, Madagascar, Vietnam, France, and then Thailand. These first experiences led to a paradox: on the one hand, the method can be applied in many cultural contexts and can lead to generic outputs (collective learning processes, a good understanding of computer simulations by stakeholders, etc.), and, on the other hand, the management of the different steps of the method seems to be very dependent on the social and cultural context.

As we decided to use this companion modeling approach in Thailand for natural resource management issues, we did some research on the learning process in Thai traditional culture. How do we understand what villagers believe to be important? What concerns or motivates the villagers? How do they perceive the world in terms of the nature of humans, and the relationship between one person and another, humans and nature, and humans and a supernatural being?

This paper is organized in two parts. The first part aims at identifying and understanding such villagers' worldview through religion, traditional literature and poetry, country music, games and folk plays, ceremonies, and festivals. At the same time, we will highlight rules, plans, and categories that influence how the Thais interpret their social environment and learn to act purposefully within it. This analysis corresponds to the culture from the northeast of Thailand. In the second part of the paper, we try to relate the main observations presented in the first part to the companion modeling approach: Which parts of the companion modeling approach and the associated methodology suit the Thai learning process? Which parts do not suit it? What indications can be derived to improve the methodology and its application to the Thai context?

Fundamental aspects of the learning process in northeast Thailand

Thai ways of thinking

Life is just for fun. One Thai national characteristic that almost all research studies have defined is enjoyment of living (*sanuk*). Thais consider that everything happening in their life is for fun. The person who knows how to do something in a funny way will be socially accepted. Thai folk culture demonstrates well the "just-for-fun" life style. Every step of life, even death, is inseparable from playing. Therefore, working must be done in a pleasant way. When gathering together to work or to celebrate any event, Thais are skilled at creating simple entertainment to cheer up the atmosphere. So, playing serves for both work and social adaptation. In the old days, Thais were mostly peasants and lived in a rural agricultural society in which rice cultivation was the dominant activity. Villagers gathered together to work at critical periods of the rice cycle when widespread labor was needed within a very short time, for example, for soil preparation, transplanting, the harvest, and rice polishing. To keep people working faster and more efficiently in pleasant and relaxed conditions, folk songs were created and chanted among them to provide rhythm and entertainment. During rest hours, peasants sometimes separated into two groups, women and men, and exchanged improvised songs in the form of short and simple poems, such as in "*Phleng Ten Kam Ram Kiew*." They laughed at words or expressions with double meanings or danced together whenever they felt like doing so. After harvesting, they had to prepare the yard for polishing rice. The way villagers trampled on the yard regularly and simultaneously gave birth to "*Phleng Song Fang*." The family that requested help provided food and drink during that special day. This mutual assistance took turns from family to family around the village and normally villagers rarely refused a request for help from their family or neighbors (Jobkrabuanwan 1982). Folk plays are always accompanied by folk songs and dances. Special characteristics of folk culture are spontaneity, improvisation, simplicity, and outspokenness. Normally, a folk play can take place spontaneously anywhere (paddy field, yard of a house or temple, even on a row boat during the high-tide season) or any time (daytime or night time). The Thai language is characterized by monosyllables and a musical tone that are easily compatible with short poems recited in folk songs. Everyone feels free to participate or not at any moment of the folk play. People can stop playing whenever they get bored. The number of players, women or men, is flexible. The most important aspect is that everyone has the same opportunity to rejoice and have fun (Jobkrabuanwan 1982, Sawadiphanit 1991).

Life as a result of previous meritorious acts. If life is just for fun, then how do Thai villagers manage to cope with serious problems that occur frequently in their lives? Since Thai villagers consider themselves Buddhists, the temptation to act according to Buddhist teaching is still highly valued by their mentality. To understand Thai popular Buddhism in its entirity, one must analyze the villagers' intellectual conception of Buddhist principles and doctrine and specify to just what extent Buddhism motivates their daily actions. For the average villager, concepts such as nirvana, the philosophical intricacies of the *dhamma* teachings, or the involved form of meditation have little meaning. Villagers draw more meaning from karma, rebirth, merit, sin, and *anicang* (impermanence). Villagers understand these concepts in simple terms. They believe in them and, as such, these concepts affect their lives. Villagers are certain that their present existence is the result of accumulated actions, both good and evil, in both their former existence and present one. In their point of view, all human beings are born according to their individual karma and thus one should not be jealous or envious of differences in status, rank, power, and wealth. However, it must be stressed that villagers are fully aware that they can change their present status and condition by their own deeds in the present. Their present actions are directed toward bettering their merit position so as to achieve a better life, both now and in a future existence. For Thai people, a better life means one of riches, power, prestige, perfect health, beauty, and very little physical labor (Suphap 1985). It is in expectation of such a life that merit is earned. If sin is higher than merit on one's karma's scale, then a life of poverty and hardship will necessarily follow. Thus, one views his or her condition with a sense of psychological balance, not rebeling against one's condition of birth while at the same time preparing to change and to view the helping of others as a meritorious act. As the villagers are ever-anxious to build up their store of merit, it is quite natural that they strive to tie the merit label to every act possible. Thus, one is impelled to show kindness toward others and render assistance willingly, show compassion toward others and alleviate their suffering, rejoice with those who are fortunate, avoid envy, preserve equilibrium in the face of other adversity or success, and view all without prejudice or preference, thus appreciating that all is subject to karma (Conze 1961, Klausner 1981).

If something happens in an unexpected or unpleasant way, or some serious problems occur in a way in which it is difficult or impossible to find a solution, the Thais just say "*mai pen rai*" (never mind). Thais are able to say "*mai pen rai*" when facing missed appointments and the lack of successful and timely task completion.

Certainly, Thais find more psychological fulfillment in the chase than in the attainment. For a voyage or journey that is fun, the end result is less important. Thus, one should not be too discontented or concerned if one is some minutes or some hours late. It is preferable to fulfill one's work or to live in a funny way. To comprehend this attitude, one must realize that one of the central concepts of Buddhist philosophy is the *law of Nature*, something which naturally exists. Whether Buddha will appear or not, it is a natural, unchanging truth that all compounded things are impermanent, stressful, and not-self. Impermanence (*anicang*) means that compounded things are constantly being born and dying, appearing, and passing away. Stressful (*dukkha*) means that people are constantly being conditioned by conflicting and opposing forces. People are unable to maintain any constancy. Not-self (*anatta*) means that they are not a self or intrinsic entity, they merely follow supporting factors (Payutto 1995). For the villagers, they believe in the concept of the transitory nature of the material world in which they live and the uncertainty and impermanence of all. Thus, one must realize the futility of worrying about material things or events. Therefore, each provisional situation is considered as a pathway to another provisional one. This will continue successively without ending. Only the enlightenment (*nirvana*) can terminate this cycle of life. But the villagers consider the enlightenment as far beyond their reach, so they are content to attach themselves to life while trying to reduce any stressful suffering by detachment as much as possible from the impermanent nature of the material world.

Confrontation avoidance: social harmony. The Buddhist religion emphasizes the positive virtue of avoiding the extremes of the emotional spectrum. In doing so, Thais believe in performing some meritorious acts. Theoretically, this applies to socially acceptable emotions such as love and friendship as well as socially disruptive emotions such as anger, hatred, and annoyance. Although overt expression of socially accepted emotions is less curbed, it is nevertheless kept well in hand, at least in terms of observable behavior. One endeavors to keep personal relationships and social interactions at a superficial, pleasant, and emotionally neutral level to preserve an aura of emotional contentment. One must not become too emotionally involved, entangled, or engaged, for too deep involvement and attachment can only lead to disappointment and suffering. As happiness translates into tranquillity and peace, to live in a proper and meritorious manner, one should, at the very least, curb the expression of one's antisocial feelings. The fact that villagers live in close and intimate physical and social contact accentuates the need for such behavior. In such an interdependent society in which mutual aid and cooperation are strongly required, overt social confrontation would make it difficult to carry out cooperative activities. Villagers mask their antisocial emotion well and preserve the facade of harmony. A complex of forces within the community is directed at maintaining the set of harmonious human relationships (Klausner 1981).

Even if there is a very strong emphasis in village social life on harmonious human relationships with one's fellow villagers and a concomitant avoidance of overt acts that express anger, displeasure, criticism, and the like, disruptive behavior sometimes does occur. To make others aware of one's anger and discontent, one always uses anonymous ways, for example, by intermediate persons, by folk plays, by folk tales, or even by supernatural beings.

Ceremonies, festivals, and folklore: social control and safety valve

Though the Thais avoid overt conflict, they often harbor this conflict. Since the direct display of antisocial feelings is not allowed, Thais have an infinite variety of ways of revealing them in a subtle, devious, and indirect fashion. For example, while preserving a smiling, friendly manner toward the object of one's anger, annoyance, and disagreement, one may practice various options such as poker-faced sarcasm, avoiding contact if possible, and cooperating superficially but using the fine edge of continual postponement or imaginary roadblocks to avoid the reality of assistance. The indirect expression of one's feelings is exemplified in a social procedure called, in Thai, *prachot* or "projected vilification" (Klausner 1981). The individual who has been hurt in some manner does not express his or her displeasure directly but turns it toward another object. A lady will often reprimand a child, whereas, in actuality, her words are meant to apply to another adult. The other adult is aware that the displeasure shown is directed against him or her. *Prachot* often occurs with animals used as a direct method of expressing antisocial emotions. In this case, one will slap a dog and speak angrily to it, but the words are usually directed at another person who, in return, will punish his or her cat and reprimand it with the same words and tone. It's not only emotionally satisfying to play this game, but one is able to preserve an outward semblance of friendly social relationships. People hope that the one who has offended and caused displeasure will receive the message of social warning and mend his or her ways.

Words of rebuke, criticism, and annoyance directed toward others are pronounced only in the confines of the family, or, if these words are expressed openly, they are masked in the form of folk songs or folk tales. The villagers feel free and secure to conceal their thoughts under unrealistic situations. In folk songs, bard singers criticized the ruling class by chanting about the miserable life of peasants who had to work hard to earn money to pay income tax, or of villagers who had to pay tax for collecting vegetables in the village's pond (Wongthet 1975). Folk tales, a rich heritage of folk culture, have provided the rural masses with a socially acceptable psychological release mechanism for their repressed antagonisms, frustrations, and anxieties against authority symbols. *The Siang Miang tales*, known as *Srithanonchai* in the Central region, provide a psychological release for the frustrations and antagonisms of a peasantry subject to the arbitrary power of the ruling aristocracy. Siang Miang, who was born of the peasantry, conquered officialdom through wit, guile, and deceit. Not only did Siang Miang challenge and ridicule authority, he emerged victorious in the battle of wits with the ruling establishment. Most of the time, rulers must rely on the peasants' cunning and genius to solve problems of state. These tales serve to caution the ruling class to appreciate the value of the peasants' practical, common-sense approach to life's problems (Kaewthep 1996). These tales also serve as instructional models of ideal behavior, again enabling the villagers to indirectly caution their elders, mentors, superiors, and rulers not to abuse their authority and to act in a just and moral fashion so as to justify respect and obedience.

If conflicts are unavoidable, an intermediate person such as the abbot, headman, and family head tries to find solutions that are compatible and flexible for every member of the society. It often appears that the villagers consciously use the spirit world as a means of assuring that harmonious social relationships will be maintained.

For example, family members are cautioned to preserve smooth social relationships, because, if they argue, show anger, and cause constant friction, the family spirit will be offended and will bring misfortune to the family. The supernatural world is always used in a manner that removes the responsibility of criticism and punishment from the shoulders of the villagers in instances in which someone is publicly criticized for committing an action detrimental to village security and stability. Such criticism is expressed through the spirit, who is supposedly offended by such antisocial behavior. Thus, the wrongdoer will be responsible for the misfortunes that may befall the village. He will have to correct his behavior and make amends for it to placate the village spirit. The wrongdoer will try to make amends. It will be very difficult for this person to get angry with his fellow villagers, who have only asked him to follow the decision of the spirit doctor. Thus, the animist beliefs and practices preserve, in a variety of ways, the pattern of serene and harmonious social relationships (Sathienkoset 1957).

Traditionally, the yearly cycle of ceremonies and festivals performs a vital function as a stabilizing social force. This is particularly true in the skyrocket festival (Bun Bâng Fai) in the northeast region in which villagers perform the skyrocket ceremony in May. As might be expected at that time of year, these ceremonies involve assuring abundant rains. Since fertility is a basic theme of these festivals, there are sure to be overt sexual overtones to the festivals. These ceremonies are important for the welfare of the village, not only in assuring adequate rainfall but also in connection with the actual health and well-being of the villagers. The villagers believe that, if they do not hold these ceremonies, ill fortune will befall them: there will be a drought and sickness. In these ceremonies, sanction is given to drinking, fighting, and speaking and acting in sexually improper ways. If men in the same village have borne a grudge silently, that grudge may surface and result in an open fight. Sometimes two villagers that have a history of ill feeling engage in a group fight. Such actions would be severely disapproved of during the rest of the year in the context of a culture in which it is mostly a sin to show dislike, discontent, and hatred and, in which one seldom sees people engage in any angry discussion, let alone a fight. These improper actions are accepted and, in fact, are expected and are forgiven during the festival (Wongthet 1975).

The Thai New Year's festivities or *Songkran*, in April, which coincide naturally with the end of the rice harvest, are normally celebrated at the temple compound. On this day, nobody, particularly women, is allowed to work. Before New Year's Day, villagers clean their house and polish an amount of rice sufficient for family consumption during the festivities. In the morning, young people undertake the ceremony of the "ritual bath" for revered monks, elders, and parents. In pouring a few drops of perfumed water on their raised hands, they wish them a happy and long life. Water symbolically purifies the soul, takes away sins, and brings back mutual forgiveness, compassion, and reconciliation to the family or local community. Later, in the afternoon, is a time for a *safety valve*. The ceremonies and festival offer more than just an opportunity for gaining merit and having fun. They also serve as an acceptable channel for giving vent to suppressed feelings and carrying out activities that ordinarily are not sanctioned in the village. Thus, women, who traditionally are not allowed to drink, to enjoy themselves in public, or to talk about sex, take the liberty to do all forbidden acts publicly once a year. This unusual habit is very helpful for keeping them in their place during the rest of the year! Once the social pressure decreases, people return to their normal life with more capability to discuss or overcome problems. These aspects are an integral part of the ceremony and festival pattern of the village. Even if not consciously realized and expressed thusly in any study of village ceremonies and festivals, these social and cultural aspects cannot be neglected.

The Thai way of learning

In the social context that overt criticism of someone is bad manners, Thai learning behavior consists of listening, observing, imitating, and repeating, and gives importance to "experience first, theory after."

Listen, imitate, and repeat. Long ago, only a few knew how to read and information was not attainable by everyone. To get people informed, *Pho Phleng* and *Mae Phleng* (wordsmiths who had skill to improvise poetic songs) were in charge of passing on useful and practical information on special occasions. In southern Thailand, a group of wandering poets came to the villages to announce the end of the year and new events for the following one. The broadcast information was composed of memorized songs called *Phleng Bork*. Villagers became informed about when and how to plow their land and sow rice. Rice varieties were selected according to the rainfall conditions of each year. Wandering poets also predicted a good, average, or bad harvest depending on normal rainfall distribution or drought. This information was taken from sacred books belonging to a few elite persons or monks in the community (Patamadit 1983). It is common to notice local bard singers who are capable of reciting hundreds of poems or reproducing new ones without knowing how to read any words. Nevertheless, the words used in these poems are surprisingly smart, witty, and sensible. These singers enjoy a certain prestige because of their knowledge and their genius as professional wordsmiths. Their knowledge includes both current events and religious lore, philosophy, local history, and customs.

Folk tales are also the source of popular wisdom. Folk tales teach and caution proper respect and reverence for one's parents, superiors, and elders. Often, the spirit world will be called upon to attest to the validity of such cultural imperatives. Clear explanations of the cause and anticipation of the effect are strongly emphasised in folk culture's transmission. It is clearly indicated that, to maintain harmony in society, all people have to do their best to meet the obligations of their social class. Doubt, questioning, and discussion are considered as a lack of respect toward elders. Therefore, misfortune could befall the one who manifests his or her ill respect. Sometimes, the sin is so serious that all the community receives punishment. Whenever there is drought, flood, or famine, these events are believed to be the effect of an immoral governor who does not govern the country with good dhamma, transparency, and justice, or of laymen who do not well respect Buddhist precepts or violate certain laws of the community.

If one persists in acting uncommonly or disobediently, society will restrict that individual by condemning that person as a fool or haunted by bad spirits; therefore, he or she has no right to stay in the community. Two solutions could be found: chase away the bad spirits by using supernatural power or exile that person. Normally, after receiving a series of traditional curative treatments (beating, threatening), the haunting spirits are supposed to be frightened and obliged to leave the body. The person is cured and becomes normal and regains the right to stay in the community. Social excommunication is the final sanction used in the case of persistent behavior. Many examples are seen in the north and northeast region (Kanjanaphant 1984).

Experiences. Exile is used not only as a way to eliminate social rebellion, it is also the crucial step in life that permits young men to grow up. But does growing up mean that one has to revolt and be exiled before returning to normal life? This way of thought is in contradiction to the concept of avoiding overt social conflict in Thai culture. Folk tales can reveal this contradictory aspect. In studying folk tales, we can illustrate the predominant themes existing in the stories as follows: the hero has to leave his birthplace for an adventurous journey to gain experiences and supernatural power, then return to his original place to impose his authority. Adventure, experience, and discovery seem to be the central interest of the audience.

Adventure is considered as the best education for life. The experiences that the hero gains are real and more important than knowledge acquired by listening to others. Departing for an adventure means that the hero has to face unexpected problems. Uncertainty is unavoidable in life. The capacity to react to uncertain and unpredictable events in a successful manner is more important than theoretical well-planned work. The famous Thai proverb "(Listening to) ten mouths does not equal what is seen with one's own eyes" confirms this idea. In rural society where oral tradition is still the most efficient way to popularize information, knowledge does not come from textbooks or theoretical discussions. Laymen acquire their knowledge by doing and experiencing. The villagers learn by participating in the activities that elders undertake. First, they observe, select, and reproduce by imitating the activities that serve them best. Later, they add new techniques or new elements discovered during their repetitive work or picked out from others' way of doing. "Try to see whether it is good or bad" are key words for the layman's learning process. Through this way of learning, elders are the most valuable human resources. Elders acquire knowledge by risky experiences undertaken during their entire life, and only in that way do they become venerable. So, the knowledge transferred by elders is normally more credible than that from the young because elders have spent a longer time testing, selecting, and modifying their knowledge. Young people, though possessing academic knowledge as well as information and news of the world beyond the village border, do not yet enjoy prestige and influence. However, as a youth, one must act properly in relation to one's parents, monks, and elders if one is to be accorded respect when maturity and seniority are finally reached.

