

**MULTI-AGENT SYSTEMS MODELING
INTEGRATING GEOGRAPHIC INFORMATION
SYSTEMS AND REMOTE SENSING: Tools for
Participatory Natural Resource Management
(Prototype for Loon in Bohol, Philippines)**

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APPROVAL SHEET

This thesis, entitled ‘**MULTI-AGENT SYSTEMS MODELING INTEGRATING GEOGRAPHIC INFORMATION SYSTEMS AND REMOTE SENSING: Tools for Participatory Natural Resource Management (Prototype for Loon in Bohol, Philippines)**’, prepared and submitted by **PAOLO C. CAMPO**, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN REMOTE SENSING** is hereby accepted.

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ABSTRACT

This research tried to develop a methodology for building a Multi-Agents Systems simulation model integrating Geographic Information Systems and Remote Sensing for participatory natural resource management. The methodology, based on a modified conceptual framework of Pahl-Wostl (2002), involved the use of MAS, GIS, RS techniques for data collection and processing, MAS conceptual and computer modeling, and MAS model verification and validation using a participatory approach. By using MAS, GIS and RS technologies in its construction and analysis, the MAS model is hoped to be used as a learning tool for the participants of an NRM situation. Moreover, the MAS model and its results are anticipated to be used as take-off points for discussion and negotiations in participatory NRM.

One of the main outputs of this research was a working MAS simulation model for the case of the Municipality of Loon, Bohol, Philippines. To be able to build the simulation model, called the Bohol model, a two-part fieldwork in the study area was conducted by a research team, which included this researcher, to familiarize themselves with the people's perception of their current NRM situation and its problems. Also the fieldwork allowed the researchers to gather spatial information on the study area, and details about activities of the locals with regards to the use of their natural resources. All these information were processed and integrated in the MAS simulation model.

The Bohol model was only a skeleton for possible future MAS models for NRM; as of now, it does not mimic the real NRM situation. A lot of assumptions have been made such as model for fish reproduction and forest growth, to make the model run. However, based on the simulations conducted, it demonstrated how individual actions of agents collectively affected its environment. Scenarios were developed based on the initial findings of the fieldwork, and these scenarios were tested inside the Bohol model. From the results of the simulation of the scenarios, the model was able to demonstrate the effects of changing the parameters of the model, specifically parameters related to agent behavior.

The use of spatially-explicit models, such as GIS and RS models, as a learning tool offer the participants of an NRM situation a new way to see their natural resources and environment by means of digital maps. It's a way for them to see their environment from "outside the box." Through its use, the MAS models may enhance the learning experience by means of a running simulation. The participants of an NRM situation may see the MAS model simulation as a "movie" about themselves and their possible future with them being the actors of this movie. Adding GIS and RS techniques to analyze the results of the simulation may add to this experience by offering ways to visualize the results of the actors' actions by means of change-detection maps, charts and cross-tabulations.

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1 Introduction to the Research Problem and Objectives

1.1 Natural Resource Management in the Philippines

The dismal state of the Philippine's natural resources calls for extra-ordinary management effort to sustain its use not only for the present but also for future generations. However, Briones (1991) noted that current policies in the management of these natural resources, from their creation to their implementation, have not made this task any easier. Ben S. Malayang III, the project coordinator of Policy Studies of the Environment and Resource Project (ERMP) says that "environmental and resource degradation was escalating" (as cited by Fellizar, 1993). Despite the total log ban, deforestation due to indiscriminate logging, slash-and-burn farming and clearing of mountainsides for housing is still rampant (The World Bank, 1989, Fellizar, *Ibid.*). Associated with deforestation is the fast extinction of various flora and fauna. Soil erosion is severe, brought about by upland farming and clearing of mountainsides (The World Bank, *Ibid.*). Some of the eroded soil drains to rivers and streams, causing the water to be silted and become shallow. Also, run-off water from fields contains chemicals and fertilizers contaminating not only the soil but also the rivers and streams where they eventually drain. This contaminated water causes problems in the aquatic resources, such as coral reefs, as they are silted over or poisoned; thus killing them (The World Bank, *Ibid.*). Over fishing and the use of destructive methods in fishing has made the fish supply very scarce (The World Bank, *Ibid.*). Conversion of mangroves to fishponds is still being done today. 95% of fishpond areas used to be mangroves, and the rate of conversion has increased due to the large economic gains promised by shrimp farming (The World Bank, *Ibid.*). Inland fisheries also suffer due to pollution. Natural resource management (NRM) has usually been sidetracked in the name of development (Briones, *ibid.*)

The Department of Environment and Natural Resources (DENR) has been the government's arm in managing the natural resources of the country; it remains beset by a myriad of environmental management problems. During the Aquino Administration¹, the government pushed for a decentralized approach to decision-making (The World Bank, 1989). However, based on Boquiren and Cabalfin's (1995: 2-3) review of the process of policy-making for NRM, which were based on their interviews of key-informants in government and non-government organizations, the process of policy-formulation and implementation has remained a top-down approach, in which the Congress of the Philippines is still the one that approves the policies. Non-government organizations (NGOs) are consulted on policy-formulation, but they have no direct influence on its approval and implementation. Even though these NGOs are consulted there is no assurance that these NGO's have consulted the locals. There is no direct participation, if there is even participation at all, of those who will be most affected by these policies, the common people. The same sentiments are shared by Fellizar (1991). For instance, at the study area Bohol

¹ Former President Corazon C. Aquino's term was from 1986 up to 1992.

province (more detailed discussions in Chapter 4), the approval of fishpond concessions is done by the Bureau of Fisheries and Aquatic Resources (BFAR) regional office in Cebu City.

1.2 The Research Problem

The top-down approach of resource management limits the knowledge about the system for both the policy-makers and the stakeholders who are directly affected by these policies. This incomplete knowledge of the system or reality for both the policy-makers and stakeholders, may lead to badly formulated NRM policies that could drastically affect the stakeholders in terms of decreased financial opportunities, or the environment, by making its exploitation unsustainable. There must be some balance between the exploitation of natural resources and economic security of the stakeholders in order to make the use these natural resources more sustainable. This balance may be achieved by gaining a better knowledge and understanding; thus NRM policies may be designed more appropriately for the system it was intended to help.

The use of Multi-Agent Systems (MAS) may be used as a learning tool for a better understanding of the system by modeling it. Modeling the system means trying to represent reality into several key elements that could approximate reality. By focusing on these key elements, a better view of how these elements actually affect the system could be seen. One major factor of an NRM system is humans or human activities. By combining human activities in the model, together with other natural processes such as forest growth and fish reproduction, the actors or participants of an NRM may be able to give 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 it to the real system. By testing first these strategies or scenarios on a MAS simulation model money, time and other costs of policy-implementation could be minimized. Analyzing the spatial data resulting from these scenarios or new strategies using GIS and/or RS techniques may be used to support the MAS model simulation during NRM negotiations between the stakeholders and policy-makers.

1.3 Objectives of the Study

This research explores the use of MAS modeling that incorporates GIS and remote sensing techniques and artifacts, in developing support tools which could be used to facilitate learning and fostering a participatory approach in policy-making for natural resource management

In particular, following are the specific objectives of this research:

- 1) Propose a methodology for developing a MAS model that could be used as a tool for NRM.

- 2) Demonstrate how GIS, Remote Sensing and Participatory techniques could benefit MAS modeling.
- 3) Build a working MAS model based on the suggested methodology.
- 4) Assess and draw insights from the learning experience.

1.4 Research Questions

Based on the objectives of this research, this researcher hopes to answer the following questions in the subsequent chapters:

- 1) What are multi-agent systems, and what are the advantages and disadvantages of using them in NRM?
- 2) What are the components and requirements for building a MAS model? What data are needed for these components, and how are these data going to be acquired?
- 3) How can GIS, remote sensing and participatory techniques and artifacts support building a MAS model?
- 4) How can a MAS model be used to facilitate learning and discussions in policy-making for NRM?
- 5) What are the prospects and drawbacks in using MAS models to facilitate learning and discussions in policy-making for NRM?

1.5 Limitations of the Study

Fieldwork for this study was conducted in two one-week episodes. It was limited by financial and time constraints. Data is limited to the kinds that could be acquired at the time of fieldwork, such as coastal resource map and fisherman activities. Assumptions, such as the process of fish reproduction and weather pattern, have to be made for the MAS model to make it function (more detailed discussion in Chapter 4). Again, due to financial and time constraints, model validation was not done as suggested in Chapter 3 of this report. Hence, the research was limited to the exploratory use of geo-information technologies and artifacts in creating tools that can facilitate a participatory approach in natural resource management.

For these reasons, this research did not intend to produce a very “realistic” model that would mimic or approximate reality. The model was only used to demonstrate the potential use/s of MAS models in NRM. This would also mean that the results of techniques for verification and validation, as suggested by this research (a more detailed discussion in Chapter 3) would be more of samples rather than actual values.

1.6 Outline of this Report

This chapter introduced the research problem and the objectives of this research. Also, the research questions to guide the discussions are enumerated. *Chapter 2* introduces the various technologies and artifacts used in the research, and how they are currently used in natural resource management. The benefits and issues that arise from such use are also discussed. *Chapter 3* presents the conceptual framework of the research. It also discusses how the tools and technologies presented in Chapter 2 are used in accordance with the framework. *Chapter 4* discusses the implementation of the conceptual framework on the study area through the methods used in acquiring the data, the kinds of data gathered, and the steps in building the MAS simulation model for the study area. *Chapter 5* contains discussions of the modeling process, the results of the simulations and its analysis. Also, discussions about the experiences in doing the fieldwork are included here. *Chapter 6* contains the synthesis of the research process. Conclusions derived from the learning experience, and further research paths are taken up in this chapter. *Chapter 7* lists the references used in undertaking this study. *Appendices* containing program codes, lists of assumptions and results of model verification and simulations are found at the last few pages of this report.

2 State of the Art in Using Geographic Information Systems, Remote Sensing and MAS for NRM

This chapter is about the different technologies or tools that were used in this research in the domain of natural resource management. The discussion for each tool would be comprised of its definition, the benefits it could provide in its use, the various techniques for analyses each tool has, and its applications in natural resource management.

2.1 Geographic Information Systems

2.1.1 Definition

Geographic Information Systems (GIS) is a computerized database consisting of data linked together by their geographic location. Proper software and hardware are needed to store and retrieve these data², and to analyze and display (by means of maps and graphs or charts) new information derived from the database (Rajan 1991, Star and Estes 1990). The database consists of two kinds of data: 1) data about the geographic location (spatial data) of objects or features being studied and 2) the thematic information or attributes of the objects or features (non-spatial data) (Star and Estes 1990).

In a GIS the “real world” or area-of-interest is usually represented in the form of map layers, each layer having a specific theme. A theme is a kind of information such as soil type, elevation or land cover. However, just like a regular paper map, not all information about the “real world” can be stored in a GIS. This limitation is due to the fact that the real world is too complex for all data about it to be represented. Besides, people perceive the “real world” in different ways (Gonzalez 2000); thus the GIS would only consist of data pertaining to what the GIS users think is part of their “real world” and as required by their applications. It would be unnecessary and wasteful to include data that is not required by an application. For example, an application for modeling physical processes may not require socio-economic profile of the inhabitants of an area.

Objects and/or phenomena about the “real world” may be represented in a GIS using two common formats: the vector format and the raster format (Aronoff 1989, cited in Gonzalez, *ibid.*). The vector data format represents objects in the “real world” as points, arcs (or lines), or polygons (see Figure 2.1) (Burrough, 1987, Star and Estes, 1990, Gonzalez, *ibid.*). This representation of objects is more applicable to discrete objects in space (real or imaginary) such as fire hydrants (point), roads (line), and property boundaries (polygons). Themes using a vector data format resemble hand-drafted maps (Korte 2001; Gonzalez, *ibid.*). In a raster data

² For this research the word *data* would refer to any information that has already been filtered or processed.

structure, as shown in Figure 2.2 the area-of-interest is usually represented as a tessellation³ of squares arranged uniformly (as in a grid), although other shapes could be used such as hexagons and triangles (Star and Estes, *Ibid.*). Each geometrical shape is called a cell, or pixel for raster images (Korte, *Ibid.*). This format is usually used to represent phenomena that are continuously varying over space which do not exhibit discrete boundaries such as land cover (Korte, *Ibid.*, Verbyla, 2002). Grid GIS models are more suitable for applications in natural resource management, urban and regional planning, land assessment environmental modeling and corridor analysis (Korte, *Ibid.*, Verbyla, *Ibid.*).

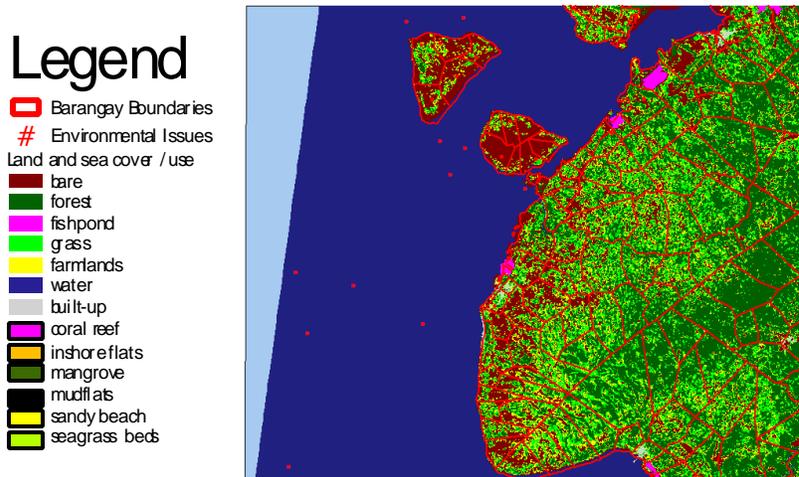


Figure 2.1 Vector data format

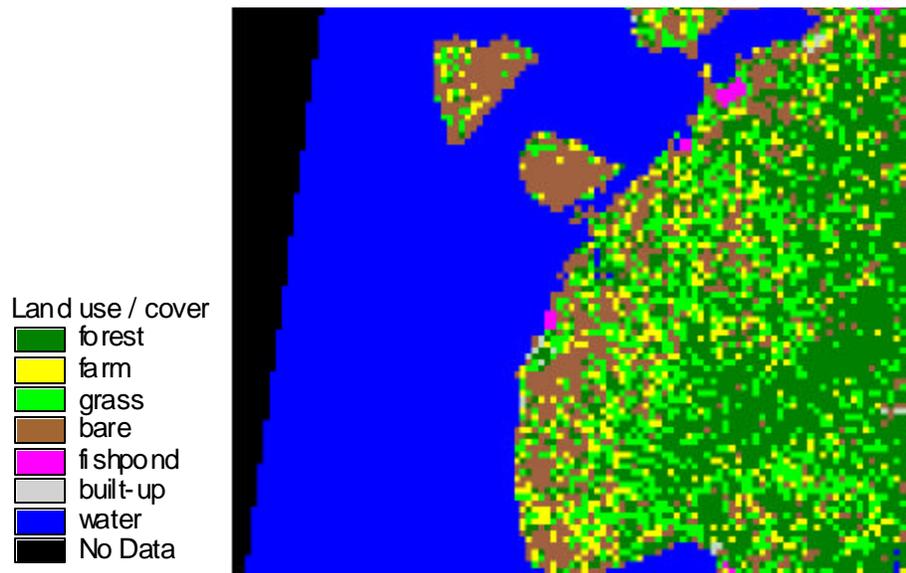


Figure 2.2 Raster data format

³ Tessellations are geometrical shapes completely covering a flat surface (Star and Estes 1990: 38).

