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SPATIAL REPRESENTATIONS ARE NOT NEUTRAL: LESSONS FROM A PARTICIPATORY AGENT-BASED MODELLING PROCESS IN A LAND-USE CONFLICT

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Abstract — The objective of this paper is to question the increasingly common choice to build and use spatially explicit models, especially in the case of participatory agent-based modelling processes. The paper draws on a combination of lessons from literature and the case of a companion modelling process conducted in the context of a conflict about land and forest management in Northern Thailand. Using insights from negotiation theories, we analyse specifically the influence of spatial representations on the way people interacted, discussed and learnt from each other in the participatory modelling process. We argue that models that are spatially too explicit and realistic can actually impede the exploration of innovative and integrative scenarios in which ecological, social and economic objectives are mutually enriching. Indeed, spatial representations might lead to think in terms of boundaries and segregated space, and therefore prevent from thinking in terms of multifunctional space and from finding innovative and integrative solutions.

Key words: agent-based model, participatory simulations, spatial representation, integrative negotiation, companion modelling, forest conservation, Northern Thailand

INTRODUCTION

Agent-based modelling allows the analysis of interactions between heterogeneous social agents and their environment and is therefore widely used in the field of natural resource management (NRM) (Bousquet and Le Page, 2004; Janssen, 2005). It can be used in a participatory way to involve non-scientific stakeholders in modelling and simulating processes (Voinov and Bousquet, 2010). Participatory agent-based modelling is then seen as an innovative way to enable various stakeholders to better understand each other and to explore scenarios that reconcile social, economic and ecological objectives in NRM. Examples of such participatory modelling processes can be found in various contexts such as fishery management

(Worrapimphong et al., 2010), conflicts over irrigation water (Becu et al., 2008), floodplain management (Metcalf et al., 2010), land-use planning (Lagabrielle et al., 2010), forest management (Simon and Etienne, 2010), soil erosion control (Souchère et al., 2010), labor migration (Naivinit et al., 2010), etc.

Many, if not most of these experiments share a common feature: their models usually rely on a spatial interface to visualize dynamics. There are several reasons for that. First, many NRM issues and conflicts do have a spatial dimension, especially when they are somehow related to land-use and land-cover change (Bonnin and Torre, 2004). Second, we live in a world which is increasingly spatially explicit, and spatial planning, participatory or not, is nowadays one of the major tool of governance (McCall, 2003). The third reason, linked to the previous one, is the development of spatial information technologies (SIT) that are increasingly sophisticated and powerful (Fox et al., 2006). In particular, agent-based models have proven their efficiency to analyse and simulate land-use change and land-use cover issues, especially when linked to geographic information systems (GIS)(Parker et al., 2003).

In this article, we examine the non-neutral choice of using spatial representations in participatory agent-based modelling processes. In other words, we question the common assumption that having a spatially explicit model is a good thing to facilitate learning and negotiation processes among multiple stakeholders. Up to our knowledge of the literature, this issue has been hardly addressed in the field of environmental modelling. A few scholars discussed the pros and cons of more or less realistic spatial representations in participatory processes. Some authors argue that the more realistic the representations are, the more the stakeholders will feel at ease with them because they are closer to their everyday life (Lange, 2001). Others point out that spatial representations that are very realistic such as those based on GIS or aerial photographs show more details and facilitates the expression of a greater diversity of perceptions, while a more abstract representation narrows the diversity of possible interpretations (Maurel, 2001). But several authors also highlight the disadvantages of using too realistic spatial representations with stakeholders. In the case of a participatory modelling process, the simpler the model is, the easier it is for the modeller to be transparent regarding its content vis-à-vis the stakeholders. A very realistic and detailed spatial interface leads to an increased “black box” effect (Dumrongrojwattana et al., 2009; Horlitz, 2007). Other authors have observed that less realistic and therefore more abstract spatial representations allow the stakeholders to create a distance from reality, which can be interesting when there are conflicts among them (Gurung et al., 2006) and /or when creative learning is expected (Dionnet et al., 2008).

If the almost systematic use of spatially explicit models has hardly been questioned in the field of environmental modelling, the question has been raised by a few scholars working in the field of community mapping and participatory GIS (Fox et al., 2006; Roth, 2007; Sirait et al., 1994). Of course, using spatially explicit representations has several advantages. In the context of conflicts over resource use between communities and state administrations in developing countries (for example in the case of the establishment of a conservation area), community based-mapping that enables the villagers to make maps of their lands and resource uses (such as in “counter-mapping” processes) have the potential to increase the legitimacy of their claims in the eyes of state administrations (Peluso et al., 2008). Participatory GIS has also been used to solve such conflicts through processes of mutual learning and increased mutual understanding (Kyem, 2004, 2006). However, the impacts of the widespread adoption of SIT are not limited to the intended objectives. This is what Fox *et al.* (2006) called the “ironic effects of spatial information technology”. SIT are indeed based on a particular conception of space, the one of resource managers, administrators and the state, which consists of “a measurable

plane with boundaries delineating homogeneous zones” (Roth, 2007). This conception of space is very different from the one used by many rural communities in developing countries, especially the spatiality of community resource management which is by nature overlapping and flexibly bounded and therefore more complex than what can be represented on simplistically bounded two dimensional patches. As a consequence, among the unintended consequences of using SIT with rural communities have been the loss of indigenous conceptions of space, increased conflicts¹ between and within communities, and increased pressure toward the privatization of the land (Fox et al., 2006; Roth, 2007; Sirait et al., 1994).

Beside these debates, little has been written about the influence of the choice of spatial representations on the contents and dynamics of participatory processes, especially in participatory modelling ones. This paper addresses this issue drawing on a combination of lessons from literature and the detailed analysis of a participatory modelling process conducted in the context of a conflict about land and forest management in Northern Thailand. Using insights from negotiation theories, we analyse the influence of spatial representations on the way people interacted, discussed and learnt from each other in this participatory modelling process. We argue that models that are too spatially explicit and realistic can actually impede the exploration of innovative and integrative scenarios in which ecological, social and economic objectives regarding land management are mutually enriching. Indeed, spatial representations might lead to thinking in terms of boundaries and segregated space, and therefore prevent from thinking in terms of multifunctional space, and from finding innovative and integrative solutions.

The paper starts with a few theoretical insights from learning and negotiation theories that were used to analyse interactions among stakeholders in the described participatory modelling process. The three following sections present the social-ecological context of the process (a conflict between two communities of farmers and the board of a national park), the main methodological principles of the participatory modelling process that was implemented (a companion modelling approach combining role-playing games and agent-based models), and a short description of the agent-based model that was built and used with the local stakeholders. Dedicated to the presentation of the results, the fifth section focuses on the scenarios simulated with the agent-based model and the effects of these simulations on the learning and negotiation among farmers and national park officers. In the subsequent discussion section, we take a step back, addressing the following question. How far can negotiation theories help us think about trade-offs and synergies in NRM? What are the potential and limits of participatory agent-based simulations to support creative and integrative negotiation processes for sustainable management of renewable resources by multiple users? And in particular, what is the influence of the use of spatially explicit models in such negotiation processes?

1. INSIGHTS FROM LEARNING AND NEGOTIATION THEORIES

To analyse interactions among stakeholders in a multi-stakeholder process, some authors use the concept of social or collective learning (Röling and Wagemakers, 1998), while others prefer talking about negotiation processes (Leeuwis, 2000). The former refer to the soft-systems approach, while the latter belong to the critical systems approach. Soft-systems thinking emerged in the 1980s as a cognitive approach to analyse multi-stakeholder systems (Checkland

¹ Fox *et al.* (2006) report cases where customary boundaries that were traditionally flexible became less flexible after experiences of community mapping, causing disputes when these boundaries overlapped with the neighbour's boundaries. Moreover, since mapping is about delineation of boundaries, it created a sense of exclusion, and in several cases, led to land privatization that exclude others.

and Scholes, 1990). These authors emphasize the fact that stakeholders have different perceptions of reality, according to their personal background, activities and specific interest. They consider that the lack of communication and mutual understanding among stakeholders is the main problem of multi-stakeholder processes. This is the reason why they emphasize the need for more dialogue, and analyse multi-stakeholder processes mainly in term of collective learning. People learn about the situation and about the other stakeholders' perceptions, and reframe their own perception of the situation. This is seen as a key preliminary step before to search for mutually acceptable solutions.

