Developing multi-stakeholder forest management scenarios: a multi-agent system simulation approach applied in Indonesia

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Abstract

Participatory approaches to development in general and natural resource management in particular are now a widely accepted management strategy. Multi-agent system (MAS), a computer-based tool, offers a promising approach for multi-stakeholder management systems such as the case involving community-managed resources. MAS provides a framework where stakeholders' (or agents) individual actions, behaviors and rational decisions can be analyzed in the context of the other stakeholders' actions and decisions. This robust approach offers a convenient analytical framework that can be used to simulate agents' actions, reactions and interactions. The approach also provides an environment where strategies or multi-stakeholder forest management scenarios can be developed and analyzed. This paper describes a MAS model developed for a forest management unit located in East Kalimantan, Indonesia. Results and experience gained from the case study suggest that MAS is a suitable approach for developing multi-stakeholder forest management strategies.

Author Keywords: Multi-agent systems; Participatory methods; Multi-stakeholder simulation; Community-managed resource

Article Outline

1. Introduction

Experience has shown that for any development to be successful, it has to include local people. In forestry, particularly in the developing world, this often applies to indigenous people or forest communities living in or near forest concession areas. Over the last decade, much has been done to develop participatory approaches to forest management. These approaches often involve different ways of empowering local communities by allowing them to be actively involved in planning and decision-making processes. The literature is rich with reports describing these approaches such joint forest management (Sarin, 2001), participatory forest management (Richards et al., 2003), social forestry (Peluso et al., 1995) and integrated resource management (Saxena et al., 2002). In addition to indigenous peoples living in close proximity to the forest, there are other actors, entities, organizations or stakeholders, who affect and/or are affected by the management of the forest. Inevitably, managing the forest resource must be a collective effort that involves all stakeholders.

To implement a participatory approach to managing the forest, there are a number of challenging tasks that must be undertaken. First is the identification of relevant stakeholders or actors who will ultimately impact the management of the forest. Second, it is important that the roles of these stakeholders are properly and adequately understood. Third, it is also significant that the behavior of the stakeholders as they perform their purposeful actions must be understood or at least considered in making strategic decisions about managing the forest. Finally, it is also imperative that the interactions between and among the stakeholders are understood and considered in planning for the management of the forest.

In view of the above, sustainable forest management should be participatory and should consider the interactions between ecological dynamics and social dynamics. A participatory approach implies that the perceptions, views and concerns of all relevant stakeholders or actors must be accommodated. In addition, incorporating the interaction between ecological and social dynamics implies that the purposeful actions of stakeholders and their decision-making behaviors should be considered and integrated along with the ecological impacts of their actions. Clearly, stakeholders or actors make anthropogenic actions and then react to other stakeholders' actions. This action and reactive interactions must be framed and analyzed within a context that includes the other stakeholders' behaviors and combined with an analysis of the ecological impacts of such actions and resulting interactions.

This paper views sustainable forest management under a multi-stakeholder or multi-actor context where actions and reactions of each stakeholder are examined in conjunction with the behaviors of other stakeholders.[1] Hence, the purpose of this paper is to describe a multi-agent simulation model of a community-managed forest.

2. Multi-agent systems and community-managed forests

Simulating a stakeholder's activities and interactions requires a tool that is able to represent the individual's knowledge, belief and behaviors. Multi-agent system (MAS) is one such tool. MAS is an emerging discipline that evolved from the general fields of decision support system, game theory and artificial intelligence. Over the last few years, there has been significant MAS development in part because of advances in information processesing, communication and computer technology. As its name implies, MAS is a general approach that takes into account the presence of multiple agents (actors or stakeholders), each with their unique views, perspectives and behavior. Each agent or actor acts or reacts (or makes decisions) as he/she pursues his/her objectives rationally, or according to his/her own rules and behavioral patterns.

There are a number of desirable features that makes MAS a suitable framework for analyzing participatory management of natural resources. First, it is an ideal environment for analyzing participatory management because the system recognizes the existence of multiple agents with their own unique style of decision-making. Second, it also recognizes the strong connections and interactions between and among the actors. The system also takes into account the unique ways each agent endowed with cognitive abilities perceives, reflects, constructs strategizes, acts and reacts to the changing resource environment as it is impacted by all the actors/agents.

MAS is a robust approach for analyzing and simulating complex systems involving multiple agents with mechanisms for coordination of independent agents' behaviors. The most significant component of MAS is an agent. While there is no generally accepted definition of 'agent', it can be considered as an entity with goals, actions and domain knowledge, situated in an environment. The way an agent acts is called its 'behavior' (Stone and Veloso, 1997). MAS focuses on systems in which many intelligent agents interact with each other. The agents are considered to be autonomous entities whose interactions can be either cooperative or selfish. That is, the agents can share a common goal or they can pursue their own interests (Sycara, 2000). Flores-Mendez (1999) stated that agents are entities within an environment with capabilities to sense, reflect and act. This means that agents are not isolated entities, and that they are able to communicate and collaborate with other entities. Hence, MAS examines individual actions (i.e. individual-based) as well as collective assessment of all agents' reflections and actions.

