A spatially-explicit individual-based model
of blue duikers population dynamics
Multi-agent simulations of bushmeat hunting
in an eastern cameroonian village

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Abstract

This paper is based on a study about the bushmeat hunting of a small antelope held in an eastern cameroonian forest village (Djemiong). This study aims at understanding how the organization of the hunting activity between the villagers may constitute a management scheme. The major hunted species is the blue duiker (*Cephalophus monticola* Thunberg). 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. A spatially-explicit individual-based model is used to compare several rules of traps' locations in space and time. The knowledge modelling that we propose is based on the use of multi-agent systems. 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. Cormas (Common-pool resources and multi-agents systems), a generic simulation environment based on Smalltalk, allows to build spatially-explicit individual-based models in a flexible way. Using this multi-agent simulation software, a model based on life-history of the blue-duiker and on hunting behaviour of the inhabitants has been built. This model integrates data from a Geographical Information System (GIS) in order to elaborate an artificial landscape similar to the village landscape. The results stress the importance of the coordination between the hunters, in particular with the appropriation of traps paths by familial networks of villagers. It seems that the spatial location of the traps has a crucial influence on the model, far more than the global hunting pressure, and also the duration of the non-hunting season.

Key-words
Bushmeat hunting, multi-agent system, population viability analysis, spatially explicit individual-based model

Introduction

The African wild fauna is among the most lush and most various of the world. Although used everywhere and from time immemorial, the wild fauna is rarely considered as a consumable resource. Its importance is often reduced to a great tourist appeal (Chardonnet 1995). Yet hunting of wild animals provide meat for the family, and as a source of income is a common component of household economies in the sub-Saharan Africa. This is not only true for people who are "hunter-gatherers", but also for so-called "agriculturalists", who use only wild resources to complement their crops and domestic productions, particularly to bridge the usual gap in production between two crops (Chardonnet, Fritz et al. 1995). Although on a small scale, traditional bushmeat hunting by agriculturalists is then essential in several African countries (Bissonette and Krausman 1995).

This paper is based on a study held in an eastern cameroonian forest village named Djemiong. In an area without any protected area, the challenge is 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*, Thunberg). Surveys have been conducted to understand the hunting behaviour of the inhabitants (Takforyan 1996).

To estimate the impact of bushmeat hunting on wildlife populations, scientists need information on the harvest rates of bushmeat species and also on the maximum possible production per unit area of forest. Mathematical models are traditionally used for wildlife resource management issues (Robinson and Redford 1994). As the purpose is to compare the ecological production with an estimated harvest, this kind of models require estimates of reproductive productivity and population density. The conclusions of the studies are often alarming (Robinson and Bodmer 1999). But in the conditions prevailing in tropical forests, estimating both existing hunting yields and maximum sustainable harvest rates presents considerable difficulties (Inamdar, Brown et al. 1999). In Cameroon, for example, the blue duikers' harvest rates have been reported as up to about 25 times greater than estimated sustainable levels, yet the off-take continues more or less unabated...

Beissinger and Westphal (Beissinger and Westphal 1998) have recently reviewed the structure, data requirements, and outputs of analytical, deterministic single-population, stochastic single population, metapopulation, and spatially explicit models used in population viability analysis. Among this wide range of models, the choice of the most appropriate will depend on the question addressed by the study.

In the Djemiong village, 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. Can the rules regulating the access to space at different moments of the year be considered as a management rule ? This is the key-question of this study. Consequently, we need a spatial and dynamic simulation of the resource component, but we also need to take into account the behaviour of the hunters, the way they interact when they decide to locate their traps on the village's territory.

A spatially-explicit individual-based model seems suitable to handle the spatial and dynamic simulation of the resource component. To tackle the problem of coordination between the hunters, we will rather refer to Multi-Agent Systems (MAS). MAS, a computer formalism coming from the field of Distributed Artificial Intelligence, are mainly devoted to the study of interactions between the basic components of a system. As a tool to build simulation models allowing to track the movement, the mortality, and the reproduction of each computer entity on the artificial landscape (the spatial grid), MAS are very similar to spatially-explicit individual-based models.

Methods

First we present the principles of MAS. Then our multi-agent simulation platform named CORMAS (Bousquet, Bakam et al. 1998) (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.

Multi-Agent Systems

The knowledge modelling that we propose is based on the use of multi-agent systems (MAS)(Ferber 1999). 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. Multi-agent systems offer a methodology and efficient tools to implement individual-based models. Lorek and Sonnenschein, who did a survey on software platforms to implement individual-based models (Lorek and Sonnenschein 1999) have counted Swarm (Minar, Burkhart et al. 1996) among them. Swarm is a software to design and implement distributed systems has been used for various applications in ecology: Arborgames (Savage and Bell) for forest dynamics, Bacsim (Kreft, Booth et al. 1998) for microbiology for instance. In the field of computer science the objective of the research is to propose organisations of intelligent agents to solve complex problems or simulate complex systems. Therefore, the main purposes of MAS research are firstly to build architectures for intelligent agents and secondly to design organisation of interacting agents to accomplish a task. MAS are useful for bottom-up simulations on the one hand to model complex decision making process for "cognitive" agents with highly developed deliberation and internal control capacities on the other hand to simulate organisation of agents.
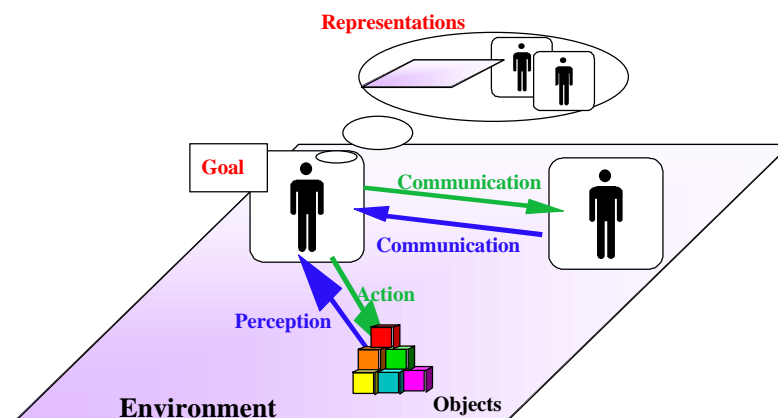

Figure 1. MAS general organisation and principles (from Ferber, 1999)

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 (Villa 1992; Congleton, Pearce et al. 1997) (Weiss 1999). 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 (Barreteau and Bousquet in

press), herd mobility in the Sahel (Bousquet, D'Aquino et al. 1999). In association with these various research projects, tools have been developed and a modelling approach has been proposed (Bousquet, Barreteau et al. 1999). To bring these tools together, we have developed a simulation environment called Cormas (Bousquet, Bakam et al. 1998) (Common-pool resources and multi-agent system).

