Integrating multi-agent systems and geographic information systems modeling with remote-sensing data for participatory natural resource management in coastal Bohol, Philippines

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This exploratory research tried to develop a methodology for building a multi-agent systems (MAS) simulation model, following the companion modeling approach, while integrating geographic information systems (GIS) and remote-sensing (RS) for data collection, processing, and analyses. One of the main outputs of this research was a prototype MAS simulation model for the municipality of Loon in Bohol, Philippines. Using the model, the researcher attempted to demonstrate how individual actions of stakeholders collectively affect the environment, thus providing the stakeholders with a new way to view their natural resources and environment. In this way, stakeholders in an NRM situation would be more involved in effectively managing their own environment and resources. Also, scenarios based on the initial findings of the fieldwork were developed for the model, whose results were analyzed using GIS techniques.

Although the Philippine government is promoting natural resource management (NRM) using a decentralized approach, such that the local government would be responsible for managing its resources, most of the management of natural resources has remained top-down. Usually, little or no participation occurs among the stakeholders in NRM policy formulation and implementation (Boquiren and Cabalfin 1995).

The top-down approach of resource management limits knowledge about the system for both the policymakers and stakeholders who are directly affected by these policies. This may lead to badly formulated NRM policies that could drastically affect stakeholders in terms of decreased financial opportunities, or could be detrimental to the environment by making its exploitation unsustainable. To help avoid these problems, a better knowledge and understanding of natural resources and their management are necessary. In this way, NRM policies can be designed more appropriately for the NRM system they were intended to help. Modeling the NRM situation may provide a solution to this end.

Geographic information systems (GIS) and remote-sensing (RS) have been used in natural resource management for gathering, integrating, and analyzing data gathered from various sources (Rajan 1991). The rapid development of GIS and RS applications together with advancements in computing has made obtaining, managing, manipulating, and analyzing data faster, easier, and more cost-efficient (Davis 1995, Korte 2001).

Despite the advantages of GIS/RS, most applications developed using these technologies are static because GIS doesn't have an inherent capability of handling time (Gimblett 2002), and this may not be enough to model the complexity and behavior of systems, and to explain their emerging patterns. Ecosystems are not static and the conditions of these systems, both local and global, change over time, and, therefore, must be considered in order to model ecological phenomena (Gimblett 2002, Biswas 1990). There is also a difficulty of relating macro-spatial patterns with decision-making activities and behavior occurring at the micro-level (Griffith and Mackemon 1981). An integrated approach to modeling, for example, coupling multi-agent systems (MAS) and GIS such as in the case of this research, may be able to overcome these obstacles.

MAS can be used as a learning tool for a better understanding of a system through simulation modeling (Barreteau et al 2001, Parker et al 2002). By focusing on key elements of a system, a better view of how these elements affect the system can be attained (U.S. EPA 2000). For example, by incorporating human activities together with biophysical processes in the model, which would have been difficult in conventional GIS/RS modeling, stakeholders can gain more knowledge of how they affect the environment and vice-versa, and, as a result, provide more focused ideas on how to manage their resources. Furthermore, by developing strategies or scenarios for NRM, these scenarios could be tested in a MAS simulation model before applying them to the real system, thus minimizing money, time, and other costs of policy implementation.

The goals of this research are to develop a methodology following the companion modeling approach (Bousquet and Trébuil, this volume) for developing a MAS model integrating GIS/RS techniques that could be used as a tool for NRM, and build a prototype MAS model based on these methods following Barreteau et al (2001), Etienne (2003), and Etienne et al (2003). This model could be used to support the process leading to a decision by facilitating communication related to negotiation. By discussing the model and its outcomes (by running different scenarios or strategies), stakeholders could reach a collective decision as to how their natural resources could be managed. This paper presents the first steps of the research that is the development of the model.

The research area is the municipality of Loon. Loon is located in the northwestern portion of Bohol Province, in the Central Visayas region of the Philippines, roughly at 123°50′E and 9°55′N (Fig. 1). Loon is around 11,200 ha and is composed of 67 *barangays* (the smallest political unit in the Philippines), 18 of which are coastal barangays. On the basis of the workshops, focus-group discussions, and interviews conducted with the local people and the local government unit (LGU) of Loon, several problems were identified (Campo 2003). The fishermen, most of which fish on a small scale, are having problems with the constant decline in the fish catch caused by overfishing by large-scale fishermen from outside Loon. The LGU, recognizing the dwindling fish stock within its municipal waters, passed a policy declaring mangrove areas as sanctuaries, prohibiting any form of human activity in these areas. Since most of the fishermen use only small paddleboats, limiting their fishing activities to shallow waters, the implementation of the policy has resulted in a reduction of the available fishing grounds. Furthermore, since a large portion of the coastline of Loon is sur-

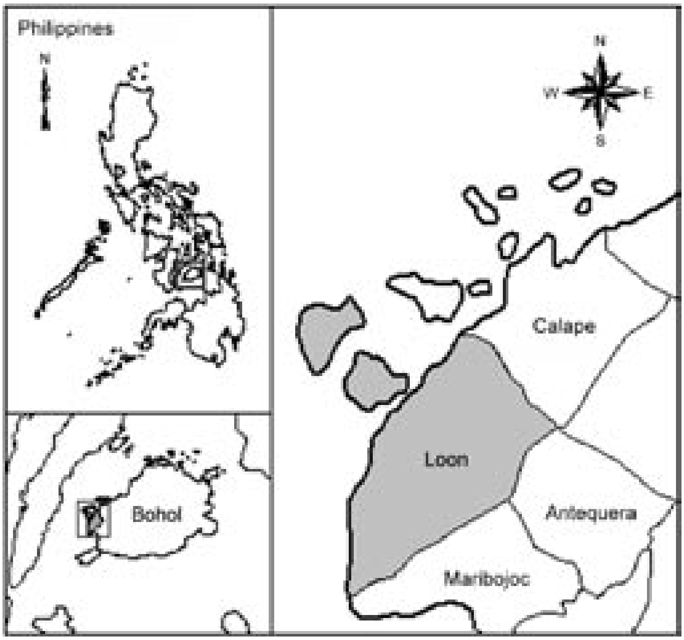

Fig. 1. Location map of municipality of Loon in Bohol, Philippines.

rounded by mangrove, and the fishermen are not allowed to cross these areas, they face the dilemma of how to go from the shore to the fishing grounds to fish. Another problem the LGU and the fishermen face is the growing number of fishponds in the municipality. Since the LGU is not the approving body of fishpond business applications, it cannot prevent the conversion of land to fishponds. Chemicals used to clean and prepare the fishponds for the next cycle of harvest are eventually drained into the sea, killing the organisms living there, including mangrove and fish. Moreover, the bottoms of the fishponds are replaced every four harvests with limestone material quarried from the mountainsides. For now, the only solution for the LGU is to set a limit on the maximum income that fishponds could generate. Severe soil erosion and river siltation during the wet season are attributed to unsuitable farming practices in the uplands, such as slash-and-burn farming, which, in turn, contributes to the continued forest denudation. Collection of wood for firewood in mangrove and forest areas has also been observed, thus increasing the loss of trees in those areas. Many problems may yet be identified. But, for this exploratory research, the initial findings give researchers preliminary ideas as to where to begin building the MAS model.