Agents operate and exist in some environment. The environment might be open or closed, and it might or might not contain other agents. If it contains other agents, it can be seen as a society of agents or MAS. Ossowski (1999) illustrated the coordination among agents as shown in Fig. 1. It sets out from autonomous agents that pursue their individual goal within the background of a common social structure. The bold arrows indicate social interaction processes that the agents are involved in and that influence the characteristics and achievement of their goals. Thin arrows denote functional effects. A chain of functional effects can be recognized:

norms influence and social interactions modify individual goals of agents so that their actions become instrumental and may lead to a collective action.

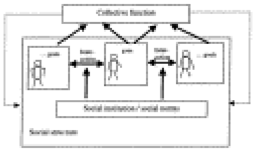

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Fig. 1. Coordination among agents (Ossowski, 1999).

The communication protocols enable agents to exchange and understand messages. For instance, a communication protocol might specify that the following messages can be exchanged between two agents (Weiss, 1999): Propose a course of action; Accept a course of action; Reject a course of action; Retract a course of action; Disagree with a proposed course of action; or Counter propose a course of action.

MAS has its roots in the emerging field of artificial intelligence. Hence, most of the early theoretical development of MAS evolved from computer-related work (Ferber, 1999 and Weiss, 1999). Recognizing the close analogy between distributed artificial intelligence and individual-based modeling, a number of authors saw the potential for adopting MAS in natural resource management particularly in areas where the management of the resources are shared among a number of stakeholders. Huston et al. (1988) were perhaps the first to put forward the notion that individuals affecting and affected by a resource are uniquely situated with their own set of beliefs, behaviors and patterns of localized action, reaction and interaction. Following this notion, Hogeweg and Hesper (1990) proposed the use of individual-oriented modeling as an approach to understanding ecological systems. Other authors adopted the same philosophy in modeling ecosystems (DeAngelis and Gross, 1992 and Grimm, 1999) including economic systems in particular (Antona et al., 1998 and Thebaud and Locatelli, 2001) and social systems in general (Axelrod, 1997; Bonnefoy et al., 2000 and Drogul and Ferber, 1994). In addition, other authors have also explored the methodological parallels between a well-known economic decision tool called game theory and MAS particularly as they relate to community-managed or common property management regimes (Bousquet et al., 1996 and Barreteau et al., 2002).

Building from these seminal works, MAS has been applied to the modeling of natural resource management. One of the first applications was on common property management regime that is pervasive among developing nations particularly with agriculture and forest-related resources. In this context, much of the initial development and application of MAS was done by Bousquet (1998). Several authors have since applied MAS to a number of cases and studies: irrigation systems (Barreteau and Bousquet, 2000), resource sharing regimes (Thebaud and Locatelli, 2001), natural resource management (Rouchier et al., 2000), game management (

Bousquet et al., 2001), economic and social development (Rouchier et al., 2001), and environmental management (Bousquet et al., 1999and Bousquet et al., 2002).

3. The case study

3.1. The site

The forest management unit (FMU) examined in this case study is located within the District of Malinau, East Kalimantan, Indonesia. The area is managed by Inhutani II, a state-owned timber enterprise. The area is approximately 48 300 ha. The area includes 14 180 ha of what is classified as limited forest production, and 34 120 ha of production forest that includes 23 890 virgin forest and 7280 ha of logged over area. The Government of Indonesia allocated the area in 1991 through a forestry ministerial decree.

According to the management plan, Inhutani II will continue logging the area amounting to 1106 ha per year or approximately 11 blocks of 100 ha. The silvicultural system implemented is Indonesian Selective Cutting and Planting System (Tebang Pilih Tanam Indonesia or TPTI). Commercial species that dominate the area are *Shorea* spp. (Meranti), *Dryobalanops* spp. (Kapur), *Dipterocarpus* spp. (Keruing), *Shorea laevis* (Bangkirai), *Palaquium* spp. (Nyatoh), *Gonistylus* spp. (Ramin) and *Agathis* spp. (Agathis).

