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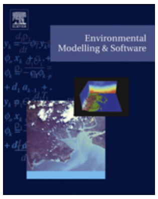

A companion modelling approach applied to forest management planning with the Société Civile des Terres du Larzac

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A B S T R A C T

To assist the Société Civile des Terres du Larzac (SCTL) in its effort to develop alternative forest management plans, a group of researchers and extension officers proposed applying a companion modelling approach. The objective was to support forest owners and livestock farmers while they worked out a solution to their forest management problems. The approach was based on the co-construction and use of an agent-based model providing a shared representation of the current management of farms and providing multiple view points on alternative forest management scenarios. The validation of the model allowed the development of a shared representation of the territory. The use of the model as an exploratory tool empowered local stakeholders to elaborate alternative management strategies for their renewable resources (forage, timber, firewood). It also expanded the discussion on forest management to a multi-scale level where managers assumed progressively a role of land administrators. When playing this role, they compared their forest policy orientations and forest harvesting decisions with farmers' individual situations and interests. Participants became aware of how spatial and temporal scales of management overlap and they progressively worked out a compromise between livestock breeding concerns of farmers and forest dynamics concerns of SCTL managers.

1. Introduction

This case study is part of the growing research field of ecosystem management applications (Bousquet and Le Page, 2004) focussing on participatory approaches that take into account interactions between natural and social dynamics. It provides a sort of integrated modelling approach (Barthel et al., 2008; Liu et al., 2008) deep-rooted in the involvement of local stakeholders into the modelling process, in order to avoid some pitfalls of multi-objective optimization techniques (Raizada et al., 2008) or multiple criteria analysis tools (Marinoni et al., 2009).

The companion modelling process (collectif Commod, 2006) based on a participatory, computer-based approach and landscape dynamics simulations supports local stakeholders in a collective reflection on spatial land pattern management. It was initiated in direct response to a request made by the Société Civile des Terres du Larzac (SCTL) to devise new ways to manage forests. An interdisciplinary team of researchers working on silvopastoral management, forestry, livestock farming systems and farm labour organisation was established to accompany local stakeholders in their search for a solution to the following question: "How can we make use of forestry resources characterised by low wood production while consolidating farmers' livestock breeding activities?" Their curiosity having been roused by the application of a similar process in a neighbouring territory (Etienne et al., 2003), SCTL managers and farmers agreed to become involved in the conception and validation of an Agent-based Model (ABM), and to participate in the design and analysis of a set of optional management scenarios.

The model conception process was inspired by modelling methodologies developed by the Companion Modelling group (ComMod). These methodologies focus on using ABMs as a means to facilitate and enhance shared learning on social and ecological dynamics' interactions rather than as a tool to pilot a socio-ecological system (Bousquet and Le Page, 2004; ComMod, 2005). This model-based approach has proven to be particularly useful when dealing with complex systems to help local stakeholders embedded in these systems to collectively compare, evaluate, and implement concrete alternative management strategies (e.g. Becu et al., 2006; Purnomo et al., 2005). As SCTL managers explicitly requested that farmers be integrated into the process, we shifted the problematic to a question of scale: "How may the breeding management plans devised by individual farmers at the farm scale be reconciled with the emergence of a forest management plan developed by SCTL managers at a territorial scale?".

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This paper describes the companion modelling steps that were followed by the stakeholders and researchers who worked together for 15 months over a 2-year period. We describe the main results of the participatory modelling process and discuss the outcomes from three different perspectives. As our approach is part of a research field that is evolving rapidly (Bousquet and Le Page, 2004; Hare and Deadman, 2004; Parker et al., 2003), we hope to provide insights and landmarks that will be useful to new users of agent-based modelling embedded in participatory ecosystem management.

2. Case study

Located in the south-eastern part of the Massif Central, the mountain range of Central France, the Causse du Larzac is an elevated (700–1100 m) limestone plateau cut off from surrounding plateaus by deep canyons. A long land use history of grazing and cereal cropping, and the particular rainfall and temperature conditions of a transitional climate bridging mountains and the Mediterranean, have led to a steppic, open landscape. Due to the karstic system, there are no permanent water sources.

Over the past few decades, deep socio-economic changes (rural migration, mechanization, and increased use of inputs) have led to a shift from a predominantly range system to agropastoral systems that depend more on forage and barley production and which are concentrated on the most fertile soils (Osty et al., 1994; O'Rourke, 1999). Simultaneously, a progressively increasing use of fuel and gas in place of firewood by farmers and other inhabitants has led to a dramatic decrease in firewood exploitation (Lepart et al., 2000). Both processes accelerated a shift from silvopastoral lands to dense forests that have no grass undergrowth. This trend was reinforced by the decline or abandonment of certain traditional practices which once helped to control shrub encroachment on pastures such as the harvest of forest by-products and the use of box (*Buxus sempervirens*) wood and leaves for handicrafts and litter production (Balsan and Bousquet, 1973).

Another important historical element is the French government's 1971 decision to enlarge the military camp of La Cavalerie, which was surrounded by the farms in this study. Between 1971 and 1981, 6300 ha of land were purchased or repossessed by the government. This social conflict ended in 1981 following the election of a new French President who decided to end the project and give the land back to farmers in the form of a 60-year lease. The farmers then created a civil society, the Société Civile des Terres du Larzac (SCTL) (De Crisenoy and Boscheron, 1986), to regulate the management of the 6300 ha of recovered land. Composed of pastures, forests, and fields, the land was divided into 40 farms that were rented in priority to the farmers who had exploited them prior to 1971. The forests located on these farms are owned by SCTL and the tenant farmers only are allowed to harvest firewood for their own domestic needs. SCTL is managed by a council whose members are elected by the farmers (Dambrin, 2001) and to whom we refer to in the remainder of the paper as the *SCTL managers*. The council currently is composed of 10 managers out of which nine are farmers and five manage farms in the study area.

Based on their perception of the past and present Larzac landscape (memories, stories, pictures…) and on their own experience as livestock farmers, SCTL managers jointly agreed to describe the changes that had taken place in their environment since the 1970s as, "a progressive closing of grazing areas to the benefit of pine stands and a densification of oak coppices leading to pasture shortage". A synchronic analysis of aerial photographs taken in 1948, 1964, 1978, 1990 and 1997 indicates a significant overspreading of *Pinus sylvestris* (PS) and a clear densification of Quercus *pubescens* (QP) coppices between 1948 and 1997 and a clear acceleration of these dynamics between 1964 and 1990 (Simon, 2004). This phenomenon is partly explained by the interruption of grazing and maintenance activities during the 10 years of *turmoil* between 1971 and 1981.

SCTL managers first thought that they faced a forestry problem and consequently asked a forestry expert for assistance. In accordance with French forest regulations, the expert established a simple forest management plan (period of validity: 1998–2012) that included yearly selective felling on *Quercus pubescens* (QP) stands and clear cuttings on the most productive *Pinus sylvestris* (PS) stands to reconvert these areas into pastures. The purpose of these cuttings was either to achieve a forestry or a grazing objective; both kinds of objectives were never sought on the same plot. The forest management plan scheduled three types of operations: wood exploitation and sale, improvement of QP wood stock quality, and the transformation of PS stands into pastures. These operations were assigned to only 280 ha of the 1930 ha of forest stands identified by the forestry expert. SCTL managers, however, were unconvinced that the expert's management plan would resolve their forest problem and consequently began searching for another solution.

The existence of this forest management plan was an advantage for this study because it gave us the opportunity to immediately compare the results worked out through the Larzac companion modelling exercise with the outputs of a conventional forestry expert approach.

3. Approach, methodology and schedule

In order to address both the managers' concerns and the research team's question, we pursued to improve the quality of the collective decision-making process and to promote local change. In this regard, a companion modelling approach was applied to promote bottom-up modelling for bottom-up decision-making. Our main goal was to support local stakeholders while they collectively designed and compared management options for their woodlands while simultaneously taking into account the impact of each option at the farm and forest massif levels.

3.1. Companion modelling approach

The companion modelling (ComMod) approach (http://www.commod.org) is a participatory approach used to support and accompany collective decision-making processes (Groot and Maarleveld, 2000; Ramirez, 2001; Borrini-Feyerabend et al., 2004). It relies on the co-construction and use with stakeholders of a model representing the functioning of their socio-ecological system (D'Aquino et al., 2002; Barreteau, 2003; Becu et al., 2006; Bousquet et al., 1996). The approach is based on the hypothesis that stakeholder participation in model development and implementation results in a model better fitted to stakeholders' needs and, consequently, is more useful (ComMod, 2005). The models developed play the role of boundary objects (Star and Griesemer, 1989) and allow stakeholders to share representations and evaluate scenarios (Etienne, 2006). Moreover, the development of a model typically follows an iterative methodological process in which each loop – also called iteration – corresponds to a succession of conceptualisation, implementation and validation phases.

