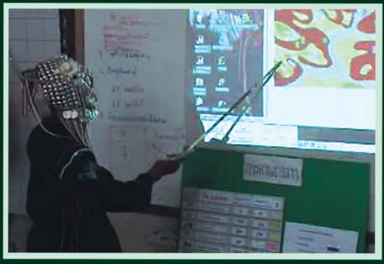
Companion Modeling and Multi-Agent Systems for Integrated Natural Resource Management in Asia



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

IRRI
CIRAD

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

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

2005

IRRI

INTERNATIONAL RICE RESEARCH INSTITUTE

The International Rice Research Institute (IRRI) was established in 1960 by the Ford and Rockefeller Foundations with the help and approval of the Government of the Philippines. Today IRRI is one of the 15 nonprofit international research centers supported by the Consultative Group on International Agricultural Research (CGIAR – www.cgiar.org).

IRRI receives support from several CGIAR members, including the World Bank, European Union, Asian Development Bank, International Fund for Agricultural Development, International Development Research Centre, Rockefeller Foundation, Food and Agriculture Organization of the United Nations, and agencies of the following countries: Australia, Austria, Belgium, Brazil, Canada, Denmark, France, Germany, India, Iran, Japan, Malaysia, Netherlands, Norway, People's Republic of China, Republic of Korea, Republic of the Philippines, Spain, Sweden, Switzerland, Thailand, United Kingdom, United States, and Vietnam.

The responsibility for this publication rests with the International Rice Research Institute.

Mailing address: DAPO Box 7777, Metro Manila, Philippines
Phone: +63 (2) 580-5600, 845-0563
Fax: +63 (2) 580-5699, 891-1292, 845-0606
Email: irri@cgiar.org
Home page: www.irri.org
Rice Knowledge Bank: www.knowledgebank.irri.org
Courier address: Suite 1009, Pacific Bank Building
6776 Ayala Avenue, Makati City, Philippines
Tel. (63-2) 891-1236, 891-1174, 891-1258, 891-1303

Suggested citation:
Bousquet F, Trébuil G, Hardy B, editors. 2005. Companion modeling and multi-agent systems for integrated natural resource management in Asia. Los Baños (Philippines): International Rice Research Institute. 360 p.

COVER DESIGN: Juan Lazaro IV
LAYOUT AND DESIGN: Emmanuel Panisales

ISBN 971-22-0208-9

Contents

Part 3. Multi-agent simulations

Part 4. Learning processes

Modeling multi-stakeholder forest management: the case of forest plantations in Sabah

Ph. Guizol and H. Purnomo

The underlying decision theory of forest management changed from decisions made by the forest manager, a single stakeholder, to a decision-making process, which involves a variety of stakeholders with different goals. From concept to implementation, forest professionals are in trouble because, despite the potential of technological progress and the development of tools to support decision-making, tools to facilitate multi-stakeholder decisions are lacking.

This paper proposes a framework to link social, economic, and biophysical dynamics using multi-agent simulation to explore scenarios of collaboration for forest plantation management. The modeling is based on decision theories. This framework uses the concept of a value-added chain as a model of alliances. The added-value breakdown analysis is a tool, which is used at the forest-plot level as a means of anticipating benefit sharing among the stakeholders before they decide to harvest; this also highlights the added-value variation from plot to plot. The framework can also take into account noneconomic-based relationships. Each stakeholder has explicit communication capacities, behaviors, and rationales, and forest management emerges from their interactions.

The purpose of this modeling is to produce shared knowledge about dynamics to facilitate coordination among stakeholders; it is a learning tool about forest management. Our main hypothesis is that stakeholders, by creating a virtual world with researchers, will learn about the effects that their own decisions might have on themselves, others, and the environment. In the case of Sabah, we are at the stage of the first loop of learning, and scenarios need to be further tested with the stakeholders themselves. This forest plantation simulation suggests that the development of sawmills adapted to plantation wood might offer a promising pathway for increasing added value and the benefits of many stakeholders, including local communities.

Principle 22 of the Rio Declaration on Environment and Development (1992) highlights the importance of local people and their participation in sustainable development. In forest plantations, this should apply to local communities living in or near forest plantations.

Malaysia, the country where Sabah State is located, is situated right in the heart of Southeast Asia and is divided into two geographical sections: Peninsular Malaysia and the East Malaysian provinces of Sabah and Sarawak in North Borneo (Fig. 1).

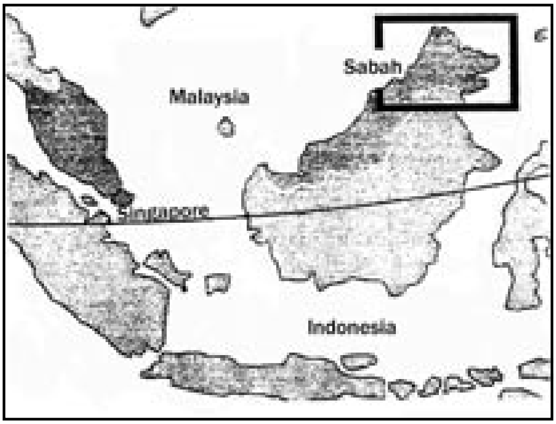


Fig. 1. Sabah location map.

The study area is located in northeastern Sabah, mostly in Bengkoka, Marudu, and Keningau districts. Grasslands, logged-over forest, and secondary forest cover most of the landscape.