The 1990s saw the emergence of critical systems approaches emphasizing the existence of conflicts and coercion among stakeholders (Ulrich, 2003). They consider that dialogue is not sufficient for stakeholders to find mutually acceptable solutions, because the most influential stakeholders could impose their views. They suggest strategically taking into account power asymmetries in multi-stakeholder arenas to enable the least influential stakeholders to express and assert their interests. Consequently, they suggest analysing multi-stakeholder processes not only in term of collective learning, but also as negotiation processes.

Authors such as Leeuwis (2000) point out that these two approaches are very complementary because a "successful" negotiation integrates much learning. But what is a "successful" negotiation? Scholars commonly distinguish between compromise and integration (Carnevale, 2006). In a compromise, each side gives up something, meeting midway between opening positions. They simply "share the cake" in a zero-sum outcome. On the contrary, in integrative negotiation, the stakeholders creatively reframe the problem to "enlarge the cake" and to identify "win-win" solutions. This process implies an important learning effort in which both sides look beyond their initial positioning to examine the underlying interests determining them, or even their deeper values. Carnevale (2006) illustrates this with the case of two sisters who argue because they both want an apple (while there is only one). In a distributive negotiation process, the two sisters would cut the apple in two pieces. In an integrative negotiation process, with a closer look at their underlying interests, the two sisters would realize that one is interested in the flesh for cooking, while the other wants the seeds for planting. In this paper, we used these theoretical insights about distributive versus integrative negotiation processes to analyse a land use and forest management conflict between a new national park and two rural communities in Northern Thailand.

2. A CONFLICT ABOUT FOREST MANAGEMENT IN THAILAND HIGHLANDS

A companion modelling (ComMod) process was conducted in 2006 in the highlands of Nan province, in the context of a conflict between a new national park being established and two Mien (or Yao) communities located near the future boundaries of the park. This conflict raised both environmental and social issues. On the environmental side, the stated objectives of the national park were twofold: (i) to protect the area from deforestation to avoid flash floods and water quality problems in the lowlands (as this area is located in the upper watershed of one of the main attribute of the Chao Phraya river, a key national source of water for rice production, industries and large cities in the central plain of Thailand), (ii) to protect the biodiversity of a special type of forest in the country. In particular, conservationists are sensitive to the preservation of the *Arenga pinata* palm, an endemic species of this region. On the social side, these highlands are populated by ethnic minorities whose livelihoods are traditionally very dependent on forests, for both economic and spiritual uses . In this area, the farmers used to

practice a type of pioneer shifting agriculture², but these farming practices have been discouraged since the enforcement of the ban on encroachment (no conversion of forest to farmland allowed) in 1989, and farmers have gradually shifted to permanent cultivation, together with a shift from self-subsistence to commercial agriculture (Trébuil et al., 2007). However, in spite of the ban, the lack of land still leads some of them to open new plots in the forest. Moreover, in local farmers' livelihood systems, the collection of non-timber forest products (NTFPs) is a key source of food and income, in particular among the most resource-poor households. Most NTFPs are for self-consumption (bamboo shoots, mushrooms, medicinal plants, etc.), but some of them, especially the fruits of *Arenga pinata*, are sold on the market. Since Thai law forbids any human activity except tourism within national parks, villagers felt threatened by its establishment. They would be more or less affected depending on the type of farm they manage.

In these two villages, three main types of farming households were identified and characterized by different socio-economic constraints, amounts of productive assets, farming strategies, and consequently contrasted interests regarding the national park issue (Barnaud et al., 2008). Type A households were very economically vulnerable landless or near landless households, highly dependent on gathering of NTFPs for the generation of cash income and family consumption. Without access to NTFPs, they would have to leave the village and work as urban wage earners. Type B farming households earned a large share of their income from agriculture and were mainly concerned by the risk of losing farm land. NTFPs were also a concern to them as it is a complementary source of cash to compensate for fluctuating farming incomes. Type C farming households had enough capital to invest in rather profitable off-farm activities allowing them to invest in large litchi orchards. Therefore, they did not feel threatened by the national park issue.

To fully understand the context in which the conflict between the national park and the villagers took place, it is also necessary to take into account political context in which it took place. In Thailand, there are several long lasting negative prejudices against ethnic minorities living in the highlands within the more powerful Thai lowlanders (McKinnon and Vienne, 1989). These "montagnards" have long been considered by the government as trouble makers. They were accused of being potential communists and opium growers during the cold war, and more recently considered as destroyers of the highland environment. In 2006, when the ComMod process began, the relations between the national park and the villagers were based on mutual mistrust and prejudices on both sides. Moreover, the general situation was unclear, with a lot of misinformation among villagers. In particular, the key questions of the future location of the park boundary and the rules to be enforced within the park regarding the collection of NTFPs had not been discussed yet beyond a limited circle of village leaders. But many of these leaders (mainly type C farmers) were not preoccupied by this issue. Therefore, there was a risk for the chief of the national park to make unilateral decisions or at best, after consulting a few village leaders only. In this context, the ComMod process was conducted to facilitate dialogue between the villagers and the board of the national park while taking into account the diversity of interests among villagers, and to support an integrative negotiation process among them.

² Also called slash-and-burn or swiddening agriculture: farmers clear a piece of forest, burn the vegetation in the dry season and cultivate this plot for a few years before to let the forest regenerate while moving to another plot. Two main types of swiddening systems were practiced in northern Thailand, the pioneer one (practiced by the Mien people in particular) being more harmful for the forest ecosystem than the rotating one.

3. METHOD: A COMPANION MODELLING PROCESS

ComMod is a participatory modelling approach aimed at facilitating collective learning among stakeholders (including researchers) about renewable resource management problems in complex socio-ecological systems (Barreteau et al., 2003; Bousquet et al., 1996). Alternating field and modelling activities in an iterative way, its main principle is to develop simulation models integrating the different stakeholders' points of view on the problem at stake, and to use them as communication platforms to collectively explore and discuss various scenarios for the future. This approach is used with two possible aims: (i) to produce knowledge on the socio-ecological systems, and/or (ii) to accompany collective decision-making processes among the stakeholders. The case study described here falls into the second category.

As in several ComMod experiments, two kinds of simulation tools were combined: Agent-Based Models (ABM) and Role-Playing Games (RPG). ABM are particularly appropriate to represent complex socio-ecological systems because of their ability to represent interactions among heterogeneous social agents and between these agents and their common environment (Bousquet et al., 1993; Ferber, 1999). RPG is an appropriate mode of communication to convey complexity as it allows multiple stakeholders to interactively examine the complex systems they are part of (Duke, 1974). In a RPG, players can discuss about and test alternative scenarios of potential solutions, but quickly the use of this tool becomes costly and very time consuming. To remove these constraints, it is possible to build a simple computerized ABM, very similar to the RPG in its features and rules, but far more cost and time-efficient to simulate scenarios. Moreover, since the RPG is based on the same conceptual model than the computer ABM, the use of the RPG can be seen as a way to "open the black box" of the computer ABM (Barreteau et al., 2001). It allows players to understand, validate and/or criticize and enrich it and, later on, to be able to follow ABM simulations and to comment their results. The model underlying both the ABM and the RPG is therefore built iteratively, based on a combination of knowledge coming from the researchers' observations and the local stakeholders' suggestions. Since the model is aimed at facilitating communication among stakeholders and not at producing scientific knowledge, the validation of the model is mainly a social validation process, i.e. we make sure that the participants agree with the content of the model, that it corresponds to their perception of reality. The RPG allows this validation in two ways : the players can say whether or not the model of the game corresponds to their perception of reality, and the researchers can observe the way players act and make decisions in the game.