When following the ComMod approach, a variety of methods are developed and tested as part of a methodological research effort (e.g. D'Aquino et al., 2002; Barreteau and Bousquet, 2000; Becu et al., 2006; Feuillette et al., 2003; Mathevet et al., 2003).

3.2. Methodology

The methodological posture was to use computer modelling and scenario simulations as part of a participatory approach that

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covered model design and development up to scenario building and analysis (Etienne and Le Page, 2002; Etienne et al., 2003, 2008). The objective was to allow stakeholders to articulate their knowledge, values, and preferences (van Asselt and Rijkens-Klomp, 2002) and to test alternative stakeholder behaviour and practices within a virtual setting (Simon et al., 2006). We selected agent-based modelling as the most suitable modelling paradigm in order to: (i) integrate the participation of stakeholders and the interdisciplinary character of the research team; (ii) account for interactions between social and ecological dynamics, the behavioural heterogeneity of the farmers, and the connections between farmers' and managers' scales of decision-making; and (iii) represent natural dynamics, current practices of farmers and their impact on the system, and new forest practices that could emerge from the participatory process (Bousquet and Le Page, 2004; Hare and Deadman, 2004; Parker et al., 2003).

Because a modelling exercise is limited by time and budget constraints, we structured our methodology into two phases: (i) an ABM was built by researchers and local professionals and validated through a participatory process; and (ii) the ABM was then used to collectively explore alternative forest policies and management strategies with SCTL managers and farmers. We thought the farmers and SCTL managers would prefer to discuss computer simulations rather than participate in role-playing games based on the hypothesis that they already were well experienced in consulting and discussing with each other. Our underlying objective was to focus as much as possible on the second phase of the methodology while still ensuring that in the first phase a common understanding of the problematic and dynamics at stake was achieved and that managers and farmers appropriated the model correctly.

3.3. Schedule

The companion modelling exercise undertaken with SCTL managers and farmers took place over 15 months spread between December 2003 and January 2006. Fig. 1 details the schedule of the six steps followed during the exercise.

Step 1 consisted of informing and sensitizing managers and farmers about the ComMod approach and took place before the research team was set up. This step gave a specific legitimacy to the approach and its facilitator because he was asked to speak about a similar process developed on the neighbouring Causse Méjan (Etienne et al., 2003), and because it was conducted first with SCTL managers and then with all the farmers. The Méjan case study thus facilitated the unfolding of the Larzac exercise by showing SCTL managers and farmers how the ComMod approach works, how interactions between breeding and forest activities can be modelled, and how agent-based modelling may be used to explore alternative management strategies. The interest and relevance of applying a ComMod approach to address stakeholders' issues was then immediately approved.

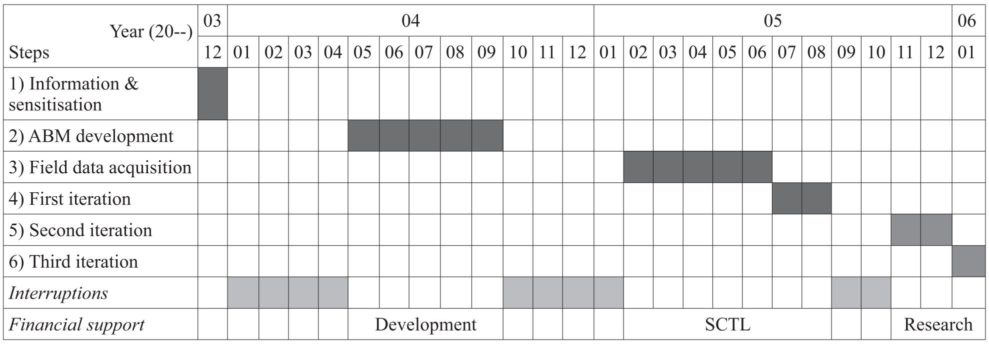
Step 2 corresponded to the first phase of our methodology and will be described in the next part. Step 3 initially was not included in the research plan; however, during the validation of the ABM, SCTL managers decided that more precise data concerning the productivity and the structure of their forests was needed. Field data based on a stratified on-field sampling consequently was acquired over 5 months by C. Simon with the financial support of the SCTL. Once this additional data was integrated into the ABM, the model was validated for a second time. The ABM described in the next part is the one that was validated at the end of step 3. Steps 4–6 correspond to the second phase of our methodology and will be addressed in the fourth part.

4. ABM development

To develop the ABM, we first elaborated a preliminary conceptual model representing the theoretical and field-based preconceptions of researchers and local Agriculture and Forest Extension Services technicians. We completed this initial conceptual work by conducting exhaustive individual interviews with farmers to gather information and data on: (i) the organisation of the spatial structure of the farm territory into paddocks; (ii) the annual grazing calendar and the underlying decision rules of use of the paddocks over the year for each animal batch; (iii) the production system; and (iv) the firewood practices. We then compared the resulting conceptual model with actual circumstances and stakeholders' conceptions, leading to the model's modification and validation (Simon, 2004). The resulting composition of the complete companion modelling group is shown in Fig. 2. Because the resulting conceptual model shared certain similarities with the model developed on the Causse Méjan (Etienne and Le Page, 2002), we decided to use part of the Méjan ABM structure and programming modules, namely the farm and paddock spatial objects, the farmer social agent, and several procedures in which only the parameters needed to be modified.

4.1. The ABM in brief

The model was developed on the Cormas platform (Bousquet et al., 1998) and the environment was set up as a realistic representation of the SCTL land, GIS imported data providing a set of ecological (land use types), agronomic (forage patches) and management entities (farms, paddocks, forest plots). Stakeholders were divided into two categories dealing with specific management entities. In the model, farmers herd their flock and harvest their firewood according to their farm structure and production



Year (20--)	03	04												05												06
Steps	12	01	02	03	04	05	06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12	01
1) Information & sensitisation	■																									
2) ABM development						■	■	■	■	■																
3) Field data acquisition															■	■	■	■	■							
4) First iteration																				■	■					
5) Second iteration																								■	■	
6) Third iteration																										■
Interruptions		▨	▨	▨	▨						▨	▨	▨	▨								▨	▨			
Financial support						Development									SCTL									Research		

Fig. 1. Schedule of the methodological steps of the Larzac companion modelling exercise with the origin of the related financial support.

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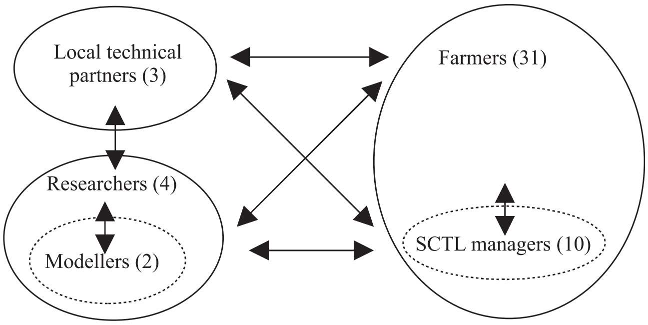

Fig. 2. Organisation of the group that took part to the modelling exercise. The arrows indicate the interactions between all the participants.

system goals. Although SCTL managers wished to define a new forest management plan, develop a timber production strategy taking into account farming criteria, and select which forest plots to harvest, in the model's representation of the system as it currently existed, their role was restricted to overseeing the activities of farmers.

The model was used to simulate different levels of collaboration between farmers and SCTL managers. Ecological (land use changes), technical (forage availability, firewood and timber production) and economic (cash and income) indicators were calculated to measure the impact of each scenario on landscape dynamics and stakeholder incomes.

4.2. *ABM creation process*

The conceptual model was co-constructed with the research team using the ARDI approach (Etienne et al., 2008). This approach provides an understandable and pedagogic framework in which to describe an ABM embedded in natural resources management. It is based on four questions that a modeller may need to address when building a conceptual model. These questions are related respectively to the stakeholders or actors (A), the resources (R), the ecological dynamics (D), and the interactions (I) between the three previous elements. The spatial and temporal resolutions, as well as the horizon of simulation are addressed later in the paper.