Smallholders believe that many opportunities are provided for forest plantation development. A lot of logged-over land is available for plantations. Sabah natives have the possibility to obtain security over land and rural people have the will to invest in forest plantations to secure their ownership of land, to rehabilitate the landscape, to rehabilitate wildlife resources for hunting, and to invest for themselves and the coming generations.

The Sabah Legislative Assembly created SAFODA (Sabah Forestry Development Authority) in 1976. Its mission is to develop highly productive forest plantations for the long-term supply of wood resources and to improve the socioeconomic status of the state and country on a sustainable basis (SAFODA 2003). Currently, SAFODA manages about 100,000 ha of land.

The local government perceives the development of forest plantations in this part of Sabah as a means to improve the landscape and smallholder income. Today, most of the land, which has been logged over and is unused, is highly fire-prone (a lot of areas are covered with *Imperata cylindrica* and large stocks of remaining deadwood). The development of smallholder plantations could also produce a variety of plantation systems. These plantations will reduce the areas' fire proneness and would involve the local population in fire control.

The wood price is a major impediment to the development of all plantations. Sabah State has already invested a lot in smallholders' plantations and SAFODA estates. So far, SAFODA plantation area amounts to 31,000 ha. The planted species are *Acacia mangium* (28,000 ha) and rattan (2,100 ha). SAFODA encouraged small landowners, adjacent to their forest plantation areas, to grow trees. Currently, these smallholder plantations amount to 3,000 ha supervised by SAFODA.

However, this development is in crisis as SAFODA faces problems in self-financing its development in the current context of low wood prices. Currently, SAFODA has to export, at a low price, fast-growing wood produced on its own plantations as the existing paper mill in Sabah (Sabah Forest Industries, SFI) is too far away from the SAFODA plantations.

The local stakeholders are disappointed and don't want to invest as long as wood prices are too low. The domestic wood price would increase if domestic downstream industries existed to buy wood. Investors would consider investments in downstream industries for plantation wood if mature plantations were available but they might postpone such investments as long as faster returns from natural forest logging exist. The challenge is to create conditions for co-development of plantation forests and downstream industries using plantation wood.

It looks like more coordination and a more bottom-up approach to the problem are needed among the Sabah plantation policy, smallholders, and the development of wood-processing industries. The goal of our model is to observe the impact of wood-processing development on land use and income of different local stakeholders. This research explores scenarios of co-development of smallholder plantations and wood-processing enterprises.

This paper presents the theoretical background on which the selected methodology relies, followed by the method and its implementation, and then a first discussion about the preliminary results, the use of simulation, and the next steps of the research.

Theoretical background of the model

In this section, we present the theories and concepts we use in our model. Forest management planning used to be a process driven by the theory of individual decision focusing on forest dynamics. The new paradigm of sustainable forest management increases the scope of forest management by recognizing the environmental, social, and economic elements of forestry as well as the multi-stakeholder and institutional dimensions of the underlying decision process (Edmunds and Wollenberg 2003, Gibson et al 2000, Ostrom 1990, Weber et al 1990). This dramatic change requires new approaches.

Forest management planning and decision theories

The underlying decision theory of forest management planning came from substantive rationality (Simon 1976). This is a deeply rooted perception of decision-making, which assumes that an objective is clearly stated, solutions are in restricted number and known, and the decision-maker is free to find the optimal solution. The decision is rational as it is a coherent sequence of stages designed to reach this objective:

> Observation/intelligence activity > objective/design > deliberation/choice > review/assessment of choice.

The process of forest planning from classic forestry textbooks is very well structured and looks the same:

> Owner objective > data analysis > decision > action plan.

Of course in detail it is much more complex, but still linear, for instance:

Land right update > description of the forest and the forest plot characteristics (soil, species, topography, history, etc.) > definition of long-term production goals, choice of species > plot classification and silviculture choices at the plot level > productivity expectation, annual allowable cut (AAC), harvest design method > operational planning of activities (maintenance, thinning, pruning, harvest) > financial assessment.

This theory consists of matching the owners' will with the potential of the forest to guarantee forest sustainability. It is a tool that evolved with the development of new technologies for environmental observation (satellite imageries, description of ecosystems) and data management (such as geographic information systems, GIS). It is in use in many countries, such as in France by the state enterprise managing the national forests (Dubourdieu 1997).

The flaws might be that, despite the development of technologies, forest management planning is a process driven mostly by an understanding of the biological subsystem only, and the interaction between biological and social dynamics is not taken into account well. Other stakeholders' objectives are seen as the "social pressure" (Dubourdieu 1997). When the social pressure increases, some participatory approaches might be introduced without fundamentally changing the nature of the decision model. National forest planning in the United States starts with an inventory, followed by a participatory process, which designs the desirable future state of the forest. The forest service then makes the final decisions, while it elaborates an action plan (Risbrudt 1999).

Simon (1976) stated that economic analysis rests on two assumptions: that the agent has as a specific goal the maximization of its profit and that it is rational. Rationality, or hard rationality, also means that the agent has all the information and that solutions exist in a limited number. Under these conditions, Simon (1976) defined the rational agent as an agent who compares the different solutions to its goal and chooses rationally one with a method, such as cost-benefit analysis.

March and Simon (1974) identified limits to the rational decision theory. They observed that, in the real world, decision-makers make decisions with a subset of information, and do not try to find the optimal solution but a satisfactory one. Simon (1976) proposed the theory of bounded rationality in which decision-makers have multiple constraints: limited information, limited time, and limited processing and memory capacities. In the real world, decision-makers use simplified sets of rules, or heuristics, to make decisions. This theory does not consider situations with multi-stakeholders.

