TURTLES ARE THE TURTLES

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ABSTRACT

Green sea turtles *Chelonia mydas* inhabit tropical and subtropical oceans worldwide. Living in the marine environment and laying eggs on the beach, they are mainly threatened by human activities (poaching, fisheries bycatch, habitat destruction, etc.). In Reunion Island, the Kélonia observatory and IFREMER develop various scientific programs to study and protect sea turtles. One of them consists in studying migrations of green sea turtles for mating purpose. As existing mathematical models struggle to take spatial dimension into account, we propose an agent-based model to study some of the numerous questions regarding green sea turtles migrations.
Coming with high expectations, experts in sea turtles also provide many heterogeneous but incomplete data. Considering available or obtainable data in one hand and the various questions of experts in the other hand, we defined an innovative modelling process in which we simultaneously conduct discussion with experts and prototyping. This paper aims at presenting our simulation model but also our approach as well as the data-collection and modelling roadmap it produced.

INTRODUCTION

Environment and biodiversity protection is one of the major actual issue. At this point, some decision-support tools are needed to assist decisioners in the process of biodiversity conservation.
This is where simulation comes into play: firstly we define the problem with as much detail as possible, then we build a conceptual model of the real system and eventually we implement it. The aim is to evaluate the consequences of multiple strategies to preserve threatened species.
In this paper, we first describe a simulation approach dedicated to green sea turtle populations. Then we discuss the design method to develop an Agent-Based Simulation (ABS) meeting thematician requirements using a platform called *NetLogo*. Lastly, we present some interesting considerations resulting from this full process.

THE GREEN TURTLES : A FRAGILE AND ENDANGERED SPECIES

Chelonia mydas, also known as *Green Turtle*, inhabits tropical and subtropical oceans and is classified among the "endangered" species of the IUCN (International Union for Conservation of Nature) Red List of Threatened Species. Like other marine turtles species, survival of green turtles is mainly dependent of direct and induced anthropogenic threats affecting all life stages. One of the major threat may certaintly be intentional harvest of eggs, juvenile and adults individuals. Habitats degradation or fisheries bycatch are also known to have detrimental consequences on green turtle populations.
In order to understand the impact and possibly control such threats, a deeper understanding of the green turtle ecology is needed. This is a major concern of researchers from IFREMER (French Research Institute for Exploitation of the Sea) and Kélonia (the observatory of marine turtles), who develops scientific programs to study marine turtles in the South-West Indian Ocean (SWIO).
The usual way to build a model in population ecology is to take advantage of mathematical approaches in population dynamics model such as (Chaloupka 2002) or in individual based model such as (Mazaris et al. 2006). Such models gave some precise formalism in population parameters but some questions like spatialization are left aside.
Indeed, green turtle is a migratory species that moves across three habitat types.
This is where our expertise in the field of Agent-Based Simulation (ABS) offers an original perspective. ABS enables experts to simulate turtles behavior and ecology while taking into account the spatial aspects of the migration events. Even if our proposal is specifically applied to the SWIO, the genericity of our model would allow us to consider any population of green sea turtles around the world.
The main difficulty of this kind of project lies in the interaction of two specific groups of scientific experts. On

one hand there are experts in the field of complex simulation and ABS. On the other hand, are the thematicians, experts in another domain of Science, such as marine turtle ecologist in our case. The latter being usually not familiar with ABS, ABS experts must then be able to support them in the development of a simulation that will help them to improve their understanding of their system. In order to work hand-in-hand, we used an innovative approach described in the next part.

MODELLING PROCESS

In an ABS, agents are entities that interact through mechanisms of perception and influence within one or more environments. Those interactions would result in fluctuations in the variables of agents and environments. It is obvious that in the development of an ABS model relative to green turtles, these turtles would be the main agents. The originality of this article's title "Turtles are the turtles", lies in the fact that the keyword `turtle` is well known in the MAS community as being the historical word for agents in the NetLogo platform (Wilensky 1999). This glance blended with the need to pinpoint our objectives has led us to establish a modelling approach, where conceptual discussion and prototyping using NetLogo were done concurrently.

In the SWIO, more than 25 years of study have produced a large amount of data, sometimes incomplete. However, despite this long term studies, large gaps still remain for instance regarding migration or physiology. Behind the apparent simplicity of green turtle life history, there are very complex interacting mechanisms driving population dynamics. The construction of the model itself help in the comprehension of the biological system.

This is the reason why we conducted modelling and prototyping simultaneously. This allow us to identify problems that we hoped to answer, thus narrowing down the amount of data that are really exploitable, to identify missing data that should be collected.

Due to the fact that we already had some experiences in development of applications with NetLogo, we were able to test various hypotheses and focus more on the thematic conception of the model than the technical side. It allowed us to close-in on the thematic patterns we wanted to modellize.

The experience earned after this step (modelling and prototyping) is the first brick to the elaboration of a more mature conceptual model, which can be afterwards implemented on a poweful simulation platform more efficient in terms of calculation and detailled in terms of knowledge representation.

