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# Sediment delivery and lake dynamics in a Mediterranean mountain watershed: Human-climate interactions during the last millennium (El Tobar Lake record, Iberian Range, Spain)

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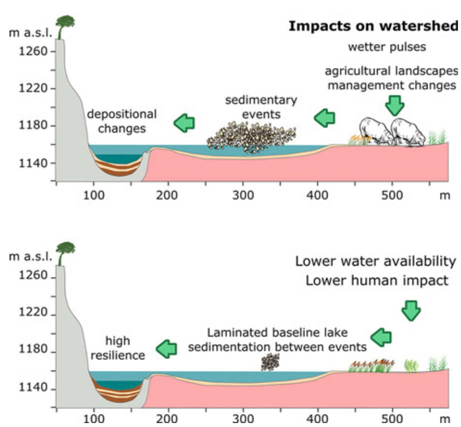
## HIGHLIGHTS

- Lake watershed highly affected by anthropic activities during the last millennium
- Proxies define 4 events of increased sediment delivery during LIA and recent times
- Events are due to positive synergies of increasing human impact and higher rainfall
- Lake system showed large resilience to land uses changes in the lake's watershed

## GRAPHICAL ABSTRACT

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## ABSTRACT

Land degradation and soil erosion are key environmental problems in Mediterranean mountains characterized by a long history of human occupation and a strong variability of hydrological regimes. To assess recent trends and evaluate climatic and anthropogenic impacts in these highly human modified watersheds we apply an historical approach combining lake sediment core multi-proxy analyses and reconstructions of past land uses to El Tobar Lake watershed, located in the Iberian Range (Central Spain). Four main periods of increased sediment delivery have been identified in the 8 m long sediment sequence by their depositional and geochemical signatures. They took place around 16th, late 18th, mid 19th and early 20th centuries as a result of large land uses changes such as forest clearing, farming and grazing during periods of increasing population. In this highly human-modified watershed, positive synergies between human impact and humid periods led to increased sediment delivery periods. During the last millennium, the lake depositional and geochemical cycles recovered

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quickly after each sediment delivery event, showing strong resilience of the lacustrine system to watershed disturbance. Recent changes are characterized by large hydrological affections since 1967 with the construction of a canal from a nearby reservoir and a decreased in anthropic pressure in the watershed as rural areas were abandoned. The increased fresh water influx to the lake has caused large biological changes, leading to stronger meromictic conditions and higher organic matter accumulation while terrigenous inputs have decreased. Degradation processes in Iberian Range watersheds are strongly controlled by anthropic activities (land use changes, soil erosion) but modulated by climate-related hydrological changes (water availability, flood and runoff frequency).



## 1. Introduction

Water and soil are two of the most important natural resources for historical and modern societies and the availability of both creates a unique link between people and their environment (Stern, 2006). This especially applies to the Mediterranean region characterized by a fragile hydrologic and environmental equilibrium with frequent droughts and severe flooding (Benito et al., 2008; Lionello, 2012). This is the case of the Iberian Peninsula, the largest territory of Southern Europe with a Mediterranean climate characterized by a hydrological deficit year around, particularly critical during the dry and hot summers.

Water availability and soil erosion have been recognized as the most significant environmental problems in the Iberian Peninsula (García-Ruiz et al., 2011, 2013; López-Moreno et al., 2007; Lorenzo-Lacruz et al., 2010), controlled by both, climate and human activities, as land clearance for crops or grazing, farming and mining developed (Carrión et al., 2010). Soil erosion is related with the absence of protective land cover whereas sediment export to lakes is determined by the onsite sediment production and the connectivity of sediment sources and the lake. The latter factor is also a function of land-use, as the sediment transport capacity is different for distinct types of land-use (Bakker et al., 2008).