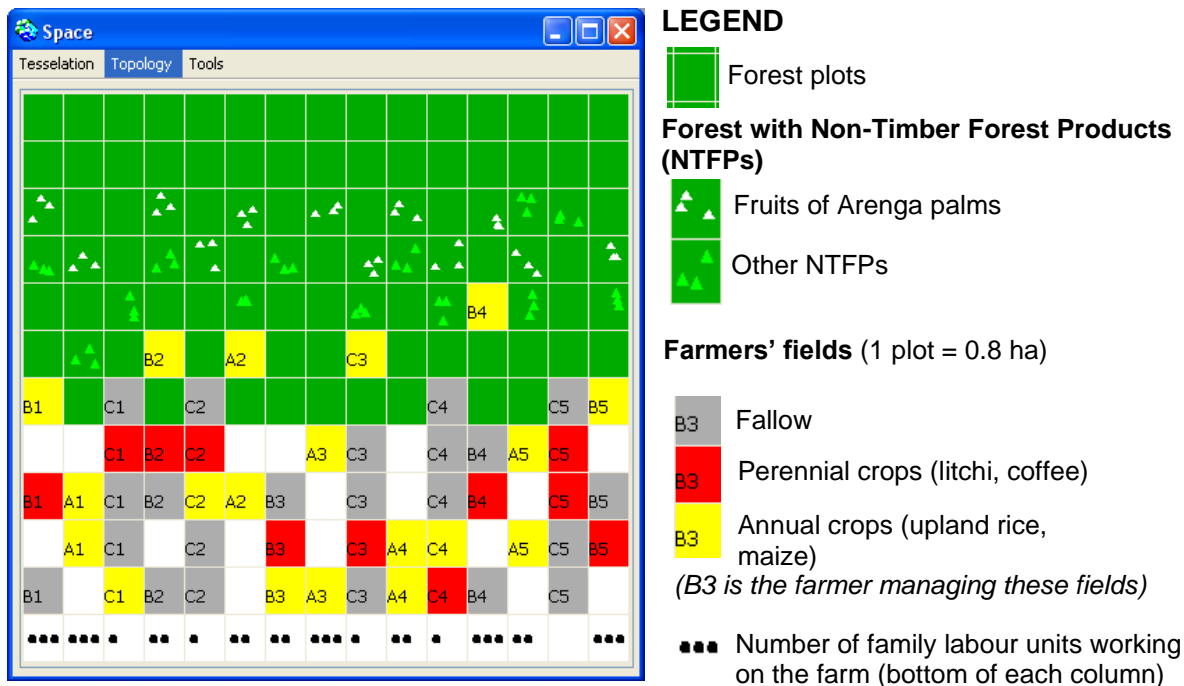
This ComMod process started with a four-month long in-depth analysis of the initial agrarian and institutional situation through individual semi-directed interviews with some 30 farmers, village leaders, national park rangers and Royal Forestry Department (RFD) foresters. This initial analysis was used to analyse the key NRM problem, the main concerned stakeholders, their initial perceptions of the situation and the social and power relations among them. The knowledge drawing from this initial analysis was also used to build a first model of the situation, under both RPG and ABM forms (Barnaud et al., 2008). The RPG and the ABM were used in (and evolved along) a series of participatory field workshops with villagers and foresters. Workshop after workshop, the RPG and ABM evolved to take into account both the participants suggestions and the evolution of the focus of discussions. Firstly, two workshops with villagers only were held in each village to allow them to reflect about the establishment of the park. Two months later, another workshop was organized with the RFD foresters and the park rangers only for them to discuss about their NRM conflict with the villagers. After another four months, a final workshop was conducted with villagers from both villages, RFD foresters and national park rangers to trigger more dialogue and better mutual understanding among these main parties in the conflict (Barnaud et al., 2008; Ruankaew et al., 2010).

This final workshop started with two RPG sessions in which farmers and national park officers played their own role (Barnaud, 2008). The spatial interface of the RPG was very similar to the one of the agent-based model (figure 1). We had decided to propose a very abstract representation of space, i.e. that did not correspond to any particular place or location, to create a distance from reality and interpersonal conflicts, in particular over the conflicting boundary issue. The gaming board was nevertheless spatially explicit. For example, the national park officers could mark a virtual boundary with removable would sticks. The objective was to allow them to address the boundary issue in a flexible and non-threatening (because non-committing) way. But there were actually no open discussions around this issue during the game. The national park officers imposed the boundary without consulting villagers. The RPG session was followed by small groups and plenary discussions supported by non-spatially explicit methods, such as a kind of card ranking activity, with cards representing different "issues" that came out of the discussions : land issue, NTFP issue, gun issue, etc. This allowed the different participants to become more aware of the diversity of interests and perceptions among them (Barnaud, 2008). Villagers realized and acknowledged that they had different stakes. For example, the most important issue was the right to collect NTFPs for the poorest ones, but for others, it was the risk to lose farm land, while a few villagers also emphasized the question of the right to carry a gun for hunting inside the park. The park rangers emphasized that, to them, the most important issue was to stop deforestation. This process triggered a better mutual understanding among them. However, in spite of these open and enriching exchanges, at some point, the participants came back to the conflicting issue of the boundary, pointing at the spatial interface of the game, and the discussions rapidly reached a standstill. "It is pointless to discuss. We have to fix the boundary, then everyone will stay in its own area, and it will be fine" said a village leader. In other terms, "good fences make good neighbours". This was a frontal confrontation in which they just fought to "share the cake" in a distributive or "zero-sum" negotiation mode - and in which the villagers had little chance to win. To overcome this situation, the following day, we suggested that the participants think in a different way, that they imagine that they had a common space to manage collectively, with no boundary. Agent-based simulations were proposed to the participants to facilitate a collective brainstorming on forest management rules in this hypothetic common space. When presenting the results of simulations, we focused on graphs and indicators - social, economic and ecological ones - instead of spatial dynamics. The objective was to move from a debate on the boundary to a debate on the rules for accessing resources. We made the assumption that this would lead the participants to realize that, beyond the conflict about the boundary, they had some common interests, and that this would facilitate a move from a distributive towards a more integrative mode of negotiation.

4. DESCRIPTION OF THE AGENT-BASED MODEL

The purpose of the model was to enable villagers, RFD foresters and park rangers to jointly explore and discuss the economic, social and ecological impacts of various sets of possible land-use and forest management rules. The general structure of the model is described in appendix 1 and its spatial interface is shown in figure 1.

Figure 1. Spatial interface of the NamHaenGame agent-based model



In the model, there are 15 farming households (5 of each socio-economic type A, B and C) displayed in columns on the spatial interface. At the beginning of the simulation, they have different amounts of cash, land resources and family labour. At each time step (corresponding to a crop year), the model implements the following sequence of activities:

- the farming households decide how to allocate their labour force (working in town or on the farm; in town, they can either work as low wage labourer, or, if they have sufficient investment capacity, they can make and sell soymilk),
- they decide whether or not to open new plots in the forest,
- they allocate crops to their fields (knowing that there are (i) cash constraints since they have to pay for inputs and (ii) labour constraints for annual crops),
- they gather Arenga fruits and other NTFPs according to collective rules varying between scenarios,
- the model calculates the family annual net income by taking the basic family needs into account (if they have debts, they work in town as wage labourers in the following year),
- the NTFPs regenerate (if farmers leave at least one unit of NTFP on a cell, there will be three units the following year, and only one unit if they take them all).

In this model, there are no direct interactions among the farming households (such as exchange of information, money, etc.). However, they interact indirectly through their environment, since their individual activities modify the forest status and depend on it for the quantity of NTFPs available for gathering. Besides, the spiritual aspects were not integrated into the model because they concerned very specific locations (places of worship in the forest) and we believed that issues related to specific places and boundaries should be discussed only after a first "brainstorming" stage of mutual learning and integrative negotiation.

Ecological indicators are used to assess the results of simulations, such as change in the extent of the forest cover and the quantity of NTFPs left after regeneration. Socio-economic indicators are also used, such as the number of villagers working in town, the level of farming households' monetary assets, or the composition of their incomes (products that are self-consumed are taken into account at their market price): income from NTFPs, from farming activities, and from off-farm activities.

5. RESULTS: PARTICIPATORY EXPLORATION OF THREE SCENARIOS

5.1. Description of the three scenarios tested with the participants

Three scenarios were simulated and discussed during the final workshop with the villagers, park rangers and RFD foresters. These simulations are presented like in the workshop. This means that we do not present results from simulations run in the laboratory (like averages from 50 simulations of a given scenario for example), but we present only the results of a single simulation for each scenario. Since there are stochastic elements in the model (cf. appendix 1), two simulations of the same scenario never give exactly the same quantitative results. However, we checked that a single run of a simulation always illustrates the same qualitative trend. Indeed, in spite of the stochastic elements, the variability remains quite low (cf. table 1). As far as the sensitivity of the model is concerned, when calibrating the parameters, we could verify that this rather simple model was quite robust, that a small change in the parameters did not change the general regime observed in the scenarios. In the context of the use of the model (for learning and communication purpose), it was not necessary to conduct a deeper sensitive analysis. Moreover, concerning the choice of the various rules and parameters in the various scenarios, we should mention that none of these scenarios claim to be realistic. They all represent a rather extreme outcome of a given trend. The objective was a learning one with simulations used to make the participants aware of key interactions in the system and their consequences, in order to stimulate enriching and integrative discussions among them. A scenario representing more accurately the current situation would probably be made of components borrowed from these three scenarios.

