SIMULATIONS ON VIRTUAL WORLDS: UNDERSTANDING THE INTERACTIONS BETWEEN ECOLOGICAL AND SOCIAL DYNAMICS

SIMULATIONS SUR DES MONDES VIRTUELS : COMPRENDRE LES INTERACTIONS ENTRE LES DYNAMIQUES ECOLOGIQUES ET SOCIALES

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Résumé
Cet article présente un logiciel, appelé CORMAS, qui est une plate-forme générique dédiée à la construction de modèles concernant les modes d'appropriation des ressources renouvelables et les processus de prises de décision qui s'y rapportent. Les théories du développement soutenables se concentrent fréquemment sur l'articulation entre les dynamiques écologiques et sociales. CORMAS permet de construire et de faire tourner des modèles, qu'ils soient théoriques ou appliqués, qui abordent cette question. A un niveau d'abstraction important, les expériences de simulation permettent de révéler ou de mettre en exergue les conséquences des hypothèses de base (parfois intrinsèques) d'un modèle théorique. A un niveau plus appliqué et réaliste, le but recherché sera davantage prospectif. Pour illustrer cette voie, un modèle concernant la chasse dans les forêts de l'Est du Cameroun est décrit.

Abstract
This paper presents a software tool, named CORMAS, which is a generic platform to design models relative to the modes of appropriation of renewable resources by human groups and to the decision-making processes. Theories of sustainable development often focus on the interface between social and ecological dynamics. Either theoretical or applied models addressing this question may be built and run using CORMAS. At a high level of abstraction, the simulation experiments are useful to reveal or emphasize the consequences of the basic (and sometimes intrinsic) assumptions of a theoretical model. At a more applied and realistic level, the simulation experiments may be useful in a prospective way. To illustrate this last purpose, this paper presents a model that deals with hunting activities in an Eastern Cameroon forest village.

1. Introduction

The recent rise of powerful computing abilities for personal computers allows to build model of complex systems, and to conduct extensive simulation experiments to explore the consequences of several scenarios to be tested. In the field of natural and renewable resources modelling, the complex system is typically made of a spatially-explicit environmental layer (the territory, called in that context the "virtual world") on which the basic entities of the model interact.

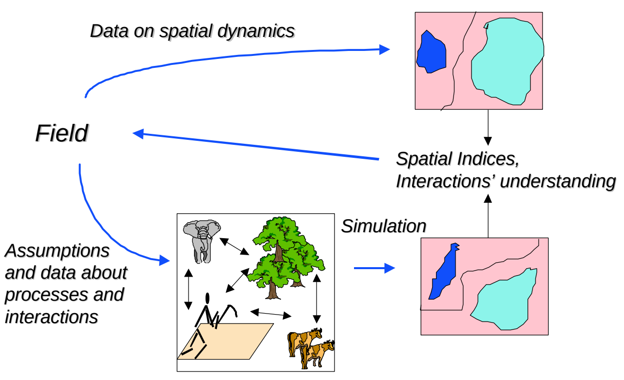

Figure 1. Simulations on virtual worlds: understanding how the interactions between the basic components of a system affect the landscape dynamics

This paper is based on a study held in an eastern Cameron forest village [1] in order to understand the viability of the game local population management. In an area without protected area the research try to understand how the resource is managed. The aim of the research is to elaborate a model in order to study the viability of this management scheme. The major hunted specie is the blue duiker (*Cephalophus monticola*). Surveys have been conducted to understand the hunting behaviour of the inhabitants. The resource is hunted six months/year and there is a spatial shifting rule. Each year each hunter changes the location of his traps. This behaviour is presented as a management rule by the hunters.
The hypothesis to test is that the rules regulating the access to space at different moments of the year can be considered as a management rule. Consequently, we need a spatial and dynamic simulation of the resource component.

2. Methods

First we present the principles of multi-agent systems (MAS). Then our multi-agent simulation platform named CORMAS [2] (Common-pool resource management and Multi-Agent Systems) is described. Using this generic tool, we have developed a model based on life-history of the blue-duiker and on hunting behaviour of the inhabitants. The individual-based model of the duiker integrates data from a Geographical Information System (GIS) in order to elaborate an artificial landscape similar to the village landscape.

