Participatory modeling and agent based simulation of complex social-ecological systems: an example of companion modeling in northern Vietnam

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Abstract:
The paper presents different uses of multi-agent modelling and gaming-simulation conducted in mountainous areas of northern Vietnam in a companion modelling approach. The first one called SAMBA illustrates the use of multi-agent modelling for testing a hypothesis about agricultural dynamics. The second one called SAMBA-Week is a combination of gaming-simulation, interviews and multi-agent modelling used to better understand individual decision making and its consequences on agricultural dynamics and land use change. We then discuss the benefits of these different tools and show how such a companion modelling approach helps us in: (1) better understanding the studied system, (2) enhancing social learning and (3) integrating interdisciplinary research.

Introduction: An evolving methodology – the Companion modelling approach

In the 1990s a research unit called GREEN was created at CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement). One of its objectives was to understand the interactions of ecological and social dynamics for the management of renewable natural resources. The use of simulation through multi-agent systems was seen as a promising tool for integrating and representing social and ecological dynamics, their interactions and the points of view of different actors on this system. Actually, multi-agent systems are particularly suitable for representing such dynamics as they are based on a set of agents evolving in an environment and communicating with each other (fig. 1).

Keynote Speech - SLAS Conference, Southeast Asia Coastal Governance and Management Forum:
Science Meets Policy for Coastal Management and Capacity Building,
14-16 November 2006, Bali, Indonesia.

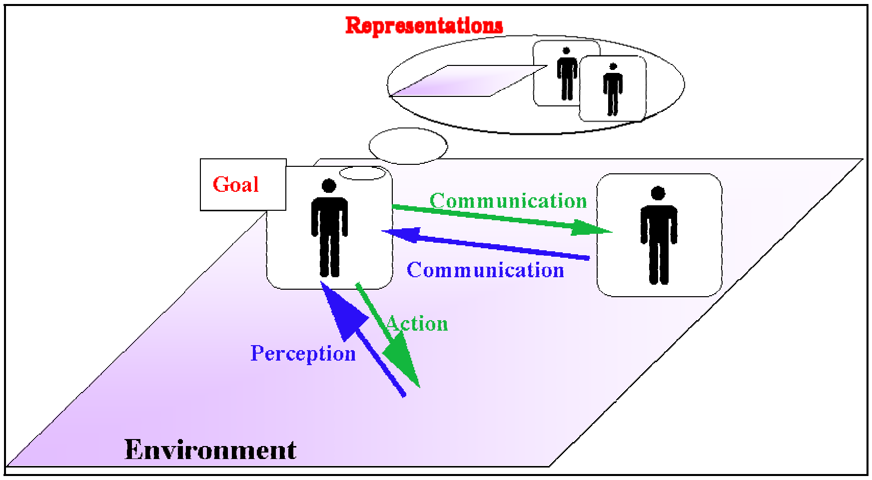

Figure 1: Schematic representation of a multi-agent system

A particular multi-agent platform called CORMAS (Common-pool Resources and Multi-Agent Sytems) and dedicated to the simulation of natural resources management has even been developed (Bousquet et al., 1998). This platform has been used to develop different models based on concrete case studies of water management, land use evolution, wildlife management and forest management (cf. http://cormas.cirad.fr for an extensive list of applications and publications).

Over the past years, researchers using this tool increasingly felt the need to further imply the different actors in one or another step of the modelling process. Gaming-simulation (also called role-playing games) has thus been seen as a complementary tool to computer-based simulations. The correspondence between multi-agent model and gaming-simulation is described in table 1.

Gaming-simulation	Multi-agent model
players	agents
roles	rules
game board	environment
game session	simulation
turn	time step

Table 1: Correspondence between gaming-simulation and multi-agent model elements (adapted from Bousquet et al., 2002)

Three different uses of the combination of multi-agent modelling and gaming-simulation can be found (ComMod Group, 2006):

- validating the model by the stakeholders;
- helping the stakeholders or the users of a model to understand the model, in particular the simplifications operated in the model and the differences between the model and the reality;
- giving the ability to the stakeholders to understand and follow a computer simulation and eventually propose new scenarios to be simulated.

