7 Participatory modelling of social and ecological dynamics in mountain landscapes subjected to spontaneous ash reforestation

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Abstract

The future of the agriculture in mountain areas constitutes an important stake for sustainable development in relation to landscape functions and their role in local economies. This future depends highly on its ability to develop innovative and multifunctional agricultural systems and to preserve its attractiveness for future generations. Encroachment and reforestation of landscapes, which comes from land abandonment and extensification of land use, raise important topical issues. In Pyrenean valleys, where the land is colonised by the ash tree (*Fraxinus excelsior*), local land managers and policy-makers want to understand better the relationships between the ecological and social processes in order to assist in the design of policies supporting constructive change. Here we present the "companion modelling" approach in which we are all together constructing a simulation model for carrying out a prospective study of land use and landscape changes in the region. According to the principles of this participatory approach, we started developing a spatialised multi-agent model, whose main conceptual aspects are presented here below. The model simulates the evolution of land cover of the agricultural landscape in relation to both the natural and anthropogenic dynamics. Ecological field studies having stressed the role of mowing and grazing practices at the parcel level on colonisation of the local landscape by the ash tree, we focus on the account of prospective change in farmers' land management practices (viewed as a set of decision rules) and their impact. This ongoing study underlines the interest of spatially explicit modelling of the inter-relationships between social and ecological dynamics at the agricultural landscape scale based on an interdisciplinary approach for dealing with rural development topical issues. Both the advantages gained and the difficulties raised are discussed.

Keywords: modelling, participation, multi-agent system, geographic information system, landscape dynamics, ecological processes, management practices, farm, Pyrenees mountains.

7.1 Introduction

7.1.1 Controlling rural landscapes dynamics

Rural landscapes and their changes are topical issues of major importance both in science and policy. There is an important international effort for the scientific assessment of global environmental change on the one hand and a growing awareness of the variety of environmental, economic and social services landscapes provide on the other hand. Indeed, a variety of landscape functions is increasingly regarded as an important basis for sustainable development (Brandt and Vejre 2003, Wiggering et al. 2003). Landscape management in a multi-functional scope is henceforth an explicit item in the agenda of public policies for agricultural and rural development, especially in Europe (e.g., Council of Europe 2000).

Both rationales result in an international research effort towards the spatially explicit modelling of the interrelationships between land use and landscape change and the simulation of their dynamics. On the one hand, landscape ecologists became aware of the importance of the implications of past, present and future patterns of human land use for biodiversity and ecosystem function, and are therefore developing progressive landscape models accounting for their socio-economic drivers, i.e. land use (Turner et al. 2003). On the other hand, land use scientists are increasingly building models on a spatially explicit basis to assess the variety of environmental, economical and social impacts of land use change for rural development (Verburg et al. 2006). A variety of approaches are being developed for building spatially explicit models integrating both land use and landscape dynamics in order to assess their historical changes and to make projections or prospects for their future. They range from the use of spatial statistics, such as models of Markov transition probabilities (Brown et al. 2000) to cellular automata and agent-based simulation models (Parker et al. 2003). The expansion of this later type of approach is very recent. It develops from an evolution in future studies (scenario methods) for supporting environmental policy-making, and also from experience gained in natural resource management (NRM) research and development (Bousquet and Le Page 2004). Methodology of future studies applied to environmental issues evolved continuously with a growing awareness of the importance of uncertainty, of individual human behaviour and of feed-back processes attached to adaptive capacities of ecosystems and social systems (e.g., Greeuw et al. 2000). NRM research developed participatory approaches in which spatially explicit Multi-Agent System (MAS) models constitute a basic media for consultation between land managers (e.g., Etienne et al. 2003).

In this chapter, we present the approach we are developing for modelling social and ecological dynamics in mountain landscapes subjected to spontaneous reforestation. Our approach makes use of recent advances in both future studies and NRM in order to contribute support to local stakeholders in their search for directions for sustainable rural development. The quality of the various landscape functions is all the more important in mountain areas because they are often of a high natural and cultural value and local economies mainly rely on primary production, tourism and leisure activities. The process of spontaneous landscape encroachment by shrubs and trees, concurrent with the decline and modernisation of mountain agriculture, has strong impacts on landscape structure, biodiversity and ecosystem function, the visual and cultural characteristics of the landscape, and on resource availability for agropastoral activities (Bignal and McCracken 1996, Chassany 1999, Caraveli 2000, MacDonald et al. 2000, Olsson et al. 2000). The future of landscape reforestation is all the more uncertain and a matter of social debate, because prospects for silviculture of spontaneous forests are not well established (Curt and Terrasson 1999). The research work we present here is aimed both at supporting local mountain development stakeholders and policy-makers, and at improving scientific understanding of social-ecological dynamics in mountain regions (Curt et al. 1999, Terrasson 1999).

7.1.2 Historical and geographical context

A participatory research project on the spontaneous reforestation of the mountain valleys of Bigorre (French Pyrenees) began in 2003 by the initiative of the Pyrenees National Park (PNP). The project had two objectives: creating knowledge about the ash tree (*Fraxinus excelsior*) overspreading phenomenon and developing references and tools to contribute to the sustainable development of the concerned territories.