3.2. The stakeholders

As pointed out earlier, MAS adopts a participatory modeling process; hence, one of the most important aspects of this approach is the identification and selection of stakeholders. In this study, the approach described by Colfer et al. (1999) was used as the framework for systematically selecting the stakeholders. Stakeholders were identified based on a number of criteria that include proximity, legal rights, traditional rights, dependency, knowledge about forest management (indigenous or modern) and culture links or forestry spirit. Proximity refers to how close the stakeholders are situated relative to the forest management unit or FMU. Legal rights are the rights allocated by the government according to, or mandated by, current laws and regulations. Traditional rights, on the other hand, refer to the rights that are usually not written but are recognized and acknowledged by the people (or the local community). Often, these rights derived from a long history of customs and traditions that existed for many years and have been accepted by the community. Dependency is related to the livelihood of the people and the degree to which they are supported by, or dependent upon, the forest. It is also associated with the local people's sources of alternative livelihoods outside of the forest itself. Knowledge about forest management refers to stakeholders' familiarity of the ecology of the forest, its history, including traditional methods and indigenous knowledge of forest management. Cultural values or forestry spirit refers to the inherent value of the forest to stakeholders, including spiritual beliefs about their lives and their link or dependence on the 'goodness' of the forest.

The '*Who Counts*' matrix approach described by Colfer et al. (1999) is basically a multi-criteria 'scoring' system where the score range between 1 and 5 (1=high, 2=relatively high, 3=medium, 4=relatively low, 5=low). The score indicate the level of importance, as perceived by each stakeholder, with respect to the different management criteria. The mean scores for each column are computed across the bottom of each table. The cut off point for the study which defined '*Who Counts*' is a mean score of less than or equal to 3. Table 1 shows that the first six stakeholders, i.e. Inhutani II, Long Seturan community, Langap community, Long Loreh community, Forestry Offices and Local Governments have score less than 3, so they were selected as participants in the simulation. These stakeholders represent agents of the MAS. There are three agent categories, i.e. local communities (Long Seturan, Long Loreh and Langap communities), governments (local and central governments) and a commercial company (Inhutani II). These stakeholders also represent those who are directly involved in the management and utilization of the forest. The location and juxtapositions of these stakeholders and the forest itself are shown in Fig. 2.

Table 1. Stakeholder identification using '*Who Counts*' matrix

Stakeholder dimension	Inhutani II	Long Seturan community	Long Loreh community	Langap community	Central governments	Local government
Proximity	1	1	1	1	4	2
Pre-existing right	5	1	1	1	5	5
Dependency	1	1	1	1	3	2
Knowledge on forest management	1	1	1	1	2	3
Forestry spirit	1	1	1	1	2	3
Daily activity on site	1	1	1	1	3	3
Legal rights	1	5	5	5	1	1
Total	11	11	11	11	20	19
Mean	1.6	1.6	1.6	1.6	2.9	2.7

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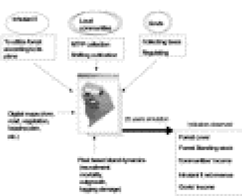

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Fig. 2. The model conceptual design.

Managers of Inhutani II stated that continued operation of the company under the current district autonomy scheme and sustained productivity of the forest are the primary goals. In addition, according to government's rules, the company must manage the forest with full consideration of the well being of the local communities living within, and in close proximity of, its concession area. While the forest was allocated legally as a concession area to the company, the local communities were also given certain rights and privileges in both the management and utilization of the forest. Local communities collect various non-timber forest products (NTFP) from the forest such as rattan, medicinal plants and other products. However, forest management plans were designed based on the needs and concerns of the company and governments without carefully considering and consulting the needs of local communities. The local communities did not have the power to influence the process of establishing, executing and monitoring the plans. Therefore, the involvement of local communities in the management of the forest was historically very low.

Certain indicators were developed to monitor the management of the forest. For the MAS simulation, five basic indicators were monitored, namely, (a) forest cover and standing stock; (b) finance performance of Inhutani II; (c) income per capita of local communities; (d) forest-related incomes of the central governments; and (e) forest-related incomes of the local governments.

4. The model and the modeling process

The conceptual diagram of the model developed in this study is shown in Fig. 2. The dynamics of the system can be generally described through the actions and activities of each agent. For instance, the state company, Inhutani II, conducts logging according to its harvesting plan, which is regulated and approved by the central and local governments. Local communities collect NTFP such as rattan, eagle wood and do hunting, fishing and shifting cultivation. Governments (central and local) collect taxes from Inhutani II. The company and local communities carry out their activities within the spatial area characterized by river and road networks, vegetation cover, logging plans and elevation. Pixel-based stand projections of forests are used to model forest growth and stand development. Stand projections consist of recruitment, outgrowth and mortality components. Indicators of forest cover, forest standing stock, communities' income, net revenue of Inhutani II and taxes collected by the governments are used to observe the outcomes of the model associated with a particular scenario.

