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Environmental and climate change in the southern Central Pyrenees since the Last Glacial Maximum: A view from the lake records

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ABSTRACT

In this contribution we compile and summarize the available paleo-environmental lacustrine data for the last 20,000 years from the southern Central Pyrenees (from west to east: El Portalet, Tramacastilla, Basa de la Mora, Estanya, Redon, Montcortès and Marcelino lakes) and present a new sequence from mid altitude (Holocene record of Lake Estanya). Multiproxy analyses of lake records have identified large vegetation and hydrological changes during last glacial, deglaciation and the Holocene periods at millennial, centennial and even decadal scales and documented their timing, intensity and varied nature. The review indicates that landscape dynamics in the Pyrenees have been greatly controlled by both long term and abrupt climate changes and, since the Middle Holocene, and particularly since Medieval times, by human activities as new transforming agent. Although high internal variability characterized every site, common temporal trends are evidenced, as well as a suggestive western–eastern gradient superimposed to the expected altitudinal one (highlands *versus* lowlands). Thus, the long-term Central Pyrenees environmental history presents a relatively high degree of internal coherence across space and provides some past scenarios of landscape-climate interactions to evaluate the expected impacts of current and future Global Change.

1. Introduction

Hydrology, surface processes and biological dynamics are particularly sensitive to climate and environmental changes in Mediterranean mountain areas (IPCC, 2013). However, research on global change impacts at these specific geoecosystems has to deal with the complex interactions between natural climate variability and ancient human civilizations. The complex landscape heritage that characterize today the Mediterranean region (Roberts et al., 2011; García-Ruiz et al., 2015) has been carved by regional and local particularities, historical contingencies and geographical and ecological features (Carrión et al., 2010).

The nature and dynamics of this complexity in Mediterranean mountain geoecosystems can only be approached throughout long-term studies of landscape evolution aimed to evaluate both the global change impact and its social and economic implications and consequences (Galop and Catto, 2014). In this context, the Pyrenees are a key region to investigate past human-climate interactions because of (i) their geographic location as a barrier and bridge between the Iberian Peninsula and the rest of the European continent and also as a corridor between the Atlantic Ocean and the Mediterranean sea, (ii) their steep altitudinal gradient, (iii) their proven sensitivity to past and recent changes (García-Ruiz et al., 2015) and (iv) their long history of human occupation and relationship with its environment (Utrilla and Rodanés, 1997; Valdeyron, 2008; Utrilla et al., 2012; Montes et al., 2016).

Low altitude areas in the Pyrenees are much prone to have been continually occupied and modified by anthropogenic activities than high altitude zones where more severe climate conditions have probably hampered stable human settlements and intense use of natural resources (Galop, 1998, 2006; González-Sampériz and Sopena, 2002; Rull et al., 2010). A particularly fruitful strategy to understand past global chagne impacts in this territory is based on the comparison and integration of sequences located at different altitudes to provide information about how, when and where natural climate dynamics have impacted environmental evolution (i.e., Morellón et al., 2012).

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The objective of this work is to synthesize available reconstructions of past landscape dynamics in the southern Central Pyrenees based on lacustrine records and contribute to shed some light on the long history of climate-humans interactions that have been shaping the Pyrenean landscape during the last millennia. A number of well-dated multiproxy lacustrine sequences, mostly published during the last decade (i.e., Pèlachs et al., 2007, 2011; Ejarque et al., 2009, 2010; Pérez-Obiol et al., 2012; Catalán et al., 2013; Cunill et al., 2012, 2013), have demonstrated the occurrence of rapid climatic fluctuations (González-Sampériz et al., 2006), not only during last deglaciation (Morellón et al., 2009; Rius et al., 2012) or, in general, the Late Pleistocene (Vegas-Vilarrúbia et al., 2013; Gil-Romera et al., 2014) but also during the entire Holocene (Plà and Catalàn, 2005; Miras et al., 2007, 2010; Pérez-Sanz et al., 2013), and particularly the last millennia (Morellón et al., 2011; Bal et al., 2011; Rull et al., 2011; Corella et al., 2011, 2012, 2014). This documented variability has affected plant cover distribution, lake level fluctuations, soil erosion and runoff generation, flood frequency, fire dynamics and even the spatial organization of human activities.

Most of the studied sequences at the Spanish side of the Central Pyrenees are located between 1600–2300 m a.s.l., hindering our understanding of landscape evolution along an altitudinal transect. Up to now, only four published lacustrine sequences are located below 1200 m a.s.l.: i) Paúl de Bubal, a pollen sequence without a robust chronological model (Montserrat-Martí, 1992; Jalut et al., 1992); ii) Estanya lake, a sedimentological and paleohydrological study covering the last 20,000 years (Morellón et al., 2009) but with paleoecological data (pollen and diatoms) only for Lateglacial and the beginning of the Holocene (Vegas-Vilarrúbia et al., 2013); iii) Marcelino paleolake sedimentary sequence, that effectively recorded the paleohydrological variability in the inner depression of a tufa-mound between 22,000-1100 years BP (Pellicer et al., in press); and iv) a 6000-years lake sedimentary record in Montcortès (Corella et al., 2011, 2012), with published pollen data only for the last 1000 years (Rull et al., 2011). In this paper, we present a compilation of these available multiproxy lacustrine sequences data from the southern Central Pyrenees and include the complete palynological record of the Estanya lake record (670 m a.s.l.). The records illustrate the relative roles of climatic shifts and human activities on long-term landscape evolution, throughout the vegetation dynamics and hydrological changes in an altitudinal transect.

