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Tracking Montane Mediterranean grasslands: Analysis of the effects of snow with other related hydro-meteorological variables and land-use change on pollen emissions

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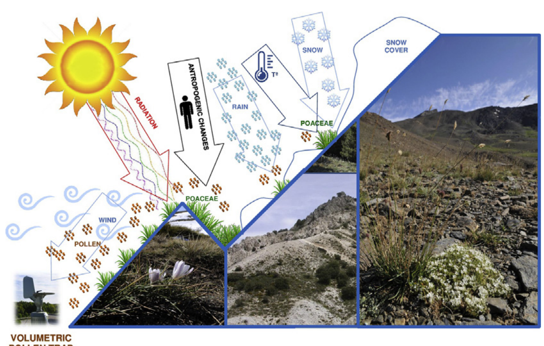
HIGHLIGHTS

- Temporal evolution of the high mountain Mediterranean grasslands was explored.
- Grass pollen emissions were used as indicators of response to environmental changes.
- Snow-packs outside the winter season is one of the most influential parameters on the pollen index.
- Changes in land use in the preferred habitats of grasses are also driver of change.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper explores the dynamics of temporal evolution of the high mountain Mediterranean grasslands, (Sierra Nevada, Spain SE). The indicator used is the emission of pollen (Pollen Index, PI) with respect to two important aspects: the incidence of the snow dynamic together with other hydro-meteorological parameters, and the changes in land use, which can Influence the evolution of the grasslands throughout time. The results reveal that pollen emissions in the last 25 years have shown a slight downward trend, with large interannual fluctuations, which are a consequence of diverse environmental factors, both general and specific to the area. One of the most influential parameters on pollen concentrations is snow cover, which reinforces the importance of the presence of snow-packs as water resource outside the winter season in the High Mediterranean Mountain environments. The changes in land use experienced in the area are a driver of change, especially due to the losses experienced in the last decades in the preferred habitats for many species of grasses. It can be concluded that the vulnerability of these ecosystems will be affected by an increase in winter temperatures and/or a decrease in rainfall (climate change) and an increase in the intensity of anthropogenic activities on land use. In this

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context, the PI is shown as a useful indicator of global change given its sensitivity to both anthropic and hydro-meteorological changes. In addition, it has a wide range of spatial detection and discrimination capacity by altitudinal dimensions.

1. Introduction

The grasses constitute a family of monocotyledonous plants that includes some 10,000 species of cosmopolitan distribution (Bouchenak-Khelladi et al., 2008). Among the outstanding species are those forming vegetation units (grasslands) present in most of the terrestrial ecozones: tropical and sub-tropical, savannas, temperate, flooded, montane, tundra, desert and xeric (Ellenberg and Mueller Dombois, 1967). In the Mediterranean Region, the grasslands, including rangeland, pastures, meadows and fodder crops, occupy up to 48% of the territory and participate in the provision of ecosystem services such as biodiversity conservation, forage and food production, carbon fixation, climate regulation, soil and water protection, pollination and nutrient storage (Hönigová et al., 2012). The pastures located in the mountainous areas of the region are also highly diversified and rich in endemic plants, with endemicity rates that can exceed 30% of the total of flora taxa in some territories (Medáil and Quézel, 1999).

Sierra Nevada is one of the highest mountain ranges in the Mediterranean Region, located in the southeast region of the Iberian Peninsula, in an east-west direction. Given its pronounced altitudinal gradient, the grasslands there present several domains. On the one hand, the psychroxerophilic grassland resides in the most developed soils, with a predominance of perennial grasses; on the other hand, starting at 2000 m a.s.l, the hygrophilous vegetation corresponds to humid grassland in summer that is covered with snow throughout most of the year, and which is known as "borreguiles" (Salazar et al., 2001). The important changes experienced in the area in the last 50 years have highlighted the serious risk of threat that these ecosystems can suffer, which is exacerbated by the particular environmental characteristics of the Mediterranean area (Beniston, 2003; Bravo et al., 2008). These important changes in the area include both pronounced climatic variations (Pérez-Palazón et al., 2015), with significant reduction of the snow cover period (Pérez-Luque et al., 2015), and changes in land use and plant cover (Jiménez-Olivencia et al., 2015).