More than a combination of tools an original approach called companion modelling has been developed by a group of researchers leading to the establishment of a charter (ComMod Group, 2003) describing the principles at the basis of this approach. This approach emphasizes the importance of field work and stipulates that research should start from problems encountered in the field, and then follow an iterative process of understanding, confrontation and analysis. Two different uses of this approach are distinguished: (1) the production of knowledge on a particular complex system and (2) the support to collective decision-making processes.

1. In the first case, the challenge of companion modeling is to deliver an improved understanding of these processes rather than a "turn key" itinerary for renewable resources management. It involves an endless cycle from field to modeling and simulation and back to the field with a continuous confrontation to theory. The model is not a simplification of stakeholders' knowledge but rather seeks a mutual recognition of everyone representation of the system through social learning.
2. In the second case, the approach proposes to accompany and to support decision making processes. It uses different modeling tools to help stakeholders to share their points of view and build a shared representation of the system, a necessary step before taking collective decisions that would affect the evolution of the system.

The research presented in this paper is an example of such companion modelling as an evolving process. Starting from the field, a hypothesis is formulated about the dynamics of the system. The hypothesis is then tested using a multi-agent model (part 1). This will in turn bring new questions that induce the development of a new methodology (part 2), et cetera. We conclude with a discussion about the benefits of the companion modelling approach and the use of multi-agent models and gaming-simulations.

1. SAMBA: testing an hypothesis through MAS modelling

The different modelling experiences presented in this paper were conducted as part of the SAM (Mountain Agrarian Systems) – Regional program in the northern Vietnam province of Bac Kan, around 150km north of Hanoi and one of the poorest provinces of Vietnam. The SAM-Regional Program was a cooperation between IRD (Institut de Recherche pour le Développement, France), IRRI (International Rice Research Institute), and VASI (Vietnam Agricultural Science Institute). The goal of the program was to understand agricultural and land use dynamics from the village to the province level in order to promote more sustainable natural resources management. Tools used by the program included monographic studies, interpretation of aerial and satellite photographs, several participatory methodologies, linear programming, gaming-simulation and multi-agent modelling.

History of the agrarian system

The monographic studies conducted in Bac Kan province made it possible for us to compile the following history of the agrarian system during the 20th century. This history can be summarized as a succession of four different kinds of land use (Castella and Dang 2002).

1. Before agricultural collectivization at the end of the 1950s, land use was relatively extensive, with a single rice crop per year in the lowlands and slash-and-burn agriculture with long fallow periods in the uplands. The Tay occupied the lowlands, and the Dao lived in the uplands.
2. During the collective period (1960–1988), lowland rice production was intensified using the technologies of the Green Revolution. The Dao people were moved to the valley bottoms to contribute to the newly founded cooperatives alongside Tay households. Cultivation of the hillsides was forbidden by local regulations, and the practice of slash and burn was restricted to a few small fields near the village.
3. In the late 1970s and early 1980s, agricultural production was unable to keep pace with the growing population of the region, whereas the hillsides continued to be underexploited. Although the resource base was maintained, the food needs of people were not being met. Beginning in 1982, a series of reforms led to the eventual dissolution of the cooperative system through a successive modalities of redistribution of paddy fields. This failure culminated in an abrupt return to traditional shifting cultivation practices and an uncontrolled rush to clear and appropriate as much upland area as possible. Within a few years most of the forests in the province had been cleared.
4. In 1990, there was a spontaneous movement among the Tay to reclaim the paddy fields that had been collectivized in 1960. Families took back the paddy fields of their ancestors, reproducing the land inequalities of the pre-independence system. The households who could secure individual ownership, first of paddy fields and then of sloping lands, intensified paddyland production by means of techniques such as rice double-cropping, chemical fertilizers, and mechanization, and then increased both their labor investment as well as their medium- and long-term investment on the hillsides, e.g., permanent agro-forestry systems, expansion of land under maize associated with pig raising, and perennial plantations. However, not all families were able to develop such sustainable land uses. Families who had joined the cooperatives in the later years of collectivization, mainly Dao ethnics, were deprived of the paddy fields on which they had been working for years, and many subsequently had no other choice but swidden cultivation. These families are now facing a critical situation of poverty, whereas, for the dominant Tay villages, agriculture has generally improved over the past decade from both an agro-ecological and a socioeconomic point of view.