With these problems in mind, the MAS model was developed to try to show how the individual activities of the stakeholders affect the environment and other stakeholders. This research also tried to introduce a simple collective decision-making activity by a group to recognize the significance of the decisions of organized groups in an NRM system, such as a group of fishermen. Furthermore, scenarios were developed to show the potential of this MAS model as a tool for enhancing a greater awareness of the current state of the environment and natural resources of the municipality, and the current trends.

In the succeeding section, the methods for the MAS modeling process developed for this research are discussed, its basis, and implementation into an actual fieldwork, including the kinds and sources of data used to develop the prototype model. After that, the Bohol model is presented. Analyses of the simulation results follow and then conclusions are drawn to synthesize the lessons learned from fieldwork and simulation results.

Materials and methods

Methodology

The processes involved in building a MAS simulation model come from and feed into different activities. Physical and biophysical processes (domain expert knowledge) are elicited from local experts for information on the various human/nonhuman processes occurring in the system. The stakeholders provide information on their activities and decision-making processes for resource management. This information is elicited by using participatory approaches, such as interviews or role-playing games (RPGs). The database will contain spatial and nonspatial data that are acquired and integrated using GIS and RS techniques. This would represent the initial state or condition of the system. The role of the experts and stakeholders in the modeling process does not end in merely providing information. Through participatory processes, they may also be given the task of verifying the contents of the database, both the spatial and nonspatial, whether they are correct, complete, or necessary, before the data are incorporated into the MAS model. After the initial MAS model is built, it has to be verified by the sources of data it uses. This can be done by asking the experts and stakeholders whether the model is close to reality or if it could be used to represent their reality. After validation, the MAS model simulation and its results could be used to foster discussion or negotiations in participatory NRM. The spatial information from the simulation could be processed and analyzed by using GIS/RS techniques, the results of which could be used to support the MAS simulation in the negotiation process. The outcome of the discussions or negotiations between the stakeholders and policymakers may be strategies or scenarios that are thought to foster sustainable exploitation of the natural resources. However, before these strategies can be applied in reality, they could be first tested in the MAS simulation model already created. Again, the process of data collection, verification, and validation would be repeated, and the results could again be used for further negotiations. Figure 2 shows the interrelationships of these processes and the basis of the methods of this research.

The steps for the MAS modeling process (as shown in Fig. 3), which follows the companion modeling approach, would have two stages, the initial stage and the continuing stage. The steps outlined in Figure 3 are performed in the initial stage, with the assumption that the NRM problem has yet to be defined and the model has yet to be conceptualized. For the continuing stage, the same steps are repeated, with the assumption that there is already a model from which scenarios or new strategies would be built upon. The stakeholders of the NRM system identify problems. Because different stakeholders would have their own perspectives about their NRM system, they may identify problems in different ways (Etienne et al 2003). These problems should be analyzed based on their similarities and differences, and later synthesized into a

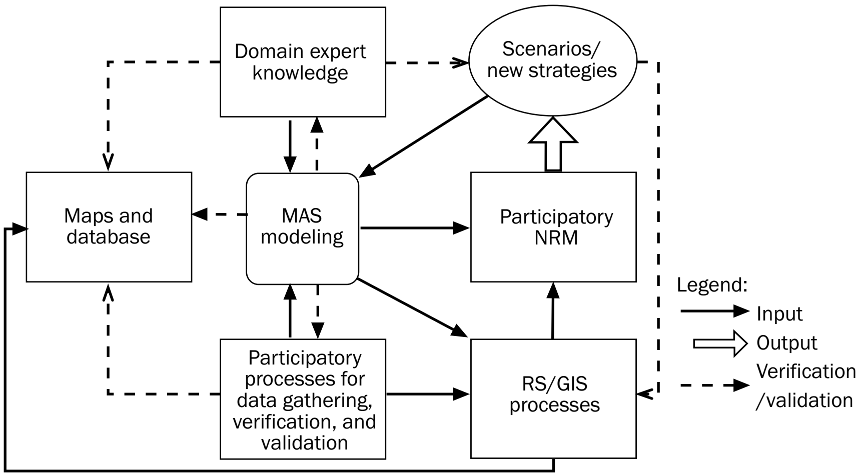

Fig. 2. MAS modeling integrating GIS and RS for participatory NRM (after Pahl-Wostl 2002).

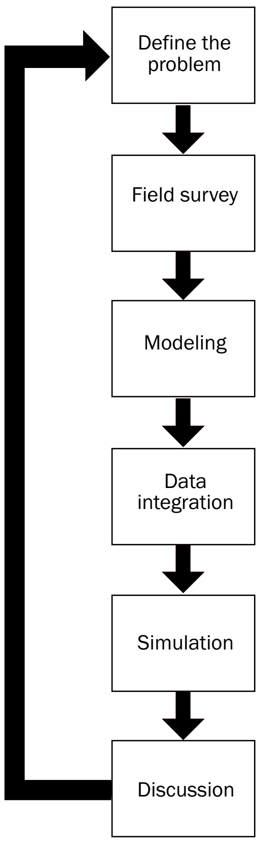

Fig. 3. Steps of the MAS modeling process.

cross-cutting encompassing problem or problems that should have been agreed upon by the stakeholders. An initial model may be an outcome of this step and would guide the collection of data during the field survey. MAS modeling involves the synthesis of various submodels, such as the activities of the stakeholders and the spatial dynamics of the environment, with the structure of the environment designed such that the submodels would function within this environment. Data integration would involve spatial data integration and file format conversion using GIS software and putting all the data and submodels together into one encompassing model, and translating it into a computer program. Simulations would be performed and the results discussed afterward with the stakeholders to validate the consistency of the model as compared to reality. The presentation of results may include change detection maps, charts, and cross-tables. A joint evaluation of the simulation results among stakeholders may result in a remodeling of the MAS or the identification of scenarios or strategies. The steps of the MAS modeling process are repeated for the continuing stage as the need arises, such as the identification of new problems and development of new strategies or scenarios.

This research is currently in its first stage of implementation. The participatory process that has been applied is limited only to data gathering, that is, ground mapping and verification with the locals, and extraction of information on the current physical and social situation of the study area and the social dynamics of the stakeholders. Model validation has yet to be performed. The use of the model in an actual NRM negotiation process is expected to occur in the second stage of the MAS modeling process.