4.2.1. *Who are the main actors who seem to or should play a decisive role in the management of the territory?*

First of all, the research team identified potential actors concerned by the managers' problematic on the basis of their own preconceptions of the social context. This first identification exercise then was discussed with SCTL managers, leading to the decision not to integrate three potential actors: hunters, tourists, and the Regional Park of Grands Causses. The exclusion of the latter two potential actors was justified because they exercise a minimal impact on SCTL forests. Hunters were excluded because SCTL managers did not considered local hunting associations to be fundamental actors in their problematic and had a conflict relationship with them.

In the end, 31 farmers were integrated into the model as the main actors with a direct impact on the resource space through their livestock breeding and firewood harvesting activities. The farmers who were selected were those whose farm territory included at least 2 ha of forest land rented from the SCTL. In the current system, SCTL managers do not carry out any direct action on the land or any indirect action on the farmers' breeding and harvesting practices (Simon, 2004). They are integrated into the model as a single, higher scale regulatory agent that only oversees the activities of individual farmer agents in the current system. On the other hand, the direct and indirect roles given to SCTL managers during the modelling exercise were integrated in the form of scenarios, i.e. of additional decision rules to the current system.

A farmer's decision-making was considered to be the ability of his corresponding agent to independently decide what to do at any given time step (Hare and Deadman, 2004). It was modelled in the ABM with simple behaviours that took into account the farm structure and the goals of the production system (i.e. meat, milk for Roquefort cheese, and farm cheese). The farmer adapts his grazing and harvesting strategies according to the different information that the farmer has or receives from the environment.

Breeding and firewood harvesting practices of spatial and temporal use of the farm territory were modelled according to the data collected during the interviews. In order to model the farmers' capacity to undertake additional in-forest actions that could be suggested during the scenario building phase, we calculated the labour hours available to each farmer according to the number of people working on the farm and the amount of time that farmers estimated was needed to carry out each breeding activity (lambing, milking, animal reproduction, sale of cheese on the markets, agricultural work, holidays …). Each in-forest action (selective felling, clear cutting, clearing of the shrub undergrowth) was assigned an available time constraint. The grazing activity when animals were on the lands of the farm territory affected by the natural dynamics at stake, was determined by the decision rules of the farmer who evaluates and takes into account the animals level of requirements, the labour time constraints, and the forage availability in the paddocks.

The one time step sequence of the ABM means that farmers' agents decide their strategy and apply their grazing and harvesting practices serially in queue order. For instance grazing is scheduled at each time step by *organising grazing practices* (Fig. 3) according to each farmer agent grazing calendar. On this basis, he puts his flocks either into the animals shed, on the crop fields or in the paddocks. In the last case, he takes into account the available forage of each paddock and his flocks' forage requirements and organises the grazing for each of his flocks. To do so, he *selects a paddock* (Fig. 3) according to criteria related to his grazing strategy and puts the flock in it. The farmer repeats this operation until the flock's forage requirements are satisfied or until no forage remains available in the paddocks. In this latter case, he puts his flock into the animals shed and *buys supplemental forage* (Fig. 3).

4.2.2. *What are the main resources to be taken into account?*

The land of the 31 selected farms covers a surface area of 8800 ha. It was characterised by a set of land uses and land covers which were first integrated into a GIS (MapInfo) before being rasterised and imported into the cellular automaton of the Cormas platform.

The land uses were based on four types: pastures (4250 ha), silvopastures (1150 ha), forests (2120 ha) and cultivated areas (1350 ha). Pastures and silvopastures are used by farmers to feed their batches of animals at different periods of the year the farmer, and the latter can be exploited for firewood. The forests either can be used by the farmer as firewood stands, hunting areas, for recreation, or be set aside. The cultivated areas are used either to produce and stock food for animals or as grazing areas.

The land covers were defined as a combination of three layers that were defined by the farmers during interviews. The herbaceous layer is considered to be the principal source of forage for flocks. The shrub layer is mainly composed of two species: *Juniperus communis* and *Buxus sempervirens* and is perceived as competing with the herbaceous layer without providing any forage. The tree layer is composed of two main species: *Pinus sylvestris* (PS) is perceived as competing with forage production and *Quercus*

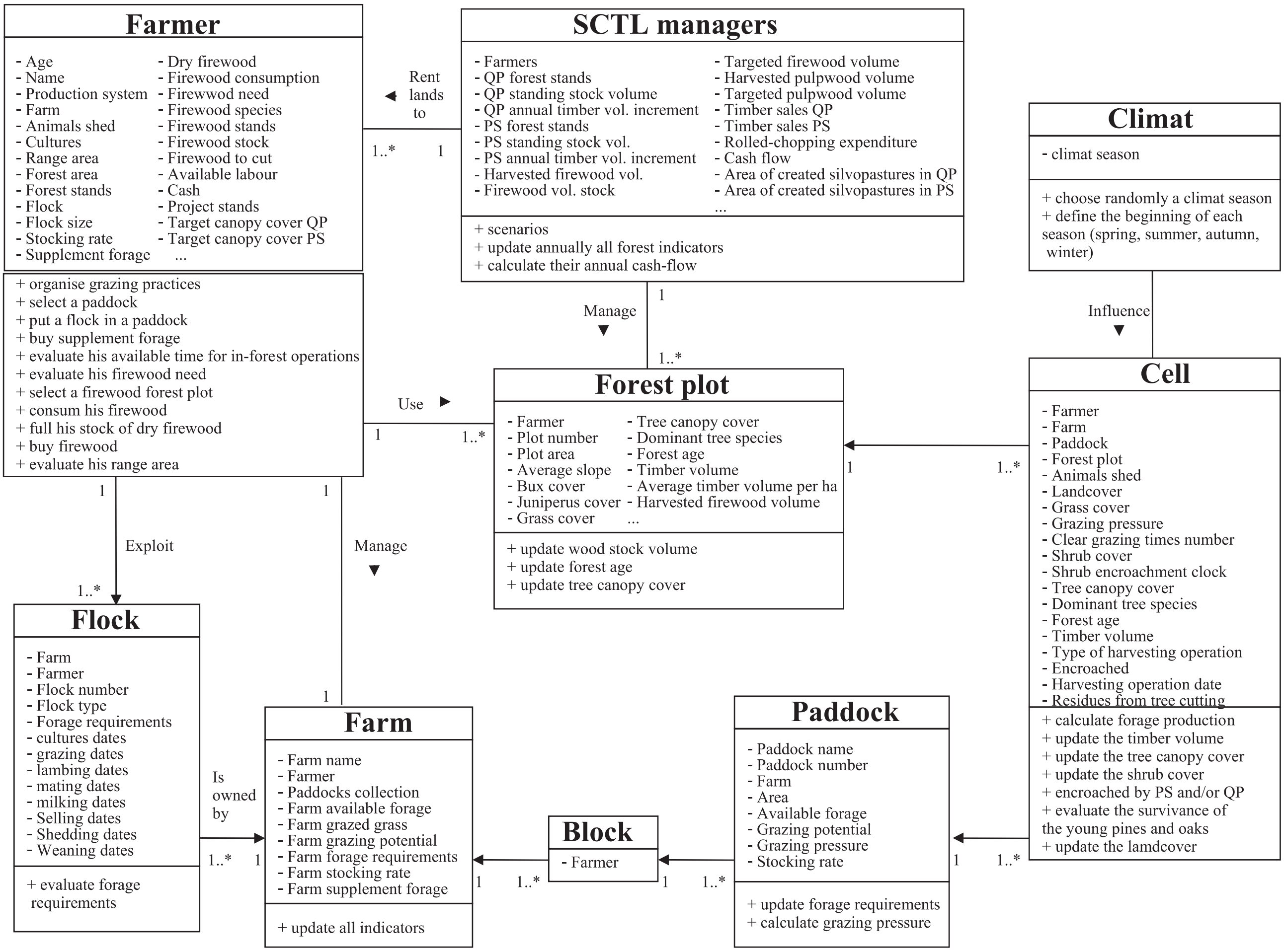

Fig. 3. UML class diagram of the ABM.

pubescens (QP) as potentially beneficial (acorns, foliage, seasonal shade).

Three classes of land cover were used to characterise each of the three layers: 25–50%, 50–75%, and 75–100%. The proportions of the three layers and the dominant tree species were obtained by studying the last available aerial photographs of the territory dating from 1997 in combination with data acquired through stratified on-field sampling (step 3), and was further validated by farmers during interviews.

The age of the forest stands was obtained by estimating the date of appearance of forest cover on old aerial photographs (1948, 1964, 1978, 1990 and 1997). It was completed by a stratified on-field sampling (step 3) to measure the timber volume, the average slope, and the annual tree increment.