The MAS model developed in this study was formulated using CORMAS (Common Pool Resources and Multi-Agent System), which is a multi-agent simulation system platform specifically designed for renewable resource management system (Bousquet et al., 1998). CORMAS is a programming environment dedicated to the creation of MAS, with specificity within the domain of natural resources management. It provides a framework for developing simulation models of coordination modes between agents and groups that jointly manage and exploit common resources (Bousquet et al., 1998). This framework is described by http://www.cormas.cirad.fr/en/outil/present.htm as consisting of three modules. The first module allows the definition of the entities of the system to be modelled, which are called agents and their interactions. The second module deals with the control of the overall dynamics (ordering of different events during a time-step of the model). The third module allows the definition of an observation of the simulation depending on viewpoints. This feature allows the integration, within the modeling process, of representation modes. Purnomo (2002) provides a more detailed description of the CORMAS-based model developed for the case study. CORMAS facilitates the model construction by providing predefined elements within these three modules.

4.1. Spatial entities

Fig. 3 describes the situation map of the study area showing the 5-year cutting blocks and the villages' rice fields. The 5-year cutting blocks were obtained from the company's forest utilization long-term plan, which is one of the government requirements. The geographic location of the rice field areas is also depicted based on the vegetation map. Using geographic information systems the areas are presented spatially as pixels, including rivers, roads, vegetation, logging plans and elevation. Each pixel represents an area of approximately 35.27 ha.

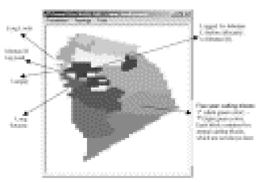
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Fig. 3. The situation map of study.

In Indonesia, forest management and harvesting operations are regulated under a selective logging system. This system allows for all commercial trees with diameters greater than 50 cm to be harvested within a cutting cycle of 35 years. However, not all trees above the 50-cm minimum diameter limit were harvested, e.g. non-commercial trees, protected trees (e.g. *Dyera costulata*, *Koompassia excelsa*, *Eusideroxylon zwagery*, *Shorea pinanga*), hollow trees, trees at steep slope and seed trees.

4.2. Forest growth projection

Diameter class projection method is one of the traditional forest growth models particularly suited for selectively-logged forests, particularly in the tropics. The basic concept of the method is that the forest is represented in a stand table containing trees organized by diameter classes. The change in the stand table is calculated over a growth period, usually between 5 and 10 years, using periodic increment data obtained from re-measured growth plots. On the basis of information generated from the permanent growth plots, upgrowth (i.e. number of trees moving up to higher diameter class), mortality and ingrowth (i.e. number of trees growing into the smallest diameter class) are calculated. Finally, forest growth can be projected within each pixel. The projection method involves estimates of recruitment (R) representing ingrowth, outgrowth (O) or upgrowth and mortality (M). For each pixel, the projected number of trees at any diameter class 'j' and after a growth period 't+1' ($N_{j,t+1}$) is defined as

(1)
$$N_{j,t+1}=N_{j,t}+R_j+O_j-M_j$$
where $N_{j,t}$ is the initial number of trees in diameter class j at time t.

These growth components were taken from Septiana (2000), who had calculated them based on permanent sample plots located in the area as shown in Table 2. Table 3 shows the historical average number of trees per hectare from 1991 to 2001. Table 4 shows the tree removal in percent based on TPTI regulations, and the estimated logging damage. Hence, the number of trees harvested at any given time period can be estimated using Table 3 and Table 4. Subsequently, the number of trees for each diameter class can be projected using the model in Eq. (1) based on the number of residual trees and the growth dynamics whose parameters are shown in Table 2.

Table 2. Stand structure growth components (Septiana, 2000)

Component	Size class (cm dbh) (lower limit of class)				
	20	30	40	50	60
Recruitment (number of trees)	1.6				
Outgrowth (movement ratio of this size class to higher size class)	0.086	0.115	0.101	0.087	
Mortality (mortality ratio of this size class)	0.020	0.010	0.020	0.015	0.020

Table 3. Number of trees per hectare of forest stand before logging

Cutting block	Size class (cm dbh)				
	20	30	40	50	60
1991/1992	16.66	7.20	4.94	3.50	11.34
1992/1993	21.16	8.58	5.32	4.02	13.02
1993/1994	24.00	7.18	4.50	3.86	12.50
1994/1995	16.01	5.01	2.62	4.63	15.00
1995/1996	17.78	6.30	3.06	5.15	16.69
1996/1997	27.80	11.89	9.16	5.16	14.78
1997/1998	22.04	9.73	7.67	3.87	13.27
1998/1999	21.71	7.93	8.31	4.13	12.07
1999/2000	20.73	9.20	6.02	3.49	12.18
2000/2001	19.56	8.93	5.33	3.07	11.60

Source: Summarized from Annual Plans of Inhutani II (1991/1992–2000/2001).