In uncertain situations, Simon (1978) proposed the theory of the decision-making process, in which a decision is the outcome of a complex system in which multiple stakeholders can interact.

The social network theory contemplates society as a complex structured system in which a stakeholder is a social entity, which can be a single person or a group with common resources and interests. The stakeholder behaves according to his/her interest but is constrained by a set of social norms (Crozier and Friedberg 1977). Social norms are a classification of the world, things, people, and people's relations with things (Weber et al 1990). In a social network, relations among stakeholders are critical as in all complex systems. In the following section, we describe how we model agents with some economic rationality.

The concept of value-added chain

We view the value-added chain as a short-lived alliance among a variety of stakeholders to produce goods from forests. This concept allows the integration of different decision levels and forces us to describe the communication patterns among stakeholders, and the perceptions and goals that govern each stakeholder's behavior. Usually, the value-added chain is reduced to the supply chain perspective of an industry trying to secure its supplies. Here, we look at it in the other way, from the forest side; the value chain concept helps to anticipate before harvest the use of the wood and benefits that wood products will generate. This is what stakeholders in the forestry sector are doing, consciously or intuitively, in real circumstances.

We assume that the decision to cut a forest plantation plot results from an agreement among key stakeholders. A piece of wood will be harvested and extracted from the plot if all key stakeholders along the value chain are satisfied with the system of alliances. If a key stakeholder, a woodcutter or a road haulage contractor, does not get what he/she really expects, wood will not be harvested and nobody will be paid. The common interest is to reach an agreement, but this is not always possible. Success or failure of the negotiation depends on the negotiation process but also on forest plantation physical conditions. For instance, if the forest is far away from the market or a factory, transportation costs might be so high that a satisfactory solution for all cannot be found.

This system of alliances is the result of negotiation among stakeholders who try to reach their own goals through such a process. It can change over space and, at any specific location, it is a snap alliance as it can change over time according to stakeholders' changing perceptions of the environment and their relationships. This allows us to represent the interaction between forest dynamics and social issues as it links these changing alliances directly to the rate of harvesting, which affects the forest dynamics.

The value-added breakdown analysis, which includes costs and added value at each stage, is a very simple and practical economic model that we use to analyze the contribution of each stakeholder to the final product price from wood standing value to the retail price of the final product. The coordination of the economic goals of diverse stakeholders through negotiation is the process used in this breakdown analysis.

Methodology

In this section, we propose a framework to represent the interactions between socio-economic dimensions and forest dynamics; this framework takes into account the critical role of communication patterns among stakeholders in the process of forest management. It uses the theory of decision-making process and the concept of value-added chain mentioned above.

Simulating for collective learning is the objective

The purpose of our model is to produce simulations. "Simulation" means making a simplified representation of a real-world situation, and animating it so that stakeholders can envision what the future situation might be. This simulation tool is not created to select a solution but rather to stimulate a discussion with the real-world stakeholders about whether a given solution might satisfy them.

A simulation tool is one tool to support a decision among a large family of decision support tools for sustainable development as described in Kersten et al (2000). These authors would class it in a subset of communication or teamwork support tools to be used when a decision involves more than one decision-maker. In practice, for instance, multi-criteria decision-making (MCDM) has been used to make decisions for forest management planning more effective (Tarp and Helles 1995). MCDM prioritizes criteria and uses them for assessing the specific performance of a system. Even though MCDM is not designed specifically as a teamwork support tool, it can be used within a participative process.

Simulation will be used within an action research process, which involves stakeholders in producing knowledge, assuming that collective action is more likely to occur based on a common representation of the environment. Interaction between simulation and stakeholders, including researchers, is also a learning process, which should influence long-term forest management. Researchers are already using scenarios generated by other participative tools in the field of forest management (Wollenberg et al 2000, 2001, Nemarundwe et al 2003).

The choice of a multi-agent systems approach

Multi-agent systems (MAS) offer a promising way to examine natural resource and environmental management issues (Bousquet et al 1999, Gilbert and Troitzsch 1999). The hallmark of MAS is the recognition of "agents," which are entities with defined goals, actions, and domain knowledge. Some degree of agent autonomy is central to the notion of multi-agent modeling (Weiss 1999). These interactions can be cooperative or selfish, with agents sharing a common goal or pursuing their own interests (Sycara 2000, Gilbert and Troitzsch 1999). Agents are entities within an environment, which they can sense, modify, and improve. This collection of agents in interaction is not a sum of isolated entities but it forms a society of agents.

Simulating the stakeholders' activities and interactions requires a tool that is able to represent the individual's knowledge, belief, and behavior. MAS have their roots in the field of artificial intelligence. Hence, most of the early theoretical development of MAS evolved from computer-related work (Weiss 1999). Recognizing the close analogy between distributed artificial intelligence and individual-based modeling, several authors saw the potential for adopting MAS in natural resource management, particularly in areas where several stakeholders share the control of renewable resources. In the field of renewable resource management, other researchers already use simulation with MAS and role-playing games to allow mutual feedback between the real world and stakeholders, and to promote communication (Barreteau et al 2001).