4.2.3. *What are the main ecological dynamics, and how are these dynamics affected by the selected actors?*

The PS and QP tree encroachment dynamics was adapted from the models developed on Causse Méjan (Etienne, 2001; Lepart et al., 1999). Tree encroachment of a cell without forest is conditioned by the presence, in the direct neighbourhood of the cell, of mature stands (i.e. older than 15 years). The survival of young PS is conditioned by the grazing pressure: if it is lower than the threshold value established by the Livestock Breeding Institute, the young pines encroach (Talhouk, 2003). For QP, the establishment of seedlings is successful only when there is no grazing or under high shrub cover (Lepart et al., 1999).

The forest stand growth was modelled by the development of their land cover, their age, and exploitation volume according to regional data of the National Forest Institute and transition matrix built from a synchronic analysis of aerial photographs (Simon, 2004).

Shrub encroachment dynamic depends on the grazing pressure on the cell (grazing pressure lower than a threshold value established by the IE).

Grass growth was based on available annual seasonal growth curves (Guérin et al., 2001) according to six periods. In early spring, full spring, late spring and autumn grass is growing more or less strongly. In summer and winter, grass stops growing and becomes degraded by drought or frost. The beginning and end dates of each season is a function of the annual climate chosen randomly by the computer among a good, average, or bad year. Grass growth in silvopastures depends also on tree cover and species (Etienne and Hubert, 1987). Both factors modify the quality and seasonal distribution of forage production (Guérin et al., 2001). The forage availability on a cell, at each time step, corresponds to the quantity of forage produced during that week and the remaining forage from the previous week.

4.2.4. *How does each actor use the resources and interact with the other actors?*

The socio-ecological interactions integrated into the ABM concern the impact of farmers' grazing and harvesting practices on the forage quantity, the tree cover, and the shrub cover, and the

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capacity of a farmer agent to perceive his environment and consequently adapt his strategy and practices.

4.2.5. Spatial and temporal resolutions and horizon of simulation

The choice of the pixel size of the cellular automata constitutes a generic topical issue when a spatially explicit agent-based model is developed. On one hand, it must allow a visualisation of the main indicators of interest for local stakeholders and provide a sufficiently precise mapping of the land management entities and ecological processes. On the other, the total amount of pixels required to map the area must remain compatible with data-processing constraints, e.g. speed of treatment, initialisation of the attributes of the cells starting from the data layers available on GIS (Etienne, 2006). In our ABM, the pixel size was fixed at 1 ha since this spatial resolution was sufficiently precise to represent the key management entities (crop fields, forest plots and farm paddocks) as well as the key ecological processes (pine encroachment and coppice canopy closing).

The time resolution chosen had to allow a representation of the main dynamics and actions to be modelled. The main limiting factor related to time step was farmers' decisions on labour allocation (Madelrieux et al., 2006). Indeed, the forest stands growth module was based on a 1-year temporal resolution, while grass growth was based on a seasonal (from 1 to 3 months) variation. Individual enquiries with farmers confirmed that available labour time was a decisive factor when deciding whether to undertake additional actions in the forest, as livestock breeding and field cropping always remain their priority. So the research team agreed on a 1 week temporal resolution.

The horizon of simulation chosen had to allow landscape dynamics to be visualised and significant changes in timber and firewood production to be registered. As the main ecological dynamics were forest encroachment and growth, the relevant time step could have been correlated to the lifetime of the dominant tree species, i.e. around 70 years for PS and 150 years for QP. However, the model also had to account correctly for the impact of breeding and harvesting activities on the evolution of forests. The time commonly planned for the latter is around 10–15 years. As our computer model prioritized the integration of socio-ecological dynamics, we had to limit our simulation horizon to 20 years.

4.3. Verification and validation of the ABM

Modelling and simulation are useful approaches to analyse a system and to explore alternative management strategies of natural resources, but their utility is dependant on adequate verification and validation (Bousquet and Le Page, 2004). Verification means building the system correctly while validation means building the correct system (Parker et al., 2003). In other words, "Is the implementation of the conceptual model correct?" and "Do stakeholders agree with the conceptual model?" In order to address both questions, we included in our modelling process two kinds of outputs to visualise and assess the behaviour of the model during the simulation and after its completion: spatial viewpoints and probes. The first were dynamic maps of given attributes (e.g. land cover, land use) that could be saved in the form of images or videos. The second were graphic evolutions of given attributes or indicators during the simulation.

4.3.1. Verification of the ABM

The research team verified the accuracy of the way available models (forest stand growth, grass and forage production, climate hazard) were adapted to the Larzac context, checking their outputs with local professionals. Pine encroachment and coppice canopy closure were modelled according to outcomes from a specific analysis. Decision rules and farmers' practices were set up after an exhaustive round of individual interviews with farmers and SCTL managers. In addition, we drew the structure of the model in two forms: a simple graph (ARDI interaction diagram) easy-to-understand by any stakeholder and a standardized diagram based on the Unified Modelling Language (Fig. 3). The verification of a computer model also can be made by analysing relationships between model parameters and the state or time path of variables endogenous to the modelled system by means of a sensitivity analysis (Parker et al., 2003). However, such techniques are not often applied to complex models (Bousquet and Le Page, 2004) and they were not used in this case study due to time constraints.

4.3.2. Validation of the ABM

Validation concerns how well model outcomes represent real system behaviour. While some techniques exist, the validation of complex system simulation outcomes remains a challenge, particularly when using an ABM whose simulations are not merely calculations of variables but rather imitations of a model's behaviour in space and time (Küppers and Lenhard, 2005; Parker et al., 2003). According to Küppers and Lenhard (2005), the knowledge produced in this case seems to be valid if some of the characteristics of the social dynamics known from experience of the social world are reproduced by the simulation. The agreement of stakeholders then may be an indicator of the validity of a simulation model (Troitzsch, 2004; Küppers and Lenhard, 2005).

To validate the ABM, we made a set of simulations of the current situation over 20 years that were collectively discussed and analysed with SCTL managers and farmers. To visualise the simulation of this "current scenario", the landcover viewpoint already used and tested on the Causse Méjan (Etienne et al., 2003) was re-used for our validation exercise. The farmers quickly grasped the cartographic representation (cells grid) and the suggested viewpoint on landcover, that permit them to easily locate their farm and name the different places of their farm.

To check the rules integrated into the ABM they were provided with diagrams, figures, and logical French sentences that resembled a programming language organised into condition sequences (If … Then … Else …).

During the simulation, they were able to visualise any indicator they were interested in, at both territory or farm level. As they were astonished by the forest dynamics over 20 years, we then described in detail the methodology that we used to quantify the determining factors of pine encroachment and coppice canopy closure dynamics. This was followed by a collective discussion on the hypothesis that underlined this methodology, i.e. that the determining factors of forest dynamics that had held true over the last 50 years would remain the same for the next 20 years. SCTL managers and farmers validated this point and agreed that pine encroachment would be the most difficult natural process to control as they already had experienced it on their farms. With regards to their respective modelled agents, they considered them to be simple representations of their actual behaviour but relevant enough to use in the discussion of the problematic at stake.

5. Using the model with managers and farmers

The second phase of our methodology consisted of using the model with stakeholders to elaborate alternative management strategies of SCTL forests. It was carried out through three participatory iterations with SCTL managers and farmers. Fig. 4 shows the succession over time of the three iterations. The first iteration consisted of developing the ABM and the use of the model by the farmers to build their individual scenarios at the farm scale and by SCTL managers to build a set of three forest management scenarios

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at the territorial scale. The second iteration consisted of the conceptualisation and implementation of the first iteration scenarios by the modelling team, their validation, simulation, and analysis with SCTL managers, and the building of a new SCTL managers' scenario in which the main advantages of the previous scenarios were combined with additional options. The third iteration consisted of the conceptualisation and implementation by the modelling team of the scenario developed in the second iteration, its validation, simulation, and analysis with farmers and SCTL managers, and the reaching of an agreement on a consensus scenario combining elements of previous scenarios.

Throughout the three iterations, the ABM was used with the stakeholders to collectively simulate, analyse, and discuss alternative management scenarios. In addition to the scenario building processes, stakeholders asked for different indicators to be calculated and to visualise them during the simulations. The ABM helped them to integrate some of the information and knowledge gathered during the previous steps into their management scenario building.

