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Woody encroachment and soil carbon stocks in subalpine areas in the Central Spanish Pyrenees

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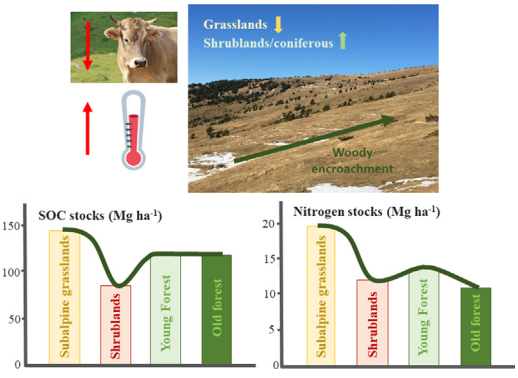
HIGHLIGHTS

- Woody encroachment has been an ongoing process in the subalpine belt of Mediterranean.
- We analyzed LULC changes and the effects of these changes in soil properties.
- Encroachment has occurred due to the expansion of coniferous forests and shrublands.
- SOC and N contents and stocks were higher in the grasslands sites.
- The woody encroachment process initially produced a decrease in the SOC stocks.

GRAPHICAL ABSTRACT



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ABSTRACT

Woody encroachment has been an ongoing process in the subalpine belt of Mediterranean mountains, after land abandonment, the disappearance of the transhumant system and the decrease of the livestock number. The main objectives of this study were: (i) to identify land use/land cover (LULC) changes from 1956 to 2015, and (ii) to investigate the effects of LULC changes in physical and chemical soil properties and soil organic carbon (SOC) and nitrogen (N) stocks. It is hypothesized that woody encroachment in the subalpine belt may lead to significant changes in soil properties, and will generate an increase in the SOC stocks. A land use gradient was identified in the subalpine belt of the Central Spanish Pyrenees: (i) subalpine grasslands, (ii) shrublands, (iii) young forests, and (iv) old forests. Mineral soil samples were collected every 10 cm, down to 40 cm, at three points per each LULC and a total of 48 samples were analyzed. The results showed that (i) woody encroachment has occurred from 1956 to 2015 due to the expansion of coniferous forests and shrublands (at the expense of grasslands), (ii) land cover and soil depth had significant effects on soil properties (except for pH), being larger in the uppermost 0–10 cm depth, (iii) SOC and N contents and stocks were higher in the grassland sites, and (iv) the woody encroachment process initially produced a decrease in the SOC stocks (shrublands), but no differences were observed considering the complete soil profile between grasslands and young and old forests. Further studies, describing SOC stabilization and quantifying above-ground carbon (shrub and tree biomass) are required.

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1. Introduction

The management of agropastoral ecosystems is one of the major challenges facing our society today, especially in Mediterranean mountain areas, due to their high vulnerability to Climate Change (Giorgi, 2006; Nogués Bravo et al., 2008; López-Moreno et al., 2017) and to the abandonment of agricultural and pastoral activities since the mid-twentieth century (MacDonald et al., 2000; Strijker, 2005; Hatna and Bakker, 2011; Lasanta et al., 2017). One of the consequences is the transformation of many fine-grained cultural landscapes into homogeneous coarse-grained landscapes (Van Eetvelde and Antrop, 2003; Lasanta et al., 2005) with socioeconomic and environmental effects on the local population and nearby areas (Mottet et al., 2006; Gellrich et al., 2007; Bernués et al., 2014).

In Mediterranean mountains, grassland ecosystems are extremely important as producers of many goods and services for society (provisioning, regulation, support, culture) and as contributors to the support of a rich biodiversity (Millennium Ecosystem Assessment, 2005; Raudsepp-Hearne et al., 2010; Bernués et al., 2014). Grasslands provide forage for large wild herbivores and for livestock, so they play a prominent role in the mountain economy and even in many country economy's (Villagrasa et al., 2015). It should not be forgotten that livestock farming contributes directly to food security and provides livelihood to almost one billion people in the world (FAO, 2009). Grasslands also play an important regulatory role; they act as firewalls in areas where the rural abandonment favors the expansion of woody communities, which increase the risk of fires (i.e., Lloret et al., 2002; Beilin et al., 2014). In addition, grasslands regulate the hydrological cycle because it has been demonstrated that spontaneous revegetation or afforestation processes of grassland areas reduce the discharge of rivers (García-Ruiz et al., 2011; López-Moreno et al., 2011; Nadal-Romero et al., 2013). The support services provided by grasslands are based on their high plant diversity, with species adapted to extreme conditions or at its distribution limit, which increases the number of endemism and provides to the grasslands a high ecological value (Canals and Sebastià, 2000). Consequently, the loss of grasslands reduces plant and faunal biodiversity (Ratajczak et al., 2012; Canals et al., 2014). In addition, grasslands, that were created, used and maintained by men for centuries or millennia, give rise to a cultural landscape of high aesthetic value, offering cultural services such as recreational (tourism), educational and spiritual services (Lamarque et al., 2014) and contributing to the well-being of rural areas (Hejcman et al., 2013; Huber et al., 2013). On the other hand, grasslands are an important source of ecological information and local knowledge on adaptation of management systems to adapt to Global Change (Fernández-Giménez and Fillat, 2012; Harsch et al., 2009).