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 the 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 "`Djemiong_Cell`", inherits from the pre-defined generic entity "`Patch`". Both "`Hunter`" and "`Duiker`" agents inherit from "`LocatedAgent`" 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
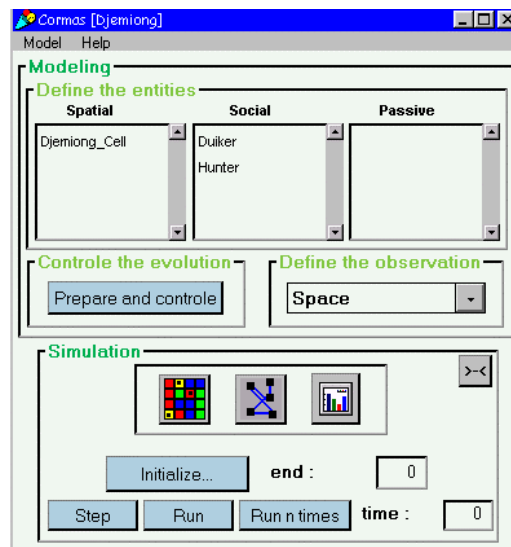
Figure 2. Cormas main interface. The Djemiong model is loaded: the elementary component of the spatial grid, named `Djemiong_cell`, and two agents, the `duiker` agent and the `hunter` agent, constitute the entities of the system.

The blue duiker model

The artificial landscape

We have elaborated an artificial landscape similar to the Djemiong village territory. The limits of the village have been defined on map with the inhabitants. Some data have been digitalized with a Geographical Information System (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. 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) (see figure 3), and the hunting localities (see figure 6).

Figure 3. The Djemiong artificial landscape. Each cell in light gray represents a 3 ha area, which is the territory's size for adult duikers. Cells with water are in dark gray, cells with road are in black. The small dots in dark gray are adult duikers with partner, the small white dots are juveniles or alone adults.

The population dynamics model

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 (Dubost 1980) (Dubost 1983) (Dubost 1983). Blue duikers are territorial animals: once they become mature and find a partner, they establish a territory and will stay in that place for the rest of their live. The average size of this territory is 3 ha, which has been set as the spatial resolution of the model: each cell of the spatial grid (figure 3) represents a 3 ha area.
A duiker agent has been created. Its attributes are the age, the sex, the gestation length 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, and also some rules for the movements (see table 1 the model's parameters).

Growth
As the time-step of the model is the week, all the temporal attributes or parameters are expressed in number of weeks. Thus at each time-step of the model, the age of each duiker agent is simply increased by one.

Mortality
About the natural mortality of the blue duiker, we know that the mortality of the young is 30% for the first 40 weeks. A basic convertion of this cohort's survival rate into a weekly natural mortality probability (M_y) stands as follow:
$$M_y = 1 - 0.7^{1/40}$$

Parameter	Condition	Value	Reference
Cell area (territory size)		3 ha	Dubost : 211 ;215
Weekly natural mortality probability			
M_y (young individuals)	$age \in [0\,;40]$	$1-0.7^{1/40}$	Dubost : 249
M_a (adult individuals)	$age \in [41\,;240]$	$1-0.95^{1/200}$	Chardonnet, 1995
M_o (old individuals)	$age > 240$	$1-0.01^{1/100}$	
Weekly hunting mortality probability	trapped patch	0.15	
Age of maturity	male	95 weeks	Chardonnet, 1995
	female	72 weeks	
Gestation length	female	30 weeks	Chardonnet, 1995
Parental care period		21 weeks	Empirical value for calibration
Hunted area by a traps path		12 or 36 ha i.e. 4 or 12 cells	Donniers : 294

Table 1. Model's parameters

This parameter applies to newborn individuals ($age < 40$). In the same way, two other natural mortality parameters have been set for adult individuals ($40 <= age < 240$), and old individuals ($age >= 240$). The threshold of 240 weeks corresponds to the fact that the blue duiker has a life expectancy of 6 years. To account for a cohort's survival rate of only 1% for old individuals, between age 240 and age 340, the corresponding weekly natural mortality probability (M_o) is equal to:

$$M_o = 1 - 0.01^{1/100}$$

In the interval, we assume that the natural mortality is low: 95% of a cohort of 40 weeks old animals reach the age of 240 weeks:

$$M_a = 1 - 0.95^{1/200}$$

Movement
At the age of 72 weeks for the female and 95 weeks for the male, a juvenile duiker becomes mature. It leaves the parental territory and looks for a partner to establish a new territory. Blue duikers are faithful: a couple of animals stays together at the same place until the death of one of them. Thus in the model, the movements only concern mature and lonely duiker agents.
The perception range of a duiker agent is defined as a 3-order recursive function based on the 4-connex neighbourhood of the cell where it is located (see figure 4).
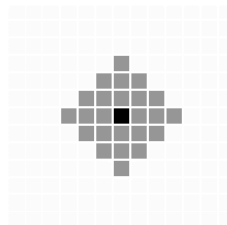
Figure 4. The *duiker* agent's perception range. A 3-order recursive function based on the 4-connex neighbourhood of the cell where it is located determines a collection of 25 cells. As the squared cells of the grid represent 3 ha, and the time-step of the model is the week, it corresponds to a weekly exploration within a radius of 600 meters from the duiker's location.

During a weekly time-step, a duiker agent is able to visit any of the 25 cells composing this area. the When a lonely adult male meets a lonely mature female, they look for a suitable cell in their common perception range to settle. The suitability is defined as follow: this new place should be empty (no other duiker agents), without water and without road.