The three scenarios are based on different sets of rules regarding the collection of NTFPs and forest encroachment. In the first scenario, NTFPs are collected without any collective management rule (individual farmers collect NTFPs as much as they want) but the ban on encroachment is respected. In the second scenario, NTFPs are collected according to the management rules currently used in community forests (collectors never take all the NTFPs available and always leave some to facilitate their regeneration) and the ban on encroachment is still respected. In the third scenario, the NTFPs management rules are enforced but not the ban on forest encroachment.

5.2. Outputs from the three scenarios testing the effects of various forest management rules

In all three scenarios, type C farmers have enough cash to invest in the relatively lucrative soymilk business in town and then reinvest this off-farm income on the farm, by planting litchi orchards, a perennial crop more acceptable to foresters and rangers. Moreover they are not affected by the decrease of NTFPs. While during the workshop the outputs related to type C farmers were also presented and discussed, here the focus is set on the comparison of the outputs for types A and B farmers.

In the first scenario, NTFPs are rapidly depleted. Incomes from NTFPs (including the self-consumed ones) of type A and B farmers are very high in the first year and then decrease abruptly and remain low during the nine following years as displayed in figure 2.2. Since their livelihoods heavily depend on incomes from NTFPs, their level of indebtedness increases rapidly (fig. 2.1). In order to survive and reimburse their debts, they send family members to work in town as low-wage labourers (fig.2.3).

In the second scenario, type A and B farmers follow a collective rule regarding the collection of NTFPs to avoid their over-exploitation (cf. appendix 1). Their incomes from NTFPs are slightly lower than at the beginning of the first scenario, but remain constant along the years (fig. 2.2). Their economic situation is much better than in the first scenario (fig. 2.1), as they can invest more on the farm and are less frequently forced to leave the village to take precarious wage earning jobs in town (fig. 2.3). Their forest income slightly decreased at the end of the simulation because they are better-off and rely less on the collection of NTFP. This scenario shows that on the long term, it is in the villagers' interest to set up and respect collective rules on the collection of NTFPs. Actually, villagers have set up such rules in "community forest" areas. Although old villagers say that young people tend to break these ancestral rules, most of the time, they are well-known and respected. This is contrary to the national park rangers' belief considering ethnic minorities as forest destroyers who only pursue short-term benefits.

Figure 2. Outputs of simulations of the three scenarios discussed with stakeholders.

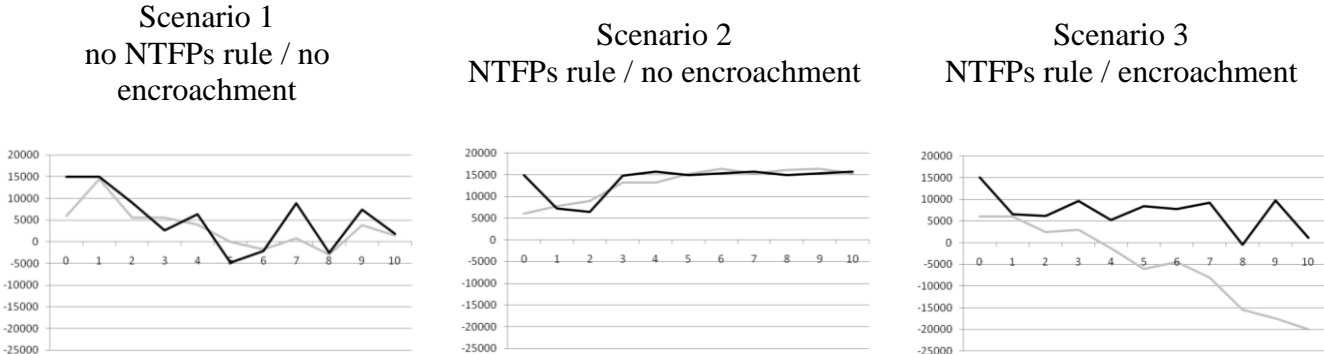


Figure 2.1. Evolution of cash for type A (gray) and B (black) farming households

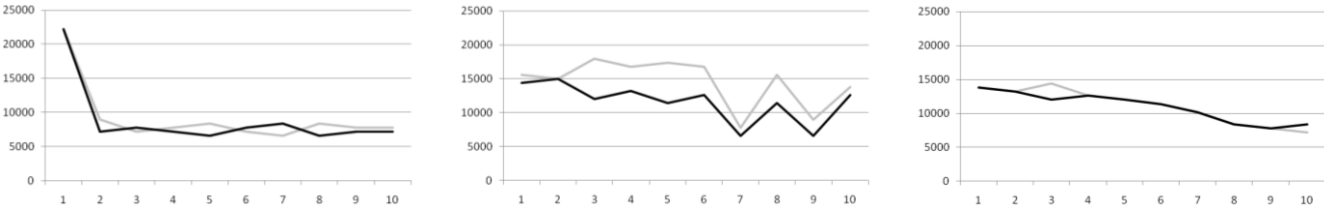


Figure 2.2. Evolution of income from NTFPs for type A (gray) and B (black) farming households

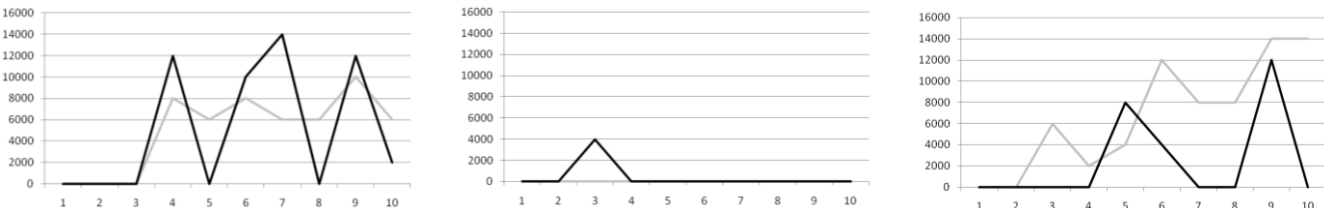


Figure 2.3. Evolution of off-farm income for type A (gray) and B (black) farming households

Table 1. Means and standard deviations (N = 30 replications of each scenario) of the key indicators in each scenario after 10 time steps

	Scenario1	Scenario2	Scenario3
Cash A	-413.3 (2098.2)	16093.3 (405.9)	-10640 (9935.6)
Cash B	-120 (2594.7)	15786.7 (319.2)	4413 (6242.9)

NTFP income A	7460 (624)	15100 (849.7)	6880 (1709.7)
NTFP income B	7540 (624)	12320 (342.8)	7320 (1617.7)
Off-farm income A	3733.3 (2911.7)	0 (0)	9533.3 (4508.5)
Off-farm income B	3666.7 (2353.8)	0 (0)	1533.3 (2909.4)

In the third scenario, the farmers still respect the NTFPs rule, but they do not respect the ban on encroachment, and regularly open new plots in the forest. In reality, this is formally forbidden by law, so it does not happen as frequently as in this scenario, but it still happens sometimes. These are either very poor or landless farmers who encroach small plots to grow upland rice or maize, or on the contrary rather healthy and influential type C families who want to expand their litchi orchard areas. This unrealistic scenario was simulated to raise the question "what would happen if farmers did not respect the encroachment ban at all?". This scenario is more favourable to these type C farmers (compared to scenarios 1 and 2 that are equivalent in terms of cash accumulation for them, the third scenario leads to an increase of 33% of cash with a final value close to 300000 THB), but very unfavourable to type A and B farmers as the forest area decreases progressively. As a consequence, the quantity of available NTFPs and related incomes of type A and B farmers also decrease (fig.2.2). The most affected are the type A farmers who are the most dependent on the gathering of NTFPs (fig. 2.1). Therefore, this scenario showed that the national park and the poor villagers have a common interest in limiting deforestation.

During the workshop with the stakeholders, we did not present a fourth scenario in which neither the ban on encroachment nor the rules regarding NTFP would be respected. Given the results of the three previous scenarios, it was obvious that such a scenario would give negative results from both ecological and social points of view, for both villagers and national park officers. Therefore, we considered it was not necessary to present it collectively, because it would have had a low added-value for the collective learning and negotiation process (and there is always a time constraint in a participatory process).

