Mid-Late Holocene climate, demography, and cultural dynamics in Iberia: a multi-proxy approach

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Abstract

Despite increasing interest in the relationship between culture transformation and abrupt climate change, their complexities are poorly understood. The local impact of global environmental fluctuations depends on multiple factors, and their effects on societal collapse are often assumed rather than demonstrated. One of the major changes in west European later prehistory was the Copper to Bronze Age transition in the early second millennium BC, contemporaneous with the 4.2 ky cal. BP event. This article offers a multi-dimensional insight into this historical process in the Iberian Peninsula from a multi-proxy and comparative perspective. Three study areas, representative of diverse ecological settings and historical trajectories, are compared. Using radiocarbon dates, ¹³C discrimination ($\Delta^{13}\text{C}$) values on C₃ plants, and high-resolution palynological records as

palaeoclimatic and palaeodemographic proxies, this study tracks the uneven signals of Holocene climate. The wettest Northwest region features the most stable trend lines, whereas the Southwest exhibits an abrupt decrease in its demographic signals c. 4500 cal. BP, which is then followed by a subsequent rise in the neighbouring Southeast. These lines of evidence suggest the possibility, never previously noted, of demic migration from the Southwest to the Southeast in the Early Bronze Age as a contributing factor to the cultural dynamics of southern Iberia.

Keywords: Holocene, Iberia, $\delta^{13}\text{C}$ values, palynology, demographic proxies, culture change, climate change, 4.2 ky cal. BP

1. Introduction

The role of climate change on human behavior, particularly in ancient societies, is a field of significant debate, in part, because of its relevance to current discussions of global climate change. In recent years, archaeologists have played an important role in gauging the relationship between large-scale climatic changes and the cultural history of hierarchical societies (Moore and Hillman, 1992; Gill, 2000; Glantz, 2001; Hassan, 2002; Mercuri et al., 2011; Rosen, 2007; van der Plicht et al., 2011). This research points to the need for more analyses of the specific dynamics of past environments as well as the manifold causes and tempos of the social dynamics of change. Models used to understand the collapse of state-level societies with intensive agriculture in tropical or arid environments, such as the Classic Maya or Akkadian states, cannot be applied to terminal episodes in far less integrated (i.e. heterarchical or middle-range) societies in more

temperate environments. Not only are regular cycles of socio-political collapse and fragmentation intrinsic features of these societies (Anderson, 1994; Hayden, 1995; Price and Feinman, 1995; Hall, 2001; Nelson and Schachner, 2002; Parkinson, 2002; Turchin, 2003; Schwartz and Nichols, 2006; Pauketat, 2007), but different ecosystems present human populations with varying degrees of vulnerability and different opportunities for adaptation and resilience (Muñoz et al., 2010).

This paper evaluates the contribution of environmental change and its complex and multifaceted relationship to the culture history of prehistoric Iberia. The environmental diversity and imposing geographic barriers separating the Peninsula from continental Europe and the African continent render it a kind of laboratory for socioecological studies. Iberia can be divided into two biogeographical regions (**Fig. 1A**): a) the Eurosiberian or Atlantic façade, featuring abundant rainfall (between 1000-2500 mm per annum) and typified by a deciduous forest cover; and b) the continental, southern and eastern Mediterranean region, warmer and drier, whose natural forests have largely disappeared and been replaced by agricultural fields, vineyards, olive groves, or scrubland (Schütt, 2005; Rivas-Martínez, 2007). Southeast Spain is currently a subdesert; it is the most arid region of Europe (**Fig. 1B**), and there, soil erosion and other degradation processes that began in later prehistory have left barren, lunar-like badlands (Castro et al., 1998, 2000).

Fig. 1. A. Biogeographic map of Europe (Rivas-Martínez, 2007). **B.** Average total precipitation in Iberia (1971-2000) (Iberian Climate Atlas, 2010: fig. 69)

The fourth through second millennia cal. BC in Iberia was a dynamic period

marked by different regional trajectories. According to conventional archaeological periodization, it corresponds to the Late Neolithic, Copper Age, and Bronze Age. Traditional accounts for these regional dynamics invoked the movement of eastern Mediterranean populations (e.g. Blance, 1961; Savory, 1968). With the application of radiocarbon dating from the 1970s, the primacy of exogenous factors was undermined, and only internal social dynamics were sought (Harrison, 1985; Chapman, 1990; Castro et al., 1999b; Gilman, 2001; Cruz Berrocal et al., 2013; Lull et al., 2011, 2013). Scholars now argue that during the Copper Age, economic intensification and social inequalities emerged and endured for several centuries (Gilman, 1987; Chapman, 1990; Díaz-del-Río, 2004). These trends continued and increased in the Southeast during the Early Bronze Age, whereas most of these polities underwent disintegration and collapse in the remaining regions. In recent decades, driving factors, such as climate and environmental changes, have been increasingly invoked in order to understand such disruptions. However, micro-regional approaches are not adequate to explain the broader macro-regional picture and hinder appraising the relative dimensions of such fluctuations (e.g. Castro et al., 1998; Fábregas et al., 2003; Nocete et al., 2005; Fabián et al., 2006; Carrión et al., 2007; López-Sáez et al., 2014; Aranbarri et al., 2015; Revelles et al., 2015; Waterman et al., 2016). Furthermore, large-scale palaeoecological overviews often do not effectively consider archaeological signatures (e.g. Jalut et al., 2009; Pérez-Obiol et al., 2011). Here we present a robust multi-proxy approach to tackle the impact of a major global climate change in the study period: the 4.2 ky cal. BP event (c. 2350-1850 cal. BC).

This research integrates diverse archaeological and palaeoenvironmental records.

Radiocarbon date frequency distributions, $\Delta^{13}\text{C}$ values, and palynological records serve as tested and reliable lines of evidence to appraise past environmental and population dynamics (e.g. Shennan and Edinborough, 2007; Carrión et al., 2010a; Muñoz et al., 2010; Hinz et al., 2012; Armit et al., 2013; Crombé et al., 2014; Manning and Timpson, 2014; French and Collins, 2015). Our aims are threefold: a) to collate independent proxies in order to shed new light on mid-late Holocene Iberia; b) to raise awareness of the important contribution of often disregarded factors, such as climate and demographic shifts, to culture change; and c) to evaluate the adequacy and prospects of such lines of evidence to illuminate multidimensional socioecological processes. To do so, this research had to tackle constraining but workable limitations. These included an unbalanced panorama of archaeological and palaeoecological research at the pan-Iberian scale, with striking differences in the availability of regional information (variable intensity in research, radiocarbon sampling, and publication of data); differential preservation and visibility of archaeological remains (depending on land-use, with lower visibility in northern Iberia), with surviving traces conditioned by prehistoric practices (e.g. some communities followed permanent lifestyles and preferred building in stone, whereas others were more mobile and led far less durable architectures), and above all, wide historical and environmental variability across Iberia. Since our attempt is preliminary in nature and meant to be a first approximation of the research topic, a case-based approach was designed to gain insight into broad patterns and tentative generalizations across the Iberian Peninsula. A strategy of regional sampling facilitated multi-proxy comparisons of a series of study areas based on careful selection criteria. Thus, the three selected study areas in the Iberian Peninsula (**Fig. 2**) feature comparable