GENERAL PRINCIPLE OF THE MODEL

The main question that we choose to deal with was the evolution of a green turtles population on several generations. The idea was to ultimately find some conditions leading to a stabilization, an increase or a decrease in the number of individuals ; the latter possibly leading to the extinction of the population.

The particular life cycle of the green turtle brings the adult to regularly travel long distances between feeding sites and hatching sites. The feeding sites are generally coastal areas where food, mainly seagrasses, is present. In the SWIO, they are mainly located on the east coast of Africa and around Madagascar. The hatching sites are beaches where turtles mate and lay their eggs. In the SWIO, they are mostly located on islands around Madagascar and in the Mozambique channel.

At this stage of the modelling process, we chose to represent only adult individuals as agents because the early phases of their life cycle are barely known to thematicians. In addition, only female turtles were taken into account. If hypothesize a balanced sex-ratio (fifty percent of female), it allows us to double the size of the population that we can simulate. Moreover, females are the ones that usually migrate and mate every two to four years, while males migration is less documented. Representing only female adult individuals allows us again to gain more calculation power when we want to simulate with NetLogo.

IMPLEMENTATION

Following our discussion with thematicians, we came up with a model that we describe in this section. This model focuses on population dynamic and will serve as a base to answer thematical questions.

Our environment: the SWIO Area

The spatial environment is a grid applied on the SWIO, where feeding and hatching sites are implemented as `patches` in NetLogo (database structure related to a portion of the space). These `patches` are created according to the real world: their geographical coordinates provided by experts are loaded in the prototype.

- **The feeding sites.** `Patches` representing those sites have a certain quantity of food that regenerates at a determined rate. However the amount of food on this site diminishes when eaten by the `turtles`.
- **The hatching sites.** Unlike feeding sites, `patches` representing the hatching sites have no internal evolution in the current version of our prototype. They are geographic locations where green turtles come to lay their eggs.

Our agents: the turtles

In our implementation, our green (real) turtles are the (agents) `turtles` and interact with other `turtles` through the environment. They have the following properties.

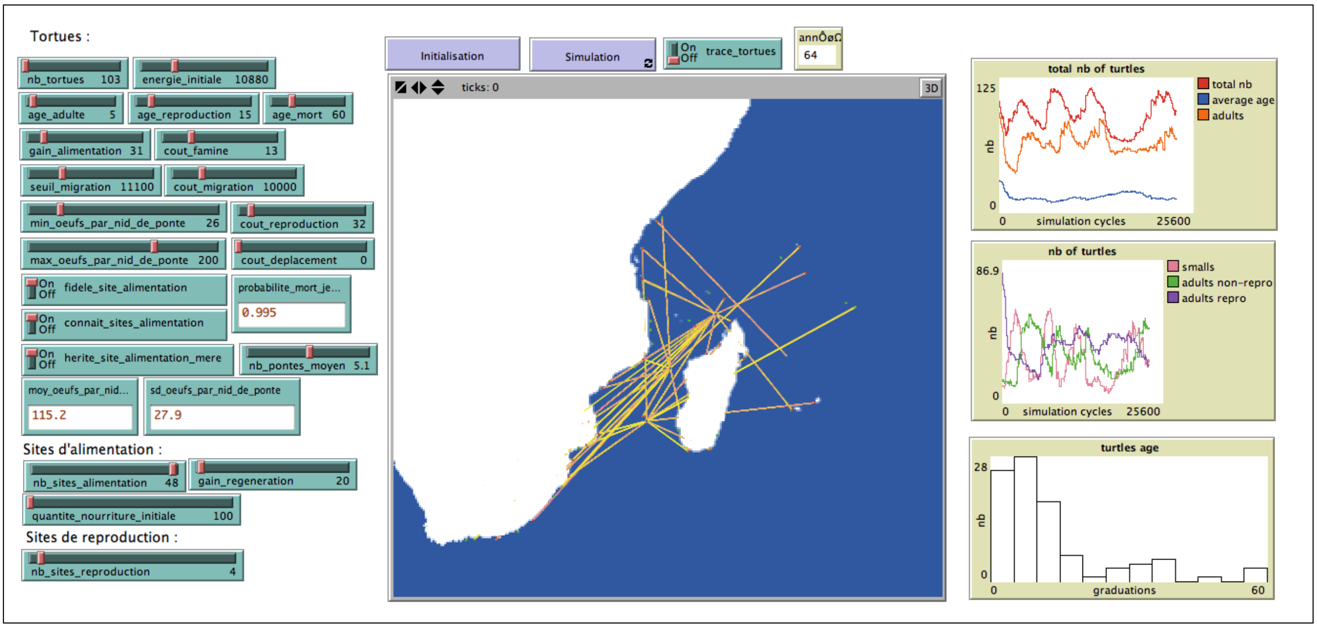

Figure 1: Prototype's GUI

- **Actions.** The main actions that `turtles` can execute are: eating (increasing their energy), migrating and reproducing (both decreasing their energy).
- **Spatial knowledge.** A green turtle almost always returns to lay eggs on the island where it was born. Each `turtle` is intrinsically linked to the `patch` representing its hatching site. However, `turtles` have access to all feeding sites' `patches`. Through this, we are able to test the influence of the fidelity of a turtle to its feeding site.
- **Birth.** The number of new `turtles` to be instantiated is calculated after each clutch, using the survival rate of juveniles (ranging from 1‰ to 1%).
- **Death.** A `turtle` is removed by the system either if it reaches the maximum age (fixed entry given by thematicians) or if it has no more energy.
- **Life Cycle.** The `turtles` stay on feeding sites where they eat available food. When a `turtle` has accumulated enough energy, it starts a migration toward its hatching site, then mates and lays eggs a certain number of times. Then it migrates back to feeding sites where it will rebuild its energy stock before the next migration cycle.