Much of the natural wealth of this territory is given by its particular topographic, climatic, edaphic and geological conditions, which in turn are the cause of great vulnerability to any change in them. The analysis and monitoring of climatic conditions and the evolutionary dynamics of plant communities become fundamental actions both to know the trend of change and its effects. In the Sierra Nevada, the tracking and monitoring of current climate conditions and future trends have been carried out for several decades (Zamora et al., 2016) in the framework of monitoring programs such as The Sierra Nevada Global Change Observatory (OBSNEV) (Bonet et al., 2011), based on the conceptual framework and the thematic areas proposed by the Global Change in Mountain Regions initiative (GLOCHAMORE), through the UNESCO MaB program (Schaaf, 2012) and the Global Observation Research Initiative in Alpine Environments (GLORIA) (Pauli et al., 2007). The monitoring of climatic variables is carried out with a fairly extensive network of meteorological stations, which since 2004 has been expanding towards higher altitudes (Herrero et al., 2011; Algarra and Herrero, 2014, 2016), where there is almost a complete lack of data. These meteorological records are the pillars underpinning the advance towards the most precise knowledge of the hydrology of the region. This knowledge, in conjunction with distributed physically-based hydrological models (Herrero et al., 2009), allows for the obtaining of time series of hydrological variables, such as the amount and duration of snow (Pimentel et al., 2015), the potential evapotranspiration (Aguilar et al., 2010), or the soil moisture, with a spatial resolution within the tens of meters. This information is important not only for the analysis of the trends on the hydrometeorological variables themselves (Pérez-Palazón et al., 2015), but also because these abiotic variables drive the changes in the plant communities that reside in this physical environment (Zamora et al., 2016).

To obtain information on the effects that environmental changes may have on plant species and populations, it is necessary to have indicators that allow predicting the intensity of the expected change and the response to it. This is essential, especially when dealing with highly vulnerable ecosystems with low resilience capacity, such as high mountain grass communities. The amount of pollen emitted into the atmosphere by the vegetation during its reproductive process has proven to be a valid indicator to know the factors that have greater effect on the biological state of the vegetation and its response to the change. Thus, pollen records have been used to know the response and environmental behaviour of different groups of plants to arid climate conditions (Cariñanos et al., 2004, 2014), as a tool for assessing the status of endangered species (Cariñanos et al., 2014), and to estimate trends in evolution of forest-forming species (Cariñanos et al., 2016). There are also some specific studies on grasses, in which the exogenous factors and endogenous processes that intervene in the release of pollen into the atmosphere have been analyzed (García-Mozo et al., 2010; García de León et al., 2015; Hernández Plaza et al., 2012). In addition to these factors, the impact of land-cover changes on the presence of grass pollen has also been explored in some areas of the Mediterranean (García-Mozo et al., 2016), although given the ubiquity and large number of existing species in some areas, this relationship is not yet clear.

In this context, it could be considered that the high dependence of the different populations of grasses present in the Sierra Nevada to the environmental conditions, and the intensity of climate change expected in the area, makes it necessary to intensify the tracking of these communities using indicators of response to these effects. Due to the Sierra Nevada's high vulnerability to climate change, and its projections of future change, it would be hypothesized that hydro-meteorological conditions and land use change are some of the variables with the greatest effect on mountain grass populations. Therefore, an analysis of pollen emissions of grasses in the Sierra Nevada environment could be used to describe temporal and spatial variation of the different grassland communities present in it, as well as to highlight the main drivers participating in its dynamics. The aim of this paper is to explore the relationship that could exist between the evolution of the montane grasslands of the High Mediterranean Mountain with two important groups of variables not well studied until now. To this end, pollen emissions derived from grass communities and their possible response to hydrometeorological and anthropogenic factors will be analyzed. Among the first, special emphasis is placed on induced effects by the snow dynamics. The anthropogenic approach focuses on the possible influence of changes in land use that occurred in the same area during the last decades.

2. Material and methods

2.1. Description of the area of study

The Sierra Nevada (Fig. 1) is a mountain massif with a surface area of >2000 km^2 and a maximum height of 3479 m a.s.l., which extends linearly 90 km east-west and an average width of about 35 km, in the southeast region of the Iberian Peninsula. The Sierra Nevada presents important natural values, which are recognized in the figures of "Natural Park", "National Park" and "Biosphere Reserve". Moreover, it is one of the main centers of diversity of the Eastern Mediterranean