Data and sources of information

Workshops were conducted with the local people to understand how the inhabitants of Loon viewed their environment and natural resources, and what they thought were the problems related to these resources. Meetings with the mayor of Loon obtained his perspectives about NRM problems in the town, and introduced the possibilities of using geo-information technology. Individual and group interviews, as well as focus-group discussions, were also conducted with farmers, fishermen, fishpond operators, and the mayor to obtain information about their activities in terms of the use of natural resources.

A Landsat 2000 satellite image of Bohol Province was acquired from the Bureau of Fisheries and it was used as the primary source of land-cover/-use information. This is a significant aspect of this research because a land-use map of the municipality was not available at the time of data acquisition, and, without the satellite image, a land-use/-cover map couldn't have been constructed. It also provided land-cover/-use information beyond the boundaries of the municipality. The satellite image was classified using e-Cognition® image-processing software, a software for remote-sensing applications. Field verification was again performed for ground-truthing of the satellite image using a global-positioning system (GPS) to locate points on the ground. This image was also used during workshops to introduce the technology to the locals. The Participatory Coastal Resource Assessment (PCRA) maps of northern Bohol were obtained from the Coastal Environment Profile of Northern Bohol (Green et al 2000), which includes Loon. Topographic maps covering the study area were obtained and used as a source of bathymetric data, verification, and geometric correction of data. Digital data on the municipal and barangay boundary maps were acquired from the Haribon Foundation, an environmental nongovernmental organization, whose study areas include the province of Bohol. Mapping activities were also carried out—the quarry sites owned by large fishpond owners were mapped, as well as the location and extent of mangroves. The GPS surveys were conducted with the assistance of the local people.

The MAS model for this research was programmed using the common-pool resources and multi-agent systems (CORMAS) platform, which is specifically designed for natural resource management applications (Le Page and Bommel, this volume).

The process of spatial data integration and spatial data importation into CORMAS is discussed in the next section.

Spatial data integration and coupling of MAS and GIS/RS

Given that the spatial data for this research are of different scales, formats, and grid systems, there was a need to process these layers of information to make them useful. The paper maps, namely, the topographic maps and PCRA maps, were digitized. Points obtained from the GPS mapping activity were plotted and stored in ArcView 3.2®, the GIS software used in this research. After this, the satellite image and digital data obtained from the paper maps were geometrically corrected to properly orient and overlay them with the digital data for the political boundaries, quarry sites, and mangrove areas. This was done by using the topographic maps and having the Universal Transverse Mercator (UTM) as the base grid system of all spatial data. The classified satellite image was then converted from raster to vector data format to be consistent with the other layers of information. After geometrically processing the spatial data, they were then integrated within ArcView 3.2®. The classified satellite image and PCRA maps were combined, resulting in a land-use/-cover map of the study area, as shown in Figure 4. In the implementation of the model, 14 classes were used for land and sea cover. However, for visual clarity, the land-use/-cover map has been generalized into four categories, namely, water with vegetation composed of sea grass/weed, coral, and mangrove cells; normal water—water without any vegetation—composed of water and mud cells; forest and nonforest cells composed of beach, flats, farm, grassland, bare soil, fishpond, and built-up area; and quarry cells.

Since there is no direct linkage between the GIS software, ArcView 3.2®, and the MAS programming software, CORMAS, a loose coupling of the two software was used. Loose coupling of software involves the software "communicating" with each other using interchange files—a file format that could be read by both software (Bailey and Gatrell 1995). In this case, the ArcView data were converted to raster data format and then to ASCII (American Standard Code for Information Interchange) file format. The header information of the ASCII data files was edited so that it could be read by CORMAS. Then, the ASCII data files were imported into CORMAS. Further data-reduction activity was done within CORMAS to reduce the number of data, thus reducing the complexity of programming codes and speeding up the simulation.

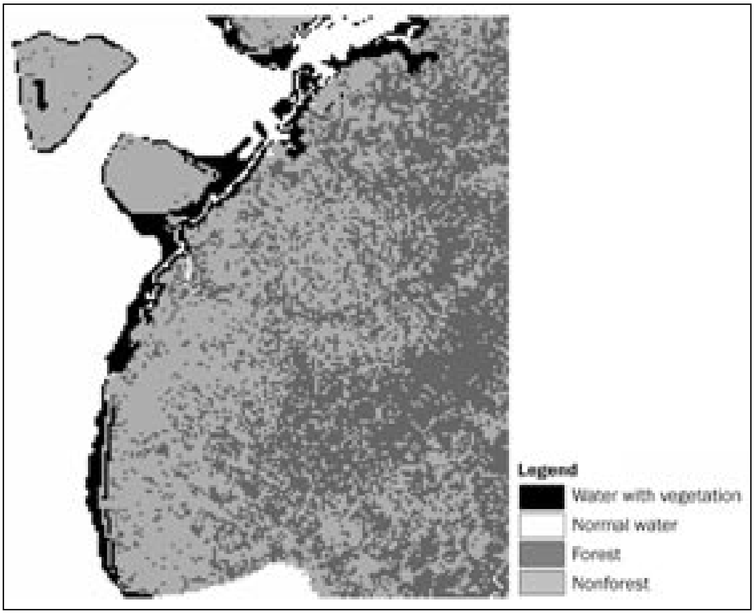

Fig. 4. Land-use/-cover map of Loon and adjacent municipalities.

Although this step could have been done within the GIS software, it was performed to demonstrate that it could also be done within CORMAS. The integration process to prepare the spatial data for use in the programming platform of the MAS model is summarized in Figure 5. The coupling process came into full circle when the resulting grid maps from the CORMAS simulations were exported back to ArcView, processed, and analyzed, the results of which are found in the simulation results.

Verification and validation of the model

As of now, this research is in its first phase and model validation has yet to be performed with scientists/experts and the stakeholders. The codes of the model were checked using built-in CORMAS tools such as the debugging tool and the "Communication's Observer Window." Because of the large size of the environment for the study area, making the simulation runs go slowly, the codes of the model were initially tested

