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A multi-proxy approach to understanding complex responses of salt-lake catchments to climate variability and human pressure: A Late Quaternary case study from south-eastern, Spain

Samantha Elsie Jones [a, g, *], Francesc Burjachs [b, a, f], Carlos Ferrer-García [c], Santiago Giralt [d], Lothar Schulte [e], Javier Fernández-López de Pablo [a, f]

[a] IPHES, Institut Català de Paleoecologia Humana i Evolució Social, Campus Sescelades URV, edifici W3, 43007 Tarragona, Spain
[b] ICREA, Catalan Institution for Research and Advanced Studies, Barcelona, Catalonia, Spain
[c] SIP, Servei d'Investigació Prehistòrica València, Spain
[d] ICTJA-CSIC, Institute of Earth Sciences Jaume Almera, Barcelona, Spain
[e] Fluvalps-PaleoRisk Research Group, Department of Geography, University of Barcelona, Spain
[f] URV, Universitat Rovira i Virgili, Tarragona, Catalonia, Spain
[g] School of Geosciences, Department of Archaeology and Geography, University of Aberdeen, St. Mary's, Elphinstone Road, Aberdeen, AB24 3UF, Scotland, United Kingdom

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A B S T R A C T

This article focuses on a former salt lake in the upper Vinalopó Valley in south-eastern Spain. The study spans the Late Pleistocene through to the Late Holocene, although with particular focus on the period between 11 ka cal BP and 3000 ka cal BP (which spans the Mesolithic and part of the Bronze Age). High resolution multi-proxy analysis (including pollen, non pollen palynomorphs, grain size, X-ray fluorescence and X-ray diffraction) was undertaken on the lake sediments. The results show strong sensitivity to both long term and small changes in the evaporation/precipitation ratio, affecting the surrounding vegetation composition, lake-biota and sediment geochemistry.

To summarise the key findings the main general trends identified include: 1) Hyper-saline conditions and low lake levels at the end of the Late Glacial 2) Increasing wetness and temperatures which witnessed an expansion of mesophilic woodland taxa, lake infilling and the establishment of a more perennial lake system at the onset of the Holocene 3) An increase in solar insolation after 9 ka cal BP which saw the re-establishment of pine forests 4) A continued trend towards increasing dryness (climatic optimum) at 7 ka cal BP but with continued freshwater input 5) An increase in sclerophyllous open woody vegetation (anthropogenic?), and increasing wetness (climatic?) is represented in the lake record between 5.9 and 3 ka cal BP 6) The Holocene was also punctuated by several aridity pulses, the most prominent corresponding to the 8.2 ka cal BP event. These events, despite a paucity of well dated archaeological sites in the surrounding area, likely altered the carrying capacity of this area both regionally and locally, particularly during the Mesolithic-Neolithic transition, in terms of fresh water supply for human/animal consumption, wild plant food reserves and suitable land for crop growth.

1. Introduction

The onset of the Holocene witnessed environmental processes which have continued until present day; however, these environmental processes have been far from stable (Mayewski et al., 2004). Evidence obtained from multiple investigations including North Atlantic deep sea cores (GRIP members, 1993); Greenland ice cores (Kobashi et al., 2007); Icelandic lake records (Geirsdóttir et al., 2013) and even ice core records from the Tibetan Plateau (Thompson et al., 2006) suggest numerous climatic fluctuations took place during the Holocene. In the western Mediterranean several aridity oscillations have been identified from both marine and terrestrial cores (Jalut et al., 2000; Combourieu-Nebout

* Corresponding author. School of Geosciences, Department of Archaeology and Geography, University of Aberdeen, St Mary's, Elphinstone Road, Aberdeen, AB24 3UF, Scotland, United Kingdom.
E-mail address: samanthajones62.sj@gmail.com (S.E. Jones).

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et al., 2009; Dormoy et al., 2009; Fletcher et al., 2010; Burjachs et al., 2016). The 8.2 event is one of the most pronounced of the Early Holocene aridity fluctuations, identified by an outstanding body of different lines of palaeoenvironmental evidence which suggest both a downturn in temperature and increase in aridity (Frigola et al., 2007; Jiménez-Espejo et al., 2007; Cacho et al., 1999; Giralt and Julià, 2003; Davis and Stevenson, 2007; Morellón et al., 2009). Aridity oscillations would have impacted the natural resources used by past societies. For example different studies suggest the 8.2 event had drastic impacts on Late Mesolithic foragers, causing the abandonment of previously settled areas (González-Sampériz et al., 2009), changes on human mobility strategies (Fernández-López de Pablo and Jochim, 2010), and the adaption of hunting techniques (such as the development of projectile points made from geometric microliths) to compensate for the scarcity of prey caused by an increasingly open environment (García Martínez de Lagrán et al., 2016). Later during the Neolithic period, González-Sampériz et al. (2008) suggest aridity impeded human settlement in the Los Monegros region of the Ebro valley; whilst during the Early Bronze Age, Lillios et al. (2016) suggest aridity caused migration from the Southwest to the Southeast on the Iberian Peninsula. These studies thus highlight a link between water availability in arid regions and population dynamics.

One of the main difficulties in attempting to analyse the potential relationship between climate change and human populations is the presence of numerous cultural and stratigraphic gaps, particularly spanning the Late Mesolithic and Early Neolithic. Furthermore palaeoecological investigations tend to be either conducted far away from archaeological sites, or based on single proxy analysis, which provide only restricted information regarding wet-dry events, temperature and human impact. This means that despite emerging data, the impacts of abrupt climatic events on past populations are still poorly understood. The use of multi-proxy analysis however, encompassing both biota and mineral-lithological data (e.g. Davis, 1994; Schütt, 1998; Giralt et al., 1999; Valero-Garcés et al., 2000, 2004; González-Sampériz et al., 2008; Jambrina-Enríquez et al., 2008; Morellón et al., 2009; Gutiérrez et al., 2013; Aranbarri et al., 2015; Revelles et al., 2015; Piqué et al., 2017) has the potential of providing more comprehensive knowledge and filling in some of these gaps.

