Modelling contrasted management behaviours of stakeholders facing a pine encroachment process: an agent-based simulation approach

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Abstract: In Southern France, the Causse Méjan is a natural ecosystem of high biological diversity. Sheep farmers, foresters, and a National Park are interacting in this land subject to pine encroachment by Pinus sylvestris and P. nigra at different temporal and spatial scales. The stakeholders are concerned by this global biological process although it affects their management goals (sheep production, timber production, nature conservation) in very different ways. An agent-based model has been built with the Cormas platform. Vegetation changes in terms of structure, composition and productivity were simulated by a cellular automata that was initialised as a spatial grid of 5726 cells representing each 4 ha and incorporating GIS data from 1990 on vegetation structure and composition and topography. The global landscape dynamics results from a combination of the natural vegetation dynamics processes related to pine dispersion and the operations performed by three kind of agents. 37 sheep farmer agents are initialised from a database. Their grazing management strategy is based on their production system, grazing pressure, distance to the shed, and their environmental awareness. The strategies of the two forester agents are related to the forest land tenure and the legal constraints to afforestation management. A National Park agent is devoted to pine trees control according to the land's value -in terms of flora and fauna- and the maintenance of open landscapes. This paper particularly emphasises the usefulness of defining spatial entities at different levels, to describe the natural dynamics processes and to integrate the specific way each agent represents its environment to determine what to do and where. The model may be used as a stimulating tool to let the stakeholders exchange their feelings about the process of pine encroachment. If this approach is successful, it may lead to the development of common land management strategies.

Keywords: Natural resource management; Agent based simulation; Multi-agent system; Spatial entities

1. INTRODUCTION

There is a new trend in environment science to model the interactions between natural and social dynamics and to simulate more accurately natural resources management. In these models, ecological systems are viewed as hierarchical dynamic mosaics of patches that are modified by processes of patch creation, development and disappearance [Allen et al., 1987].

Recent works apply for an adaptive management approach to frame operational practices and provide a sound foundation for decision making [Gentile et al., 2001]. They stress the need to perceive ecosystems as entities with an intrinsic value and as complex self-regulating, dynamically changing systems [Ciancio et al., 1999]. The models developed under this framework are strategic planning tools designed to support adaptive management by projecting the consequences of alternative scenarios at the scale of landscape units [Kurz et al., 2000] or by testing management hypothesis permitting to sustain a mosaic of early and late seral vegetation patches [Lesica and Cooper, 1999]. Many of them are based on cellular automata where landscape simulation is based either on stochastic simulations [Flamm and Turner, 1994] or on object-oriented modularity [Derry, 1998]. Some of them are also dealing with long-term vegetation response to grazing [Wiegand and Milton, 1996; Weber et al., 1998].

This need of a behavioural approach of landscape dynamics, lead to the development of agent-based simulation tools involving multi-agent systems [Ferber, 1999; Weiss, 1999].

In Southern France, the Causse Mejan is a natural ecosystem of high biological diversity. Sheep farmers, foresters, and a National Park are interacting in this land subject to pine encroachment by *Pinus sylvestris* and *P. nigra*. In this context, an agent-based model called "Mejan" was developed with a view to simulating contrasting scenarios of behaviour in front of this encroachment process. After a brief overlook on the main features of the MAS, the paper emphasises on the usefulness of defining spatial entities at different levels, either to describe the natural dynamics processes or to integrate the specific way each agent represents its environment in order to determine what to do and where.

2. THE MODEL

The basic principle behind the design of the MAS was that the different categories of agents managing the natural resources (farmers, foresters and conservationists) were all affected by the strong encroachment of native pastures by Scots pines and Austrian black pines, but on very different temporal and spatial scales. And as this global biological process affected their development objectives (sheep production, timber production, nature conservation) in very different ways, a companion modelling approach [Bousquet et al., 2002] appeared as a good way to support the elaboration of a collective management plan. The MAS was developed with the Cormas platform [Bousquet et al., 1998] on a realistic representation of the Causse Mejan space.