2.1. Multi-Agent System

The knowledge modelling that we propose is based on the use of multi-agent systems [3]. In order to model complex phenomena multi-agent systems represent agents of the observed world and their behavior. Creating a multi-agent system means reproducing an artificial world resembling the observed world, in that it is made up of different actors, in order to conduct diverse experiments. Each agent is represented as a computerized independent entity capable of acting locally in response to stimuli or to communication with other agents.

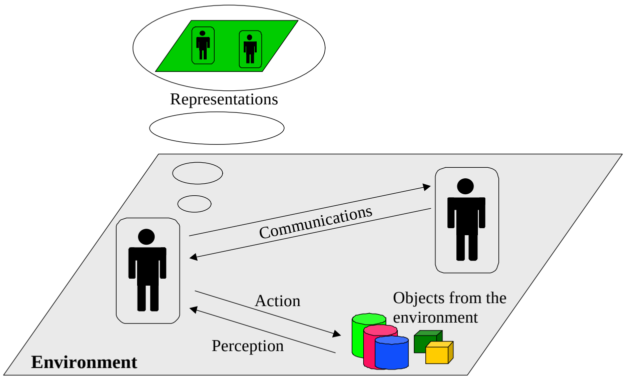

Figure 1: MAS general organisation (from [3])

When the aim is to solve distributed problems, we generally use "cognitive" agents with highly developed deliberation and internal control capacities. When we wish to simulate populations of agents, emphasis is generally placed on the notion of environment. We examine the relations between agents via their actions on the environment. Ecologists and social scientists are today contributing to the development of multi-agent simulation methods via a wide variety of applications and several methodological studies [4] [5]. The *Green* (Renewable Resource Management and Environment) research team is studying renewable resource management. To this end, it is seeking to understand the interactions between natural and social dynamics. To understand the complexity of these interactions, we use a simulation methodology which makes use of multi-agent systems. Models have been developed on the theme of irrigated land management in Senegal [6], fuelwood management [7], herd mobility in the Sahel [8] and potlatch type exchange structures [9]. In association with these various research projects, tools have been developed and a modelling approach has been proposed [10]. To bring these tools together, we have developed a simulation environment called *Cormas* [2] (Common-pool resources and multi-agent system).

2.2. The CORMAS platform

The Cormas platform has been developed to propose a multi-agent framework dedicated to the interactions between a group of agents and a shared environment. It aims at simplifying the task of resource management simulation. This environment was built using VisualWorks software. It uses and proposes SmallTalk as a development language.
Using the properties and facilities of object-oriented programming, Cormas provides pre-defined generic entities from which the specific agents of any model built with this software have to inherit.
The upper part of main interface (see figure 2) shows the modelling area. The first step of the modelling process is to specify the entities. In the blue duiker model, there are 3 classes of agents. The basic spatial entity, named "*Cellule_Djemiong*", inherits from the pre-defined generic entity "*Patch*". Both "*Chasseur*" and "*Cephalophe*" agents inherit from "*AgentSitue*" the generic methods specific to the situated entities. Once the characteristics (attributes) and the behaviour (methods) of each single entity have been designed, the second step of the modelling process consists in specifying the time dynamics of interactions between these entities. This poses scheduling problems. For this reason, in the case of simulations, we isolate the control part of the dynamics. It is as important for the modeller to define the control as it is to define the behaviour of agents. Indeed, the different types of control determine the sensitivity of simulations. Additionally, some specific simulation tools are available to run the model