Saline lakes are highly sensitive to hydrological processes, which control the ecosystems they support. They differ from fresh water lakes, in that geochemical variability and mineral precipitation during periods of water deficit or lake infilling is an important process. A range of mineral compositions can precipitate from these lakes depending on the surrounding geology, temperature and evaporation/precipitation rates (E/P). Celestine ($SrSO_4$), aragonite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$, halite (NaCl), calcite ($CaCO_3$) and gypsum ($CaSO_4$)) are just some examples of the minerals which can precipitate from salt lakes; carbonates and sulphates are the most frequently identified mineral families in palaeoecological records in the Mediterranean region of the Iberian Peninsula (e.g. Davis, 1994; Giralt et al., 1999; González-Sampériz et al., 2008; Morellón et al., 2009). Despite these additional influences, the sensitivity of saline lakes means that, with the aid of multi-proxy analysis, they are ideal sedimentary systems to investigate the impacts of climate change on past societies, particularly the Villena Lake, which is directly adjacent or in close proximity to a number of archaeological sites (e.g. Soler-García, 1960, 1965; Fernández-López de Pablo, 1999; Fernández-López de Pablo et al., 2011a, 2011b; Martí and Juan-Cabanilles, 2002; Machado Yanes et al., 2009; Jover Maestre et al., 2014).

This current investigation is based on multi-proxy analysis (pollen, lithology, mineralogy, chemical composition) from saline lake sedimentary deposits (Villena Lake), adjacent to and in close proximity to archaeological sites spanning the Mesolithic to Late Bronze Age (~10,400–3200 cal BP); thus providing a unique opportunity to produce integrated palaeoenvironmental and archaeological records for investigating variable impacts of climate change and environmental change on prehistoric societies. The investigation focuses in particular on the environmental impacts of long-term and abrupt climate change so as to better understand changes in human resource availability.

2. Site description

The former endorheic lake of Villena (38°37′46.8″N and 0°55′11.6″W), which is about 4.5 km in length and 2 km wide at its widest point, is located in a depression generated by the Vinalopó tectonic fault (Rodríguez-Estrella, 1977) in the upper Vinalopó Valley, on the south-eastern Iberian Peninsula (Fig. 1). Artificial drainage (Acequia del Rey) has been in place since 1803 which empties into the Vinalopó River to the south (Gil-Olcina, 1984). The former lake occupies a wide corridor with an average altitude of 550 m asl. The region is bounded by Mesozoic calcareous mountain ranges no higher than 1000 m asl that belong to the eastern edge of the Baetic system. Within the catchment of the Villena Lake, the hill geology encompasses Triassic dolomite and gypsum to the North, Northeast and Southeast; Tertiary and Cretaceous limestone to the West and Southwest; and Triassic dolomite, Cretaceous dolomite, limestone, sandstone, and Tertiary marls to the Northwest (IGME, 1984). According to Torre-García and Alías-Pérez (1996) part of the former Villena Lake receives salty water from seasonally dry ravine channels and fountains, which become active during periods of high rainfall. Aquifers provide the most important water contribution, sometimes as fountains of fresh and salt water. Average summer temperatures for Villena and the Alicante region during 2017 were 21.5 °C at night and 30.5 °C during the day. Average winter temperatures during 2016/2017 were 8 °C at night and 17.5 °C during the day. Rainfall ranged between 0 and 15 mm during the summer of 2017 and 25–205 mm during winter 2016/2017 (Aemet, 2017). The main vegetation currently growing around the lake consists of Amaranthaceae scrub, whilst scattered pine can be seen on the surrounding hills (pers. Obs, 2014). Torre-García and Alías-Pérez (1996) describe the vegetation within the upper Vinalopó Valley as dominated by *Pinus halepens*, and shrubs such as *Rosmarinus officinalis* and *Ulex parviflorus*.

The region is particularly rich in archaeological sites ranging from the Epipaliolithic to the Bronze Age. Sites within a 5 km radius of the Villena Lake include Casa Corona (Mesolithic-Chalcolithic – Fernández-López de Pablo et al., 2013); Pinar de Tarruella (Epipalaeolithic – Fortea Pérez 1973); Cabezo Redondo (Bronze Age – Hernández Pérez, 2005); Terlinques (Bronze age – Jover Maestre et al., 2014; Machado Yanes et al., 2009); and Casa de Lara (Neolithic – Soler-García, 1960; Guilabert-Mas et al., 1999; Fernández-López de Pablo, 1999; Martí and Juan-Cabanilles, 2002). Previous works at the Villena Lake include the archaeological surveys (at Arenal de la Virgen) undertaken in the 1960s by J.M. Soler-García (1960, 1965), identification of the first evidences of lake catchment occupation of notches and denticulates Mesolithic in the Iberian Peninsula (Fernández-López de Pablo et al., 2011a); identification of Early Neolithic cardium pottery (e.g. Soler-García, 1960, 1965; Ferrer-García, 2006; Fernández-López de Pablo et al., 2011a), analysis into the seasonality patterns of Mesolithic land snail consumption (Fernández-López de Pablo et al., 2011b); isotopic land snail analysis to investigate climate change between the Younger Dryas to Early Holocene transition (Yanes et al., 2013); and a palynological investigation to examine the causes of vegetation change during the Late Quaternary (Yll et al., 2003).

The palynological work undertaken by Yll et al. (2003) focuses

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