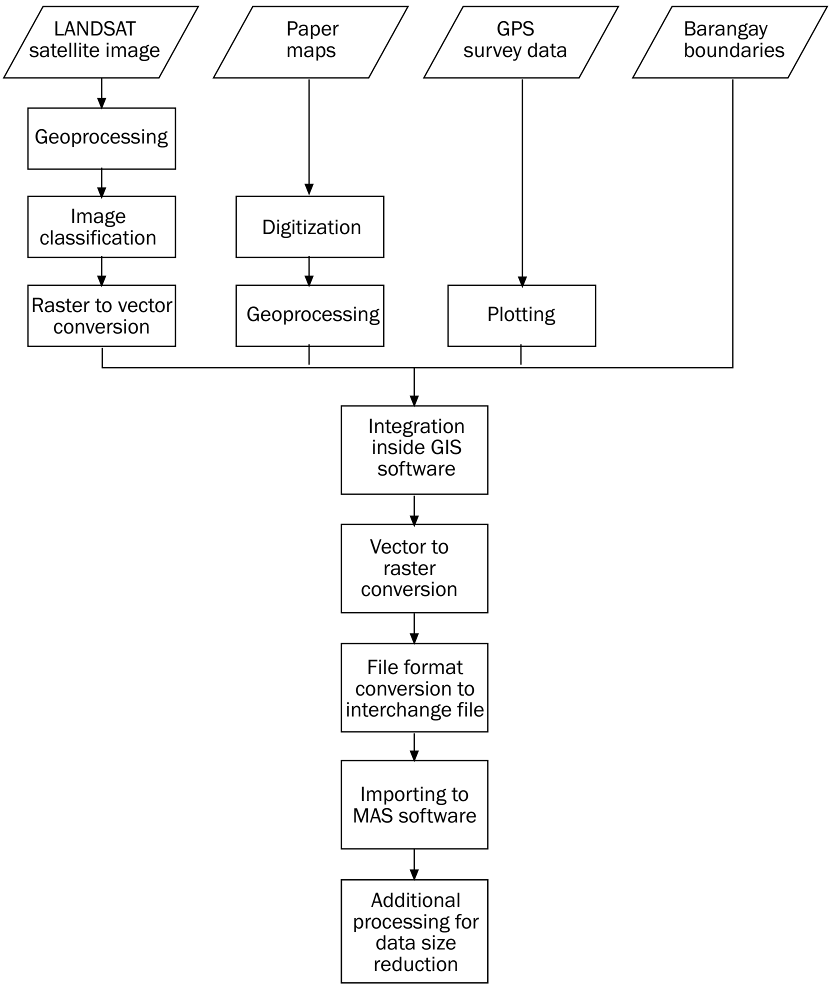

Fig. 5. Integration process to prepare the spatial data for use in the programming platform.

using a smaller environment—a 20 × 20-cell grid that was randomly produced. The consistency of the model with respect to reality will be discussed later in the discussion of results.

General presentation of the model

The different entities defining the static structure of the model are illustrated using a class diagram (Fig. 6). This was developed and, later, refined with the help of participants and trainers during the training conducted by CIRAD for its Asia IT&C Project on Multi-Agent Systems, Social Sciences, and Integrated Natural Resource Management, and through the advanced MAS course at the CIRAD-Ballairguet campus in Montpellier, France. This class diagram shows the entities inside the model, their attributes and procedures, and their interrelationships. More detailed explanations of the entities and their interrelationships follow.

Spatial entities

The study area was represented using a raster grid, having dimensions of 183 rows by 162 columns, with each cell being equivalent to 1 ha. Aside from having attributes built within CORMAS, four more attributes were added to the cell entity to accommodate different resources and/or characteristics that it may have. The spatial dynamics built for the environment were simple growth models for forests (which are applied to forest and bare soil cells) and fish stocks (which are applied to water, mud, coral, sea grass, and mangrove cells). In the case of a forest cell surrounded by other forest cells, at the next time-step, the amount of biomass of a forest cell is given by this equation:

$$b_t + 1 = bt + 0.0000337 * (b_t + \sum b't,i), \qquad i = 1 \text{ to } 8$$

where t = current time-step, $t + 1$ = next time-step, b = tree biomass of cell, and b' = tree biomass of neighbor cell.

In the case of a coral cell surrounded by other coral cells, its fish stock at the next time-step is given by this equation:

$$s_{t+1} = s_t + 0.0005 * \{[s_t * (1 + v_t/100)] + \sum [s'_{t,i} * (1 + v'_{t,i}/100)]\},$$
$$i = 1 \text{ to } 8$$

where t = current time-step, $t + 1$ = next time-step, s = fish biomass of cell, s' = fish biomass of neighbor cell, v = vegetation biomass of cell, and v' = vegetation biomass of neighbor cell.

Changes in the type and amount of resources remaining or existing in a cell would bring about a change in state of the cell. In general, cells containing vegetation less than 50% of its carrying capacity will change into a basic cell. For example, a forest cell with less than 50% vegetation will turn into bare soil, and a coral reef cell would turn into a basic water cell if the coral vegetation it contains drops to less than 50% of its carrying capacity. Farms abandoned by farmers revert back to bare soil.

The aggregates (Le Page and Bommel, this volume) created for the model were mainly for purposes of initialization and the creation of instances of new inhabitants, and were set up so that other processes could be added later. The aggregates, namely, "Barangay Boundary" and "Loon," represent political units within and around the municipality. These aggregates are important because the activities of the inhabitants are restricted within these political units.