Formulation of the hypothesis

Mechanisms for the redistribution of the means of production were poorly documented even though they are responsible for most of the recent changes in land use. Several reasons can be put forward to explain the lack of documentation:

- Local decisions often superceded official policies. The official policies were clearly documented, but in a crisis context (especially regarding production cooperatives), decisions of the local authorities were not well documented.

- Changes were extremely rapid with a new land policy every four years,
- The extreme diversity of local situations and characteristics of the different villages including their natural environment, resources endowment, accessibility, and ethnic groups.
- Some of the land tenure conflicts are not yet settled today and it remains taboo to discuss these issues.

We thus had to formulate a series of hypotheses regarding the past and future impact of land rights and access to resources on (i) agricultural and environmental dynamics and (ii) farming system differentiation. Our hypotheses are summarized as follows:

Ecosystem use was gradually intensified through four successive stages:

- Land use rights distribution for the lowlands associated with free access to the uplands and higher upland labour productivity as compared to the lowlands led to agricultural intensification in the uplands through shifting cultivation.
- Once the limits of suitable land for slash-and-burn practices were reached, rice systems were intensified in the lowlands and livestock herds were expanded.
- From 1990, secure land tenure in the lowlands and later in the uplands became strong incentives to increase labour investment in annual crops and later medium and long-term investment in perennial crops (for example fruit tree plantations).

We developed the SAMBA multi-agent model to test these hypotheses and assess their validity domain.

The SAMBA model

The SAMBA model has been implemented using the Cormas multi-agent platform (Castella et al., 2005). It is composed of two main entities:

- the land represented by a 50x50 grid is characterized by its suitability for irrigated rice, its land use and its remoteness from the village,
- household agents who have needs depending on the number of mouths to feed and labour force.

Households follow a quite simple rule of behaviour: they first allocate their labour force to irrigated rice cultivation. If it is not enough to cover their needs, they allocate the exceeding labour force to upland rice cultivation and if their needs are covered by irrigated rice cultivation, they allocate their labour force surplus to perennial crops.

At initialization, "*paddyField*" cells are distributed according to the number of mouths to feed, and after four time steps, they are re-distributed according to the labor force of each "*HouseHold*" agent. The simulation then runs during four more time steps. The total duration of one simulation is eight time steps. The resulting land use dynamics are presented in figure 2.