Collective information. In the past, for other kinds of news such as political, social, or economic news, whenever villagers got news from any source of information, they did not believe it totally without verifying it. In the northeast, they had a special process for verifying information called *sokan*. First, they gave high credit to the person who broadcast the news. If that person was credible, the news was believable. In rural society, in which social behavior was tightly controlled, villagers recognized highly credible persons. Normally, these were the abbot, senior, and heads of the village or schoolteachers. Villagers came together at the village's temple or school to discuss and analyze the news with these people. The abbot or chief of the village often became a referee or jury in these circumstances. These people first asked everyone to give his or her idea, to present strong and weak points, and then to choose together the best solution. The community considered it each person's responsibility to broadcast and verify news. The most important news always concerned food, for example, the time to catch fish in rivers, collect vegetables, hunt in the forest, or slaughter a buffalo or a cow, so that village members could participate in the activities in time. If some people got the news and kept it for themselves, the community punished them by boycotting them: these people were not informed of any news for the next occasions (Sawadiphanit 1991).

Implications and observations from concrete experiments

The analysis presented above points out many features that are important for understanding both individual and social behavior of northeastern Thai stakeholders in general. More precisely, it gives insight into the way stakeholders may perceive the companion modeling approach and act during the collective learning process. In the discussion below, we try to relate the above analysis to the theoretical elements of the companion modeling approach. For this discussion, we also extract some observations from three experiments conducted in 2002 and 2003 in northeast Thailand (see Suphanchaimart et al, this volume). While establishing these relationships, we try to propose some lessons for the use and adaptation of the companion modeling approach.

We divide the discussion into three parts. The first part discusses the individual features and the second part discusses the social influence. The third part discusses the uses of artifacts for collective learning processes.

The individual path

A very important aspect presented earlier is the concept of karma and merits, which is the foundation of autonomous behavior. In addition to this notion of given karma is the role of individual experience in the learning process. Each individual has to gain experience by himself/herself and learning comes from experience. Although learning and experience are essentially individual, observation and imitation of others are also considered in the learning process. The role of theory and discussion is not as important.

These elements correspond with what was observed during the role-games in the villages. The players took part in the action proposed by the role-game in a very individual way. Certainly, in the game, farming is an individual activity that can be done without exchanges. However, few discussions on crop choices occurred during the experiences. Imitation processes may have occurred during the role-games. For example, during the games, some farmers introduced farm ponds in their fields. During the following steps, other farmers gradually introduced ponds on their farm, but there was no discussion about that (at least visible discussion). During the games, farmers experienced original land uses. In one game, one farmer used his plots for fishponds. Another farmer split his land in two to have orchards on the upper land and rice in the lowland. These experiences were certainly observed by the other players, but not discussed. This is consistent with the notion of individual autonomy, whose foundations are presented above.

Because of this autonomy and the emphasis on the individual path, there seems to be less room for what Jager (2000) calls social comparison in the individual decision-making process. Social comparison means that a player will quantitatively and socially compare his/her conditions with another stakeholders' conditions. The observations made during the experiences confirm this. We did not observe farmers' decisions based on discussed quantitative comparison. This can be observed also during the other steps of the companion modeling approach. First, it is almost impossible to have group discussions on the behavior of such or such a player (we will come back to that point in the next section on social control). Second, during the individual interviews, even if one player knows what the other players did during the game and can restate it, he/she will not easily comment on behaviors, reasons, and differences.

Thus, the role-game method that is used as a step of the companion modeling approach seems to correspond well with the individual learning process at stake in northeast Thailand. This leads us also to think that the individual process of social comparison is very difficult to investigate. Companion modeling seems to be a relevant approach but the first experiments do not show its efficiency for that purpose.

Social structure and social control

The second important aspect discussed earlier is social control. The structure of Thai society appears clearly during the experiments. There are different classes of stakeholders: farmers, traders, administrators, researchers. Mixing people from these different classes in a common role-playing game is something very challenging that needs to offset some perceptions of the society. The first challenge is to invite together stakeholders from different social statuses. A role-playing game corresponds to an arena of social confrontation where people will be forced to interact, as in reality. If there are no interactions in reality, no interactions occur during the role-playing game. This is what happened during the experiments. Invited stakeholders coming from upper organizational levels did not participate at all in the role-game but delivered a discourse after the experiment. What makes these tensions acceptable is the fact that the game is *sanuk* (fun). Some transgressions of the social structure are possible during the role-game. This will be discussed in the next section.

Among members of the same social classes, social control is also very strong because of the social harmony principle. One should not express an opinion on differences in results with other actors. One of the companion modeling principles is that this modeling should help in collective discussion. In other cultural contexts, collective debriefing of role-games is very important: players explain the reasons for their choices, which helps in the common understanding. During the role-games, we never succeeded in having the collective discussions. Stakeholders cannot collectively justify their own actions (which may show too much self-esteem) or comment on others' actions (underestimation of the others). Stakeholders cannot express any comment that could be interpreted as a competition. For that aspect, the companion modeling approach is not suitable. However, surprisingly, the computer multi-agent systems (MAS) model can be helpful for this aspect. During the experiments, we realized that we had good discussions when we presented the simulations as "actions of other players." Then, the stakeholders were active in commenting on the observed actions. For instance, surprised by actions observed at the interface of the model, they said, "these players are not Lao," which relates the players' actions to their culture.

The last point discussed here is the importance of the social network. As stated earlier, social harmony is based on the stability of the social network. Several observations during the role-games confirm this conclusion. We give here two examples observed during the role-games. In September 2002, an important trader was invited to play with the farmers. When the game took place, we realized that the middleman who usually acts as an intermediate between the farmers and the trader was playing the same role in the game, and that the selected players were actually members selling sugarcane to this trader in reality through the quota leader. This allowed the trader to stay relatively apart from the farmers during the game, but to control the sugarcane exchanges. The second observation occurred during a game in April 2003. We realized that the players acting as middlemen between the factory and the farmers and who were supposed to compete for sugarcane were in fact exchanging sugarcane among themselves in a complex and not economically rational way. When interviewed about that fact, the players explained their kinship relationships and expressed the need for sharing the resources among the stakeholders. Thus, the earlier analysis and observations during experiments converge to emphasize the very important role of social structure. The maintenance of the social structure is a very important objective of the players, and it is a means for performing the actions proposed by the game. The consequence for the companion modeling is that the organizers have to analyze the social structure of the group they will play with, and strengthen markedly the ability to observe and analyze the interactions among stakeholders during the game.

Tools for mediation

The companion modeling approach proposes the use of two kinds of artifacts, role-playing games and computer simulations, to mediate the discussion and enhance the collective learning process. How do stakeholders perceive these artifacts? How relevant is this idea of tools for mediation in collective learning processes?

The first point we discuss in this section is the difference between reality and artifacts. It appears from the observations during the experiments and from the interviews the day after that it is very difficult for players to differentiate reality and role-playing games. The participants play in the game like they act in reality. The game imposes some constraints that they do not have to face in reality and, conversely, the game does not reproduce the full complexity of reality. However, during the individual interviews after the game, we noticed that the players did not understand well why we asked two times what is their decision-making process, in reality and in the game. The differences that can be discussed are the differences brought about by the structure of the game and not by the decision-making process. This commitment in the game is observed in all the countries where we played role-playing games. But it seems to us that in northeastern Thailand this assimilation between virtuality and reality is much stronger. This may be related to the *anicang* (impermanence) concept of Buddhist philosophy. Life itself is one experience among others, one scenario among others. The role-playing game proposes another kind of virtuality and the gap between the role-playing game and reality may be less important than in other cultures.

This has consequences for the second point: What is the possible use of the companion modeling approach? Players act in a way similar to how they act in their reality. The realism is individual but also collective. As discussed, players bring into the game their individual decision-making process and their social structure and their social control system. Thus, it is difficult to use the game as a virtual world in which new rules could be discussed. We have seen in other contexts (Gurung et al, this volume) that during the games interactions occur that are almost impossible in reality because the game offers a virtual world offering some freedom, especially social freedom. Earlier, we saw how Thai culture offers some room for the expression of feelings. First is the *prachot* procedure (the role of the intermediary). Second is the role of festivals, which can be used for the transgression of social rules. This happened one time during the experiments in the village. One farmer, a lady, expressed in a very funny way her dissatisfaction with the "big trader." She did it in a very theatrical way to show with her body language that it was for fun. Everybody laughed, but of course there were no consequences or at least no discussed consequences. This corresponded more to a process of reduction of pressure, as explained earlier, rather than a commitment in a collective discussion to possible changes. Thus, one could expect the role-playing games to be used as an intermediate, or a mediator, to express feelings and create a new world in which discussions could be possible. This does not happen and seems to be very difficult because the game and reality are too closely related. Thus, the collective learning process is also socially controlled. For that aspect, during our experiments, we did not take into account the *sokan* (process of verifying information) principle, as explained earlier. The experiments took place at the Tambon Administrative Organization, which is a relatively new organization in charge of the local management of resources. This organization did not play any role or express any interest in the process. Thus, before organizing companion modeling experiments, one should try to understand who the reference persons and institutions are for the collective learning process. Again, this emphasizes the need to understand the social system with which we interact.

The last point that we discuss here is the concept of scenario. The companion modeling approach stipulates that the players should collectively propose scenarios of change, which may happen or which they would like to test. But, during the three experiments we carried out, this did not happen. When requested for scenarios to simulate, in the game or in the model, the players were unable to propose anything. This can be partly related to the social control discussed above, which does not favor the expression of ideas on what the system could or should be. But this was not successful also during the individual interviews. One can relate this again to the karma and the *anicang* (impermanence) concept, that actual existence and its events are due to past actions, the uncertainty and impermanence of everything, and the importance given to the journey rather than the achievement. The expression of a theoretical scenario is thus very difficult to achieve. However, this reinforces the importance of the role-playing game. Players do not propose scenarios, but they act out scenarios. During the experiments, we could observe innovations in the introduction of new crops, farm ponds, a new allocation of land, new activities such as fisheries or integrated farming, and new systems of exchange. Players also react well to scenarios imposed by the organizers such as changes in the prices of commodities. They do not comment but they adapt their behavior.

As a brief conclusion to this section, we realize that the distinction between the game and reality is very fuzzy, that the companion modeling approach facilitates the collective learning process through experience and observation (among players themselves and between organizers and players), and that one should not expect much collective discussion. With the kind of realistic games proposed, virtuality cannot be used by the players to step back and collectively discuss reality.

Conclusions

Our conclusions are drawn from our better understanding of some Thai cultural aspects that concern the learning process and the relationships with virtual reality, and from the first experiences we had while applying the companion modeling approach. As this is the first analysis, we cannot be very firm in our conclusions but rather can give some indications.

- The tools proposed by the companion modeling approach are suitable to the Thai cultural background because this method is based on tools that use experiences and games. Experience with and observation of others are the main driving forces of the collective learning process. Thai learning behavior gives importance to "*experience first, theory after*." Thais learn by listening, observing, memorizing, experiencing, imitating, and repeating. Furthermore, the fun aspect (*sanuk*) is of great importance in the learning process.
- The collective discussions that are supposed to emerge from the use of these tools in the framework of the companion modeling approach do not really occur. This is due, on the one hand, to a convergent effect of individualism, strong social structure, and a fundamental culture of conflict avoidance, and, on the other hand, to the great difficulty in distinguishing reality from virtuality and theorizing scenarios.

Although these first indications should be confirmed by new experiments, scientific discussions, and more theoretical investigations in social sciences (on the concept of scenarios, for instance), preliminary recommendations can be derived from this work. The first is the importance of the social organization. One should have a good knowledge of the social organization before playing the game. Emphasis should also be given to the observation of social interactions during the game. This task requires the involvement of well-trained social scientists. The second recommendation is to emphasize experience, both individual and collective. Culturally, people learn individually and collectively by experience and observation. Involvement in role-playing games and the interactive use of simulations correspond to that behavior. It is also through games that people express scenarios and adaptations to external constraints. This guides us to adapt the companion modeling approach so that it will emphasize role-playing games, lead to game organizers proposing scenarios of change, and use computer simulations more interactively.

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Notes

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Training on multi-agent systems, social sciences, and integrated natural resource management: lessons from an Inter-University Project in Thailand

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In this new century, there is an urgent need to integrate and organize knowledge into suitable frameworks to examine essential problems with the people involved in solving them. Recent advances in computer science, particularly distributed artificial intelligence and multi-agent systems (MAS), are creating a strong interest in using this new knowledge and technologies for various applications to better deal with the increasing complexity of our fast-changing world, particularly for studying interactions between societies and their environment. By emphasizing the importance of interactions and points of view, the MAS way of thinking can facilitate high-level interdisciplinary training and collaborative research among scientists working in ecology and social sciences to examine complex problems in the field of integrated natural resource management (INRM).

This paper describes how a recent project based on a series of short courses in the field of MAS, social sciences, and INRM at three different universities in Thailand tried to transfer European expertise and research results to an Asian audience of graduate and postgraduate students and young researchers interested in innovative and action-research–oriented interdisciplinary approaches. The course structure, organization, and contents are described and assessed. The course participants are characterized and their opinions are used to evaluate the strengths and weaknesses of this very interdisciplinary training program.

The first sustainable outputs and key preliminary lessons learned from this innovative collective learning experience are presented. In conclusion, the authors suggest ways to support the emergence of a regional network of "MAS for INRM" practitioners in Southeast Asia to build on the dynamics begun by this project and serve the need for such interdisciplinary training across Southeast Asia.

In this new century, knowledge management faces two major challenges. The first one deals with the adequacy between globalization and fragmented knowledge among disciplines on the one hand and multidimensional realities requiring transdisciplinary approaches on the other hand. The second challenge is the continuous and accelerated improvement of knowledge in many fields, which is making knowledge organization more and more difficult to achieve but also more and more crucial for students and educators. There is therefore an urgent need to integrate knowledge across scientific disciplines, as well as with other sources of information, into suitable frameworks to examine essential problems with the people involved in solving them. Nowadays, it is necessary to give equal importance to stakeholders' opinions, traditional representations, and science-based information. Principles to organize knowledge to face the challenge of complexity, uncertainty, and fast changes are required. Edgar Morin (1999), who spent many years studying complexity issues, considers that training students to establish linkages among knowledge from different disciplines and sources is of paramount importance for the next generations.

In the field of renewable natural resource management, adaptive management is required to deal with complex and unpredictable situations (Holling 1978, Lynam et al 2002). The functional integrity of the ecosystem can increase in parallel with the adaptive capacity of resource managers. Particularly, this can be achieved through a better coordination among these managers and a greater collective ability to recognize and agree upon points of intervention to improve the sustainability of resource management (Ostrom et al 1994).

At the same time, modeling is increasingly seen as a suitable approach for examining complex resource management problems. In this field, it is now widely accepted that modeling should proceed iteratively, by successive approximations, usually from simple to more complex representations of the system dynamics. Far from being the work of scientists in ivory towers, these iterative, applied, and action-research–oriented modeling activities should be implemented in close interaction with field work and stakeholders looking for solutions to the real-world problem under study. Stakeholders should play an important role in the construction and the validation of such models. Later on, they should be able to use them with scientists to explore the effects of different options and scenarios of resource use to negotiate and reach a compromise on suitable rules and action plans to be implemented collectively. We call the "companion modeling" approach (Bousquet et al 1999) such a collective learning process for INRM. While it is usually easier to find scientists in the fields of agroecology and biology to analyze a specific resource management problem from their point of view, there is still a need for capacity building in the "softer" field of social sciences to examine such problems with "hard" scientists, and for training both types to collaborate in a truly interdisciplinary and innovative "third" way (Röling 1999).

Recent advances in computer science, particularly in the fields of distributed artificial intelligence (DAI), agent-based modeling (ABM), and multi-agent systems (MAS), have created a strong interest in using such innovative technologies to examine complex issues and better deal with the increasing complexity of the real world. MAS are computational systems relying on the technology of cellular automata, in which various autonomous agents interact in a given environment. They are based on the principles of distribution, interaction, and control (Ferber 1999). More information on MAS can be found in the introductory chapter of this volume by Bousquet and Trébuil. Recently, significant progress has been made in simulating societies in interaction with their environment (Gilbert and Troitzsch 1999, Jager 2000, Moss 2002) and innovative approaches such as MAS can create artificial societies (Weiss 1999).

MAS simulations are being increasingly used to deal with ecological and socioeconomic issues arising from the management of scarce resources by multiple users (Janssen 2002, Bousquet and Le Page 2004). When this approach is applied to INRM problems, such as when modeling situations of conflict among 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.

The MAS way of thinking emphasizes interactions and diversity of points of view for analyzing interactions between societies and their environment. It could facilitate the design of high-level interdisciplinary training and research among ecologists and social scientists working in renewable natural resource management and on INRM problems. Many case studies examining concrete resource management problems have recently started in several Southeast Asian countries and a sample of them are presented in the contributed chapters of the present volume.

Today, these problems at the interface between the environment and society are frequent in the fast-growing economies of several Asian countries, particularly in situations where limited, or even shrinking, natural resources are exploited for multiple uses by competing users. Many examples in forest, water, and biodiversity management, etc., are regularly making the headlines of local newspapers. At the same time, there is a trend toward the decentralization of natural resource management. For example, in Thailand, Tambon (subdistrict) Administrative Organizations (TAO) have been installed across the country under the new "people" charter approved in 1997 and are managing an increasing share of the public budget. It is therefore urgent to train a new generation of natural resource managers equipped with approaches, concepts, methods, and tools to face the increasing complexity and uncertainties of situations at the grass-roots level. They should be able to organize and interconnect knowledge from various sources to rapidly manage changing ecological and socioeconomic environments and avoid the occurrence of acute resource management conflicts.

To contribute toward such a goal and as MAS for resource management are still little known in Southeast Asia, in October 2001, we implemented a training project composed of a series of eleven short courses on MAS, social sciences, and INRM that were organized in rotation at three public universities in Thailand: Chulalongkorn, Chiang Mai, and Khon Kaen universities. It was financially supported by a grant from the Asia IT&C initiative of the European Commission, the French Cooperation, the International Rice Research Institute (IRRI), and the Centre de cooperation internationale en recherche agronomique pour le développement (CIRAD).

Objectives

This article describes how this interdisciplinary training project was designed and implemented to transfer European expertise and research results in the field of MAS, social sciences, and INRM to an Asian audience composed of mainly graduate and postgraduate students or young researchers interested in interdisciplinary approaches to research in the field of renewable natural resource management.