2. 1 The land

The natural resources available were defined by topographical position, vegetation structure, land tenure status and heritage value (fauna, flora and landscape). The topography was accounted by a map of ridges and dispersal catchments based on topographic maps. All the vegetation data came from ecological surveys carried out by the National Park [Parc National des Cévennes, 1999]. Vegetation structure was described by a land-use map describing vegetation forms according to the combination of vegetation layers (tree, shrub or grass). Woodlands were described more precisely through dominant species, age and canopy cover. Agricultural activities were spatially characterised by the land tenure of each farm, the location of the shed and the cultivated areas. The natural heritage value was assessed by a set of maps accounting for landscape units, the location of endangered plant species and the home range of the eight key species considered as the main conservation target of the National Park [Jestin and Rousselle, 1997].

All these maps were overlapped and transformed into a 200m x 200m square grid that was imported into the cellular automata of the Cormas platform. This permitted to initialise the spatial grid of the model, represented by 5726 cells of 4 ha. The size of the cell was selected as a compromise between the time required to run a simulation and the relevant scale to account for the different ecological processes. A 200m x 200m unit was considered as a minimum to model pine dynamics, as satisfactory to represent the home range of the endangered butterflies and birds, and even if it was too big to account for the location of endangered plant species, it was tolerated for plant conservation under the principle of precaution.

2.2 The landscape dynamics

The landscape evolved as a result of the natural spread of conifers and the range management and timber harvesting regimes. An ecological model based on pine seed dispersal according to tree age, dominant wind and topography accounted for vegetation changes due to pine encroachment [Etienne, 1999]. The intensity of the encroachment and the speed of the trend can be reduced by range or timber management decisions. Each cell had the ability to memorise any operation applied on the trees by any of the agents.

2.3 The sheep farmers

37 sheep farmer agents were initialised from a database providing information on their production system, grazing pressure on rangelands, environmental awareness, availability of a chain mower, attitude towards pine encroachment, year of retirement and most probable production system after retirement. Their grazing management strategy was modelled according to their production system (meat or milk, intensive or extensive), grazing pressure, distance to the shed, and pine canopy cover on rangelands. Their behaviour in front of pine encroachment was affected by the labour time available to cut pine trees, the amount of land tenure tax, the amount of timber harvested and the rangeland productivity. Figure 1 shows the sequence of actions coded into the model to simulate the behaviour of each farmer at each runtime (one year). The basic grazing pressure, defined according to real data, is adjusted year by year according to changes in rangeland productivity provoked by pine encroachment. Pine control is decided according to the available labour or to the possibility to get financial support from other partners such as the National Park. Farmers' environmental awareness, farmers' acceptation to collaborate, time since the last collaboration, and labour force to share are the four criteria taken into account during the negotiation process.

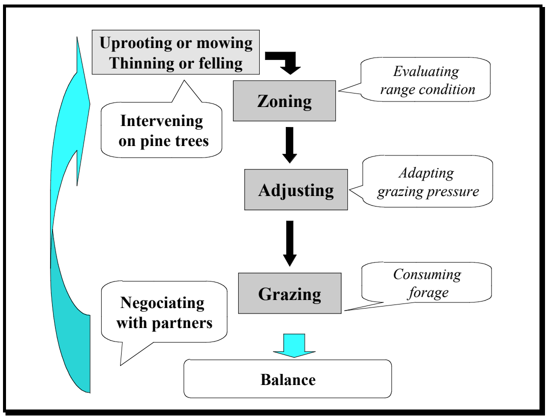

Figure 1 : The farmers actions

2.4 The foresters

Two types of foresters were generated by the model. One dealt with the management of afforestations and was charged with legal constraints to be respected (return of the debt, thinning schedule, reafforestation after felling). The other dealt with native woodlands exploitation and the organisation of the supplying of pulp industry.

In order to simulate forest management planning, the woodlands were divided into wood-lots automatically generated by the model according to three rules : the trees have to belong to the same age class, the cells must be contiguous and the patch must respect a minimum size.