degrees of archaeological survey and palaeoenvironmental fieldwork, radiocarbon sampling, and published research, while also representative of diverse ecological settings that can be confidently envisaged as paradigmatic of the major cultural processes under scope. These three areas are 1) the Northwest (NW), representing the Eurosiberian biogeographical region, featuring low levels of cultural change before and after the 4.2 ky cal. BP event; 2) the Southwest (SW), with a mixture of Atlantic and Mediterranean characteristics and showing an intermediate degree of culture contrast between the Copper and Early Bronze Age; and 3) the arid Southeast (SE), representative of the Mediterranean domain and exhibiting a marked cultural disruption between the Copper Age (Millaran) and Early Bronze Age (Argaric).

Figure 2. Study regions discussed in this paper and archaeological sites: Northwest (864 dates, 280 sites), Southwest (667 dates, 200 sites), and Southeast (561 dates, 86 sites)

1.1 The Copper to Bronze Age transition in Iberia

Between c. 3500-1000 cal. BC (5500-3000 cal. BP) Iberian peoples lived by herding and farming, but a wide variety of historical trajectories, environmental constraints and archaeological signatures structured very distinctive cultures. In the Late Neolithic and Copper Age (c. 3500-2200 cal. BC) the three study areas were quite dissimilar. Northern Iberia yields partial and elusive traces of human activity, predominantly of either funerary or domestic nature (Fábregas and Ruiz-Gálvez, 1998; Harrison, 1994; Parcero and Criado, 2013). In the NW and northern Portugal, Copper Age lowland settlements are scattered, although some larger hilltop sites suggest aggregation and semi-permanent villages (Sanches, 1992; Parcero and Criado, 2013:254-

255). The low conspicuity of most material remains beyond monumentalized places – megalithic tombs and some rare ditched or stone-walled settlements – stems from a combination of the ephemeral character of everyday life and perishable materials involved (mud, wood) and the adverse preservation conditions of the area, with acidic thin soils and rugged topography prone to dispersion and denudation, and difficulties involved in surveying these forested landscapes.

By contrast, Copper Age communities in southern Iberia are much more visible archaeologically (Chapman 1990, 2008; Lull et al. 2011, 2013, 2014; Aranda Jiménez et al., 2015). In view of the massive nature and excellent preservation of settlements and the richness of burials, some such prehistoric organizations are claimed to be state-like polities, e.g. Copper Age communities in the Guadalquivir Basin (Nocete et al., 2008, 2010, 2011), or the El Argar culture during the Early Bronze Age (Castro et al., 1999b; Chapman, 2003, 2008; Lull et al., 2011). However, considerable debate exists on this issue, and other scholars advocate that these political entities were ephemeral and did not go beyond the chiefdom-like threshold (e.g. Díaz-del-Río, 2004, 2011; Bartelheim, 2012; Cruz Berrocal et al., 2013; Gilman, 2013). Ongoing debate also exists on the nature (whether full- or part-time) of craft specialization (copper-based metallurgy, ceramics, flaked and groundstone lithics), the social and symbolic role of long-distance exchange (in copper, slate, variscite, amphibolite, North African ostrich eggshell and ivory), and the functions, temporality of occupation (seasonal or permanent), and relationships between traditional site types (numerous lowland pit sites) and newly discovered ones (some minority stone-walled locations such as Los Millares or Zambujal and frequent large ditched enclosures such as Perdigões or Valencia de la Concepción) (Gamito, 2003;

Jorge, 2003; Chapman, 2008; Nocete et al., 2008; Díaz-del-Río, 2011; García Sanjuán et al., 2013; Márquez-Romero and Jiménez-Jáimez, 2013).

Cultural changes occurred c. 2200 cal. BC, at the onset of the Early Bronze Age, although with significant regional variability. In Area 1, the NW, this transition is difficult to ascertain and the Early Bronze Age is sometimes referred to as a “dark age”. Most forms of monumentality disappear, and the preferred settlement areas are the uplands, suggesting an emphasis on livestock-raising (Fábregas, 1998; Fábregas and Ruiz-Gálvez, 1998; Bettencourt et al., 2007; Ontañón, 2013; Parceró and Criado, 2013: 255). In the Southwest, most settlements were abandoned, and new ones, such as Agroal (Lillios, 1993) or El Trastejón (Hurtado et al., 2011) were established, although villages from this period, in general, are poorly known in this region (Gamito, 2003). As in the earlier Copper Age, burials occurred outside settlement areas, but were housed in individualized stone cist tombs grouped into cemeteries. In the Southeast (Aranda Jiménez et al., 2015), most sites were abandoned and new settlements on terraced and easily defended hilltops were established. In the Southeast during the Early Bronze Age (Argaric), stratified societies emerged, and agriculture and craft production intensified (Castro et al., 1999b; Lull et al., 2011). Mortuary practices changed dramatically, and the dead, in individual or double graves, were typically buried underneath houses. Throughout the Peninsula, long-distance exchange connections were either discontinued or concentrated in more local regional networks.

1.2 Climate and demography as explanatory factors in Iberian archaeological scholarship

Prior to the advent of radiocarbon dating, archaeologists argued for exogenous factors instigating the above-mentioned cultural changes, mainly for the Spanish Southeast and the Portuguese Estremadura region. For example, some scholars proposed that the Iberian Copper Age was the result of eastern Mediterranean colonists who came to Iberia in search of metals and set up outposts, whereas the subsequent overthrow of the colonists by the indigenes explained the Argaric period (Blance, 1961). Environmental explanations were also offered. Savory (1968) suggested that for the earlier Bronze Age in Iberia “it is natural to suppose that increasing dessication during the sub-Boreal climatic phase, which may already have been a factor in the migrations of the Beaker Folk, played a part in all this” (Savory, 1968: 193). Walker (1985) also suggested that climate change, involving aridity and irregular rainfall during the third millennium cal. BC, created a situation of ecological stress. These environmental models, however, did not gain much ground in Spanish and Portuguese archaeology. This is likely because of its alignment with history and art history, which shared similar idealist perspectives (Hernando Gonzalo, 1987: 171).