5.3. Learning and negotiation effects of participatory simulations on the participants

Since the participants had played several gaming sessions with a RPG based on the same conceptual model, they could easily understand the computer ABM simulations. The different categories of participants (park rangers, RFD foresters and three types of farmers) ostensibly validated these three scenarios. For each scenario, they confirmed that "it would indeed happen this way if the rules were set up this way". They often gave themselves the explanations behind the observed trends. This participatory simulation session stimulated a constructive discussion leading the different categories of participants to conclude that beyond their differences, they had three major common interests: (i) the sustainable management of NTFPs (biodiversity conservation for the park, maintenance of a major source of income for most of the villagers), (ii) limiting deforestation (maintenance of forest cover for national park, maintenance of the amount of forest products for villagers), and (iii) protecting the forest from fire (for the same reasons as deforestation). The well-off type C farmers (including the village leaders) who participated in the workshop might have found that they had nothing to win under this agreement, but they actually supported it because it was in their interest to show to the national park that they were not "forest destroyers". Indeed, improving their relationships with the park rangers would give them a chance to increase their room for manoeuvre in future negotiations regarding the exact location of the park boundary on their village territory. The workshop facilitation team suggested writing down the ideas of this collective agreement in the form of a Memorandum Of Understanding that was signed by all the participants. In subsequent

interviews, several participants pointed out this MOU as one of the most positive achievements of the ComMod process.

6. DISCUSSION

Following this presentation of what happened in the ComMod process, we can examine the questions formulated at the beginning of the article: how far can negotiation theories help us think about the trade-offs and synergies between the three pillars of sustainable development? What are the potential and limits of participatory agent-based simulations to support creative and integrative negotiation processes for sustainable management of renewable resources by multiple users? And in particular, what is the influence of the use of spatially explicit models in such negotiation processes?

6.1. A move from a distributive to an integrative mode of negotiation

The conflict examined in this article is a typical situation of apparent incompatibility between ecological, economic and social interests among heterogeneous stakeholders. The various concerned stakeholders considered that there were no possible synergies (only trade-offs) between poor villagers' livelihoods, forest conservation and social equity. To analyse this situation, we chose to look at the various stakeholders' strategies, interests and values, and to analyse their power relationships. This led to analyse their interactions in term of negotiation. At the beginning of the process, the protagonists of this conflict considered their interests as being incompatible and mainly focused on the boundary issue. They confronted each other point of view on a distributive mode, arguing over the way to "share the cake". In such a distributive mode, the power asymmetries are determinant, the least influential stakeholders have little chance to win the fight. In this case study, the chief of the national park could simply decide unilaterally both the boundary of the park and the rules within it. But by doing so, he would increase the risk of the villagers deciding to get revenge by setting up fire to the forest in the park. This would remain a zero-sum outcome. It is interesting to notice that in this context, the ecological stakes are hold by the most powerful stakeholders³, while in many other contexts, the conservationists are the least influential (Mathevet, 2004). The concept of integrative mode of negotiation, describing a process in which the stakeholders reframe the problem to try to "enlarge the cake", is an interesting way to explore synergies between ecological, social and economic stakes. In the described negotiation process, there was a move from a distributive to an integrative mode of negotiation: the stakeholders reframed their way to tackle the problem by accepting to stop focusing on the park boundary. Focusing on the boundary corresponds to a segregationist vision of land management, with on one side, an area where nature is protected, and on the other side, a space where it is transformed and exploited. The agent-based simulations suggested a more integrative vision of the space and its use. This was obviously a very hypothetic and unrealistic scenario, since at the end there will necessary be a boundary. However, this exercise allowed the stakeholders to better understand each other's interests and values beyond their initial positions in the conflict. The stakeholders could make explicit and express more precisely what they wanted and needed from the forest environment. This led them to recognize that a co-management was possible to satisfy their respective needs, and that they were potential synergies between ecological (biodiversity conservation, maintenance of forest cover), economic (better farming households incomes), and social preoccupations (less inequalities, less villagers forced to leave the village to take precarious jobs in town). This corresponded to an exploration of synergies among forest ecosystem services, a way to preserve both regulating ecosystem services (protection of the upper watersheds of the country from

³ In 1989, a major shift occurred in the forest policy of the government of Thailand from a focus on forest exploitation to an increased conservation pressure on remaining forest areas.

deforestation and loss of biodiversity) and provision ecosystem services (collection of NTFP to sustain villagers' livelihood). Beyond this single area, this case study questions the pertinence of a segregationist vision of space to deal with environmental issues in Northern Thailand at a time when the number of conservation areas is rapidly increasing. This reinforces the statement made by Roth (2004) who highlighted that the national parks' perception of space in Thailand is at the origin of endless conflicts in this country.

6.2. Methodological factors to facilitate integrative negotiation processes : the non-neutral role of spatial representations

What are the potential and limits of participatory agent-based simulations to support integrative modes of negotiation? There are of course some general considerations regarding the choice of a participatory agent-based modelling process. For example, agent-based models offer an intuitive representation of socio-ecological systems, with social agents interacting with each other and with their environment (Bousquet and Le Page, 2004). They are therefore particularly appropriate to assess the ecological, economic and social effects of different scenarios, and therefore think about the synergies between ecosystem services and between the three pillars of sustainable development. Moreover, the participatory nature of the ComMod process, i.e. the specific combination of gaming sessions with agent-based simulations, allowed the participants to fully understand, criticize and modify both the model features and operational rules and the key ecological, economic and social interacting dynamics at stake. The ABM became to them a virtual laboratory to better understand the way different dynamics of the system interact and to explore the functioning of this complex system under different scenarios.

Beside these general considerations, we want to emphasize the specific influence of the choice of a spatial interface in a participatory modelling process. This choice is indeed far from being neutral. In the described process, the spatial interface was a highly simplified representation of the area (fig. 1). It was voluntarily unrealistic to provide the participants with a non-threatening environment. In a process relying on GIS or actual topographic maps, it is more difficult to establish a gaming atmosphere distancing the participants from their current interpersonal conflicts and to stimulate more creative learning processes among them. The choice of an unrealistic spatial representation probably contributed to the fact that they easily projected themselves in this imaginary common space, with no boundary, which helped them to reframe the problem and enter in a more integrative mode of negotiation.

However, a closer look at the participatory process shows that during the final workshop, despite the fact that they had experienced gaming and simulation activities with a very unrealistic spatial interface, the discussions ineluctably came back to the boundary issue. The context obviously played a major role to explain that, since the national park was *de facto* about to delineate its future boundaries. But in spite of this, one can wonder whether the very choice of a spatially explicit interface, even an unrealistic one, contributed to their thinking in terms of strict boundaries and segregated space. During the participatory process, the participants started to reframe the problem and think in terms of potential synergies instead of boundaries when they were invited to look at graphs presenting the effects of different sets of forest management rules on various social and ecological indicators, i.e. when they were invited to look at a different kind of interface and not the spatial one. According to Roth (2007), the use of two-dimensional spatial representations modify the way people perceive and manage space and resources. This author suggests that in the context of NRM in Northern Thailand, the use of maps and GIS led to a transition from a conception of space with overlapping and flexible boundaries (corresponding to the traditional communities' way of thinking about land use and natural resource management) to a conception of space with strict and fixed boundaries leading

to think in terms of exclusion and inclusion (corresponding to the state top-down and centralized way to manage natural resources through the delineation of reserved and protected areas).

The lessons from the participatory modelling experiment reported here lead to add a hypothesis to Roth’s conclusions. We suggest that in participatory modelling processes the systematic and exclusive use of spatially explicit models might actually favour modes of negotiation of the distributive type (in which people only try to “share the cake”) and impede the emergence of creative and integrative negotiation processes in which people try to reframe the problem to “enlarge the cake”. Indeed, the use of two-dimensional spatial representations guides the participants to delineate areas with specific uses and prevent them from thinking in terms of multifunctional use of the space. It is not easy to represent and think the multiple, overlapping and evolving functions of a given area on a two-dimensional representation. And still, in many NRM contexts, this could be a way to explore innovative scenarios in which ecological, social and economic objectives are not necessarily competing but potentially mutually enriching.

Of course, we do not claim that researchers should stop using spatially explicit models to deal with NRM issues. There are several participatory experiments that demonstrated that the use of spatially explicit interfaces had major advantages. For example, D’Aquino et al. (2003) described a ComMod process in which the participants (local farmers and land managers) co-designed the spatial interface of a role-playing game, according to their conception of space. This process empowered local stakeholders and initiated a local decision-making process about land-use management that led to concrete and implemented collective action plans. In another participatory process using an agent-based model linked to a GIS, Etienne *et al.* (2003) emphasized the possibility to use the diverse layers of the GIS to display the stakeholders’ various perspectives, which contributed to social learning and the emergence of a compromise. In a participatory GIS process in the context of two competing objectives over land-use, Kyeem (2006) also used a combination of GIS maps to locate precisely the conflicting areas and to allow the stakeholders to solve the conflict by making spatial trade-offs. However, in this example, we can see one more time that the map is a tool leading to the mitigation of conflicts by segregating land-use and negotiating trade-offs more than searching synergies and integration.