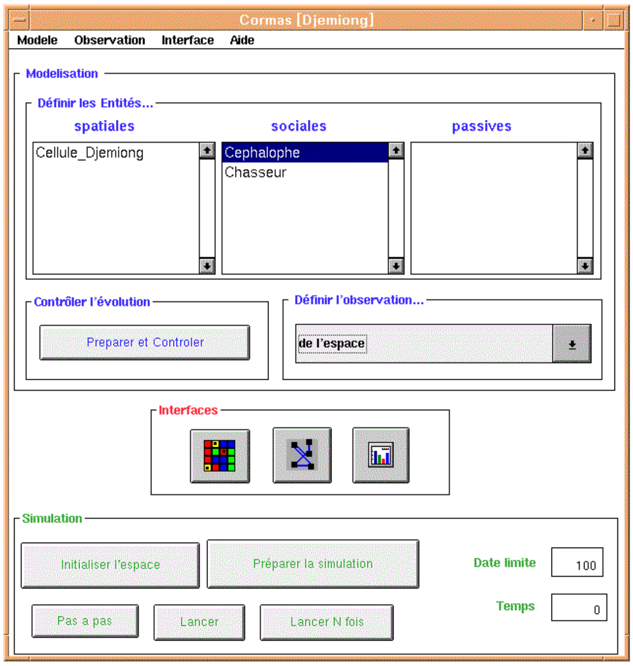

Figure 2: Cormas main interface

2.3. The blue duiker model

We have elaborated an artificial landscape similar to the Djemiong landscape. The limits of the village have been defined on map with the inhabitants. Some data have been digitalized with a GIS. The spatial resolution is three hectares, because this is the averaged area of the blue duiker habitat. The roads, the rivers and the hunting localities are the three layers of the GIS. We have used the IDRISI software. The GIS exports Ascii data. A file is created for each layer reporting the information on each cell. Then the Cormas platform imports these data. The patch has an attribute for each layer : water (yes/no), road (yes/no), hunting locality (number from 1 to 29), see figure 3 and 4.
This artificial landscape is used to simulate the artificial population of blue duiker taking into account that the blue duiker will not install its territory near the water nor the roads.
Several data has been collected to simulate the life history of the blue duiker. Most of the knowledge has been obtained from the work of Dubost [11][12][13]. The animal lives in a three hectares territory. The mortality of the young is 30% for the first 40 weeks. At the age of 18 months for the female and 24 months for the male, the young leave the parental territory. When a young adult male meets a young female they look for a territory to establish. After reproduction, the duration of the gestation is 13 months. The blue duiker has a life expectancy of seven years.
A duiker agent has been created. Its attributes are the age, the sex, the duration of gestation and the partner. The behaviour of the blue duiker is implemented through one method that uses the above life-history parameters to define, with a weekly time-step, the growth, mortality, and reproduction functions.

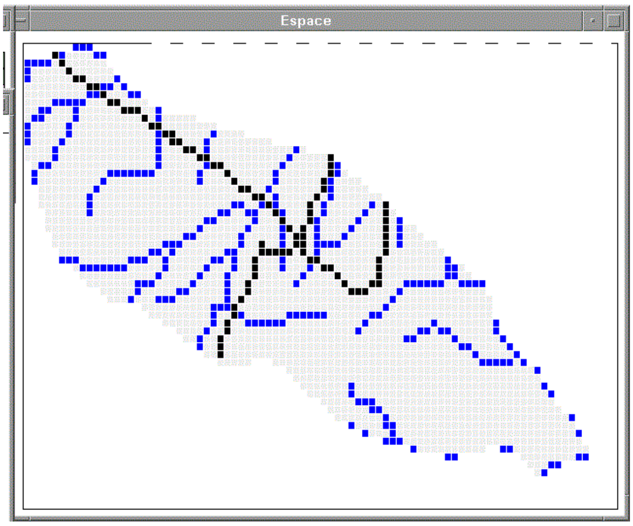

Figure 3: water (dark blue) and road (black) patches' attributes of the Djemiong artificial landscape.

A survey was held on the village to know where the hunters have been harvesting for the last eleven years. This spatial information has been reported by refering to 29 hunting localities (see figure 4).