As radiocarbon dating began to be applied in the 1970s, scholars increasingly recognized that cultural phenomena, such as megaliths or the building of fortified sites, traditionally regarded as derived from external agents, actually predated their supposed exogenous models (Chapman, 1991: 66-89). Thus, most turned to focusing on local social or economic factors to account for the changes between the fourth-second millennia cal. BC. Divergences in regional histories were explained by internal forces, such as the Secondary Products Revolution (Harrison, 1985), craft specialization, and subsistence intensification (Lull, 1983; Gilman, 1995; Lull et al., 2011). When

demography is considered, it is viewed as an endogenous factor and inferred from settlement size and counts, the frequency of tombs (e.g. Chapman, 1990), and, more recently, quern counts (Risch, 2002). However, ever since “diffusionist paradigms had been discredited and replaced by a radical autochthonism” (Aranda Jiménez, et al., 2005: 55), demic migrations have been excluded from cultural narratives.

On the other hand, the environment, particularly in arid Southeast Spain, has begun to play an important role in these explanations. Gilman and Thornes (1985) were the first to systematically analyze the role of the environment on cultural development in the region between the Neolithic and Bronze Age. Using site-catchment analysis for 39 settlements, they assessed the potentials for dry- and wet-farming in the arid lowlands and interior uplands of the region, and determined that most sites indeed appear to have been selected for their access to irrigable land, with this preference increasing over time. This research, however, was predicated on the “premise that the climate has remained relatively stable over the past 6000 years” (Gilman and Thornes, 1985: 13). Hernando Gonzalo (1987) questioned their assumption, highlighting the differences between the past and present landscapes. Recent palaeoenvironmental studies suggest that later prehistoric forests and soils have substantially degraded due to anthropic activities and indeed temperature and rainfall fluctuated, but their overall values were similar to today’s (Castro et al., 1994; Castro et al., 1998: 62-68; Castro et al., 1999a, 1999b, 2000; Gale, 1999; Aranda Jiménez et al., 2015:60-61). Beyond the Southeast, however, there has been a general reluctance to relate cultural change to climate dynamics, perhaps due to concerns with determinism. The 4.2 ky cal. BP event or Bond 3 event (Bond et al., 2001) and its relationship to Copper and Bronze Age cultural changes has received little

attention by Iberian scholars, save a few exceptions (e.g., Fábregas et al., 2003; López-Sáez et al., 2014). With the current availability of extensive surveys, and chronometric and high-resolution environmental data for later prehistoric Iberia, the time seems ripe to propose more nuanced and holistic explanations for human cultural dynamics at the peninsular scale.

2. Materials and Methods

2.1. Radiocarbon dates

For the demographic proxy, 2,092 radiocarbon dates between 6000-3000 cal. BP from 566 sites (settlements and burials) in the three study regions were used to create summed calibrated radiocarbon date range distributions (SCDRDs) (**Supplementary Material: Table 1, References**). These include: Area 1 - Northwest Iberia (864 dates from 280 sites); Area 2 - Southwest Iberia (667 dates from 200 sites); and Area 3, Southeast Iberia (561 dates from 86 sites). These dates were selected from a comprehensive (and currently unpublished) dataset of over 7000 radiocarbon dates for the Iberian Peninsula compiled by Antonio Gilman, with some augmentation by the authors. Quality checking of the database was based on well-contextualized and high quality radiocarbon assays. We only included AMS radiocarbon dates (marked with * in their lab. ref.) or radiocarbon dates on short-lived material (antler, acorn, bone, cereal, esparto, seeds, bark, twigs, pollen in archaeological context). In addition, radiocarbon dates on unspecific material referred to as charcoal or wood (both long-lived and short-lived) have been considered provided the $SD \leq 5\%$ of their BP age (SD values =5% are included only if such SDs values are ≤ 100 years). These charcoal samples are important

due to their contribution in order to assess vegetal C₃ samples with associated $\delta^{13}\text{C}$ values.

Geographic coordinates were standardized as decimals so that they could be plotted and analyzed for correlations with longitude and latitude. The dataset underwent an auditing process. These dates were calibrated with a Markov-chain Monte Carlo simulation using the IntCal13 curve (Reimer et al., 2013) with the BChron package (v. 4.0) in the R programming language (v. 3.2.0). A total of 2,000 burn in simulations were used with 10,000 simulations thereafter taken every 8 steps for each region (Parnell et al., 2008). Confidence bands were generated by randomly sampling each region by the number of sites present 10,000 times, then generating a unique loess smooth for each alternative history. The standard deviation for each region was calculated using this loess smooths, and 1σ (68.2%) and 2σ (95.6%) confidence bands were generated. Significance was assessed using Bayesian change-point analysis (Barry and Hartigan, 1993) using 2,000 burn in simulations and 10,000 mcmc simulations (Erdman and Emmerson, 2007) using the bcp package (4.0.0). The first standard deviation calculated from posterior variance across posterior means was used to determine uncertainty in SCDRDs for each region. A general linear model (GLM) was created, assuming quasi-Poisson distributed error was used to estimate a general trend, with deviations beyond the confidence interval used to assess boom-and-bust trends in human activity across Iberia.

2.2. Carbon isotope discrimination and its use as a climate proxy

Stable carbon isotope ratios have been used as a climate proxy in both dendroclimatology (Leavit and Long, 1988; Dupouey et al., 1993; McCarrol and Loader,

2004; Robertson et al., 2010) and ecology (Picon et al., 1997; Diefendorf et al., 2010; Werner and Máguas, 2010). In archaeological investigations, stable carbon isotope discrimination values ($\Delta^{13}\text{C}$) can be useful as a climate indicator because C_3 plants are abundant macrobotanical ecofacts in archaeological sites around the world. In the past they have been used in the Iberian Peninsula to compare the Bronze Age climate with present-day conditions (Aguilera et al., 2009), and to identify the effects of the Medieval Warm Period in the Alentejo of Portugal (Drake et al., 2012). They have also been used to identify an impact of the 4.2 ky cal. BP event in Anatolia, where it corresponds to lower $\Delta^{13}\text{C}$ values (Riehl et al., 2008, 2014).

Values of $\Delta^{13}\text{C}$ can serve as climate proxies because they can identify water stress in C_3 plants. The C_3 respiration consists of three important steps; the diffusion of CO_2 through the stomata, the separation of carbon from oxygen via photosynthesis, and the fixation of that carbon by Ribulose-1,5 -biphosphate carboxylase oxygenase (RuBisCo). There is a kinetic bias against the diffusion of the heavier stable isotope of carbon ($^{13}\text{CO}_2$) through the stomata, and an inefficiency in fixing ^{13}C to sugars (Marion 1981). This occurs because when stomata close in response to drought, the internal cellular partial pressure of CO_2 (c_i) drops, reducing the discrimination against heavier isotopes. These discrimination factors can be expressed as ^{13}C discrimination values (Farquhar et al., 1982, 1989). In the event of low water availability, many C_3 plants will close their stomata to reduce moisture loss through respiration. This has the effect of decreasing internal CO_2 partial pressure inside the leaf, thus reducing the discrimination factors against the fixation of ^{13}C . As a consequence, low $\Delta^{13}\text{C}$ values can be interpreted as at least partial evidence of aridity, whether through individual plant response (Farquhar et

al., 1984) or as an artifact of adaptations to arid environments (Diefendorf et al., 2010). Values of $\Delta^{13}\text{C}$ can be calculated from $\delta^{13}\text{C}$ values, which are reported with radiocarbon dates (Stuiver and Polach, 1977).

