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Adapting grazing practices to limit the reforestation of mountainous summer pastures: A process-based approach

Laure A. Vacquié [a, *], Thomas Houet [a], David Sheeren [b], Nicolas de Munnik [a], Virginie Roussel [a], Julien Waddle [a]

[a] GEODE Laboratory, Toulouse Jean Jaurès University, 5 alleys Antonio Machado, 31000 Toulouse, France
[b] University of Toulouse, INP-ENSAT, UMR 1201 DYNAFOR, 31326 Castanet-Tolosan, France

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ABSTRACT

European mountain landscapes are experiencing massive land-use changes and high rates of natural reforestation since the 1950s. Summer pastures are particularly sensitive to those dynamics since their natural state depends on human activities. A process-based model - SHIELD (Simulating Herd Impact on Encroachment in upLanD) – has been developed to identify the key leverages of pastoral practices to limit the natural reforestation in the Haut-Vicdessos (Pyrenees Mountains, France). Simulations are compared to observed land cover changes to validate the model's structure. Scenarios are simulated to assess various grazing practices on reforestation dynamics: a baseline scenario and three scenarios with contrasted pastoral management: (i) reintroducing herds with no human supervision, (ii) reintroducing herds supervised by a shepherd and (iii) increasing the cattle load without supervision. Results show that supervising the intensity of land units' occupancy can be as efficient as increasing the cattle load to limit the ongoing trends of reforestation.

Software availability

Name of software: Netlogo
Developers: Laure Vacquié, Thomas Houet, David Sheeren
Contact address: GEODE Laboratory, Toulouse Jean Jaurès University, 31053 Toulouse, France
Phone: +330563503689
Email: laure.vacquie@univ-tlse2.fr (Laure Vacquié)
Hardware required: 32-bit or 64-bit PC with Windows 8, Windows 7, Vista, 2000 or XP; Mac OS X 10.6 or newer
Software required: Netlogo software (http://ccl.northwestern.edu/netlogo). MS Office Excel for modifying input files
Program language: Scala, Java
Availability and cost: Freeware (including demo data set) downloadable upon request by emailing at laure.vacquie@univ-tlse2.fr.

1. Introduction

While in most developed countries agriculture has intensified in the past decades, leading to more homogeneous and mono-functional landscapes (Brandt, 2003), it does not apply to all agricultural systems. Mountainous landscapes are essentially composed of small fragmented agricultural entities mainly oriented toward livestock farming. Agro-pastoral landscapes in the Pyrenees Mountains are traditionally used for multiple purposes and consist of a mosaic of crops, grasslands, moors and closed forest, with scattered or clustered trees on open lands (Etienne, 2006; Balent and Gibon, 2011). They present a high ecological value by providing habitats to several endemic species and agricultural resources (Vacquié, 2011; Chétalat et al., 2013). However, they are identified as highly vulnerable to environmental, societal and economical changes (Grandjean et al., 2014; Houet et al., 2012). Reforestation is perceived by local farmers and stakeholders as an irreversible loss of their natural heritage and as unfavorable to touristic development (Gillet, 2008). The settlement and expansion of forests typically result in a decrease in landscape heterogeneity, threatening the spatial distribution of endemic species and ecosystems' attractiveness (Galop et al., 2011). The impacts of land abandonment on the quality and viability of landscapes are raising

* Corresponding author.
E-mail addresses: laure.vacquie@univ-tlse2.fr (L.A. Vacquié), thomas.houet@univ-tlse2.fr (T. Houet), david.sheeren@ensat.fr (D. Sheeren), nicolas.demunnik@univ-tlse2.fr (N. de Munnik), virginie.rouss@gmail.com (V. Roussel), julienwad@wanadoo.fr (J. Waddle).

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major concerns for politicians, planners and local stakeholders concerned with mountain land use (Busch, 2006).

Mountain pastures (referred as uplands hereafter) are dynamic systems subjected to natural vegetation dynamics controlled by livestock activities (Galop et al., 2011). A better understanding of pastoral ecosystem dynamics is needed (Peringer et al., 2013). Depending on socio-economic and geographical contexts, land management actions can either drive pastoral lands toward a more intensive land use (Rao and Pant, 2001) leading to an overall stability of uplands, or towards a more extensive land use resulting in tree encroachment and reforestation dynamics (McDonald et al., 2000; Gartzia et al., 2014). Overall, management practices, i.e. stocking rates and grazing routines (location and duration of grazing), can have a major impact on landscape structure by influencing vegetation dynamics and trees establishment (Julien et al., 2006; Gibon and Balent, 2005). Although current livestock activities help maintaining pastoral lands, historical practices also have a strong influence on mountain landscapes (Balent et al., 1998; Mottet et al., 2006). For centuries, traditional pastoral systems have shaped a variety of mountainous landscapes across Europe as the result of various management strategies and policies, local human decision-making and physical factors (Olsson et al., 2000; Tasser and Tappeiner, 2002).