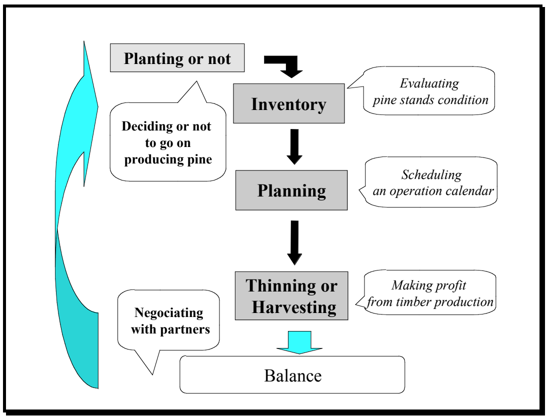

Figure 2 : The foresters actions

The foresters defined their management strategy according to the dominant pine tree species, the age of the woodlot, the amount of timber harvested and the amount of working days available to manage pine trees. Figure 2 shows the sequence of actions coded into the model to simulate the behaviour of a forester at each runtime.

Heritage value of the dispersal catchment, ridge encroachment level, foresters' income-loss compensation, National Park cash availability, are the four criteria used during the negotiation.

2.5 The conservationists

Land management by the National Park rangers was directed to pine destruction according to a land valuation based on flora and fauna heritage value and the maintenance of open landscapes. They were able to get financial support for the control of pine encroachment but were designed to spend this money on two different ways. One manner corresponded to select the sectors of the territory where strategic operations against pine encroachment can be developed. In this case they decided to clear first cells with high heritage value or ridges hanging over catchments with bare landscapes. The other way was to select farmers whose environmental awareness would permit to collaborate with, through cost-shared actions on their farm. In this case, they decided to clear first all the invaded cells of the selected farms. Figure 3 shows the sequence of actions coded into the model to simulate the behaviour of the conservationists at each runtime.

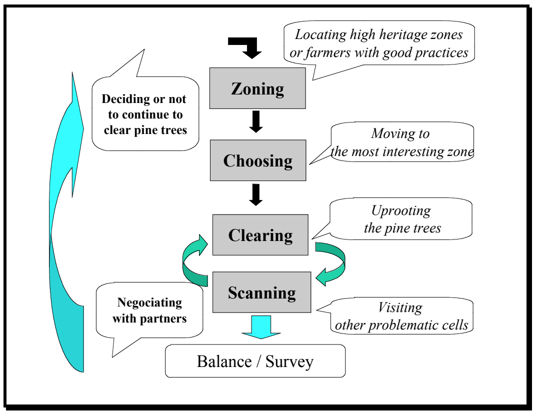

Figure 3 : The conservationists actions

2.6 The markers

A set of markers were elaborated to monitor the evolution of the land and of the agents resources. Some of them provided global indicators on land use (area of dense woodlands, area of pine-invaded pastures, area of native pastures) or land quality (sum of cells with endangered plat or animal species, landscape value, rangeland grazing potential of each farm). Others gave an idea on land productivity (stocking rate on each farm, available wood for timber or pulp on each woodland) or land products (amount of harvested wood for timber or pulp). Others accounted for the amount of work effort developed by each agent to control pine encroachment by hand or by roller-chopping. Finally, two other markers were yearly calculated to give an idea of the indirect financial impact of pine control: the land tenure tax (much higher on woodlands than on grasslands) and the timber income loss (inversely proportional to the age of felling).

3. FUZZY SPATIAL ENTITIES

Spatial entities defined at different levels are required to build up management units making sense according to the specific perception of the ecosystem that each agent uses to determine its actions [Le Page et al., 2001]. Six specific spatial entities were determined so far.

MjRidge1 entities gather all ridges already invaded or planted with pine trees. MjRidge2 entities gather all ridges next to be invaded by pine trees. Both ridges have a fixed shape but their size varies according to the number of cells occupied by pine trees. They constitute a key management entity to stop pine seeds overspreading for a long period but they require a delicate compromise between foresters and conservationists.