Values for $\Delta^{13}\text{C}$ used in this study were calculated using reported $\delta^{13}\text{C}$ values from radiocarbon dates using the following formula:

$$\Delta^{13}\text{C} = (\delta^{13}\text{CO}_2 - \delta^{13}\text{C}) / (1 + \delta^{13}\text{C}/1000)$$

where $\delta^{13}\text{CO}_2$ was set to -6.38‰ based on historical data from Antarctica (Elsig et al., 2009). These $\Delta^{13}\text{C}$ data were then analyzed over time for each region.

2.3. Palynological data and anthropogenic signals

Pollen records provide a fully tested and reliable signal of anthropogenic impact. Palynology has been mainly used to track vegetation evolution and subsistence strategies, and is seldom deployed as a diachronic demographic proxy, either to reveal population concentrations (Scarre, 2001) or to reconstruct micro-regional patterning (Hinz et al., 2012). All pollen records from the three study areas were screened in order to exclude those with uncertain chronological setting (e.g. no radiocarbon dates or low resolution for the time frame 6.5-3.5 ky cal. BP), low sampling resolution for the mid- Holocene (300 years/sample) or low pollen counts (200 grains per sample). The selected records were mostly obtained from mires, marshes and lakes. A total of 24 pollen records were used (**Fig. 3, Table 1**). They were gathered from the European Pollen Database (<http://www.europeanpollendatabase.net>), the Spanish research project Paleodiversitas (Carrion et al., 2013; <http://www.paleodiversitas.org/>) or directly provided by researchers. Pollen percentages (**Fig. 6**) were calculated from terrestrial pollen sums,

excluding ferns, aquatic plants and non-pollen palynomorphs. Quantitative data were only available for the Northwest and Southwest, not for the Southeast. When available, the original counts were considered. However, in some cases, percentage data were digitized from the published diagrams. We recalibrated radiocarbon dates from pollen records with Calib 7.1 using the Intcal09 calibration curve (Reimer et al., 2009). The age-depth model of each pollen record was obtained using the Clam software developed by Blaauw (2010), using a smooth-spline solution. All ages are expressed as cal. yr BP.

Figure 3. Study regions and pollen cores: 1. PR2; 2. PRD4; 3. Chan do Lamoso; 4. Pena da Cadela; 5. Chan da Cruz; 6. Lucenza; 7. La Roya; 8. Alto de la Espina; 9. Monte Areo; 10. Beliche; 11. Las Madres; 12. El Acebrón; 13. S11; 14. Medina; 15. Padul; 16. Borreguiles de la Virgen; 17. Rio Seco; 18. San Rafael; 19. Baza; 20. Cañada de la Cruz; 21. Siles; 22. Ojos de Villaverde; 23. El Sabinar; 24. Elx.

Table 1. Palynological records used from the three study areas.

2.4. Pollen-based palaeoclimate reconstruction

The standard Modern Analog Technique (MAT) (Guiot, 1990) was applied to two pollen sequences (PRD-4 and S11) to estimate palaeoprecipitation and palaeotemperature during the mid-Holocene by following the recommendations proposed by Peyron et al. (1998) and Ortu et al. (2008). The MAT was used to reconstruct the mean annual temperature (T_{ann}), total annual precipitation (P_{ann}), the mean temperature of the coldest month (T_c) and the mean temperature of the warmest month (T_w). The modern pollen database used includes near 1000 modern pollen spectra from the Iberian Peninsula collected by the authors (Davis et al., 2013). Each modern sample site was assigned to a modern climate based on the Digital Climatic Atlas of the Iberian Peninsula (Ninyerola et

al., 2006, 2007). To evaluate the reliability of the estimation by MAT, the climate parameters for each surface sample were estimated using the other modern samples. The difference between present-day climate data at the pollen sites and the estimated climate at each site indicates the reliability of the results (**Table 2**).

Table 2. Correlation coefficients between observed and reconstructed values of climate parameters obtained using the MAT approach. RMSE: root mean square error.

3. Results

3.1. Radiocarbon dates and demographic dynamics

Fig. 4. Radiocarbon summed calibration range distributions in the three study regions. Carbon discrimination ($\Delta^{13}\text{C}$) values are represents in the lower plot. Mid-Holocene $\Delta^{13}\text{C}$ values were around 20‰ in the Northwest, while later values in the Southeast and Southwest were 17.5‰.

Figure 4 (above plot) shows the frequency of AMS dates for the three regions, with the 4.2 ky cal. BP event indicated. Until 4500 cal. BP the three regions show roughly parallel trends, with a spike at 4700 cal. BP. After 4500 cal. BP, the three regions diverge, with the Southwest showing a marked decrease, the Northwest also decreasing (but not as significantly), and the Southeast continuing to increase.

A GLM for the three regions (**Fig. 5**) shows their trends more clearly. These plots suggest that the only region where a case can be made for influence from the 4.2 ky cal. BP event is the Northwest (although it is otherwise the most stable region demographically). Both the Southeast and Southwest have increasing human activity trends that begin at 5500 and 4500 cal. BP, respectively. The Southeast GLM does not

fall outside the confidence bands, while the Southwest deviates, indicating an increase, and subsequent decrease, in activity in the region.

Fig. 5. SCDRDs by region with 1σ and 2σ confidence bands, general linear models, and Bayesian change-point-probabilities. The Northwest and Southeast do not show sharp punctuations that deviate far beyond the 2σ confidence band, while the Southwest shows a highly punctuated population event prior to 4200 cal. yr BP. The Northwest and Southwest have accelerated declines after 4.2 kya, while the Southeast shows evidence of stability based on a cap in change point probabilities until 3900 cal. yr BP.

3.2. $\Delta^{13}C$ values

For $\Delta^{13}C$, higher values indicate wetter conditions, and lower values suggest either drier conditions (Farquhar and Richards 1984) or drier-adapted flora (Diefendorf et al., 2010). **Supplemental Fig. 1** shows that from about 5.7 to 4.7 ky cal. BP, there is evidence for increased aridity due to lower $\Delta^{13}C$ values, with a recovery around 4.7 ky cal. BP. The nadir of $\Delta^{13}C$ is between 4.9 and 4.7 ky cal. BP, after which things quickly stabilize to a wetter climate (but not as wet as before). There is no evidence for an arid episode around 4.2 ky cal. BP with this dataset.

