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Research paper

# Taking into account farmers' decision making to map fine-scale land management adaptation to climate and socio-economic scenarios

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## HIGHLIGHTS

- Participatory regional scenarios combining climate and socio-economic change.
- Role-playing game to map quantitatively small-scale changes in land management.
- Drought frequency interacts with socio-economic context to determine farm adaptation.
- High mountain conditions strongly constrain available options for farm adaptation.
- Recurring drought threatens mountain agriculture and farmers livelihoods.

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## ABSTRACT

Mountain grassland ecosystems are particularly vulnerable to direct climate impacts and to indirect climate change impacts through farmers' management adaptation. We modelled expected spatio-temporal trajectories of land management of a mountain grassland landscape in the French Alps under a range of short-term climate and socio-economic scenarios which were constructed using an advanced participatory approach with a variety of stakeholders. First, regional experts from nature conservation and agricultural extension were involved in the co-development of detailed qualitative climate and socio-economic scenarios, expressed as coherent storylines. Second, to map land management adaptation to these storylines, we used a role playing game whereby farmers were put in an imaginary future situation and asked to make decisions under scenario constraints. For each scenario, game outcomes were used to map future land management at parcels to landscape scales. Main adaptations were conversion from mowing to grazing and increasing manured area, with varying proportions and locations for these two types of changes differing across scenarios, though overall small. These results highlight the limited adaptability of current farmers given a strongly constraining natural and social context. Beyond research outputs, this framework generated interesting outcomes for stakeholders and raised their awareness about the socio-ecological system's vulnerability to future changes.



## 1. Introduction

Mountain ecosystems are highly vulnerable to climate change and extreme events (Engler et al., 2011), such as the increased occurrence of drought observed over the last decades (Lemaire & Pflimlin, 2007) and predicted in the future (IPCC, 2012). Because mountain livestock farming relies mostly on local grassland production (Lemaire and Pflimlin, 2007), the vulnerability of managed grasslands to climate change results from a combination of direct responses of vegetation, and of indirect effects through the impacts on vegetation of management adaptations (e.g., grazing or mowing) (Vittoz, Randin, Dutoit, Bonnet, & Hegg, 2009). Therefore, and because agricultural decision-making is influenced by a variety of drivers (e.g., policies, societal values) (Nettier, Dobremez, Coussy, & Romagny, 2010), the socio-economic and ecological contexts in which climate problems occur are likely to be as important as the climate shock itself (Fraser et al., 2011).To enhance the understanding of the complex interactions and the dynamics of change of all these parameters, environmental and land-use scenarios have been developed and used.

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Scenarios are "plausible and often simplified descriptions of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships" (Millennium Ecosystem Assessment, 2005). "Predictive" scenarios of the type "What-if" address the specific question: "What will happen, on the conditions of specific events?" (Borjeson, Hojer, Dreborg, Ekvall, & Finnveden, 2006), as we did in this study. Answers to this question can be attained by quantitative (e.g., simulation modelling; Schroter et al., 2005) or qualitative scenarios (e.g., SRES storylines) or both (e.g., Millennium Ecosystem Assessment, 2005; Walz et al., 2007). Each method has advantages and drawbacks but qualitative scenarios allow to take into account more variability and uncertainty than quantitative models (Coreau, 2009) and are more understandable for communicating information about the future than numeric tables or graphs (Alcamo et al., 2006; van Vliet, Kok, & Veldkamp, 2010).

Usually, scenario building follows a framework composed of five main steps: (1) defining the focal question, (2) identifying the key drivers, (3) determining the scenario logics, (4) describing scenario assumptions using qualitative scenario storylines, and (5) assessing scenario outcomes or developing quantitative scenarios based on a numerical model (Metzger, Rounsevell, Van den Heiligenberg, Perez-Soba, & Hardiman, 2010). Qualitative and/or regional scenarios tend to involve stakeholders and experts in a set of procedures through which they work together to develop the storylines (steps 1 to 4) (Alcamo et al., 2006; Volkery, Ribeiro, Henrichs, & Hoogeveen, 2008). Their involvement is particularly valuable due to their extensive local knowledge (Swetnam et al., 2011; Walz et al., 2007) and the fact they are very likely to be actors themselves (Bohunovsky, Jager, & Omann, 2010). Several methods are used in participatory scenario development such as interviews or focus groups, stakeholders panel workshops, gaming workshops, policy exercises, or story and simulation approaches (Alcamo et al., 2006).