The mountains of Bigorre are in the western part of the French Central Pyrenees. Local landscapes are shaped by an old agro-silvo-pastoral tradition (Gibon and Balent 2005). The economy of the region is mainly based on agriculture and tourism, and landscape amenity is very important. The agricultural land, located between 500 m and 1,500 m a.s.l., is mainly occupied by grasslands. It is experiencing a significant encroachment by the ash tree. This species, which is pledged to traditional agro-pastoral systems, is ever-present in the landscape as loose hedges or isolated trees. Since the 1950s, while the number of farms has been reduced by a three factor, more than one-eighth of the used agricultural area has been colonised by ash (Mottet 2005). Local land planners and those involved in development are concerned about the impact of reforestation on the sustainability of agricultural activities, biodiversity, landscape amenity, and on the prospects for economic valorisation of the spontaneous forest settlements. This raises the question for the future of mountain agriculture, which is specialised in breeding and its ability to develop innovative systems in response to the expectations of society and to maintain its attractiveness for future generations.

7.1.3 Integrative modelling of social and ecological dynamics

Our participatory research project brings together researchers from ecology, agricultural and forestry sciences, and geo-informatics (members of the DYNAFOR research unit) and a set of institutional stakeholders of the rural development from the study area (DDAF65, CDA65, CRPGE: see acknowledgements). It began with the building of a visualisation toolkit of future landscape scenarios (Gibon et al. 2006). Now our approach is focusing on building a MAS simulation model for prospecting a set of landscape-change scenarios based on the principles of the "companion modelling" (ComMod 2006).

The rationale for using this participatory method is to involve the local resource managers and policy-makers of the peripheral area of the National Park of the Pyrenees into the various stages of the model development, in order to facilitate sharing knowledge about political measures able to support sustainable development of the mountain area under consideration. Recent works showed that the individual behaviour of the farmers and land owners, as regards maintenance or abandonment of the agricultural use of their land, is an important factor for the spatial patterns of landscape reforestation (Gellrich et al. 2007, Mottet et al. 2006). The objective of our participative research is the co-construction of a simplified and shared representation of the situation at the landscape/village scale that can make it possible to assess scenarios of land use change according to various assumptions about forthcoming changes in the local environment and public policies. It relies on the development of a common view of the interactions between the change of agro-pastoral land management and the processes of ash tree encroachment.

From the research point of view, our first question has been to perform an interdisciplinary assessment of the relationships between the social and ecological dynamics at the landscape scale. In a first step of the project (2003-2006), we characterised the main aspects of the processes involved from various field studies: the ecological processes of ash tree colonisation and their impact on biodiversity (Julien 2006, Julien et al. 2006); the variety in the structure, spatial layout and land use practice of the individual family-farms and their evolution since the 1950s (Mottet 2005, Mottet et al. 2006). A study of the growth potential of spontaneous ash tree forest and its interest for wood production according to two silvicultural management schemes has been started since 2005.

The participatory prospective study we report here benefits from the results of these various research studies, aiding in the development of a common integrated view (i.e., a conceptual model) of the interrelationships between land use and landscape change.

7.2 Study area and data sets

The studied area is the agricultural landscape of Villelongue village (42°57'N, 0°3'W), located about 180 km to the southwest of Toulouse, and 20 km to the south of Lourdes. It covers a small catchment of approximately 2000 ha in the peripheral area of the Pyrenees National Park (Fig. 7.1).

The average annual temperature is 12.5°C (6°C for January and 20°C for August) and the average annual precipitation is 1,000 mm (59 mm for July and 111 mm for April; data from Meteo France, years 1983–2001). Common lands and summer pastures represent about 1,700 ha. Private agricultural land, which covers about 300 ha, lies between 450 and 1,300 m a.s.l. Often steeply sloped (7% of the surface area has a slope over 30%), this land is currently worked by eight farmers.

Most of the farmland utilised area is dedicated to grassland for pasture and haymaking. The agricultural holdings are quite small (average of 18.2 ha) and have extensive livestock farming systems: goat, cattle or mixed cattle and sheep farming (mainly for meat).

The village conditions in 2003 are used as the baseline to simulate the interactions between land use options and ash encroachment for the long term (30 years). Spatial information is maintained in a geographical information system (GIS). Each cell of the landscape map is characterised with a land cover category (cropland, grassland, encroached grassland, young reforestation, woodland, building, and other), a land use category (crop, meadow, pasture, abandoned, wood, and urbanised), slope (less than 10%, 10 to 30%, 30 to 50%, and more than 50%), and identification numbers (farmer, cadastral parcel, and agricultural parcel). Agricultural parcels are used as the basic units for simulating the farmers' technical management of the farmland. Each farm is characterised with the farmer's age, a type of land management strategy, the size of its herd, the cadastral parcels it includes and its agricultural parcels, i.e., its land management units (Fig. 7.1). Types of land management strategy are characterised into the four categories established by Mottet (2005) at the farms in the region.