Significant differences in the available data for each region, however, suggest caution in this interpretation. For example, while the Northwest is associated with the highest values for the 6500-5300 cal. BP period, which is consistent with this region being the wettest region, the lack of $\Delta^{13}C$ from the Northwest for the period following 5300 cal. BP skews the results. The Southwest and Southeast (both more arid regions) dominate the later samples, so we get lower values.

3.3. Palynological Record

Selected pollen records from the Northwest and Southwest are presented in **Figures 3 and 6**. The results of palaeoclimatic reconstructions made from the two pollen sequences (PRD-4, S11) are shown in **Fig. 7**.

Figure 6. Selected pollen cores from Northwest and Southwest

Figure 7. Palaeoclimatic reconstructions made from PRD-4 and S11. Reconstructed parameters: P_{ann} , mean annual precipitation; T_{ann} , mean annual temperature; T_c , mean temperature of the coldest month; T_w , mean temperature of the warmest month (see also **Supplemental Materials: Figure 1**).

3.3.1. Northwest Iberia

Studies on past environmental changes in Northwest Iberia have been carried out using different types of archives, such as peat-bogs, complex polycyclic soils, colluvial soils and lacustrine sediments, and mainly involving disciplines, such as geochemistry and palynology (Martínez-Cortizas et al., 2009). Studies on landscape evolution in NW Iberia show that c. 7.0-5.0 ky cal. BP, soil erosion began to be a widespread phenomenon. The trigger factor was probably an increase in cattle pressure and the corresponding system of slash and burn agriculture. Pollen diagram from the peat record of Charca do Chan da Cruz (Ramil-Rego, 1993) shows a significant anthropization impact c. 7.0-6.5 ky cal. BP. This signal is associated with low-elevation mountain settings, reflecting the presence of semi-mobile Neolithic shepherds, who exploited these easily accessible pasturelands (Martínez-Cortizas et al., 2009). Later, c. 6.5-6.0 ky cal. BP, the first indications of agriculture appeared in the pollen record of Chan do Lamoso

(Ramil-Rego et al., 1998; Muñoz-Sobrino et al., 2005). However, around 5.0 ky cal. BP a shift to a colder, relatively drier and windier environment accelerated landscape changes over the next two millennia. This tendency drastically reduced deciduous forests and increased scrublands, ferns and synanthropic taxa, which again testify to agricultural and livestock activities.

In short, the fifth millennium cal. BP was likely a breakpoint in forest dynamics, as up to this time the tree cover remained fairly stable. In coincidence with the Bell Beaker phenomenon, forests suffered an abrupt deforestation as a result of a significant increase in human activities (agriculture and grazing). While these facts are very clear throughout the fifth millennium, so it is that deforestation was progressive, increasing steadily and reached its peak in the last centuries of the fifth millennium cal. BP, as in the early centuries of the fourth millennium cal. BP (López-Sáez et al., 2011a). Perhaps this anthropic process was accelerated by the dry and cold climate trend. Pollen records show that these changes in landscape were not limited to the more accessible areas, such as the coast; mountainous environments also suffered anthropic pressure. Thus, the process can be generalized to the entire northern Iberia (Muñoz-Sobrino et al., 2005).

An excellent example of the palaeoenvironmental trajectory of Northwest Iberia is the PRD-4 pollen record (López-Merino et al., 2012; Kaal et al., 2013). In this record, the phase between 6.6-4.8 ky cal. BP (Neolithic and Chalcolithic) is characterized by deciduous forest species (**Fig. 6**), especially deciduous *Quercus* accompanied by *Alnus*, *Betula* and *Corylus*, which coincides with a progressive increase in macroscopic charcoal concentration and moderate levels of anthropozoogenous (*Plantago lanceolata*, *P. major/media*, *Urtica dioica*) and synanthropic taxa (Cichorioideae, Cardueae, *Asphodelus*

albus, *Aster*, *Rumex acetosella*), as well as coprophilous fungal spores (*Sordaria*, *Sporormiella*, *Podospora* and *Cercophora*). The data point towards the creation and maintenance of pasture using fire. At c. 4.8 ky cal. BP, the abundance of synanthropic and anthropozoogenous taxa and coprophilous fungi diminished abruptly, and remained negligible until c. 3.5 ky cal. BP. Throughout its second phase (c. 4.8-3.5 ky cal. BP), post-disturbance indicators such as *Polypodium vulgare* and *Pteridium aquilinum* show elevated values. This may be related to an intensified natural fire regime, witnessed by the larger macroscopic charcoal concentrations. Further evidence of a fire-induced woodland opening is the increased percentages of carbonicolous fungal spores (*Anthostomella* cf. *fuegiana*, *Coniochaeta* sp.). The palaeoclimate reconstruction performed in PRD-4 (**Fig. 7**) shows how P_{ann} remains more or less constant between 6600 and 5000 cal. BP, although with a decreasing trend, showing a clear minimum at 5650 cal. BP (< 1000 mm/yr) coincident with a marked decline in all parameters of temperature. After c. 4.8 ky cal. BP, P_{ann} increases again following an oscillating trend until 3.5 ky cal. BP. A new minimum value for P_{ann} is attested at 3750 cal. BP. A phase of climatic deterioration to colder and probably drier conditions is detected c. 4250-4150 cal. BP, characterized by decreasing values of deciduous *Quercus* and *Betula*, T_w , T_c and T_{ann} . Since 4.0 ky cal. BP, deciduous forest regression is detected in the pollen assemblages, especially by decreasing percentages of *Quercus*. This phase c. 4.8-3.5 ky cal. BP roughly coincides with Neoglacial climate deterioration, with strong fluctuations in temperature and humidity (Martínez-Cortizas et al., 1999; Magny et al., 2009) as stated in the palaeoclimate reconstruction performed: the beginning (4.8-4.1 ky cal. BP) and end

(3.9-3.5 ky cal. BP) of which were particularly cold, dry and windy in Northwestern Iberia (Fábregas-Valcarce et al., 2003).

The worsening of the climate in NW Iberia is corroborated by geochemical proxies in peat-bogs, suggesting a continuous decrease to temperatures of up to 2-2.5°C colder than present until c. 4.5 ky cal. BP; following this the temperature rose by about 1°C, remaining stable until a cooling and drying trend set c. 4.2 ky cal. BP (Martínez-Cortizas et al., 2009). The reconstruction made by Fábregas-Valcarce et al. (2003) indicates that a drying trend was set at the end of the sixth millennium cal BP until c. 4.7 ky cal. BP, when humidity may have reached the lowest observed values. From c. 4.6 to 4.3 ky cal. BP, rainfall increased by about 45% and by 4.2 ky cal. BP it reached a maximum for the period; however, since this date, rainfall decreased again to a minimum, slightly higher than the previous one. These data are consistent with the PRD-4 palaeoclimate reconstruction, which shows minimum values of P_{ann} at 5650 cal. BP and maximum values c. 4.2-4.0 ky cal. BP and a decreasing trend until 3750 cal. BP.