When the research of a partner and a suitable territory remains unsuccessful, mature and lonely duiker agents just choose a destination randomly among empty cells (without any other duiker agent) of their perception range. These rules, synthetized in figure 5, lead to spatial distributions of the duiker agents like the one displayed in figure 3.
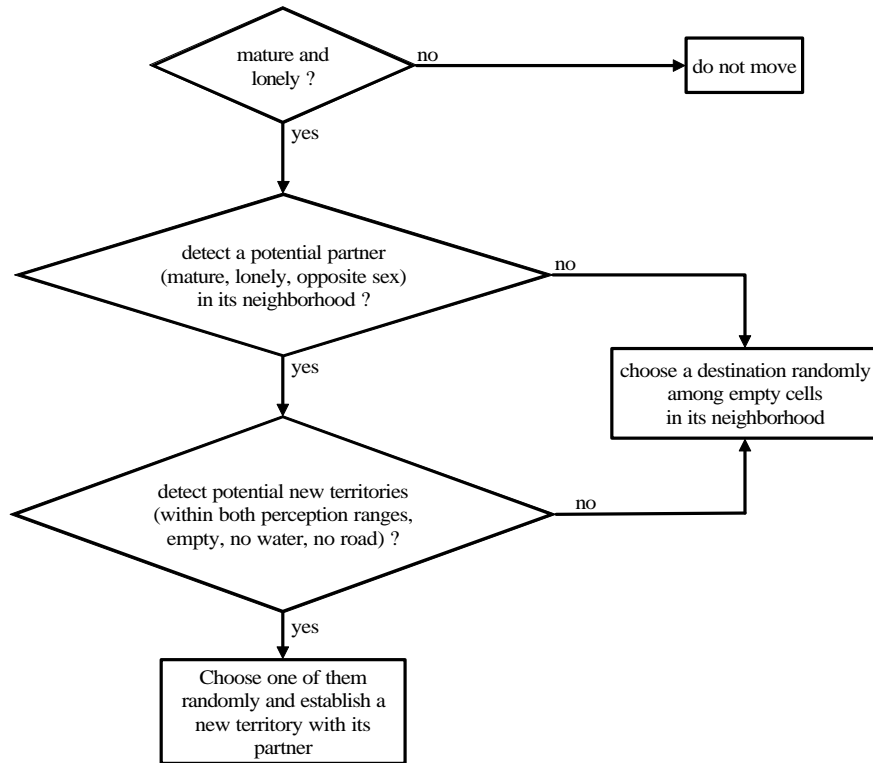

Figure 5. Flow chart for the duiker's movement. The migratory behaviour of the duiker's agent is then simply a combination of "if condition then statement1 else statement2" elements.

Reproduction

A female duiker agent becomes gravid as soon as it finds a partner and establish a territory. After a 30 weeks gestation length, a newborn duiker agent is created. It will stay in its parents' territory until its maturity. The female duiker agent can not be fertilized again until its young reaches the age of 21 weeks. This parameter, defined in the model as a parental care period, has been estimated to calibrate the model so that the average interval between two successive births is about 13 months, which is a value found in the literature.

The simulation of this biological and ethological model will constitute the preliminary experiment of the next session.

The hunting model

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 referring to 29 hunting localities (see figure 6 and table 2).
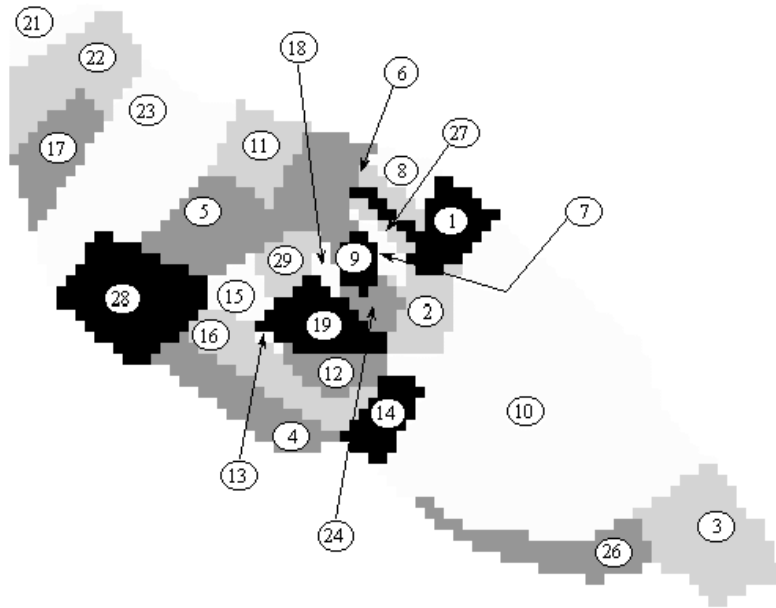
Figure 6. The 27 hunting localities of the Djemiong village, identified by a number. Table 2 gives some characteristics. In the upper part of the map, the localities 17, 21, 22 and 23 have not been surveyed, then they will not be considered in the model.

Hunting locality's number	Total cells' number	Total territories' number (no water, no road)	Maximum traps' path size (number of cells)
1	59	48	12
2	44	31	12
3	117	106	12
4	71	59	4
5	159	142	12
6	15	12	4
7	14	10	4
8	25	16	4
9	19	11	4
10	596	522	12
11	55	44	12
12	33	24	12
13	3	3	4
14	39	35	12
15	26	18	4
16	71	54	4
18	9	5	4
19	58	45	4
24	19	10	4
26	71	60	12
27	10	7	4
28	116	96	12
29	29	24	4
Total	1658	1382	

Table 2. The Djemiong village's hunting localities

In the Djemiong village, the hunting activity only occurs during the gap in production between two agricultural seasons. In the model, each year, there will be a 26 weeks agricultural season, during which the traps are removed from the space, followed by a 26 weeks hunting season. During the hunting season, 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. If we work with the low hypothesis, in the model, a traps' path should then be distributed among 8 cells (3 x 8 ha). In fact, the results of the field survey suggest that there are two kinds of hunting localities. The hunting localities 1, 2, 3, 5, 10, 11, 12, 14, 26 and 28 (see figure 6) are the more faraway from the village and also the larger one (see table 2). They are mainly used as hunting areas, and in average more heavily hunted than the other one, closer to the village (located at the roads' cross, near the locality 9, see figures 3 and 6), that are used for agriculture during 6 months. To account for this heterogeneity, the traps' paths will be distributed among 12 cells in the larger hunting localities, and only among 4 cells in the smaller one (see table 2).

The probability for a duiker located in a hunted patch to be caught defines the capturability parameter. Its value has been set to 0.15, and will be used as an additional weekly mortality probability denoted **H**.

Overall Djemiong model

A general flowchart (figure 7) shows how the hunting activity is added to the biological model. The grey boxes represent steps that are affected by this addition. Apart the steps where the traps are located and removed, which constitute the hunting model, the initialisation of the duikers agents' population that will be hunted is made from a structured and stabilized population obtained by running the biological model during 100 years. Obviously, the mortality function is also affected by the hunting activity, by the way of an additional mortality probability.

Experiments

The objective of the model is to provide insights into the analysis of this feature: what is the influence of the way the traps' paths are located during each hunting season on the population viability but also on the level of catches ? The following simulation experiments' plan has been designed.