Following a presentation of the course structure, organization, and contents, the way the project is improving knowledge and technology cross-flow and the management of interdisciplinarity is assessed. An analysis of the participants and collaborative institutions is made. Their inputs helped to evaluate the strengths and weaknesses of the program design and mode of implementation. Its effects on the extent of partnerships in this fast-developing scientific field are also described. The presentation of the first sustainable outputs of this project and useful lessons learned to facilitate the implementation of similar training activities in Southeast Asia in the future are also dealt with. Finally, several perspectives and prospects for reinforcing the momentum created by these training activities are suggested.

Materials and methods

Sources of information

The information analyzed in this article comes from various sources and materials. The initial project document (Bousquet 2001) was used to present the design and organization of the course. A series of successive training reports produced after each successive short course was used to analyze the participation and to monitor trainees' progress. The project database on trainees and their institutions provided information to prepare several figures illustrating this paper. The series of course evaluations by the participants carried out upon completing each of the 11 training sessions held from October 2001 to April 2004 was the main source of information to analyze trainees' needs, the relevance of the concepts and topics presented by the instructors, and the strengths and weaknesses of these short courses. Individual interviews with six core trainees who attended at least six courses were also conducted during the preparation of this article. The topics discussed during these interviews were as follows: efficiency of the transfer of knowledge and know-how, assessment of the organization and management of the courses and suggestions for improvements, management of interdisciplinarity, emergence of sustainable outputs and impact of these courses, and new partnership mechanisms emerging from the project activities.

The following indicators were monitored to assess the transfer of knowledge and know-how during the training process: evolution of the participation (number and educational background of trainees and collaborative institutions), number of trainees' own applications being developed, number of trainees' M.Sc. and Ph.D. research proposals and theses integrating the MAS approach, number of complementary MAS training courses taken overseas, and number of university courses including presentations of MAS for the INRM approach.

Course structure and organization

Figure 1 displays the general structure of this interdisciplinary training process, which took advantage of the respective expertise available at the three collaborating Thai public universities to organize each of the successive short courses.

Apart from the 2-week introductory course on MAS for social sciences and INRM, all the following ones were 1-week training sessions. A different instructor led each course. These instructors are specialized in diverse but complementary fields and are all recognized as leaders in their respective scientific areas. Almost all of them are members of a European community of scientists working on social simulations. Table 1 shows the scheduling, location, main themes, and key concepts introduced during the 11 successive short courses offered under this project.

Different combinations of teaching methods and tools were used during each course. Generally, on each day, two 90-minute lectures alternate with presentations of case studies, group exercises, hands-on exercises, or personal work. A large quantity of

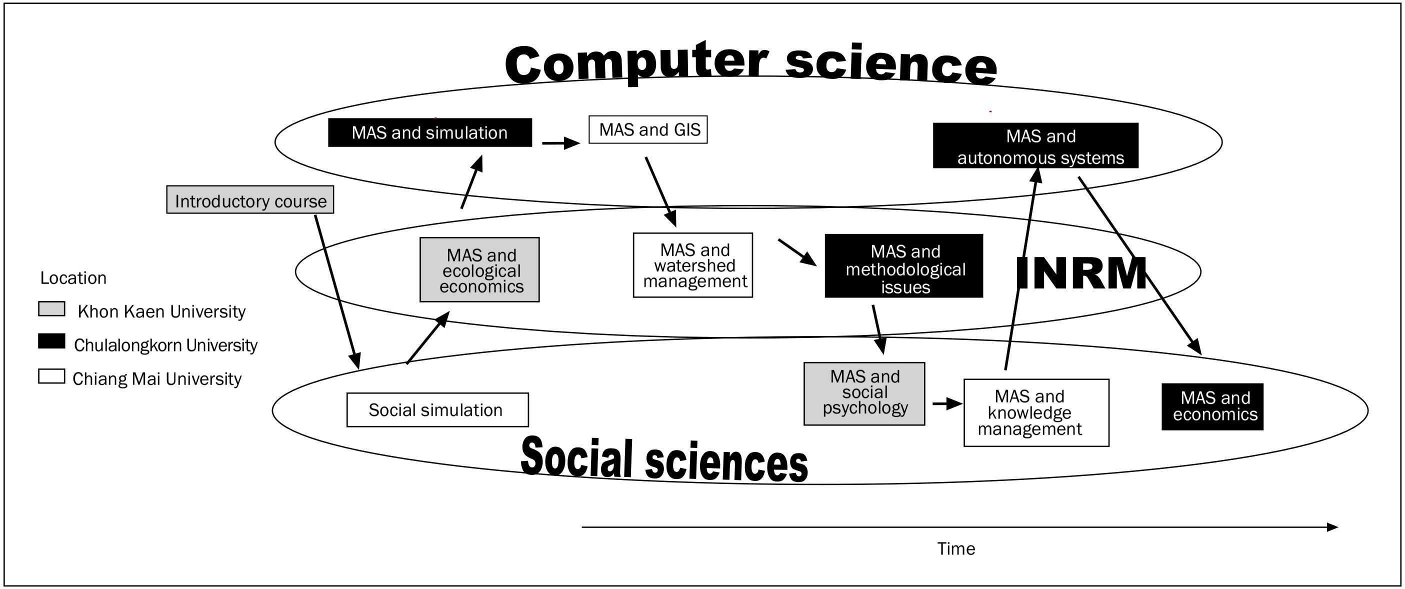

Fig. 1. General structure of the interdisciplinary training course on multi-agent systems, social sciences, and integrated natural resource management in Thailand.

visuals were used as most of the sessions rely on video projections. At the beginning of each course, all the slides used by the instructors, a series of key reference papers for further reading, a CD with these files, and the software used during the course as well as the computer exercises were provided to the trainees.

Networking, exchanges, and group dynamics were sustained by the subscription of each trainee to a global electronic discussion list (with a Q&A service) linked to a Web site specifically designed for MAS users in INRM (http://cormas.cirad.fr). On this site, trainees could find more information (reference papers and tutorials, completed case studies, new versions of software, opportunities for further training, etc.) and particularly a library of already developed MAS models providing more inspiration.

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Following the main introductory course, the successive course instructors presented different disciplinary points of view, key concepts, and experiences on the use of MAS in social sciences and INRM (Table 1). Because several new concepts were introduced during each course and all the sessions were conducted in English, the contents were rather difficult to follow for some participants. The use of MAS simulations by all instructors established a link between sessions.

The teaching and use of the CORMAS (common-pool resources and multi-agent systems) simulation platform in most of the courses is another important linkage. Provided free to all participants, this simulation platform is the key reference computerized tool used in this program (Bousquet et al 1998, see also the contributed chapter on CORMAS by Le Page and Bommel in this volume). Vensim, NetLogo, and SDML (Strictly Declarative Modelling Language) were other software packages also introduced during these short courses.

As soon as this project began, the participants were encouraged to conceive, design, and gradually build a personal application on a concrete problem related to their academic interest or professional activity. In the middle of the week, time was made available to work on these personal projects through interactions with other trainees and the instructors. The last morning of each training session was frequently allocated to the presentation of several trainees' applications, each one being followed by a collective discussion and comments from the instructors. This was very useful because the quasi-absence of completed case studies in Southeast Asia at the beginning of this program limited the illustration of lectures by examples dealing with local problems in Asian contexts.

Participants and their institutions

Most of the trainees were graduate and postgraduate students, young or more senior university researchers, but also officers from development-oriented government agencies of the Thailand Ministry of Agriculture and Cooperatives (MOAC) who were interested in interdisciplinary and applied approaches to research in the field of participatory resource management. Figures 2 and 3 show that these trainees came from 11 countries and many more institutions. Of the current total of 85 participants, Thailand (47), the Philippines (14), and Vietnam (7) were the main contributors. The presence of a small minority of European trainees in several short courses had a posi-

Table 1. Contents of the Asia IT&C initiative training program on multi-agent systems, social sciences, and integrated natural resource management, Thailand, October 2001-spring 2004.

Step no.	Month /year	Location /univ.[a]	Main theme	Main instructor/ institution	Key concepts introduced
1	Oct. 2001 (2 weeks)	KKU	Introduction to MAS for INRM	Dr. F. Bousquet IRRI-CIRAD, Thailand	Overview of the main concepts
2	Feb. 2002	CMU	MAS & social simulation	Prof. N. Gilbert University of Surrey, UK	Simulation in social sciences, emergence
3	Apr. 2002	KKU	MAS & ecological economics	Dr. M. Janssen Vrije Universiteit, NL	Resilience, models in ecology & economics
4	Apr. 2002	CU	MAS & computer sciences	Prof. A. Drogoul Paris VI University, FR	Agents in computer science, distribution
5	Oct. 2002	CMU	MAS & geographic information systems (GIS)	Dr. S.P. Kam, IRRI, PHIL Dr. C. Le Page, CIRAD, FR	Spatial dynamics, scaling issues
6	Oct. 2002	CMU	MAS & integrated watershed management	Dr. O. Barreteau Cemagref, Montpellier, FR	Integrated modeling, companion modeling
7	Mar. 2003	CU	MAS & the environment: methodological issues	Prof. S. Moss Manchester Metro. Univ., UK	Validation of models, abstraction
8	Apr. 2003	KKU	MAS & social psychology	Dr. W. Jager University of Groningen, NL	Social psychology, decision-making processes of agents
9	Oct. 2003	CMU	MAS & knowledge management	Prof. N. Röling Wageningen University, NL	Tools for participatory decision-making, soft science
10	Mar. 2004	CU	MAS & autonomous systems	Dr. J.P. Muller CIRAD, Montpellier, FR	Autonomy, learning in computer science
11	Apr. 2004	CU	MAS & economics	Dr. A. Kirman, Greqam Aix-Marseille Univ., FR & M. Antona, GREEN CIRAD, FR	Decentralized economics, public policies, & public action

[a]CMU = Chiang Mae University, CU = Chulalongkorn University, KKU = Khon Kaen University.

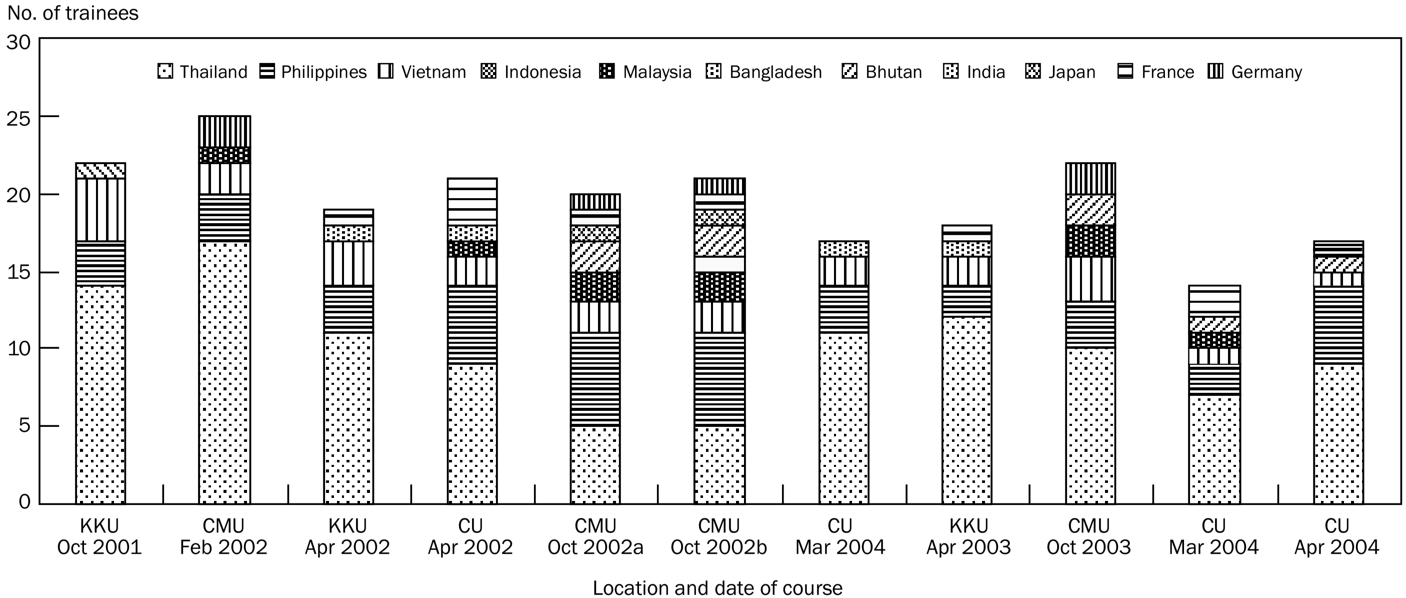

Fig. 2. Number and country of origin of the trainees who took part in the short courses of the interdisciplinary training program. CMU = Chiang Mae University, CU = Chulalongkorn University, KKU = Khon Kaen University.

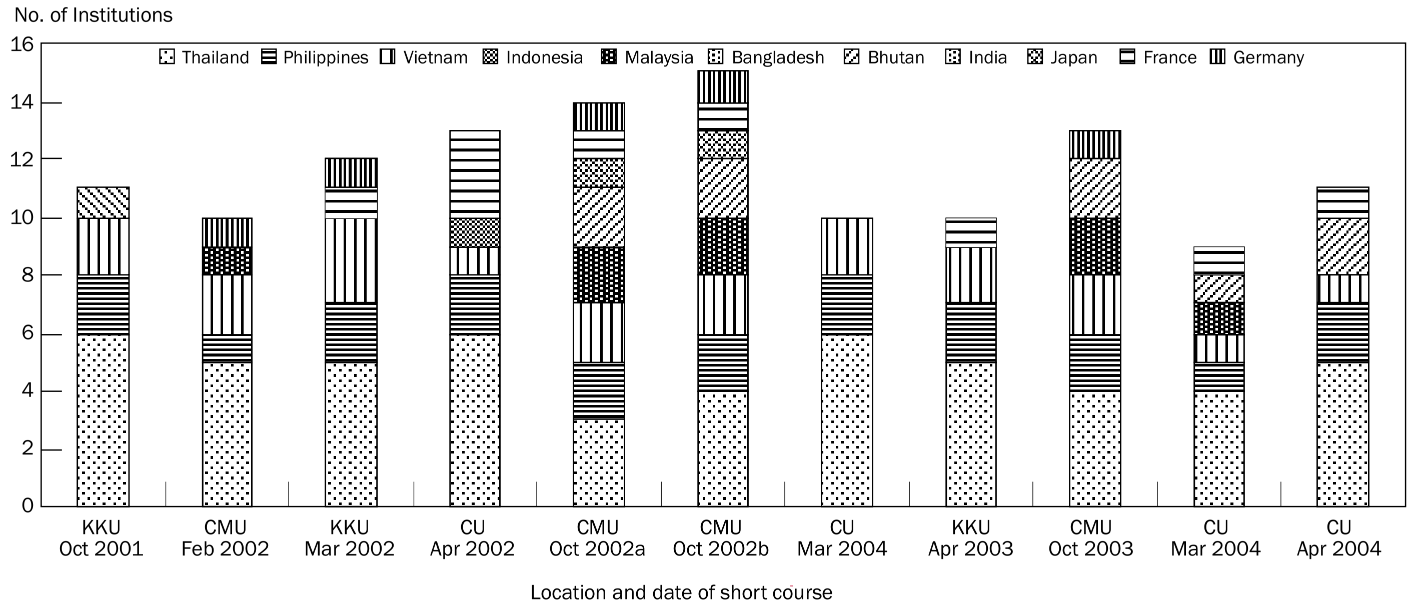

Fig. 3. Number of collaborating institutions by country in the short courses of the interdisciplinary training program. CMU = Chiang Mae University, CU = Chulalongkorn University, KKU = Khon Kaen University.

tive effect on the group dynamics through the sharing of different viewpoints and the establishment of new professional contacts.

Trainees applied electronically to attend a particular short course, but many new ones were colleagues of former participants. No special advertising for these courses was done as the target size of the audience was limited to 16–20 full trainees per session plus several observers. This limited group size was set up to guarantee the quality of the support provided by the trainers, particularly during computerized hands-on exercises on new software or the design and construction of personal case studies.

The heterogeneity among the trainees, in terms of background knowledge about MAS, social sciences, and INRM, was important and tended to increase over time. Figure 4 displays the initial field of specialization of the trainees. This diversity of educational background among the trainees responded to a similar diversity of specialization observed among the main instructors.

At completion of the training process, three types of participants could be distinguished:

- A core group of regular participants who attended most of the short courses and who were also developing personal applications based on their new knowledge.
- Less regular participants who joined only the short courses dealing with themes of their interest; most of them were not involved in building their own applications.
- Observers who just wanted to familiarize themselves with MAS and attended one or several courses depending on their main themes.

Table 2 shows the changing sizes of these subgroups during the training process depending on the specific theme of each short course. In general, each course was attended by around 10 to 12 core participants, 6 or 7 less regular participants, and 2 or 3 observers. The management of such heterogeneous groups was a challenge for the trainers.

Results and discussion

Strengths and weaknesses of the training process

The following analysis is based on a review of the course evaluations by the participants. Table 3 shows that the overall course effectiveness assessed by the trainees was very satisfactory.