Modeling forest management

In our model, we recognize two different levels of decisions (Fig. 2). At the first level, each agent has an individual bounded rationality. The agent makes decisions according to its goals. It is constrained by its social norms, its limited knowledge of the

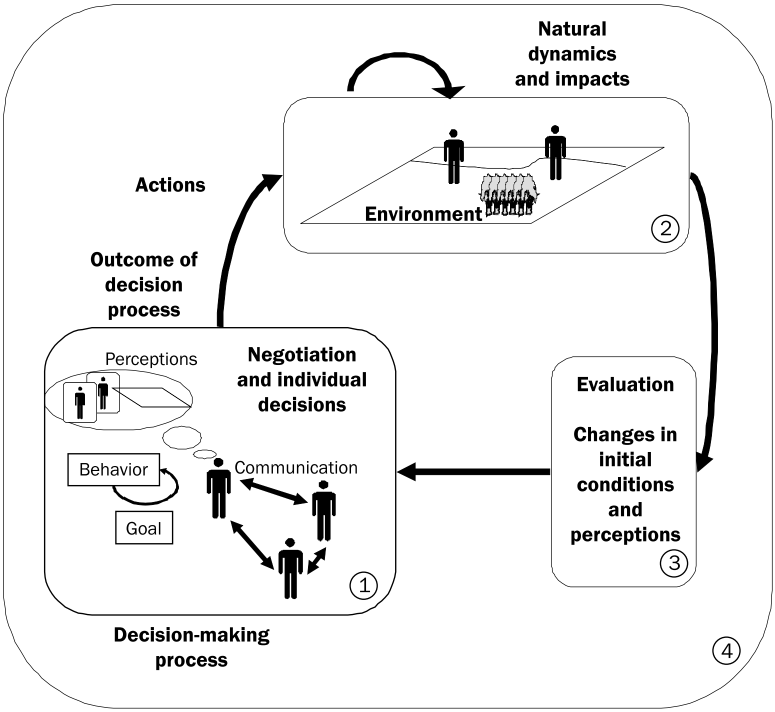


Fig. 2. Theoretical model of forest management. Block 1: Inside agents have goals and behavior, and they make individual decisions; from the whole block emerge decision processes produced by these agents in interaction. Block 2: The environment (space, forests as renewable resources, noncommunicating agents, objects as roads, etc.). Decision processes in block 1 affect environmental dynamics. Block 3: A phase of analysis and evaluation. Block 4: The level of emergence of forest management.

environment, and its relationship with other stakeholders. It also has some economic rationality, and we use the value chain to represent it (Fig. 3).

A second level of decision is the outcome of a set of agents' interactions that these agents are able to communicate. This set makes up a social network. At this level, agents are coordinating their decisions and some form of negotiation takes place. This decision has an effect on their environment. A phase of intelligence, review, and assessment allows stakeholders to modify some of their perceptions and behaviors before a second loop starts.

A type of artificial forest management emerges following a number of these loops—it is a third level or emergence level. We also want to assess the scenario occurring at this level.

From stakeholders to agents

We identify stakeholders according to the criteria of the "who count matrix," namely, proximity to the forest plantation, legal and traditional rights over the forest plantation, dependency on the forest plantation, and knowledge of forest plantation management (Colfer et al 1999). Stakeholder characteristics were recognized through field visits and discussions. Researchers facilitated the discussion to establish stakeholder identities,

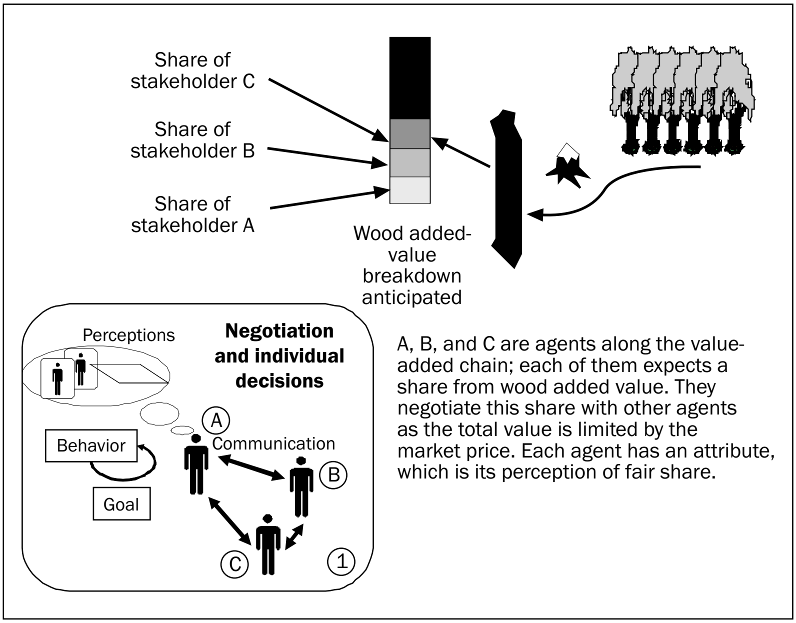


Fig. 3. Multi-stakeholder decisions and the value-added chain.

their rationale, and their behavior and actions. These characteristics formed the basis for the MAS model to be subsequently developed.

An agent, which is here a computed representation of a stakeholder, might have an economic behavior. To model this specific behavior, we use the added-value chain concept described above. Agents in the model are anticipating the outcome of their decisions during the decision process. The stakeholder evaluates the outcome of the process vis-à-vis his/her goals (Table 1).

The distinction between a communicating agent and a noncommunicating agent is key. In Figure 2, some agents are not communicating and are part of the environment. As Holling (1999) remarks, there is a difficult trade-off between keeping the model simple enough for sharing information with real-world stakeholders and complex enough for understanding. Stakeholders, with researchers, should reassess this distinction about agent communication capabilities because some agents can move from one condition to another.