Preliminary experiment: the blue duiker's population dynamics model

To calibrate the population dynamics model, we simulate during 5000 weeks (nearly 100 years) the evolution of the system without any hunting activity. 10 different values (randomly chosen) of initial population abundance have been tested. According to this value, duikers agents are created by assigning their sex with a ratio 1, their age randomly between 0 and 80 weeks, and their location randomly within the spatial grid.
From this initial experiment, after the 5000 weeks, the population of duikers agents is recorded. It will be used as a starting point for all the experiments with hunting activities.

First set of experiments: repeating the 1995 hunting's data

The field survey's data report 90 hunting actions with the corresponding hunting locality for year 1995. This hunting pressure will be the standard one in the model: each hunting action will generate a set of either 4 or 12 cells to be switched to a "hunted" state. If the space available in a given hunting locality is not sufficient (i.e., its total number of cells is less than 4 or 12 times the number of hunting actions reported), we just switch all the cells of the hunting locality to the "hunted" state.
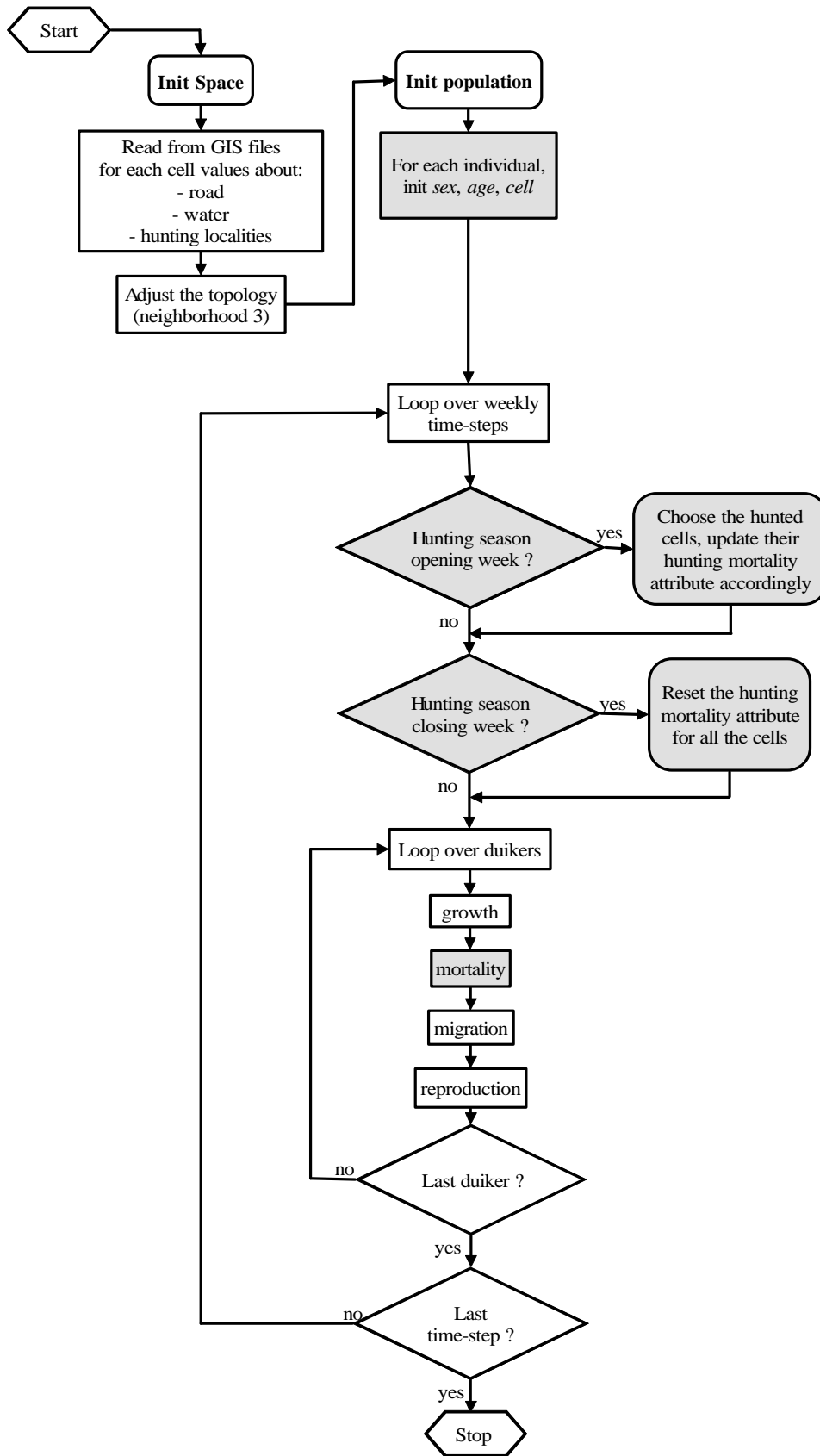
```
                 ┌─────────┐
        Start ───┤Init Space│          ┌──────────────┐
                 └────┬─────┘          │Init population│
                      │                └──────┬───────┘
        ┌─────────────┴──────────┐    ┌───────┴────────┐
        │  Read from GIS files    │    │ For each individual,│
        │ for each cell values about:│  │ init sex, age, cell │
        │       - road            │    └────────┬───────┘
        │       - water           │
        │  - hunting localities   │
        └─────────────┬──────────┘
        ┌─────────────┴──────────┐
        │  Adjust the topology    │
        │   (neighborhood 3)      │
        └────────────────────────┘
```

Choose the hunted cells, update their hunting mortality attribute accordingly

Loop over weekly time-steps

Hunting season opening week ?   yes   no

Hunting season closing week ?   yes   no

Reset the hunting mortality attribute for all the cells

Loop over duikers

growth

mortality

migration

reproduction

Last duiker ?   no   yes

Last time-step ?   no   yes

Stop

Figure 7. The Djemiong model's overall flowchart.

We will begin to use the model to test the influence of the hunting activity's periodicity. This feature is considered as a classical management tool. The first scenario, denoted R1, will continuously repeat the 1995 hunting data (see figure 8), as in the second one, denoted R2, the traps will be removed from the spatial grid every 26 weeks, and located again at the same place (figure 8) every six months. As this 6-months periodicity for the hunting activity corresponds to the reality of the Djemiong village, the next experiments will all include this feature.

Figure 8. Locations of the traps' paths on the model's spatial grid for experiments R1 and R2. The first layer, (slight grey), represents standard cells. The second layer is the presence of water (medium grey), the third one is the presence of road (in black), and the last one (dark grey) is the presence of traps.