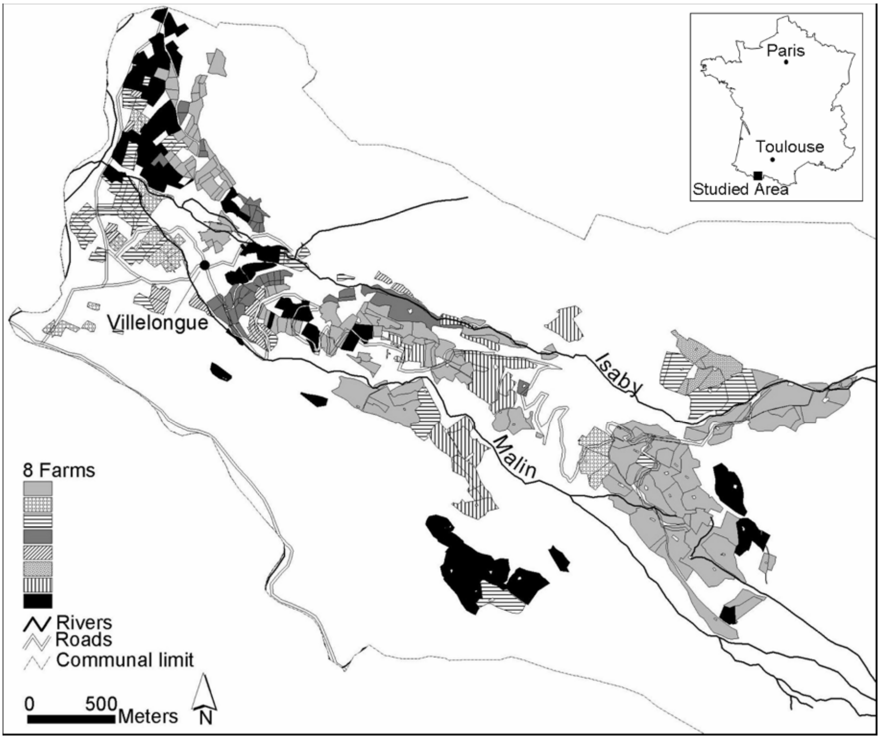

Fig. 7.1 Layout of territories of the farms in the Villelongue village (peripheral area of the Pyrenees National Park). Agricultural parcels of each of the farms are represented using a specific grey nuance. Unfilled areas correspond to village buildings, abandoned farmland and common grazing lands

7.3 Methodology and practical application to the data sets

The questions, of the local participants in charge of rural policy-making, concern anticipating the spatiotemporal dynamics of the landscape reforestation process and their impact on local economy (through change in landscape functions) on the one hand, and assessing the land management orientations that can help control the process on the other hand. The common understanding we built for the interactions between the ecological processes and the agricultural land use lead us to assume change of land management at the individual farms as the main proximate factor driving the landscape reforestation patterns. Therefore we considered it necessary to simulate and evaluate on a spatially explicit basis, assuming changes in individual farmer behaviour in regard to land management and their impact on land covers, according to various scenarios of change of public policies. We selected the multi-agent system (MAS) method for computer modelling, because of its capacity to represent behaviours of actors in their environment (Pahl-Wostl 2005, Parker et al. 2003), and the platform CORMAS (Bousquet et al. 1998) as model development tool, which is well adapted to NRM simulation (e.g., Etienne et al. 2003).

7.3.1 The companion modelling framework

There are several ways of integrating participation of local actors in the development of a model. Parker et al. (2003) identify three main levels of interaction between actors and the model: the actors participate in the design process itself, the actors use the model in the form of role playing games, the actors use the model as a fully functioning scenario-analysis tool. These three levels of interaction between actors and the model can also be combined into a given participatory modelling approach. But the above-mentioned authors note however that the third level of interaction is the most widespread in the literature.

The "companion modelling" approach we adopted (see upper section) relies indeed on a co-construction of the models used with the actors of concern (D'Aquino et al. 2002). The scientific posture adopted in this approach, designed by a research group of the CIRAD Montpellier (Bousquet et al. 1996, Barreteau et al. 2003) and applied for several years for supporting NRM in various contexts (Etienne et al. 2003, Castella et al. 2005), is based on an ethics of transparency concerning the mobilised knowledge and the formulated assumptions (ComMod 2005). The participatory building and use of simulation models and/or role playing games help common learning about the dynamics of socio-ecological systems, and the exploration of scenarios supports reflexion and collective decision-making (Bousquet et al. 1996, Barreteau et al. 2003, Becu et al. 2006).

The development of our model follows an iterative methodological process including conceptualisation, implementation and validation phases in several loops. Conceptualisation and validation phases are carried out through workshops between researchers and local partners, and meetings with researchers only. During these workshops, the results of research studies and expert views of local partners are discussed and combined for modelling the current condition of the land use/landscape system under study, and a set of plausible evolutions for the next 30 years are created.

The implementation of the computer model is carried out in parallel to facilitate feedbacks with the conceptualisation phases. This procedure makes it easier to detect inconsistencies or gaps in the conceptual model and thus helps to improve it. The validation phases consist of a comparison of the implemented and the conceptual models by researchers and local partners, according to the method of social validation of simulation models (Bareteau et al. 2003, Castella et al. 2005). This method is in agreement with the view that the concept of validity is dependent on the purpose of the models under examination (Küppers and Lenhard 2005).

Simultaneous to the conceptualisation of the model, we have commonly agreed which fields should be explored in the scenarios for the future: the demography of the farm population, the municipal policy of urbanisation, and the agricultural and environmental national policies. Indeed scenarios that will be analysed are “external” scenarios (Börjeson et al. 2006, Simon et al. 2006), i.e., scenarios that focus on factors of change beyond the control of the future-study’s participants – here the local partners. The ex-ante definition of scenario topics enables us to direct the construction of the simulator and make sure it will integrate the required elements to address them and assess their impact.