2.1.2 Benefits of using GIS

What are the benefits of implementing a GIS in terms of data managing and analyses? Korte (2001: 49-54) listed several reasons for this:

- 1) Data in a GIS is more secure and more organized as compared to paper maps. Paper maps are easily misplaced, misfiled, or even lost. Having a digital central database for all of those maps would avoid these kinds of problems. Also, data could be given different access levels depending on the user, thus only specific persons may be allowed to edit, update, or view the data.
- 2) Redundancy is reduced, controlled or eliminated. In a GIS, themes are stored only once, whether they are stored in one server or distributed over several servers, thus eliminating or, at least, reducing the chances of redundancy. Different mapping themes could make use of one data set thus making the produced maps more consistent in information and precision.
- 3) Revisions may be made faster and easier as compared to working with paper maps. Since the themes are in digital form, an object or several objects in a layer may be edited without affecting other objects in that layer.
- 4) Queries, analyses and visualization (more detailed discussion in the next section) of the maps are easier to perform as compared to using paper maps and manual filing systems. Since most of these operations are routines commonly found in most GIS softwares, and that the power of personal computers is exponentially growing over the years, these operations can be easily performed systematically and repeatedly. Also, some types of analyses that would be difficult to perform manually, or even analysis techniques unheard of before are now available for computer users.
- 5) Data integration throughout an organization could be easily done. Different data from different sources are usually difficult to integrate and be used efficiently in an analysis because they are of different scales, and of different grid coordinate systems. In a GIS, because of having a common reference system, these problems are eliminated and thus, can be used more efficiently in an analysis.

In short, GIS offers its users a more efficient way of performing tasks because less time is spent on each task. GIS benefits from being able to manage and analyze spatial data in digital form and being able to effectively communicate information visually, just as a paper map could. People are more inclined to understand pictures (maps and graphs) better than just plain text.

2.1.3 GIS Analyses Techniques

There are several basic techniques being used in most, if not all, GIS software packages. Korte (2001: 91-99) classified them into three fundamental types of GIS analyses: attribute data queries, spatial data queries, and set queries. *Attribute data queries* refer to the search and display of data answering a set of criteria. Questions

such as “Which objects are less than 1 hectare?” and “What areas are classified as forests?” fall under this category. *Spatial data queries* use proximity operators such as “within,” “between,” and “beyond.” Questions such as “Which built-up areas are within the delineated zone for forest land?” and “What land covers are found inside the areas classified under public and alienable lands?” are under this category. *Set queries* are queries that compare or combine query sets⁴ using logical (or Boolean) operators such as “intersect,” “union,” and “minus.” These operations are usually used for site selection models.

Aside from these basic operations, there are also specialized GIS analyses functions available for the user. These functions are (Korte 2001: 100-108) network analysis, buffering, modeling and analysis of digital terrain models (DTM), and Grid Cell GIS modeling and analysis. Network analysis is used for systems using networks such as road networks, utilities and transmission. Buffering generates area features around objects using a specified distance. For example, to answer the question “Which areas are within 100 meters from the fire hydrant (point entity)?” the buffering operation would create a circle that is 100 meters in radius centered on the fire hydrant. The areas created from buffering operations could be manipulated and queried just like any other layer. Digital terrain models are used to create 3-dimensional representations of a surface such as the earth’s surface. The surface can then be displayed, manipulated and analyzed in a number of different ways. Surfaces could be compared, added together, etc. Although Korte (*ibid.*) separated Grid Data analysis as a specialized form of analysis, most grid and vector data analysis techniques are analogous to each other.

2.1.4 GIS Applications in Natural Resource Management

How can we use GIS in natural resource management? Rajan (1991: 103) grouped GIS applications for NRM according to how GIS is used:

- 1) For display of thematic and locational data;
- 2) For calculation of area and length of map features;
- 3) For reclassification of thematic attributes of map features;
- 4) For overlay of features along with associated thematic attributes of two or more geographically coincident maps;
- 5) For computation of distances; and
- 6) For comparisons and contiguity indications.
- 7) For generating future scenarios.

Based on these applications, different models can be created to represent the real world (Rajan 1991; Star and Estes 1990). Using the data in a GIS environment, these models may be employed to analyze trends, identify the factors that contribute to these trends, explore alternative solutions to the problems, and they may even show the possible outcomes to the system of the decisions made (Rajan, 1991).

⁴ Query sets are the results of search or query operations (Korte, 2001: 93).

Furthermore, different statistical analyses on the system and change detection applications could be performed on the area-of-interest (Rajan, *ibid.*) These statistical analyses may include descriptive statistics, regression, correlation and cross tabulation (Star and Estes 1990). Table 2.1 shows a descriptive list of some GIS applications in NRM (Rajan, 1991: 103).

Table 2.1 GIS Applications in Natural Resource Management

- | |
|--|
| <ul style="list-style-type: none">- Land use changes, land site planning, farm land location- Crop harvest projections- Forest inventory, mapping, monitoring and management- Soil inventories- Watershed delineation and management- Surface water detection- Geological resource mapping and exploration, geological hazard monitoring- Delineation of agricultural extension areas- Solid waste disposal site planning- Flood damage study- Endangered species / habitat tracking- Erosion and sedimentation selection- Road planning- Electricity / gas / water distribution system design- Design, siting and scheduling of irrigation systems- Environmental impact assessment- Population distribution study and urban growth |
|--|

There are a lot more applications that may exist today. “GIS applications are only limited by the quality, quantity and coverage of data that are fed to the system (Rajan 1991: 101).” There have been moves for developing dynamic maps to answer the criticisms about GIS only presenting a “snapshot’ of a situation at certain moment in time (Gonzalez, 2000: 102).” Having only captured an instance of a situation, it may not be enough to model the complexity or behavior of an NRM system, and this research hope to address this shortcoming of GIS by using a spatially-explicit MAS simulation model (to be discussed in detail in the subsequent sections).

2.2 Remote Sensing

2.2.1 Definition

“According to the American Society of Photogrammetry remote sensing is the measurement of information of some proportions of an object or phenomena by a recording device, that is not in physical or intimate contact with the object or phenomena (Colwell 1983 as cited by Porwal 1997: 15).” These systems, usually aircrafts or satellites (Sabins 1986), are equipped with sensors that could record the

incident radiation from the target or object of interest. Incident radiation is electromagnetic energy that encounters matter (Sabins 1986: 3).

Electromagnetic energy is composed of waves occurring at equal intervals of time moving at the velocity of light (Sabins, *ibid.*). Based on its definition, electromagnetic waves are characterized by three properties, its wavelength, frequency and its speed, and the relationship of these properties is given by the equation (Sabins, *ibid.*):

$$c = \lambda \nu;$$

Where:

c = velocity of light in vacuum

λ = wavelength

ν = frequency

At different wavelengths across the electromagnetic spectrum⁵ electromagnetic (EM) energy interacts with objects in different ways and the amount of radiation measured by the sensors varies. The sensor stores the incident radiation at different EM wavelengths in a form of a satellite image composed of pixels with each pixel being a digital number (DN) ranging from 0 to 255 for 8-bit satellite data, and 0 to 2047 for 11-bit satellite data, with 0 as the minimum and 255 (or 2047) as the maximum values of the DN, representing the intensity of radiation detected by the sensor. If the amount of incident radiation on an object is plotted against the electromagnetic spectrum, a graph is formed and is called the spectral signature. The spectral signature is distinct⁶ for different objects; therefore the objects are identifiable. The image is then pre-processed, manipulated and analyzed (for more in-depth discussion refer to Sabins 1986 or Edwards 2000).

An image can be characterized by three terms (Green, E. 2000: 43-44):

- 1) Spatial resolution – This refers to the area covered by one pixel in an image. Sabins (1986) describes spatial resolution as the minimum distance at which objects close to each other could be separated.
- 2) Temporal resolution – This refers to the time interval between successive observations of the same point.
- 3) Spectral resolution – This refers to the number and width of bands (or regions on the EM spectrum) that are recorded by a sensor. A sensor recording several bands are called multi-spectral.

⁵Electromagnetic Spectrum is the continuum of energy whose wavelengths vary from nanometers to meters, and traveling at the speed of light in a vacuum (Sabins 1986).

⁶ It must be noted, that although these signatures are distinct, they are not unique (Lillesand and Kiefer, 2000). In the natural world, there are variations in these signatures forming patterns; thus it is more appropriately called a *spectral response pattern* rather than a signature (Lillesand and Kiefer, *ibid.*).

Table 2.2 shows a summary of the more common sensors in the market and their spatial, temporal, and spectral resolutions. The use of imagery from any of these satellites would depend on the intended application.

The process of manipulating the data captured by these recording devices, or systems, is called *Image Processing* (Star and Estes 1990). There are many techniques involved in image processing, such as visual interpretation and digital interpretation. Visual interpretation uses the eyes of the interpreter for identifying objects, thus experience and common sense is very important for the interpreter (Edwards 2000). For multi-spectral classification of image data, digital classification is required. The methods for classifying multi-spectral images are called supervised and unsupervised classification (Edwards 2000), which consist of different classifiers or classification algorithms.

Remote sensing technology provides another source of information that can be used in different applications. As with other technologies, however, it comes with certain drawbacks. Cloud cover in tropical areas is very common, and this makes interpretation of images of areas covered by clouds impossible. The use of radar images (images acquired using the microwave region wavelengths) helped solve this problem (Rajan 1991); texture analysis is used to classify radar images. This technology requires trained personnel, powerful hardware and efficient software for manipulating and interpreting the images (Rajan, *ibid.*).

2.2.2 Benefits of using RS

The advantage of using remote sensing is that information from the same area could be easily obtained at different times (Davis et al. 1995). This is important in change-detection applications. Since remote sensing systems can cover a large area (depending on the sensor), the users are provided with an overall picture of the area-of-interest (Davis, *ibid.*). Although satellite images are quite expensive, in the future it might prove to be more economical as compared to tradition techniques of data gathering over a large area such as ground survey and aerial photography (Davis, *ibid.*).

2.2.3 RS Applications in NRM

Remote sensing has a lot of applications in various fields. In NRM, remote sensing is used for mapping and modeling resources. Table 2.3 shows the current applications of remote sensing technology in NRM (Das, Sarma and Kalra 1994: 354).

Table 2.2 Comparison of Popular Satellite Sensors

Sensor	LANDSAT	NOAA	SPOT	IRS1A
Country	United States	United States	France	India
Altitude	705Km	861Km / 845Km Perigee	832Km	904Km
Type	Sun-synchronous	Sun-synchronous	Sun-synchronous	Sun-synchronous
Repeat Coverage	16 days	Daily, composite monthly	26 days (at nadir)	22 days
Inclination	98.2	98.9	98.7	99.5
Sensor Package	<p>Thematic Mapper (TM) 30 meter resolution</p> <p>Band 1 – 0.45 – 0.52 μm Blue Band 2 – 0.52 – 0.60 μm Green Band 3 – 0.63 – 0.69 μm Red Band 4 – 0.76 – 0.90 μm NIR Band 5 – 1.55 – 1.75 μm IRed Band 7 – 2.08 – 2.35 μm IRed Band 6 – 10.4 – 12.4 μm Thermal (120m)</p> <p>Multispectral Scanner (MSS) 80 meter resolution Band 1 – 0.50 – 0.60 μm Green Band 2 – 0.60 – 0.70 μm Red Band 3 – 0.70 – 0.80 μm NIR Band 4 – 0.80 – 1.10 μm NIR</p> <p>Swath width: 185Km</p>	<p>AVHRR – Advanced Very High Resolution Radiometer 1.1 – 4Km resolution</p> <p>Channel 1 0.58 – 0.68 μm Channel 2 0.725 – 1.10 μm Channel 3 3.55 – 3.93 μm Channel 4 10.30 – 11.30 μm Channel 5 11.50 – 12.50 μm</p>	<p>HRV – High Resolution Visible Imaging System Nadir and Off-nadir viewing 20 meters resolution</p> <p>Band 1 0.50 – 0.59 μm Green Band 2 0.61 – 0.68 μm Red Band 3 0.79 – 0.89 μm NIR</p> <p>Panchromatic band: 10m resol. Pan 0.51 – 0.73 μm Green, Red</p> <p>Swath width: 60 m</p>	<p>LISS I – Linear Imaging Self Scan 72.5 meter resolution</p> <p>0.45 – 0.52 μm 0.52 – 0.59 μm 0.62 – 0.68 μm 0.77 – 0.86 μm</p> <p>Swath width: 148 Km</p> <p>LISS II – Linear Imaging Self Scan 36.25 meter resolution (2 Cameras) Same as above Swath Width: 74Km per camera (145Km together)</p> <p>Sensors are CCD arrays working in push-broom mode.</p>

Table 2.3 Possible Uses of Remote Sensing Techniques in Assessment, and Monitoring of Land and Water Resources

A. Soil and Land Resources	<ul style="list-style-type: none"> - soil characteristics, soil survey, and land use planning - watershed characterization and management - waste land mapping and monitoring
B. Soil Salinity	<ul style="list-style-type: none"> - extent of saline and sodic areas and effect of reclamation measures - seasonal water logging, extent of wetland areas
C. Soil Erosion and Soil Conservation	<ul style="list-style-type: none"> - fluvial erosion, extent and depth of gullies - eolian erosion, sand dune movement - shifting cultivation
D. Agricultural Disasters	<ul style="list-style-type: none"> - desertification, arid land forms and changes in vegetative cover - agricultural drought management - extent and damage due to floods
E. Water Resource	<ul style="list-style-type: none"> - surface water bodies, ground water targeting - soil moisture status and soil moisture mapping - irrigation scheduling, evapotranspiration estimation

Aside from the applications listed above, Rajan (1991) added the following: Coastal zone studies, which include change detection and monitoring; mangrove preservation, whose activities include mapping and identification of species; fisheries development, wherein sea surface color and temperature measurements, and mapping of fishing grounds are the usual activities; mineral exploration; and, human settlements mapping / impact assessment. Porwal (1997) also included wildlife habitat analysis. "The modern remote sensing techniques, using sensors in the visible, thermal, and microwave regions of the electromagnetic spectrum, have been found to be valuable in evaluation, monitoring, and management of land, water, and crop resources (Das, Sarma and Kalra 1994: 354)".