5.1. First iteration with farmers and managers

5.1.1. Elaboration of individual scenarios with farmers

The first iteration resulted in the elaboration of the individual management scenarios of each of the 31 farmers through private interviews. The farmer's perception of the forest stands located on his farm was discussed in order to elicit his wishes in terms of forest management and harvesting operations to be undertaken and the associated goals (silvopastures development, creation of new pastures, timber harvesting for his own requirements …). The interaction with the facilitator helped the farmer to clarify some of his forest management propositions and get precise information on forest spatial distribution (forest maps), productivity (timber volume), and technical feasibility of the operations. It led to a written scenario where the farmer located the intervention plots, detailed the type of operations, and scheduled these over the next 10 years.

The analysis of the 31 interviews permitted to identify four main management options: (i) forest management is not desired (11 farmers); (ii) forest management is not useful (four farmers); (iii) forest management is desirable (10 farmers); and (iv) forest management is necessary (six farmers).

The arguments put forward in option (i) were that the current structure of the farmers' forests was perfectly adapted to their breeding activity and was maintained in a sustainable manner through grazing or firewood harvesting. Option (ii) was supported by many arguments: woodlands provide firewood, so their spreading is beneficial and effective to reduce the impact of successive droughts; the pine encroachment process was too strong and advanced to fight against; the breeding system depended almost exclusively on croplands and very little on pastures and forests; or the farmer had plenty of forage and the woodland was dedicated to hunting. The farmers that promoted option (iii) had enough rangeland but they were confronted by strong PS encroachment and wanted to limit it. Others had old QP coppices and wished to exploit the firewood and create additional silvopastures. In option (iv), PS overspreading endangered grazing activities and it was vital to recover some pastures from the current SCTL forest stands.

5.1.2. First scenario building exercise with managers

To start the elaboration of their scenarios, SCTL managers decided first to analyse the farmers' individual scenarios. Based on this analysis, they worked out four categories of forest stands: (1) stands included in a farmer's management project (130 ha); (2) stands set apart by the farmers for firewood harvesting (840 ha); (3) stands belonging to farms where farmers were opposed to any forest operation (190 ha); and (4) stands belonging to farms where farmers had no personal goal but accepted SCTL forest operations (940 ha). On the basis of this categorisation, the SCTL managers identified four main questions: Why didn't farmers imagine more forest management projects? Should managers continue to allow farmers to independently choose their firewood forest plots or should this decision be the result of a joint agreement between farmers and managers? What should managers do with farmers who did not respect SCTL management rules? What should be done about forest stands where farmers do not have any specific management goal?

This reflection led to imagine three types of scenarios. The first, called farmers' projects scenario (scenario 1–1), compiled and administrated all of the farmers' individual projects at the farm scale. It aimed at evaluating the impact of a set of forest management projects built without any formal coordination between

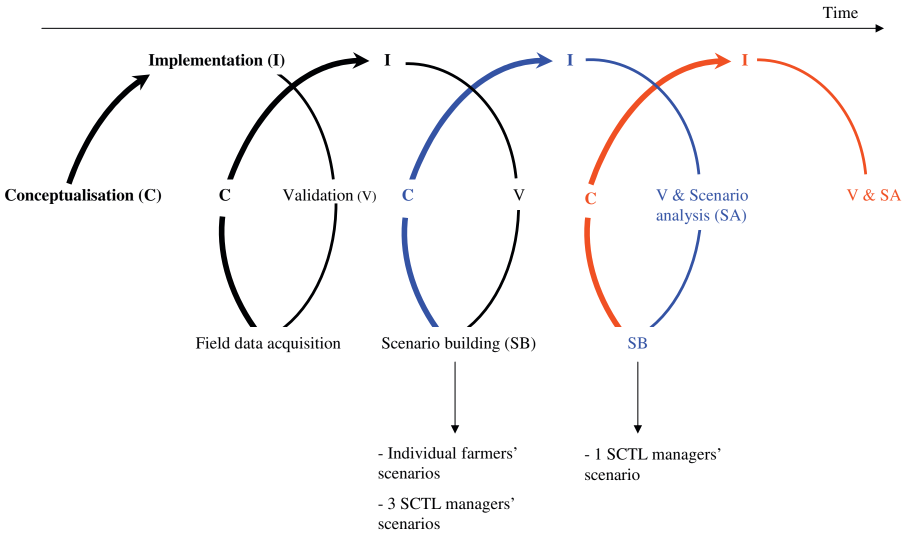

Fig. 4. Successive iterations crossed by the approach with their respective methodological steps. The first iteration is in black colour, the second in blue colour, and the third in red colour.

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stakeholders, on the forest massif, and at assessing, at the farm scale, the economic profitability of the projects. Because this scenario did not manage a sufficiently large area of forest (only 6% of the forest massif), SCTL managers elaborated a second scenario by adding to scenario 1–1 some harvesting operations in-forest stands of the 4th category (scenario 1–2). Finally, they shifted their focus from impacting forest dynamics to targeting the economic profitability of forest management (scenario 1–3).

Scenario 1–1 compiled all of the farmers' individual projects and fixed an annual timber volume to be harvested at the territorial scale that was indexed on the annual SCTL forest increment. They also defined rules to prioritize forest operations by giving first priority to the farmer with the largest area encroached by forest, but only allowed one harvesting operation per year to ensure that there would be a yearly rotation between the farms.

Scenario 1–2, added to scenario 1–1 forest stands of the 4th category, where a high thinning intensity was applied according to the results of real in-forest experiments of three selective felling intensities (30%, 50% and 70% of the PS cover). Harvested plots were selected according to a minimum standing timber volume fixed by the local pulp wood harvesting enterprise and the same annual timber volume target as in scenario 1–1 was chosen. Specific rules were established for rehabilitating the harvested forest plots according to the grazing interest of the plot (roller-chopping only when box cover was less than 50%).

Scenario 1–3 strictly addressed the economic profitability of forest management and targeted a positive SCTL cash flow by balancing wood sales and costs related mainly to the mechanical cleaning of harvested plots. Four key criteria were collectively identified: exploitable wood volume, wood market prices, and slope and shrub density constraints (as supplementary costs). According to harvesting enterprise standards, forest stands with slopes greater than 25 degrees were removed, as well as any PS plot where the standing volume was lower than 100 m^3/ha and any QP plot whose volume was lower than 60 m^3/ha. Thinning operations were assigned to the best standing volume plots with the same annual timber volume to be harvested as in scenario 1–1. Thinning was always a systematic selective felling to reach a forest cover of 30%. The mechanical cleaning rules of scenario 1–2 were re-used.

5.2. Second iteration with managers

The three scenarios of the first iteration were implemented in the ABM by the modelling team. Several spatial viewpoints and probes, such as forage availability or supplemental forage purchased, were integrated into the ABM in addition to those of the stakeholders to take into account the theoretical and technical disagreements of some local partners in regard to the decisions made by SCTL managers. The underlying idea was to discuss these elements during the collective scenario simulations and, through the ABM's role as a boundary object in a mind opening process, to compare different points of view of the same simulation. Positive results obtained with SCTL managers' indicators could be confirmed, contradicted, or moderated by other indicators that were ignored by SCTL managers. In addition, the research team developed an easy-to-understand basic scenario to highlight and discuss the individual impact of farmers' grazing and harvesting activities on the evolution of the landscape. This scenario simulates the sudden disappearance of all agents (as in 1971) and allows the easy visualisation of ecological dynamics in the absence of cropping, grazing, and felling (scenario β).

A new workshop then was organised with SCTL managers to validate the implementation of the first iteration scenarios and analyse their outcomes not only in terms of absolute values but comparing them to each other.

5.2.1. Using the ABM as a participatory simulation tool

The scenario analysis was conducted by comparing, for each scenario, a set of attributes and indicators that could be visualised in the form of dynamic maps or graphs. Fig. 5a,b provide an example of maps used with managers. These figures are two snapshots of land cover viewpoint at the beginning (Fig. 5a), and the end (Fig. 5b) of scenario 1–1. The graphs were used to monitor the simulation outcomes at the territorial scale as well as the farm scale.

The following discussion provides an extract of the collective analysis carried out with SCTL managers by comparing results at both the territorial and farm scale. Farm 7 was considered as a good sample as its farmer often was used as a reference by SCTL managers, because he harvested firewood in PS forest stands, his grazing strategy was mainly oriented on pastures and silvopastures, and his farm was one of the most affected by pine encroachment.

Scenario 1–1 generated a limited impact on the wood resource (only 80 ha are harvested during the simulation) and consequently a progressive and strong closing of grazing areas to the benefit of pine stands and a densification of oak coppices leading to pasture shortage. The firewood harvesting practices of f7 could not compensate for the strong dynamic of pine encroachment on his farm. Farmers' individual management projects, mainly oriented around the best standing volume forest plots, did have a significant impact on the global wood stock volume but this impact was limited over time; after the first 6 years of simulation, the total wood stock volume of exploitable pine forests started to increase again (Fig. 6) while that of oak forests was almost unaffected (Fig. 7). The analysis of the global financial indicator showed a deficit in the SCTL cash flow mainly related to the importance of the expenditures related to the mechanical cleaning of harvested forest plots for grazing.