Expected results

We expect that the structure of the added-value breakdown, although analyzed at each forest-plot level of a map, will differ according to the forest-plot location, and this would reflect potential benefit-sharing variation. This would link economic issues to spatial structure (Fig. 4). Negotiations will take place on each patch of the map, revealing linkages between economics and space.

A simulated forest plantation management will emerge from our model and we will be able to observe it on a spatial grid over a long simulated time on the spatial

Table 1. Respective goals and strategies of the selected stakeholders.

Stakeholder	Goal	Strategy
SAFODA	Improve its returns	By reducing its costs and increasing its revenue.
Smallholders	To improve their well-being	They have lands and can expand the plantations. If wood price is high enough, they expand their plantations for pulp or timber. If their pulpwood plantations are not commercially viable, they can convert them to timber-wood plantation or other uses.
Buyers	To improve their profits	They take care of logging and transportation costs. They need a margin of 20%.
Government	Forest sustainability	More smallholders, more wood resources, and forest landscapes.

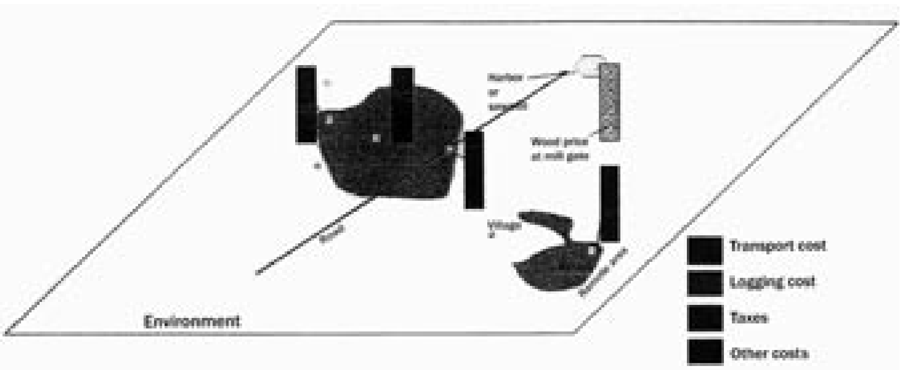


Fig. 4. Negotiations take place on each patch of the map, revealing links between economics and space.

grid. We will observe the impact of the simulated dynamics on each agent income that we can derive from added-value breakdowns. We expect that such simulations will help stakeholders to react and express themselves and will allow us to learn more about the processes and their needs (Fig. 5).

Model implementation

The choice of the CORMAS simulation platform

We use common-pool resources and multi-agent systems (CORMAS, Le Page and Bommel, this volume), a simulation platform specifically designed for renewable resource management systems. CORMAS provides a framework for developing simulation models and offers predefined elements, which users can customize to a wide range of specific applications (CIRAD 2001).

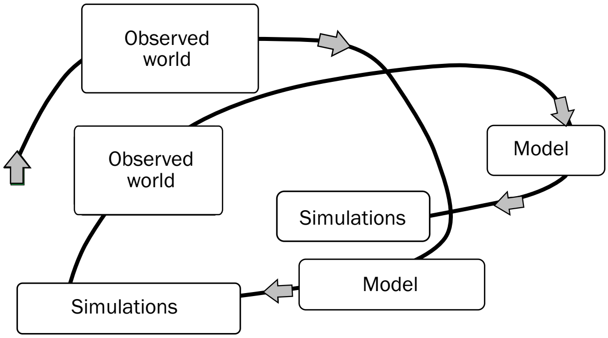


Fig. 5. Simulation as a research action tool for companion modeling (modified after Bousquet et al 1999).

We chose the CORMAS platform as it focuses on interactions between social and resource dynamics, based on spatially defined communication patterns. In CORMAS, communicating agents are already predefined with a set of attributes and processes used for sending a message, which makes it easy to simulate communication. Effects on forest resources can be visualized on a simulated grid or map.

Agents' attributes

The stakeholders we identified, based on the criteria mentioned previously, are SAFODA, smallholders, buyers (for pulp and sawmill), and the government. Table 1 describes the respective goals and strategies of those stakeholders.

We create agents from information we have about stakeholders. Basically, we define the initial conditions, the agents' attributes and their relationships with other agents and (forest) resources, the forest dynamics, as well as the way agents are able to adapt to change; agents are at least reactive to environmental change, but they can also learn. During a process of evaluation, they can change their perceptions about the environment and other agents and add addresses of new agents to their list of attributes (box 3 in Fig. 2). Among agent attributes are agent goals, their perceptions of the environment (resources and other agents), and their ability to communicate. Agents might also have a bank account as another attribute. We observe the effects on the forest resources and on agent changes in attributes (perceptions, bank account, and addresses of other agents, for example).

Biophysical and economic data

We obtained biophysical and economic data from SAFODA and the literature. At this stage, we have not incorporated real spatial data into the model. Presently, the model has used a map displaying a typical spatial configuration of forest plantations.

We analyze the growth volume model to represent plantation dynamics. Table 2 shows the dynamics of pulpwood growth volume that is used in the simulation. After 10 years, the mean annual incremental growth is 14 m^3 ha^{-1}.

Model overview

The conceptual model is presented in Figure 6. In this conceptual model, a sawmill that does not exist currently is added. Figure 6 shows that SAFODA and the smallholders grow *Acacia* on their plantations. Then they negotiate with a buyer to sell their timber. The buyer sends the wood he buys to mills. The wood for pulp is taken to the harbor for export if there is no pulp mill. The government observes the impacts of stakeholder interactions on the income of smallholders, pulp availability, and landscape.