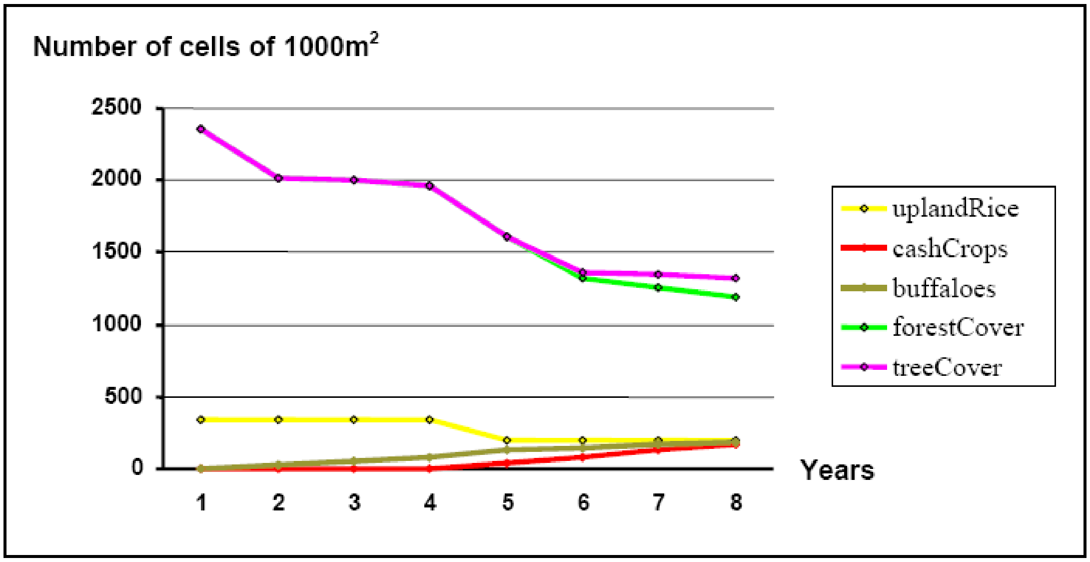

Figure 2: Evolution of land use in a SAMBA simulation

But more than the global evolution of land use, the important output of the model is the differentiation between households. Actually one can see three different types emerging from the simulation. These are presented in figure 3.