MjFarm entities aggregate all the cells managed by the same farmer. So it determines a stable entity for the time period corresponding to the farmer's active life. Once the year of retirement is reached, the model is supposed to assign the farm to a new manager. According to the availability of heirs, the size of the neighbouring farms, the hunting pressure on the surroundings or the level of speculation on land property, the farm will move from a system to another or will be aggregated to another farm.

MjHeritage entities represent spatial units corresponding to compact patches defined by a certain level of heritage index and which size is large enough to warranty a sustainable conservation of endangered animals and plants.

MjWoodland entities gather all the pine woodlands ready to be managed. As the age of management and the size of the management units differe according to the pine dominant species, two types were determined : one corresponding to *Pinus sylvestris*, the other to *Pinus nigra*.

MjWoodlot is a spatial entity imposed by a very specific management rule. It lays on a double threshold : a time limit that obliges the foresters to apply a same management technique in a relatively short period of time (5 years); a size limit, large enough for the logger to accept the exploitation.

Cormas ensures the coherence between dynamics running at different spatial levels by the mean of a double referencing system between aggregated and aggregative entities. For instance, a wood-lot being felled due to an action of the forester agent, then a specific internal control process, to be written by the modeller, will update the aggregated components (i.e. the cells) accordingly.

Spatial entities were used both to help the stakeholders to view the results of the simulations and to model the way agents manage their resources. So they must provide a representation realistic enough to account for current forestry practices but so simplistic to permit to be easily built up and updated by the model.

For instance, foresters stressed that they were used to divide their pine plantations into wood-lots to plan and apply their thinning and felling schedule. The size of the wood-lots and the periodicity of intervention coded in the model fit exactly with the real behaviour of this category of stakeholder. But the procedure to split a woodland into 5 wood-lots and sort them to apply successively the thinning and felling interventions uses random draws. So the shape of this spatial entity and the exact time scheduling of the operations applied on it differ slightly from the reality.

Two examples illustrate the way management entities were temporary and were defined by fuzzy limits. The National Park determined its primary actions according to an intermediate spatial level defined as "heritage units", which were portions of space that require a sustained conservation effort. At the beginning of the simulation, five major conservation spots were clearly identified by the aggregation of the heritage indexes (figure 4a). Two of them are characterized by an exceptional heritage value (pink and dark red) one has a high value and the two last a medium value (orange).

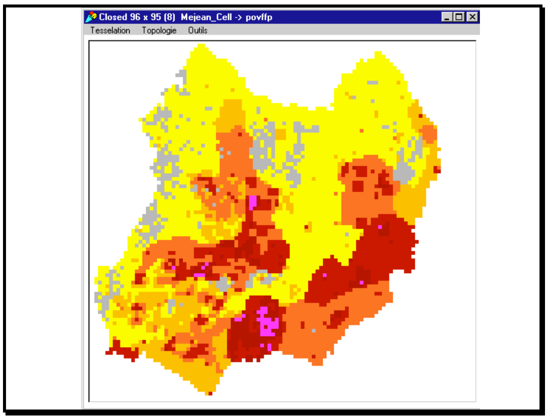

Figure 4a : The heritage units at the beginning

After 20 years, the location and the configuration of the heritage units is completely modified (figure 4b) because part of the endangered species were damaged by pine encroachment.