7.3.2 A tool: the multi-agent system modelling

In the companion modelling approach, the model plays the role of an intermediary object that allows for the sharing of knowledge and representation, and assessment of scenarios for change (Etienne 2006). Multi-Agent Systems (MAS) are Artificial Intelligence tools particularly adapted to the simulation of dynamics of natural resource management systems, and the exploration of hypotheses about their future (ComMod 2005). A MAS is able to represent a common resource space in which several categories of computer entities “agents” are able to get information from their environment, operate on it and interact with other agents (Ferber 1995, Franc and Sanders 1998, Parker et al. 2003). These agents can be computer implementations of various actors that operate on the resources or that are dependent on them, and make their decisions according to their own decision criteria with regard to the spatial and temporal characteristics of the common space (Bousquet et al. 2002).

We adopted this formalism for representing simultaneously (1) the farmers’ land management rules according to their individual strategies and the conditions of their immediate and overall environment, (2) the ecological processes of colonisation and encroachment of the grasslands and (3) the interactions between land use and ecological dynamics.

7.3.3 A method: the ARDI (Actors, Resources, Dynamic, Interactions) approach

The first phase of our companion modelling approach consisted in collectively identifying the relevant actors to be represented, their management entities, and the ecological dynamics to be considered. For this purpose, we used the ARDI method that suggests answering the four following questions (Etienne 2006):

- Who are the main actors (A), who have or can have a decisive role in land management on the landscape considered? While identifying them, one has to differentiate between the "direct" actors, whose practices have a direct impact on land cover dynamics, and the "indirect" actors, whose actions influence the direct actors and induce change in their management practice.
- Which are the main resources (R) to be taken into account?
- What are the main ecological dynamics (D), and how are these dynamics affected by the actors selected?
- How does each actor use the resources and interact (I) with the other actors?

The answers to these questions were first formalised in the form of structured diagrams developed during workshops between researchers and partners. These diagrams were used to facilitate both a common understanding between the workshop participants, and the computer implementation of the answers.

We wrote detailed minutes of every workshop in order to monitor the choices agreed upon and their rationale, and to facilitate common decision in case of potential revision later. Additionally, we updated a structured review detailing the state of development of the model after each workshop and business meeting.

We consider these documents important for several reasons: (i) they facilitate the integration of new partners into the project; (ii) they will support the ex-post evaluation of our project, and (iii) they will facilitate the refutability of the model developed.

7.3.4 A requirement: a simplified but relevant simulation model

The modelling choices rely on our objective to develop a simplified but relevant model of the interactions between the social and ecological processes. The objective of simplification comes from our desire to facilitate the understanding of the model operation and building assumptions and its use as a simulator of various scenarios for change. The objective of relevance refers to the capacity to simulate the spatiotemporal land cover changes on a sound basis as regards to the evolution of the landscape properties consecutive to land use change. The objectives of simplicity and relevance are often in opposition to one another. This led us to compromises in the selection of system entities to be represented in the model and the degree of accuracy adopted for it. In particular, the choices of spatial resolution (size of the pixel) and temporal resolution (time step of the simulation) of the MAS model have been very challenging within the participatory group. The knowledge gained in the research studies on the socio-technological dimensions of local land management practice and their rationale, the ecological processes of landscape colonisation by the ash tree and their interactions under local conditions played an important part in the common design of the simulation model and the levels of simplification which could be applied to its different parts.

7.4 Results

7.4.1 The SMASH model

The result of our participative work is the creation of the SMASH multi-agent model (Spatialised Multi-Agent System for ASH colonisation of landscape). SMASH is based on a set of sub-models accounting for social dynamics (land use according to farmers' farm-management strategies) and ecological dynamics (process of grassland encroachment by the ash tree in relation to land use practice). The various sub-models are built with common representations agreed upon within the participatory research group from both scientific knowledge from our research team and expert knowledge from our partners. The SMASH model is currently under development. We present here the most important aspects in reference to the steps of the ARDI method.

7.4.2 Social actors and natural resources management

The static structure of the model is synthesised in a class diagram (Fig. 7.2) using UML conventions (Unified Modeling Language) (Muller 1997). This diagram specifies the key classes and their relations.

The main direct social actor is the farmer. He is considered to manage a farm made up of spatial entities (its farmland) and non-spatial entities (its herd). His behaviour has a direct impact on ash colonisation of grassland through his agricultural land use practices at the parcel level (mainly mowing and grazing), which itself depends on his farm management and development strategy. We plan thereafter to model other social actors playing a part in agricultural land management and the land use dynamics, e.g., people which purchase agricultural barns to turn them into holiday houses (agent "secondary resident"). These people are regarded in the model as indirect actors who impact on land management decisions of the farmers.