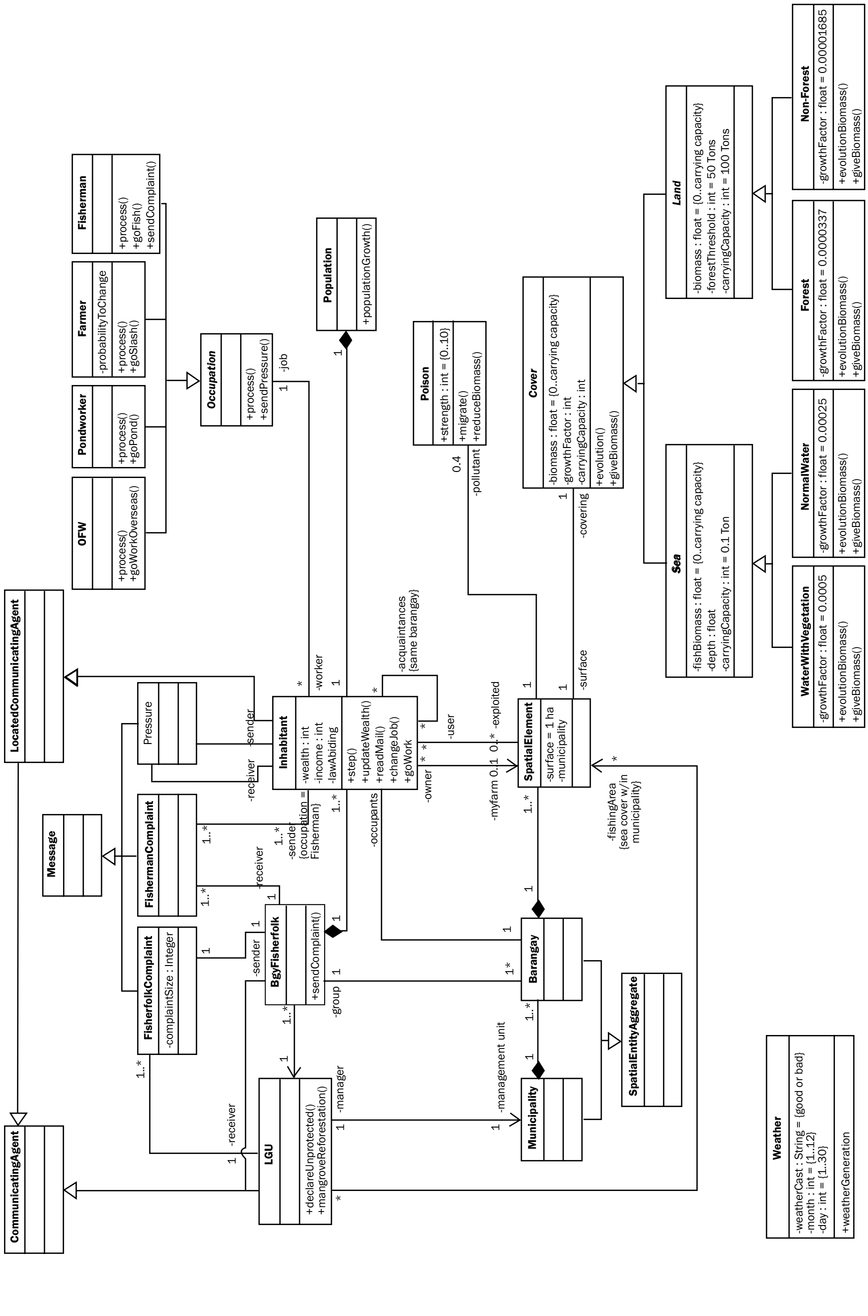

Fig. 6. Bohol model class diagram.

Social agents

The "Inhabitant" class represents the local people of Loon, at the household level. An inhabitant can be categorized as one of several types depending on occupation—fisherman, slash-and-burn farmer, fishpond worker, or overseas Filipino worker (OFW)—and it belongs to a barangay in the municipality. An inhabitant, depending on its occupation and related activities, affects a cell by reducing its resources or changing its state. A fisherman exploits the fish resources of water cells. A farmer may cut the trees contained in a cell and convert the cell to a farm. Other minor activities aside from its main occupation are quarrying, collecting firewood in mangroves and forests, and collecting shells to augment its income. These minor activities also reduce the resources contained in a cell. An inhabitant earns income from selling the products it is able to get or produce from its environment. In the case of a fishpond worker, it has a monthly wage with additional income proportional to the amount of fish it is able to harvest. Daily living expenses are deducted from the income of an inhabitant. An inhabitant also has the ability to change occupations. A farmer and fishpond worker may decide to change its occupation after every harvest. A fisherman can change its occupation every 30 steps or working days. An OFW no longer changes occupation. An inhabitant will change to a prospective occupation if its net income is less than zero or if its prospective occupation, determined by the "Pressure" messages (discussed in the next section) sent by its acquaintances—the other inhabitants of its barangay—offers better income. The process of changing occupation is described in the activity diagram shown in Figure 7.

The LGU class represents the local government unit in the area and it has the task of performing several activities depending on the scenario being run. Every year, it can perform mangrove reforestation (the number varies depending on the interactions among agents) and declare the reforested areas as sanctuaries in cells where the fish stock has been depleted. The cells are beside mangrove cells and are located in shallow waters. Also, the LGU can grant access to mangrove areas within barangays whose fishermen have a low fish catch.

Three classes of groups of agents were created depending on the occupation of an instance of an inhabitant. The groups are mainly used for initialization. However, future changes could be accommodated for the activities of the groups. A "BgyFisherfolk," a group composed of fishermen, is able to retrieve messages from its members and it sends a message to the LGU based on the messages received. Its role in the model, at this point, is to represent how the fishermen may communicate with the LGU.

Passive entities

Fishponds, after the harvesting process, are treated by the fishpond workers with chemicals to kill any remaining parasites. These chemicals are later drained into the sea. The chemicals are represented as a class of situated passive objects called "Poison" having an assumed "lifespan" of from 8 to 10 days. The movement of a "Poison" is based on a simple migration model, wherein, at every time-step, it would move to a neighboring cell with less than 4 other poison objects, and it affects sea grass, coral, mangrove, mud, or water cells by reducing the resources that the cell contains. After several time-steps corresponding to the lifespan, it "dies" and is removed from the simulation.

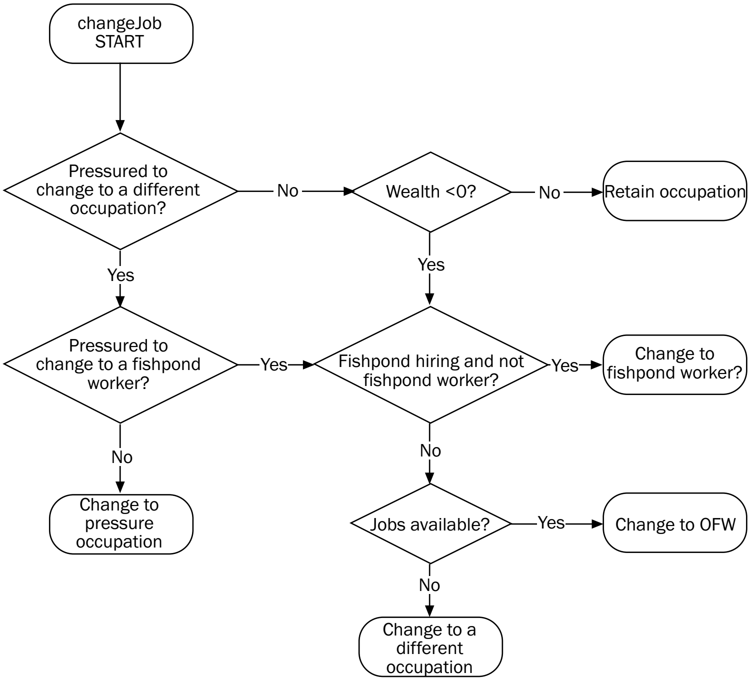

Fig. 7. Activity diagram for changing occupation.

A simple model of weather was made and it is dependent on the months of a year and is represented by the "Weather" class. The first half of the year, representing the dry season, would have less chance of having bad weather than the later months of the year.

Three kinds of messages are included in the model to facilitate communication between agents. An inhabitant sends a "Pressure" message, containing information about the sender's occupation and income, to its acquaintances if its daily income is greater than its daily living expenses and if its wealth is greater than or equal to zero. During the process of changing occupation, an inhabitant reads all the "Pressure" messages sent to it and then chooses the occupation with the highest average income and compares it to its own income. If the inhabitant's current income is less than that of the highest average income, it is pressured to take on that occupation with the highest average income. If a fisherman catches less than 1 kg of fish, a "FishermanComplaint" message is sent by the fisherman to its respective BgyFisherfolk group to inform it of a low fish catch. In turn, the BgyFisherfolk would send a "FisherfolkComplaint" message to the LGU to inform the LGU that the barangays have a low fish catch. The LGU, depending on the scenario, may grant access to mangrove cells equal to the number of "FisherfolkComplaint" messages received from the BgyFisherfolk groups.