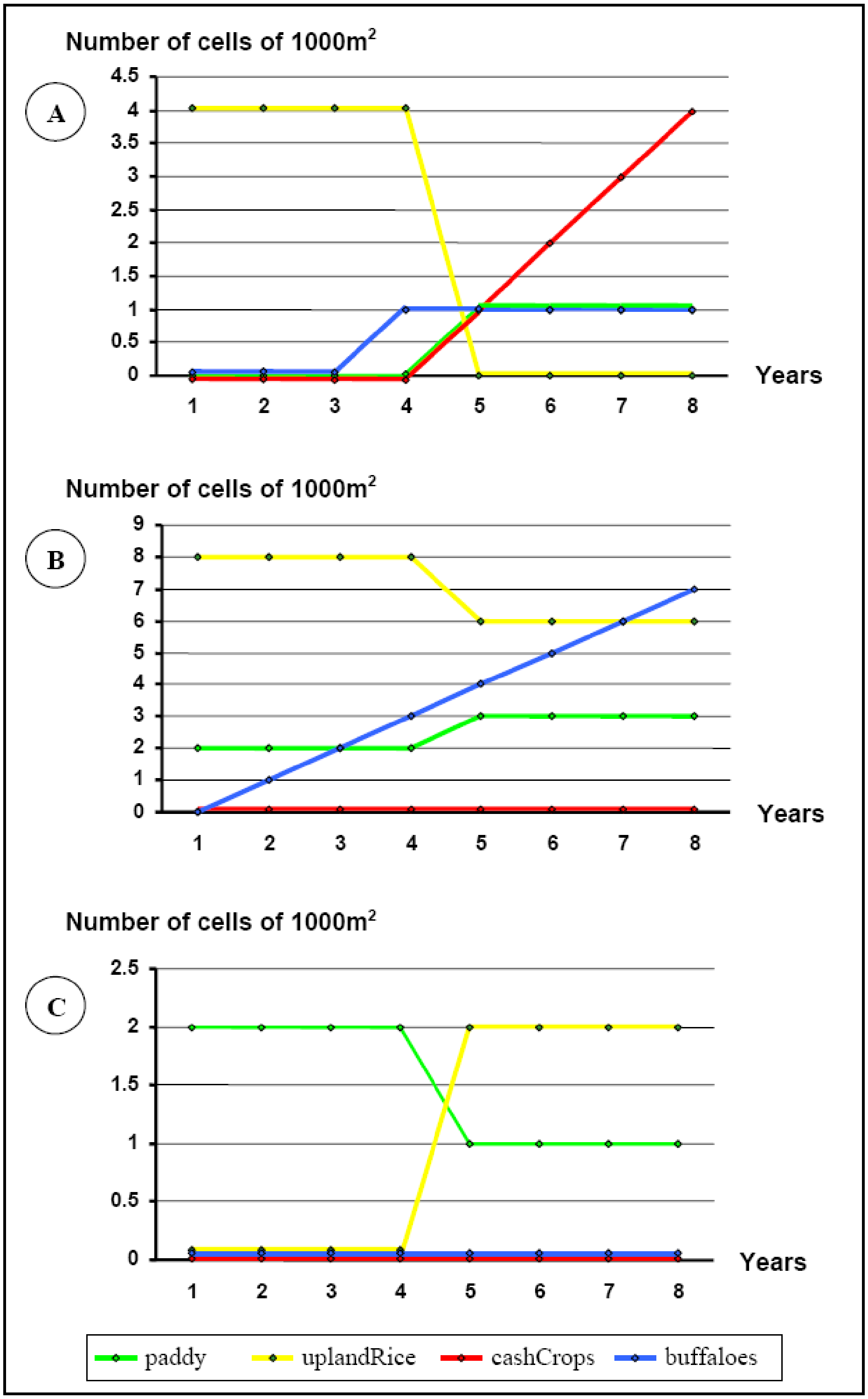

Figure 3: Typical output of a simulation with three types of households

Such results confirmed our hypothesis on the importance of households' demographic composition during the different rounds of paddyfield allocation. However, this hypothesis could only apply to a specific period, i.e. until the beginning of the 1990s, and could not explain the changes observed over the last 10 years. A new policy of allocation of forest land to households combined with economic liberalization and the development of ambitious government projects for the alleviation of poverty and for reforestation in the mountains accelerated the process of agricultural transformation. We thus had to develop a new model that would account for the recent agricultural dynamics but also for the diversity of situations in a single province.

2. SAMBA-Week: developing a methodology to understand on-going dynamics

From the model to the game

Our first idea was to transform the SAMBA multi-agent model into a gaming-simulation, thus having stakeholders simulate their own situation and behaviour through a game. This gaming-simulation had two different objectives: first, the validation of the SAMBA multi-agent model, and secondly we hoped that through the game we could better understand the behaviours of stakeholders in order to explain on-going agricultural dynamics.

A first gaming-simulation has been conducted and confirmed that gaming could be a precious tool to gather information (Boissau et al., 2004). The exercise was a helpful tool for facilitating communication between researchers and farmers. Even if the participants felt a little confused at the beginning, they rapidly became engrossed in the game and became very serious about the actions they had to perform. Moreover, they recognized similarities between the game and reality in their own village. We found similarities and real continuity between field studies previously conducted in the same commune, the SAMBA multi-agent model derived from these studies, and observations during the gaming-simulation. However, in order to go deeper in the understanding and collect more accurate information, we decided to extend the gaming-simulation to a one week session called SAMBA-Week including gaming-simulation, interviews and multi-agent modeling.

The SAMBA-Week sequence

The grid of the simulation environment was represented by a game board composed of cubes with each side painted a different color; each color represented a type of land use or cover (Fig. 4).

Figure 4: The game board used for the SAMBA gaming-simulation (photograph by J.C. Castella)