Organization and structure

Strengths. The diversity of disciplinary backgrounds among the different course instructors, all having the MAS approach and tools in common, could be seen as a “unique opportunity” (as one core trainee put it) to become familiar with MAS and their use in various fields. The organized interactions between trainers and trainees having a chance to interact with specialists about their own personal projects also received high marks. The choice of presenting a whole research approach and process during a five-day short course was also appreciated. Participants had time to discuss

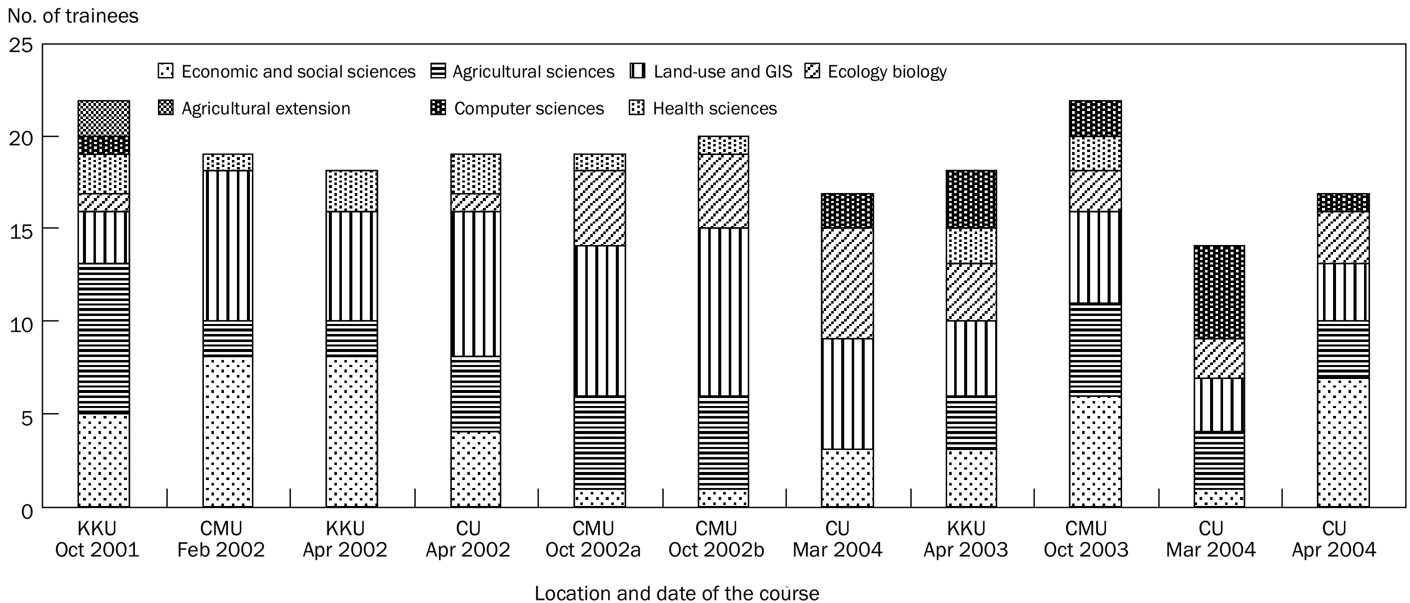

Fig. 4. Academic background of the trainees who took part in the short courses of the interdisciplinary training program. CMU = Chiang Mae University, CU = Chulalongkorn University, KKU = Khon Kaen University.

difficult topics and to integrate relevant new knowledge into personal applications that were gradually built between successive courses.

The courses were held between university semesters. Their timing and duration were convenient to most of the trainees, who like this research-oriented training on a university campus providing a suitable atmosphere for the transfer of new knowledge. The networking of many institutions of higher education in the region along the way was also a plus according to many core trainees, and some of them found that the number of partner organizations and participants was still too limited.

Weaknesses. In theory, a better chronological order among the instructors and their respective disciplines could have been imagined to avoid too much "jumping" from one view to the next. Under an externally funded project mode of operation, many logistical constraints interfered and limited the possibility to plan a smoother succession of the themes and topics to be covered during the whole training process. But some trainees looked for ways to engage trainers further in the collaborative process.

The management of heterogeneous groups needed improvements as, in the beginning of the training process, few specific activities were available for newcomers who did not plan to build personal applications. During group exercises, techniques like the so-called "snowball" discussions (two trainees analyze a question, then they pool their findings with those of another couple of trainees, and so on, to produce a unified view and answer) were emphasized to help them catch up with the core group.

This short-course model was not very adapted to the construction of a full case study from A to Z to describe the problem, identify the relevant theory and concepts, make methodological choices, and continue with detailed stepwise procedures for model development. Such a process was requested by several core trainees and is being implemented with them under separate specific projects. The short course format did not allow enough time for computer exercises. Following a few courses, several trainees found that more real-world activities were desirable. Role-playing games (a tool frequently associated with MAS models in companion modeling) were inserted in the program of the following sessions, with one with villagers in Khon Kaen Province during the April 2003 course.

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Strengths. The fact that these short courses covered diverse themes and issues in MAS for INRM, from various disciplinary points of view, and were led by instructors who are leaders in their fields were seen as key strengths of this training project. Core trainees also found a suitable balance between theoretical/abstract and applied/practical contents to understand the subject matter and to be able to apply this new knowledge. The construction of a collection of models providing numerous examples and case studies ("I always need an example" said a trainee) was also assessed as an appropriate choice. Core trainees also liked the possibility to combine different tools in the development of their applications. Attempts at bridging the gap between computer scientists and other specialists by using simple tools to stimulate the collective construction of new models were also well received. In particular, the usefulness of the diagrammatic representations (class, activity, and sequential diagrams) of the unified modeling language (UML) for such a purpose was confirmed.

Table 2. Composition of the audience during the short courses of the interdisciplinary training program.

Numbers	Location and date									
	KKU Oct 2002	CMU Feb 2002	KKU Mar 2002	CU Apr 2002	CMU Oct 2002[a]	CU Mar 2003	KKU Apr 2003	CMU Oct 2003	CU Mar 2004	CU Apr 2004
No. of core trainees	10	14	14	12	10	7	7	11	10	11
No. of new trainees	12	7	4	7	10	10	11	10	3	3
No. of observers	5	4	1	2	5	0	2	1	1	3

[a]CMU = Chiang Mae University, CU = Chulalongkorn University, KKU = Khon Kaen University.

Table 3. Average scores and standard deviation of the overall course effectiveness for the successive training sessions of the interdisciplinary training program according to the trainees. Rating scale: 1= poor, 5= excellent.

Item	Location and date									
	KKU Oct 2002	CMU Feb 2002	KKU Mar 2002	CU Apr 2002	CMU Oct 2002[a]	CU Mar 2003	KKU Apr 2003	CMU Oct 2003	CU Mar 2004	CU Apr 2004
Mean score	4.36	4.50	4.10	4.50	4.67	4.21	4.33	na	4.64	4.50
Standard deviation	1.03	0.50	0.29	0.50	0.47	0.41	0.60	na	0.48	0.63

[a]CMU = Chiang Mae University, CU = Chulalongkorn University, KKU = Khon Kaen University.

Weaknesses. Because there were several weak articulations between the themes of successive courses, the self-updating of the global picture by the trainees themselves was a difficult exercise. In the later courses, more support and time for critical discussions on the contents of the course were provided to help the trainees achieve such a continuous reconstruction by integrating the new knowledge acquired over the last course in the whole picture. But very few trainees managed to perform such a difficult intellectual process by themselves. Efforts were also made to better manage the language barrier by clarifying all key concepts and specific terminologies in lay language. With time, more Asian applications were made available in the second half of the training process to provide an easier understanding of case studies by the participants. At that time, some of the most advanced trainees were also requesting the introduction of other ways to represent and formalize knowledge in MAS in the remaining short courses.

Knowledge transfer: assessment of trainees' cumulative improvements

When asked if they observed cumulative improvements in their knowledge and skills related to these interdisciplinary courses, the core trainees answered "yes," "absolutely yes," "of course," or "yes, very effectively, more or less linear." If some of them found that these improvements are following a linear pattern, others say that a given course (usually the joint courses on watershed management and linking MAS with GIS held at CMU in October 2002) accelerated this process by providing them with a clearer view of several key concepts and a more global perspective of the training process in which they were taking part. They also agreed that such a progress was facilitated by the structure of the training process itself.

The fact that, altogether, 14 applications are currently being developed across five countries (seven in Thailand, two in the Philippines, Vietnam, and Indonesia, and one in Bhutan) to examine concrete INRM issues is also a relevant indicator of the progress made by core trainees. The development of such personal projects seemed to be necessary to guarantee continuity in the effort to improve the trainees' skills in using the approach, methods, and modeling tools introduced to them during the short courses.

Two core trainees have already taken several weeks of complementary training in France on MAS modeling using CORMAS and two more will follow their path in 2005. The MAS approach has also been integrated into the Master of Sciences theses defended by four project trainees from Bangladesh, Bhutan, the Philippines, and Thailand. Seven others from Bangladesh, the Philippines, Thailand, and Vietnam have prepared proposals for doctoral studies in this field and have been accepted at universities in France, Japan, Canada, and Thailand. They are going to invest in this field to deepen the transfer of knowledge and know-how on MAS for INRM as much time is needed to assimilate innovative approaches, methodologies, and tools for sustainable impact.

Several participants have already used MAS and shown their first applications in conference presentations. Other core trainees are already teaching MAS for INRM modules at their respective universities, particularly in Thailand and the Philippines. Trainees are becoming trainers as the contents of these courses are being introduced in graduate study programs at several universities: two short courses and workshops for M.Sc. students were held in 2002 at the University of the Philippines-Diliman campus, a new course on "Simulation with the MAS Approach" is now being offered at Ubon Ratchathani University in northeast Thailand. This approach is also being presented in the new Post-Graduate Training Program in Systems Agriculture of the Faculty of Agriculture of Khon Kaen University and will be taught in the new Master of Science Program in Agricultural Technology and Natural Resource Management at Chulalongkorn University in Bangkok. Consequently, a significant dissemination of the contents of this training process across national institutions of higher education is already under way.

Management of interdisciplinarity

Interdisciplinary exchanges between instructors and trainees occurred permanently during this training project, but also among trainees. They were sustained by the diverse academic profiles and professional experiences (lecturers, researchers) of the European instructors and the selection of the Asian participants. Figure 4 shows that a high level of interdisciplinarity among trainees has been maintained during the whole training process. But the level of representation of the different disciplines has varied over time. Although many trainees coming from the social and economic sciences participated in the first four courses, their number decreased when the themes of the subsequent courses covered the use of GIS and watershed management; then, a partial recovery in their participation occurred during the last two courses focusing on economics and social psychology. While several agricultural scientists attended almost every course, more trainees coming from ecology and biology joined them at the end of the series of short courses. Figure 4 shows that, so far, the most stable group of participants had an academic background in land-use studies and GIS.

In this project, the interdisciplinary exchanges were guided by the existence of a broad common approach to the use of MAS among the trainers. This approach was explained to the trainees at the beginning of the process, but, with many newcomers joining in the subsequent courses, it was necessary to find ways to recall and re-explain it with more details. Several core trainees among the most experienced ones also requested to discuss explicitly the different points of view and possible conflicts between the contents of presentations made by different instructors.

It remained difficult to establish strong linkages among computer scientists, ecologists, and social scientists for them to work on common applications as interdisciplinary teams in their institutions. But the fact that several computer scientists joined in the last courses is encouraging. It is interesting to observe that it is not among the partner institutions that are well known for their early work on systems thinking in agriculture and resource management that we observe the emergence of interdisciplinary teams in MAS for INRM. The difficulty of establishing collaboration among staff from different faculties could partly explain this rather unexpected situation.

The use of simple modeling tools, such as UML diagrams, proved to be effective in stimulating interdisciplinary exchanges of views when conceiving a new model, and before its implementation and coding in a computer language by a specialist. The "snowball" discussion technique also created greater participation and interactions among trainees having different disciplinary backgrounds to produce ideas and come up with a unified view on the subject matter. The organization of the successive courses in different settings, taking advantage of the strong expertise of each institution (GIS at CMU, role-playing games at KKU, ecology and social sciences at CU), also helped to sustain interdisciplinary exchanges. We see trainees becoming more and more interdisciplinary-minded, but we have yet to assess changes in their professional practices at their respective institutions. Nevertheless, some participants would like to see a suitable pathway along which trainees could monitor gradual improvements toward mastering interdisciplinary research.

Extended partnerships

The emergence of a regional network of core MAS for INRM practitioners was observed. Its members, linked by a strong bond and common interest (and friendship), are sustaining the effort thanks to regular "get-together" events during the past short courses. If this young network still needs external support at this stage, several core participants are already realizing that external funding is also a weakness of the current process. Fifteen institutions, particularly from Thailand, Vietnam, and the Philippines, are involved in sharing knowledge and experiences in modeling and simulation, but also differences in their respective social and cultural systems and environments. Their network of contacts, especially in Europe through the course instructors' teams, is already extensive. But it could easily be much broader if the trainees were more active exchanging messages on the global CORMAS electronic discussion list.

Beyond the joint publication of a first set of MAS-based applications in the present volume, core trainees said that more people and institutions will become involved in the undertaking in the years to come as they expect to initiate follow-up MAS-based applications projects among former participants in this project and their respective contacts. They also want to see a stronger Asian network of practitioners disseminating MAS-based modeling approaches applied to INRM and social dynamics.

Some trainees think that they will have the capacity to influence scientists and experts in mission-oriented research and interdisciplinary practices, particularly computer scientists. They think that they will be in positions to influence policy design through MAS simulations. They also want to move toward setting up an Asian Club for Social Simulation and organizing a conference on MAS for INRM in Asia to share and discuss experiences among project participants. Such activities could help widen the influence of their young network by inviting other Asian country representatives, such as from Japan, China, etc.

Conclusions: preliminary sustainable outputs and perspectives

On the basis of this series of 11 courses and numerous case studies being developed across the region, these project activities delivered promising collective learning methods and tools to enhance stakeholders' participation in resource management. Participants discovered a new way of thinking and an innovative approach to interpret their environment and real-world phenomena. They said that they were broadening their knowledge and vision. Now, they understand a new research paradigm for INRM, which is more applied, more "useful," and more action-oriented. This "different way to look at things" is also characterized by an increased awareness of the need to take into account agents' behavior and diversity of viewpoints when designing applications.

We are now witnessing the emergence of a regional network of MAS for INRM practitioners in Southeast Asia who are selecting this field for their masters and doctoral studies. They are also disseminating the message in their respective institutions, developing practical applications on local real-world issues, and are already engaged in the joint publication of their results. They are also discussing ways to structure and reinforce their recent regional network.

Such innovative ways of looking at resource management problems and of thinking about how to alleviate them collectively need to be further introduced in existing graduate study programs at various institutions of higher education to meet the future demand in resource managers at the local level. It is also desirable to study how more young scientists could be exposed to these ideas and methods early in their professional career. In collaboration with Chulalongkorn University, the authors are currently in the process of establishing an international graduate study program in this field in Thailand. It will build on the dynamics created by the training process described in this article and serve the future needs for similar training across Southeast Asia. To avoid some of the weaknesses of the past project, such a new program would have to be more connected to local research support programs and less dependent on external funding. A specific "E-collective learning on companion modeling project" has also been launched recently to build a well-documented site on the Web that will support other types of learning activities such as lectures and training courses, participatory modeling and simulation workshops at different research sites, etc. Beyond training activities, these new projects should have strong research components to continue the adaptation of the companion approach to the Asian context and the development of local case studies examining concrete problems by using state-of-the-art methods and tools in the fast-developing field of MAS for INRM.

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Notes

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A methodology for building agent-based simulations of common-pool resources management: from a conceptual model designed with UML to its implementation in CORMAS

C. Le Page and P. Bommel

Since 1995, our team has been developing a simulation platform called CORMAS (common-pool resources and multi-agent systems). It provides facilities to build and analyze agent-based models (ABMs) that represent ecosystems where various human activities compete for the use of natural resources. Few agent-based simulations can be mathematically proven, but they can be analyzed inductively. It is therefore important that simulations be replicated before they are accepted as correct. To tackle this thorny issue of ABM replication, we believe that, during the design process, a careful representation of the conceptual model is paramount. In this paper, we advocate using UML (unified modeling language), which is a formal language to describe systems using the object-oriented paradigm. An archetypical agroforestry system is presented here, and serves as an example to design a very simple model dealing with common-pool resources management. Different types of UML diagrams are also introduced to describe the static structure of the model, as well as that of the dynamic processes. Adaptation of these diagrams for implementation using the CORMAS platform is detailed. Then, a simple simulation scenario is presented to illustrate how it is done in CORMAS, and a sensitivity analysis on one parameter of the model is conducted.

Common-pool resources (CPR) management involves interactions among stakeholders and groups of stakeholders in using the resources. It is about decision making in space. In the process of decision making, each individual stakeholder tries to achieve a personal goal, and at the same time may also be constrained by some regulations or rules established at a collective level (group or institution). As natural resources are most often heterogeneously distributed, this will influence the actions of several stakeholders on these resources. For instance, each user will determine strategic places according to some specific criteria. But access rules, a key issue in CPR, may prevent the achievement of some activities. Access rules are often related to the spatial characteristics of the environment, such as slope, distance, elevation, adjacency, connectivity, etc. Hence, it is crucial to take into account the spatial aspects of CPR management.

Agent-based models (ABMs) are particularly well suited to represent ecosystems where contrasting human activities compete for the use of natural resources in space. ABMs are based on the principles of multi-agent systems (MAS), a research field in computer science focusing on distributed artificial intelligence. An agent is a virtual entity, a computer component, such as a software (program) or a hardware (robot), that is driven by individual objectives, capable of perceiving its surrounding environment and capable of acting on its environment, and that can also communicate directly with other agents (Ferber 1999).

Using MAS to investigate how CPR can be managed is fast becoming a research field. From a theoretical point of view, ABMs of individual decision making have been studied (e.g., Jager et al 2000) and, recently, Deadman and Schlager (2002) have reviewed their use in the specific context of common-pool-resource management institutions. Since 1995, the Green research unit from the French Agricultural Research Center for International Development (CIRAD) has been developing a simulation platform, CORMAS (**co**mmon-**p**ool **r**esources and **m**ulti-**a**gent **s**ystems), which views CPR from a more generic and practical perspective (Bousquet et al 1998). Our seminal objective was to be able to design models more easily, rapidly, and efficiently based on interactions between natural and social dynamics in the context of CPR management. Today, among the existing agent-oriented simulation platforms (Gilbert and Bankes 2003), CORMAS remains very open by not imposing any predefined individual decision-making process on an agent, or coordination protocols between agents. This flexibility also leaves the responsibility to describe all the details of the model to the model designer. Moreover, according to the scientific reproducibility principle, it should be possible for anybody with basic skills in modeling to build the model again, to reimplement it by using any appropriate simulation toolkit (not necessarily the one used originally), and to verify that the results obtained are the same as the ones originally published. This is very challenging as the model becomes complex. Today, it is one of the biggest concerns of scientists from the fields of social science, economics, and ecology in using ABMs to simulate artificial societies or ecosystems (Hales et al 2003).

To ensure a rigorous description of a particular ABM, providing the source code appears to be a necessity, but it is definitively not sufficient. In between the literal description of a model and its implementation in a computer using a specific programming language, a formal representation of the conceptual model is vital. Recently, a standard methodology, UML (unified modeling language), has emerged (Bergenti and Poggi 2002). Recently the Foundation for Intelligent Physical Agents (FIPA) has even proposed a specific extension of UML toward multi-agent systems.[1]

Our objective is to present a methodology for designing an ABM with CORMAS through a formal UML representation of the corresponding conceptual model. A simple but complete model will help to illustrate what the UML represents and how to run models with CORMAS. The scope of this paper is more about how to design an ABM with CORMAS, rather than about the substance of the model. Hence, before describing the toy-model, we will first introduce the formal concepts used in the set of basic UML diagrams, as well as the related conventional notations. Second, we present an archetypical model of CPR management, the slash-and-burn toy-model. A literal description of the model is proposed, followed by the conceptualization of

[1]www.auml.org.

the model using UML. Third, we present the implementation of the conceptual model with CORMAS and propose a set of simulations.