Sequence of operations

For the Bohol model, a base sequence diagram was created and, for other scenarios, the sequence was modified to accommodate new tasks. One time-step is equivalent to one day. The sequence of operations is illustrated in Figure 8, which shows all the possible activities that could occur in a time-step. A time-step begins with generating weather, that is, whether the weather is good or bad, as this will govern the rest of the actions of the entities. Poison entities are then activated. The inhabitants are activated to perform their tasks according to their occupation. At the end of a month or after every 30 time-steps, jobs outside the municipality are made available to the inhabitants. Also, depending on the scenario, the LGU agent may give limited access to mangrove areas. At the end of a year, the population of inhabitants is made to grow and, depending on the scenario, the LGU may perform mangrove reforestation. Cellular automata processes are performed near the end of a time-step.

Results and discussion

Scenario selection

Though the stakeholders were not the ones who developed the scenarios, the researcher based the formulation of the scenarios on what could interest the stakeholders. Eight different scenarios were developed based on the combinations of the role of the LGU in NRM and the attitude of the people toward rules or policies. The LGU has the option of having or not having an NRM policy by actively performing mangrove reforestation, and listening to the fishermen and giving access to mangrove areas, or ignoring the fishermen. On the other hand, the inhabitants have three potential behaviors toward NRM rules: always obey them, always ignore them, or have varying tendencies of breaking the law on sanctuaries. This tendency of breaking the law is represented by an attribute of an inhabitant having values from 0 to 1, with 0 always being a law-breaker and 1 always being a law-abider.

Simulation results

Because many parameters could be analyzed in the model, the discussion of results here is limited to four indicators: number of mangrove cells, amount of fish stock, average daily income of fishermen, and the population of fishermen. To illustrate the effects of varying inhabitant attitudes, the results of the scenarios were grouped, keeping either the activities of the LGU constant, as shown in Figure 9, or the activities of the inhabitants constant, as shown in Figure 10.

For scenarios 1, 2, and 3, the LGU does not perform any NRM tasks, that is, no mangrove reforestation occurs, and it ignores the complaints of the fishermen. For scenario 1, all inhabitants are following the policy on mangroves, that is, fishermen do not fish in mangrove areas and farmers do not gather wood. For scenario 2, all inhabitants break the policy, and, for scenario 3, inhabitants randomly break the policy. In these scenarios, the number of mangrove cells decreased sharply at around time-step 70 because of the chemicals released in the water after the first harvest of fishponds. After this, the decrease in mangrove cells slows down for scenarios 1 and 3 as most of the mangroves around the fishponds have been destroyed. Firewood being collected by some inhabitants in scenario 3 resulted in a lower number of mangrove cells vis-à-vis

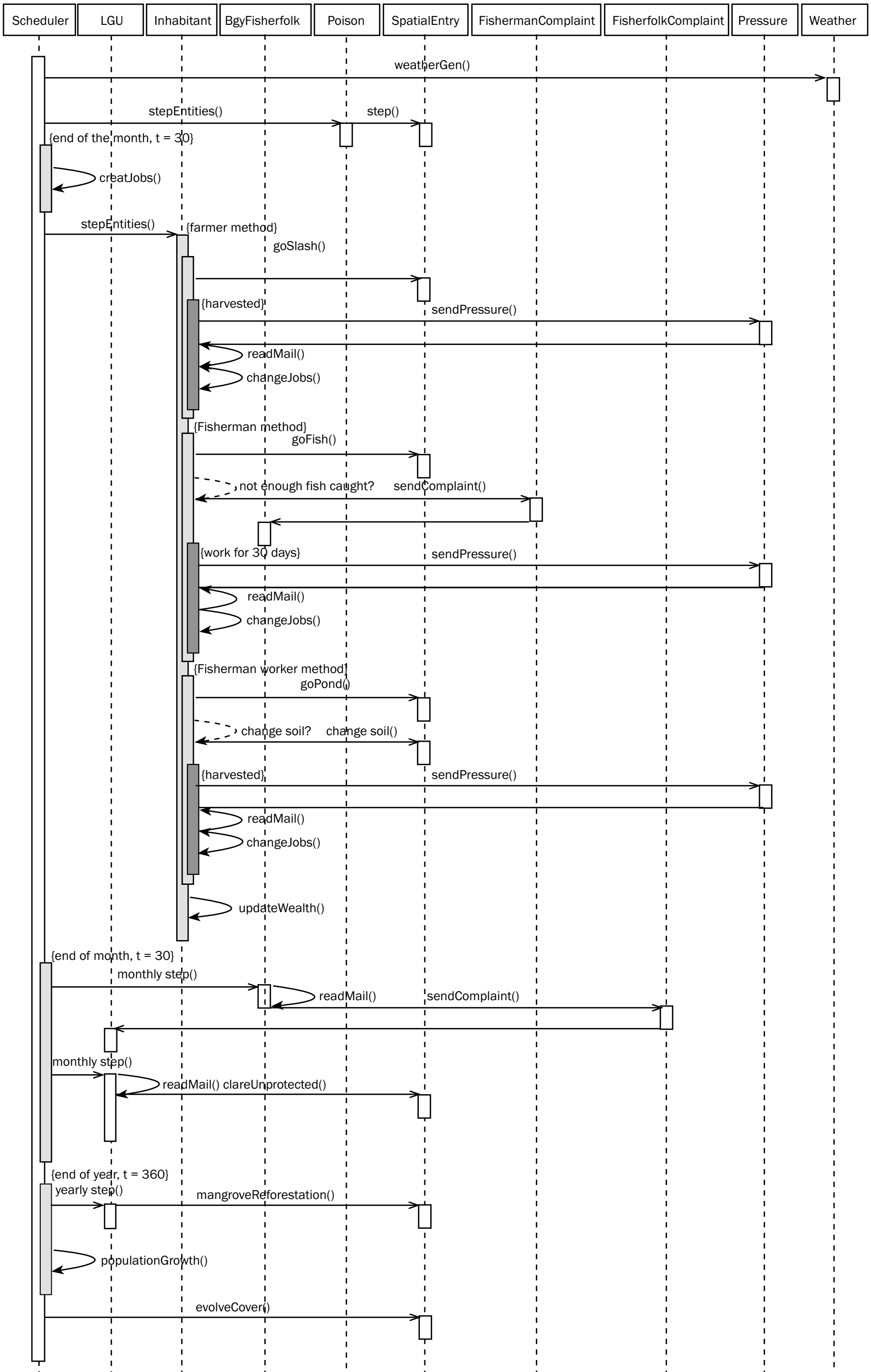

Fig. 8. Bohol model sequence diagram.

scenario 1. For scenario 2, the continuous high rate of decrease in mangrove cells is due not only to the chemicals being released but also to the continuous collection of firewood by farmers breaking the law. It could be said that the aggregation of small activities, such as firewood collection, has a big impact on the resources.