In fact, a shift towards colder and drier climatic conditions can explain an aggravated natural fire regime and opening of the woodland c. 4.2 ky cal. BP, a trend also found in other pollen records from Northern Iberia such as Chan do Lamoso and Pena da Cadela peat-bogs (Ramil-Rego et al., 1998; Martínez-Cortizas et al., 2005; Mighall et al., 2006) by decrease of deciduous *Quercus* and increase of *Pteridium* and macrocharcoals. This is also tracked at Lucenza lake's core (Santos et al., 2000; Muñoz-Sobrino et al., 2001) where ca. 4050 cal. BP a notably decrease in deciduous *Quercus* values is confirmed in coincidence with *Erica* and *Artemisia* increase. Finally, this shift is also apparent in La Roya lake pollen record (Allen et al., 1996) where c. 4.0 ky cal. BP

vegetation change with high increase of xerophytic (*Juniperus*), pyrophilous (*Ulex*) and thermophilous (*Olea*) taxa and *Quercus* decreases. For instance, in Monte Areo peat-bog pollen record (López-Merino et al., 2010) the deterioration of environmental conditions is indicated by the disappearance of *Pinus pinaster* pollen and lower meso-euthropic algae (*Spirogyra*) percentages. In the nearby PRD-2 pollen record, from c. 4.0 to 3.5 ky cal. BP a change in the vegetation composition also occurred, with increased abundance of coprophilous fungi and an intensification of fire regime (Carrión et al., 2010b). In the mentioned Monte Areo pollen record, as well as in the Alto de la Espina peat-bog sequence an increase in indicators of anthropic erosion (*Glomus* and *Pseudoschizaea*), *Erica*, ferns, and synanthropic taxa (Cichorioideae), and the loss of deciduous *Quercus* is detected since c. 4.0 ky cal. BP related to a new phase of cereal cultivation and grazing pressure during the Early Bronze Age (López-Merino et al., 2010).

3.3.2. Southwest Iberia

In this area available high-resolution pollen records are rather scarce. The pollen sequence from the S11 core (Jiménez-Moreno et al., 2015), taken in the Guadalquivir freshwater marshland, shows a decreasing trend in deciduous *Quercus* and *Pinus pinea*-type percentages c. 4.2-4.0 ky cal. BP. At the same time, a progressive decrease in *Isoetes*, a shallow water aquatic fern, and in anthropozoogenous taxa (*Plantago*) is also observed; while xerophytic and coastal halophytic communities (*Artemisia*, Chenopodiaceae) and dry-adapted and thermophilous shrubs (*Olea europaea*, Ericaceae) increase significantly (**Fig. 6**). These indicators can probably be interpreted as an increase in aridity in the area, which would have induced forest reduction around the marsh and

would have triggered lower freshwater levels, or more frequent instability or eutrophication in the marsh. This abrupt climate event is faithfully observed in the S11 palaeoclimate reconstruction (**Fig. 7**) from a very abrupt P_{ann} decline of at least 45 mm/yr, which in turn coincides with maxima in temperature parameters (T_w , T_c , T_{ann}) at c. 4100 cal. BP.

In this sense, this aridification process does seem to play the main role in transforming the vegetation in Southwestern Iberia c. 4.2 ky cal. BP, considering that in this period anthropogenic pressure greatly slowed down, as observed elsewhere in the area (Reed et al., 2001; Fletcher et al., 2007, 2013). Later, a new arid phase is detected in S11 pollen record c. 3.7 ky cal. BP with new maximum temperature values.

In Southern Portugal, in the Guadiana estuary, the pollen record from Beliche marshland (Fletcher et al., 2007) shows a similar pattern to the S11 core. Between c. 6.5-5.0 ky cal. BP evergreen *Quercus* forests dominated the landscape with pine formations (probably *Pinus pinea*) located in dune environments. However, c. 4.8 ky cal. BP the percentage of evergreen *Quercus* decreases while synanthropic herbs, serial shrubs (Ericaceae) and xerophytic taxa increases, showing the first human impact on the landscape. Although oak forests subsequently recovered c. 4.6-4.2 ky cal. BP, their percentages decreased again c. 4.2 ky cal. BP but now more markedly and coinciding with a maximum of xerophytic taxa. A similar process is demonstrated in Medina lake (Reed et al., 2001), Las Madres and El Acebrón lakes (Stevenson & Moore, 1988; Stevenson & Harrison, 1992; Yll et al., 2003) pollen records, where a maximum of aridity c. 4.2-4.0 ky cal. BP caused an increase of *Juniperus*, *Olea* and xerophytic taxa and conversely decreasing values of wetland taxa (Cyperaceae, *Myriophyllum*).

3.3.3. Southeast Iberia

Within this study area, available palaeoenvironmental data come mainly from the Baetic range: El Sabinar palaeolake (Carrión et al., 2004), Ojos de Villaverde wetland (Carrión et al., 2001b), Padul, Baza, Cañada de la Cruz and Borreguiles de la Virgen peat-bogs (Pons & Reille, 1988; Carrión et al., 2001a, 2007; Jiménez-Moreno and Anderson, 2012), and Siles and Río Seco lakes (Carrión, 2002; Anderson et al., 2011). Between c. 6.5-5.8 ky cal. BP the overall pattern of the regional landscape corresponds to mountain pine forests (probably *Pinus nigra* or *P. sylvestris* in Nevada range) accompanied at lower altitudes by deciduous *Quercus* and other mesophilous taxa (*Betula*, *Corylus*, *Alnus*). These species progressively replaced pine forests by c. 5.8-5.3 ky cal. BP, during a relatively humid period attested by the abundance of wetland taxa (*Typha*, *Potamogeton*). From c. 5.3-4.1 ky cal. BP and especially since 4.8 ky cal. BP, evergreen *Quercus* forests replaced the previous ones enriched in Mediterranean elements (*Pistacia*, *Phillyrea*, *Myrtus*) and xerophytic taxa (*Juniperus*, *Artemisia*, *Chenopodiaceae*, *Ephedra*). Between c. 4.2 and 3.5 ky cal. BP, evergreen oak forests reach their maximum development, whereas hydro-hygrophilous (wetland) herbaceous taxa and *Chara* sharply decrease and algal populations increase (*Zygnemataceae*); all these signals are indicative of low lake levels and a trend toward eutrophic conditions. An increase of xerophytic taxa (*Artemisia*) c. 4.1 ky cal. BP in the pollen record of the high-altitude Río Seco lake (Anderson et al., 2011) is remarkable. Although evidence of human impact is detected in most of the above-mentioned pollen records, these are mainly due to cattle herding paths through these mountains (Carrión, 2001; López-Sáez et al., 2011b). In the transition

between the fifth to fourth millennium cal. BP, however, the recurrence of anthropogenic fires leads to a gradual disappearance of the forest cover, most evident during development of the fourth millennium cal. BP (Gil-Romera et al., 2010). This trend can be correlated both with the advent of abrupt climate change c. 4.2 ky cal. BP, as well as the cultural transition resulting from the collapse of Los Millares culture and the emergence of El Argar (Carrión et al., 2003).