In fact, we do not have any information about the precise location of a traps' path within a hunting locality. It seems reasonable to assume that the location remains the same each time a hunter decides to access a locality, as we did to define scenario R2. This interpretation let the data say more than they can, because the scale at which information from the survey is available does not fit the scale at which the hunting process is handled in the model, that was laid down by the ethological processes. To test the effect of this assumption, a third scenario (denoted R3) has been defined. It takes back the R2 scenario but at the beginning of the 6-months hunting season, each traps' path is randomly re-located within the same hunting locality.

The previous experiments are not very realistic, because the location of the traps always refer to the same data collected in 1995, whereas one of the main results of the field survey claims that the hunters avoid to choose the same hunting locality from one season to another. This feature is described as a way to preserve the resource. A second set of experiments deals with this feature, by integrating the hunters' behaviour into the model.

Second set of experiments: the traps' paths locations are decisions made by hunters agents

90 hunters agents have been created. Each one has a collection of 4 precise traps' paths, which is randomly initialized from a set of 4 hunting localities. The probability of a hunting locality to belong to this collection is based on its relative size (see table 2), so that the larger hunting localities will be used by more hunter agents than the smaller one. A first

scenario, denoted H1, states that a hunter agent chooses its current traps' path randomly among the 3 one he was not using during the previous season.
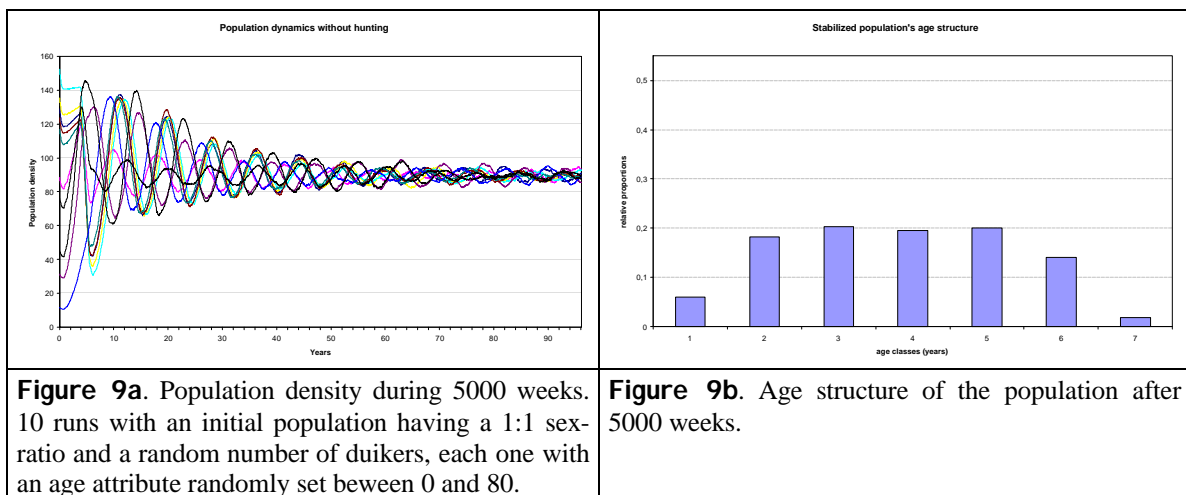
This scenario stands for individual turnovers without any coordination between the hunters. To account for such a process, a second experiment (H2) defines 30 groups of 3 hunter agents. The 4 precise traps' paths are assigned to these collective entities, that may represent kinship networks of hunters from the same family. The individual turnovers' rule also applies here, but with an additional constraint: a traps' path remains not hunted by any of the 3 group's members during 3 successive seasons.

Results

All the experiments have been run 10 times to test the robustness of the results.

Preliminary experiment: the blue duiker's population dynamics model

The results for population density (figure 9a) suggest that the model converges with damping oscillations to a steady state of approximately 90 animals per km2 (the 10 runs' average for the population density after 5000 weeks is equal to 89.53, the standard deviation is equal to 2.11).


Figure 9a. Population density during 5000 weeks. 10 runs with an initial population having a 1:1 sex-ratio and a random number of duikers, each one with an age attribute randomly set beween 0 and 80.

Figure 9b. Age structure of the population after 5000 weeks.

**Figure 9**. Evolution of the population without any hunting activity.

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. The oscillations are due to the random initialization of the population, particularly for the age, so that there is initially a very large cohort of youg duiker agents. Progressively, the age structure of the population will reach a steady-state equilibrium according to the 3 age-dependent natural mortality probabilities (see figure 9b).

Hunting experiments

The 5 hunting experiments have been run during 1300 weeks, i.e., 25 years. For all the experiments, the population density, the total number of cells trapped and the total catches have been recorded each week. For each scenario, a couple of charts shows the evolution of the population density and the evolution of the total catches (see figures 10 to 14).


Figure 10a. Evolution of the population density.   **Figure 10b**. Evolution of the catches
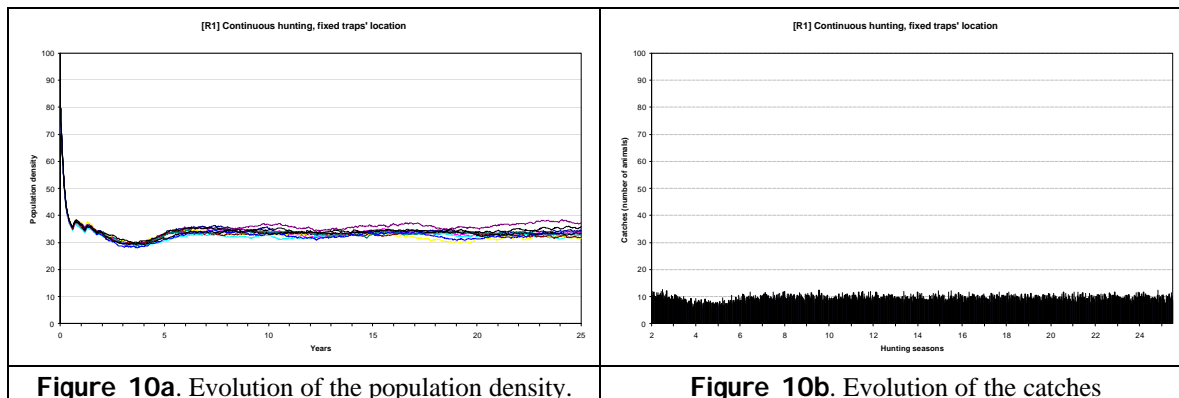
Figure 10. 1300 weeks of simulation with scenario R1: continuous hunting and fixed traps' location (see figure 8).