For scenarios 1, 4, and 7 presented in Figure 10, all the inhabitants follow the law. The LGU does not perform any tasks in scenario 1. For scenario 4, the LGU performs mangrove reforestation, and, for scenario 7, the LGU performs mangrove reforestation and gives access to mangrove areas. There is not much difference in the graphs of the number of mangrove cells as all inhabitants are following the policy. Surprisingly, although mangrove reforestation is being performed in scenarios 4 and 7, it hardly contributed to a higher number of mangrove cells. This may be because the LGU's mangrove reforestation efforts are insufficient to have a positive effect on the number of mangrove cells. However, giving limited access to the mangrove areas, as seen in the graphs of scenario 7, contributed to a higher fish stock and about $0.20 more income per day for the fishermen than in the other scenarios. This higher amount of fish stock may have resulted from the fishermen fishing in different areas, therefore allowing other parts of the fishing grounds to replenish their fish stock and not be completely depleted.

As shown in the graphs of Figures 9 and 10, several relationships could be established. The increase in population of fishermen due to inhabitants changing occupations is a major cause of the depletion of fish stock vis-à-vis the effect of the chemicals. Obviously, less fish stock would mean less income for fishermen. Although

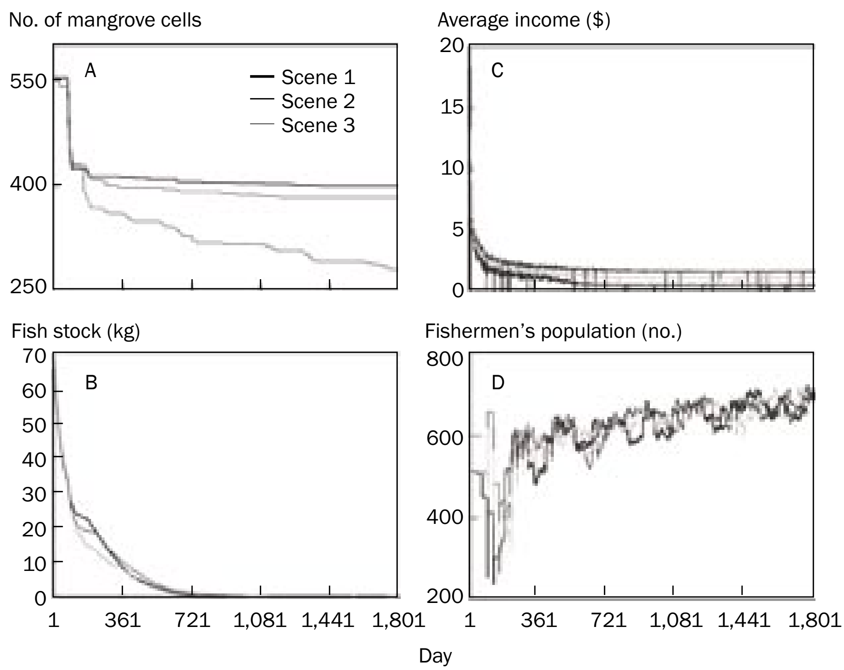

Fig. 9. Results of scenarios 1–3 after a 5-year run: (A) number of mangrove cells, (B) average fish biomass, (C) fishermen's average income, and (D) fishermen's population.

the population of fishermen would have sudden increases and decreases, the general trend is that more and more inhabitants are becoming fishermen, while there are fewer farmers and fishpond workers. The decrease in mangrove area is more affected by the poisonous chemicals than is the collection of firewood.

To observe the changes in land use/cover of the environment, a cross-tabulation of the initial state and the final state of scenario 7 was prepared. The values in the diagonal of the table, which are also the intersections of corresponding land use/cover in the initial and final states, show the number of cells that did not change per land use/cover. The intersection of the row for sea grass and the column for water yields a value of 89, which means that 89 cells have changed from sea grass to water after the 5-year run. The other nonzero values not on the diagonal indicate that 86 cells have changed from coral to water (cells covered by dead corals were assumed to be the same as water), 158 cells have changed from mangrove to mud, 28 cells have changed from forest to farm, and 1,240 cells have changed from forest to bare soil. The sea grass and coral cells that have changed into water, and the mangrove cells that have changed into mud, are found surrounding the fishponds, as shown in Figure 11, indicating that the change was caused mainly by the poisonous chemicals. The forest cells that have changed into farms are those converted by the slash-and-burn farmers. Most of the forest cells that have changed to bare soil used to be old slash-and-burn farms that have been abandoned. A total of 1,601 cells (or 5.4%) of the environment have changed in just 5 years. A change from bare soil to forest would not be observed in the 5-year run as the growth of forest cover is programmed to occur only after 10

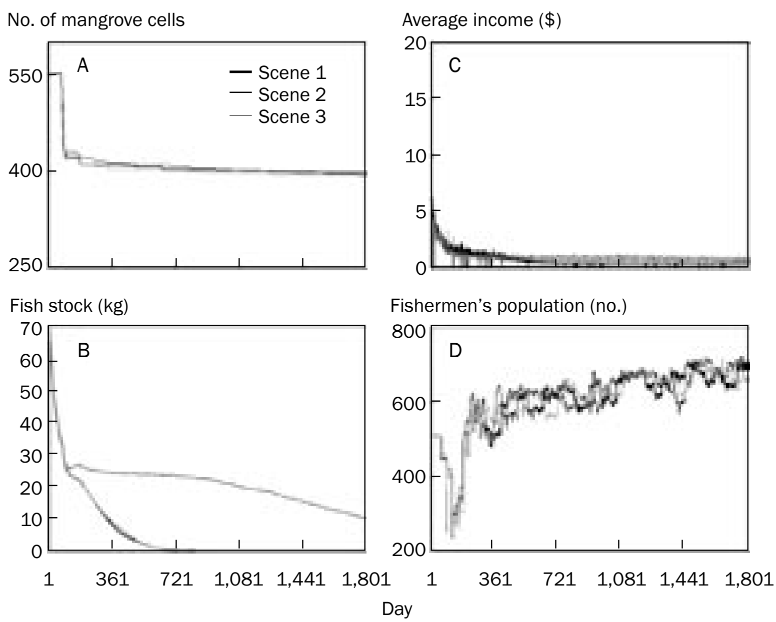

Fig. 10. Results of scenarios 1, 4, and 7 after a 5-year run: (A) number of mangrove cells, (B) average fish biomass, (C) fishermen's average income, and (D) fishermen's population.