If the sawmill exists, its primary goal is to maximize its profit. In the model, the sawmill can be set up anywhere on the map. It produces a demand for wood at a sawed-log price. The buyer takes into account the sawmill location to calculate the sawed-log price.

Spatial representation

The current study represents the forest landscape as pixels, including the explicit location of SAFODA and smallholders' plots, the sea, road network, pristine forest, agricultural land, and the harbor. Each pixel represents an area of 25 ha. Figure 7 shows an example of a virtual map of forest landscape where SAFODA, smallholders, and

Table 2. Wood growth for pulpwood plantations.

Item	Year									
	1	2	3	4	5	6	7	8	9	10
Volume (m^3 ha^{-1})	0	5	15	25	35	50	70	100	120	140
Annual volume increment	–	5		10	10	15	20	30	20	20

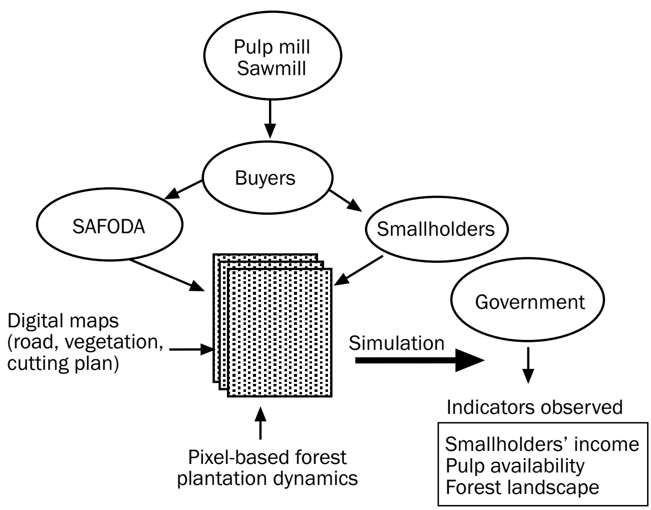


Fig. 6. An overview of the model.

1_n: SAFODA forest management plots (age 1 to 10)
2: Smallholder plots
3: Sea
4: Road network
5: Pristine forest
6: Agricultural land
7: Harbor
8: SAFODA field office

Fig. 7. Representation of forest landscape. Large plots marked 1 are SAFODA forest management plots. The different gray areas relate to the plot wood stock, while black illustrates that the plot is ready to be cut. The small triangles represent smallholders located in their forest plots at the beginning of the simulation (2). The black area at the bottom of the map represents the sea (3) and the harbor (7). In the top right of the large area marked 5 is the pristine forest. The white areas (6) represent land devoted to agriculture. The Y-shaped lines (4) are roads, with different gray colors relating to road quality and to different transportation costs.

the harbor are located. Small triangles represent smallholders. They can move during the simulation if they are not satisfied with their plot production at the beginning of the simulation.

We developed a spatially explicit algorithm to compute the transportation cost. The algorithm calculates the cost between the plots and mills by considering the existence of the roads and their quality. If there is a road, the distance cost is lower than if there is no road. Similarly, the better the road quality is, the lower the distance cost. The algorithm seeks the path providing the lowest distance cost. This is done by looking at the distance cost of the eight cells surrounding the one in which the wood is located. If the cells have exactly the same distance cost, then the algorithm looks at the next range of cells surrounding those eight cells, and so on.

Agent interactions

Figure 8 illustrates the interactions among agents as a sequence diagram in unified modeling language (UML). SAFODA has only pulp plantations, but smallholders might have small plots for pulpwood and also plots for sawed timber. When SAFODA has a plot ready to be cut, it sends a message to pulp buyers. If they are interested, negotiation between the buyers and SAFODA follows. The negotiation results between SAFODA and buyers will affect SAFODA's strategy to replant in the following years. If SAFODA implements a benefit-cost analysis for each plot, it will then have two options: to grow or not to grow trees. If it uses a plant-cut-replant approach, it will grow trees regardless of income produced from the plantation.

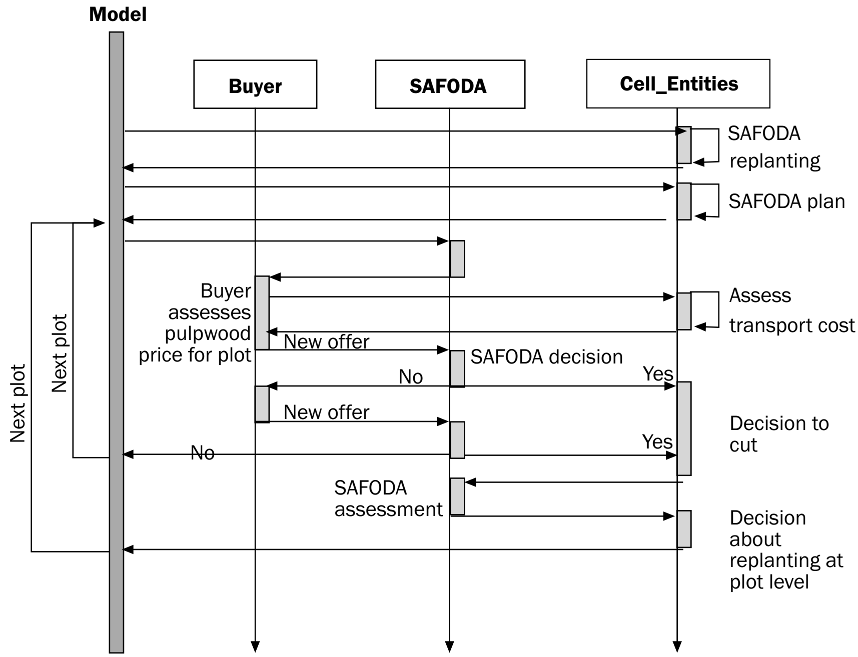


Fig. 8. Sequence diagram of agent interactions during negotiation.