CONCLUSION

Noting the ubiquity of spatially explicit models in NRM, this paper questions the non-neutrality of such spatial representations. In the literature, one can find some pros and cons of using more or less realistic spatial representations, and of using more or less spatially explicit methods and representations (they are summarized in the table 2). This paper adds an element to this debate, by arguing that spatially explicit models and representations used in negotiations around NRM can lead to a focus on the division of space (discussions about who gets how much of the pie) rather than a discussion of innovative solutions based on multi-functionality of space (which make it more possible for the stakeholders to reframe the problems, express their underlying interests, and eventually find more win-win solutions).

Table 2. Some pros and cons of using more or less realistic and spatially explicit interfaces in participatory processes

	Pros	Cons
Using realistic spatial representations	- Participants feel at ease with realist representations because they are closer to their everyday life (Lange, 2001).	- Realistic and detailed representations increase the "black-box" effects (Horlitez, 2007; Dumrongrojwatthana et al., 2009)

	- Realistic representations show more details and facilitates the expression of multiple perceptions (abstract ones narrow the possible interpretations) (Maurel, 2001)	- Realistic representations prevent the stakeholders from taking a distance from reality (and interpersonal conflicts, etc.) (Gurung et al. 2006)
Using spatially explicit representations	- Most NRM issues do have an explicit spatial dimension (Bonin and Torre, 2004, Kyem, 2006) - Spatial planning, participatory or not, is nowadays one of the major tool of governance (McCall, 2003) - Since administrations use spatially explicit representations, local people should learn to draw their map to assert their interests (counter-mapping) (Peluso et al. 2008, D'Aquino, 2003)	- Using spatially explicit representations can lead to loss of indigenous conceptions of space, increased privatization of land, increased conflicts (Sirat et al. 1994; Fox et al. 2006; Roth, 2007) - Using spatially explicit representations can lead to a focus on the division of space rather than solutions based on multi-functionality of space (this paper).

There are multiple cases where the use of spatial interfaces has a true added-value. Moreover, we live in a world in which spatial representations and spatial data are overarching, and this trend is on the increase with recent progresses in spatial technologies and their democratization (Pettit et al., 2011). Therefore, in many cases, the use of spatial representations will be almost inescapable at some stage of the process, especially at operationalizing stages. Consequently, this paper does not promote the non-use of spatial representations. Rather, we underline their inherent limits and biases to call for the use of diverse and complementary types of interfaces and representations. Typically, at early stages of participatory modelling processes, it can be interesting to explore various types of interfaces (and in particular non-spatial or highly virtual spatial interfaces) to favour sharing of knowledge and perceptions, facilitate creative reframing of the issues at stake and explore new ways to integrate diverse human activities in land management. Later on, more realistic models based on spatial representations can be needed to facilitate concrete decision making processes (such as land-use planning, choice of infrastructures, etc.).

In terms of future research needs, it would be interesting to investigate more systematically the effects of the use of more or less spatially explicit models in NRM. A first step could be an ex-ante analysis and comparison of a variety of participatory modelling processes using different kinds of representations -more or less spatially explicit, more or less realistic. A second step would be to carry out at the same time, in the same context but with different people, a series of participatory modelling experiences using different kinds of representations, and to investigate afterwards their different effects on the learning and negotiation processes.

REFERENCES

- Barnaud, C., Trébuil, G., Dumrongrojwattana, P., Marie, J., 2008. Area Study prior to Companion Modelling to Integrate Multiple Interests in Upper Watershed Management of Northern Thailand. *Southeast Asian Studies* 45(4) 559-585.
- Barreteau, O., Antona, M., d'Aquino, P., Aubert, S., Boissau, S., Bousquet, F., Dare, W., Etienne, M., Le Page, C., Mathevet, R., Trébuil, G., Weber, J., 2003. Our companion modelling approach. *Journal of Artificial Societies and Social Simulation* 6(2) 1.
- Barreteau, O., Bousquet, F., Attonaty, J., 2001. Role-playing games for opening the black box of multi-agent systems: method and lessons of its application to Senegal River valley irrigated systems. *Journal of Artificial Societies and Social Simulation* 4(2).

- Becu, N., Neef, A., Schreinemachers, P., Sangkapitux, C., 2008. Participatory Modeling to Support Collective Decision- Making: Potential and Limits of Stakeholder Involvement. *Journal of Land Use Policy* doi:10.1016/j.landusepol.2007.11.002.
- Bonnin, M., Torre, A., 2004. Typologie de liens à l'espace impliqués dans les conflits d'usage. Étude de cas dans les Monts d'Ardèche. *Les Cahiers de la multifonctionnalité* 5 17-30.
- Bousquet, F., Bakam, I., Proton, H., Le Page, C., 1998. CORMAS: common-pool resources and multi-agent systems, In: Pasqual del Pobil, A., Mira, J., Ali, M. (Eds.), *Proceedings of International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems: Benicasim (Spain)*. Berlin (Germany): Springer-Verlag, pp. 826-837.
- Bousquet, F., Barreteau, O., Mullon, C., Weber, J., 1996. Modélisation d'accompagnement : systèmes multi-agents et gestion des ressources renouvelables, *Quel environnement au XXIème siècle ? Environnement, maîtrise du long terme et démocratie: Abbaye de Frontevraud*.
- Bousquet, F., Cambier, C., Morand P., Quensière J., Mullon C., Pavé, A., 1993. Simulating the interaction between a society and a renewable resource. *Journal of Biological Systems* 1(1) 199-214.
- Bousquet, F., Le Page, C., 2004. Multi-agent simulations and ecosystem management: a review. *Ecological modelling* 176 313-332.
- Carnevale, J.P., 2006. Creativity in the outcomes of conflict, In: Deutsch, M., Coleman, P.T., Marcus, E.C. (Eds.), *Handbook of conflict resolution: theory and practice*, 2nd edition, 2nd Edition ed. Jossey-Bass: San Francisco, pp. 414-435.
- Checkland, P., Scholes, J., 1990. *Soft systems methodology in action*. Wiley and sons Chicester.
- D'Aquino, P., Le Page, C., Bousquet, F., Bah, A., 2003. Using Self-Designed Role-Playing Games and a Multi-Agent System to Empower a Local Decision-Making Process for Land Use Management: The SelfCormas Experiment in Senegal. *Journal of Artificial Societies and Social Simulation* 6(3) 5.
- Dionnet, M., Kuper, M., Hammani, A., Garin, P., 2008. Combining role-playing games and policy simulation exercises: An experience with Moroccan smallholder farmers. *Simulation & Gaming* 39(4) 498-514.
- Duke, R.D., 1974. *Gaming: the future's language*. SAGE Publications, Halsted Press, New York.
- Dumrongrojwatthana, P., Trébuil, G., Le Page, C., Gajaseni, N., 2009. Participatory design and use of a simplified landscape in a simulation model for mitigating land use conflict in Northern Thailand highland, *Emergence in Geographical space : concepts, methods and models: Paris*.
- Etienne, M., Le Page, C., Cohen, M., 2003. A Step-by-step Approach to Building Land Management Scenarios Based on Multiple Viewpoints on Multi-agent System Simulations. *Journal of Artificial Societies and Social Simulation* 6(2).
- Ferber, J., 1999. *Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence*. Addison-Wesley Longman, Boston.
- Fox, J., Suryanata, K., Hershock, P., Pramono, A.H., 2006. Mapping power : ironic effects of spatial information technology *Participatory learning and action* 54 98-105.
- Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., Goss-Custard, J., Grand, T., Heinz, S.K., Huse, G., Huth, A., Jepsen, J.U., Jørgensen, C., Mooij, W.M., Muller, B., Peer, G., Piou, C., Railsback, S.F., Robbins, A.M., Robbins, M.M., Rossmannith, E., Ruger, N., Strand, E., Souissi, S., Stillman, R.A., Vabø, R., Visser, U., DeAngelis, D.L., 2006. A standard protocol for describing individual-based and agent-based models. *Ecological Modelling* 198 115-126.