It can be observed that RS and GIS applications in NRM go hand in hand. To maximize the information that can be derived from RS, additional information is needed, and can be provided by GIS (Star and Estes 1990). On the other hand,

remote sensing can provide data at different times and scales appropriate for different GIS applications (*Ibid.*).

One important application of RS in the Philippines is the forest resource inventory that was conducted in 1987 (The World Bank 1989). Both visual and digital classification techniques were used to classify SPOT images for the entire Philippines. LANDSAT satellite imagery taken in the 1970's, NAMRIA topographic maps, forest resource condition maps, and ground surveys were used to assist in the classification of the images and these served as baseline data for the assessment of forest resources (The World Bank, *ibid.*). Although the forest resource inventory was more of a mapping exercise, it showed the bigger picture of the situation of the country. Prior to this forest resources inventory, statistics about the coverage of mangrove areas were erroneous (Dames World International, et.al., 1989). However, this error was not known until the forest resource assessment using satellite imagery was conducted. Being able to map the resources at scales as big as the entire Philippines at a very short time provided new and sometimes shocking information on the conditions of the natural resources of the country.

2.3 Participatory Methods

2.3.1 Definition

Participation involves cooperative effort among the different stakeholders involved in the management of the natural resources. It also implies that the local people are actively involved in the process of decision-making wherein their insights, experiences, knowledge and interests are taken into consideration (Rikken 1993). The aim of participatory approaches is to let people identify their problems and not outsiders who assume what their problems are (Gosling and Edwards, 1995 as cited by Ockelford and Reed 2002). Narayan (1995: 51) explains that the "participation of the people is not something that could be placed at anytime and anywhere in a process. They should be involved from the very beginning to end of a process," i.e. they should be part of problem-identification to implementation of the solutions. It is believed that local knowledge and technologies is useful for planning and implementation of a program or project because the plan becomes more tailored to the needs of the community, and, in its implementation, the community itself would be the one to manage and control its resources (The Program Support Staff, Upland Development Program, DENR, 1994).

2.3.2 Kinds of Participation

Pretty et al. (1995 as cited by Gonzalez 2000) enumerates the following kinds of participation according to the roles of the participants in specific stages of the development process:

- 1) Passive participation – the participants are informed of the projects to be implemented or have been implemented
- 2) Participation in giving information – participants are made as sources of information; findings and neither shared nor validated
- 3) Participation by consultation – based on the responses of participants in interviews or consultations, the problems and the solutions to these problems are identified by an external entity
- 4) Participation by material incentives – the people participate only as long as their efforts are reciprocated
- 5) Functional participation – specialized groups are formed depending on the needs or requirements of the external agency controlling the project
- 6) Interactive participation – local people are directly involved in analysis together with other stakeholders resulting to continuous involvement of the participants
- 7) Self-mobilization – a project is locally initiated, external agencies provide support but the control and ownership of the project remains with the people.

The role of the people in the development process is directly related to the chances of a project or program in succeeding, that is, the bigger of the role of the participants in the development process, the bigger is the chance of the project or program to succeed. To give an example, the Integrated Social Forestry Program, which was launched in the early 80's, relied on the participation of the local people in reforestation, wherein the people did reforestation work for monetary compensation. (Dames Moore International, Inc., et.al., 1990). Although the people participated in the program, the program is said to be a failure because, instead of making the locals self-reliant, they have become dependent on the program's compensation (Dames Moore International, Inc., et.al., *Ibid.*). The same situation occurred with the Watershed Management and Erosion Control Project (The World Bank, 1989). "Top-down planning and implementation has led to the dependence of the inhabitants on public funding, but limited budgetary resources imply that this cannot continue indefinitely (The World Bank, *Ibid.*)." In contrast, a project by the Philippine Center for Water and Sanitation: The International Training Network Foundation⁷ or ITN called "Replicating Integrated Community-Managed Approach in Water and Sanitation" emphasized on, among other things, the sense of ownership of the project by the community, and the use of local knowledge, technology and resources in operating and managing the project (Philippine Center for Water and Sanitation: The International Training Network Foundation, 2002). Results of one of the participatory assessments of the target areas, specifically Piglawigan, Esperanza, Agusan del Sur, showed that the people were able to understand their shortcomings in terms of water management and they appreciated the tools that were used to help them understand their current situation. After the assessment, the community seems to be pro-active in terms of improving their situation. Fellizar (1993: 52-55) emphasized on the importance of community participation in the success of projects or programs when he cited cases of community participation using a community-

⁷ Philippine Center for Water and Sanitation is an NGO focusing on Philippine water resources.

based resource management (CBRM) approach that were successful in the people's efforts for proper natural resource management:

- 1) In the cases of Western Zamboanga Peninsula Subanon Association (WEZPESAI) and the Bigkis-Lakas Alquerque, the members of the community organizations were the ones protecting their own resources by policing its extraction.
- 2) In the case of a Guba, a barrio in Cebu City, a system of cultivation introduced by an external agency was transferred by word of mouth between the farmers when the farmers realized that the system was working for them. Some of these farmers even became trainers to new farmers, government, and NGOs who were interested to learn of this technology.
- 3) In the case of Apo Island in Negros, Siliman University, through the Marine Conservation and Development Program (MCDP), introduced a fish sanctuary project to the locals. At the beginning, the people hardly supported the project because of fear that Siliman University might have ulterior motives in the implementation of the project. However, when the local people were made part of the project, from planning to its implementation, their fears disappeared and supported the project. At the end of the project, the people of Apo Island have full management of the functioning marine reserve of the island.
- 4) A deep-sea fishing corporation in Eastern Samar, initiated by the Philippine Business for Social Progress (PBSP), is being managed by the fisherfolk organizations of the area, with the help of local NGOs. This involved the management of wharf and ice plant set-up by the fisherfolk organizations themselves. The fisherfolk organizations have already started doing deep-sea fishing to ease the pressure on coastal fisheries while earning more income as compared to municipal fishing.

2.3.3 Why use participatory approach?

Why is there a need for participation of the local people? One reason is that the local people have a better knowledge and understanding of their situation and their environment as compared to outsiders (Narayan 1995, Dayal, et.al., 2000). By using the participatory approach, the local people would start analyzing their own situation, identifying their problems and, possibly, even think of the viable solutions to their problems. "Participatory activities are a learning process for the communities and institutions (Dayal, et.al., *Ibid.*)." This in turn would help the external planners and decision-makers understand the local situation and, hopefully, they would be able to develop policies that are more appropriate for the local situation (Gosling and Edwards 1995 as cited by Ockelford and Reed, 2002). Data collection may be hastened by using participatory methods (Dayan, *Ibid.*). Project design may be improved when the local people actively participate by providing pertinent inputs and increased support, thus making the project sustainable (Bamberger, 1986). The participatory process "adds ownership to findings and commitment to action (Dayan,

Ibid..” A project is more likely to succeed if there is active participation among the local people (Narayan 1995).

2.3.4 Applications of Participatory Approach in NRM

There are several approaches to participatory NRM. Some of them are:

- 1) Participatory rural appraisal (PRA) – This approach uses the locals’ ability to assess their current situation and communicate their knowledge by means of diagrams, maps, models, estimates and ranks (The Program Support Staff, Upland Development Program, DENR, 1994). The Upland Development Program is using this approach.
- 2) Participatory Coastal Resource Assessment (PCRA) – This approach is used to collect and analyze information on coastal resources from the local users of coastal resources (Walters, et.al., 1998). The Coastal Resource Management Project of the DENR is using this approach.
- 3) Community-Based Resource Management (CBRM) – is an approach developed by the Environment and Resource Management Project of the Institute of Environmental Science and Management, University of the Philippines, Los Baños, Laguna, Philippines and the School for Resource and Environmental Studies, Dalhousie University, Halifax, Nova Scotia, Canada (Fellizar, Jr., 1993). It is defined as “a process by which the people themselves are given the opportunity and/or responsibility to manage their own resources, define their needs, goals and aspirations, and to make decisions affecting their well-being (Fellizar, Jr., *Ibid.*.” This approach is being used in a lot of aspects of natural resource management such as forestry resource management (e.g. Forest Occupancy Management Program, 1974, and Communal Tree Farming, 1979) (Fellizar, Jr., *Ibid.*). Some government-initiated programs for forestry are Integrated Social Forestry Program (ISFP) and National Forestry Program (NFP) (Fellizar, Jr., *Ibid.*). In the field of fisheries, the Coastal Resource Management uses CBRM as one of its components (Fellizar, Jr., *Ibid.*). CBRM is also applied in the field of mining (through the Mining Act of 27 June 1991), irrigation (e.g. Participatory Approach Project), and Lake Resources (e.g. Resource Management Council).

These examples emphasize the use of local participation in certain portions of project planning and implementation. Also we could see that participation can be used in most aspects of natural resource management, if not all its aspects. The extent of participation of the local communities in the above-given examples ranges from being mere data sources to being operators and managers of the projects. In this research, as illustrated in the conceptual framework (detailed discussion in Chapter 3) the local community is thought to be not just mere data sources, but they may also be part of validation and negotiation of NRM policies.

2.4 Multi-Agent Systems Modeling and Simulation

2.4.1 Definitions

What is MAS modeling? What is a MAS simulation? Before answering these two questions, a definition of what a model / modeling and simulations are needed. A model is a representation of reality (Grant, et.al., 1997: 18) and modeling is the process of building or representing this reality. Depending on the application, the essential components or elements of “reality” are identified and the relationships of these components are established (Grant, et.al., 1997: 18; US EPA, 2000). Different professionals use models to project outcomes, analyze trends, or to assess environmental impacts (US EPA, 2000). By using models “reality” could be dissected and studied closely (*Ibid.*). When we use models to imitate the behavior of reality, this process is called simulation (Grant, et.al., 1997: 22).

With simulations the concept of time is explicit, and the system changes with the passage of time (Grant, et.al., 1997: 18). With the use of arithmetic and logical operations the structure (state) of a system and its behavior (change-of-state) are defined (Grant, et.al., 1997: 22). Why is this concept important in NRM? Biswas (1990: 7) reasoned that “environmental models, most of the time, are not static.” The conditions of these systems change with time; thus the models must consider the changing conditions if they are to mirror reality (*Ibid.*). Furthermore, since dynamic models are more flexible for refinement as compared to static models, they could be fine-tuned as more data are collected (*Ibid.*).

Most of spatial models in geography were static, until recently (Griffith and Mackemon, ed. 1981). And one of the more common problems of spatial analysis is that it is difficult to relate macro-spatial patterns with decision-making activities and behavior occurring at the micro-level (Griffith and Mackemon, *Ibid.*). As mentioned in the discussion of GIS, it, only being able to produce static models, is not enough to model the complexity and behavior, and to explain the emerging patterns of systems such as a natural resource environment. An integrated approach to modeling may be able to overcome these obstacles. By means of coupling (detailed discussion in the next section), in this case GIS and MAS, the benefits of both systems could be reaped.

What then is MAS? Multi-Agent Systems or MAS is an agent-based model that originated from distributed Artificial Intelligence (DAI), a sub field of Artificial Intelligence (AI) (Gilbert and Troitzsch, 1999 as cited by Rubio, 2002: 17). Agent-based models try to incorporate human behavior and interaction, and try to assess how these activities affect the system (Pahl-Wostl, 2002). MAS in NRM have two major components, the actors or the agents situated in an environment. The agents or actors are intelligent and autonomous (meaning they have localized decision-making tasks) objects in the system that have certain relationships with each other and its environment, and interact with each other and with the environment (see Figure 2.3) by means of operations or tasks (Ferber 1995,1999 as cited by Bousquet

and Le Page, *forthcoming*). Usually, in this system, humans are the agents of the system, but agents may also be animals that have something at stake with the resources. It could be viewed that these agents share something in common in the system, that is they utilize the resources found in the environment; therefore we could say that natural resources are a common pool resource (CPR)⁸ being exploited by the agents.

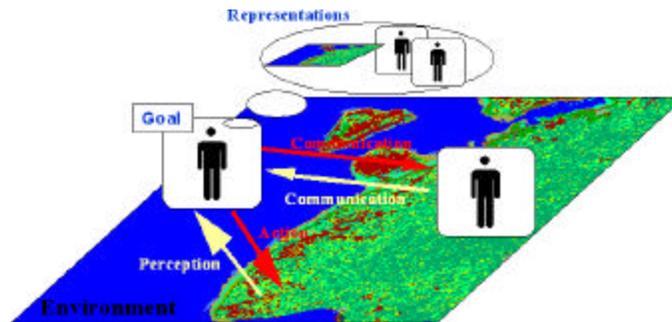


Figure 2.3 A Multi-Agents Systems (Ferber, 1999 as cited by Bousquet and Le Page, *Forthcoming*)

In a MAS, agents do not have a complete idea of the system, limited actions and interactions, and a limited perception, just like the real actors in an NRM situation (Sycara, *undated*). Also there is no global or central control of the system, and information is distributed (Sycara, *undated*). Updates may be implemented immediately as an event occurs (synchronous) or there is a delay in the implementation of the effects of an event (asynchronous). These agents may be designed to be selfish or they may be designed to cooperate to achieve a common goal (Sycara, *ibid.*). Some MAS studies focus on the understanding of emerging patterns on a global or macro scale of the system brought about by the localized actions and interactions of the agents.