At c. 4.2 ky cal. BP an arid event is also observed in other regional palynological records from coastal areas, such as the marshland records from San Rafael (Pantaléon et al., 2003) and Elx (Burjachs et al., 1997), where evergreen *Quercus* forests dominated until c. 5.1 ky cal. BP to progressively disappear, especially from c. 4.1 ky cal. BP when an extremely arid phase took place (maximum of *Artemisia* > 60% in San Rafael).

4. Discussion

This paper takes a multi-proxy and regional approach to the cultural, demographic, and environmental changes that occurred between 6000-3000 cal. BP in the Iberian Peninsula. Although regional and temporal differences exist in the quantity and quality of data collected, some patterns are apparent and warrant further consideration (Fig. 8).

Figure 8. Summary of multi-proxy results. Yellow: little change; orange: moderate change; red: significant change

One of the most intriguing of these is the decline in population in the Southwest and increase in the Southeast, beginning around 4500 cal. BP. This suggests the

possibility of interregional population dynamics that might account for some of the cultural changes in the Early Bronze Age of the Southeast, such as population nucleation. Although our dataset used was restricted to high-quality dates, the demographic patterns observed for the Southeast find support in surveys and excavations conducted over the last decade. For the Southeast, archaeologists have posited an increase in population, starting either in the Millaran period or the Early Bronze Age (Lull, 1983). Some absolute palaeodemographic estimates have been presented, based on diverse measures. Following Chapman's (1991: 213-214, table 14) estimates, the total population of the Southeast would have increased from ~4,000 inhabitants in the Chalcolithic to ~10,000 people in the Argaric period (Aranda Jiménez et al., 2015: 58). He also subdivided the SE into three subareas and used site size to demonstrate divergent regional dynamics (Chapman, 1991: 220, table 16): a sharp increase in demographic density in the Vera Basin and eastern Granada between the Chalcolithic and the EBA (from 2.94 and 1.13 inhabitants/km² to 6.5 and 1.76), whereas southern Almería featured a marked decrease (from 2.0 to 1.14 inhabitants/km²). More recent absolute estimates for the Vera Basin present an increase from ~500 inhabitants in the Chalcolithic to >2500 in Argaric times (Castro et al., 1998:71, fig. 17). All in all, there is consensus on two points: a) a steady population growth from the Neolithic, reaching its climax within the Vera Basin in Argaric times, when population “may have doubled or even tripled” (Aranda Jiménez et al., 2015:59), and b) this trend is parallel to the decrease in the frequency of sites, probably due to aggregation dynamics: “this higher intra-site density contrasts with the site numbers” (Castro et al., 1998:70).

A second important result is that the $\Delta^{13}\text{C}$ and pollen data (including the pollen-

based palaeoclimate reconstruction) all suggest important climatic and environmental factors that may have shaped demographic and cultural dynamics, most notably aridity. However, their divergent levels of resolution, and the different timing of important shifts, by data class within each region, suggest that we need to approach these with caution. Overall, the Northwest shows more stability than the Southwest or Southeast, and this trend is paralleled by similar cultural dynamics (more stability in NW than SW and SE). This result is supported by the work of Carrión et al. (2010a), who outlined patterns of vegetation change for the mid-Holocene in the Iberian Peninsula, emphasizing strong regional differences, mainly related to the Eurosiberian and Mediterranean biogeographical regions. While in the Mediterranean region a large heterogeneity in vegetation change has been pointed out, in the Eurosiberian one, comprising the north and the northwest, as well as in other areas with Atlantic influence, a more homogeneous picture has emerged.

Third, in all three regions, the $\Delta^{13}\text{C}$ data indicate an arid episode lasting from 5400 to 4600 cal. BP, but does not reveal an event at 4.2 ky cal. BP (**Fig. 4**, lower plot). This is in marked contrast to the pollen records for the Southwest, which point consistently to an event at 4.2 ky cal. BP (**Fig. 6; Fig. 7**) The $\Delta^{13}\text{C}$ data are, however, consistent with previous findings by Finne et al. (2011), who reported increased aridity between 5400 and 4600 cal. BP based on multiple climate proxy records including sea surface temperatures (SST), stable oxygen isotopes from speleothems, and absolute temperature reconstructions. A sharp decrease in palaeorainfall occurred at 5100 cal. BP for the Eastern Mediterranean from 450 mm/yr to just over 200 mm yr based on stable oxygen isotope data from Soreq cave near Jerusalem (Bar-Matthews et al., 2003). The

calcium carbonate and dolomite records used by Cullen et al. (2000) to argue for a severe 4.2 ky cal. BP event also show significant increases around 5.1 ky cal. BP. For this same period, low lake levels are seen in Spain, Portugal, and Greece (Harrison and Digerfeldt, 1993). An increase in *Pseudoschizaea* from Lake Siles in southern Spain indicates an arid episode at 5200 and 4100 cal. BP (Carrion, 2002). Reduced rainfall and decreased sedimentation in Sanabria Lake mark a shift to lower precipitation in Northwest Iberia in the mid-Holocene, between 6.8 and 4.8 ky cal. BP (Jambina-Enríquez et al., 2014). Arid conditions onset somewhat later in northeastern Iberia around 5.0 ky cal. BP in the vicinity of Villarquemado Lake (Arabarri et al., 2013). Lake Estonia, in the same region, shows evidence for anoxia and gypsum-forming events between 5940 and 4910 cal. BP, suggesting increased evaporation (Morellón et al. 2008). Pollen data from Borreguiles de la Virgen in Southeast Spain indicate aridification from 7.0 ky cal. BP, with particularly dry conditions around 5.2 and 4.0 ky cal. BP (Jiménez-Moreno and Anderson, 2012). Broadly, these regional climate records are indicative of mid-Holocene aridification, with evidence for increased evaporative pressures. The $\Delta^{13}\text{C}$ data are consistent with these data; in particular, they indicate that increases in population in Southeast and Southwest Iberia from 5500 to 4500 cal. yr BP occurred in the context of aridification of the Peninsula. In the Northwest, the onset of arid conditions is associated with a drop in SCDRDs, though this is only to the 1σ level (**Figure 5**).