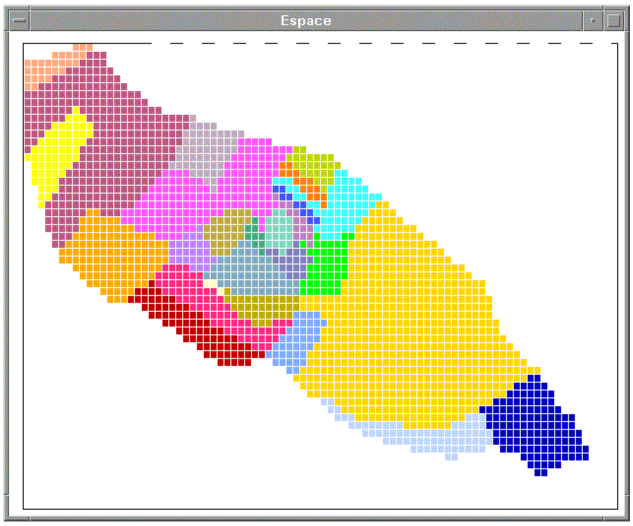

Figure 4: locality patches' attribute of the Djemiong artificial landscape.

Each hunter puts traps in the forest along a path. The path covers an area which can be estimated in a range from 25 hectares to 100 hectares. In the model, we have considered that a path composed of 30 traps covers a 24 hectares area. It means that 8 patches are concerned. The probability for a duiker located in a hunted patch to be caught defines the capturability parameter. Its value has been set to 0.025.

3. First experiments and preliminary results

The main goal of this model is to test the long-term viability of the management by reproducing the behaviour of the hunters. A hunter agent has been created. Its behaviour is very simple. At each hunting season (every 26 time steps, to account for a six months hunting season), each hunter agent chooses a hunting locality to puts his traps. Within the locality, 8 neighbouring patches are selected and marked as hunted (their "hunting pressure" parameter is set to "true", and they appear red-coloured, see figure 5) during six months. At the end of the hunting season, the "hunting pressure" parameter is reset to "false" for every patch of the spatial grid, and the duikers population evolve during six months (26 time-steps) without suffering an additional mortality due to the hunting activity.

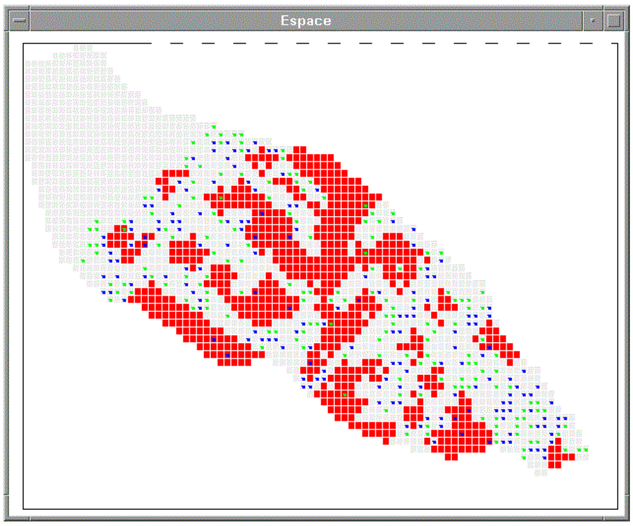

Figure 5: snapshot of the spatial grid during a hunting season. The duiker agents (female are green coloured, male blue) passing through a red (hunted) cell encounter an additional mortality.

To examine model behaviour the following steps were taken. To calibrate the population dynamics of the model, we simulate during 100 years the evolution of the system without any hunting activity. 10 different values (randomly chosen) of initial population abundance have been tested. The results (see figure 6) suggest that the model converges with damping oscillations to a steady state of approximately 70 animals per km^2. This is an important result because this is the density observed in the non hunted forest of the region. Thus, by simulating the behaviour and the interactions of the animals at a microscopic scale we observe a population property at a global scale. This constitute an empirical validation of our individual-based model.

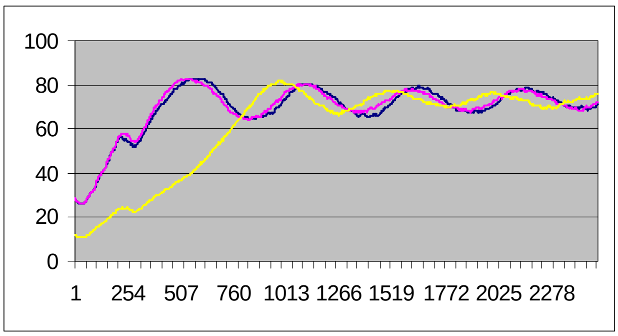

Figure 6. 10 runs of the model without hunting activity, random initial population abundance. X-axis is the time-steps (in week), Y-axis represents the population density (number of animals per km^2)