Quantitative land-use change models used to integrate storylines to visualize alternative land-use configurations are typically statistically-calibrated models (Verburg et al., 2002), economic models (Janssen & van Ittersum, 2007), or agent-based models (Valbuena, Verburg, Veldkamp, Bregt, & Ligtenberg, 2010). While economic models assume perfect rationality of stakeholders, agent-based modelling (ABM) has the advantage of allowing spatial analyses of the interactions between agents and their environment (Matthews, Gilbert, Roach, Polhill, & Gotts, 2007), by taking into account explicitly a greater complexity of agent-decisions making processes (Valbuena et al., 2010). In ABMs, the decision-making process of agents is generally based on rules defined and parametrized with either artificial or empirical data. As it requires complex and intensive data gathering (Smajgl, Brown, Valbuena, & Huigen, 2011; Valbuena, Verburg, & Bregt, 2008), only a limited set of parameters is usually taken into account. Moreover, in ABMs, decision-making is often the only cognitive component explicitly considered to explain how agents change their land-use practices under changing conditions. The assumption of a simple and stable set of preferences and decisions that underlies modelling approach is insufficient in case of non-linear change (Meyfroidt, 2012). Similarly to ABMs, role-playing games (RPG) focuses on the role of agents of land-use changes (as opposed to drivers as in statistically-calibrated models), but RPGs, by putting real stakeholders in a close to real situation during the game (Castella, Trung, & Boissau, 2005), allow measuring and analysing impacts of the real complexity of human cognition and social interactions. Moreover, stakeholders can debate whether the model represents how they played the RPG, and how the RPG differs from reality (Janssen & Ostrom, 2006). Because of the additional knowledge gained from RPG compared to surveys, RPG can also be used to develop more realistic ABM (Janssen & Ostrom, 2006; Smajgl et al., 2011). Validation of modelling results dealing with the complexity and uncertainty of human decision-making requires further interviews with stakeholders involved or experts to verify the plausibility of the simulated results (Valbuena et al., 2010).

Considering the advantages and shortcomings of various existing approaches, this study aimed at developing and testing a framework combining a role playing game with ancillary technical information and spatial statistics on current land-use to model spatially-explicit, fine-scale land-use adaptation to climate and socio-economic change, taking into account real farmers' decision making, beliefs and values. For that purpose, we used a three-step participatory scenario approach combining: (i) the development of regional expert-based qualitative storylines at regional scale, (ii) identification and quantification of local land-use adaptation using a RPG with farmers and (iii) a systematic mapping of these land-use adaptations on the real landscape at field scale. The integration of these three steps, combining qualitative and quantitative methods from different disciplines, allows to integrate and to translate qualitative driving forces and farmers land-use decisions into spatial map of land-use change at small-scale.

This framework was tested on a municipality hosting a long term socio-ecological research platform (LTSER) where detailed data on vegetation, climate and farming systems have been collected for a decade. These highly detailed data and local knowledge allowed us to easily test and put into practice the framework.

## 2. Study area

The study site (45°03′N, 6°24′E) is located within the municipality of Villar d'Arène, located in the Ecrins National Park (Central French Alps). The total area of the south-facing slopes used for livestock production is 13 km$^2$ and the elevation ranges from 1552 to 2500 m asl. Climate is subalpine with a strong continental influence due to a rain shadow with respect to dominant westerly winds. Mean annual rainfall is 956 mm and mean monthly temperatures of −4.6 °C in January to 11 °C in July (at 2050 m above sea level). Only, 40% of annual rainfall occurs during the growing season (April–September). The alpine meadows above 2200 m have been grazed extensively in summer for centuries, but the former arable land on terraced slopes (1650–2000 m) was converted at the beginning of the 20th century into grasslands that are now grazed or mown where they are accessible to machinery (Girel, Quétier, Bignon, & Aubert, 2010). All grassland types (Table 1) have been managed at low intensity with low stocking rates, very low manure inputs (every two or three years) and a single annual hay cut. Farmers try to be fodder self-sufficient for the long winter season (6 to 7 months) given the cost of fodder. Eight farmers remain today, of which five farm full-time, one farms part-time and two are retired but continue to farm. The eight farms can be classified into three categories according to their production systems: (1) lamb production (three farms, mean = 21 livestock units (LU), 19 ha); (2) production of calves and heifers (three farms, mean = 67 LU, 55 ha), (3) mixed sheep and cattle production (two farms, mean = 54 LU, 48 ha). During summer, the alpine meadows are managed by a shepherd who looks after the local sheep herds along with his own

**Table 1**
Current characteristics of grasslands types of Villar d'Arène (minimum–maximum).

| Grassland type | Altitude range (m) | Slope (degree) | Forage production (T/ha) |
|---|---|---|---|
| Terraces mown and manured | 1584–1944 | 0.16–37 | 3.07–4.63 |
| Terraces mown | 1554–1938 | 1.12–61.3 | 3.00–4.87 |
| Terraces grazed | 1539–1794 | 0.39–59 | 2.98–4.86 |
| Unterraced grasslands mown | 1854–2013 | 1.65–34.2 | 3.57–4.64 |
| Unterraced grasslands grazed | 1702–2024 | 1.28–43.7 | 3.12–4.90 |
| Alpine meadows | 2228–2710 | 0.33–63.5 | 3.16–4.18 |