With or without the agents, the environment behaves, that is it also changes with time. To model this behavior a cellular automata (CA) is used. CA is a cellular model in which an array of programmed automata or “cells” interact with one another (Goncalves 1994). Each cell is characterized by three properties (Goncalves, *ibid.*) :

- 1) state – is an attribute of a cell signifying its type
- 2) neighborhood – is the set of cells that affects the state of the cell in question.
- 3) program – is a set of rules that controls the changes of the state of a cell depending on its current state and the state of its neighborhood.

For a rectangular array of cells, the neighborhood may be the cells located in the 4 cardinal directions (see Figure 2.4); this is called a von Neumann neighborhood. It may also be the 8 cells surrounding the cell in question; this is called a Moore neighborhood (see Figure 2.5). According to Star and Estes (1990) the use of a

⁸ Common Pool Resource is defined as “those resources that are subtractable and for which exclusion of potential users or appropriators is difficult (Ostrom, Gardner and Walker 1994 as cited by Deadman et al 2000).”

Von Neumann or Moore neighborhood depends on “characteristics of the data and the objectives of the exercise.” For example, a rectangular road network, wherein diagonal motion is rare or impossible to occur, a Von Neumann neighborhood would be appropriate. In this research, the cellular model used for the MAS model uses a Moore neighborhood because it is assumed that the processes involved in the model may occur in all directions.

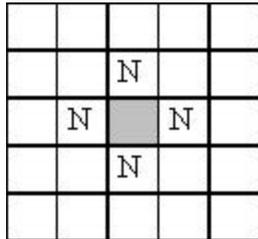


Figure 2.4 von Neumann Neighborhood

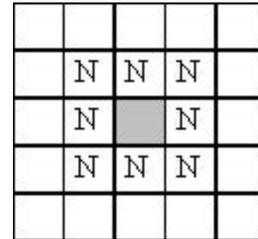


Figure 2.5 Moore Neighborhood

One important characteristic of MAS researches is that it is highly multi-disciplinary and is not only limited to AI; that is, the ideas in the MAS model may come from non-AI fields such as biology, sociology, economics, philosophy, organization and management science and complex systems. In the real world there are a lot of processes (e.g. physical, social and biological processes) happening and that not one field of study could provide all the necessary data needed to model these processes. However, the integration of different data from different fields may be problematic.

Some other issues or questions concerning the use of MAS and agent-based models are (Pahl-Wostl, 2002: 240-241):

- 1) How intelligent should the agents be?
- 2) How and how much should be the interaction of the agents?
- 3) How complex should the system be?

The above-mentioned questions would guide the modeler in the design of the model in terms of the spatial resolution of the environment, kinds of agents to include, the length of a time-step of the model, kinds of tasks to be performed by the agents and the model itself, the data required to perform these tasks and other information needed to meet his/her goals.

2.4.2 Coupling

There are cases wherein a certain software doesn't have enough tools needed to complete the task at hand and could be found in other softwares, or there are other softwares that could perform a certain task better than the one being currently used. To be able to use both softwares they have to be linked together or “coupled.” Coupling softwares can be done several ways (Bailey, T. and Gatrell, A., 1995: 57-58):

- 1) *Full integration* involves integrating all the capabilities of one software inside another software, such as putting all kinds of statistical computations inside a GIS software. Although there are some softwares using this method, it may not be practical for software developers to include all these capabilities in just one software;
- 2) *Loose coupling* involves providing softwares the ability to “communicate” with other softwares. This is done by giving the software *importing* and *exporting* capabilities. This means that the file format being used by one software, by exporting, is changed to a format that could be read or imported by other softwares. Although this method “offers some flexibility it is inefficient (Bailey, T. and Gatrell, A., *ibid.*)”; and
- 3) *Close coupling* involves using macro language facilities of a particular software to use the faculties of another software without leaving the software being used. This may be the better alternative among the three methods, and is being explored by researchers.

In this research, a MAS software, Cormas, was coupled with a GIS software, ArcView. The spatial data from ArcView was exported to be used by the MAS model, and the resulting spatial information after simulation was exported back to ArcView (detailed discussion of the process is found in Chapter 4). Since Cormas 2002 version doesn't have facilities for GIS tasks, and this researcher doesn't have knowledge in programming macros, loose coupling between Cormas and ArcView was used.

2.4.3 Unified Modeling Language

Before coding or programming the simulation model on any programming platform, a blueprint of the model is needed. This will guide the programmers when coding the components of a model, much like the way a blueprint is needed for constructing a building. The Unified Modeling Language™ (UML) developed by the Object Management Group (OMG) serves as the industry-standard language to meet this purpose (UML Resource Center 2003). The UML is used for specifying, visualizing, constructing and documenting the architecture – or the structure and design – of a system (Introduction to UML 1997). Although the UML was designed for software systems, it could be used for other applications such as for business modeling and non-software systems (*ibid.*). Surveys for software development show that failure to use UML in the design of software systems has led to the failures of these projects (*ibid.*). In other words, UML has become an essential tool for system design and implementation.

UML diagrams are used to communicate the model architecture with other modelers and programmers. Without showing the nuances of codes of the model, these diagrams help modelers and programmers understand the structure and design of the model; they could then translate to model to other programming platforms when there is need to do so. Because of its simplicity, the UML diagrams, when properly

explained, can also be used to communicate the model with laymen, such as the stakeholders and policy-makers. In this research, it is used for building MAS simulation models.

UML is independent of the hardware, operating system and programming language when using it for any type of application (*ibid.*). It could be used for both object-oriented (OO) and non-OO languages for programming systems (see Introduction to UML, *op.cit.* for detailed discussion). UML uses 12 types of diagrams grouped in 3 categories (*ibid.*):

- 1) *Structural Diagrams*, which include the class diagram, object diagram, component diagram and deployment diagram;
- 2) *Behavior Diagrams*, which include the use case diagram, sequence diagram, activity diagram, collaboration diagram, and state chart diagram; and
- 3) *Model Management Diagrams*, which include packages, subsystems and models.

For the purpose of this research, three types of diagrams would be used for MAS modeling, namely the class diagram, sequence diagram and activity diagram. Only three diagrams were used in this research because these three diagrams, as listed below, are sufficient enough to explain the structure and behavior of the MAS model developed for this research. Based on the lectures of the Training on MAS, GIS and Watershed Management,⁹ following are the characteristics of these diagrams:

- 1) The *class diagram* shows the attributes and operations of a class¹⁰ or entity possesses, as well as the relationships of this class from other classes. The attribute of a class is a particular property of the class, and a class may have zero or more attributes. The operations of a class are the tasks the class could perform.
- 2) The *sequence diagram* shows the step-by-step flow of actions and interactions of the objects in the model over time.
- 3) The *activity diagram* shows the flow of actions for a particular operation of an object in the model and it appears in the form of a flow chart.

For further details about UML, the website of OMG¹¹, offers more references and examples. The UML diagrams of the model for this research are discussed in Chapter 4.

2.4.4 Benefits of MAS Modeling in NRM

According to Barreteau et.al. (2001) MAS simulation models may be used in the following ways: (1) For research, the models may be used for experiments on

⁹ This training course was the 5th Session of the Asia IT&C Project on Multi-Agent Systems, Social Sciences and Integrated Natural Resource Management sponsored by CIRAD and conducted at the Multiple Cropping Center, Chiang Mai University, Thailand held from 14 to 25 October, 2002.

¹⁰ A class or entity is a representation of a type of object found in the "real world."

¹¹ The website of OMG is located at <http://www.omg.org>.

systems that are very hard to observe due to their complexity and the slowness of the processes occurring in these systems. By means of these models, these experiments could be repeated and controlled for different scenarios; (2) as a tool for training and teaching, the system could be explained with the use of these models. The rules of these models may be modified so that the effects of these modifications could be observed and assessed. Sensitivity analysis could also be performed on these models to test its resiliency and how it behaves given surprises or sudden change in state of the system; and (3) as a decision support tool, it could be used to support the process leading to a decision. It can be used for facilitating the communication related to the negotiation. By discussing the model and its outcomes, the stakeholders and decision-makers may come to a collective decision as to how the natural resources could be managed.

2.4.5 Applications of MAS in NRM

Numerous studies from different parts of the world have been made using MAS modeling for NRM. Barreteau et al. (2001) used MAS modeling and Role-Playing games in the management of irrigated systems for the Senegal River Valley. Trebil et al. (ongoing study) focus their study on the application of companion MAS modeling for integrated watershed management as applied to steep land management in Northern Thailand. As an MSc thesis, Rubio (2002) did a study on application of MAS modeling to coastal zone management and planning with a case in Ormoc City, Philippines. The Mae Salaep role-playing game by Ekasingh et al. (on-going research), deals with the use of a role-playing game associated with multi-agent model for integrated watershed management. From these examples we could see how the many facets of NRM, from irrigation to watershed management, could be modeled using MAS models. Also, some these examples show one method of extracting rules for behavior of agents are applied. Although the method for eliciting rules from stakeholders in this research only involved individual and group interviews and workshops, it would be interesting to explore the use of role-playing games in the local setting, to see how people react to such games and to find out how it would be affect the dynamics of participation among the local people.

2.5 Summary of the Review

Based on the review of the different geo-information technologies available to facilitate natural resource management, the following could be inferred:

- 1) Models are very powerful tools that could be used for studying and understanding systems-of-interest, communicating about the characteristics of these systems and providing a take-off point for discussion or negotiation;
- 2) The modeling process plays a very important role for better understanding of the system; thus leads to better management of this system. In some cases, the modeling process is as important or even more important than the model itself (Randy, J.S. and P. Khanna,1990: 19);

- 3) Satellite imagery could provide timely data that is especially useful when there is problem in data availability. Integrating this data together with other data from different sources into a GIS is useful in modeling the biophysical environment of the agents in the MAS model;
- 4) Because RS and GIS models are static, it's is not enough to model the complexity and behavior, and explain the emerging patterns of systems such as a natural resource environment. Moreover, these models fail to consider the impact of human activities in NRM systems;
- 5) MAS models try to avoid the inherent problems of other modeling techniques by being able to take into consideration the human factor in natural resource management, which is usually absent in other modeling techniques;
- 6) MAS models do not have the goal to predict or to find the optimal solution to problems, but instead it seeks the better understanding of the system. Alternative paths are identified and are studied as to how these alternatives would impact the system;
- 7) By using a participatory approach, MAS modeling is a good venue for active/interactive policy-testing and learning in NRM because it provides the policy makers and stakeholders their respective voice in the model; their activities could easily be represented and presented to the whole group;
- 8) Using a spatially-explicit MAS model is very advantageous in the sense that it could display the simulation by means of maps that "behave." The stakeholders and policy-makers could see themselves as being part of a system and hopefully would see how their individual actions and decisions affect this system. Furthermore, the spatial component of this type of MAS model could be analyzed in GIS/RS;
- 9) The role of GIS and RS in the modeling process does not end in just merely providing data for the model. By coupling MAS with GIS/RS, the flow of information is cyclic. This means that GIS/RS provides information for the MAS simulation, and the results of the simulation is then brought back to GIS/RS for further analysis and validation, which can eventually be used as a new input for the MAS model; and
- 10) MAS modeling process is never ending. As long as the system exists, its management should be continuous and should be able to adapt to the new conditions of the system. This offers increase in the chances of continuous participation of the stakeholders and policy-makers in debating or negotiating about the management of natural resources.

Based on the technologies and artifacts discussed in this Chapter, MAS models may be used as tools for learning in participatory NRM. RS and GIS techniques may improve the analysis and communication of the results of the simulation of MAS models to the participants of the NRM situation.

3 Conceptual Framework and Methodology

3.1 Conceptual Framework: MAS Modeling for Participatory NRM

Employing learning tools that could facilitate a joint-learning process in NRM may bridge gaps in knowledge of an NRM system. In so doing, a common understanding of the NRM system and its problems could be attained between the stakeholders and policy-makers; thus NRM strategies could be more directed towards solving these problems. The various technologies or tools discussed in Chapter 2 could be used hand-in-hand towards developing a learning tool for participatory NRM. More specifically, a MAS model supported by GIS and RS techniques in its construction, verification and validation would be developed to demonstrate and analyze the effects of human activities on the natural resources. Based on discussions that could arise from this joint-learning activity, new strategies or scenarios could be developed for managing the resources, resulting to an interactive policy-making process.

To develop a MAS model as an effective learning tool to facilitate NRM using a participatory approach, there is a need to solicit, verify and validate information from various sources. Expert Knowledge from scientists or experts provides information on processes happening in reality, may it be biological (e.g. fish-reproduction process) or non-biological (e.g. soil erosion) in nature. The stakeholders provide the information on their activities and decision-making processes. By applying GIS and RS techniques to spatial information (e.g. maps) these information may be integrated digitally and then included into the MAS model as its environment. Participatory natural resource management involves the stakeholders and policy-makers in discussions for analyzing the current situation of the NRM system and then developing scenarios or strategies on how to effectively manage the exploitation of the available natural resources in the system.

How then are these concepts related to each other? Figure 3.1 shows the interrelationships of these concepts. This is also the basis of the proposed methodology in this research.

In this study, the goal of the MAS modeling process is to be able to build a model of how the natural resources are being exploited, and to be able to use this model to facilitate a participatory approach to NRM. The processes involved in building a MAS simulation model come from and feed into different activities:

- 1) Domain expert knowledge are elicited from local experts for information on the various human /non-human processes occurring in the system. The stakeholders would provide information on their activities and decision-making processes that they do. These information would be elicited by using participatory approaches, such as interviews or role-playing games.
- 2) The database would contain spatial and non-spatial data that are acquired and integrated using GIS and RS techniques. It would serve as the initial state or condition of the system.