With the help of the facilitators, the participants designed a virtual landscape resembling their own village on the game board. They drew cards that accounted for the composition of their virtual families and the numbers of paddy fields and buffalos they owned in the game. They then had to manage their production to feed their families. Through these actions, the farmers were able to change the land use and the land cover represented by the different colors on the game board. For an individual action, such as opening upland fields as close to the house as possible or turning upland rice fields to fallow after several years of cultivation, to become a rule, it had to be either repeated by many players independently or agreed upon by all the participants as the usual way to do things in the context of their village. The same was true for the parameters of the model they were constructing jointly, e.g., yield of main crops, labor requirements for each of their actions; these resulted from a consensus among all the participants and were often the occasion for lively discussions. At the end of each round of the game, the income generated from the different activities was computed, and the players received virtual money computed as rice equivalent. This reward for their decisions and actions was first reinvested in basic food consumption. When the financial balance of a household agent was positive, he or she was able to buy pigs or buffaloes or nonagricultural products. Conversely, when the balance was negative, the household agents had to borrow money from others or from the bank or engage in off-farm activities. About 6 years could be simulated in the successive rounds of the game, and the one-day session ended with a collective debriefing. All the actions of the individual players were recorded along with all the interactions and discussions. The role-playing game proved to be a very powerful tool that enabled us to observe the actions of the player-farmers, elicit their decisions in context, and discuss with them the land use that would result from the actions they had undertaken in the gaming simulation (Greenblat 1981, Castella et al. 2003, Boissau et al. 2004). The rules of the RPG were intentionally kept very open to allow the players to explore solutions that the researchers might not have included in the model or that the players themselves might not dare to risk in real life. This brought to light valuable information about how farmers deal with risk and uncertainty and how they adapt to changing circumstances or to an unexpected outcome of a decision they made. Contrasting strategies of the players were identified, including repetition, imitation, innovation, and cooperation. The behaviors that had been used during the game were then discussed collectively and linked with stories or events that had really happened.

During the following three days, two processes were undertaken in parallel:

- Individual interviews were carried out with the players to understand the rationale behind the actions they had undertaken during the game. They were asked to justify their actions round after round, for example, with regard to their economic situation, their past actions, the actions of the other players, their real-life situations, etc. These questions were intended to help us understand what had happened during the game. The interviews also tackled the question of the difference between the game and reality from both a general and a more individual point of view. Finally, the interview ended with an assessment of the game by the interviewee.
- A computerized multi-agent simulation of the game was implemented. The model, and especially the behavior of the agents, was based both on our observation of the game and on the information obtained during the individual interviews. This first model was intended to replicate as faithfully as possible the sequence of the game, by specifying only general rules for individual behaviors and land-cover dynamics, as identified during the two previous steps. These rules were then used to simulate potential scenarios identified by the participants, for example, scenarios with population 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 the computer simulation. The session typically started with the presentation of the simulation that replicated the game session they had played a few days before. Through this presentation, the players became familiar with the computer model and learned to follow a simulation on the screen. For example, they were able to describe the changes in the landscape and to infer the behaviors of the agents. Other scenarios were then presented to the participants and discussed. Computer-simulated scenarios allowed us to simulate, in a shorter time, longer periods than those used in the game and therefore to show farmers the long-term implications of their choices. The discussion focused in particular on the similarity between the simulated scenario and past, present, or future reality; the likelihood of the scenario actually happening; the problems that would result; and possible ways of solving them (Boissau and Castella, 2003).

3. Discussion: The benefits of the ComMod approach

We presented above two different uses of simulation that are part of a single process aiming at understanding a complex reality. In this section, we propose to discuss the methodology, the different uses of simulation and the companion modelling process as a whole.

Modelling to better understand the system

If in both cases presented above the goal was to better understand a particular situation and its dynamics, the method used was different. In the first case (SAMBA), a hypothesis has already been formulated and the objective of the model is to test this hypothesis. It is thus a deductive approach. By contrast, in the second case (SAMBA-Week), gaming is used to make the stakeholders build by themselves a model of reality and for the researcher to infer from it behavioural rules and resulting dynamics. This approach is thus inductive.

Whereas these two approaches could appear somehow contradictory, we think that they can easily be complementary as part of a whole process. Both of them give answers to different questions at different steps of the research process.

In the case of the SAMBA multi-agent model, simulation can be seen as a tool helping thought. In social sciences, especially sociology and social anthropology, as compared to "hard" sciences, experimentation is hardly possible. Therefore, explanations of any phenomenon are generally given in a literary form and refutation goes through the identification of some error in the reasoning and/or the identification of any counter-example. Thus, simulation can be a very useful tool to detect our own errors in reasoning as it gives us the opportunity to "test" our reasoning by putting our hypotheses in the machine and see if the consequences are the ones we had pictured.