**Figure 11a**. Evolution of the population density.   **Figure 11b**. Evolution of the catches
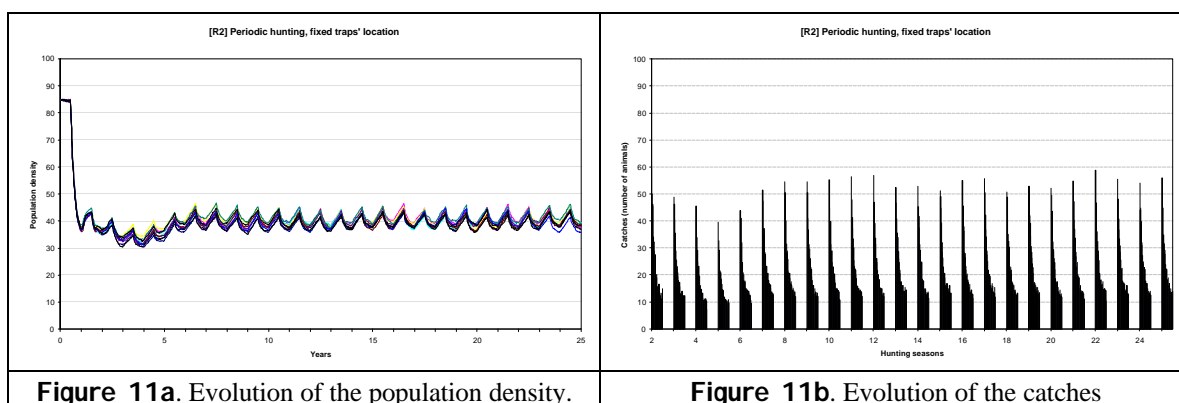
Figure 11. 1300 weeks of simulation with scenario R2: periodic (every 6 months) hunting with same traps' location (see figure 8).

Figure 12a. Evolution of the population density.   **Figure 12b**. Evolution of the catches
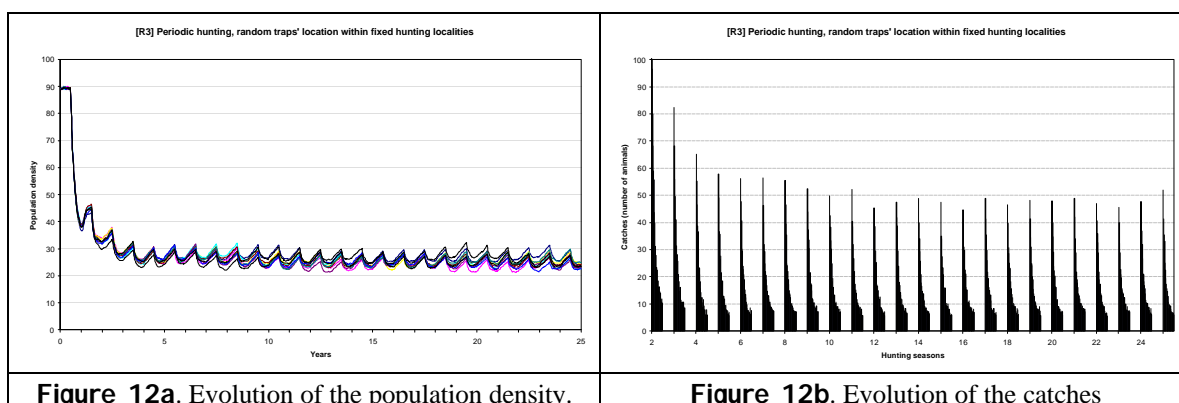
Figure 12. 1300 weeks of simulation with scenario R3: periodic (every 6 months) hunting, random traps' location within the hunting localities used in 1995.

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| **Figure 13a**. Evolution of the population density. | **Figure 13b**. Evolution of the catches |
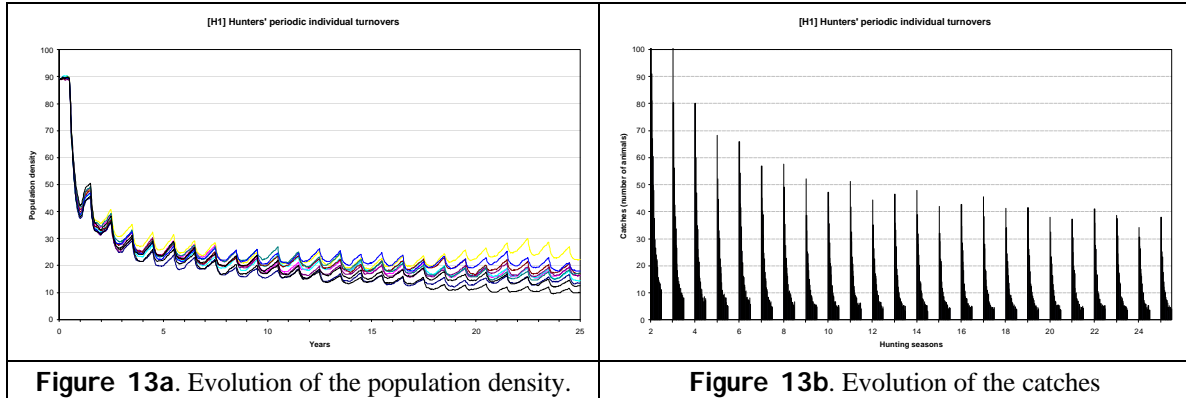
Figure 13. 1300 weeks of simulation with scenario H1: 90 hunters practising individual turnovers among a set of 4 given traps' paths.

| **Figure 14a**. Evolution of the population density. | **Figure 14b**. Evolution of the catches |
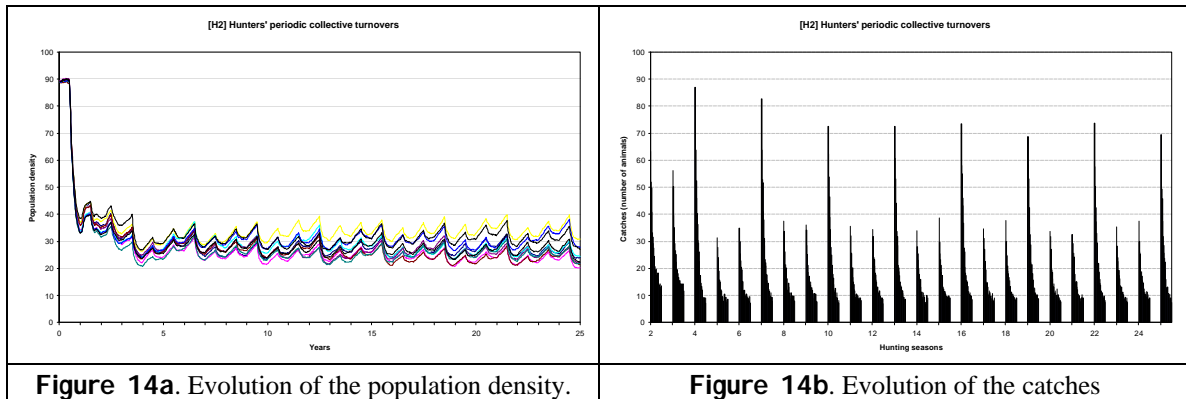
Figure 14. 1300 weeks of simulation with scenario H2: 30 groups of 3 hunters practising collective turnovers among a set of 4 given traps' paths.