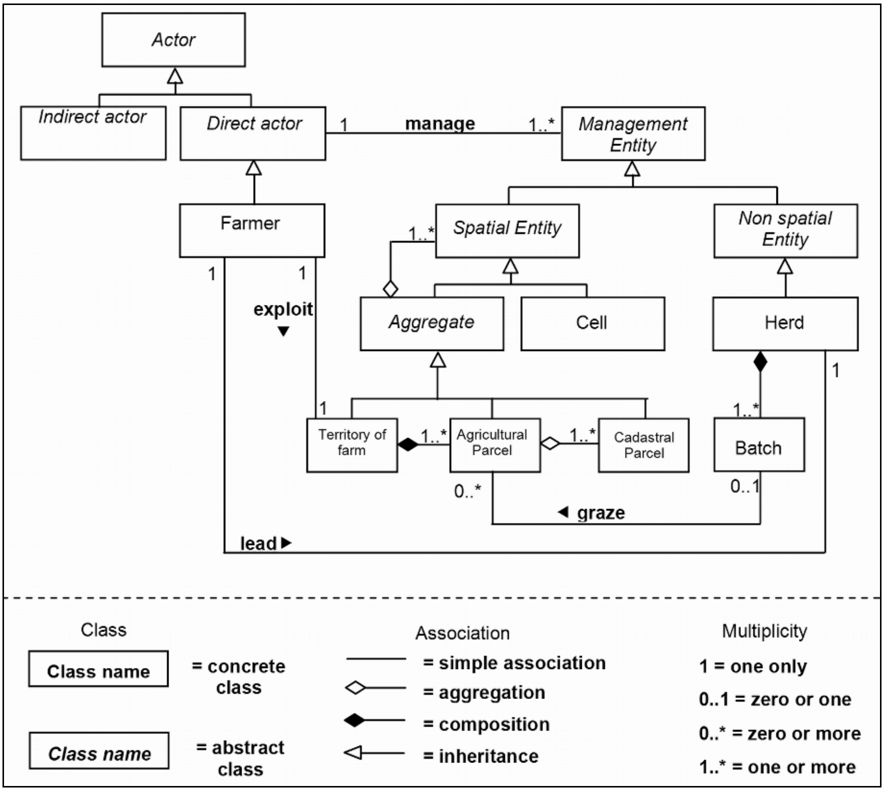

Fig. 7.2 Simplified UML class diagram (Muller 1997) illustrating the key entities of the SMASH model

Landscape space is represented by a grid of elementary space units, the cells. Each cell is characterised with a set of attributes, among them land cover, which allows for the characterisation of the dynamics of installation and expansion of the ash tree in the landscape: i.e., cropland, grassland, encroached grassland, young reforestation, woodland, building, and other.

Three essential spatial entities are superimposed on the spatial grid: the cadastral parcel, the agricultural parcel and the territory of the farm.

The cadastral parcel is the basic unit for land transactions in regards to ownership (transfer by inheritance; sales) and land use rights (land renting). These changes interact for a large part with the individual farm development strategies and individual farmland restructuring. They later impact in return farmers' land management and land use.

The agricultural parcel is the basic unit of the farmland technical management at the farm level. Every agricultural parcel is currently defined in the model as an aggregate of cadastral parcels, characterised by a land use category: crop, meadow, pasture, wood, abandoned land (i.e., in a transition state characterised by the lack of a regular agricultural use). The technical actions operated by the farmer on the agricultural parcels result from his year-round management strategy of the farmland he works. The whole set of agricultural parcels managed by a farmer constitutes the territory of his farm (his farmland).

In the local conditions, the farmer's land management strategy is driven by his herd feeding objectives. Herd feeding year-round includes a wintering period when the herd is fed hay (harvested on the farm meadows) and cereals and maize (harvested on the farm croplands), and a grazing season during which the herd gathers grass on the farm pastures and meadows by themselves, and additionally on the common grazing lands during summer time. The land management strategy consists in a year-round adaptive plan (set of rules) with regard to the spatio-temporal arrangement of mowing operations on the farm meadows, and the batching and allocation of herd animals to farm pastures and meadows, and to common lands. This plan and the climatic conditions of the year determine the harvest type and consumption yield of the grass produced at every grassland parcel. It impacts in return on the dynamics of ash installation in space and time.

7.4.3 Dynamics of the natural resources and ecological processes

Spontaneous reforestation can result not only from a complete abandonment, but also from an extensification of land use (Baudry 1991). Ecological studies carried out by members of our research unit showed that, under the conditions of the study area, (i) every agricultural parcel is subject to an ash seed-rain, because of the spatial distribution of old ash trees throughout the landscape (Julien 2006), and (ii) while mowing prevents efficiently ash colonisation in mown grasslands (i.e., meadows), grazing alone cannot prevent it, when the grazing intensity results in an annual consumption rate of the herbage biomass produced by the parcel below a certain threshold (Julien et al. 2006) (Fig. 7.3). The threshold corresponds to a quantity of grazed herbage amounting to 50% of the grass produced (Balent, comm. pers.).

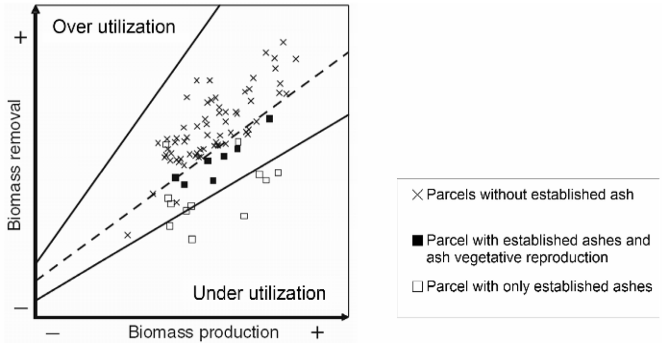

Fig. 7.3 Model of the interactions between the installation of ash trees and land use of the agricultural parcels in the PNP peripheral area (Julien et al. 2006). Parcels located in the area above the upper line suffer from an over utilisation and the ones located below the lower line an under utilisation. The dotted line represents a threshold of intensity of use (ratio biomass removal/biomass production) below which the ash can establish in grasslands which are regularly grazed but not mown

During the participatory workshops, we could build from these results and additional results about ash populations' growth a simplified model of the dynamics of land cover succession in the form of rules of transition. The resulting diagram (Fig. 7.4) indeed illustrates the close interactions between human interventions and those related to the natural processes at the agricultural parcel level: for example, a pasture becomes colonised by ash if it is not grazed for three consecutive years or if the grazing pressure is lower than the threshold for a five years period. A colonised pasture, if not sufficiently grazed, becomes encroached by ash after seven years when there is not any farmer action such as for instance roller chopping.