Moreover, simulation and the act of modelling in particular can be a precious help for the researcher in clarifying his thinking/hypothesis/theory. Especially, it can help in identifying any kind of presupposition as well as the conditions under which the theory applies. When someone wants to build such a model, he has to define the different agents, their rules of behaviour and the different types of interactions between them. Any missing element may lead to a bug or an inconsistent behaviour of the whole system thus forcing the researcher to specify the missing elements or to clarify incomplete ones. In this way, the construction of the model will bring new questions, leading the researcher to have a closer look at the field. Modelling is thus a process that brings the researcher back and forth from the field to the model.

In our case, modelling is more than just writing computer programs, and can be seen as part of the research as it implies a real reflexivity. By modelling, the researcher is constantly confronted to his own reasoning, its weaknesses and its limitations. In many respects, the modelling process can be considered as more important that the resulting model or its outcomes.

This is particularly true as the validation of multi-agent models is still an open question and there is still no validation theory for such models. As methods used to validate mathematical models are not applicable to these models, one way to overcome the problem would be to achieve some kind of social validation. For example, Barreteau et al. (2001) transformed their multi-agent model into a gaming-simulation and presented it to stakeholders in order to validate the model. Another way to increase the validity of such model is to imply the stakeholders in its construction from the very beginning. That is what we did with the SAMBA-Week experience.

The methodological hypothesis at the beginning of the development of the SAMBA-Week methodology was that stakeholders would behave in the game as they do in reality. Such a hypothesis may be quite strong (Daré, 2005) and also quite difficult to verify. During individual interviews following the gaming session, we tried to evaluate the distance between the game and the reality at both individual and collective levels. If we can say that the course of the game was overall very close to the reality, we could also notice that differences could have a very important role in our understanding of the system. Actually, the most important point was not so much that the game would be a perfect picture of the reality but rather that we (researchers and stakeholders) had played that game together. The game session could then become a common basis for discussion and similarities as well as differences between the game and reality are points of departure for a better understanding of the system. A typical discussion during the interview following the game session could be presented as follows:

"- Why did you do this in the game?
- For this and that reason.
- Do you do the same in reality?
- No. Because the conditions are different
- What are these differences?
- …"

The game becomes a reference point and actions in the game as well as actions in reality are justified by reference to it. This is particularly useful in a situation as the one in Vietnam where there is generally a large difference between the discourse and the practice. When people are asked about their practices they would generally answer you with the official discourse. For example, they hardly admit that they practice slash and burn cultivation because this practice is officially forbidden. The task of the researcher is thus to try to go behind this official discourse to understand what are the real practices. It generally implies establishing trust in the relationship and spending extended periods of time on the field. Through the game and the SAMBA-Week methodology we achieved collecting reliable information in a quite short period of time. Of course, such information may not be as precise as in an ethnographic survey but, depending on our final objective may be either sufficient or a strong basis for going further.

Social learning

"Social learning reflects the idea that the shared learning of interdependent stakeholders is a key mechanism for arriving at more desirable futures" (Leeuwis and Pyburn, 2002). Social learning is based on a constructivist paradigm. In this view, there is no given objective reality but rather different actors who have different perceptions of the world. Reality is socially constructed. In such a perspective, natural resources management is not a top-down process which goal would be to reach some optimal solution but rather a bottom-up process based on the exchange of different points of view and the co-construction of some desirable future.

Companion modelling, including participatory simulation and gaming, can be a very useful approach in a social learning perspective. Actually, the SAMBA multi-agent model could be qualified as "armchair modelling": based on data and some understanding of the field, the researcher emits a hypothesis and tests it through the construction of a model. On the other side, the SAMBA-Week methodology really reflects a social learning process in which the model is collectively constructed with the actors. We imposed only the structure of the game and most of the elements of the game were decided by the participants. These elements were proposed by the participants and discussed among them before to be integrated into the game. For example at the beginning of the game we asked the participants to draw their village and the surrounding landscape on a piece of paper. After discussion and collective agreement, this drawing was somehow "rasterized" and used to initialize the game board. The mean production levels of the different crops and the labour force needed were also agreed collectively.