UML overview

The "unified modeling language" (UML) is a description language, specifically a graphic-based representation language of models. It is an open tool designed to be independent of particular programming languages (such as Java or Smalltalk). UML is a formal and normalized language and was accepted by the OMG (Object Management Group) in 1997 (OMG 2003a,b). From then on, UML is the reference in terms of object modeling: a universal language for object-oriented languages. The specifications of the most recent official version (1.5) are available from the OMG Web site.[2]

This paper is dedicated to modelers and scientists willing to build ABMs on a framework such as CORMAS,[3] Swarm,[4] RePast,[5] etc. Whatever the targeted platform, the UML diagrams are used to explain a model and they have to be independent from the platform and the computer language. Indeed, an ABM described with UML is an abstract representation that gives a simplified picture of the real world. Because UML is based on simple graphic notations, with UML diagrams, an ABM should be understandable even by noncomputer scientists. UML can be seen as a dialogue tool that should facilitate communication among scientists, modelers, and stakeholders. Our goal here is not to review all the formal aspects of UML, but at least to give useful insights for nonspecialists who may be interested in using UML to specify ABMs.

Formalizing the structure of a model using the UML class diagram

The UML class diagram is the basic building block for conceptual modeling. It shows all the classes (or a part) and their relationships that are relevant for the purposes of the phenomenon to be modeled. Drawing the class diagram is the first and the main stage of the modeling process. This stage is particularly fruitful when it takes place during a collaborative working session.

Creating a simple and understandable class diagram can be a long and difficult process. In practice, the first step consists of identifying the relevant real-world types of entities and then mapping out each of them using the concept of *class*. A class can be considered as a description of objects having a similar structure and similar behavior and sharing a common semantic. Practically, a class is defined by a list of characteristics (called "attributes") and a list of behaviors (called "operations"). Attributes represent the static part while operations represent the dynamic part. A class can also be viewed as the "generator" of the objects (called "instances" of the class). In other words, a class describes a structural model for a set of similar *objects*, called instances of this class (see Fig. 1).

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[2]Pending issues for UML specification are available from the OMG official Web page: www.omg.org/technology/documents/formal/uml.htm.

[3]http://cormas.cirad.fr.

[4]http://wiki.swarm.org.

[5]http://repast.sourceforge.net/.

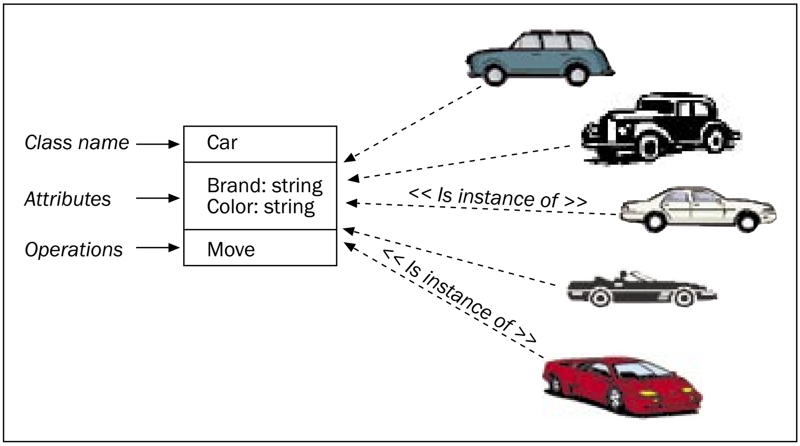

Fig. 1. Class and instances. The five cars on the right are the objects. Even if they are different, they belong to the same concept, the Car class, which has two attributes (brand and color) and one operation (move).

An object encapsulates its data in order to better control any modifications. Indeed, as seen from the outside (i.e., by the other objects), an object shows only its external interface, which is a set of *public* operations. UML specifies visibility of operations and attributes with markers before the names: "+" stands for public and "–" for private. Mostly, an attribute is private: nobody except the object itself can directly access its value and change it. Conversely, a public attribute can be accessed and modified by other objects. If necessary, two corresponding accessing operations are defined. The "reader"-accessing operation returns the value of the attribute and the "writer"-accessing operation allows one to change the value.

UML promotes a development process that is iterative and incremental. According to a standard software life cycle,[6] UML proposes different types of class diagrams. In a class diagram at the "analysis" stage, many details are omitted, such as visibility, types of attributes and types of values returned by operations (if any), and parameters (arguments) of operations (if any). The same diagram at the "design" stage introduces all these details. Conventionally, the types are indicated after a colon, and the potential arguments of operations are indicated between parentheses (see Fig. 2).

Relationships between classes are called *associations*. Associations are drawn as straight lines between the two rectangular boxes representing the classes. Usually, an association is denoted by a verb describing its semantic. The extremities of an association should indicate its *multiplicity* (an integer value or a range of integer values) and its role (a string label) played by the related class in the context of the association. Additional *comments* are shown as text strings (not enclosed in parentheses) within a note icon directly linked to the related element to be commented.

To make such abstract notions clearer, let us formalize with UML a pattern commonly used in the field of renewable resources management. Imagine a portion

[6]The main stages of a software life cycle are (1) "analysis," (2) "design," (3) "implementation," and (4) "tests and maintenance." Mostly, an analysis diagram is sufficient to describe the structure of an ABM.

of land covered by a land cover with a biomass that grows up according to the standard logistic equation. Figure 2 shows the corresponding class diagram at the design stage.

Two classes are defined, LandUnit and LandCover. These two classes are connected through an association semantically understandable as "a land unit is covered *by* a land cover." From a land-unit perspective, the associated land cover may be simply called *cover*. This is a role played by a land cover through the eyes of a land unit. Symmetrically, from a land-cover perspective, a land unit may be seen as a *place*. By drawing the number 1 at both extremities of this association, we state that a given land unit is covered by exactly one land cover (i.e., a land unit without land cover makes no sense in this context), and reciprocally a given instance of land cover is located in exactly one land unit. Figure 2 contains another example of association, which is a bit particular as it is reflexive. Associations in UML express interactions between agents in multi-agent systems. Reflexive associations express interactions between similar entities. Here, the connection between any particular land unit and its four neighbors depicts the structure of a standard "von Neumann" cellular automata network. ABMs dealing with renewable resources management are frequently using such a structure to represent the environment.

In UML, "underlining attributes" means to give them a special status. An underlined attribute corresponds to a "class variable," whose value is specific to the class itself and therefore will be the same for all the instances. Returning to Figure 2, we can interpret the diagram for the LandCover class. Every instance of land cover has a biomass, but two different instances may have two different values of biomass. The same reasoning could not be applied for the intrinsic growth rate *r* and the carrying capacity *K* (the two parameters of the logistic equation). Two different instances of the same kind of land cover should share the same values for *r* and *K*, as if they belonged to the LandCover "species". Then, the *growth* operation will be a matter of updating the value of the *biomass* instance variable, by referring to the previous value of the *biomass* attribute and to the two class variables *r* and *K*. Moreover, in UML it is possible to indicate values. In Figure 2, we can see that *r* is a float equal to 0.4 and *K* is an integer equal to 1.

Associations starting with a lozenge are simple associations with the special semantic "is made of" ("is aggregated from"). The multiplicity is represented by the symbol "1..*", which means that a woodlot can be composed of at least one land-unit

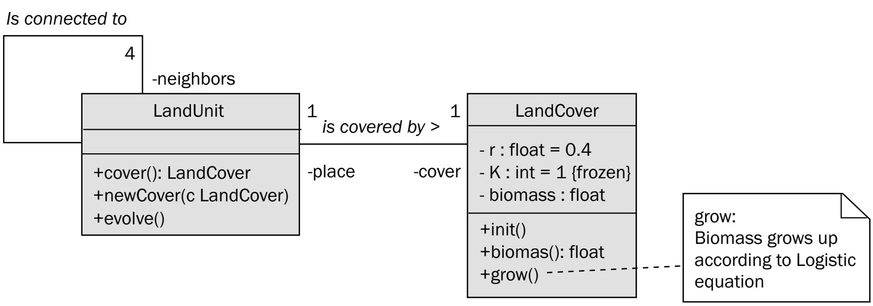

Fig. 2. UML land-use pattern (at design stage).

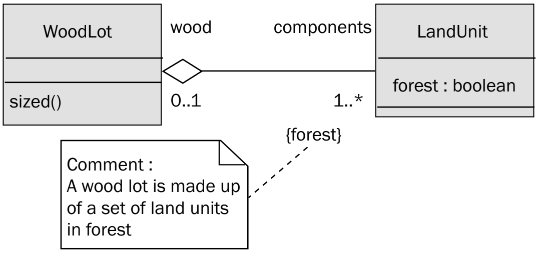

Fig. 3. Example of UML aggregation. A WoodLot is made up of forested land units. A forested land unit belongs to a WoodLot and plays the role of a component of this WoodLot.

instance up to any number of instances. For instance, in Figure 3, a woodlot is defined as an aggregate of (at least one) land unit respecting a constraint: being forested. In UML, constraints express conditions or limitations. They have to be written between curly brackets.

Now, let us present a quite different concept from association: *generalization* is an intellectual mechanism for either refining a concept (specialization) or abstracting a concept (generalization). This mechanism is a *second abstraction* level (after the notion of class regrouping similar objects). Generalization means relating several classes that have some properties in common to a more general "super class." Thus, a specific class is a specialization of a more general class. As a corollary to that, a subclass inherits the features of its super class (attributes, operations, associations, and constraints). However, a subclass may redefine a part of the description that it "inherits." Figure 4 represents a hierarchy of specialization for the LandCover class.

To better understand inheritance principles, let's detail the *Pasture* class as it appears in Figure 4. Because a pasture is a kind of land cover, it inherits one instance variable (age) and three class variables (implantation cost, upkeep cost, and suppression cost). The values for implantation and upkeep costs are redefined. Because a pasture is also a kind of changing cover, it is characterized by one additional instance variable (neglected duration) and two additional class variables (transition age, whose value is redefined, and natural succession, which is also redefined at the level of Crop as a class association from Crop to Fallow, meaning that the next stage of a pasture will be a new instance of fallow). Finally, because a pasture is also a kind of crop, it has two more additional class variables (price per Kg and production per Ha), whose values are redefined.

Depicting model dynamics

Dynamics diagrams are common mechanisms for describing system evolution over time. In UML, several types of dynamics diagrams allow us to describe the behaviors of the entities and their interactions. Each type provides a slightly different capability that makes it more appropriate for certain purposes. We promote three types of representations for specifying the dynamics aspects of an ABM: activity diagrams (intra- or interobject dynamics), state-transition diagrams (internal dynamics of an object), and sequence diagrams (dynamics among objects).

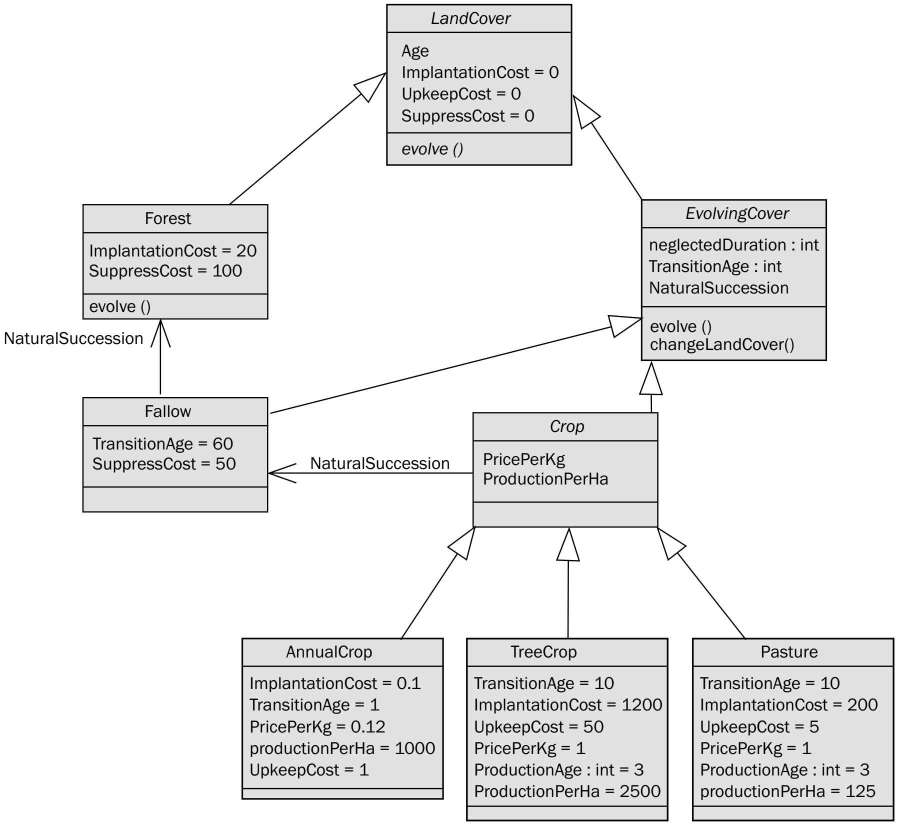

Fig. 4. Hierarchy of specializations for the LandCover class.

Sequence diagrams. The sequence diagram describes the sequence of messages that are exchanged among objects over time. These exchanges are shown along the objects' lifelines. An object's lifeline represents an instance of the class, that is, an individual participant in the interaction. Arrows between the lifelines denote communication between the instances. From top to bottom, the order of messages along a lifeline is significant, as it denotes the order in which these messages will occur. A message defines one specific kind of communication in an interaction. These communications are used to invoke an operation. In any parts of a UML sequence diagram, conditions (called "guards,"which are enclosed by square brackets) can be used if necessary.

Discrete time-step schedulers (such as CORMAS) slice the time stream in homogeneous time-steps and activate the model objects sequentially. For example, a time-step duration can be equivalent to one year. Each year, the scheduler activates the model entities that perform their annual activities. To explain this regular sequence of activities, which can be interpreted as the dynamic part of a simulation scenario, a UML sequence diagram is suitable. Figure 5 shows a very simple sequence diagram for a model with nothing but an intrinsic dynamics of land-cover changes.

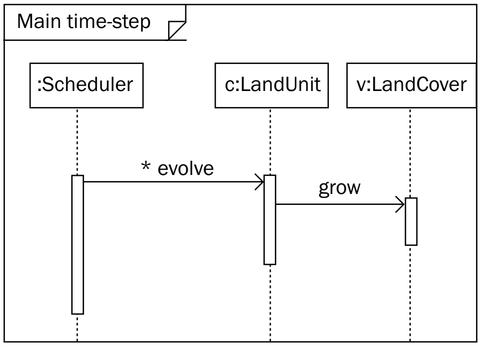

Fig. 5. A simple example of a UML sequence diagram.

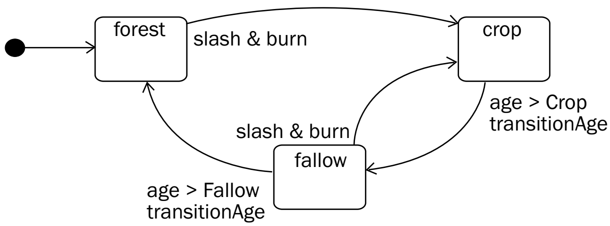

Fig. 6. A simple example of a UML state-transition diagram.

The scheduler sends the "evolve" message to a set of land units. The "*" character before the message name indicates that this message should be repeatedly sent to a set of instances. When a given instance of LandUnit receives this message, it is activated and in turn sends the "grow" message to its land cover.

State-transition diagrams. State-transition diagrams are used to describe the behavior of one object. They show the possible sequences of states through which an object instance can proceed during its lifetime as it reacts to events (for example, signals, operation invocations).

Figure 6 displays the three states that a LandUnit can have. A transition is crossed from one state to another when an event occurs. At this stage, the origin of this event is unknown. It may arise from internal activities (age higher than transition age) or from external actions (slash and burn).

The black dot represents a pseudo-initial state. It can be omitted; it just helps to fix the starting point to read the graph. The events are a kind of stimulus. They trigger the transition to the next state.

Activity diagrams. Activity diagrams are commonly called "control flow" and "object flow" models, and they can be seen as a revision of the standard flow-chart diagrams. The purpose of an activity diagram is to describe a set of activities by representing actions and their consequences. Actions can be described by natural language. A transition is a relationship between two activities indicating that an instance will enter the second activity and perform specific actions as soon as the previous activity has ended. When several kinds of instances are involved in the set of activities to

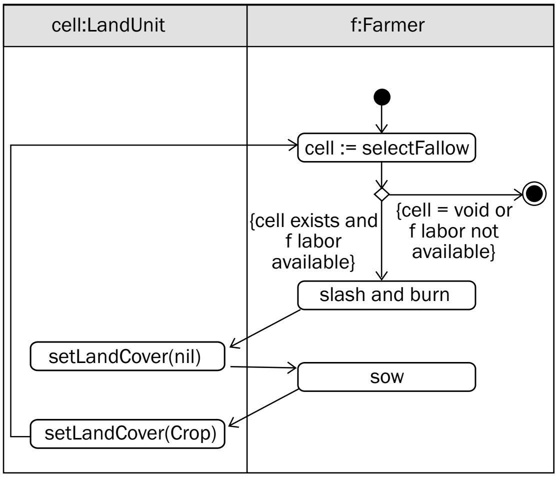

Fig. 7. A simple example of a UML activity diagram.

be described, “swim lanes” (one per instance) delimited by vertical solid lines are introduced. The relative ordering of the swim lanes has no semantic significance.

The activity diagram shown in Figure 7 represents a chain of activities between a land unit and a farmer.

At the first stage, the farmer selects a land unit covered by fallow. When this activity ends, a transition is fired to a “decision point” (a lozenge). According to the guard’s value, the main activity may finish or may enter into a loop (while the farmer’s manual labor is available and a land unit has been selected). This loop consists of several activities: the farmer slashes and burns the plots (we can suppose that this activity decreases the manual labor) and the cover of the land unit is removed and then the farmer sows and a new crop is implanted on the land unit. At the end of the loop, a new land unit is selected. The same activity of a farmer can be represented with another activity diagram (see following figure) that adds an “object flow” (Fig. 8). In parallel to the sequence of activities, an instance of LandUnit, called a “cell,” is shown through its different states.

A simplistic and archetypical model of CPR management: the “slash-and-burn” toy-model

To manage a common resource in a sustainable way, it is often asserted, referring to Hardin’s seminal paper about the “Tragedy of the Commons” (Hardin 1968), that some restrictions should be imposed by an authority on individual practices. The model presented here, called “slash and burn,” illustrates how the interrelated dynamics between individual and collective representations of a renewable resource may influence individuals reciprocally. It was inspired by a previous CORMAS model elaborated by a geographer, J.L. Bonnefoy (Bonnefoy et al 2000, 2001).