Table 4. The percentage tree removal (based on TPTI) and damage in different logging activities

Logging	Size class (cm dbh) (lower limit of class)				
	20	30	40	50	60
Inhutani II's logging					
Cut (%)	0	0	0	80	80
Damage (%)	50	40	30	20	10
Communities' logging					
Cut (%)	0	0	0	5	10
Damage (%)	7	3	2	1	0

Logging damage varies in its form and extent. The method and intensity of logging will influence the degree and type of damage (Alder and Synnott, 1992). Sist et al. (2003) noted that logging in Inhutani II is done using high felling intensity (>9 trees per ha or ∼80%), which resulted in high damage to residual trees. The percent of dead trees due to felling were estimated for the different diameter classes as follows: 50% for 1–5 cm, 40% for 20–30 cm, 30% for 30–40 cm, 20% for 40–50 cm, 20% for 50–60 cm and 10% for higher than 60 cm. In contrast, expected mortality in traditional logging done under low felling intensity (manual harvesting system) is only approximately 1–2 trees per ha (or ∼10%). Therefore, it created low damage to the residual stands. Table 4 also shows the data of different logging scheme and their impacts. Logging (L) and its damage (LD) changes model Eq. (1) into

(2)

$$N_{j,t+1}=N_{j,t}+R_j+O_j-M_j-L_j-\mathrm{LD}_j$$

4.3. Social entities

A social entity may represent a person, a group of people, or an institution with homogeneous characteristics. A social entity is called an agent. An agent might locate in a spatial entity and has capability to communicate and act. In this study, an agent is an actor or a chosen stakeholder, i.e. Inhutani II, local communities (i.e. Long Seturan, Long Loreh and Langap communities), local and central governments.

Revenues for Inhutani II come solely from selling the logs. Harvested logs are a function of stand structure of the logging block area, diameter cutting limit and exploitation factor. According to TPTI rule, the diameter cutting limit for production forest is above 60 and 50 cm for limited production forest. Exploitation factor is the efficiency of converting timber stand into logs, which is 70%.

The communities' income was represented by the income per household and limited only to cash income. In the simulation, the assessed income comes primarily from the forest and ladang (rice field). The incomes from non-forest sources were ignored because of their complexity and difficulty of obtaining data. 'Illegal' logging conducted by the communities was also neglected since it is a sensitive issue and no reliable data can be obtained. The communities used timber primarily for building their houses, churches and others such as a village hall. Although the communities are involved in small-scale logging, in practice the operation is actually done by the logging company while the local people received small amounts as ‘royalty’ fees. Financial arrangements with the logging company are varied and are calculated based on the amount of timber logged.

5. Scenario development and hypothesis testing

Developing scenarios is one of the convenient ways that management strategies can de devised and evaluated. Scenarios become even more important in the case of community-managed resources that are shared among many actors or stakeholders. Under a resource-sharing environment, several actors have to coordinate the management and exploitation of the shared resource, the benefits, and the externalities generated by the actions, reactions, or decisions made by individual agents. Clearly, being able to simulate the individual decisions and the dynamic impacts of the agents’ interactions allow for a more rationale development of management strategies of community-managed resources. The sections that follow describe the cases of collaborative forest management and testing of a hypothesis about the impacts of different management scenarios.

5.1. Collaborative management of forest and development of scenarios

One of the advantages of a MAS model is the ability to simulate or imitate the anticipated development and evolution of the resource based on the expected collective actions and reactions of stakeholders or agents. These actions and interactions can be cooperative or non-cooperative. Collaborative management of forest is defined simply as sharing in the production and utilization of timber. Production sharing can happen if there is agreement between the timber company, Inhutani II, and the communities and approved by the governments. Collaborative management is considered a success if the cost of collaboration is lower than the benefits gained from it. Collaboration is a social phenomenon that can happen because the agents, or the stakeholders, want to achieve their collective goals. In order to achieve their goals, they work cooperatively with other agents.

A bounded rational economic behavior was observed as the primary agent's motivation for having collaboration. This implies that agents will collaborate if it is economically profitable and is supported by their economic rationale. Or, at the very least collaboration is not prohibited by their beliefs. In the simulation, each agent does two primary things: executes what the agent usually does or plans to do to achieve his/her goal and interacts with other agents to seek ways to improve the agent's goal attainment.

Fig. 4 shows the agents’ interactions using sequence diagrams of the unified modeling language. For instance, arrow 1 indicates that the central government calls for a proposal to manage an area of forest. Inhutani II sends a proposal that comprises a management plan as denoted by arrow 2. The central government evaluates the plan and gives approval or disapproval denoted by arrow 3. Then the central government informs other stakeholders, as represented by arrows 4, 5, 6 and

7, about this approval. Inhutani II logs the area according to its plan and generates income. Inhutani II pays taxes to the central and local governments.

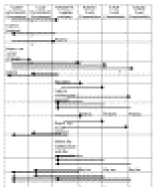 Full-size image (18K)

Fig. 4. Unified modeling language sequence diagram of the agent interactions.