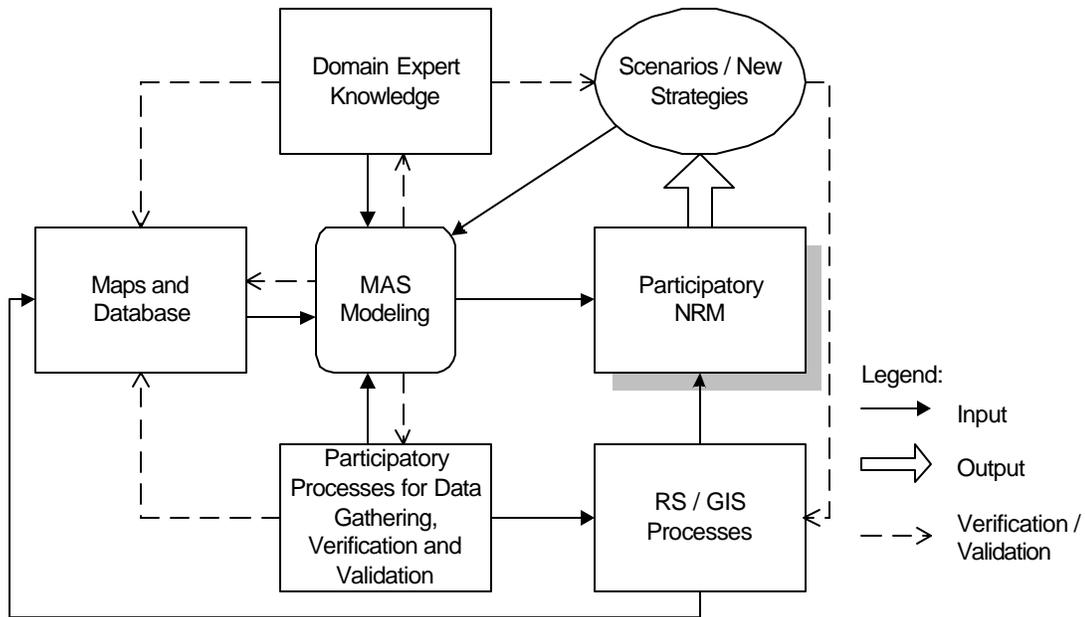


Figure 3.1 MAS Modeling integrating RS and GIS for Participatory NRM (After Pahl-Wostl 2002)

- 3) The role of the experts and stakeholders in the modeling process doesn't end in merely providing information. Through participatory processes, they may also be tasked to verify the contents of the database, both the spatial and non-spatial, whether they are correct, complete or necessary, before the data is incorporated into the MAS model. After building the initial MAS model, it has to be verified by the sources of data used by the model. 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.
- 4) 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, and the results of which could be used to support the MAS simulation in the negotiation process.
- 5) The outcome of the discussions or negotiations between the stakeholders and policy-makers may be strategies or scenarios that are thought to foster sustainable exploitation of the natural resources. However, before these strategies are 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.

3.2 Methodology: Activities of the MAS Modeling Process

Following the conceptual framework, a research methodology is proposed to meet the objectives of the MAS modeling process. The proposed methodology would be composed of two stages, the initial stage and the continuing stage. The initial stage assumes that the NRM problem has yet to be defined and the model has yet to be conceptualized. For the continuing stage, it is assumed that there is already an existing model from which scenarios or new strategies would be built upon. Summary of the modeling process is given in Figure 3.2. The succeeding sections would discuss the details of activities involved in accomplishing every step of the modeling process for the two stages.

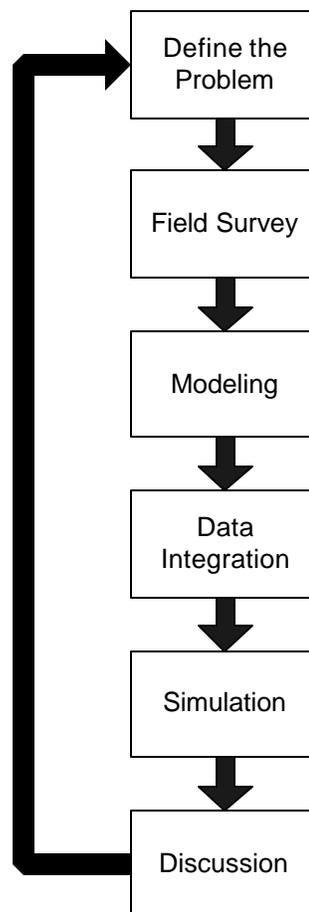


Figure 3.2 Activities of the MAS Modeling Process

3.2.1 Initial stage

Defining the problem

At the beginning of the modeling process, the most critical aspect that has to be considered is definition of the problem. A single entity or group cannot decide what the problems of the system are and then decide the solutions to these problems. Using such a top-down approach in policy-making often leads to failures of projects. To avoid this pitfall, a reconnaissance survey conducted for both the policy-makers and the locals would be needed to gather ideas about the current NRM situation. Perceived problems from the viewpoint of local community and the policy-makers need to be identified. To do this, both the local community and the policy-makers should be asked as to how they see their environment. This is to take into consideration that different people see reality in different ways and, therefore, would have different ideas of what the problems of this reality are. In a venue for discussing the concerns of the stakeholders and policy-makers such as a community meeting or group interviews, they would be able to learn how each of them sees their reality and that would lead to better understanding how each one is affected by the management of the resources. The problems identified by both groups should be compared, and later on synthesized into an encompassing problem or problems that should have been agreed upon by both groups. Individual interviews of the locals could also help in gathering information about the system. From the information gathered at this stage, some important components of the MAS model could be identified such as which agents to include and which aspects of the environment to be considered. As the agents and aspects of the environment are identified, an initial model of the NRM system could be made, establishing how the agents and the environment are related to each other. The initial model would guide modeler/s as to which data to gather and how to acquire them.

Field survey

A field survey is a technique for gathering data wherein the people assigned to gather data would go to the study site and perform data-gathering tasks with the local people. Assuming that an initial model has been made, data gathering should be performed to determine the spatial and non-spatial components of the model, such as physical and biophysical maps (e.g. land use/cover maps, elevation maps, soil maps, etc.) of the area-of-interest, political maps (e.g. municipal and barangay boundary maps, maps of sanctuaries), and reports pertaining to the social, economic, and environmental conditions of the area. These reports may be acquired from different government agencies, such as the Department of Environment and Natural Resources (DENR), Bureau of Fisheries and Aquatic Resources (BFAR) and National Statistics Office (NSO). Field verification of the

spatial data should also be considered. GPS¹² surveys would help in determining the positions of several objects on the ground or check the positions of objects initially identified. Group and individual interviews with the identified agents of the model would provide the rules or behaviors of the agents in the model. Other techniques could also be used to extract these rules such as role-playing games as used by Barreteau et al. (2001). An important thing to consider in gathering rules from the stakeholders is that the techniques for data-gather should have facilities for validation or they can be validated by other techniques.

Modeling

Information gathered from the stakeholders about their activities and decision-making rules would be broken down into simple rules that could be easily translated into codes that could be handled by the programming language or platform. After translating the interviews into rules for the agents, these rules need to be translated to sub-models to be incorporated into a larger model – the MAS model. The rules would be used to model the behavior of the agents. Consultations with experts from various fields such as biology or geology would help determine the physical and biophysical processes from which the rules of the cellular automata would be derived. Also, based on the CA and agent behaviors, the structure of the environment should be designed to accommodate all the spatial data that has been gathered.

These sub-models and the MAS model itself would be represented by means of UML diagrams. By using UML diagrams, the components and the processes in the system, and how these components and processes are related to each other in the system would be defined. Later, the UML diagrams would be used as a guide the programmers for the MAS model construction.

Data integration

Data integration means putting all the data and sub-models together into one encompassing model inside the computer. This step contains two main activities:

- 1) Spatial data gathered would usually be of different scales and probably of different grid systems, so they have to be converted and transformed to be able to be accommodated into the GIS. These maps will be digitized¹³ and processed to ensure that they match and can be overlaid properly. The overlay process is the process of stacking or putting the layers of information on top of each other; thus analysis could be performed on a specific location or area of the maps based on the information of each of the stacked layers

¹² GPS or Global Positioning Systems make use of receivers in determining the precise location of points on the ground.

¹³ Digitizing is the process of transforming analogue data (e.g. paper maps) to digital format to be put inside a computer.

(Burrough, 1987). Satellite images would be processed using remote sensing techniques and then put inside the GIS. GPS data from the field survey could be used to verify the processed maps. When all necessary data have been put inside the GIS they are now ready to be put inside the MAS model. However, this can only be done if the platform used to program the MAS model can “read” the file format of the GIS software used. If this is not the case, the digital maps have to be converted to a file format that can be accepted by the modeling platform. This process of converting file formats between two platforms occurs if there is loose coupling involved between the GIS and MAS models.

- 2) The rules of the agents, cellular automata, other objects and the MAS model itself would be translated into computer language or codes. The UML diagrams would guide the programmers in the building the MAS models. From these diagrams, the agents would be programmed with different characteristics and behaviors. Also, the cells composing the environment would be given different characteristics and behaviors. The proper order of activities would also be programmed at this stage. The digital maps are incorporated into the MAS model. This will serve as the initial state of the environment of the MAS model. Model verification would be part of the programming activity to ensure that the model is working, as it should be. Model verification involves correcting errors to checking the adequacy of the structure of the model (Parker et al., 2002: 37). Codes that would cause the model to stop are corrected and codes for performing tasks would be checked if they are indeed performing these tasks correctly as intended.

It should be noted that there are many modeling platforms and languages for perusal by the modeler. Table 3.1 shows the different programming platforms commonly used for MAS modeling.

Table 3.1 Platforms for MAS modeling (Bousquet 2001 as cited by Rubio, forthcoming)

Platform	Implementation	Author	Description
Generic – for environmental applications	Swarm StarLogo	Minar et al., 1996	tools are based on principle more friendly user
Ecosystem- oriented - for ecological system modeling	Ecosim Cormas	Lorek and Sonnenschein, 1999 Bousquet et al., 1998	simulate ecosystems or resource management problems
Dedicated - for more specific application	Manta Aborscape Bacsim	Drogoul, 1994 Savage and Bell Kreft et al., 1998	focuses on task allocation in a society of insects forest dynamics with emphasis on diversity microbiological

	Mobydic	Ginot and Le Page, 1998	dynamics of fish populations
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As the programming platforms given above are designed specifically for a certain application, the modeler should choose the appropriate platform for his/her application to make the task of programming easier. It should be noted that the UML diagrams are not dependent on the programming platform to be used for the MAS model, that is, the UML diagrams could be translated into a program using any programming platform. Also, the modeler should not limit himself/herself to the programming platforms listed above. The model could also be programmed using programming languages such as Java and C++ depending on his/her capabilities and needs.

Simulation

After the MAS model has been verified, simulations on the model can now be performed. The simulation is run up to a certain number of time steps depending on the purpose of the simulation. A time step may be as short as a day or be as long as a decade. One time step depends on the design of the model. The actual time for running a simulation will depend on the complexity of the model and the capabilities of the computer running the model.

Discussion

At this step the model needs to be validated to ensure that the MAS model is correct for the system being modeled, and this involves comparing the model outcomes with empirical data, other existing models, or theories about reality (Parker et al. 2002). Validating the model against the database consists of comparing the model outcomes with empirical data. Empirical data may be socio-economic data statistics (maybe from the National Statistics Office). Spatial data could be checked against existing information, such as field surveys and satellite images. Satellite imagery taken at different times could be compared at the corresponding times of the model. Field surveys could validate changes in the environment. The rules for biophysical processes could be validated with different experts of various fields to check if the current configuration of the environment is possible or the kinds of changes and the rate of change are plausible. Questions such as “Do you do this?” or “Have you actually done this or would you consider doing this action?” could be used to see if the behaviors of the agents realistic. Workshops, group and individual interviews, and role-playing games could be used to solicit the information required. Also, at this stage of the process, assumptions could also be validated to see if they are reasonable enough or should they be considered for more in-depth study.

Based on gathered reactions and information about the model, analysis could be focused on certain aspects of the model such as the resource with the most impact on the agents and vice versa. From the analyses, new questions could be posed and new strategies could be formulated. The discussion should involve all the stakeholders to be able to design the goals that would benefit the entire community. Ideally, it would be good if all stakeholders would be represented and would discuss different issues face-to-face with everyone else. However, this is difficult to achieve. Putting different people of different social classes and roles in the community in one place would sometimes, if not always, influence the amount and kind of interaction. Again, different approaches such as workshops, interviews and role-playing games could be used to for this purpose.

3.2.2 Continuing Stage

Changes in the model due to criticisms or incorporating of new strategies from the discussions will be accommodated during this stage. Basically the same processes as in the initial stage would be followed at this stage. Additional data, both spatial and non-spatial, would be gathered if so required. UML diagrams will be modified to accommodate the changes in the model. Re-programming and verification of the MAS model in the modeling platform would be performed. Scenarios or new strategies will be implemented in the existing simulation. The stakeholders and policy-makers would again analyze the results of the simulations. This whole MAS modeling process would be repeated as deemed necessary by the participants of the participatory NRM process.

4 Multi-agent Systems Modeling in Bohol, Philippines

4.1 Background of the Study Area

The island of Bohol, the 10th largest province in the Philippines, is located in the Central Visayas and is a province in Region VII. It is approximately 124°10'E longitude and 10°N latitude (see Figure 4.1). It is surrounded by the islands of Southern Leyte in the northeast, Cebu in the west and northwest, and Mindanao in the south. The northern coast of Bohol is bounded by Camotes Sea, the southern coast by Mindanao Sea, and Bohol Strait in the west portion. Much of Bohol Island is generally flat with level to moderately-rolling lands, which covers 47% of the total land area.