At the same time, pulp and sawed-timber buyers are looking for wood from smallholders. If smallholders have plots ready to be cut, they send a message to buyers and negotiation follows. Negotiation about wood prices also occurs between buyers and mills. Smallholders also take into account outcomes of past decisions to decide about future activities. If they obtain a good income from the plantation, they expand it on new unproductive land. Buyers propose prices to tree growers, that is, SAFODA and the smallholders, based on the prices at which they can sell the wood to mills or at the harbor for export. The wood transportation cost from plots to roads is higher than from the road to the mill.

Simulation results

Initial conditions and scenarios

The structure of the initial condition is described in Figure 7. SAFODA manages its large plantation plots located nearby the road, while smallholders manage small plantation plots located far away from the road. The locations of small plantation plots used to be agricultural land. Natural forests still exist north of the plantations. There is no sawmill or pulp mill in the area and the wood is transported to the harbor.

Evaluation and observation

Model evaluation. A study was planned to develop and verify the model. The dynamic responses implicit in many natural resource management settings add to the challenge of interpretation and testing (Barreteau et al 2001). We evaluated the present model using two criteria: (1) the logic of the model and its outcomes and (2) the similarity between predictions and expectations. The model met these criteria. The assessment that the model was reasonable was based on a systematic checking of all the relationships within the model, from the simplest submodel (forest plantation growth) to the more complex submodels (e.g., the agents' communications). Finally, we assessed the outputs of the model. This assessment led to the conclusion that the model complied with the patterns we expected before.

Envisioning scenarios of forest plantations. Under the current scheme, after 10 years, the smallholders move to sites close to the road network to maximize their benefits in relation to transportation costs (Fig. 9). If existing plantations are not financially sustainable, smallholders just abandon them. They leave their plots and look for new accessible plots closer to the main road. This will decrease the available wood for pulp, degrade the forest landscape, and decrease their income.

Figure 10 presents a scenario with the establishment of a sawmill. Smallholders convert most of their pulpwood plots into sawed-timber plantations. These sawed-timber plots are commercially sustainable and give more income to smallholders. The smallholders leave several plots, which are far away from the road network. The forest landscape is larger vis-à-vis a scenario in which a sawmill does not exist.

Conclusions

Policymakers should be able to assess the very long-term effects of their decisions, such as the establishment of plantations or wood-processing industries. Simulations, which involve stakeholders' knowledge, are one way to examine this issue, as they

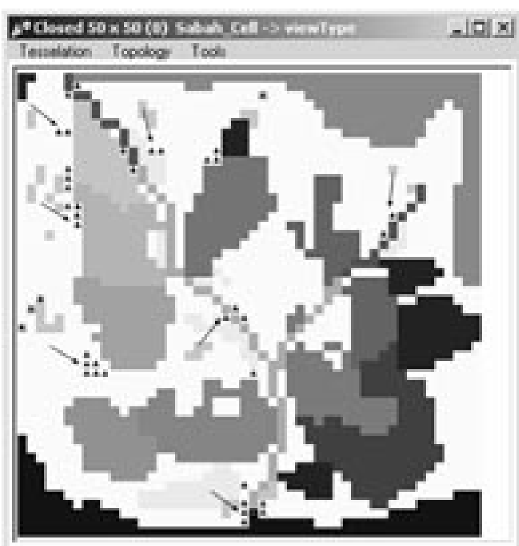


Fig. 9. Smallholders abandon their plantations and move to locations closer to the road as indicated by the arrows.

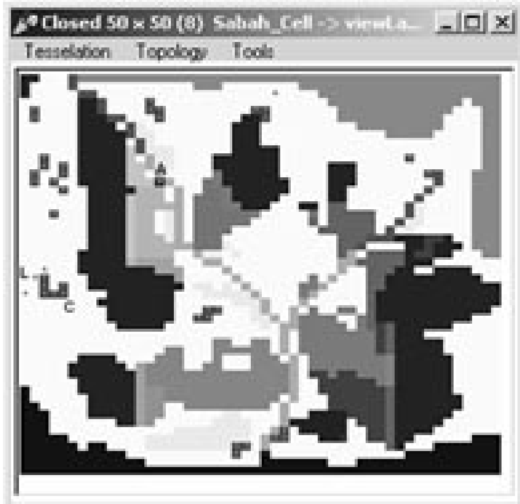


Fig. 10. Scenario of the impact of the establishment of a sawmill. A is a sawmill, L represents areas from which smallholders left, and C represents areas converted into sawed-timber plots.

allow the representation of complex coordination among multiple individual decisions through a negotiation process, and its effects on plantation resources and income generation.

In this article, we proposed a theoretical framework to design a model of multi-stakeholder forest management and its ongoing implementation under the CORMAS platform. It is a practical way to envision long-term scenarios of forest management involving multi-stakeholders. We have found the model to be useful for developing scenarios and observing the likely effects of each scenario on the forest landscape and on the well-being of stakeholders.