Scenario 1–2 demonstrated that it was possible to maintain the initial proportion of pastures, silvopastures, clear and dense forests at the territorial scale by harvesting 600 ha of forests over 20 years. However, the SCTL cash flow indicator showed a far greater deficit than in scenario 1–1. The analysis of the situation of f7 showed a global decrease of the total farm forage production per year that was nevertheless significantly less important than in scenario 1–1.

Scenario 1–3 proved the possibility of reaching a positive annual cash flow for SCTL operations and evidenced the capability of SCTL managers to earn profits. However, it had almost no impact on forest encroachment dynamics at either the territorial or farm scale and the total forest area increased significantly.

Scenario β, compared to those of the current scenario, led SCTL managers to focus their attention on farmers' firewood harvesting activities. They concluded that firewood harvesting practices had a significant impact on pine encroachment and coppice canopy closing dynamics.

5.2.2. Second scenario building exercise with managers

The preceding comparative analysis of simulation outcomes of the four scenarios led SCTL managers to imagine possible improvements. They all agreed that farmers' individual projects alone were not enough to sufficiently impact forest dynamics and that some SCTL forest operations consequently were needed. Concerning their financial objective, they decided to reduce the expenditure related to the roller-chopping operations by introducing a new selective criterion: "clean only when it is worth it" depending on "the farmer's capacity to control the forest encroachment dynamic by grazing". This step of the SCTL managers' decision-making process was particularly interesting since the managers made a direct link between one of their management rules with the behaviour and practices of the model's agents. This demonstrated a true appropriation of the ABM as

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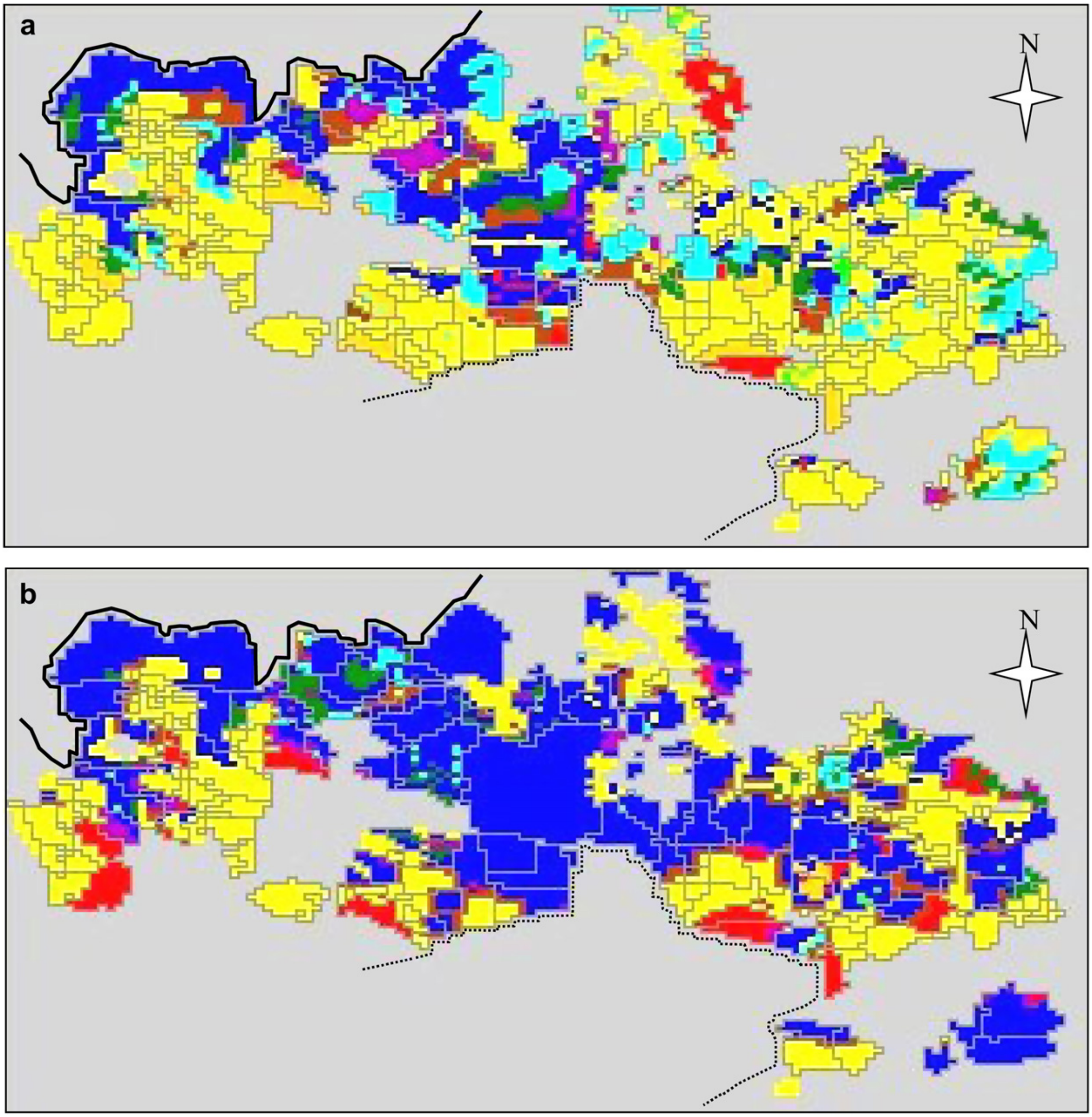

Fig. 5. Rasterised maps of the northern half of the territory (17 of the 31 farms) at the initialization of the model (a) and at the end of the simulation of the scenario 1–1 for a time horizon of 20 years (b). It shows the landcover viewpoint: forest stands are in blue (dense canopy cover in dark blue, clear canopy cover in light blue), shrubs are in red, grass is in yellow. The intermediate colours (orange, purple, green and brown) are different combinations of trees, grass and shrubs (e.g. dense silvopastures are in dark green). The grey full lines are the limits of the paddocks, the black full line is a topographic rupture, and the dotted line is the limit between the military camp and the studied territory.

a negotiation tool with farmers. The managers also decided to explore different options to promote firewood harvesting practices at the territorial scale to better control forest dynamics. On this basis, SCTL managers decided to synthesise their conclusions, impressions, and the knowledge produced into a new combined management (scenario 2–1).

In scenario 2–1, SCTL managers selected the forest plots to be harvested according to a trading capacity indicator (i.e. technically exploitable but not necessarily profitable). For pine forests, they planned a systematic clear cutting on the most productive pine forest plots as required by a few farmers in their individual forest management projects and as recommended in the expert forest plan. In addition, they planned a selective felling in the 1st and 3rd categories of forest stands, and fixed the forest cover objective at 30%. For oak forests, they planned a systematic selective felling in the 1st and 3rd categories of forest stands and fixed the forest cover objective at 50%. They planned a mechanical cleaning effort only on the farms that had used at least 80% of the annual farm forage production the previous year, and only for harvested forest plots with a box cover of less than 50%. To control their financial indicator, SCTL managers targeted a positive bi-annual cash flow. Finally, they decided to multiply by four the annual timber volume to be harvested.

5.3. Third iteration with managers and farmers

After scenario 2–1 was implemented in the ABM by the modelling team, a workshop was organised in January 2006 that gathered together all of the SCTL managers, 15 farmers, local partners, and the modelling team. For SCTL managers, the aim was

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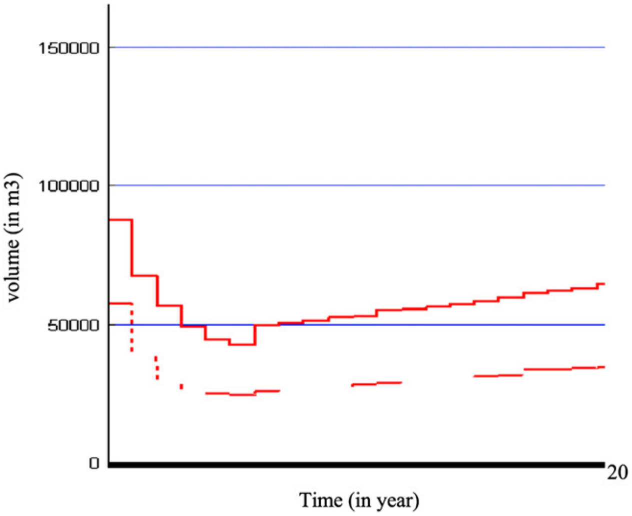

Fig. 6. Evolution of the total wood stock volume of SCTL pine forests (full line) and of SCTL exploitable pine forest (dotted line) (simulation outcomes of the scenario 1–1).

to present, explain, and detail their proposals for forest management to the group of farmers in the form of a restitution of their work. For the local partners, the objective was to discuss the management choices in terms of silvopastoral operations and their impact on farmers' grazing activities. For the modelling team, the principal objective was to confront the objectives and concerns motivating SCTL managers and farmers with the corresponding overlapping of spatial (farm/forest massif) and temporal (short- and mid-term goals from a sheep breeding perspective/long-term goal from a forest dynamics and landscape perspective) scales of forest management.