2. The southern Central Pyrenees: geographical setting

2.1. Geological framework and sites location

The Pyrenees is an alpine range stretching for about 450 km from the Cantabrian to the Mediterranean Sea (Fig. 1A). According to the geological structure, three main zones are distinguished: i) the Axial Pyrenees, with igneous and metamorphic rocks of Paleozoic age (Teixell, 1992); ii) the Internal Sierras, mainly composed of limestones from the Cretaceous, Paleocene and Eocene age (Muñoz, 1992); and iii) the External Sierras with Triassic limestones, marls and evaporites and Upper-Cretacous to Eocene carbonatic rocks (Rosell, 1994).

The lacustrine sequences from the Central Pyrenees included in this review are located in the three structural units: Portalet peatbog (42°48′N, 0°23′, 1802 m a.s.l.) and Redon lake (42°38′N, 0°46′E, 2240 m a.s.l.) are placed in the Axial Pyrenees, whereas Tramacastilla (42°43′N, 0°23′W, 1640 m a.s.l.) and Basa de la Mora (42°32′N, 0°19′E, 1914 m a.s.l.) lakes are located in the Internal Sierras. Finally, Montcortès (42°19′N, 0°59′E, 1027 m a.s.l.), Estanya (42°02′N, 0°32′E, 670 m a.s.l.) and Marcelino (42° 08′N, 1°00′E, 648 m a.s.l.) lakes are in the External Sierras (Figs. 1A and 2).

2.2. Climate characteristics

The study sites are located in the southern slopes of the Central Pyrenees, in the transitional zone of Mediterranean and Atlantic climate regimes. As shown in Figs. 1B and C, the area has high temperature and precipitation gradients which are determined by both the altitude and the proximity to the Atlantic Ocean or the Mediterranean Sea. Mean annual precipitation (MAP) in western locations (El Portalet and Tramacastilla) is high (1450 and 1380 mm respectively, see location in

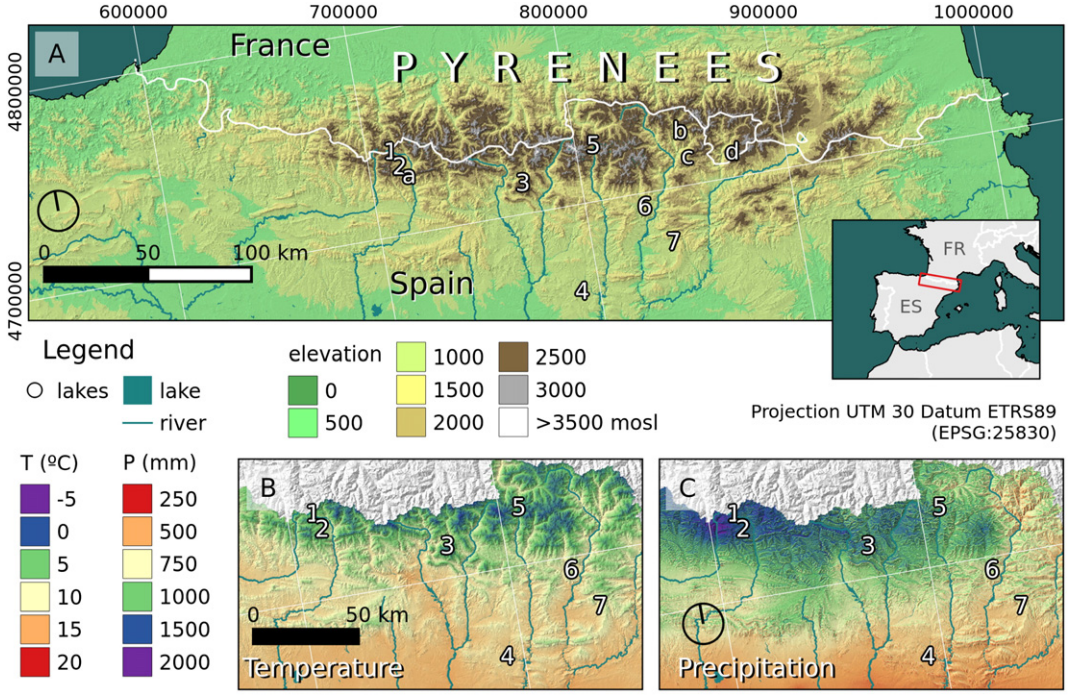

Fig. 1. A) General location of the study sites: 1. Portalet; 2. Tramacastilla; 3. Basa de la Mora; 4. Estanya; 5. Redon; 6. Montcortès; 7. Marcelino (lacustrine sequences considered in this work); a. Paúl de Bubal; b. Estanilles and Boldís-Montarenyo; c. Burg and d. Perafita, Estanyons and Orris (lacustrine sequences cited in discussion). Gradient of mean annual temperature (B) and total annual precipitation values (C) of the Central Pyrenees.
Map sources: elevation data from ASTER GDEM v2 (METI/NASA, 2011), hydrology from IGN-CNIG 1:200K base map (BCN200) and climate data from Digital Climatic Atlas of the Iberian Peninsula (Ninyerola et al., 2005).