- Grimm, V., Berger, U., DeAngelis, D.L., Polhill, J.G., Giske, J., Railsback, S.F., 2010. The ODD protocol: A review and first update. *Ecological Modelling* 221 2760-2768.
- Gurung, T.R., Bousquet, F., Trébuil, G., 2006. Companion modeling, conflict resolution, and institution building: sharing irrigation water in the Lingmuteychu Watershed, Bhutan. *Ecology and Society* 11(2) 36.
- Horlitz, T., 2007. The Role of Model Interfaces for Participation in Water Management. *Water Resources Management* 21(7) 1091-1102.
- Janssen, M., 2005. Agent-Based Modeling, In: Proops, J., Safonov (Eds.), *Modeling in Ecological Economics*. Edward Elgar Publishers: Cheltenham, pp. pp. 155-172.
- Kyem, P.A., 2004. Of Intractable Conflicts and Participatory GIS Applications : the Search for Consensus amidst Competing Claims and Institutionnal Demands. *Annals of the Association of American Geographers* 94(1) 37-57.
- Kyem, P.A., 2006. Finding commun ground in land-use conflicts using PGIS : lessons from Ghana. *Participatory learning and action* 54 36-40.
- Lagabrielle, E., Botta, A., Daré, W., David, D., Aubert, S., Fabricius, C., 2010. Modelling with stakeholders to integrate biodiversity into land-use planning - Lessons learned in Réunion Island (Western Indian Ocean). *Environmental Modelling & Software* 25(11) 1413-1427.
- Lange, E., 2001. The limits of realism: perceptions of virtual landscapes. *Landscape and Urban Planning* 54(1-4) 163-182.
- Leeuwis, C., 2000. Reconceptualizing Participation for Sustainable Rural Development: Towards a Negotiation Approach. *Development and Change* 31 931-959.
- Mathevet, R., 2004. *Camargue incertaine*. Sciences, usages et natures, Paris.
- Maurel, P., 2001. Les représentations spatiales : concepts de base et éléments de typologie, In: Lardon, S., Maurel, P., Piveteau, V. (Eds.), *Représentations spatiales et développement territorial*. . Hermès: Paris, pp. 75-108.
- McCall, M.K., 2003. Seeking good governance in participatory-GIS: a review of processes and governance dimensions in applying GIS to participatory spatial planning. *Habitat International* 27(4) 549-573.
- McKinnon, J., Vienne, B., 1989. *Hill tribes today*. White Lotus-Orstom, Bangkok.
- Metcalf, S.S., Wheeler, E., BenDor, T.K., Lubinski, K.S., Hannon, B.M., 2010. Sharing the floodplain: Mediated modeling for environmental management. *Environmental Modelling & Software* 25(11) 1282-1290.
- Naivinit, W., Le Page, C., Trébuil, G., Gajaseeni, N., 2010. Participatory agent-based modeling and simulation of rice production and labor migrations in Northeast Thailand. *Environmental Modelling & Software* 25(11) 1345-1358.
- Parker, D.C., Manson, S.M., Janssen, M.A., Hoffmann, M.J., Deadman, P., 2003. Multi-Agent Systems for the Simulation of Land-Use and Land-Cover Change: A Review. *Annals of the Association of American Geographers* 93(2) 314-337.
- Peluso, N.L., Afiff, S., Rachman, N.F., 2008. Claiming the Grounds for Reform: Agrarian and Environmental Movements in Indonesia. *Journal of Agrarian Change* 8(2-3) 377-408.
- Pettit, C.J., Raymond, C.M., Bryan, B.A., Lewis, H., 2011. Identifying strengths and weaknesses of landscape visualisation for effective communication of future alternatives. *Landscape and Urban Planning* 100(3) 231-241.
- Polhill, J.G., Parker, D.C., Brown, D.G., Grimm, V., 2008. the ODD Protocol for Describing Three Agent-Based Social Simulation Models of Land-Use Change. *Journal of Artificial Societies and Social Simulation* 11(2) 3.
- Röling, N., Wagemakers, M.A., 1998. *Facilitating Sustainable Agriculture : Participatory learning and adaptive management in times of environmental uncertainty*. Cambridge University Press: Cambridge.

Roth, R., 2004. Spatial Organization of Environmental Knowledge: conservation conflicts in the Inhabited Forest of Northern Thailand. *Ecology and Society* 9(3) 5.

Roth, R., 2007. Two-dimensionnal maps in multi-dimensional worlds : A case of community-based mapping in northern Thailand. *Geoforum* 38 49-59.

Ruankaew, N., Le Page, C., Dumrongrojwattana, P., Barnaud, C., Gajaseni, N., van Paassen, A., Trébuil, G., 2010. Companion modelling for integrated renewable resource management: a new collaborative approach to create common values for sustainable development. *International Journal of Sustainable Development & World Ecology* 17(1) 15 - 23.

Simon, C., Etienne, M., 2010. A companion modelling approach applied to forest management planning. *Environmental Modelling & Software* 25(11) 1371-1384.

Sirait, M., Prasodjo, S., Podger, N., Flavelle, A., Fox, J., 1994. Mapping customary land in East Kalimantan, Indonesia : a tool for forest management. *Ambio* 23(7) 411-417.

Souchère, V., Millair, L., Echeverria, J., Bousquet, F., Le Page, C., Etienne, M., 2010. Co-constructing with stakeholders a role-playing game to initiate collective management of erosive runoff risks at the watershed scale. *Environmental Modelling & Software* 25(11) 1359-1370.

Trébuil, G., Ekasingh, B., Edmunds, M., 2007. Agricultural Commercialisation, Diversification, and Conservation of Renewable Resources in Northern Thailand Highlands. *Moussons* 9/10 131-155.

Ulrich, W., 2003. Beyond methodology choice: critical systems thinking as critically systemic discourse. *Journal of the Operational Research Society* 54 325-342.

Voinov, A., Bousquet, F., 2010. Modelling with stakeholders. *Environmental Modelling & Software* 25(11) 1268-1281.

Worrapimphong, K., Gajaseni, N., Le Page, C., Bousquet, F., 2010. A companion modeling approach applied to fishery management. *Environmental Modelling & Software* 25(11) 1334-1344.

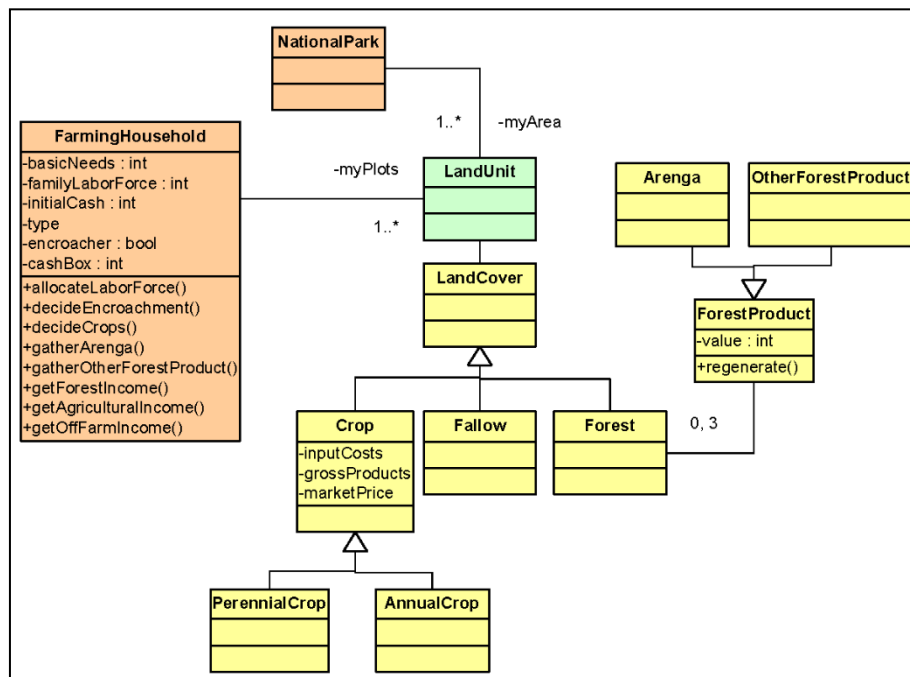
APPENDIX: description of the NANGAME agent-based model

The model was developed with the Cormas4 platform (Bousquet et al., 1998). The source code of the model to be loaded into Cormas, written in Smalltalk, is available at: <http://cormas.cirad.fr/logiciel/NanGame.zip>. The model is described according to the “Overview-Design concepts-Details” (ODD) protocol proposed (2006) and recently updated (2010) by Grimm and his colleagues. ODD is nowadays a standard format to communicate the structure and content of spatial agent-based models for socio-ecological systems (Polhill et al., 2008).