Inhutani II calls for proposals for collaboration. Communities in Seturan, Loreh and Langap may send a proposal. Traditionally these local communities cultivate rice fields and collect NTFP. They extend their rice fields annually to accommodate any population growth or increased needs. If Inhutani II accepts their proposal, they will prefer to collaborate in forest management rather than extending their rice fields. Participating communities pay fees to Inhutani II and taxes to central and local governments.

Details about these interactions are described by Purnomo (2002). It should be pointed out, however, that under a collaborative scheme, each agent does not want to be worse off in any collaboration. The following are possible collaboration scenarios formulated in consultation with the stakeholders: (1) negotiating areas where local communities can have rights to log; (2) local communities are restricted to only implement logging in a 'traditional' way; (3) local communities pay fees to Inhutani II amounting to 20% of their net revenue of logged timber; and (4) local communities pay 10% of their net revenues as fees to local and central governments.

The MAS model was simulated for 20 years to observe the long-term effects of a scenario. The simulation outputs of the collaborative management in comparison with non-collaborative management are given in Table 5 for biophysical indicators and Table 6 for economic indicators. This simulation is assumed to use a 35-year cutting cycle as required by the TPTI forest management system. Economic indicators were estimated by using verified secondary economic data such as timber price, rice field price, NTFP prices and taxes.

Table 5. Simulation results of biophysical indicators under the two scenarios

Simulation year	Remaining virgin forest (in thousand ha)		Forest standing stock (million m^3 volume)	
	Non-collaborative	Collaborative	Non-collaborative	Collaborative
1	44.2	44.2	42.8	42.7
2	43.4	42.4	41.9	40.6
3	41.7	42.1	40.2	40.0
4	41.2	41.6	39.7	39.3
5	40.2	40.6	38.5	38.1
6	38.7	39.1	36.5	36.0
7	37.3	37.7	35.2	34.7
8	36.6	37.6	34.6	34.7
9	35.9	37.4	34.2	34.6
10	35.2	37.1	33.7	34.4
11	33.2	35.3	32.3	33.0
12	32.3	34.6	31.8	32.5
13	31.2	33.5	31.1	31.8
14	30	32.5	30.4	31.2
15	29.1	31.7	30.1	30.8
16	27.6	30.3	29.2	29.9
17	26.5	29.2	28.6	29.5
18	25.3	28.1	28.1	29.0
19	24.1	26.9	27.5	28.5
20	21.9	24.9	26.3	27.2

Table 6. Simulation results of economic indicators under the two scenarios

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Year	Inhutani II net revenue (in million Rp/year)		Communities' income (in million Rp/year)		Incomes of ce[...] Rp/year)
	Non-collaborative	Collaborative	Non-collaborative	Collaborative	Non-collaborati[...]
1	1600	1800	2.2	3.2	453
2	12 200	12 700	2.2	5.1	458
3	9270	3600	2.5	4.8	363
4	8200	8730	2.5	4.7	340
5	16 600	16 800	2.5	3.4	660
6	14 500	14 600	2.5	2.9	1020
7	17 600	17 600	2.5	2.6	787
8	6680	359	2.5	3.1	376
9	5190	265	2.5	2.8	312
10	5840	2260	2.5	3.0	364
11	6790	5660	2.5	2.8	1000
12	5620	5840	2.5	2.6	409
13	6350	6450	2.5	2.5	550
14	4080	4080	2.5	2.4	567
15	1700	1740	2.5	2.4	349
16	63	99	2.5	2.4	686
17	3590	3590	2.5	2.4	456
18	4870	4910	2.5	2.4	501
19	2130	2130	2.5	2.3	516
20	386	595	2.5	2.5	927
Aver.	6660	5650	2.4	3.0	555

Full-size table (27K)

Note: Assumed 1 US$=9000 Rp (Rupiah is an Indonesian currency).

When the 'right to' log is given to local communities, their income significantly improved. However, since the local communities are permitted to cut 10% of trees at diameter class above 50 cm, the logged-over forest can still be considered virgin forest. It can also be assumed that, with this harvesting strategy, the communities can implement logging activities with low damages. Fig. 5 shows the maps of two different forest management schemes.

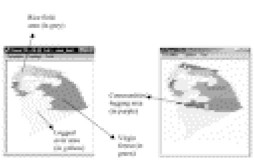 Full-size image (13K)

Fig. 5. The simulation map results of non-collaborative and collaborative management.