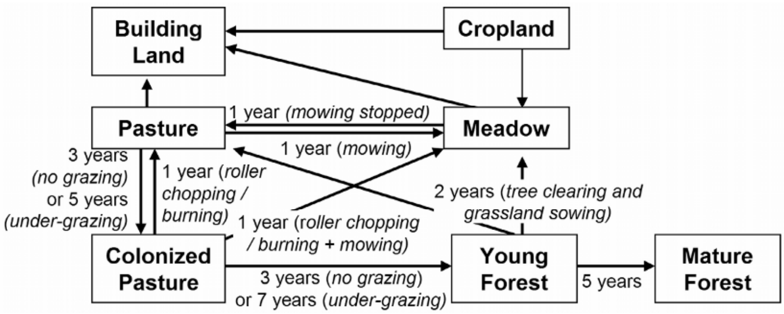

Fig. 7.4 Diagram of transition of natural resources in the case study area

Applying this model requires the assessment of the grass production yield and the herbage consumption for the pasture (grazed-only grasslands). Therefore we introduced in the MAS (1) a grassland model to estimate their grass production on a realistic basis and (2) a detailed model of technical management of the grassland parcels to estimate the herbage consumption by the herd.

The grassland production model used is derived from a dynamic model of herbage accumulation according to grassland category, growth cycle and climatic factors established from studies in other valleys in the Pyrenees (Duru et al. 1998). In this model, three types of grasslands based on annual productivity are considered: poor, medium and productive meadows; for their successive growth cycles, their respective grass growth is modelled from daily climatic data (temperature and rainfall). In SMASH, we use a simplified model according to grassland category and cycle consisting of a growth curve at a 15 day step calculated from the Duru et al.'s model and local meteorological data (see the first cycle of grass growth in Fig. 7.5). We use it to estimate annual grass production on the grassland parcels according to the technical operations carried out, to the date on which they took place, and their duration in the case of grazing operations. The impact of the variations in annual climatic conditions is not yet integrated into the calculation of the grass production.

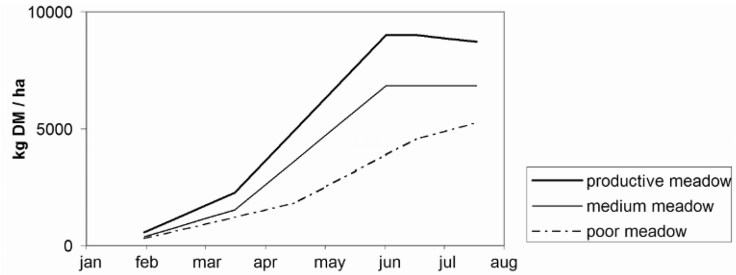

Fig. 7.5 Model of the cumulated grass production during the first cycle of grass growth under the study area conditions (in kg of dry matter per hectare)

The simulation of the operations made on the farm's meadows and pastures at the parcel level from the application of the farmer's land management strategy thus allows for the calculation of the annual herbage consumption on every parcel, by cumulating the days of pasture it provided the herd with over the grazing season.

7.4.4 Dynamics of the use of the agricultural parcels and management of the farms

In farming systems research, farm management year-round and farm development over many years are today generally regarded as general strategies driven by farm-family factors, aims and values (family size and composition, livelihood needs; labour force available, etc.), factors of the local environment (e.g., local market of the agricultural lands; interactions with other farmers, secondary residents, etc.) and overall environment (public policies and agricultural markets). Four strategies have currently been identified among the farmers of our study site: patrimonial strategy, selective strategy, retreat strategy, and niche strategy (Gibon et al. 2006). Within this framework, various research studies showed the livestock farmers' decision making with respect to the farm technical management results from an adaptive behaviour, especially in relation with climatic uncertainty and its impacts on grass production (Duru et al. 1988).

From former modelling of fodder systems (Gibon et al. 1989, Girard et al. 1996), we represented the organisation of the land management practices on the farm parcels to combine (i) a year-round action plan specifying the technical operations to realize on the various agricultural parcels and (ii) methods and rules of adjustment of the plan through the year according to the climatic hazards.

The year-round action plan in reference to production system and main climate characteristics includes periods and related rules for technical operations at the parcel level: for early grazing (e.g., pasture of the meadows before the growth of the hay), spring pasture, first and second mowing, summer, and autumn grazing. The plan includes the definition of the set of parcels at which each type of operation has to be done. It is also at this level that the farmer takes into account the operational constraints on the parcels induced by other land use stakeholders.

In SMASH, actions which apply to the agricultural parcels are carried out every 15 days. This time step was selected to allow a relevant representation of the interactions between the characteristics of the climate of the year, and the dynamics of grass production and consumption at the parcel level. A coarser time step (annual for example) would smooth and simplify the assessment of the annual consumption of grass on the grazed parcels in such a way that would not fit with a realistic enough modelling of the ecological process of colonisation of the pastures by the ash.