There are multiple potential climatic forcings for this long-lasting event. The first is a persistent positive North Atlantic Oscillation (NAO+) which lasted from 5100 to 4300 cal. BP (Olsen et al. 2012). NAO+ conditions typically result in increased precipitation for Central Europe but lower precipitation for the Mediterranean region

(Hurrell, 1995). Contemporaneous with this NAO+ episode was a sharp and unprecedented increase in the El Niño Southern Oscillation (ENSO) index lasting from 4900 to 4400 cal. BP (Moy et al., 2002). This change marks the beginning of ENSO variability for the Holocene - the last comparable episode of ENSO activity was in the Younger Dryas. These records likely indicate ideal conditions for agriculture in the Southwest; a survey of fluvial data in Iberia indicates that the western half of the Peninsula experienced a relatively high frequency of flooding events between 4000 and 3000 cal. BP. Both eastern and western Iberia saw a relatively higher frequency of flooding between 4900 to 4100 cal. BP (Benito et al., 2014). The decline in flooding and reduced NAO+ and ENSO events appear to have negatively affected population growth in the Southwest.

Fourth, what the $\Delta^{13}\text{C}$ and pollen data do show is that despite a trend toward a drier, more arid climate, overall human activity across the Iberian Peninsula increased during the fourth and third millennia cal. BC. Even though conditions may have been arid, there was apparently enough arable land to facilitate an expansion of settlement and agriculture. The Southwest, in particular, would have had more aridity from NAO+ activity. Though these effects may have been mitigated due to increased ENSO activity, they may have also contributed to milder, wetter winters in the Mediterranean. The decline of both NAO+ and ENSO activity beginning around 4500 cal. BP may have changed these climatic dynamics from Southwest Iberia, possibly encouraging some migration into the Southeast. An additional possibility is that eastern Iberia presented a wetter, more humid climate. Past analysis of $\Delta^{13}\text{C}$ indicate that the region received 19% more precipitation in 3000 cal. BP than it does today (Aguilera et al. 2009), and from

3000 to 2000 cal. BP, there were sharp increases in flooding events in the Iberian Peninsula (Benito et al., 2014).

Finally, and perhaps most notably, the demographic changes observable in the radiocarbon record and some of the climate shifts seen in both the $\Delta^{13}\text{C}$ and pollen records occurred *before* the cultural changes associated with the Copper to Bronze Age transition. Thus, the relationship between the 4.2 ky cal. BP event, culture change, and demographics in late prehistoric Iberia is more complex than previously envisioned and involved important regional variability and interregional connectivity.

5. Conclusions

We have compared three lines of evidence as proxies of prehistoric demography and climate: ^{14}C SCDRD, $\Delta^{13}\text{C}$ values, and high-resolution palynological determinations. These data suggest that population growth and/or migrations in the Southeast and Southwest occurred in the context of mid-Holocene aridification. Pollen data in the Southwest, in particular, shows evidence for a sharp shift to arid conditions around 4.2 ky cal. BP., though this event does not show up in all climate proxy records for Iberia in this and other studies. However, even partial, biased and problematic indirect proxy measures, such as the ones deployed in this study, can provide insights into prehistoric patterning otherwise inaccessible (Scarre, 2001).

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Table 1

Site	Nature	Latitude N	Longitude W	Altitude	References
Northwest Iberia					
PRD-4	Colluvial soil	42°32'46"	8°31'42"	300	López-Merino et al. (2012) Kaal et al. (2013)
PRD-2	Colluvial soil	42°32'47"	8°31'40"	190	Carrión et al. (2010b)
Monte Areo	Peat-bog	43°31'44'	5°46'08"	200	López-Merino et al. (2010)
Charca do Chan da Cruz	Peat-bog			800	Ramill-Rego (1993)
Chan do Lamoso	Peat-bog	43°29'54"	7°33'09"	1039	Muñoz-Sobrino et al. (2005)
Lucenza	Lake	42°35'32"	7°06'47"	1375	Santos et al. (2000) Muñoz-Sobrino et al. (2001)
Pena da Cadela	Peat-bog	43°29'16"	7°26'18"	970	Martínez-Cortizas et al. (2005) Mighall et al. (2006)
Alto de la Espina	Peat-bog	43°22'52"	6°19'38"	650	López-Merino (2009)
La Roya	Lake	42°08'02"	6°47'28"	1608	Allen et al. (1996)
Southwest Iberia					
S11	Marsh	36°57'48"	6°22'58"	2	Jiménez-Moreno et al. (2015)
Beliche	Marsh	37°16'	7°27'	25	Fletcher et al. (2007)
Medina	Lake	36°37'04"	6°03'02"	30	Reed et al. (2001)
El Acebrón	Lake	37°04'02"	6°33'03"	25	Stevenson & Moore (1988) Stevenson & Harrison (1992)
Las Madres	Lake	37°09'18"	6°51'21"	2	Stevenson & Harrison (1992) Yll et al. (2003)
Southeast Iberia					
El Sabinar	Palaeolake	38°12'	2°07'	1117	Carrión et al. (2004)
Ojos de Villaverde	Wetland	38°48'	2°22'	870	Carrión et al. (2001b)
Padul	Peat-bog	37°00'21"	3°36'43"	700	Pons & Reille (1988)
Siles	Lake	38°23'21"	2°30'34"	1320	Carrión (2002)
Cañada de la Cruz	Peat-bog	38°03'53"	2°41'22"	1595	Carrión et al. (2001a)
Baza	Peat-bog	37°14'01"	2°42'31"	1900	Carrión et al. (2007)

Borreguiles de la Virgen	Peat-bog	37°03'15"	3°22'40"	2945	Jiménez-Moreno and Anderson (2012)
Río Seco	Lake	37°02'	3°20'	3020	Anderson et al. (2011)
San Rafael	Marsh	36°46'25"	2°36'05"	1	Pantaleón et al. (2003)
Elx	Marsh	38°10'28"	0°45'10"	1	Burjachs et al. (1997)

Table 2

Climatic parameters	Correlation coefficient	RMSE
S11		
Tc (°C)	0.934	1.40
Tw (°C)	0.920	1.35
Tann (°C)	0.934	1.25
Pann (mm/yr)	0.815	168.28
PRD-4		
Tc (°C)	0.942	1.38
Tw (°C)	0.930	1.33
Tann (°C)	0.940	1.23
Pann (mm/yr)	0.820	166.57

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Northwest (PRD-4)

Southwest (S11)

Figure 7

Figure 8

NORTHWEST								
Culture								
Population								
Humid/Arid ($\Delta 13C$)	Stability (17.‰ VPDB)	?	?	?				
Vegetation (pollen)					Initial deforestation and anthropisation			
SOUTHWEST								
Culture					Population dispersal and regionalism			
Population					Population decline			
Humid/Arid ($\Delta 13C$)			High Variability					
Vegetation (pollen)					Increased aridity			
SOUTHEAST								
Culture					Social stratification, village nucleation			
Population					Population growth			
Humid/Arid ($\Delta 13C$)	?	?	?	?	Stability, below 17.5‰ VDBP (drier)			
Vegetation (pollen)					Increased aridity			
	6000 BP	5500	5000	4500	4200	4000	3500	3000
		COPPER AGE			BRONZE AGE			