The remaining virgin forest is higher under a collaborative scenario compared to the non-collaborative. This may be due to the allocation of areas within the concession to local communities under the collaborative scenario. Under this scenario, areas logged by local communities following the traditional and less destructive logging methods are likely to develop, and be classified, as virgin forest. This is in contrast to non-cooperative scenario where the same areas may be logged by the timber company itself, or by non-collaborative agents that may not follow the logging method prescribed by the timber company. As stated earlier, the communities are restricted by Inhutani II to use a traditional way to log those areas allocated to them. This arrangement resulted in less logging damage. Consequently, the net revenue of the timber company from log production decreases. However, fees paid by the local communities as compensation for logging rights can offset the revenue reductions from log production.

The 'logging rights' fee determines the revenue addition for Inhutani II. Collaboration between the local communities and the timber company involves a logging rights fee of 20% of the revenue derived from logging. On the other hand, 10% of local communities' revenues are paid as 'fee' to local and central governments. The license agreement spells out the details of the collaboration between the government and the timber company, including associated license fees and royalty fees paid to the government. Other costs of collaboration, including transaction costs, were not included here due to its difficulty to assess.

5.2. The hypothesis testing

The results of the 20-year simulation shown in Table 8 offer some insights with respect to the impacts of the collaborative and non-collaborative scenarios on biophysical and economic indicators. However, based on this information alone, it is difficult to conclude whether the two scenarios are actually yielding statistically significant results. Hence, it may be meaningful and useful to do a statistical test of their difference or similarity.

Barreteau et al. (2002) described the use of simulation models as both learning and research tools. As a research tool, a simulation model is often used to test a hypothesis (Barreteau et al., 2002 and Grant et al., 1997). In this case study, it may be meaningful to determine whether two scenarios (i.e. collaborative and non-collaborative) are actually yielding statistically significant results. Hence, it may be meaningful and useful to do a statistical test of their difference or similarity. The general hypothesis examined in both scenarios is whether collaborative forest management (CFM) provides better outcomes than single-actor forest management (non-collaborative). Since no assumption on specific distributions of the simulation results was imposed, distribution-free nonparametric statistical methods, specifically the one-sample sign test of the median method, was most appropriate. This nonparametric test is a robust alternative to the standard *t*-test and can be used when the distribution of the sample cannot be assumed to follow, or violates, the normal distribution. Further, if it cannot be assumed that the population is symmetrically distributed, then the test also applies to median values rather than the means (Rosner, 1995 and Sokal et al., 1995).

The one-sample sign test of the median hypotheses are: H_0: the population medians are all equal vs. H_1: all the medians are not equal. The hypothesis is formulated formally as follows:

H_0: $m_{ci}=m_0$
H_1: $m_{ci}\neq m_0$

where the prefix 'ci' is for indicators of collaborative management indicators, while '0' is for non-collaborative indicators. The indicators tested and the results of the tests are summarized in Table 8.

To test the hypothesis, the simulation was replicated several times for collaborative management and once for non-collaborative; one for each formulated scenario. The non-collaborative scheme did not have random variables; hence, it is a deterministic model. While there is only one baseline simulation for deterministic models, stochastic models on the other hand consist of a set of replicate simulations. Grant et al. (1997) proposed a formula of determining minimum simulation replication for hypothesis testing. In this case 14 simulation replications was deemed sufficient. Table 7 shows 14 simulation outputs of non-collaboration and collaboration schemes.

Table 7. The simulation results for non-collaboration and collaboration schemes

Scenario	Replication number	Collaborative management area (in thousand ha)	Remaining virgin forest (in thousand ha)	Logged forest area (in thousand ha)	Rice field area (in thousand
Non-collaborative.	1	0.0	21.9	24.8	6.0
Collaborative	1	4.1	24.9	22.6	5.1
Collaborative	2	7.9	25.0	22.5	5.1
Collaborative	3	3.8	24.9	22.6	5.1
Collaborative	4	7.6	24.7	22.8	5.1
Collaborative	5	3.9	25.0	22.5	5.1
Collaborative	6	6.7	25.0	22.5	5.1
Collaborative	7	4.3	25.1	22.4	5.1
Collaborative	8	6.5	24.9	22.6	5.1
Collaborative	9	6.6	24.5	23.0	5.1
Collaborative	10	5.4	25.3	23.6	3.8
Collaborative	11	2.9	25.1	23.8	3.8
Collaborative	12	3.5	25.6	23.2	3.8
Collaborative	13	6.3	25.0	23.8	3.8
Collaborative	14	2.9	25.1	23.7	3.8

Full-size table (29K)

The CFM scenario shows better results on most indicators as shown in Table 8. No statistically significant difference (at 99% confidence level) was observed between the two scenarios on the standing stock, Inhutani II net revenue and income of local governments. This implies that involving local communities of forest dependent people in the forest management scheme would achieve better sustainability outcomes. Moreover, collaboration between stakeholders should be encouraged and made explicit in order to achieve better outcomes.