PROTOTYPE

The Graphical User Interface (GUI) of our prototype (Figure 1) is classically composed of four main areas of information that shows (from left to right):

- Variable parameters, to define simulation scenarios
- Control elements, to initialize and launch simulations
- A representation of our environment, to visualize the movement of the turtles in the SWIO
- Graphical output, to follow the evolution of system's indicators requested by thematicians.

The first simulations were just for model calibration. Most of the parameters have been determined based on thematicians knowledge (experiments and litterature). Some were not enough documented and hence went through a more delicate process; particularly at this stage, parameters which fell under the energetic aspect have been determined fairly empirically.
When our parameters were set up, we were able to launch simulation tests to study the influence of individual variations on the evolution of global population of green turtles and visually observe their behaviours: changing of feeding sites, modifying of migration periodicity or duration, etc. even if some parameters are still ignored at this stage (water currents, air temperature, etc.)

RESULTS

Simulation results

Our prototype allowed us to put in evidence evolution trends of the population of green turtles on several generations. Thus, in the upper right corner of the figure 1, we can notice important oscillations in the number of turtles. Those oscillations are in relation with inter-annual variations observed in the real world. But this prototype and the underlying simple model quickly reach certain

limits. For example, it is impossible at this stage to highlight the intra-annual cycle that corresponds to seasonal turtles' reproduction.
We identify some conditions that could lead to the stabilization, increase or decrease of the turtles' population. One of the most sensitive parameter is the low probability of survival from egg to adult. Energy parameters although played a key role in population trend, eg. food regeneration rate on feeding sites: if it is not swift enough or the number of turtles present on the site is too important, the turtle population is either greatly reduced or goes to extinction.
Another important result is that through our prototype we were able to overview the consequences of a sudden disappearance of a specific feeding site, thanks to the spatialization.

Approach results

Even if the simulation results are thematically relevant, our process method are in fact our main interest, because without the involvement of this domain's experts, we would end up solving wrong or irrelevant issues. This is why we choose to develop the prototype together with the modelling stage. As soon as our experts change something in their conceptual model, we tried to incorporate the changes into our prototype.
We worked together to build up a roadmap which contain the to-do list for both simulation and fieldwork. With this approach, we were able to identify:

- which objectives should be successful or not
- which data will be useful or not
- which data should be collected in order to reach our goals (eg. energy cost for movement, tracking of some turtles' migration path, etc.)

In the forthcoming development, we will first develop a model that implements the energetic aspect of actions. Using this base, we will then build two different models:

- The first model will deal with the variability (periodicity and quantity) of turtle's track on the beach to test if it does rely upon environmental parameters (sea surface temperature, ocean currents, etc.).
- The second model will take into account the strategy of sites selection (both feeding and nesting sites) to assess long term population viability.

When those models will be validated, we will try to merge them into one global model in order to find a temporal pattern and spatial partition. In the outlook of this project, we are going to take advantage of this first experience on NetLogo in order to achieve a more mature conceptual model, whose implementation will be made on GEAMAS-NG (a complex system's simulation platform that we develop in our laboratory).

CONCLUSION

In this paper, we presented a collaborative method and a NetLogo prototype focused on green turtles in the SWIO, in order to bring the right support to the project by clarifying what should be done or not, both in the real and virtual world (respectively fieldwork's collect of data and simulation's step of development).
Practically, we worked on two description documents:

- the description of the conceptual model
- the description of the computational model.

The conceptual description specifies the model according to how the experts think turtles shoud be modelled, while the computational description specifies the model as it is (or will be) implemented. Our task is to reduce as much as possible the gap between these two documents (called implementation gap). This reduction imposes changes on both documents, and therefore efforts have to be done by both experts in simulation and experts in fields to:

- Improve the computational description in order to make it closer to the experts' expectations
- Re-formulate the conceptual model, or even simplify it, in order to meet the technical constraints (and limits) of the computing.

In the end, the smaller this implementation gap, the more relevant our prototype. Only when this relevancy will become acceptable, the effort to migrate from "prototype" to "end-user tool" should be considered.
Our experience through this project has shown that using of NetLogo (as prototyping platform) contributes to significantly reduce the implementation gap. Indeed due to its simplicity of use, it brought both kind of experts around a set of common bases. Moreover due to a rapid development with it, it accelerates interaction between those communities.

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