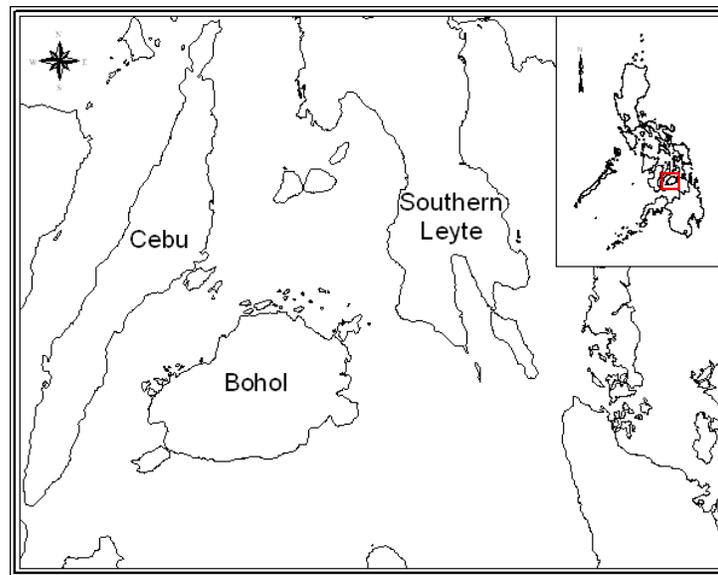


Figure 4.1 Location Map of Bohol, Philippines

Bohol has a temperate climate and rainfall, and is characterized by two distinct seasons: the dry season, which occurs from late January to May; and the wet season, which is from June to December. It has an annual precipitation of 200 cm of rainfall. Temperature ranges from 26°C to 29°C.

The Municipality of Loon, the main study area, is located at roughly 123°50'E longitude and 9°55' (see Figure 4.2). It is considered to be on the northwestern portion of Bohol. Loon is roughly around 11,200 hectares and is composed of 67 barangays, 18 of which are coastal barangays. It is bounded by the municipalities of Calape in the north, Antequera in the east and Maribojoc in the south.

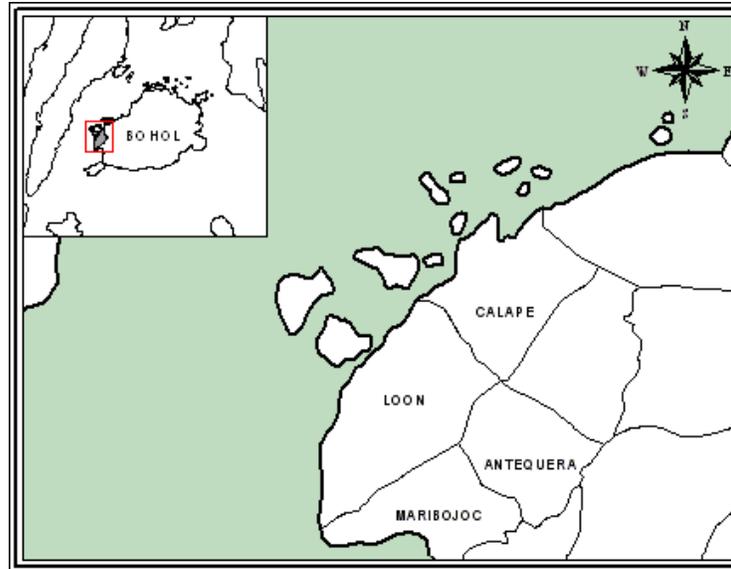


Figure 4.2 Location Map of the Municipality of Loon, Bohol

Mualong, a major river system in Bohol, is found in Loon. Within the municipality there are also two springs and two creeks. Soil depth in Loon is shallow with an average depth of 28 cm only, making it very vulnerable to erosion brought about by agricultural activities.

Loon has limestone and silica deposits, which are commonly used for bottoms of fishponds. Various species of mangroves are also found in the municipality such as Rhizophoraceae, more locally known as “bakhaw.” The coastline is lined by sea grass beds and algal beds with some coral patches and reefs. Recently, fish catch has been low and the sizes of those caught are much smaller than the maximum sizes those fishes can attain (see Fig. 4.3). This indicates intense fishing pressure in the area, as even young fishes are being caught. Although fisheries are the main economic activities in northwestern Bohol, current normal fishing methods generate low income only.

Five major issues have been listed with regards to the natural resources of the northwestern portion of Bohol:

- 1) Over fishing is occurring in the area, aggravated by fishing of outsiders.
- 2) The locals are still using destructive fishing techniques.
- 3) Improper waste disposal and industrial infrastructure development has been contributing to problems of pollution.
- 4) Inappropriate land management techniques being used in the upland areas are causing run-off and siltation of the coast.
- 5) There is lack of coordinated planning and enforcement, and weaknesses in institutional capacities.

These information were taken from the Coastal Environmental Profile of Northwestern Bohol, Philippines by Green, et.al. (2000).

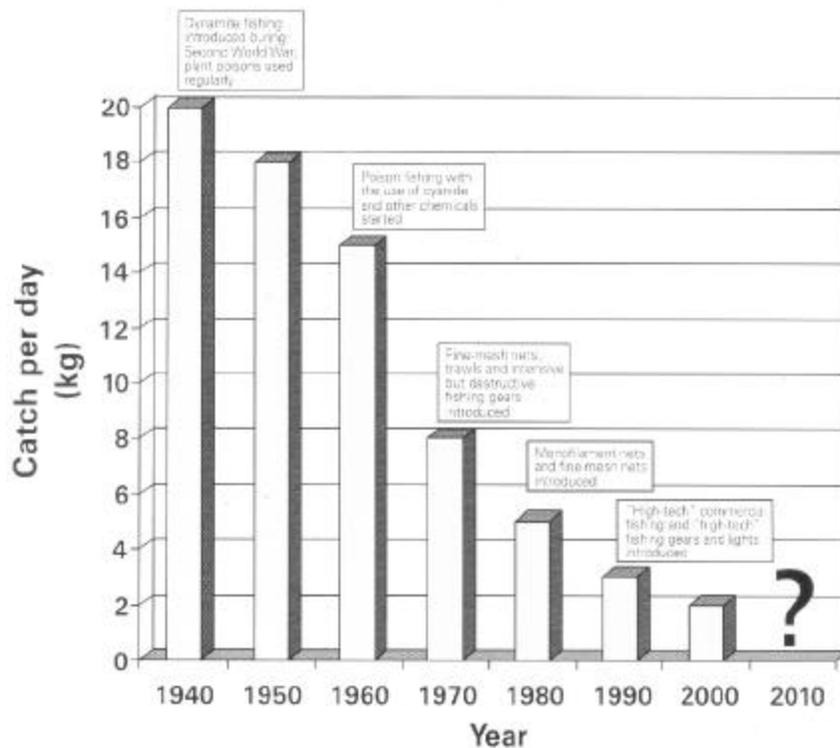


Figure 4.3 Declining fish catch of the fishermen of Loon, Bohol (Green, S.J., et al., 2002).

4.2 The Modeling Process as Applied to Loon, Bohol

4.2.1 Field Survey

Survey equipment

A 1989 Landsat satellite image of Bohol province was available from the Bureau of Fisheries. This satellite image was used as a guide and as a learning tool during the fieldworks (more details in the succeeding paragraphs). A topographic map (1:50,000) was also available. A global positioning system or GPS (Trimble® Pathfinder) was the available tool for marking important locations. A laptop TOSHIBA Satellite 2800 series was used to load the Landsat satellite image and show it to the participants of the workshop.

Survey team

A 6-member research team familiarized itself with the natural resource management problems in the study area in order that together with local perspectives, come up with research topics wherein MAS and geo-information tools and techniques can play important roles. The team was based in Barangay Lintuan and stayed with a

non-government organization (NGO) called *Samahan ng mga Kababaihan ng Lintuan*, an organization dedicated to the empowerment of the women in this barangay. This group helped facilitate the fieldwork, meetings, and interviews with the people of Loon.

Survey - Workshop

A reconnaissance survey was conducted from 28 January to 2 February 2002. It was aimed at understanding how the inhabitants of Loon viewed their environment and natural resources, and what they think are the problems related to these resources. The research team went to 6 barangays from within and outside of Loon and conducted workshops with the members of the respective barangay. Each workshop had from 10 to 20 participants, with one barangay having at least 40 participants. The workshop started with an introduction to the research and its goals; after which, the locals were asked to draw on a sheet of manila paper how they view their community and their resources, giving emphasis on what they think is the boundary of their community. During this activity, the participants were divided to 2 or 3 groups (in one instance four, because of the size of participants). The participants were all asked to help sketch their community as to how they see it (see Fig. 4.4). Later, a representative from each group was asked to explain what they have drawn as a group (see Fig. 4.5).



Figure 4.4 The participants drawing their community.



Figure 4.5 A representative of the group explaining the sketch the group has drawn.

The next activity involved showing the satellite image of Loon to the participants, as shown in Fig. 4.6. The satellite image was explained in layman's terms. A discussion regarding the similarities between the satellite image and their drawing was then initiated between the participants and the research team. After which they were asked if the research is useful for them, and, if so, how is it going to help them and their community. Also, the team explained how the day's activities are going to be used in the research. The workshop was ended with the intention of returning to their communities and presenting the initial results of the research.

In between the workshop activities, field verification especially for identifying mangrove areas was conducted around the community, taking GPS readings of important locations. This is to gather data for the classification of the satellite image.



Figure 4.6 The participants viewing the satellite image.

LGU

A meeting with the mayor of Loon was also arranged not only as a courtesy call, but also to get his perspective about NRM problems in the town, and introduce the possibilities of using geo-information technology (see Figure 4.7). During this meeting, the research and its objectives were presented. The satellite image was also shown and explained to the mayor, and he was asked how the research could benefit his local government unit (LGU) and the municipality (more details in Chapter 5).



Figure 4.7 Meeting with the mayor of Loon

Second fieldwork

The second fieldwork was conducted from 18 to 24 August 2002. It was done to demonstrate the initial model in order to verify and refine previous assumptions thereby, come up with a more detailed model of the problem area. In order to gain more insights on the activities of the stakeholders that were considered in the model,

the second fieldwork team conducted group and individual interviews for the following:

- 1) A group of small farmers were interviewed to determine their activities in farming (see Fig. 4.8).
- 2) A group of fisher folks was interviewed to acquire knowledge about their fishing activities (see Fig. 4.9).
- 3) Another group of fisher folks from another barangay in Loon were interviewed for a different reason. They are fisher folks who have protested against the local government unit (LGU) with regards to mangroves and sanctuaries, but were just ignored by the LGU.
- 4) A fishpond operator was interviewed to gain insights on their practices in fishpond operation and management.
- 5) The mayor was interviewed again to gain more information. The interview with the protesting fishermen was not mentioned due to the sensitivity of the issue.



Figure 4.8 The subsistence farmers of Barangay Lintuan, Loon



Figure 4.9 The fisher folks locating their fishing grounds on the map.

Field verification was again performed to check the satellite image. Both land and sea verification activities were performed with the use of a GPS to locate points on the ground. Also mapping activities were done - the quarry sites owned by large fishpond owners were mapped, as well as the location and extent of mangroves.

Secondary data gathering

Secondary spatial data required for modeling were land use/cover maps, locations and extent of sanctuaries, quarry sites, bathymetric data, coastal resources map and political boundary data. These were gathered from different sources:

- 1) The Coastal Environment Profile of Northern Bohol, which includes Loon, was acquired from the regional office of BFAR in Cebu City since it was not available in the provincial capitol. This profile contains the Participatory Coastal Resource Assessment (PCRA) maps of Northern Bohol.

- 2) The comprehensive land use plan (CLUP) of the municipality was acquired from the LGU.
- 3) Topographic maps made by the National Mapping and Resource Information Agency (NAMRIA) of the study area were acquired.
- 4) Digital data on the municipal and barangay boundary maps were acquired from the Haribon Foundation, an environmental NGO, whose study areas include the province of Bohol.

4.2.2 Initial Model

Based on the first fieldwork, the agents of the system were identified, and an initial structure of the model was built. Figure 4.10 shows the interactions between the agents of the model with its environment. The agents of the model are enclosed in boxes, while the land uses / covers of the environment are not enclosed in boxes. The arrows show the direction of the actions / interactions, with double arrows meaning interactions between agents. It could be seen in this initial model that only actions are performed on the environment and interactions are only limited to the agents of the model. A Simple class diagram of the agents were also made showing the attributes and methods or main tasks of each agent. This is shown in figure 4.11. Also, the rules for the environment and agents of the initial model are shown below. After the second fieldwork, a new model, the Bohol model, was created based on the initial model (to be discussed in detail in the subsequent sections of this chapter).

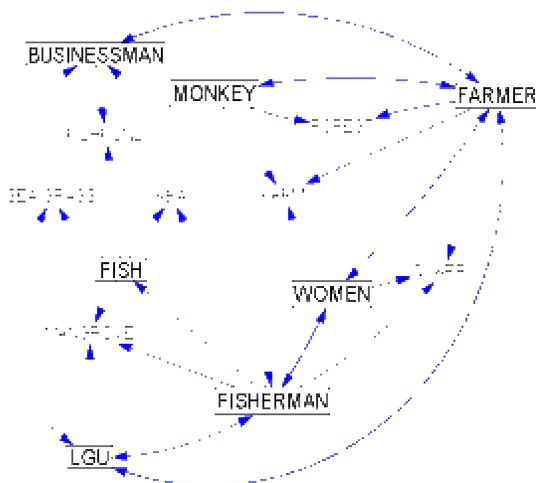


Figure 4.10 Agent-Environment Interactions

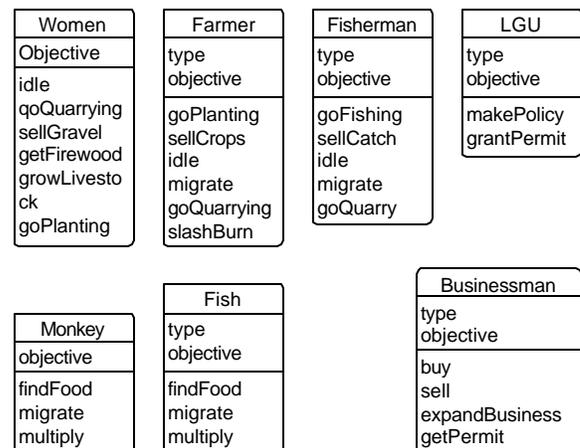


Figure 4.11 Initial Class Diagram of the Bohol model

Rules for the environment of the initial model

- 1) Mangroves
 - decrease due to firewood harvesting
 - increase when replanted

- sedimentation
- 2) farm products
 - decrease due to bad weather, monkeys
 - parcel (Cadastral Survey) / CPR level
 - decrease when soil productivity is low
 - sold to market and/or businessmen
- 3) quarry
 - decrease proportional to the number of people engaged in quarrying
 - finite resource, does not regenerate
- induced erosion
- 4) forests
 - decrease due to slash and burn farming
 - increase when replanted
 - habitat for monkeys
- 5) fishponds
 - increase when permits are granted
 - affect coastal water quality
- 6) sea grass/weeds
 - decrease due to low water quality
 - increase with high water quality

Rules for the agents of the initial model

- 1) fish
 - decrease due to fishing
 - migrate when mangroves decrease
 - reproduce when mangroves increase
- 2) fisherman
 - fish offshore when fish population is low
 - sell catch to fixed buyer
 - turn to quarrying when fish is low
 - migrate when no income
- 3) farmer
 - sell produce to middlemen
 - slash and burn forests for planting
 - kill monkeys that eat crops
 - turn to quarrying to increase income
- 4) monkeys
 - reproduce fast
 - decrease when no crops to eat
- 5) LGU
 - set policies (zoning, reforestation, etc.)
 - grant permits to businessmen
 - give incentives
- 6) businessman
 - get permits for business
 - buy and sell produce
 - lend money to farmers and fishermen
- 7) women
 - grow livestock
 - go quarrying to increase income
 - go gardening to increase food supply
 - collect firewood
 - collect water

4.2.3 Spatial Data Integration

The topographic maps used in this research followed a grid system called Universal Transverse Mercator (UTM) using Luzon datum. This information is important because this would be the common grid system to be used in all spatial data to properly locate and overlay them inside a GIS software. The topographic maps were scanned and were used to geometrically correct the satellite image. This is done to properly orient the satellite image to the common grid or coordinate system to be used for all spatial data in this research. The satellite image was then classified using e-Cognition® image processing software, a software for remote sensing applications using object-oriented classification techniques.