An important portion of Mediterranean mountain grasslands are semi-natural, being the result of human intervention for millennia, eliminating woody species with fires or shrub clearing to generate extensive summer pastures that were used by extensive livestock (Didier, 2001; Roepke and Krause, 2013; Sanjuán et al., 2017). The persistence of these grasslands largely depends on the continuity of grazing and the clearing of woody plants (When et al., 2011; Gartzia et al., 2014).

In the Central Spanish Pyrenees, the semi-natural grasslands reach in altitude to approximately 2400 m a.s.l., coinciding with the upper limit of the subalpine belt and the maximum level for the development of shrubland, while *Pinus uncinata* would reach up to 2200 m a.s.l. (García-Ruiz et al., 1990; Badía and Fillat, 2008). These grasslands were created by human fires from the mid-Holocene, but more actively from the Bronze Age to the Middle Ages, when much of the subalpine belt was deforested to graze transhumant livestock (Bal et al., 2011; Cunill et al., 2012; Pérez-Sanz et al., 2013). However, since the middle

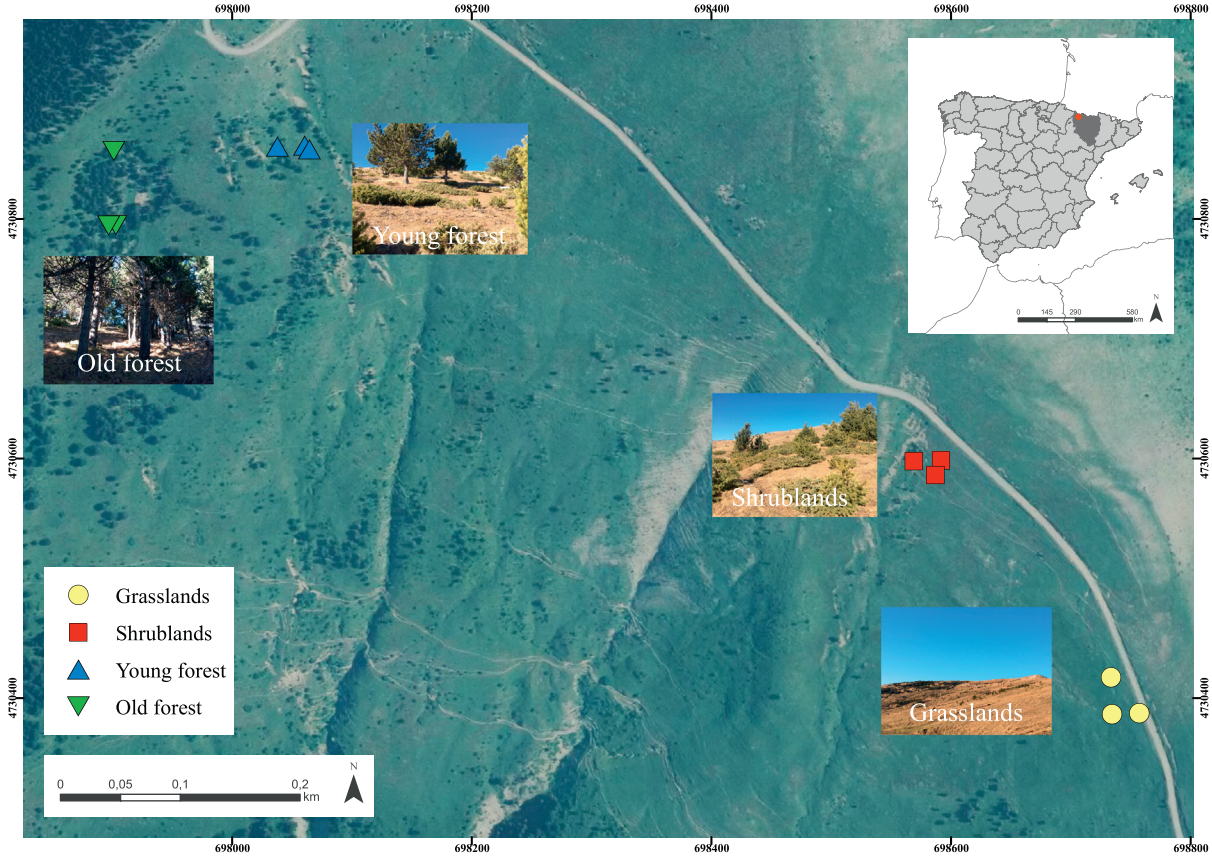

Fig. 1. Location of sampling points and the study area (Central Spanish Pyrenees).