7.4.5 Implementation of the model and coupling with GIS

A first prototype version of the model SMASH is implemented using the CORMAS platform (Bousquet et al. 1998) in Smalltalk language. This version is intended to test the validity of the basis of the conceptual modelling and is currently limited to the most common farmer strategy on the study site: the "patrimonial" strategy (Dedieu et al. 2007).

The initialisation of the cell attributes is made with the vector data resulting from the geographical information system (GIS) developed on our study site under the ArcView 3 software. The changeover from their vectorial representation in the GIS to the matrix representation of the spatialised multi-agent model required a rasterisation of the vector layers. We used import-export procedures available in ArcView to rasterise a vector layer in a matrix of numerical values, which is saved with the text format, and we imported into CORMAS the resulting file to initialise attributes of the cells space.

The choice of the cells' size constitutes a generic topical issue when developing a spatialised multi-agent system. It must allow a visualisation of the principal indicators of interest for local actors, and provide a sufficiently precise mapping of the land management entities and ecological processes, while the size of the rasterised representation of the geographical area must remain compatible with the 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).

For supporting the choice of a suited cell size, we carried out a comparative analysis of the effects of the rasterisation of the vector layer of agricultural parcels according to various levels of granularity using two methods:

- by the centre of pixel (the only method implemented in ArcView 3): the pixel is affected to a parcel if its centre is included in it;
- by the relative majority surface (method which we implemented in the form of additional script): the pixel is affected to a parcel if the square intersects at least 1 parcel – in that case the pixel is affected to the parcel of which it contains the greatest surface; if the background has the greatest surface, the pixel is not affected with a parcel.

Thus, we compared the results of the two methods for several pixel sizes (100 m², 200 m², 400 m², 2,500 m²) using the following comparison criterion: calculation of the least square of the relative variations of surface of the farm, each one being balanced by its relative surface. A size of 200 m² (side of 14.14 m) was thus retained. The effect of a shift of a half-pixel on X or Y was also tested to select the one minimising the criterion among the 4 possibilities.

7.5 Validation and discussion of results

Our current results consist mainly of two methodological advances: (i) progress in the production of an integrated framework of the interrelationships between social and ecological systems for the modelling of landscape dynamics, from a combination of field studies, interdisciplinary analysis, and participative workshops, and (ii) its expression into modelling choices for simulation of scenarios. Complete simulation outputs are not yet available, unlike most of the other models presented in this book.

The main objective of this model study, which assesses possible future landscape development in our case study area, is not to predict or prospect future land cover change per se, but to develop an integrated understanding of how the underlying processes operate and interact, and to elicit their driving forces in order to be able to design and assess a set of scenarios to help facing uncertainty.

The intent of our scenario study is to develop "realistic" prospects of the impacts of a set of assumed changes in local and global environments from an account of socio-ecological systems features with significant impact on the quality of the scenario's results (e.g., Greeuw et al. 2000). In particular, uncertainty (climatic risk) and human behaviour (adaptive character and individual variety) are important examples of dynamic features. For predictive scenario purposes, models like cellular automata, Markov chains or neural networks usually compute a set of parameters (transition potentials, transition matrix, weights and biases of activation functions) from training sets of past data in order to minimise an error criterion or maximise a likelihood coefficient. The main limitation of these models is that they behave like a black box with good predictive abilities but poor explanatory power. Creating a glass box with a transparent surface, out of a so-called black box for such models, is difficult because of their fundamental nature, in which it is not always possible to meaningfully associate parameters or functions with real processes (Monteil et al. 2005). In our case, the purpose is clearly to account for ecological and social processes, especially for human behaviour variety and reflexivity, using models of decision-making processes in a mechanistic, formal, and spatially explicit way, at different levels from the parcel, the farm level, to the whole landscape.

Taking into account social interaction, adaptation, and individual decision-making will make the model difficult to validate using classical procedures, because basic rules cannot be directly related to the observation of a single output. However, various kinds of validation may be applied to such models. Rykiel (1996) distinguishes between operational validation (i.e., demonstrating that the model outputs meet some performance standards required for the model purpose) and conceptual validity (i.e., ensuring that assumptions underlying the conceptual model are correct or justifiable and that the representation of the system in the model is reasonable for the model's intended use). The validation of our MAS model falls into the latter category.

We included in our modelling process some facilities for computer model verification (correct implementation of the conceptual model) on the one hand, and validation of the conceptual model with local partners on the other hand. These facilities include several kinds of outputs to visualise and assess the behaviour of the model, either when a simulation is running, or after its completion:

- Spatialised points of view: a dynamic map of given attributes of selected classes can be displayed during the simulation (e.g., land cover, land use); each point of view can be displayed when the simulation is paused, at pre-selected time steps or at the end of the simulation. In addition, the CORMAS platform makes it possible to save JPEG images or AVI videos for preparing meaningful outputs before a workshop with local partners;
- Probes: they graphically plot the evolution of given attributes or indicators through time once the simulation is completed;
- Transcript window: this window displays textual messages as the simulation runs; this facility is useful to demonstrate what the model does when running it in a step by step mode;
- MS Excel data file: in the course of the simulation, a text file is saved with all the operations performed by farmers, and all the transitions that occurred in land use and land cover at the parcel level. After the simulation is completed, this file is imported into an Excel workbook (Fig. 7.6) with a script, which performs a formatting of the operations, hierarchically structuring the lines according to years and fortnights, colouring the background of cells according to the type of farmer operation, and activating the filtering mode of Excel. This makes it possible to analyse the succession of all the operations simulated, qualitatively and quantitatively, to filter the output according to a selected year or fortnight by clicking on small buttons in the margin, or again according to a selected farmer or agricultural parcel with drop-down list boxes. Transitions in land use and land cover are analysed within the same worksheet. Other worksheets containing pre-defined dynamic crosstabs allow for the provision of crossed data between columns (e.g., number of operations by parcels, quantity of dry matter annually cropped by parcel or type of operation, etc.). Additional crossings can be interactively performed thanks to Excel facilities.