The population density charts display the 10 curves, whereas the total catches chart display the weekly average values calculated from the corresponding 10 runs. The first hunting season has always a drastic effect on the population. This unusual event is not shown on the catches' charts to have an adapted scale for the Y-axis.

Some indicators are summarized in tables 3 and 4 (respectively for the first and second set of experiments). The first indicator is the hunting coverage, expressed in number of cells, that gives information about the global hunting pressure. The second one is the population density after 25 years, which gives information about the population's viability under each scenario. The last one is the total catches during the 25 years, which gives an idea of the efficiency of the several scenarios to provide bushmeat for the hunters.

For the first set of experiments, the global hunting pressure being equivalent for the 3 scenarios (table 3), the results show that the population decreases rapidly to a lower density in approximately 6 years, then reaches an equilibrium state which is stable for experiment R1 and periodic for R2 and R3 (figures 10a, 11a, 12a). This convergence passes through a minimum value which is lower than the equilibrium value for scenarios R1 and R2, whereas this is not the case for scenario R3. This is probably an artefact due to the fixed location of the traps, which is also visible on the catches' charts (figures 10b, 11b, 11c).
The impact of the hunting's periodicity is clearly shown by the comparison of the population density after 25 year, which is about 5 animals per Km^2 less for R1 than for R2, and also by the comparison of the total catches during 25 years (table 3).

It is interesting to compare this effect with the one due to the re-location of the traps' paths within the hunting localities (R3). The population density is here around 15 animals per Km^2 less for R3 than for R2. This result suggests that the spatial location of the traps is a much more sensitive feature than the temporal one. The impact on the catches is similar if we look at the global results (table 3). Going into the details of figures 11b and 12b, we can see that for both scenarios R2 and R3, the captures during the first weeks of the hunting seasons are about 50 animals, whereas during the last one, they go down to around 15 animals for R2 but less than 10 animals for R1.

Experiments	Hunting coverage (cells' number)	Population density after 25 years (number of animals / Km^2)	Total catches during 25 years (number of animals)
R1 – Continuous hunting, Fixed traps' location	722.9 (4.7)	33.64 (1.8)	14321.9 (405.7)
R2 – Periodic hunting, Fixed traps' location	718.6 (7.4)	38.20 (1.1)	16036.8 (346.5)
R3 - Periodic hunting, random traps' location within hunting localities	717.3 (9.2)[*]	23.62 (0.7)	13400.9 (219.6)

[*]Calculations based on 25 * 10 = 250 data

Table 3. Global results for the first set of experiments (repeated 1995 locations)

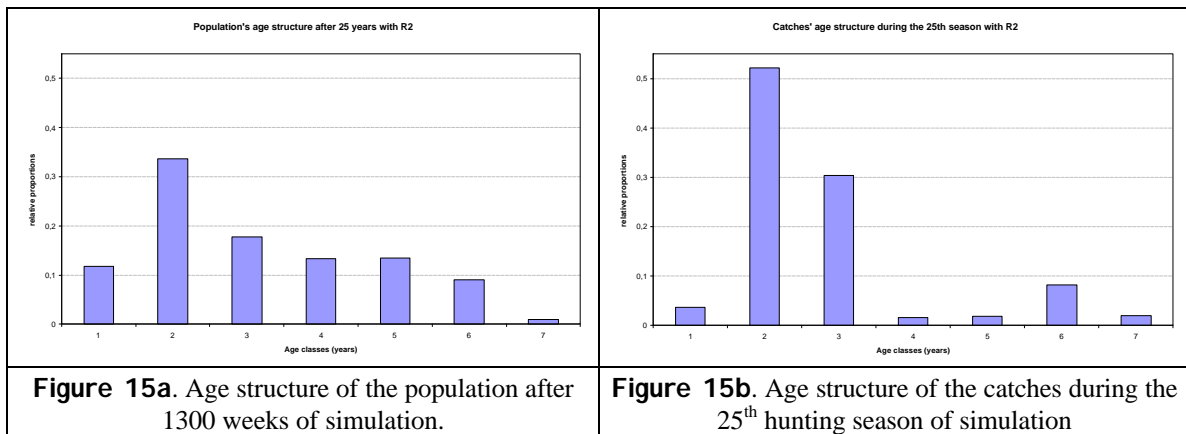| Experiments	Hunting coverage (cells' number)	Population density after 25 years (number of animals / Km^2)	Total catches during 25 years (number of animals)
H1 – Hunters' periodic individual turnovers	640.8 (28.4)[*]	15.77 (3.4)	12073.7 (766.1)
H2 – Hunters' periodic collective turnovers	747.2 (26.5)[*]	24.21 (3.4)	13970.3 (824.3)

[*]Calculations based on 25 * 10 = 250 data

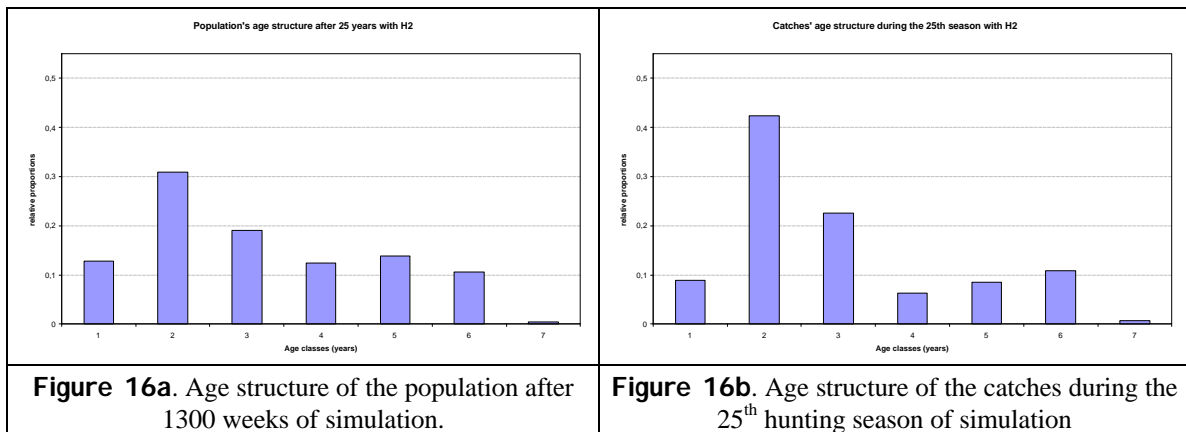**Table 4**. Global results for the second set of experiments (with hunters agents)