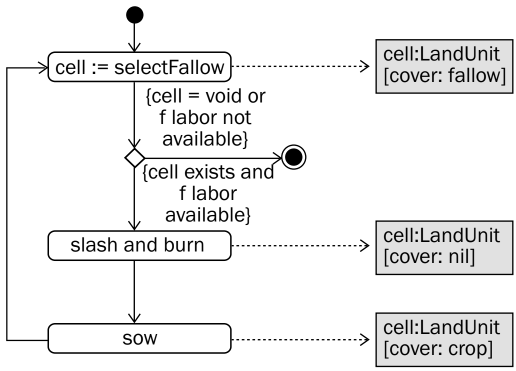

Fig. 8. A simple example of a UML activity diagram with object flow.

Literal description of the "slash-and-burn" model

A virtual forest landscape is set as a square lattice made up of 50 by 50 hexagonal LandUnits. Each LandUnit, which represents a homogeneous portion of space, may be covered by forest or not. For any LandUnit without forest, the chance of forest recovering is proportional to the number of neighboring LandUnits being covered by forest.

Some farmers are located on a given LandUnit. With each time-step, they move from the LandUnit where they are located to a neighboring one. With a limited perception range around their location, they can perceive the neighboring forest, if there is any. When they do not perceive any forest, they simply move randomly; otherwise, they decide whether or not they move toward a neighboring LandUnit covered by forest to "slash and burn" it.

A ForestDepartment is in charge of periodically organizing (not every time-step) a census of the forest resource by identifying, sizing, and marking patches of contiguous LandUnits being covered by forest (called WoodLots). Marks set on the WoodLots are about protection of the forest resource: if the size of a WoodLot is below the authorized minimum size, it will be marked "protected." To determine the authorized minimum size, the ForestDepartment requests that all the farmers individually report each of their perceptions of the WoodLot's mean size; the highest value among all the reported values is the authorized minimum size.

Individual farmers use a memory (with limited capacity to store) to remember the sizes of the WoodLots they have encountered; when their memory becomes full, they just forget about the less recent stored value. Two contrasting strategies of individual farmers ("conformist" and "nonconformist") are illustrated using two factors affecting their decision-making process: the first factor is related to their reported value of the minimum size—for "conformist" farmers, this will be the arithmetic average of the recorded values; for "nonconformist" farmers, it will be the highest value from the recorded values. The second factor is related to the way a farmer decides whether he/she will slash and burn a perceived LandUnit covered by forest. A "conformist" will certainly respect the protection mark set by the ForestDepartment, whereas a "nonconformist" will refer to his/her personal computed average value—if the size of the WoodLot is higher than this value, the nonconformist will decide to slash and burn the LandUnit even if it belongs to a WoodLot marked as protected.

Conceptualization of the "slash-and-burn" model using UML

Class diagram of the model at the analysis stage. Figure 9 represents a class diagram of the slash-and-burn model described earlier.

The left part of the class diagram describes the spatial aspect—the landscape is composed of two types of entities: the elementary level (LandUnit) and the aggregated level (WoodLot). The components of a WoodLot are instances of LandUnit that are connected and in a forest state (constraint). On the other hand, one LandUnit may belong to a WoodLot if its state is forest. The size of a WoodLot is the number of its components. A WoodLot can be declared protected or not.

When deforested, a LandUnit can recover its forest according to a probability (probaForestRecover). We assume here that this probability, equivalent to a recovery rate, is a constant value shared by any deforested LandUnit (it is then a class variable).

The landscape is made up of 2,500 LandUnits. A comment related to this multiplicity states that these elementary spatial entities are organized as a "50 × 50" square spatial grid.

A Farmer entity can be regarded as a composite entity. Indeed, farmers have their own inner state (perception range, etc.) and inner behavior (goSlashAndBurn or moveRandomly), but they also own a specific strategy that can change over time: they can be conformist or nonconformist. In this particular model, "Strategy" is an abstract class, meaning that its raison d'être is only to serve as a generalization of the two specific strategies. "Strategy" declares two abstract methods that are refined in both subclasses ("Conformist" and "NonConformist"). This object architecture is called *polymorphism*; it allows users to specify similar behaviors but can be carried out differently. This structure will be convenient for discriminating the two strategies. For instance, to state that, for the conformist, the reported value is the arithmetic average of the values stored in "cuttingMemory" (one of the attributes of the Farmer class, see Figure 9), and that, for a nonconformist, it is the highest value from the one stored in "cuttingMemory," it is simply a matter of writing two different versions of the same method called "reportValue."

Class diagram of the model at the design stage. Figure 10 represents the same slash-and-burn model, but in a detailed design stage. In this stage, more details are revealed, such as visibility, types of attributes, by-default values, and parameters of operations.

A lot of additional information is thus provided in Figure 10 compared with Figure 9. For instance, for attributes, it is indicated that the default value for the class variable probaForestRecover (LandUnit class) is set to 0.0025. For operations, if we look at the Farmer class, we can note from the "+" sign that "goSlashAndBurn" and "sendReport" are the two main behaviors available for outer use (public methods). The other operations are for private use: – perceive( ):LandUnit [*]) is a private method without argument that returns a set of LandUnits.

The sequence diagram. The sequence diagram shows the basic order of a series of operations in a simulation. The sequence diagram in Figure 11 shows how the

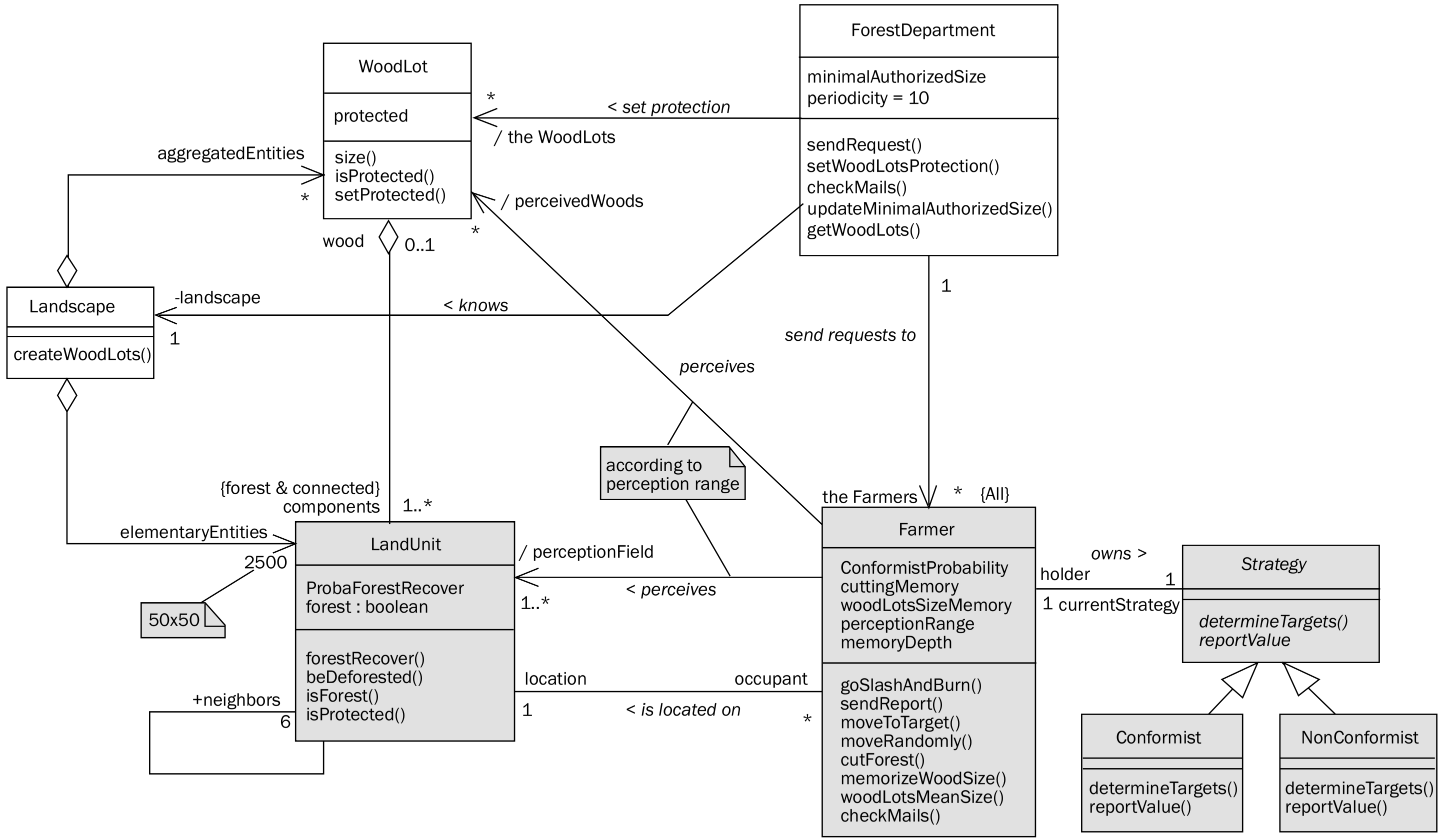

Fig. 9. UML class diagram of the "slash-and-burn" model at the analysis stage.

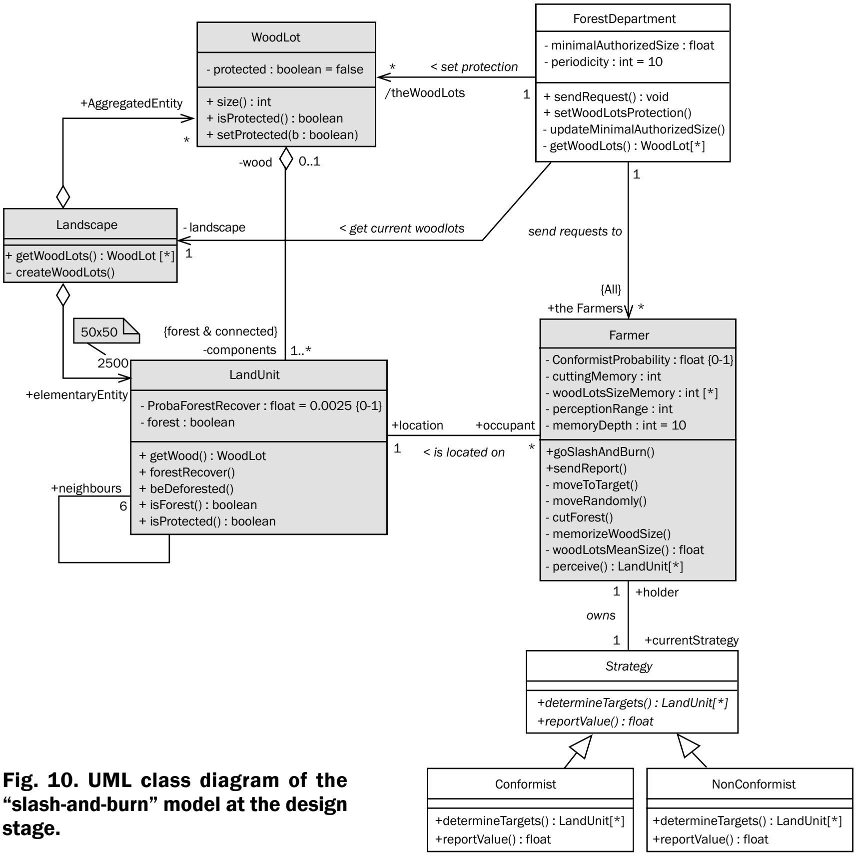

Fig. 10. UML class diagram of the "slash-and-burn" model at the design stage.

scheduler activates the entities of the slash-and-burn model. Each year (assuming that a time-step is equivalent to one year), the scheduler activates the LandUnits for forest recovering, then activates the farmers to perform their annual activities and the ForestDepartment to set the WoodLotsProtection.

In drawing the sequence diagram, a modeler has to take note of the risk in representing all the possible message exchanges over time; this can lead to an incomprehensible diagram that defeats the purpose of UML. A sequence diagram should be restricted to the main operations that are triggering the internal behaviors of each entity of a model, and therefore should avoid delving into any internal details of such or such operations. Rather than producing a single but complicated sequence diagram, a better solution would be to restrict it to its simple expression, as in Figure 11, and to associate it with other sequence diagrams (Fig. 12) or activity diagrams (see Fig. 14).

A specific internal periodicity of activities exists for the ForestDepartment. On the left of the activity lifeline of the ForestDepartment, a guard condition (between square brackets) depicts this specific periodicity.

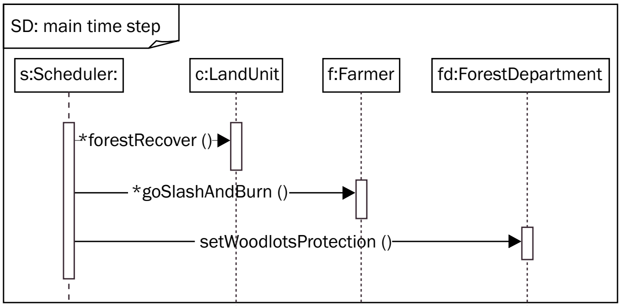

Fig. 11. UML sequence diagram of the main step of the scenario defined in the "slash-and-burn" model.

The WoodLots can be considered as a reification of a point of view. They are the minimum spatial unit in the eyes of the ForestDepartment. Unlike the LandUnits, which are created during model initialization, some WoodLots can also be created during the run time. To have a reference on them, the ForestDepartment asks the Landscape to identify them, which means creating new WoodLots from the LandUnits according to the constraint {forest & connected}. "getWoodLots()" is the only public operation of the Landscape class (see Fig. 9).

State-transition diagram. Figure 13, a statechart, displays the two states that a LandUnit can have. The transitions come about because of events that are launched by internal activities (forestRecovering) or external actions (cut).

Activity diagram. The diagram shown in Figure 14 is the activity diagram of the "setWoodLotsProtection" method from the ForestDepartment class. The ForestDepartment sets protection for the WoodLots after comparing their size with the minimum authorized size. This threshold is updated through a request sent to the Farmers.

What is described in Figure 14 is somehow redundant with the details given in Figure 12. It is another way to represent the activity of the ForestDepartment.

Implementation of the "slash-and-burn" model in CORMAS

CORMAS overview

CORMAS provides a guide in building ABMs through its interface. It offers some facilities to incorporate data coming from geographic information systems (GIS) in order to define and describe "spatial entities." Neighboring interactions among these "spatial entities" can represent natural dynamic processes (i.e., vegetation dynamics, erosion, pollutant diffusion); this is equivalent to a cellular automata layer. CORMAS also facilitates the design of "social entities" (the "agents") representing the key stakeholders of the system under study. There is a set of predefined mechanisms for the location, perception, and movement of the agents, as well as for direct communication between them. Additionally, CORMAS has some tools to define specific markers (probes) to analyze simulation results, as well as viewpoints to allow visualization of the simulation from a particular perspective. It also provides a sensitivity analysis module to run sets of simulation experiments that automatically increases the values

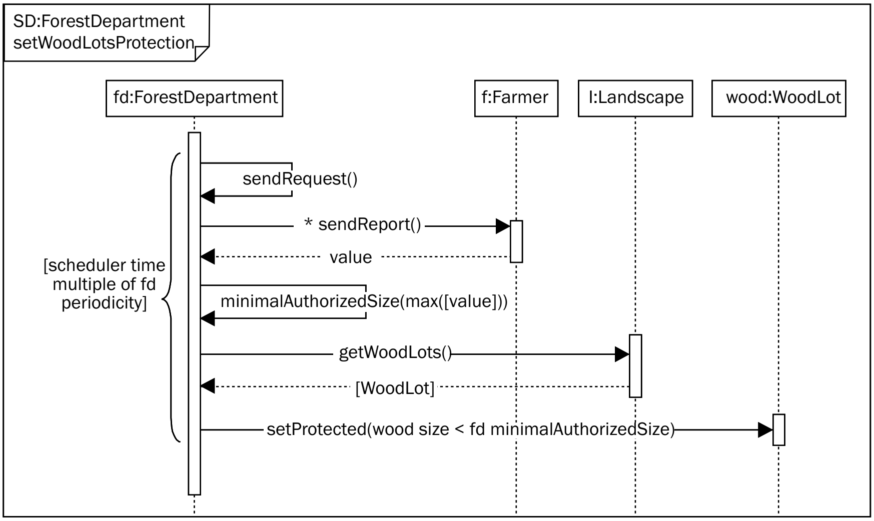

Fig. 12. UML sequence diagram of ForestDepartment's main step: setWoodLotsProtection.

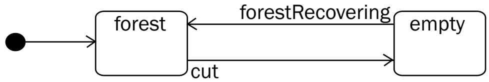

Fig. 13. UML state-transition diagram of the LandUnit class of the "slash-and-burn" model.

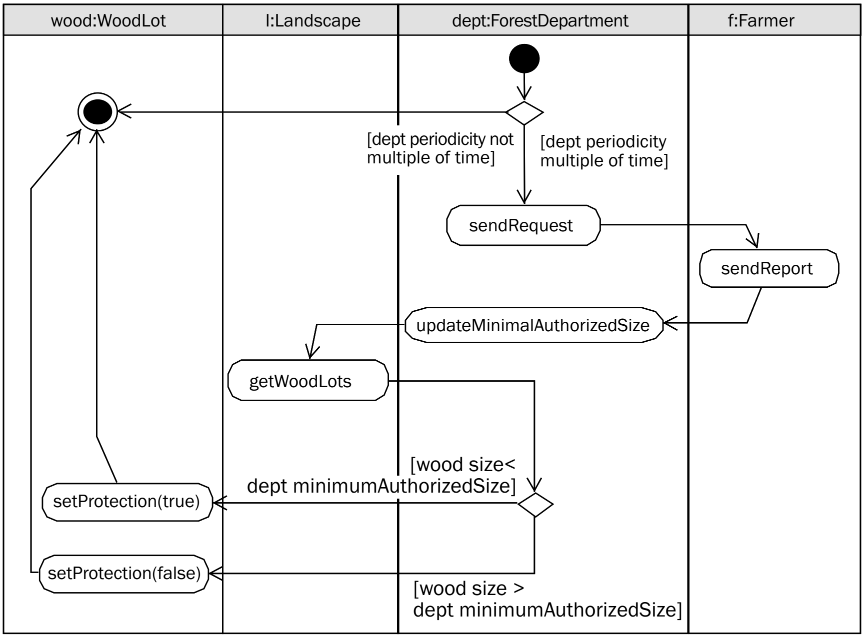

Fig. 14. Activity diagram of setWoodLotsProtection method from the ForestDepartment class of the "slash-and-burn" model.

of parameters within a given range. Finally, CORMAS allows exporting of the data produced by the simulation into spreadsheet or database software.