Human impact in Iberian landscapes has been particularly intense during the last two millennia (Barreiro-Lostres et al., 2014; Corella et al., 2013; García-Ruíz et al., 2013; García-Ruiz, 2010; Pèlachs et al., 2009; Roberts et al., 2004). The Iberian Range, located between the Castille Plateau, the Ebro Basin and the Mediterranean coast, provides an excellent case–study for the complex interactions of human activities and climate change in Mediterranean mountain areas at a larger time scales than recent global changes. In this fragile ecosystem, societal and cultural changes have frequently resulted in the collapse of land management systems, higher fire frequency and intensity, and the activation of erosion processes (García-Ruiz et al., 2013). In particular, the evolution of the Iberian Range landscapes has been mainly a history of deforestation, linked with a unique and deep-rooted historical feature: the establishment during Medieval times of a highly complex system of sheep transhumance – the '*Mesta*' – that had intense social and economic implications and a high impact in mountain landscapes (Montserrat Martí, 1992; Pascua Echegaray, 2012). Furthermore, social factors such as population growth or collapse linked to migrations, wars or large-scale diseases have a large impact on the intensity of soil conservation works in mountain areas, with large environmental implications in the landscape (Esteban Cava, 1994; García-Ruiz et al., 2013; Valbuena-Carabaña et al., 2010). Finally, the 20th century witnessed some of the largest changes in the Iberian Range, as most rivers were regulated (Lorenzo-Lacruz et al., 2010), and after the 1950s, rural mountain areas were abandoned and population pressure greatly decreased, resulting in lower soil erosion due to vegetation recolonization (García-Ruiz et al., 2013).

In the Mediterranean region, lake sediments have been shown to be exceptional archives of past environmental and climatic evolution at the regional scale (see Lionello, 2012; Magny et al., 2013; Moreno et al., 2012; Roberts et al., 2012). In the Iberian Range, due to the dominant carbonate nature of the rock formations, most of the lakes are of karstic origin (Valero-Garcés and Moreno, 2011). Although both lake basins and watersheds are relatively small, intense depositional processes commonly leads to high sedimentation rates and thick deposits, providing long continuous sedimentary sequences with a high temporal resolution and an exceptional sensitivity to both regional hydrological balances and human induced land-use changes (Valero-Garcés et al., 2014). As observed by Dearing and Jones (2003), small lakes draining small-medium catchments (<1000 km$^2$) provide the largest number of sediment flux palaeorecords, from a variety of climatic zones. These studies also showed that during the Late Holocene, climate has been largely subordinate to human impact as main controller of long-term shifts in sediment loads, though the evidence for intense impacts from short-term climatic phases is also abundant. Small basins are most responsive to external impacts and will show the largest changes in sediment flux.

In this paper, we investigate the evolution of El Tobar Lake and its watershed during the last millennium using a multi-proxy analysis of the sediment sequence and historical and documentary data. The objectives of this study are: i) to reconstruct the main depositional phases in the lake, particularly sediment delivery fluctuations, and ii) to explore the relationships between these sediment delivery dynamics and natural (climate) or anthropic (land use changes) forcings. The results provide a general framework for the recent hydrological and land use changes in the region and long-term data to evaluate local and regional management policies.

## 2. The Iberian Range: climate, landscapes and human activities

### 2.1. The study area

El Tobar Lake (40°32′N, 3°56′W; 1200 m a.s.l.) is located in the *Serranía de Cuenca* (Western Branch of the Iberian Range), at the headwaters of the Tagus River (Fig. 1A). Jurassic and Cretaceous carbonatic formations dominate in the region, and karstic processes are main geomorphic agents (Fig. 1B). They led to the formation of lake basins behind travertine dams e.g., Lake Taravilla (40°39′N, 1°58′W, 1100 m a.s.l., Moreno et al., 2008) and in flooded sinkholes, as occurs in the seven karstic lakes of Cañada del Hoyo (39°N, 1°52′W, 1000 m a.s.l., Barreiro-Lostres et al., 2014) and also in El Tobar Lake (Vicente et al., 1993).

The watershed, although relatively small, is one of the largest in the region (1080 ha surface area) and is drained by several ephemeral creeks. The low altitude areas (~1100 m.a.s.l.) of the watershed are carved in easily erodible materials (Upper Triassic Keuper facies, composed by mudstones and gypsum rocks). Keuper facies act as an impermeable layer sealing the base of the Jurassic and Cretaceous regional aquifer. The limestones and dolostones formations dominate the catchment highlands (~1400 m.a.s.l.). A number of sinkholes occur in the watershed, likely developed by dissolution of the evaporitic Keuper facies and the overlying Jurassic and Cretaceous limestones and dolostones formations, that have been also