How "good" is the resulting model?

Based on the observation of the game session and the interviews conducted during the following days, we infer rules of behaviour that are incorporated into the multi-agent model. This may be the most difficult task as it relies on interpretation. We have shown that it is even very difficult for someone to interpret the rules behind his own behaviour even if this one is quite simple (Boissau et al., 2005).

Two different processes help us in validating in some way the model:

- by comparing the outputs of the simulation with the ones of the game. One may compare for example the evolution of the land use, households' indicators (wealth, number of buffaloes, area of different crops, etc) and global indicators.
- by presenting the simulation to the participants of the game and asking them to assess it.

What do people learn from SAMBA-Week?

It is quite difficult to say exactly what participants learned from the SAMBA-Week process as our main objective was mainly the understanding of dynamics and we did not implement any evaluation of the impact on participants. However we can mention some elements that would need to be further explored.

First of all, participants often mentioned during the interviews that the game gave them a deeper understanding of the system as a whole and how individual actions combined together may influence their system and particularly the evolution of land use. This is actually the quality of such models to translate reality in another scale of time and space. In the game, participants played about 6 years in one day, with a village reduced to 10 households. It is thus very easy to see for example how the land use evolved over the game session and participants know that it only evolved through their combined individual actions. Through the game, participants can see the system as a whole whereas in reality they generally only see part of it.

Another important concern of the participants was the exploration of scenarios: "What would happen if we do this or that?" Such scenarios could easily be constructed with the multi-agent model and people are able to follow, comment and interpret the evolution of such simulations on the computer screen. In such a simulation, ten years or more can easily be simulated in a few minutes. Moreover, parameters can easily be adjusted to test slightly different scenarios. Such scenarios do not pretend to have any predictive value but rather constitute a basis for discussion with and among the participants. In this way, they may consider the consequences of their present actions on the long term. For example in a village where we conducted the SAMBA-Week process, villagers had just planted pine trees as part of a reforestation program. By running a simulation focusing on the growth of pine trees, participants could see by themselves that in the future it would have an influence on availability of grazing areas and thus on cattle raising. They also better understand how interrelated their actions are: interdependence between different individual actions but also interdependence between the different uses that can be made of one resource. Such a point could have been made in many other ways but in our case the important parameter is that participants have somehow constructed the model by themselves and therefore feel much more concerned. They often want to "play" with the model they have built and to test different options. It gives rise to discussions about the outcomes of the model and their consequences.

Such methodology thus enhances discussion about practices, potential problems and the future of the system. For the stakeholders, it generally brings more questions than answers but however may constitute an important step of a long process aiming at helping stakeholders to manage resources in a more sustainable way.

A platform for interdisciplinary research

The last point we would like to make is that both the methodology and the tools (gaming-simulation and multi-agent modelling) presented here are not discipline specific. The companion modelling approach has been developed by a group of researchers from different disciplines (geography, ecology, economics, anthropology …) who had often to collaborate with people from other disciplines about problems of natural resources management. Having experienced the difficulties of interdisciplinary research, they developed an approach that is anchored to the questions encountered on the field rather than starting from the theory, which is highly discipline specific. The different tools used in this context thus also need to be open to any discipline. Actually, both gaming-simulation and multi-agent models have been used in all kinds of disciplines. Through their openness, such tools can be used as a platform for interdisciplinary research. We do not say that the use of such tools may necessarily lead to real interdisciplinary interactions but rather that it may be easier for researchers from different disciplines to discuss together around a game or a multi-agent model used in a companion modelling approach. The different researchers are also part of the system they study; with a particular perception of it, and in this way also need to participate in the social learning process just as any other stakeholder.

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