Overview

The NanGame model is a spatially-explicit agent-based model that was derived from a role-playing game to promote and extend the scope of discussion between stakeholders in the case of a new national park and two villages facing a conflict about access to forest and land resources in the highlands of Northern Thailand. The static structure of the model is depicted in the UML class diagram below

Appendix 1. UML class diagram of the NanGame agent-based model



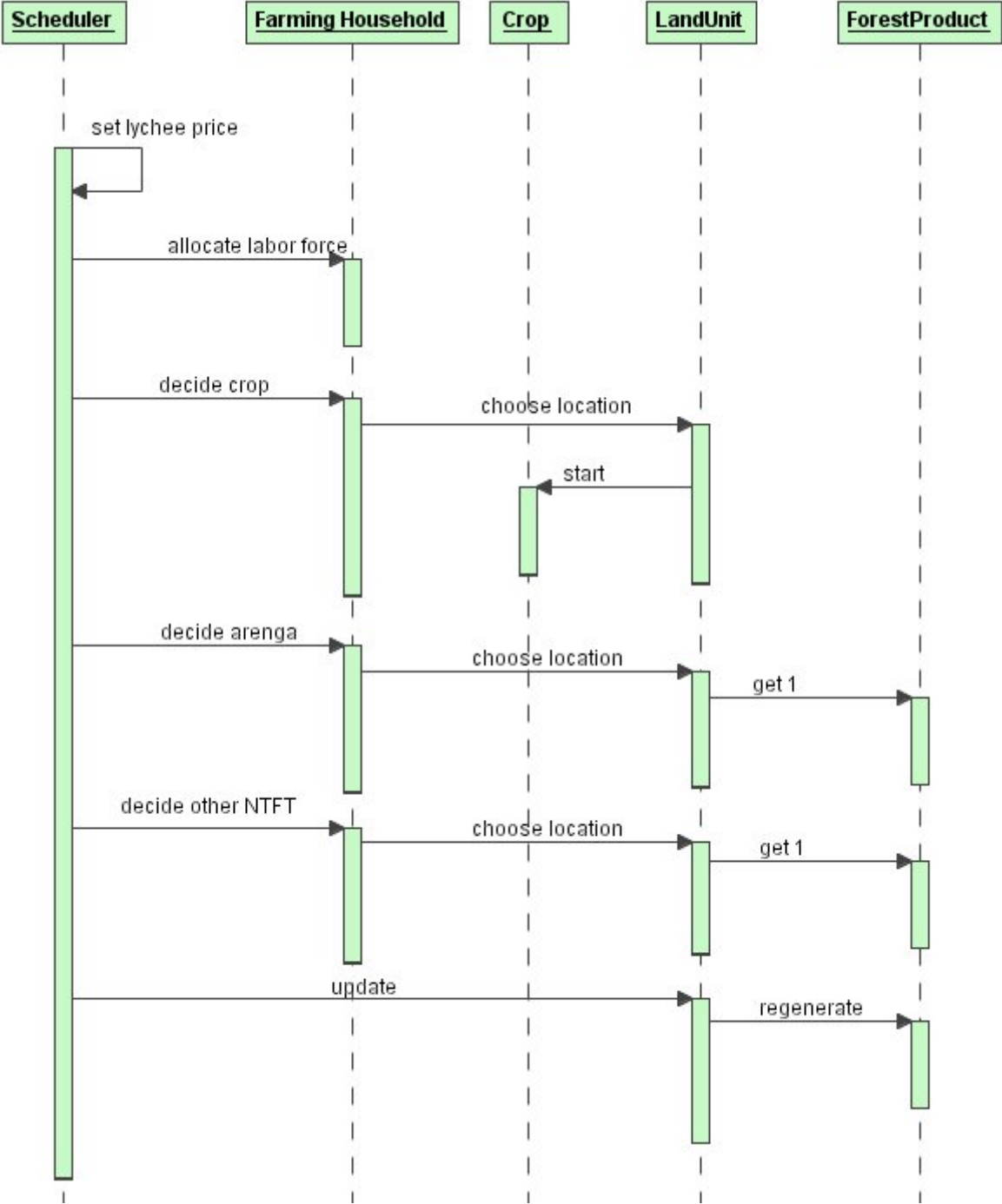
The key entity of the model is the « Farming household ». Basic needs and the initial amount of cash are the two main characteristics allowing differentiating the three types of farming households represented in the model. Each farming household has successively to make decisions about the allocation of the family labor force (on farm or in town), the crops to be grown in their plots and the gathering of two types of renewable non-timber forest products (the corresponding algorithms are detailed in the last section of this appendix).

The spatial resolution was set to 0.8 ha (5 rai in the Thai area measurement system), which corresponds to the average size of plots for the region represented in the model. A spatial grid made of 11 x 15 cells provides a schematic representation of the interface between a village

⁴ <http://cormas.cirad.fr/indexeng.htm>

and the forest (see figure 1). The model is a discrete time-step model. Each time step represents one year and the time horizon to run scenarios was set to 10 years. The sequence of operations in each time-step is shown in the UML sequence diagram below.

Appendix 2. UML sequence diagram of the NanGame agent-based model



The parameters of the NanGame agent-based model are listed in the table below.

Appendix 3. Table of parameters

Entity	Parameter	Value
Annual crop ~ Lychee	Investment cost	0 ~ 4 KTHB
	Input cost	3 ~ 6 KTHB/yr
	Gross product	8 ~ 10 KTHB/yr
	High market price factor*	1.6
Forest products	Price	3 KTHB
	K (carrying capacity)	3 units per cell
Household (types A ~B ~C)	Basic needs	19 ~22 ~38 KTHB/yr
	Labor coef needs**	2 KTHB
	Cash threshold gathering	5 ~15 ~20 KTHB
	Income worker in town	10 KTHB/yr
	Income soymilk seller	20 KTHB/yr
	Investment in soymilk	40 KTHB

*For lychee only, applied in years 3, 7 and 9

** Coefficient used to calculate the extra basic needs correlated to the amount of labor force in the family

Design concepts

The human decision criteria - the decision-making process of the agent "farming households"- are not based on optimization principles but rather a heuristic approach with sequential decisions.

The NanGame agent-based model includes some randomness. At each time-step, the farming households ready to engage in gathering forest products are randomly sorted. In the scenario with encroachment, the selection of encroaching farming households (2 from type A; 2 from type B; 3 from type C) is randomly made. Independent farming households are the only level of decision-making entities in the model; they have neither adaptive behavior nor memorization.

Details

Initialization

15 farming households are initially created, 5 from each type, with the characteristics derived from the constant values indicated for each type in the table of parameters above (appendix 3) and the specific values indicated in the table below:

Farmer	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5
Nb plots	2	2	2	2	2	3	4	3	4	3	5	5	5	5	5
Family size	3	2	3	2	2	3	2	2	3	3	3	3	3	3	2

The spatial location of the plots is shown in figure 1, as well as the location of forest plots holding 3 units of forest products.

Input

The market price of lychees is increased by 66% in years 3, 7 and 9.

Submodels

Off-farm activity (*allocate labor force*): when a household's cashbox reaches the amount set to invest in soymilk (40,000 THB), this activity is started. Once started, whatever the cash balance of the household, each year two members are busy doing it. If not engaged in soymilk, each year a farming household considers whether the cash balance is negative or not. If it is negative, all members except one go working in town.

Farming (*decide crop*): firstly, a farming household with existing plots of perennial crops has to pay the related input costs. Second, the priority is to plant one plant of annual crop - for self consumption. For this to effectively happen, a double condition has to be verified : to have enough cash to pay for the input cost and to have one family member left in the village. Third, for all the remaining plots with no crops (neither perennial nor annual), if there is enough cash to invest in perennial crops, the farmers plant some perennial crops (there is no labor constraint to establish a perennial crop). If they do not have enough cash for perennial crops, but enough cash for annual crop and the required labor force, they plant some annual crops. If neither annual nor perennial crops are possible, the plot stays as fallow.

Forest product gathering (*decide arenga, decide other NTFP*): below a given threshold of cash specific to each type of farming household and to each kind of product; and if enough forest products is available, the decision to go gathering products is taken. If not enough forest products is available, the last households in the random order are "the losers".

Forest products regeneration (*regenerate*): to keep it as simple as possible, both types of forest products follow the same regeneration rule: if no unit was left after gathering, the next time-step there will be only one unit available. If at least one unit was left after gathering, the next step the carrying capacity of the forest plot (three units) will be provided.