A second set a simulation experiments uses the hunting data relative to 1995 collected on the field [1]. 90 hunting actions have been reported with the corresponding hunting locality. Applying the procedure described above, each hunting action generates a set of 8 patches to be switched to a "hunted" state. If the space available in a given hunting locality is not sufficient (its total number of patches is less then 8 x the number of hunting actions reported), we just switch all the patches of the hunting locality to the "hunted" state, assuming that the size of hunting actions are smaller in intensively exploited localities. The same data and the same spatial repartition procedure have been used repeatedly 50 times. The results (total population abundance in figure 7 and total catches in figure 8) of ten runs show that there is an important decrease of the population due to the hunting activity. After 50 years (2600 time-steps), the total density has gone down 10 animals per km^2

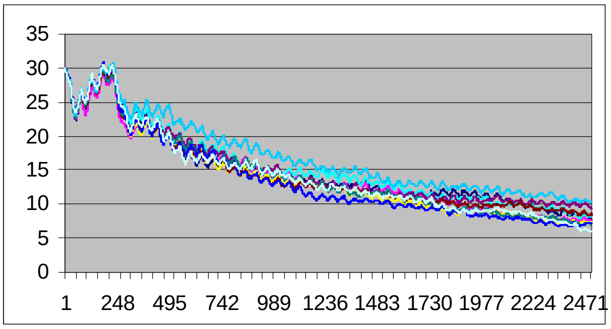

Figure 7: total population abundance under the repeated 1995 scenario (10 runs)

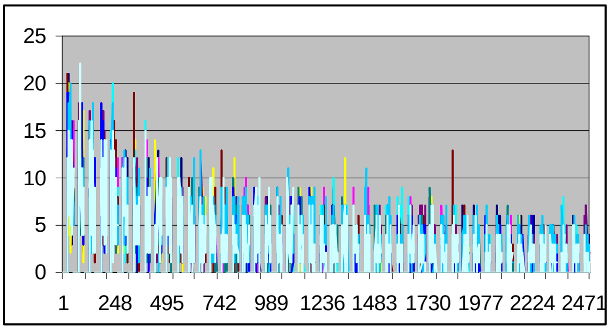

Figure 8: total catches under the repeated 1995 scenario (10 runs)

The catches also progressively decrease from a maximum of 20 animals trapped during the first week of the first hunting seasons down to 5 animals at the beginning of the last hunting seasons, after 50 years.
To illustrate the kind of scenarios that are able to be tested using the model, we simulate now the effect of a protected area in the north of the Djemiong village territory. To allow the comparisons with the previous experiment, we just move the hunting actions reported on the northern localities to the southern one, concentrating the hunting pressure in this area. Because the northern localities are in average smaller than the southern, the outcome of the location of the 90 hunting actions into the spatial grid was in the first case that 34.4% of the space was hunted, as in the second case (protected area), this ratio reaches 39.2%. Even in this more intensive (at a global scale) context, the results (total population abundance in figure 9 and total catches in figure 10) of ten similar runs show that the decrease of the population due to the hunting activity is much less important. After only 5 years (260 time-steps), the global density becomes stabilized around a value of 23 animals per km^2. In terms of catches, the result is similar: after about 5 years, an equilibrium is reached: a maximum of 10 animals are trapped during the first week of the hunting seasons. It is interesting to note that the catches and the abundances of the population vary with the same intensity from one experiment to the other: they have both doubled. It was far less intuitive for the catches. These results are aggregated at a global level, and obviously in the second experiment, there is a great inequality between the hunters: the more favoured are the one who put their traps in the hunting localities at the boundary with the protected area.