Land abandonment of agro-pastoral lands has been predominant in many parts of the Pyrenees, with a concurrent decrease of land-use intensity of traditional uplands and an increase of forested lands (Mottet et al., 2007). Spontaneous reforestation processes on former open-lands have been observed in the French Pyrenees over the past 60 years (Garcia-Ruiz et al., 1996; Cohen et al., 2011; Sheeren et al., 2012; Galop et al., 2013). They are expected to intensify in the upcoming decades, leading to an upward shift of forest ecosystems. Although reforestation can have positive outcomes (e.g. carbon storage, soil restoration, etc.) it can also have a lasting effect on environmental aspects such as biodiversity (Laiolo et al., 2004), water supply (Szczypta et al., 2015) or landscape attractiveness (Mottet et al., 2006). Moreover, reforestation on formerly open land is often perceived by local users as a cultural loss tied to traditional activities (Hochtl et al., 2005). Overall, encroachment and reforestation are a threat to the support of mountain agro-pastoralism since they usually leads to a decrease in forage quality and requires significant financial resources to restore uplands to their original state (Houet et al., 2015). While at the global scale reforestation dynamics are strongly influenced by climatic factors, i.e. temperature variations (Kessler et al., 2007), at local/regional scales they are closely related to land use and land cover changes (LUCC) (Chauchard et al., 2007; Millington et al., 2007; Wallentin et al., 2008), and especially to the abandonment or decrease of land use intensity of summer uplands (Métailié and Paegelow, 2004). Thus, agro-pastoral activities are considered as a major factor driving reforestation patterns, and more generally the spatial organization and composition of mountain landscapes (Vacquie et al., 2015).

In the recent years, a large number of prospective studies have been developed to better understand the complexity of driving factors of LUCC and distinguish their respective and combined effects on landscape dynamics by combining spatially explicit models and scenarios-based modelling approaches (Verburg et al., 2006a; Houet et al., 2010). Many prospective studies exist at the global scale and usually focus on the impact of human activities and climate change on LUCC (Millennium Ecosystem Assessment, 2003; IPCC, 2000). Using global driving factors (e.g. demographic changes, economic growth, etc.) they are used to describe alternate futures to assess the consequences of LUCC and the degree of adaptation and vulnerability of various landscapes (Alcamo et al., 2006). Concurrently, several European projects have been focusing on rural development and agricultural policies issues by adapting quantitative indicators of change used at global scales to spatial and temporal scales that relevant for regional studies (Klijn et al., 2005; Rounsevell et al., 2005; Verburg et al., 2006b). Mountainous pastoral systems in particular require considering a wide range of factors, i.e. natural, socio-economic, political and historical, to produce meaningful results (Krausman et al., 2003). Thus, model-based approaches are promising tools to better simulate the effects of natural dynamics and their underlying processes on LUCC while accounting for interactions between them and their environment (Parker et al., 2003; Snow et al., 2014). Moreover, spatially explicit agent-based models (ABMs) can be used as an effective tool to implement alternate agro-pastoral management strategies and identify areas at stakes to guide planners' or local stakeholders' decision making to better anticipate future changes (Gibon et al., 2010; Anselme et al., 2010).

The objective of this paper is to present a spatially explicit model accounting for the interactions between grazing activities and land cover dynamics: the SHIELD (Simulating Herd Impact on Encroachment in upLanD) model. Based on different grazing management strategies in uplands, it aims to help identify the key leverages of grazing practices to limit natural reforestation. Indeed, one important aspect of upland management consists in defining a suitable stocking density, i.e. the “number of animals to graze per unit area of land for a specific amount of time” (Malecheck, 1982) that allows an optimal forage consumption and limits the loss of ungrazed vegetation (Cannas and Pulina, 2007). The reduction of livestock density is considered as a major potential factor driving reforestation processes (Améstegui et al., 2010). We assume that other management strategies could be efficient as well, even though varying cattle load is not always considered as an adaptive solution for farmers because of technical and/or economic reasons. The model focuses on the interactions and feedbacks between three parameters that drive land cover dynamics: vegetation successions, cattle activity and tree growth. The model validation and the assessment of its sensitivity to input parameters are conducted by comparing simulations to the current land cover map. Then, scenarios of pastoral practices are simulated and compared to provide insights on their respective influence on the encroachment and natural reforestation of uplands.

2. Study area

The study area is located in the Central French Pyrenees and covers approximately 13 km^2 (Fig. 1). The modelled area, the upland of Bassiès, is part of a national research observatory of the Haut-Vicdessos valley, and spans from the subalpine beech forest (approx. 1500 m a.s.l) to the alpine grasslands (approx. 2700 m a.s.l.). A subalpine pine forest (*Pinus uncinata*) spans above 1800 m a.s.l. It is an emblematic species of the Pyrenees capable of surviving in difficult bio-climatic conditions with a high capability of establishment in abandoned open lands (Cantegrel, 1984). At lower elevations on slopes of the intermediary farms lands, a beech forest (*Fagus sylvatica*) is also present. Its maximal elevation has gradually increased over the years due to both land use and climatic changes accordingly to LULC trends observed in the Pyrenees (Bolliger et al., 2007).

The Haut-Vicdessos is representative of land uses shifts that took place in many parts of the Pyrenees since the mid-1950s. In a context of intense rural depopulation and economic crisis, the population gradually decreased causing a progressive abandonment of farmlands (Galop et al., 2011). Cattle are mainly present in the southern part of the Haut-Vicdessos valley that offers a better accessibility and forages. Conversely, livestock presence in the upland of Bassiès has disappeared in 2014. Consequently, with a long