Table 8. Testing similarity of indicators between collaborative and non-collaborative scenarios

SFM indicators	Hypothesis testing	The collaborative scenario compared to the non-collaboration one
Remaining virgin forest (ha)	Reject H_0[a]	Significantly bigger
Rice field area (ha)	Reject H_0[a]	Significantly lower
FMU Standing stock (million m^3 volume)	Accept H_0[a]	No significant change
Inhutani II net revenue (Rp/year)	Accept H_0[a]	No significant change
Communities' income (Rp/year)	Accept H_0[a]	Significantly higher
Income of central government	Reject H_0[a]	Significantly higher
Income of local government	Accept H_0[a]	No significant change

6. Policy implication

The promotion of collaborative management is based on the assumption that effective management is more likely to occur when local resource users shared or have exclusive rights to make decisions about, and benefit from, resource use. In addition, Castro and Nielsen (2001) also indicated that one major justification for co-management is the belief that increased stakeholder participation will enhance the efficiency and perhaps the equity of the intertwined common property resource management and social systems.

There is no general formula to design CFM that will work across all types of FMU. Moreover, there is no one-fits-all forestry program that can serve as a blueprint that has to be implemented rigidly. On the contrary, CFM has to be designed in an open environment and must be flexible enough to accommodate local conditions (Sukwong, 2000). For instance, Sarin (2001) described the failure of top down 'participatory' forestry project conducted by the Uttar Pradesh Forest Department under a devolution program. The project resulted in the disempowerment of women and disenfranchised the poorest.

The impacts of scenarios where there is sharing of power among stakeholders in making decisions and exercising control over resource use should be known and well understood before they are implemented. Simulating these scenarios using MAS is a robust and flexible way to examine the impacts of many collaborative arrangements (Fahey and Randall, 1998) and ultimately help design CFM strategies.

Most Indonesian production forests have been allocated legally as concession areas to logging companies through timber license agreements. To manage these concessions effectively, timber companies must invest in areas necessary to be able to harvest (e.g. roads, machineries, equipment) as well as for protection and reforestation. Consequently, forest policy makers are faced with the problem of dealing with timber companies and their need to meet their investment objectives, as well as the needs of local communities who are heavily dependent on the forest for their livelihood. This situation requires prudent balancing of these needs and also calls for collaboration and sharing among the different stakeholders including the timber companies and local communities. This collaboration was simulated in this case study. Different collaborative arrangements including rights, responsibilities, returns and relations were examined.

The details of collaboration may differ from site to site. Each FMU may have a different collaboration scheme or arrangements. Stakeholders generally compare the benefits and costs of collaboration under different collaborative arrangement. If the outcome is beneficial then collaboration is feasible. The benefits and costs might include tangible and intangible benefits. Stakeholders must be aware of the existence of different collaboration costs, such as the costs of specifying the rights and obligations of each stakeholder; the costs of enforcing these rights, and the costs of monitoring collaboration. Since simulation is a robust way to determine the impact of a positive arrangement scenario (Painch and Hinton, 1998) then we propose to use it in the implementation of CFM.

7. Conclusions

This paper has demonstrated the use of MAS as a procedure that can be used to develop multi-stakeholder forest management scenarios. Experience from the development literature has shown that for development efforts to be successful, they must actively engage and involve all stakeholders that affect, and are affected by, community-managed resource typically found in the developing world.

Collaboration between concessionaires and the communities appears to be the most suitable alternative for sustainable forest management particularly in improving the local communities' incomes and livelihoods with minimal decrease in the quality of the forest. This implies that collaboration between stakeholders should be encouraged and specific enough in order to achieve better management of forests.

Collaboration arrangements may differ from site to site. Each FMU may have different types of collaboration with different arrangements among stakeholders. Consequently, CFM strategies can be designed and implemented according to the economic objectives of both the communities and the concession holders (i.e. timber companies), and within the production limits of the forest itself. For instance, local communities may generate income from the collection of NTFP, or from harvesting timber made possible through 'rights' shared by the timber company with the local communities to log a part of the forest. In turn, the communities pay the company a minimal amount of fee for timber harvesting within the company's concession area. Such arrangement enables CFM to be implemented while satisfying both economic objectives of the communities and the timber company, as well as protect and maintain the health and productivity of the forest itself.

This paper has demonstrated the use of MAS in modeling collaboration arrangements. Insights gained from the research point to the need for the use of MAS as a learning tool. This constitutes a challenging research area. It would be interesting to explicitly model not only the behavior of the agents but also the different patterns of learning and how the learning process subsequently affects the stakeholders' future actions and reactions with respect to the ultimate goal of sustainable resource management.

Acknowledgements

This study was partially funded by a cooperative project between the University of Illinois and the Center for International Forestry Research (CIFOR). The views expressed herein are solely of the authors and do not necessarily reflect the official views of CIFOR.

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