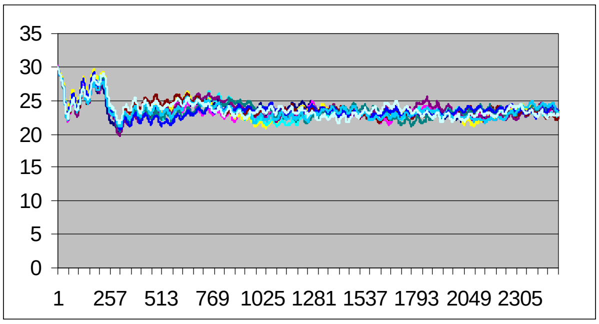

Figure 9: total population abundance under the protected area scenario (10 runs)

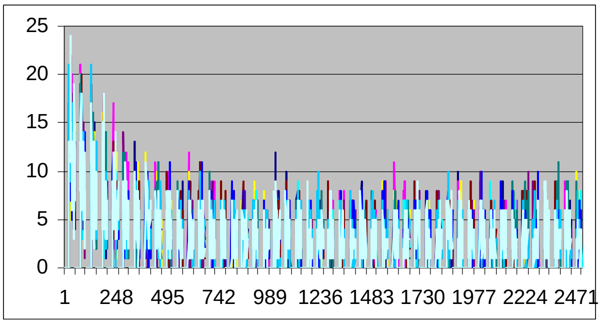

Figure 10: total catches under the protected area scenario (10 runs)

The experiments described here point out the crucial influence of the spatial dimension. The classical models of exploited population dynamics (for example in fishery science) often do not take into account this aspect, and incorporate as input parameters data on global catching effort. Cormas allows to build spatially-explicit models in a flexible way. The second advantage of multi-agent models relies on the possibility to define agents with adaptive behaviour. In the previous experiments, the hunter agents are extremely schematic: from a season to another, they go back to the same hunting locality. A stimulating direction of research that we are currently exploring concerns the addition of autonomous decision-making processes to the hunter agents. Our goal is to test various modes of coordination between then versus the "null hypothesis": no coordination at all.

4. Discussion

The African wild fauna constitutes a vital source of dietary protein for the local human inhabitants. Since the beginning of the century protected areas have been presented as an appropriate management system to preserve the resource. The major problem of this management system lies in the existence of local populations who are consequently excluded from an environment exploited for years. This environment has a role for the alimentation, the economy and has also a socio-cultural role. Conflicts are emerging in some parts of the world. Protected areas authorities try to preserve the resource from depletion and apply sanctions. Local populations carry on a traditional activity which became illegal. After the era of preservation we are living the era of conservation/participation. Participatory projects try to link a viable management of the resources and the local development (integrated conservation-development projects). Rather than indicating the "right way" to preserve the resources, the participatory approach should facilitate the coordination of actors through a shared decision-making process [15].
It is not always a natural way for a scientist impregnated with the prejudices of its own culture to try to identify in

the local and customary organisation of resources exploitation some rules that deal with resources management. On the other hand, it is not always easy for a manager to explain the reasons of its management choices to the local people and to reach their agreement. The patrimonial approach relies on the principle that each party involved in the exploitation of the natural resource can negotiate its own future. This fact stresses the importance of the communication. A first point is to find a practical common language that can be used to express the different viewpoints. To go a bit further, one need to have a tool that allows to compare the potential consequences of these different viewpoints. Something that could help to demonstrate to the others the usefulness of a proposal. Most often, mathematical equations would not constitute an appropriate medium. Our idea is to test the relevance of MAS in the context of patrimonial approaches. Such models offer the possibility to build a shared representation of the system, and then to test several scenarios collectively designed.

We need to define a methodology to insure that the model is perceived by every party as an acceptable common representation of the system. Because the screen of a computer displaying small dots moving around a spatial grid made of coloured cells may appear quite as far from the reality as a mathematical equation, we suggest to test the social validation (the people who are represented by agents in the model recognise its relevance) of the MAS in an intermediate step. Instead of showing demonstrations with the computer, we propose to organise a role-playing game session and to let the people play a given role (defined as the translation of the corresponding agent in the MAS). This methodology is currently tested in the context of a study of irrigated systems in Senegal [16]. The first results are promising.

The ultimate step would be to use the MAS, once it has been accepted as a legitimated tool, as a helpful guideline during the negotiation process. This acceptation should come from the comparison between a run of the model and the final situation of the role-playing game.

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