The problematic at stake was explained again by SCTL managers and a simulation of the current scenario was made. SCTL managers then introduced each of their scenarios and an open discussion was held on the objectives they targeted, the management rules they chose, the criteria they used, and the harvesting operations they planned for each scenario. The research team made sure that all of the information integrated into the scenarios was addressed. Simulations of the complete set of scenarios (scenarios 1–1, 1–2, 1–3, 2–1, and scenario β) were made. We collectively analysed the simulation outcomes making use of different indicators and spatial viewpoints selected either by managers, farmers, modellers, or by local partners.

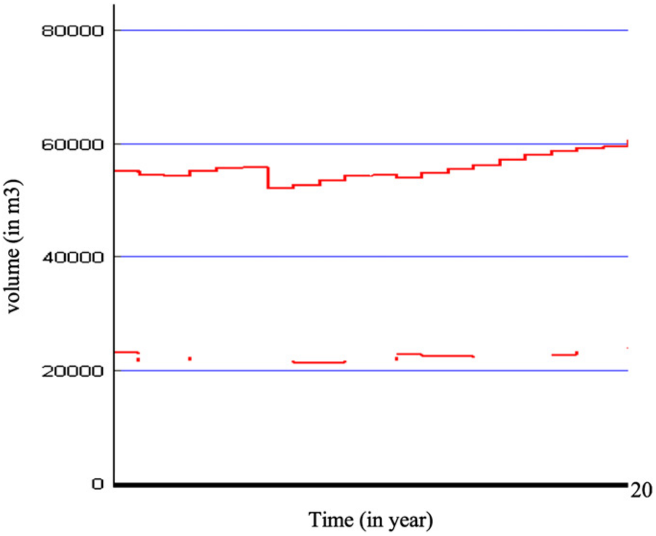

Fig. 7. Evolution of the total wood stock volume of SCTL oak forests (full line) and of SCTL exploitable oak forest (dotted line) (simulation outcomes of the scenario 1–1).

The collective simulations and analysis led farmers to express some disagreements with the management orientations of scenarios 1–1, 1–2 and 1–3. Respectively, they thought that these scenarios did not have a sufficient impact on the forest resource, did not take into account SCTL's limited budget, and did underline how much SCTL was overly constrained by the profitability goal. However, they all agreed that scenario 2–1 was a good synthesis of their wishes and their perceptions of the role SCTL should play in the management and control of the forest resource. In particular, they validated three decision rules: to work in priority with volunteer farmers, to promote farmers' firewood management and practices to control forest dynamics, and to respect farmers' firewood forest stands by excluding them from SCTL harvesting operations.

The discussion process unfolded with very little disagreement between managers and farmers, which struck us as odd. We tried to test the apparent agreement between managers and farmers by addressing some aspects of the managers' synthesis scenario that might be subject to debate. In particular, we wanted to discuss the managers' criteria for mechanical cleaning of harvested areas, one based on the capacity of farmers to make use of new grazing areas. It was a way to evaluate the real degree of acceptance of this scenario by farmers. This additional discussion led the farmers to maintain their point of view about the scenario 2–1 and to affirm their wish to apply it concretely.

Lastly, throughout the third iteration the local partners debated the possibility of adapting farmers' breeding strategies and silvopastoral practices to improve the synergy between the forest management planning and farmers' activities. The discussion mainly addressed the alternative strategies and practices farmers could apply to better control tree and shrub encroachments and to take advantage of the new silvopastoral areas obtained from dense forests. While farmers thought that it was possible to explore and debate short-term technical solutions, they felt that more in-depth analysis and a mid-term assessment of the impact of alternative practices on forest dynamics would be necessary. In this regard, they asked the modelling team to organise some additional simulation exercises focusing on their individual farm situations. Although this demonstrated a real interest on the part of farmers in the use of the ABM as an exploratory tool and for analysis, we were not ready to accompany this next step due to time and budget constraints. The Larzac exercise thus ended at this stage of the collective decision-making process. The stakeholders consequently decided to leave the virtual world of simulations and start to concretely apply some of their proposals on the basis of what they learnt during the companion modelling process.

6. Discussion of the outcomes

We analyse and discuss here the outcomes of the participatory modelling process from three different perspectives: that of the SCTL managers, the forestry expert, and the researcher scientists.

6.1. From the managers' perspective

The companion modelling approach led SCTL managers and farmers to independently address their forest management issue from both a strategic and a technical viewpoint.

SCTL managers improved their strategic approach to the planning of forest management by exploring alternative management strategies and objectives and by formulating these in the form of four different scenarios. Because they could test their proposals and analyse their impact in time and space (at farm and territory scales) virtually, they were able to collectively learn how the system worked, how to adapt to forest dynamics, and how natural and human systems interacted. Consequently, they were able to adapt the way they considered an issue which, in turn, enabled them to define a solution that better fit their perception of natural resources management and their objectives. They moved from considering that a combination of individual strategies at the farm scale (scenario 1–1) could solve their problem and avoid thwarting farmers' wishes to considering that a concerted and negotiated action plan at the massif scale was necessary. They thus progressively oriented their forest management strategy towards a compromise between their roles as representatives of farmers and as administrators of the land association. The analysis of the simulations outcomes helped them to take into account the spatial organisation of forest plots according to the design and production system of a farm, as well as farmers' representations and uses of forests. Consequently, they integrated into their final proposal costly elements (selective felling, shrub clearing) that only make sense when the priority is the sustainability of farm operations and productivity. Lastly, they used the ABM to test different objectives of their management plan, from restraining forest dynamics as much as possible to constraining the forest management plan by a financial indicator. They finally imagined a compromise solution and decided to widen the forest area potentially concerned by harvesting operations by selecting the forest plots according to a trading capacity indicator. They also accepted that priority be given to the control of forest dynamics and the improvement of their farmers' livelihood in the place of maximizing profits through the sale of timber.

SCTL managers also developed their own technical expertise of silvopastoral management by imagining original options that went beyond the conventional standards suggested by local technical partners. In particular, in their scenarios they planned stronger selective felling intensities than those recommended by the local forest and agriculture extension services for silvopastoral operations (Guérin et al., 2005). They choose not to meekly follow the silvopastoral felling intensity recommendations but rather to question and adapt these recommendations according to their silvopastoral objectives and needs. Again, they selected an economic criteria based on a forest cash indicator, whereas the local partners argued for an economic profitability assessment of silvopastoral management integrating short-term indicators. In addition, they choose to assume medium and long-term perspectives in regards to the increase of available forage especially during dry seasons, the improvement of the quality of standing timber, greater flexibility provided to grazing practices, and the possibility of diversifying production systems (Guérin et al., 2001).

The management decisions planned by SCTL managers, especially when they diverged from the viewpoint of the local forest and agriculture extension services, partly question the paradigm of community-based management. To what extent may all knowledge sources be considered as legitimate? Are the social and environmental constructs developed by local actors necessarily a guarantee of natural balance, social equity, and profitability in resource management? To what extent may the facilitator of such a local project of natural resources management orientate the decision-making process towards a compromise between different viewpoints in a context of private ownership of resources? Should the facilitator encourage reflection about the governance of natural resources?

6.2. *From a forestry expert's perspective*

To sort out the differences between the forestry expert's approach and the collective expertise process two facts must be recalled. First, SCTL managers never apply the forest management plan proposed by an expert in 1998. Second, after the end of the ComMod process, they started to work with volunteer farmers, they engaged in several harvesting operations and converted several dense forest plots into silvopastoral areas. Moreover, they elected and now pay a farmer to oversee the technical aspects of SCTL forest activities, and they established some contacts with local private forest enterprises. Recently, they started discussing with the local government the possibility of developing a collective project of wood briquettes production to make use of their low production pine forest stands.