In the specific case of this Sabah plantation model, setting up a sawmill adapted for processing small logs from plantations might be a large incentive for smallholders to develop plantations, including in areas far from roads. The sawmills would increase the value of wood. The outcome, besides landscape management, is also better income for smallholders. Without a sawmill, smallholders move to sites close to roadsides and abandon their remote plots. Thus, the wood supply to enterprises, smallholder income, and forest areas decline. Nonetheless, this work in Sabah is in the very early stage of an action research process that we will continue.

In the next steps, we will involve the stakeholders more intensively in the modeling process to develop communication and reciprocal learning across stakeholders and researchers. Although we did our best in representing stakeholders' behavior, we did not make formal knowledge elicitation and representation during the process of building the simulation. We intend to improve the agents' learning process, coordination, and cooperation among them as well as the spatial representation of the area.

References

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. J. Artif. Societ. Social Simul. 4(2). Available at http://jasss.soc.surrey.ac.uk/4/2/5.html, accessed 20 May 2001.

Bousquet F, Barreteau O, Le Page C, Mullon C, Weber J. 1999. An environmental modelling approach: the use of multi-agent simulations. In: Blasco F, Weill A, editors. Advances in environmental and ecological modeling. Amsterdam (Netherlands): Elsevier. p 113-122. http://CORMAS.cirad.fr/pdf/gowith.pdf.

CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement). 2001. Natural resources and multi-agent simulations. http://cormas.cirad.fr/en/outil/outil.htm, accessed 25 February 2002.

Colfer CJP, Brocklesby MA, Diaw C, Etuge P, Günter M, Harwell E, McDougall C, Porro NM, Prabhu R, Salim A, Sardjono MA, Tchikangwa B, Tiani AM, Wadley R, Woelfel J, Wollenberg E. 1999. The BAG: basic assessment guide for human well-being, criteria and indicators. Toolbox Series No. 5. Bogor (Indonesia): Center for International Forestry Research. 79 p.

Crozier M, Friedberg E. 1977. L'acteur et le system. Paris. Paris (France): Le Seuil. 500 p.

Dubourdieu J. 1997. Manuel d'aménagement forestier. Office National des Forêts, Lavoisier Ed. 243 p.

Edmunds D, Wollenberg E, 2003. Local forest management: the impacts of devolution policies. London (UK): Earthscan Editions. 208 p.

Gibson CC, McKean MA, Ostrom E. 2000. People and forests, communities, institutions, and governance. Cambridge, Mass. (USA): The MIT Press. 274 p.

Gilbert N, Troitzsch KG. 1999. Simulation for the social scientist. Buckingham (UK): Open University Press. 273 p.

Holling CS. 1999. Introduction to the special feature: just complex enough for understanding; just simple enough for communication. Conserv. Ecol. 3(2):1. www.consecol.org/vol3/iss2/art1.

Kersten G, Mikolajuk Z, Gar-On Yeh A, editors. 2000. Decision support systems for sustainable development: a resource book of methods and applications. Boston, Mass. (USA): Kluwer Academic Publisher. 423 p.

March JG, Simon HA. 1974. Organizations. New York (USA): Wiley. 262 p.

Nemarundwe N, de Jong W, Cronkleton P. 2003. Future scenarios as an instrument for forest management: manual for training facilitators of future scenarios. Bogor (Indonesia): Center for International Forestry Research. 31 p.

Risbrudt CD. 1999. L'aménagement des forêts nationales aux Etats Unis. In: L'aménagement forestier, hier, aujourd'hui, demain. Revue Forestière Française, special issue. p 317-321.

SAFODA (Sabah Forestry Development Authority). 2003. www.sabah.gov.my/kpsp/safo_index.htm, accessed 25 February 2003.

Simon HA. 1976. From substantive to procedural rationality. In: Latsis SJ, editor. Methods and appraisal in economics. Cambridge (UK): Cambridge University Press. p 30-131.

Simon HA. 1978. On how to decide what to do. Belle J. Econ. 9:494-507.

Sycara K. 2000. Multi-agent systems (a subtopic of agents). American Association for Artificial Intelligence (AAAI). www.aaai.org/AITopics/html/multi.html, accessed 19 September 2001.

Tarp P, Helles F. 1995. Multi-criteria decision-making in forest management planning: an overview. J. Forest Econ. 1(3):273-306.

Ostrom E. 1990. Governing the commons: the evolution of institutions for collective action. Cambridge (UK): Cambridge University Press. 280 p.
Weber J, Betsch J, Cury P. 1990. A l'interface hommes-nature: les resources renouvelables. CND, programme environment, colloque recherché et environment, Strasbourg, 24-25 September 1990. p 39-50.
Weiss G, editor. 1999. Multi-agent systems: a modern approach to distributed artificial intelligence. Cambridge, Mass. (USA): MIT Press. 618 p.
Wollenberg E, Edmunds D, Buck L. 2000. Anticipating change: scenarios as a tool for adaptive forest management—a guide. Bogor (Indonesia): Center for International Forestry Research. 38 p.
Wollenberg E, Edmunds D, Buck L, Fox J, Brodt S. 2001. Social learning in community forests. Bogor (Indonesia): Center for International Forestry Research. 209 p.

Notes

Authors' addresses: Ph. Guizol, Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), Bogor, Indonesia, e-mail: p.guizol@cgiar.org; H. Purnomo, Center for International Forestry Research (CIFOR) and Faculty of Forestry, Bogor Agricultural University, Bogor, Indonesia, e-mail: h.purnomo@cgiar.org.