



Confounding legacies of land uses and land-form pattern on the regional vegetation structure and diversity of Mediterranean montane forests



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ARTICLE INFO

Article history:

Received 10 July 2016

Received in revised form 31 October 2016

Accepted 1 November 2016

Keywords:

Historical ecology
Large herbivores
Forest management
Pastoralism
Grazing
Forest uses

ABSTRACT

Grazing by livestock and logging are among the main widespread forest uses in mountain forests. Centuries of these anthropogenic disturbances have shaped forests in Europe, especially in the Mediterranean region. Since the 19th century, pastoralism and forestry have experienced deep changes. The present study aims to assess and quantify the effects of these changes in forest uses along with environmental variables on forest vegetation structure and diversity in order to disentangle the role of landform *versus* land uses on ecological diversity in Mediterranean Pyrenees forests. Forest uses history was inferred from historical records and census whereas environmental variables, forest structure and diversity proxies were collected and measured based on 42 plots within 5 forests situated on the French-Spanish boundary. Both variables of environment and forest uses explained forest structure and diversity pattern. The most important part of the forest structure and the diversity pattern were due to the joined effect of forest uses, environmental and spatial variables. As expected, altitude, slope, temperature and precipitation were the main environmental drivers of forest structures and diversity. Among forest uses, the historical forestry treatment and the historical dominant livestock also strongly controlled the forest structure and diversity. Forest uses and environmental variables are closely related since forest use pattern is constrained by physical features. Covariation among forest uses and environmental variables produce confounding effects that make difficult the determination of the exact causal relationships. The contributions of forest uses, environmental and spatial variables were not disentangled due to large covariance between each variable.

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1. Introduction

Land uses have globally changed owing to diverse driving forces (Lambin et al., 2001). Such changes can be divided into changes in land cover, e.g. forest transition following land use abandonment, (Rudel et al., 2005) or changes in practices in an extant cover, e.g. forest use changes, (Gimmi et al., 2008). The ecological consequences of land cover changes, notably of land abandonment, have been well studied (Chauchard et al., 2007; Niedrist et al., 2009). However, consequences of changes in traditional management practices in extant covers have been less investigated.

In the Mediterranean region, forests are exploited for centuries, at least, by local societies to meet their needs. Grazing and logging are one of the main widespread forest uses in Mediterranean forests (Barbero et al., 1990; Fabbio et al., 2003) and these practices are gathered under the term “sylvo-pastoralism” when they take place in the same forest (Rapey et al., 2001). Past and present anthropogenic disturbances are powerful drivers shaping forest ecosystems (Dupouey et al., 2002; Foster et al., 2003; Chauchard et al., 2013), although it appears that natural disturbances such as wildfires can be a component of the ecosystem for long time (Leys et al., 2014).

Since the 19th century, pastoralism, as traditional non-timber forest use, has experienced a net decrease in the northern Mediterranean basin, linked to rural exodus and abandonment of traditional practices (Barbero et al., 1990). Logging is still used but management practices have changed, notably due to the increasing use of fossil fuel during the second half of the 20th century that

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resulted in a coppice regime change (Barbero et al., 1990), i.e. decrease of firewood harvesting and charcoal production. It is expected that these forestry changes may result in transformation in vegetation features (Cierjacks and Hensen, 2004; Onaindia et al., 2004; Torras and Saura, 2008) including forest structure and species diversity or distribution (Bodin et al., 2013; Fortuny et al., 2014). These changes can affect resilience and stability of forest ecosystems notably facing changes in disturbance regimes such as fires. Indeed, structural and species diversity levels are important factors of resilience and stability of forest ecosystems (Lähde et al., 1999; Neumann and Starlinger, 2001; Pommerening, 2002).

It is well known that environmental variables, e.g. soil or topography, have a key role on the organisation of vegetation pattern. But, environmental variables, as forest uses variables, are generally scale dependent (Levin, 1992) and their values are not randomly distributed in space, likely linked to the properties of natural landscape. Even if forest uses and environmental factors can each separately have an effect on ecosystems, their interactions are important in determining the structure, the composition and the dynamics of many systems (Paine et al., 1998; Kulakowski et al., 2011). To assess the function of forest uses on the ecosystems, it is essential to reconstruct the history of social disturbances (Axelson et al., 2002; Veski et al., 2005; Gimmi et al., 2008), while taking into account the variation in environmental factors and the contribution of the spatial structures (Schwarz et al., 2003; Gazol and Ibanez, 2009).

This study aims to quantify and disentangle the functional properties of changes in pastoralism and forestry practices on the present-day vegetation structure and vascular plants diversity while taking into account environmental variables and spatial structures. The investigations were carried out in forests from the Mediterranean Pyrenees, which showed different histories of local uses, allowing precise comparisons in the same geographical and environmental context. The present paper (1) defines the forest uses and environmental variables that strongly influence current vegetation structure and plant diversity, (2) describes the effects of past and present forest use changes and environmental variables, and (3) determines covariation between these explanatory variables and to attempt to disentangle the relative contribution of historical forest uses, environmental variables and spatial structure. A previous paper highlighted that understorey plant assemblages characterized by their species list (presence/absence) and their life traits were selected according to both past land uses and landscape slopes (Fortuny et al., 2014). The present investigation is more complex by taking into account as response variable the whole plant community (under- and overstorey) and woody debris, characterized by quantitative values of diversity (e.g. richness), biomass (e.g. basal area), leaf area index and growth form.