Without debating the relevance of the strategic orientations and actions planned in the expert's forest management plan, we still can conclude that, rightly or wrongly, SCTL managers were not satisfied with the plan. Consequently, what did the companion modelling exercise unblock, and how did this happen?

By addressing their problematic through a participatory, open minded learning process, SCTL stakeholders could formulate their own expectations about forests. They developed a multi-objective silvopastoral management plan that differs greatly from the expert's plan in so far as the objectives of their plan cover both forest and livestock. They also elaborated specific technical options that differed from the forestry expert's recommendations and from those of the range extension service in order to better meet their specific goals. In contrast, the forestry expert's approach was informed by a "traditional" vision that assumed forestry objectives took precedence over livestock objectives and, consequently, that livestock-oriented forestry operations had to adapt to his recommendations rather than the other way around (Bland and Auclair, 1996). The conventional approach to forest management decision-making does not actively or directly provide stakeholders a voice in the process. Instead, it focuses exclusively on the forestry expert's views (Chauvin, 2002; Boutefeu, 2005) which are based on his skills and his perception of the context, stakes, and needs. This kind of approach does not sufficiently address the plurality of possible perceptions and viewpoints, and continues to concentrate on a few indicators of forest profitability based on good forest practices and techniques.

Another interesting result of the companion modelling process was the progressive appropriation by SCTL managers of the forestry expert's management plan. When analysing the content of their scenarios, we observed that they progressively decided to test some of the forestry expert's proposals and even integrated part of these into their final proposal. This seems to demonstrate that the decision-making process that leads to the development of a forest management plan is at least as important as its content. It also suggests that strategic and technical decisions only are relevant when they are understood and appropriated by those who will put them into action. A combination of different expert and scientific knowledge sources enables very well structured and relevant solutions to be built, but innovative and original sources of information held by stakeholders often fail to be integrated, which means that the solutions may not be applied by the stakeholders who are directly concerned (Levrel et al., 2009). Our methodological approach does not focus on the "quality" of the solutions that are developed but rather on the "quality" of the process that leads to them because we believe this is a better guarantee of the sustainability of the forest management. Our participatory approach should be seen as a framework in which a forestry expert could assume the role of an actor in a collective of expertise in which he may share his knowledge and skills. This is in contrast to his conventional role of being *the one who knows* (Boutefeu and Arnould, 2006). The development of a forest management plan with multiple uses and objectives, "at the crossroads of the different users" (Arnould, 2002), one based on

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dialogue and negotiation between users, remains an important issue in forestry (Décamps, 2005; Laroussinie and Bergonzini, 1999; Brun, 2002; Subotsch-Lamande and Chauvin, 2002; Thang et al., 2007). In this regard, the methodology we applied, based on an easy-to-understand model interface and design, demonstrates several advantages and the potential to open forest management planning to stakeholders that differ from the ones who conventionally are involved. Furthermore, our methodology steers the decision-making process towards dialogue and negotiation between different stakeholders who hold their own perceptions, interests, and objectives. In other words, it provides the methodological guidance to move from a DAD model, in which a forestry expert, "Decides, Announces and then Defends", towards a CAC model, in which all stakeholders, "Converse for a negotiated definition of the problem, Analyse all possible solutions and, finally, Choose on the basis of transparent criteria" (Mermet et al., 2004).

6.3. *From the researchers' perspective*

From the perspective of research scientists, two questions arose out of the modelling exercise. The first question refers to the consequences of the co-occurrence of the different roles we played during the modelling exercise. Three of these roles, those of modeller, facilitator, and mediator, are basically inherent to the approach (Van den Belt, 2004). As modellers, we ensured that the model accurately reflected the stakeholders' thoughts about their actual problems. As facilitators, we prepared the talks for the workshops and guided the discussions. As mediators, we ensured the transfer of information between SCTL managers and farmers when we worked with them separately. While these three roles challenge researchers by demanding rigorous mental discipline, some experience with group dynamics, and the ability to adapt to the specificities of the social context, their co-occurrence is integrated into the companion modelling approach. On the other hand, the initially unplanned data collection exercise that was undertaken by one member of the research team on the request of, and funded by, SCTL (step 3) complicated the unfolding of the last steps of the process. By assuming the role of a "forest advisor" in the eyes of SCTL managers and farmers, this scientist introduced a confusing co-occurrence with the other three roles. Based on this experience, we consequently support the call of the signatories of the ComMod charter (ComMod, 2005) for a clear and transparent separation between those individuals who are embedded in the methodological approach and assume the roles of modellers, facilitators, and mediators, and those individuals who contribute technical or scientific insights to the collective debate.

The second question referred to the farmers' "soft" reaction and common acceptance of the SCTL managers' final proposals, even though some decision points clearly could have resulted in sharp arguments between them. SCTL managers benefited from the companion modelling approach to formulate and change their expectations of a forest management plan. They thus moved from behaving as representatives of SCTL farmers to assuming a role of administrator and manager of SCTL lands. Consequently, they progressively elaborated a real forest policy based on compromises between their two main activities (farmer and manager). This means that they assumed the responsibility of translating a forest problematic into strategic and technical decisions that were collectively formulated and accepted with farmers. This empowerment process led SCTL managers to integrate into their forest management decisions some long-term objectives at the territorial scale that greatly differed from the type of goals they are accustomed to as farmers, and are more oriented to the short- and medium-term and defined at the farm scale.

Since it took some time for SCTL managers to reach this compromise in their decisions, we can wonder why it moved quickly to an agreement with the farmers. There are probably two reasons behind this surprising result: the unfolding and scheduling of the methodological approach and certain specificities of the Larzac social context. The first deals with the difficulty that we experienced in fully integrating the farmers into the companion modelling exercise. This mistake was not related to a black box effect (Barreteau et al., 2001) that may have resulted from our initial methodological choice to concentrate on the use of the ABM for scenario building rather than on its appropriation by stakeholders. Indeed, both managers and farmers largely interacted with the model by suggesting new criteria and indicators, and by using it as an exploratory tool and for analysis. On the other hand, the way we scheduled different steps of the method was in part a failure because farmers were left outside of the project framework for a 5 month period. Consequently, while the modelling exercise led both managers and farmers to confront their previous visions and understanding of the system dynamics and interactions, the former benefited more from the use of the ComMod exploratory tools than the latter. One result was a loss in motivation on the part of some farmers whose farms were not greatly affected by forest encroachment. This reveals the difficulty for modellers embedded into such participatory approaches to manage frequent collective workshops and deal with delays due to a lack of information on key aspects of the functioning of the system. As priority must be given to active stakeholder participation, companion modelling facilitators always will have to find a balance between the limited time stakeholders have available and the fact that a typical iteration (conceptualisation, implementation, validation) is time consuming.

Does this imply, however, that managers and farmers benefited from different learning processes and opportunities in this case study? Up until present, we only have evaluated SCTL managers' and farmers' respective learning as the result of a process (Daré et al., 2009), i.e. what the stakeholders produced (criteria, indicators, scenarios, draws, ideas…) during the modelling exercise. Concerning the evaluation of the *process* of learning (Daré et al., 2009) generated by the modelling exercise, a post-evaluation by a political scientist is currently in progress and should contribute some insights on this challenging issue.

The second reason that may partly explain the farmers' reaction is that SCTL managers are predominantly elected from among the farmers and are probably those with the greatest capacity to build consensus. The farmers therefore probably were accustomed to relying on them and on their capacity to defend the farmers' representations of the forest and to integrate key farm management entities. In addition, after having considered the forest problematic for several years, farmers welcomed the managers' final proposal because it consisted of a combination of forest and livestock objectives and integrated individual farmers' interests in the global forest strategy at the massif level. Finally, part of the negotiation process between SCTL managers and farmers most likely took place outside of companion modelling arenas during the traditional social meetings that they have organised ever since the struggle against the extension of the military camp. This last point, i.e. the specific social and historical context of the Larzac, largely facilitated the unfolding of the companion modelling approach since local stakeholders already were used to collective discussion and negotiation. The exercise thus raises interesting issues for ComMod practitioners. For example, to what degree should a companion modelling approach be expected to take over from the existing social network? Should a ComMod approach, and in particular if it is carried out over a long period as in our case study, only complement such networks? Are the democratic debates held within the working framework suggested by the approach necessarily more productive than those that

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take place within the existing social network? Did the partial transfer of the debate to traditional social networks contribute to a better continuity of the project, i.e. its appropriation by stakeholders and its concrete application?

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