For the second set of experiment, we can see that the H1 scenario is the worse: after 25 years, the population (figure 13a) and the captures (figure 13b) are still decreasing. The low value for the hunting coverage (table 4) suggests that there is probably a problem of spatial congestion (90 * 4 = 360 individual traps' paths have to be defined, some of them should overlap, and then all the hunter agents could not access to their path if it is already occupied by others). There is probably another reason to explain the difference of about 9 animals per Km^2 with the population density of H2 (table 4). The lack of coordination between the hunter agents for scenario H1 should erase the effect of the individual turnovers. Figures 14a and 14b illustrate this positive impact of coordinated turovers' rules, with the artefact of the period-3 synchronized collective turnovers.

It may be surprising to note that the overall results of these two sets of experiments (table 3 and 4) show that the best scenario seems to be scenario R2, which is defined without any rotations of the traps' paths. Two remarks can be made. First, a look at figure 8 shows that in 1995, some hunting localities were unused: with the R2 scenario, they act as a hunting preserve. In the H2 experiment, all the 27 hunting localities being distributed to establish the 30 * 4 = 120 traps' paths, this effect does not exist.

Furthermore, the catches' global indicator is expressed in number of animals. It does not account for the size of trapped animals, and because only young animal are moving, qualitative difference in the age distributions of the catches between a scenario with fixed traps' location (R2) and a scenario with variable traps' locations (H2) may be expected. Figures 15a and 16a show the relative contributions of the age classes to the total population just before the 25th hunting season. Compared to figure 9b, these distributions illustrate the impact of hunting, but the important point here is that they are very similar: for the R2 experiment, the contribution of the big animals' age classes (year 4 to year 7) is 36.9%, for the H2 experiment, it is 37.3%.

| **Figure 15a**. Age structure of the population after 1300 weeks of simulation. | **Figure 15b**. Age structure of the catches during the 25th hunting season of simulation |

Figure 15. Scenario R2: periodic (every 6 months) hunting with same traps' location.

| **Figure 16a**. Age structure of the population after 1300 weeks of simulation. | **Figure 16b**. Age structure of the catches during the 25th hunting season of simulation |

Figure 15. Scenario H2: 30 groups of 3 hunters practising collective turnovers among a set of 4 given traps' paths.

Figures 15b and 16b show the relative contributions of the age classes for the last (25th) hunting season, respectively for scenario R2 and H2. These results confirm the above intuition: the contribution of the big animals age classes (4 to 7) is twice higher (26.2%) for the H2 experiment than for the R2 (13.6%).

Discussion

We discuss three subjects in that section. Firstly, we draw conclusions on the management of the resource by the hunters in Djemiong. Secondly, we discuss the multi-agent methodology, and lastly we propose an approach to give back the results of a MAS.

Resource management in Djemiong.

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 impose some constraints to preserve the resource from depletion and apply sanctions. Local populations carry on a traditional activity which became illegal. Many people has argued that before the creation of a protected area, one has to examine if local people are not already managing their resources. The local management schemes have to be described and their functionality may be discussed. Modelling is a useful methodology to test the functionality of management rules.

In the case of Djemiong village, 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. Before the simulations, by observing and discussing with the hunters, there was an hypothesis of local management of the blue duiker through the seasonality of the hunting activity. This seasonality resembles the management rules adopted in other countries to protect the renewable resources. Simulation shows that there seems to be more causality in the dynamics of spatial distribution of the catching effort. By studying this phenomena one observe that the rotation is efficient if there is a coordination among agents. This lead to the social structure of the society. In Djemiong village, the position of the traps are socially decided. Social sub-groups have preferential access to parts of the forest and decide collectively each year which place will be hunted. These places are inherated in the families. Thus, the management of the resource is more complex than imagined : it has to be understood through the links between social organisation and spatial structure. Dealing with that complexity, multi-agent simulation is used to identify the relevant organisation level (groups rather than individuals) and the relevant spatial scale (path rather than hunting localities).

Multi-agent simulations

While presenting the multi-agents systems we have claimed that MAS offer efficient tools to implement and simulate individual-based models but also provide a more general framework to study organisations of agents. This assertion can be discussed on the basis of the application presented here.

Firstly we have proposed a model of the blue-duiker population dynamics. This model belongs to the category of models named i-state configuration models by Maley and Caswell (Maley and Caswell 1993). The objective is to simulate the interaction between autonomous individuals and thus to observe the emerging dynamics in a bottom-up approach. In the field of IBM models Uchmanski (Uchmanski and Grimm 1996) presents these models in opposition to i-distribution models which aims more at understanding the role of inter-individual variability in models designed at the population level.

Secondly we have presented a model of hunter agents. Two versions are proposed : one with hunter agents which perceive their environment and act on their environment, one with groups agents able to coordinate the actions of several hunter agents. This part of the model emphasizes the relevance of multi-agent systems. A multi-agents systems deals with problems of interactions of agents across various scales (not solely the individuals) and models both the autonomy of the agents and their organization. The assumption is that the dynamics of the system has to be understood by the balance between autonomy and organisation. Few Ibm models in ecology dealing with interaction across trophic levels have the same implicit assumption. Very few simulates the interactions between agents at various levels such as the individuals and the group.

In his paper on the complexity of ecosystem Holling (Holling 1987) proposes three concepts that dominates perceptions of ecological causation , behavior and management. The first is the constant nature. The second is the resilient nature. This second viewpoint emphasizes variability and non linear causation due to small scale events. Most of the Ibm models have been designed with that perception. The third viewpoint is one of organisational change (nature evolving). This perception requires not only concepts of function but concepts of organisation that concern the way elements are connected. Recent work in hierarchy theory (Allen and Hokstra 1992) proposes an approach to ecological questions by studying the interactions between different levels : organism, populations, communities, ecosystems, landscapes and biomes. « A part from organism and biosphere levels, there is plenty of room for entities from almost any type of ecological system to be contained within an entity belonging to any other class of the system. » We think that Mas is a relevant methodology to model the organisation of entities interacting across scales.

Models and participatory approach

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.

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. 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 acceptance should come from the comparison between a run of the model and the final situation of the role-playing game.

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