Furthermore, the algorithmic procedures coding the dynamics of the system can also be visualised. This makes it possible to understand why a result is observed, and thus can validate or improve the corresponding rule. Meetings between researchers and partners showed that unexpected results are particularly profitable because they force us to analyse why they are computed by the model, and thus to validate the rule or modify it, or to add new outputs.

	A	B	C	D	E	F	G	H	I
1	YEAR	Fortni	Farmer	OPERATION	Agric. Parcel	Dry Matter	Unit	Batch	Remark
103	year 1	fn 12							
112	year 1	fn 13							
169	year 1	fn 14							
170	year 1	fn 14	Farmer 1	grazing	AgricP 1303	-1024	kg DM	Batch 1	Prioritary AgP
171	year 1	fn 14	Farmer 1	grazing	AgricP 1902	-15551	kg DM	Batch 1	sufficient
172	year 1	fn 14	Farmer 1	mowing	AgricP 101	10070	kg DM		
173	year 1	fn 14	Farmer 1	mowing	AgricP 1302	7265	kg DM		
174	year 1	fn 14	Farmer 1	mowing	AgricP 8	4635	kg DM		
175	year 1	fn 14	Farmer 2	providing fodder		585	kg DM	Batch 1	
176	year 1	fn 14	Farmer 3	providing fodder		6630	kg DM	Batch 1	
177	year 1	fn 14	Farmer 3	mowing	AgricP 16	5886	kg DM		
178	year 1	fn 14	Farmer 4	grazing	AgricP 15	-3770	kg DM	Batch 1	insufficient
179	year 1	fn 14	Farmer 4	grazing	AgricP 21	-396	kg DM	Batch 1	insufficient
180	year 1	fn 14	Farmer 4	grazing	AgricP 22	-72	kg DM	Batch 1	insufficient
181	year 1	fn 14	Farmer 4	providing fodder		1222	kg DM	Batch 1	

Fig. 7.6 Operations performed by farmers; each line represents an operation with its properties: the date (year and fortnight), the farmer, the type of operation (grazing, mowing grass, or providing supplementary fodder to meet herd requirements) with coded background colour, the agricultural parcel concerned, the quantity of dry matter, the batch of herd and any potential commentary

The implementation and the validation of the SMASH simulation model are currently under progress, so the model has not yet been used for simulation of scenarios of change. The next steps of our work plan address the conceptual validation of the farm's technical management model according to the patrimonial farmer strategy (i.e., the most frequently observed strategy under the current conditions), then the implementation and integration of the other farmer strategies to account for the variation in their individual behaviour, before starting the development of scenarios.

7.6 Conclusion and outlook

For supporting local policy decision makers in a Pyrenean mountain area, who are in the search for paths for sustainable landscape development, we developed a methodology for landscape change simulation based on the co-construction of a multi-agent model in a participatory research framework. The objective of our work is to run an integrated prospective analysis of both land use and landscape change that can account for the interactions between the two of them. Such a use of the MAS technology has yet to date little representation in the literature (Parker et al. 2003). The use of MAS simulation models for supporting policy decision makers until now has mainly been based on expert models developed by researchers, which are then proposed to the policy decision makers for validation and use, e.g., modifications of variables or parameters can then be applied for simulation and analysis of scenarios (Antona et al. 2002).

The participatory construction of the SMASH model allowed for a fruitful interaction between the participants of the project (researchers and local partners). The exchange of general ideas and concepts, and information about the individual perceptions used for addressed themes, facilitated the emergence of an integrated understanding of the socio-ecological system's operation under consideration, and the construction of a conceptual model of the dynamic relationships existing between land management and landscape. Thus, it facilitated an interdisciplinary integration of both scientific and local expertise and enabled a more robust knowledge of the interactions between ecological and social processes, which can help to better deal with topical issues of sustainable rural development in the study area.

The iterative character of the method used for conceptualisation, implementation, and validation helped the appropriation of the model developed by each of the participants of the project. It made it possible to maintain a balance between the two objectives of our project - production of scientific knowledge and support of policy decision making.

This co-construction process should also easily enable the creation of alternative scenarios, thanks to the knowledge acquired by the participants, as well as the analysis of their results, because the participants have seen how the driving pressures of change were integrated into the computer model.

The experience we gained in our case of study stresses that even within a co-construction process, the contribution of scientific knowledge and data analysis remains critical for the modelling of socio-ecological dynamics. If part of the conceptualisation relied on enquiring workshops bringing together researchers and local partners, a significant part of the time was nevertheless devoted to carrying out concrete integration of scientific knowledge into computable entities, rules and processes using the results of disciplinary and interdisciplinary fields studies and scientific conceptual frameworks. The respective degree of scientific and other stakeholder investment in the participatory modelling of interactions between social and ecological processes, and their respective contributions in terms of knowledge and expertise, remain a matter of debate, at the crossroads between research and development.

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