The product of which is a land use/cover map in raster format. The output was later converted to vector format (see Fig. 4.12) using the same software and was put inside ArcView 3.2, a very popular commercial GIS software. The necessary bathymetric data, the area with depths of 10 fathoms or less, was digitized from the topographic map (see Fig. 4.13). The PCRA map for Loon and adjacent municipality was digitized from the profile (see Fig, 4.14). Although a digital copy of this data is available from a commercial company, the cost of acquiring this data is expensive and is not covered by budget for the research. The results of the mapping activity using a GPS were plotted inside ArcView (see Fig. 4.15). The PCRA map and land use/cover map and quarry sites map were later combined into one layer to represent both the land and sea cover.

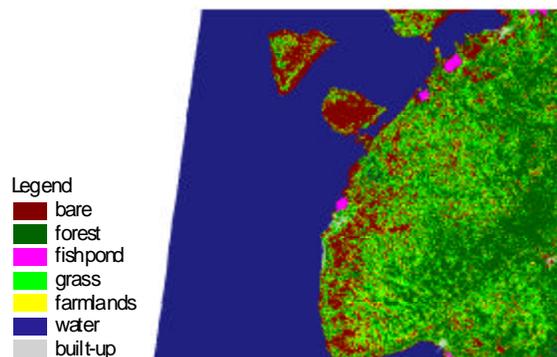


Figure 4.12 Classified Satellite Image

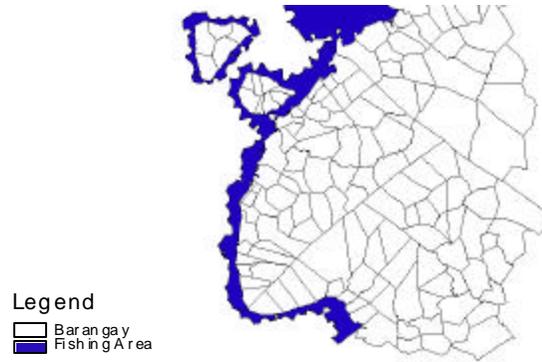


Figure 4.13 Depth of 10 fathoms with barangay boundaries as reference.

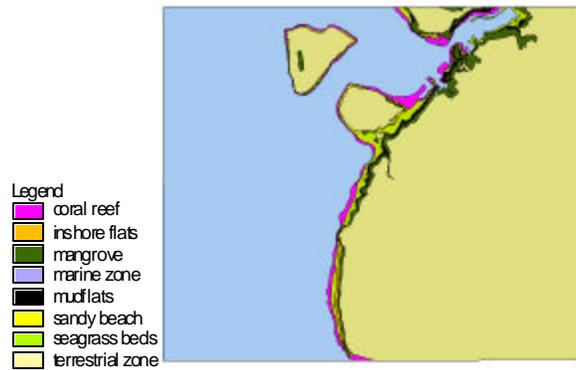


Figure 4.14 PCRA Map of Loon, Bohol

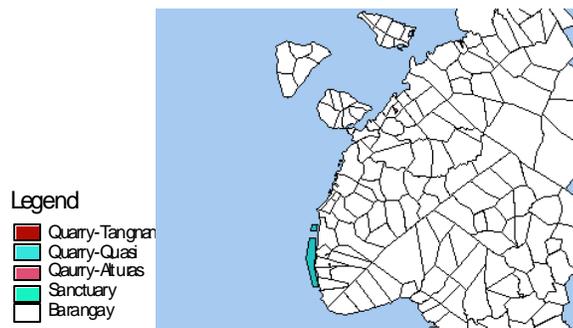


Figure 4.15 Results of GPS survey with barangay boundaries as reference

The spatial data were then converted to raster format with a pixel size representing 1 hectare on the ground so that it could be handled by Cormas, the platform to be used in programming (to be discussed in the next section). This resulted in raster maps, each with dimensions of 188 rows and 224 columns. Within Cormas, the spatial data was again processed. The land / sea cover map was reclassified to include information on bathymetry and municipal boundary. This activity was done to reduce the number of data to be used, making the model more efficient in terms of reducing the complexity of the codes and for speeding-up the simulation. Summary of data about the environment of the model will be provided in the next section.

Figure 4.16 provides a summary of the spatial data integration process used in this research.

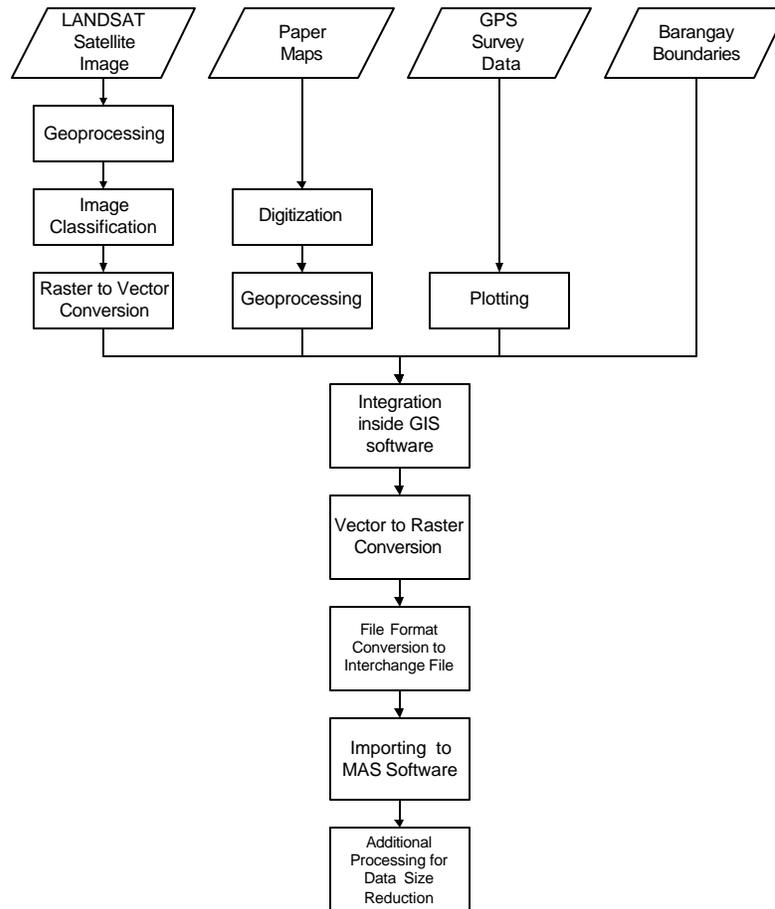


Figure 4.16 Spatial Data Integration Process

4.2.4 MAS Modeling

Cormas

The model for this research was programmed using Cormas or Common-Pool Resources and Multi-Agent Systems. This is an object-oriented programming platform done in VisualWorks using Smalltalk programming language. Although there are many other programming platforms available for MAS modeling, Cormas is specifically designed for natural resource management applications. Within Cormas, several intuitive commands have already been built-in to get the modeling started. The modeler could also design his own commands (or methods) to suite his/her needs, making it very robust. For this research the model developed would be referred to as the Bohol model.

The Cormas platform is divided into three modules. As seen from Figure 4.17, these modules are for the following purposes:

- 1) definition of the entities of the model – This module allows the modeler to create the class “moulds” of the entities of the model.
- 2) control of the simulation - This module allows the modeler to specify the sequence or order of tasks to be performed by the model.
- 3) defining the method of observation of the simulation model:
 - a. the “Environment” - shows the map of the environment being used, changes happening in the environment, as well as the movement of the agents and other objects could be viewed in this window (see Fig. 4.18).
 - b. the “Communications’ Observer” (see Fig. 4.19) allows the modeler / user to view which agents are communicating. Lines between communicating agents would be displayed in this window.
 - c. the “Charts” window (see Fig. 4.20) is used to view results of probes of a model. A probe is a counter of objects or entities and can be programmed to record a population or quantities of objects found in the model.

Cormas could handle both raster and vector data. Any size of raster map or number of polygons of a vector can be handled in Cormas; however, computing speed is limited by the type of computer that is running the simulation model. For this research, the raster format was used since the researcher only has limited knowledge in programming in Cormas. For more information on Cormas, please visit <http://cormas.cirad.fr>.

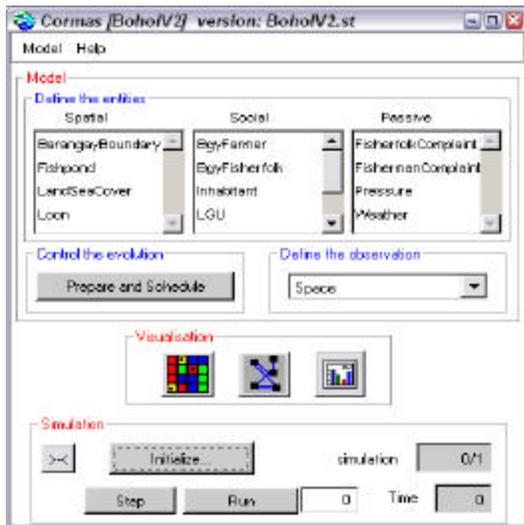


Figure 4.17 Cormas Interface

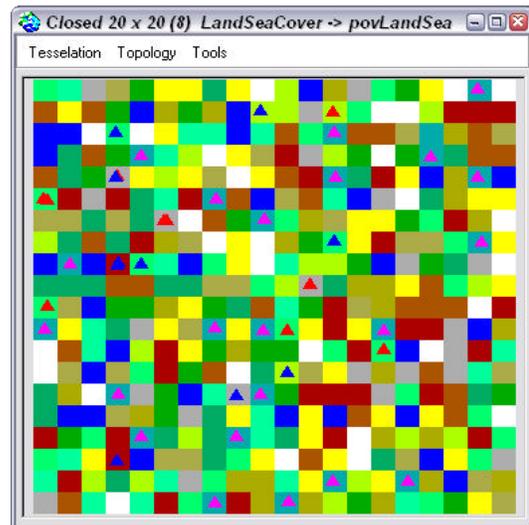


Figure 4.18 Environment Window

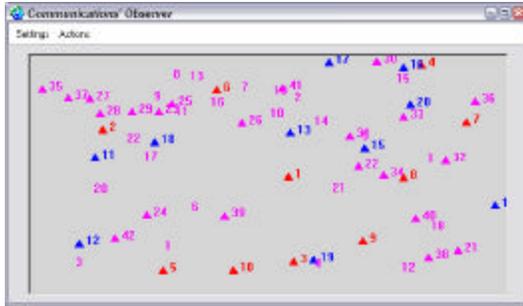


Figure 4.19 Communications' Observer Window



Figure 4.20 Charts Window

Class Diagram

The production rules of the agents were derived from the interviews with the stakeholders. In this research, the rules are summarized with UML diagrams.

As mentioned in Chapter 2, the Class diagram shows the kinds of objects or entities that could be found in the model, their hierarchy (and order of inheritance), and how each entity is related to the other entities. For the Bohol model the class diagram is shown in Figure 4.21.

The different entities in the class diagram are connected by several types of lines or arrows:

- 1)  – Entities connected with this symbol correspond to a line of inheritance and order of hierarchy between classes of entities. For example, The *LandSeaCover* class belongs to the class of *ElementarySpatialEntity*. This means that aside from the attributes and methods (or tasks) specifically defined by the modeler for the class of *LandSeaCover*, it also “inherits” or would gain the attributes and methods of the *ElementarySpatialEntity* class. Furthermore, from Figure 4.21, the class of *LandSeaCover* also inherits the attributes and methods of *SpatialEntity*, and *Object*, the highest class of entities in the model.
- 2)  – Entities connected with this symbol correspond to a line of action/interaction. For example, instances of the *Inhabitant* class may act upon the instances of the *LandSeaCover* class. However, the reverse is not possible, i.e. instances of *LandSeaCover* class may not act upon the instances of the *Inhabitant* class.
- 3)  – Entities connected with this symbol corresponds to two-way interaction. That means the instances of these classes of entities may act upon each other.
- 4)  – Entities connected with this symbol corresponds to composition of the class of entities. For example, the class *BgyFisherfolk* is composed of instances of the class of *Inhabitant*.

Further explanations on the above-given entities are found in the succeeding sections.

Spatial Entities

- 1) The elementary spatial entity is a class of entity in Cormas and it defines the environment of the model. There is only one elementary spatial entity in Cormas environment — the cell. For the Bohol model, the LandSeaCover (this is the name of the class of elementary spatial entity) is defined by several attributes and uses several methods. The basic attribute that will be used to represent the land and sea cover/use is “state.” A state is an attribute of a cell signifying its type. Table 4.1 shows the land and sea covers used and how they were represented in the environment of the Bohol model.