The CORMAS simulation toolkit is being developed continuously, through a step-by-step enriching process, by selecting what is of general interest in specific models and by "pushing it up" at the generic level. CORMAS comes with a library of existing models that can be divided into three categories: didactic models[7] to illustrate the main concepts and principles of ABMs, theoretical models[8] to investigate by simulation the field of theory building, and models oriented toward real-world case studies (Bousquet et al 2001) to better understand complex environments. Simple "quick and dirty" models, collectively designed with stakeholders through role-playing games, are also developed with CORMAS to support collective decision-making processes in complex situations (D'Aquino et al 2003). Stakeholders learn collectively by creating, modifying, and observing simulations. In such situations, CORMAS proved to be very convenient in allowing the integration of run-time modifications or new features suggested by the participants.

Adjusting the conceptual model to the CORMAS simulation platform

Starting from the class diagram of the model at the design stage (see Fig. 10), a new class diagram has to be designed to fit the particularities of the software that will be used. We thus adapt this first description of the slash-and-burn model to the CORMAS simulation framework. The idea is to use the generic CORMAS elements (classes with attributes and methods that already exist) as much as possible. A class diagram of the CORMAS Entity package is available at the CORMAS Web site.[9] By taking advantage of inheritance from suitable generic spatial, social, and passive entities, some attributes and methods needed by the particular entities of the model are handled by reusing those existing at the more general level of the corresponding superclasses.

Figure 15 presents the class diagram of the "slash-and-burn" model adapted to fit the framework proposed by CORMAS.

The WoodLot class is set as a specialization of SpatialEntityAggregate. The LandUnit class is set as a subclass of SpatialEntityElement, which represents the smallest spatial entity (minimum granularity level) in CORMAS. To account for the concept of Landscape, we refer to the generic class called SpaceModel in CORMAS, which allows us to create and to refer to all the spatial entities. ForestDepartment is set as a kind of Agent, and Farmer is a specialization of AgentLocation, which is a kind of Agent located on a SpatialEntityElement in CORMAS.

A new class, denoted SlashAndBurn, now appears in the UML class diagram represented in Figure 15. This class is devoted to the design of simulation scenarios. In CORMAS, such a control level is specified through two roles: the first role is to create the initial situations for the simulation experiments, and the second role is to schedule the simulation experiments. The initialization process consists of creating and initializing all the instances from the classes corresponding to the conceptual entities of the model at time 0. Once created and initialized, these instances are stored in

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[7]See, for instance, http://cormas.cirad.fr/en/applica/plotsrental.htm.
[8]See, for instance, http://cormas.cirad.fr/en/applica/ecec.htm.
[9]http://cormas.cirad.fr/en/outil/uml-kernel.htm.

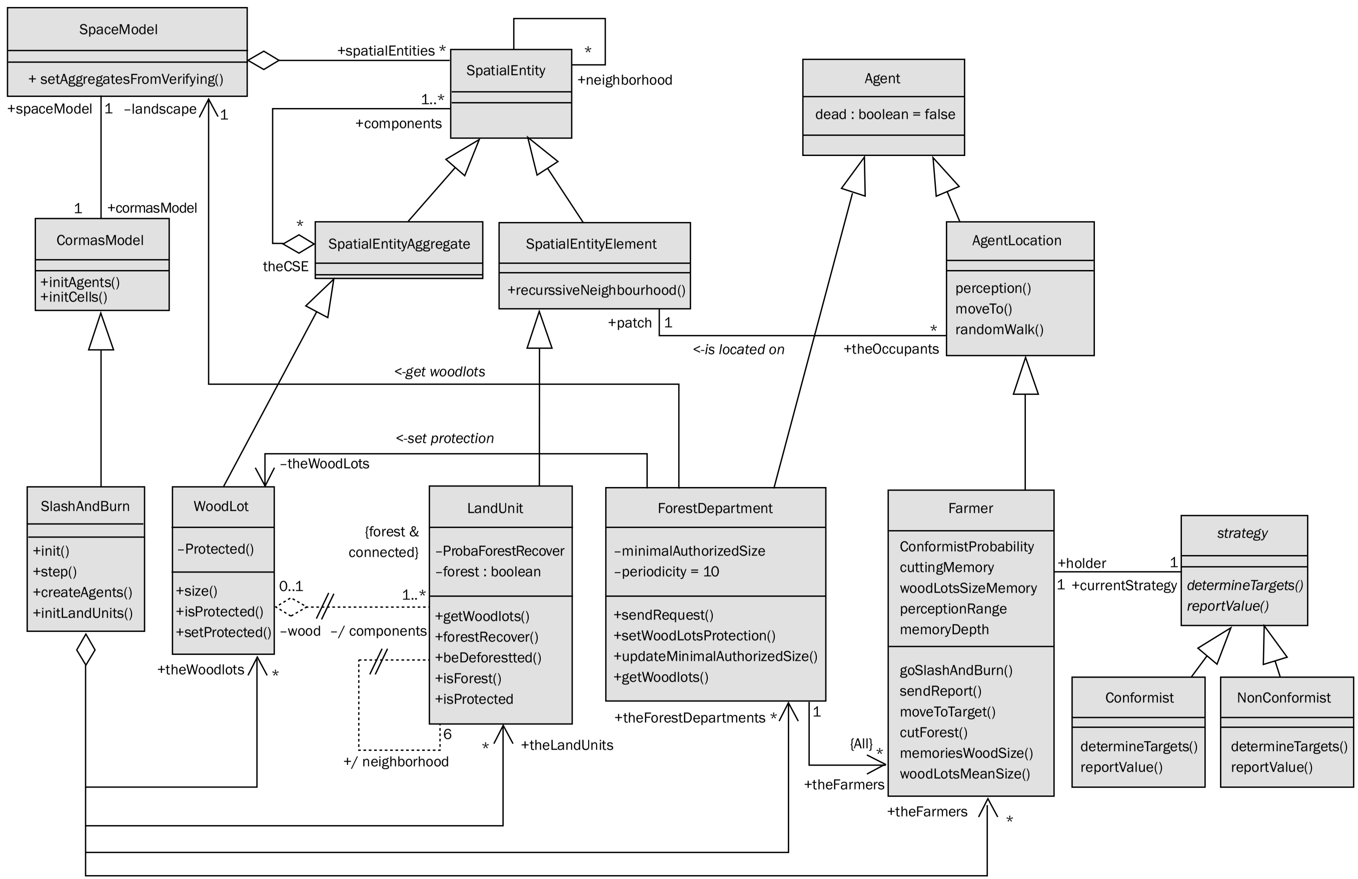

Fig. 15. UML class diagram of the “slash-and-burn” model adapted to the CORMAS simulation toolkit.

collections that are automatically created as attributes of the SlashAndBurn class. In Figure 15, these collections appear as the roles called "theLandUnits," "theWoodLots," "theForestDepartments," and "theFarmers."

Now that we have a CORMAS superclass associated with each specific class of the SlashAndBurn model, not only attributes and methods of superclasses are directly reuseable, but also associations between superclasses. For clarity, or just to emphasize important relationships, it may be convenient to "refine" such associations, which is a way to name them with a semantic adapted to the topic of the model. To signal this kind of refinement, we propose here to use one of the existing UML stereotypes: a symbol "//" that crosses the subassociation. For clarity, in Figure 14, we also shaded these associations dark gray. Hence, for instance, the aggregative association between the CORMAS classes SpatialEntityAggregate and SpatialEntity is refined to stress the importance of the aggregative association between the WoodLot and LandUnit classes.

Implementing the conceptual model within CORMAS

This paper does not discuss all the details of model implementation in CORMAS. The whole code of the model can be downloaded from the CORMAS Web site.[10] To illustrate the translation of UML diagrams into the Smalltalk language that is used in CORMAS, we cite here the main method for the ForestDepartment class as an example. The corresponding UML activity diagram is shown in Figure 14. It is about the process of marking the WoodLots protected or not:

```
                    setWoodLotsProtection
"updates the Minimal Authorized Size and sets the 'protected' attribute of the woodlots to 'true'
if its size is below this threshold"
((Cormas timeStep \\ self periodicity) = 0) ifTrue: [
    self updateMinimalAuthorizedSize.
    self theWoodlots do: [:aWoodlot |
                aWoodlot protected: aWoodlot size < self minimalAuthorizedSize]]
```

To gain access to the WoodLots, the ForestDepartment requests the Landscape to perform the aggregation. In CORMAS, the SpaceModel class (which was used here to represent the concept of Landscape) is equipped with a set of generic aggregation methods. One of these generic methods (setAggregate:from:verifying:) is used here (see the code below):

```
theWoodLots
"Request the Landscape to perform the WoodLots aggregation"
"then get the updated collection of WoodLots"
self landscape
            setAggregates: WoodLot
            from: LandUnit
            verifying: [:c | c forest].
^self landscape spatialEntities at: #WoodLot
```

[10]http://cormas.cirad.fr/en/applica/SlashAndBurn.htm.

A simple simulation scenario

To be able to run a simulation experiment, a "scenario" has to be specified. With CORMAS, the scheduling process is based on discrete time-steps. In contrast to events-driven schedulers that activate the agents when given events occur, a discrete time-steps scheduler activates the existing instances of the model on a regular basis. In the SlashAndBurn model, the time-step duration is equivalent to one year. Each year, as is summarized in the sequence diagram shown in Figure 11, the scheduler activates the land units for forest recovering, then activates the farmers to perform their annual activities, and, finally, but only every 10 years, the ForestDepartment performs its activity. We decided arbitrarily to use the value 10 for the specific internal periodicity of activities of the ForestDepartment. This choice is denoted in the UML class diagram at the design stage (see in Figure 9 "periodicity" in the definition of the ForestDepartment class).

This is only half of what is called a "scenario." We also need to define an initial situation; this means creating the desired number of entities, and assigning initial values to all the attributes of each entity. With CORMAS, it is possible to load the initial values of the attributes of elementary spatial entities directly from an ASCII file.

The other initial values are given directly in the UML class diagram at the design stage (see Fig. 9). One additional parameter is used to initialize the population of farmers: the total number of farmers, which here is a constant arbitrary number set at 40. This parameter could have been set as an attribute of a conceptual entity "Population," but it does not make sense for this particular model. Because 40 is related only to the initial instantiation of the farmers, it is defined as a characteristic of the slash-and-burn model itself. The initial spatial distribution of the population of farmers also needs to be specified. In this case of simple simulation scenario, each farmer is randomly located on one of the 2,500 LandUnits.

Using markers (probes) to compare scenarios

Markers do not necessarily belong to the model itself unless they are used internally by any particular entity as criteria for a decision-making process. Markers may also be considered as external viewpoints established by anyone who examines the simulation with specific appraisal criteria. CORMAS provides facilities to employ such markers. The designer of the model has to write "probes," which are Smalltalk methods that return the values that are automatically recorded by CORMAS at the end of each simulation time-step. The user may choose to export these data or to plot them as time-series within CORMAS. The three markers used in this case to compare scenarios are the number of forested LandUnits, the number of WoodLots, and the WoodLots' mean size.

Measuring model sensitivity

To test the variability of the results when some randomness is incorporated into the model (random numbers are typically used to break ties among equivalent possibilities), it is necessary to repeat the same simulation experiment. To be able to perform a statistical analysis, a reasonable number of replications (at least 30) should be done.

The scenario builder of CORMAS proposes to select the parameters whose sensitivity is tested automatically. For each of these parameters, a range of values and a step of variation are given.

We propose here to test the probability of one farmer being conformist. Being equal to 0 means that all 40 farmers are behaving according to the nonconformist strategy; on the other hand, being equal to 1 means that all 40 farmers are behaving according to the conformist strategy. If we let this parameter range from 0 to 1, with a step of variation of 0.25, it defines five different simulation experiments; as it is to be repeated 30 times, this makes a total of 150 simulation runs.

Results

How many time-steps should we run in the model? This question is often crucial when some of the underlying assumptions become unrealistic in the long term. With this toy-model, we decided to run 300 time-steps for each simulation experiment, mainly because then the landscape evolution has converged toward a stabilized situation.

Rather than producing crudely the 30 time-series for the three markers for the five simulation experiments, we present here the average and standard deviation values calculated at the final time-step (t = 300) from the 30 repetitions (see Fig. 16). By doing this, we can discuss the effects of the proportion of conformist farmers in terms of final states, but not in terms of trajectories.

These results suggest the existence of an exponential relationship between the proportion of conformists and the number of forested LandUnits (Fig. 16A), and a sigmoid relationship between the proportion of conformists and the number of WoodLots (Fig. 16B). On the other hand, it seems impossible to detect any clear relationship between the proportion of conformists and the WoodLots' mean size (Fig. 16C), although, when the population of farmers is made up exclusively of conformists, the WoodLots are twice as big as when there are some nonconformists.

We will not discuss much here about the significance of such relationships. We can simply note that the first marker (number of forested land units) is somehow a combination of the two others (number of WoodLots and WoodLots' mean size). By just assessing the "ecological impact" of the farmers' strategy by looking at the number of forested land units, and/or by looking at the number of WoodLots, we can talk about a "gradual positive impact" of the proportion of conformist farmers. Actually, as soon as there are some nonconformist farmers in the population, the WoodLots' mean size does not increase.

Conclusions

We presented a model prototype and the main stages of its design—from a literal description of the context to a set of UML diagrams describing its structure and dynamics, up to its implementation and some simulation results. This highlights the development of the static model and its evolution from the "analysis stage" up to its adaptation into the CORMAS framework. Indeed, ABMs are often considered as black boxes containing hidden strange behaviors. Some simulation outputs may come from bugs or from biases that lower our confidence in the simulation results. To improve this situation, we emphasize three crucial points.

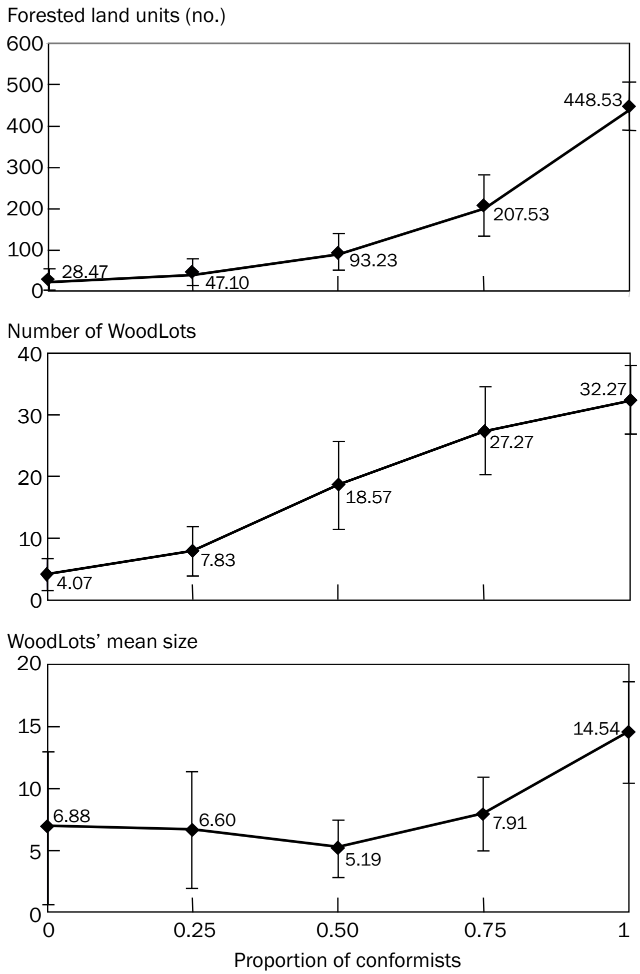

Fig. 16. Average and standard deviation values for (A) the number of forested land units, (B) the number of WoodLots, and (C) the WoodLots' mean size for increasing values of the proportion of conformists within the population of 40 farmers.

The model structure should be described from scratch, without reference to any simulation software. Description of a model should be sufficiently clear to implement it on any platform. A static or dynamic UML diagram should be as clear and simple as possible, and at the same time without missing crucial information. Because the UML formalisms contain only a few meaningful elements, notations should be strictly respected to obtain the essence of a model without ambiguity.The UML diagrams and textual documents should be considered as the "real" model; the model's translation into computer code has to be seen as just one implementation. A single model description should be enough to get the same results when replications are run on various platforms. "A result that is reproduced many times by different modelers, reimplemented on several platforms in different places should be more reliable," according to Hales et al (2003). The benefit of designing conceptual models before rushing to implementation is not only a matter of enabling replicability. Following Heemskerk et al (2003), we believe that conceptual models are efficient tools to foster collaborative work between ecologists and social scientists. Modeling with UML does not mean that the model is well designed!

From an epistemological point of view, as stated by Popper, a UML model, like any other model, should be refutable (Popper 1985). Although never completely attaining formal proof, we can become more confident of a model over time by inductively analyzing the simulation results through sensitivity study. Designing and coding a model is only half of the work. Evaluating a model by means of sensitivity analysis is the other half of the modeling process. It may lead to modifications of the model, when new questions come up. This dynamic loop nurtures a learning process.

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Notes

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International workshop on multi-agent systems for integrated natural resource management in Southeast Asia

Suan Bua Resort, Hang Dong District, Chiang Mai Province, 19-21 October 2003

Contents of the discussions after each oral presentation

Summary prepared by the editors

This section summarizes the main exchanges that followed each successive oral presentation made at this workshop. In parallel, the authors were preparing new versions of the manuscripts of their articles to be sent to external reviewers before their publication in this volume.

Session I. The modeling process, from reality to conceptual models

P. Promburom: Integrated multi-agent systems for collective watershed management: model abstraction and design

- N. Suphanchaimart: What land-use scenarios seem to be adapted to the current agricultural circumstances?

PP: Different scenarios could be proposed according to the different points of view of each main individual or institutional stakeholder. They could be explored separately or by using a more collective process aiming at the definition of a new scenario acceptable to all. At this stage, no final decision has been made yet about the precise procedures to be followed in this case study on the assessment of land-use scenarios.

- D. Macandog: Were the policies used in the past efficient?

PP: It depends on the location, but the current trend in northern Thailand is characterized by more flexibility and an increase in the population participating regarding land-use issues.

- G. Trébuil: To improve the "planning process" is mentioned as an objective of this case study. Is this compatible with the use of a companion modeling approach to implement this research?