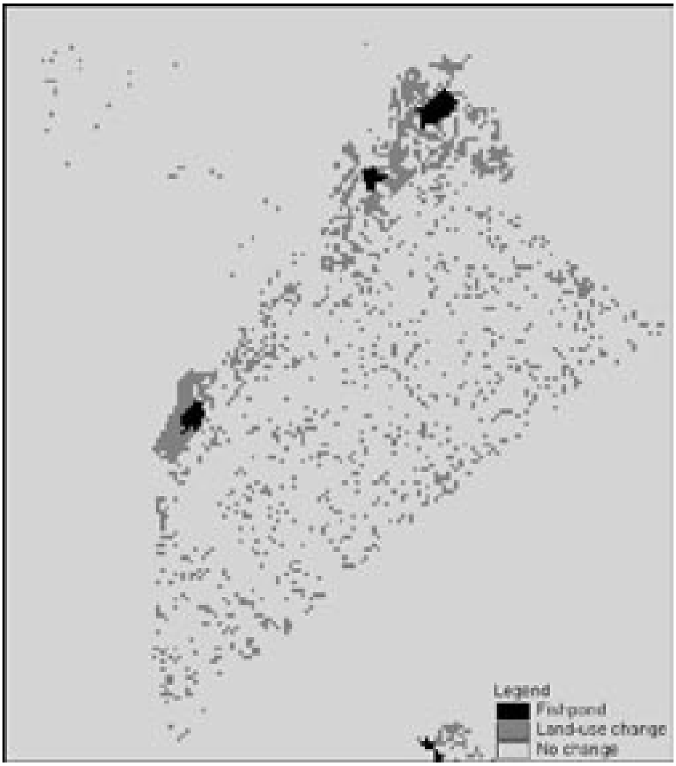

Fig. 11. Bohol environment land-use/-cover change map.

years. Although there is mangrove reforestation, it did not appear in the cross-tabulation as the reforested mangroves may have reverted to their previous states before the end of the simulation. The cross-tabulation cannot show the transitional states of the environment.

As this research is still in its first stage of implementation, some inconsistencies with the results emerged from the results of the simulations, as expected. For example, a decrease of up to 100 mangrove cells due to the chemicals released from fishponds in just a few days seems to be too great. The same reasoning could also be applied to the sea grass and coral covers. Also, fish stock going down to almost zero in just 2 years would be highly improbable as the average fish catch in the area at present is about 2 kg per day per fisherman and about 3.5 kg in the previous decade (Green et al 2002). By continuing the implementation of the methods and validating the model with scientists/experts and with the community, it is expected that these assumptions would be made more precise and the variables of the model would be further calibrated to produce more realistic results.

Conclusions

GIS and RS technologies have made it possible to perform resource inventory over a very large area for a short period of time. Maps produced using these technologies may give stakeholders a broader view of their area and some information regarding their current NRM situation. But, because they are just static pictures, the information provided by these maps may not be enough and we are left with questions such as “What is now happening to these resources, what could possibly happen to these resources in the future, and what can we do about it?” These questions may not be easily answered by just using GIS and RS techniques. By coupling GIS and MAS, these maps are given life. Similar to watching a home movie, the actors of the MAS simulation model (the stakeholders and policymakers) may see themselves moving in their environment. As the simulation progresses, they may observe and relate their activities to the changes in the supply of their natural resources and also observe and relate how their individual actions, when taken collectively, could change their environment. From what they may learn from watching a “movie” about themselves and their possible future, they may be able to develop new strategies or come up with scenarios that may lead to a sustainable use of natural resources; thus, MAS models could foster the development of scenarios or strategies for NRM. Moreover, these scenarios or strategies could be tested on the existing MAS model. By being able to test these strategies, the set of strategies could be filtered or sorted out depending on their viability; thus, the costs of implementation of new strategies could be minimized.

For now, the effectiveness of the Bohol model as being a “movie” cannot be ascertained because the model has not been validated with the stakeholders. To make this an effective tool that stakeholders would understand, there should be a consensus among them as to what indicators would be useful for them and how the model and indicators would be displayed so that the simulation model and its results could be more easily understood, as suggested by Etienne et al (2003). The prototype Bohol model itself was a bit ambitious to have included a lot of parameters, some of which don’t have a major role in the simulation itself, and present a multitude of NRM problems while lacking data, leading to inconsistent and misleading results. Although these inconsistencies are expected, given that the model is exploratory in nature, it may be better in the future to start out with a model with a small scope, so that data gathering could focus on fewer, more specific areas to ensure that every aspect of the simulation model is necessary. Later, what seems to be lacking could be added.

During the fieldwork conducted for this research, several observations were made that may help facilitate a smoother and more efficient execution of tasks in the future. Linkages with NGOs based at the research site could provide not only logistics, such as organizing activities with the stakeholders, but could also provide information regarding the current socio-political situation of the area that may not be easily observed in the field. This information would guide the researchers in formulating activities with the stakeholders and help avoid antagonism. Linkages with organizations in the area may help improve the relationship between researchers and the stakeholders as these organizations may have already established a good reputation with them. This good rapport and trust may eventually carry over to future studies of a similar nature. Another important insight gained from the fieldwork is that the stakeholders’ or the end-users’ receptiveness to new methodologies and new technologies is an important factor in the amount of support and cooperation these people would give to the research. The research would be hard-pressed in gaining support and momentum if the stakeholders themselves were not convinced that technology could help them, as some people may believe, especially those who come from the poorest municipalities. And, finally, the MAS modeling process itself may be a good learning experience, which could increase awareness among the stakeholders of the NRM system and their existing and potential problems.

Further research may lead to refinement of the research questions and objectives, the methods used, and the model itself. The preliminary simulations presented in this paper show that an interesting aspect to focus on would be the mangrove-fishpond interaction or the impact of fishponds on their surroundings. It might be interesting for higher government to see how the growth and maintenance of fishponds, even the kind of animals being grown in the fishponds, actually affect their surroundings and vice-versa since it is a higher government unit that approves fishpond permits and not the local stakeholders. There is still a need to validate the model with the stakeholders. Role-playing games may be developed and played with the stakeholders to validate the model and also help the stakeholders relate better to the simulation model, and possibly even use it in the negotiation process. It would also be interesting to know if the same model could be used at different levels of the negotiation process, such as negotiations between the local stakeholders and the LGU, and negotiations between the LGU and government entities at the national level.

As a whole, research activities, such as this, have the ultimate goal of providing effective techniques and tools for learning and negotiation processes that may lead to a more sustainable management of natural resources and the environment. Improvement of methods and techniques used for MAS modeling must be fine-tuned for achieving this goal.

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Notes

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