Table 4.1 Look-up Table for LandSeaCover

Sea Cover	State	Land Cover / Use	State
Beach	1	Forest	100
Flats	3	Farm	200
Sea grass / sea weed	4, 41, 42 or 43	Grassland	300
Coral	5, 51, 52 or 53	Bare soil	400
Mangrove	7, 71, 72 or 73	Fishpond	500
Water	9, 91, 92 or 93	Built-up area	600
Mud	10, 101, 102 or 103	Quarry site	800

In the table above, the sea cover state would be represented by 1 to 3 digits. The last digit represents the town where inhabitants could perform activities. The digit 2 represents Loon. For example, a fisherman from Loon could only fish in cells with state 42, 52, 72, 92 or 102. For this research Fishpond refers to both fish-pond and shrimp-pond.

Aside from the basic attributes built within Cormas, other attributes have been added to this class of elementary spatial entity:

1. res1 – this layer stores information about the resources or characteristics of the cell and may correspond to different kinds of resource or characteristics depending on the land cover
2. res2 – this is another layer that stores information about the resources or characteristics about a cell and is used when a land cover has more than 1 resource or characteristic
3. res3 – this layer stores information about erosion or can also be a timer for a cell depending on the type of land cover
4. sanctuary – this layer stores information as to which cells are part of a sanctuary or not
5. barangay – this layer stores the barangay id of a cell

A summary of the first four attributes and their corresponding meanings is given in Table 4.2.

Table 4.2 Summary of attributes for LandSeaCover

Land / Sea Cover	res1	res2	res3	Sanctuary 0 = false 1 = true
Beach	N/A	N/A	N/A	0
Flats	N/A	N/A	N/A	0
Sea grass / sea weed	Fish stock (in Kg)	Biomass of sea grass / weed (in Kg)	N/A	0
Coral	Fish stock (in Kg)	Biomass of coral (in Kg)	N/A	0
Mangrove	Fish stock (in Kg)	Biomass of mangrove (in Kg)	N/A	1
Water	Fish stock (in Kg)	N/A	N/A	0
Mud	Fish stock (in Kg)	N/A	N/A	0
Forest	Biomass if trees (in Kg)	N/A	N/A	0
Farm	Productivity of soil (form 0 to 16 with 16 as very productive)	Timer for fallow	N/A	0
Grass	N/A	N/A	Erosion volume (in m ³)	0
Bare soil	Biomass of trees (in kg) if there are trees growing	N/A	Erosion volume (in m ³)	0
Fishpond	Has fish stock (in Kg) > 0 No stock = 0 Pond needs to be prepared = -1	Unoccupied = -1 Occupied = 1	Number of times harvested	0
Built-up Area	N/A	N/A	Erosion volume (in m ³)	0
Quarry	Quarry volume (in m ³)	N/A	N/A	0

The methods or tasks used by the environment are:

1. fishCA – controls how the fish stock increases in the fishing areas of fishermen. Depending on the remaining fish stock of its neighborhood and itself, a fraction of both stocks is added to its current fish stock. The method of growth in the Bohol model was just assumed. Cells that use this method are sea grass, coral, mangrove, water and mud.
 2. forestCA – controls the growth of forests. This also depends on the amount of biomass of itself and its neighbors, wherein a fraction of both are added to its current biomass. Cells that use this method are forests and bare lands. When bare lands reach a certain level of biomass, it is then classified as forest. This was also assumed.
 3. newState and updateState – are the methods for cellular automata that change the state of a cell for the next time step. In the Bohol model the state of a cell changes depending on the amount of resources of itself and its neighboring cells.
- 2) There are two types of composite spatial entity in Cormas: fragmented spatial entity and aggregate. Composite spatial entities are built from or are composed of the elementary spatial entities and are grouped together by means of common attribute/s. An aggregate is composed of cells that share common attribute/s and are adjacent to each other, while fragmented spatial entity may contain cells that are non-contiguous. In the Bohol model, aggregates were used but no methods were developed for the use of these aggregates because there were no information available for processes that would involve aggregate spatial entities at the time the Bohol model was developed.

The following are the composite spatial entities used:

1. BarangayBoundary – used to group the cells by barangay
2. Loon – used to group the cells that are part of Loon municipality
3. Fishpond – used to group fishpond cells, with each group representing a particular group or company. It has two attributes: myUnion, which has contains the number of employees it has; and vacancy, which represents the number of applicants it could accept as workers. In the Bohol model, the number of fishponds and number of pond workers do not increase. There is one worker for every 2 fishponds.

Social Agents

- 1) Inhabitant is a class of situated and communicating agent. This means that agents of this class could move around and affect the environment, and they could communicate with other agents. The Inhabitant class, aside from the attributes built within Cormas, has the following attributes:
 1. occupation – this is the main attribute of inhabitants that differentiates one inhabitant from another. Possible values of which are farmer, fisherman,

pondworker and ofw. A farmer inhabitant is actually a slash-and-burn farmer. A fisherman inhabitant is a subsistence fisherman. A pondworker inhabitant is an inhabitant working as a fishpond manager. An ofw is an inhabitant who is working outside Loon. An inhabitant may change occupations, however, once its already an ofw, it can't change back to any of the other occupations

2. character – this is the inhabitant's ability to tolerate pressure from other agents. Its value is a randomly generated value between 0 and 1, with 0 as being automatically giving into pressure and 1 being never pressured.
3. lawAbiding – a value that characterizes the inhabitant's chances of breaking the law (or policy). Its value ranges from 0 to 1, with 1 being always a law-abider and 0 being always a law-breaker.
4. myBarangay – contains the barangay to which the inhabitant belongs
5. myGroup – contains the group to which the inhabitant belongs
6. myHome – contains the cell where the inhabitant stays when the weather is bad
7. wealth – the amount of money the inhabitant has at the end of the day
8. salary – the amount of money an inhabitant regularly earns, that is if it is a pondworker or ofw
9. pressure – contains the occupation an inhabitant may be inclined to take if it decides to change jobs
10. weather – contains the condition of weather, that is if its good or bad
11. myFarm – contains the cell where a farmer inhabitant does its farming
12. myOldFarm – contains the cells of farms a farmer inhabitant has fallowed or farms he has allowed to rest to recover its productivity
13. myCrop – the amount of crop a farmer inhabitant could harvest. The value of myCrop is directly proportional to the money the inhabitant farmer is going to earn after harvest
14. catch – the amount of fish a fisherman inhabitant has caught for the day. This value is equivalent to a certain amount of money at the end of the day.
15. myShell – the amount of shell a fisherman inhabitant has gathered for the day. . This value is equivalent to a certain amount of money at the end of the day.
16. myPond – contains the cells a pondworker inhabitant manages
17. myQuarry – contains the cell where an inhabitant can quarry. Once established, the inhabitant will always go back to this place when it needs to quarry
18. rocks – contains the amount of quarry an inhabitant was able to gather for the day. This value is equivalent to a certain amount of money at the end of the day.
19. timer – for a farmer or pondworker inhabitant, this serves as a countdown counter until it could harvest its farm or ponds, respectively
20. timer2 – another timer or counter used by a pondworker inhabitant to keep track of number of days it has been working. At day 30, it earns a salary and the value of timer2 resets to 0.

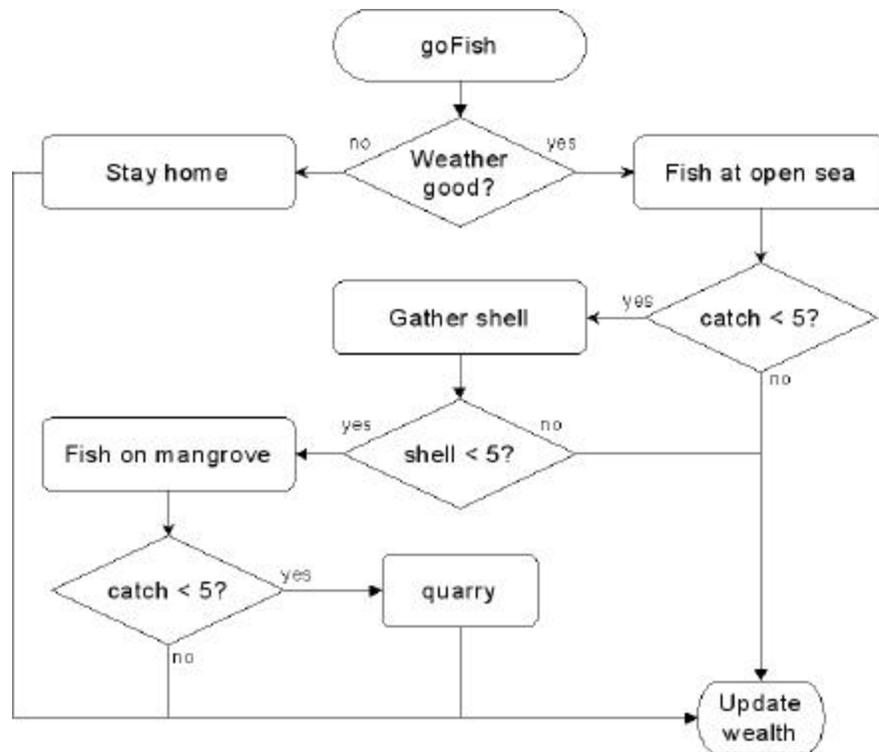


Figure 4.23 goFish Activity Diagram

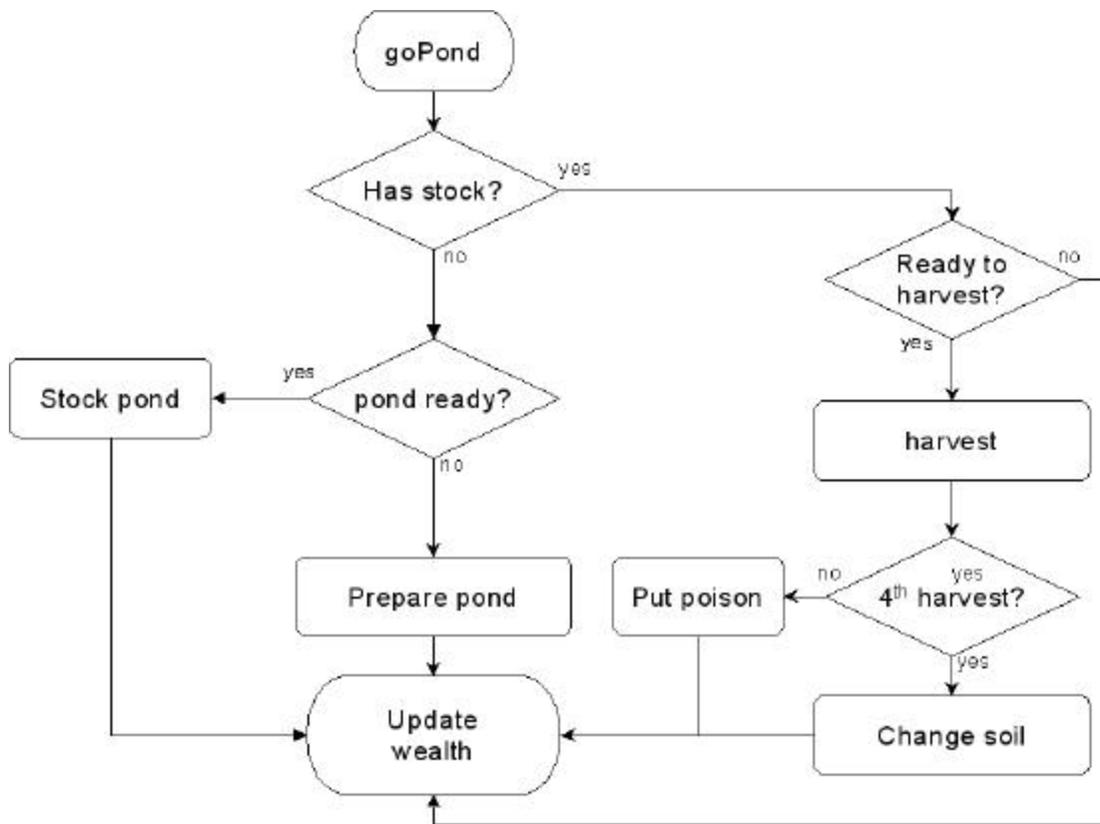


Figure 4.24 goPond Activity Diagram

- 2) In Cormas, the instances of a class of agents could be grouped together. The relationship between an agent and a group of agents is similar to that of a cell and an aggregate of cells. Three classes of groups were created based on the occupation of the inhabitant. These groups were basically used for initializing (or the starting state) the Bohol model and are not visible in the environment of the model. They are the following:
 1. BgyFarmer – this class is a simple group used to represent the group of farmers per barangay
 2. BgyFisherfolk – this class is a communicating group of agents that is used to represent the group of fishermen per barangay. It has a particular task or method wherein based on the complaints of its members, it will send a message, a FisherfolkComplaint, to the LGU.
 3. PondWorker – this class is a communicating group of agents that is used to represent the group of pond workers per group of fishponds. Although this contains no methods or tasks, this could be used for future scenarios by adding method/s or task/s.

- 3) LGU – The LGU agent is a communicating agent in the Bohol model and cannot be physically seen in the environment. It has two main methods, namely:
 1. declareUnprotected – is a method used only in certain scenarios wherein the LGU would “listen” or heed the complaints of the fishermen and grant access to protected areas. The model for this method was only assumed.
 2. mangroveReforestation – is also a method used only in certain scenarios wherein the LGU would plant mangroves on cells that are near other mangrove areas, and whose fish stock has gone below a certain level. Although the LGU of Loon is initiating mangrove reforestation, this method, in general, was only assumed.

- 4) Poison – Not all agents are human, in this case the Poison agent is a class of a situated agent that moves and affect its environment. The agents are created when pond workers harvest the fish and release poison in the sea. It has one attribute, which is “strength.” As it moves through the cells, its strength is reduced until it reaches zero and “dies.” At the same time, it reduces the amount of resources found in a cell. If the resource/s of a cell reaches a certain level, the cell’s state is changed. The behavior of the poison agent was assumed.

Passive Objects

- 1) Messages – Messages are objects in Cormas that allow communicating agents to “talk to each other.” We may view this as a conversation, e-mail, or