PP: Effectively, the classic planning methods could be in contradiction with an adaptive management of resources with all concerned stakeholders.

- N. Suphanchaimart: Stanislas Boissau's work in North Vietnam shows that, when resources become scarce, managing rules will emerge. Maybe hill people have their own rules to deal with scarcity. This does not mean that people will systematically overexploit the resource.

- T.R. Gurung: Following your presentation, it seems that there are more contradictions than complementarities among the various stakeholder strategies. Don't you think that it will be difficult to reach a shared representation of land use in this watershed?

PP: The authors of this communication think that these differences are not so important and that it is possible that this research will help to bridge these various viewpoints.

- H. Purnomo: What is the meaning of adaptive learning?

PP: We plan to implement interactive learning activities about resource management to facilitate the adaptation of stakeholder behaviors to differing points of view and to the effects of their practices on their common environment.

- G. Trébuil: Don't you think that it will be useful to build more abstract landscapes to produce a more generic tool and to facilitate the up-scaling of this case study?

PP: Yes, we will think about this because the development agencies concerned are receptive.

N. Bécu (paper presented by F. Bousquet): A methodology for eliciting and modeling stakeholders' representations with agent-based modeling: application to watershed management in northern Thailand

- G. Trébuil: How much time is needed to analyze the information gathered by using the proposed procedures?

FB: It is a very long effort indeed. The data analysis followed a 3- to 4-month-long stay in the villages for the researcher to become familiar enough with the villagers before starting to analyze their representations. Different methodologies were used in this research: ethnographic survey, transcript analysis, and playable stories. The transcript analysis for a sample of 14 farmers took one year by working on it full-time.

- N. Suphanchaimart: This research is based on collaboration with a limited number of farmers. How did you select them?

FB: They were chosen to maximize the diversity of farmers' circumstances to be analyzed.

- G. Trébuil commented on the difference between the proposed methodology and the more classic tradition of working in a more descriptive fashion, on a very large sample of farms. The agrarian systems research method leads to the preliminary identification of several main categories of farmers, before selecting a limited sample of diverse resource persons for further in-depth analysis of their decision-making processes. He also underlined the fact that the preliminary results presented in this paper show that transcript analysis and playable stories provided a deeper understanding and better results than the ethnographic survey, but at the cost of a more time-consuming effort.

W. Wardhana: Modeling forest management on the edge in Java

- B. Ekasingh: What were the reasons for the very rapid increase in illegal logging operations in 1997 and 1998?

WW: They were linked to the end of President Suharto's regime, leading to a steep devaluation of the local currency. An increasing number of industrial exporters started to export wood products as there was also a higher market demand. The very poor social conditions of people living near the forest also led to an increase in the illegal harvesting of trees.

- B. Ekasingh stressed the important role of prices and their fluctuations in understanding such a situation.
- D. Macandog raised the question of the representation of the central and local governments as noncommunicating agents in the model.

WW accepted that the current representation in the model is a very simplified one compared to reality.

- P. Promburon asked why the government was modeled as a nonlocated Agent.

WW: We made this choice as some entities may not need to be visually represented.

- F. Bousquet: It is important to decide about the necessary level of complexity to incorporate in a model depending on its objective. How did you choose what will be represented or not in your model?

WW: This model was constructed to observe stakeholder behavior and to better understand the system. Another objective will be to present the model to the stakeholders so that they can better understand the consequences of their actions, especially for the state-owned company, which may consequently change its policy toward a better management system.

- B. Ekasingh asked for precision about the type of property rights governing access to the forest.

WW explained that, officially, it is a state-owned forest but de facto the forest is an open-access resource.

D. Magcale-Macandog: Development of a multi-agent systems model of agroforestry adoption on smallholder farms in the Philippine uplands

- W. Wardhana: How is the land tenure system influencing land use by farmers?

DM: Ninety percent of the farmers have titles and land-use rights. Only those who are still practicing shifting cultivation do not have land titles. If the formal owner is not the farmer, he is consulted on the choice of crops to be planted.

- S. Boissau: How did the model evolve from one version to the next?

DM: New entities and new interactions were added and represented in the new versions. For example, in the second version, farmers were situated at various elevations but were not practicing agroforestry. Decisions regarding tree planting were introduced in the third version of the model.

- S. Boissau: What will be the objective of the role-playing game proposed in the next step?

DM: The role-playing game will be used to build a platform for discussion among the different stakeholders. The model is built to help design the role-play, and the role-play will be used to stimulate communication and exchanges with and among the stakeholders.

Session II. Models and role-playing games

S. Boissau: Co-evolution of a research question and methodological development: a companion modeling experiment in northern Vietnam

- P. Promburom: What results are expected from the two most abstract role-playing games? If they are not similar, how are you going to proceed?

SB: The two games are examining two different concrete problems (grazing-land management and forest management) and they do not produce similar results. But both games are sources of inspiration for building a multi-agent model dealing with the emergence of collective rules in resource management.

- W. Naivinit: What are the differences between the first series of games and the last ones that are more abstract?

SB: The relationship between the game and real circumstances was very strong in the first series of games. The players kept asking for the addition of new entities and this was very interesting for making a diagnosis of the situation. But these numerous entities were increasing the "noise" in the game and were limiting the possibility of analyzing the central question of our research; hence, the creation of a second series of games easier to control.

- N. Suphanchaimart: Could you be specific about the process of changes in land resource management regimes?

SB: A collective land management regime seems to be able to emerge in an endogenous way. But private property does not seem to emerge from an increase in land pressure. It is rather imposed from the outside on the local stakeholders.

- H. Purnomo: In Indonesia, in some cases, we observed changes from common to private property and, during the economic crisis, an evolution toward an open-access regime, then another transition to common property again. Do you also observe an evolution from private property to free-access rules?

SB: Such a process is not observed at this study site.

- T.R. Gurung: What are the reasons for having two different more abstract games? If you change the resource under study, don't you think that it is normal that the rules guiding the emergence of management regimes will also be different?

SB: We needed some diversity of concrete situations while examining a similar central research question. Yes, the rules for access to grazing land or the forest could differ, but the key question is the process of emergence of collective management rules.

T.R. Gurung: Companion modeling to improve water sharing at rice transplanting in the upper Lingmuteychu watershed of west-central Bhutan

The participants were divided into two groups to discuss two questions based on T. Gurung's presentation.

- Question one: How to involve local leaders (officials?)? The groups proposed two opposite answers: involve the politicians as agents in the role game, or invite them as observers.
- Question two: How to use a MAS to help communication among stakeholders? The answers were
  - To find a win-win situation and present it to the stakeholders.

- To assess quantitatively the benefits of sharing water.
- To test two scenarios, one with traditional rules and one with rules that emerged from the role-playing game.
- To explore various protocols of exchange between water and labor.

N. Suphanchaimart: Role-playing games to understand the expansion of sugarcane in paddies of upper northeast Thailand

- F. Bousquet underlines the similarities between these role-playing games and those used during the "SAMBA week" in northern Vietnam (cf. S. Boissau's presentation). This case study could also lead to more abstract experiments about the decision-making rules for crop allocation to the land or regarding the effects of cultural factors influencing farmers' decisions on crop selection.
- B. Ekasingh underlines the importance of developing a computer model following these various gaming simulation sessions. She is also encouraging everyone to work more on the cultural dimension of decision-making mentioned in the presentation.

NS explains that a simple MAS model developed by F. Bousquet already exists, but that there is still a need to involve more diverse stakeholders.

- F. Bousquet mentions that there are strong similarities between the last two presentations and that another possible evolution of the current "sugarice" game could be the design of a more abstract one.

NS agrees and thinks that the use of a more abstract game could make the players more creative when looking for changes in and improvements to their current circumstances.

- T. Gyamtsho: What are the effects of this change in land use on food security?

NS: Negative effects on the rainfed lowland rice subsystem could be forecast if the trend observed in which upper paddy areas are converted into sugarcane plantations continues.

C. Vejpas: Participatory modeling for managing rainfed lowland rice biodiversity in lower northeast Thailand

- B. Ekasingh: What are the results of the first gaming session? Do you aim at conserving rice biodiversity?

CV: They confirm the results obtained during the sample description survey and are consistent with our understanding of the real situation. A second game will look at the issue of rice biodiversity conservation.

- D. Macandog: How did you conduct the initial surveys and how did you assess farmer motivations regarding the choice of rice varieties?

CV: A sample description survey was carried out on a large number of farms in the whole province. Results of numerous previous studies on this topic were also used.

- P. Promburom asks to clarify the research question and the expected outputs of this case study.

CV: The first objective is to understand how the existing rice seed management system is operating before defining improvements that could be acceptable to the main stakeholders in this system.

- N. Suphanchaimart: What kinds of interactions among players are allowed or observed?

CV: Players can exchange seeds among themselves, but this was not observed during the first gaming session held in the vicinity of seed production centers.

- B. Ekasingh: Did you try to introduce a new variety in the game?

CV: Yes, we did, and we found that its adoption was more related to social conditions than to physical ones.

- B. Ekasingh thinks that seed availability is a major factor for adoption.
- T.R. Gurung: Following the initial detailed analysis of the stakeholders, what results were taken into account to build the role-playing game?

CV: Our understanding of how farmers manage the procurement of rice seeds at the individual level was used to build the first game. Later on, other results from the preliminary survey will be used to define a second game representing the rice seed procurement system at the provincial level.

Session III. Multi-agent simulations

G. Lacombe and W. Naivinit: Understanding farmers' adaptation to rainfall variability in the rainfed lowland rice ecosystem using multi-agent systems modeling

- T.R. Gurung: Can this model be used to assess how farmers are using the water stress threshold in their rice nurseries when making decisions about water use?

WN: This prototype model represents biophysical processes only and does not include individual agents using the resource yet. Therefore, at this stage, it cannot be used to study many other interesting water management issues.

- D. Macandog: How were existing crop-water models used in the development of this application?

WN: They were analyzed and used in the conception of the multi-agent model. But most of them can only be used at the field level and not at the catchment level.

- S. Boissau: What is the influence of the shape of the farmers' fields in the spatial interface of the model (fields of various sizes are represented by hexagonal cells exchanging water with their six neighbors)?

FB: The isotropic hexagonal shape of the cells is the most adapted one to simulate diffusion processes. In this application, the rice fields are made of aggregates of hexagonal elementary cells, the shape of which is not very important by itself.

- P. Promburom: The model is based on surface and underground water diffusion processes, but how is water pumping in the farm ponds taken into account?

WN: The model already has an "irrigation" function corresponding to pumping in the farm ponds.

Le Canh Dung and Nguyen Nhi Gia Vinh: Development of a multi-agent model for Bac Lieu: a case study in the Mekong River Delta

- W. Naivinit: What is the level of poverty threshold used in this case study?
  LCD: US$10 per capita per month.
- N. Suphanchaimart: Why did you choose the week as the time unit?

LCD: This time scale is similar to the decision-making rhythm in use on local rice and shrimp farms.

P.C. Campo: Integrating MAS and GIS modeling with remote-sensing data for participatory natural resource management in coastal Bohol, Philippines

- W. Wardhana: The tools used in this study are costly. What solutions do you see to this problem to promote their wider use?

PC: Establishing collaboration with local organizations could help remove such an obstacle. Nongovernmental organizations particularly seem more appropriate than local government units to adapt and to use this methodology.

Sk.M. Anwar (communication presented by F. Bousquet): Dynamic simulation of land-use change in periurban agriculture

- H. Purnomo underlines the usefulness of the techniques used to understand and model changes in landscape patterns by comparing the maps obtained from remote-sensed data and from the MAS simulation. The goal is not to reach a perfect correspondence but to capture the same type of dynamic emergences. There are still few articles about such a methodological approach in the literature.
- S. Boissau: A similar methodology has been used by the regional component of the Mountain Agrarian Systems Project in northern Vietnam and the results are expected soon.
- P. Campo: What are the effects on the selected indices of a change in the size of the elementary cell on the spatial grid?

FB: It is certain that the size of the elementary cell affects the values of some indices, such as boundary indices, but no in-depth analysis was carried out on the precise aspects.

- T. Gyamtsho: Is it possible to produce maps of future land use based on the past changes observed?

FB: The results of this research provide an understanding of the processes that are structuring and changing the agricultural landscape. If the conditions and processes remain the same, it is indeed possible to show how the landscape structure could evolve. But a key weakness of this study was that no field investigation to understand stakeholders' decision-making rules and processes was achieved. The existing results cannot provide an in-depth interpretation of the land-use changes.

- N. Suphanchaimart: How are the levels of the indices changing on the different maps from 1986 to 2001?

FB: This has just been requested of the authors of this article by one of their external reviewers and the results will be included in the published version of this article.

- G. Trébuil underlines the need to take into account the determining factors and driving forces of land-use changes and the danger of coming back to more correlative, statistical, but less explanatory approaches. For example, how could a sudden crisis or an abrupt change in the evolution of the local agriculture be taken into account in the proposed type of analysis?

FB: Indeed, this research is mainly a methodological development effort and it should be presented as such in the collective book under preparation.

P. Guizol and H. Purnomo: Modeling multi-stakeholders' forest management in Sabah

- S. Boissau: Why do you need to insert actual spatial data in your model?

HP: This is to facilitate the dialogue with some stakeholders. But this choice of more realistic and less abstract maps could present some disadvantages if the stakeholders focus their attention on some precise details, for example. Past experiences in northern Vietnam, northeast Thailand, and Bhutan have demonstrated that we can work with farmers by using abstract landscapes.

- F. Bousquet: It is interesting to observe that quite often farmers are more comfortable with such abstract landscapes than researchers who frequently ask for more realistic features. What are the rules selected for the behavior of smallholders in your model?

HP: Presently, they are attracted by the proximity to the road and the sawmill to maximize their income. Future versions of the model will propose other kinds of behavior related to beliefs, the negotiation of the price of wood with the trader, etc.

Session IV. Learning processes

I. Patamadit and F. Bousquet: Cultural aspects of learning processes in the Thai context: implications for the companion modeling approach

- B. Ekasingh: Thai people are often very quiet during official meetings but more keen to discuss during informal meetings. The conclusions on the potential of companion modeling should be postponed until after many other experiences. But it is true that it is difficult for Thai people to express themselves in front of others.
- IP-FB: The fact that Thai people discuss very easily in some kinds of meetings proves that the role game may not be good for that. But, we observe that simulations are efficient to facilitate discussion because stakeholders can comment on actions of artificial agents. Thus, they do not criticize anyone.
- N. Suphanchaimart: It is difficult to make conclusions on the relation between the game and reality. The game imitates reality and is determined by physical conditions.
- S. Boissau: The interviews after the game are important to understand what part of reality is imported.
- R. Gonzalez: The role of the facilitator is crucial to observe the behavior and to synthesize. It is important to explain the whole process to the farmers before starting the experiments.

G. Trébuil and F. Bousquet: Interdisciplinary training on multi-agent systems, social sciences, and integrated natural resource management: lessons from a regional interuniversity project in Thailand

This presentation aimed at stimulating exchanges among the workshop participants about the several aspects of the training process implemented during the past two years that are not yet giving satisfactory results.

What about setting up working interdisciplinary teams and strengthening collaboration among agriculturalists, ecologists, social scientists, and computer specialists?

- P. Promburom, Le Canh Dung, T.R. Gurung: Interdisciplinary practices are not yet satisfactory because each organization and discipline has its own focus, and individuals have their own preferred disciplinary themes. Social scientists are more interested in abstraction, whereas biophysicists like to look at the ecosystem dynamics. As multi-agent systems are still very new in the local academic landscape, it is still difficult to draw attention to this approach. In general, the modeling approach itself is neither widely used nor popular in the Southeast Asian region as the past era of crop modeling failed to stir interest in and wide use of such tools.
- P. Campo: Individual scientists who are working in a given discipline and are used to its way of solving problems could bring their interest and point of view to interdisciplinary teams anyway. But educational systems are not providing incentives to support this kind of innovative approach, as in the Philippines, where hard sciences such as mathematics receive high priority. Only a few computer scientists have research-oriented activities in the region. There is still a need for more training programs on systems thinking and knowledge integration.
- B. Ekasingh: Colleagues need to be trained in systems approaches before they can see the importance of doing things in an interdisciplinary way.
- N. Suphanchaimart, H. Purnomo, D. Macandog: Depending on her/his own educational and academic background, each member of our network is in a different situation. In the Thai education system, there is no institution teaching interdisciplinary practices. We are still at the very beginning. On the contrary, there are well-developed programs for more conventional training in each discipline. We need to realize that a very important investment will be needed before changes in the way of thinking can be observed in several scientific communities, such as economists. A three-year effort is not enough to achieve such a goal.
- W. Naivinit: The Smalltalk computer language used by the CORMAS platform is not widely known among the local computer scientists and they do not seem to be willing to add this language to their programming skills in addition to more common ones such as Java.
- Vinh Nih Gia Nguyen: I am a computer scientist and, beyond the discussion about the choice of a given software or programming language to model people behavior, we also need to think about concrete and useful applications. I found our use of unified modeling language (UML) diagrams a good way to learn together as a team.
- P. Promburom: Computer scientists do not have problems to secure rewarding jobs and, if we can recruit one of them, two years are necessary before she/he can adopt and function with a systems approach.
- B. Ekasingh: Perhaps CIRAD and IRRI could also explain why it is difficult to convince computer scientists to join our teams?
- G. Trébuil: There are presently many different computer modeling approaches that can be applied in the fields of agriculture and renewable resource manage-

ment depending on the research object, the objectives of the research, etc. But, because of its fundamental interdisciplinary focus, with the interface between ecological and social dynamics, the proposed use of multi-agent systems requires the existence of interdisciplinary teams, including a computer scientist, and they are never easy to set up and maintain.

- D. Macandog: I found that interpersonal relationships could play a very important role and that it was easier to try to work with junior colleagues.

Do we need to set up a specific program to teach the use of multi-agent systems for integrated natural resource management in the Southeast Asian region?

- D. Macandog: Our network still needs new opportunities for training on this approach and these tools.
- H. Purnomo: Regional organizations such as SEARCA-SEAMEO could be approached to help organize future training events.
- P. Promburom: It takes one or two years to train a young scientist in systems thinking and approaches. Even if training on systems thinking is still not very developed, rather than building something from scratch, it could be more efficient to identify an institution at which systems approaches are already being taught. And then graft the approach and tools proposed by our group to these existing programs.
- C. Vejpas: It should be possible to insert new training modules on the pro posed concepts, approach, and tools in existing courses. A new training process in 12 steps will be difficult to repeat.
- D. Macandog and H. Purnomo: Opportunities could also be offered by emerging disciplines such as bioinformatics, social informatics, and virtual or cyber societies.