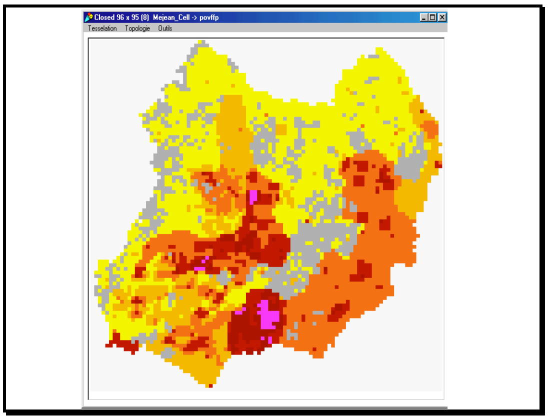

Figure 4b : The heritage units at mid-run

Foresters planned their operations according to two main rules: one based on the production objective, the other scheduled according to the successive steps of wood-lots management. Austrian black pine afforestations were established for timber production so they are submitted to a strict management schedule with a first thinning at an age of 30, a second thinning around 50 and the final harvest around 70. To stick as much as possible with this management planning, foresters determine homogeneous woodlands (contiguous patch of the same age) and divide them into wood-lots according to the previously detailed rules. Cells encroached by Scots pines are exclusively devoted to firewood or pulp production and are considered as woodlands when the trees are over 20 years old. But they are exploited only at age 40 and according to the market demand.

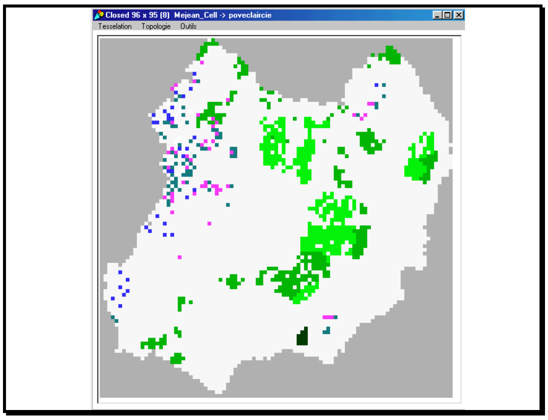

Figure 5a : Woodlands and woodlots at mid-run

At mid run (Figure 5a), the majority of black pine woodlands were partly thinned according to a partition into woodlots (medium green). Scots pine woodlands were quite rare (blue spots) and a few of them had been exploited (pink cells).

At the end of the run (figure 5b), thinning operations on black pine afforestations went on (dark green). But two management entities dramatically changed: the oldest pine stands moved back to native pastures and get out of the foresters scope meanwhile an important new territory of Scots pine woodlands fell under their management.

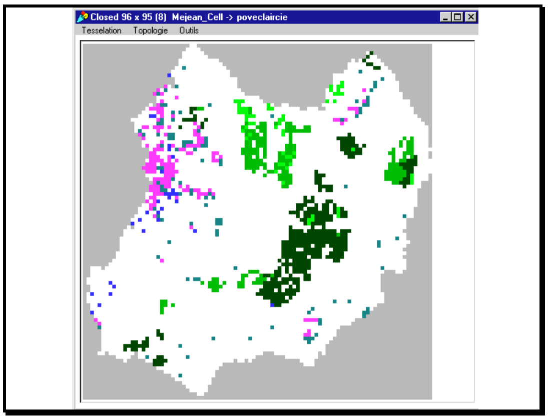

Figure 5b : Woodlands and woodlots at the end of the run

4. CONCLUSIONS

Compared with other models developed under a similar agent-based simulation approach, the Mejan model proposed two advances. First, the construction of flexible spatial entities allows one to focus part of the modelling work on relationships among dynamic processes at several levels. These spatial entities were defined at different levels, either to describe the natural dynamics processes or to integrate the specific way each agent represented its environment to determine what to do and where. Second, it provided a more dynamic characterisation of the space where several agents are moving and co-ordinating their activities [Pepper and Smuts, 1999]. This permitted to better integrate how each action of any agent modified the shared environment and consequently impulsed a retroaction on the other agents [Bousquet and Le Page, 2001].

Such an agent-based modelling approach may be used as a stimulating tool to let the stakeholders exchange their feelings about the process of pine encroachment. If this approach is successful, it may lead to the development of common land management strategies. The development of an adaptive version of the model [Janssen et al, 2000] with the possibility to compare different management scenarios and to evaluate their impact on social, economic and ecological issues will constitute a promissory step towards a more integrated evaluation and elaboration of resource management policies.

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