2. Methods

2.1. Study area

The study area consisted of five montane forests located in the eastern French Pyrenees on the northern slopes of a range along the French-Spanish boundary corresponding to the crests up to 1256 m above sea level (asl) at the Puig Neulós in the east and, 1450 m asl at the Roc de France in the west (Fig. 1). The two forests in the western part are forests of the municipalities of Maureillas-Illas and Céret. The two forests of Sorède and Laroque-des-Albères in the east are French state forests. Both municipal and state forests are managed by the French national forest administration (*Office national des forêts*, ONF), but the stakeholder is the city for municipal forests, and the ONF for state forests. The eastern forest of the study area is a Natural Reserve (La Massane NR) located in the municipality forest of Argelès-sur-Mer. This forest

was designated as Nature Reserve in 1973, but was already protected since the early 1950s. Approximately 10 ha of the inner forest zone were fenced-off by the RN managers since 1954 to exclude livestock grazing. The fence consists of a wire netting of 1.10 m height without fastening in the soil. No forestry intervention was conducted in the Massane forest during the studied period except black pine plantation for soil protection after the wildfire of 1880 (Chauchard et al., 2006).

From the Middle Age to the beginning of the 20th century, the forests were widely used for grazing (cows, sheep, goats, horses, and pigs), for charcoal production, for firewood and wood for shipbuilding. During the 20th century, these forests were managed for timber production, protection against erosion, landscape preservation and also biodiversity conservation. Except in the Massane forest (Argelès-sur-Mer) where forestry has been abandoned notably for ecological conservation during the 20th, timber is the current forestry treatment in the study area. During the first half of the 19th century, sheep dominated livestock herds (Fig. SM.1). At the end of the 19th, livestock composition changed since sheep husbandry was largely substituted by cattle in the eastern part of the study area. Generally, livestock decreased since the 18–19th century transition (Fig. SM.1). However, each forest has its own grazing and forestry history that is analysed in the [Supplementary Material](#), from the eastern to the western forest. Generally, the livestock of municipalities (i.e., the overall livestock from the municipality inhabitants) exhibited the same trend than municipal forest livestock authorized to graze in the forest, supporting the general trend observed at the forest scale (Fig. SM.1). On the contrary, no direct link can be made between trends of inhabitants and livestock. Indeed, the number of local inhabitants has increased in the study area during the study period independently from agricultural processes (Fig. SM.1).

In this study, we focused on the lower montane belt of five selected forests. The mean altitude of sampling stands is about 800 ± 185 m asl, and the mean slope is about $26 \pm 6^\circ$ (Table 1). Bedrock is composed of shale and gneiss and soils belong to the acid (pH 4.3 ± 0.4) brunisol category (Servant, 1970). The lower montane vegetation belongs to the acidic beech forest type (Dupias, 1985). The woody community is dominated by beech (*Fagus sylvatica* L.) mixed with other broad-leaved trees, mainly white oak (*Quercus pubescens* Willd.), chestnut (*Castanea sativa* Mill.) and whitebeam (*Sorbus aria* L.). Individuals of maples (*Acer campestre* L.), lime tree (*Tilia cordata* Mill.), wild cherry-tree (*Prunus avium* L.) and holm oak (*Q. ilex* L.), are scattered throughout the forests. In the understory, beech is the main species along with European holly (*Ilex aquifolium* L.) in some places and, individuals of chestnut, whitebeam, common hazel (*Corylus avellana* L.), briar-root (*Erica arborea* L.) and Italian maple (*Acer opalus* Mill.) are also locally abundant. The herbaceous vegetation is dominated by *Deschampsia flexuosa* (L.) Trin., *Galium pumilum* Murray, *Hieracium murorum* L., *Conopodium majus* (Gouan) Loret, *Luzula forsteri* (Sm.) DC. and *Veronica officinalis* L.

The climate is typical of the Mediterranean mountains, with warm and dry summers, and cool winters. Precipitations are mainly concentrated in spring and autumn, and summer precipitations are provided by thunderstorms. Climate data are not available in forests nor at their altitude, but simulated data based on geographic coordinates x, y, z (long., lat., alt.) can be inferred for each study site from the AUREHLY meteorological model (Benichou and Le Breton, 1987). Between 1961 and 1990, the mean annual precipitation is 1038 ± 70 mm, and mean annual temperature is $12.1 \pm 0.7^\circ\text{C}$, with the coldest month in February ($5.6 \pm 0.8^\circ\text{C}$) and the warmest in July ($20.4 \pm 0.8^\circ\text{C}$). The forest components of the study area are along an east-west gradient from the Mediterranean coast to the inner Pyrenees, which create a gentle climatic gradient with a decrease in temperatures (about

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