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Short Paper

Patterns of human occupation during the early Holocene in the Central Ebro Basin (NE Spain) in response to the 8.2 ka climatic event

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ABSTRACT

The Central Ebro River Basin (NE Spain) is the most northern area of truly semi-arid Mediterranean climate in Europe and prehistoric human occupation there has been strongly influenced by this extreme environmental condition. Modern climate conditions single out this region due to the harsh environment, characterised by the highest absolute summer temperatures of the Ebro River Basin. The Bajo Aragón region (SE Ebro River Basin) was intensively populated during the Early Holocene (9400–8200 cal yr BP) but the settlements were abandoned abruptly at around 8200 cal yr BP. We propose that this “archaeological silence” was caused by the regional impact of the global abrupt 8.2 ka cold event. Available regional paleoclimate archives demonstrate the existence of an aridity crisis then that interrupted the humid Early Holocene. That environmental crisis would have forced hunter-gatherer groups from the Bajo Aragón to migrate to regions with more favourable conditions (i.e. more humid mountainous areas) and only return in the Neolithic. Coherently, archaeological sites persist during this crisis in the nearby Iberian Range (Maestrazgo) and the North Ebro River area (Pre-Pyrenean mountains and along the northwestern Ebro Basin).

Introduction

Prehistoric and historic societies around the world, particularly those located in semi-arid areas, have been highly vulnerable to abrupt climatic changes, with numerous examples of widespread abandonment, migrations and even cultural collapses. Examples include the Eastern Sahara occupation during the Holocene humid period (Hoelzmann et al., 2001), the Neolithic migrations that occurred in Europe (Turney and Brown, 2007), and the population decreases in the North American Great Plains during the Altithermal period of the Middle Holocene (Meltzer, 1999). In several cases, environmental crises caused by increased aridity have been considered a main trigger in civilization collapse, as the Akkadian Empire, the Argaric Culture and the Maya Civilization, although other possible socio-economic factors have also been considered (respectively, Cullen et al., 2000; Carrión et al., 2007; Haug et al., 2003). The Ebro River Valley (NE Spain) has a long history of human occupation (Utrilla, 2002; Montes et al., 2006) and because of the harsh environmental conditions that characterise this Mediterranean area it provides several examples of the complex interplay of climate and human societies. In addition, this region includes the Bajo Aragón area, an ecologically “fragile” area characterised by a strong water deficit (López-Martín et al., 2007).

The Holocene (last 11.5 ka) has been classically considered a climatically stable episode, especially when compared with the last glacial period. However, there is increasing evidence of significant climate variability at suborbital scales during the present interglacial at a global scale (Mayewski et al., 2004). In the Iberian Peninsula several sites document large climate variability during the Holocene and particularly the strong impact in vegetation communities and hydrology during the Early Holocene (Ramil-Rego et al., 1998; Sánchez-Goñi and Hannon, 1999; Carrión, 2002; Plá and Catalan, 2005; González-Sampériz et al., 2006; Davis and Stevenson, 2007; Morellón et al., 2008).

The 8.2 ka event is one of the most significant climate crisis of the last 11.5 ka and was globally identified as a short cold and arid period (Alley and Agustsdottir, 2005; Rohling and Pälike, 2005). This event appears to have been generally cooler over much of the Northern Hemisphere, and it is also characterised by: i) a widespread aridity in low latitudes (de Menocal et al., 2000; Gasse and Van Campo, 1994); ii) enhanced seasonality (Baldini et al., 2002); and iii) dry northerly winds influence in the western Mediterranean (Frigola et al., 2007). Although many new paleoclimate records have contributed to reconstruct the climate variability associated to this event (see compilation in Mayewski et al., 2004), the forcing mechanisms remain under discussion (Bauer et al., 2004; Rohling and Pälike, 2005). Global climate models (GCM) show that colder conditions in the north Atlantic would translate into more arid conditions in the continental areas of the Mediterranean region, including the Iberian Peninsula

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(Wiersma and Renssen, 2006). In this sense, it is not difficult to imagine how ecosystems could have been easily destabilized in the Central Ebro Basin during short climate crises, with great consequences for the already scarce vegetation, fauna and humans during the Prehistory.

In this paper we present a detailed compilation of the radiocarbon-dated settlements located in the Ebro Basin between 11,500 and 6500 cal yr BP and analyse the relationship between their occupation patterns and the climate evolution reconstructed from available regional palaeoenvironmental sequences. Our results point to the

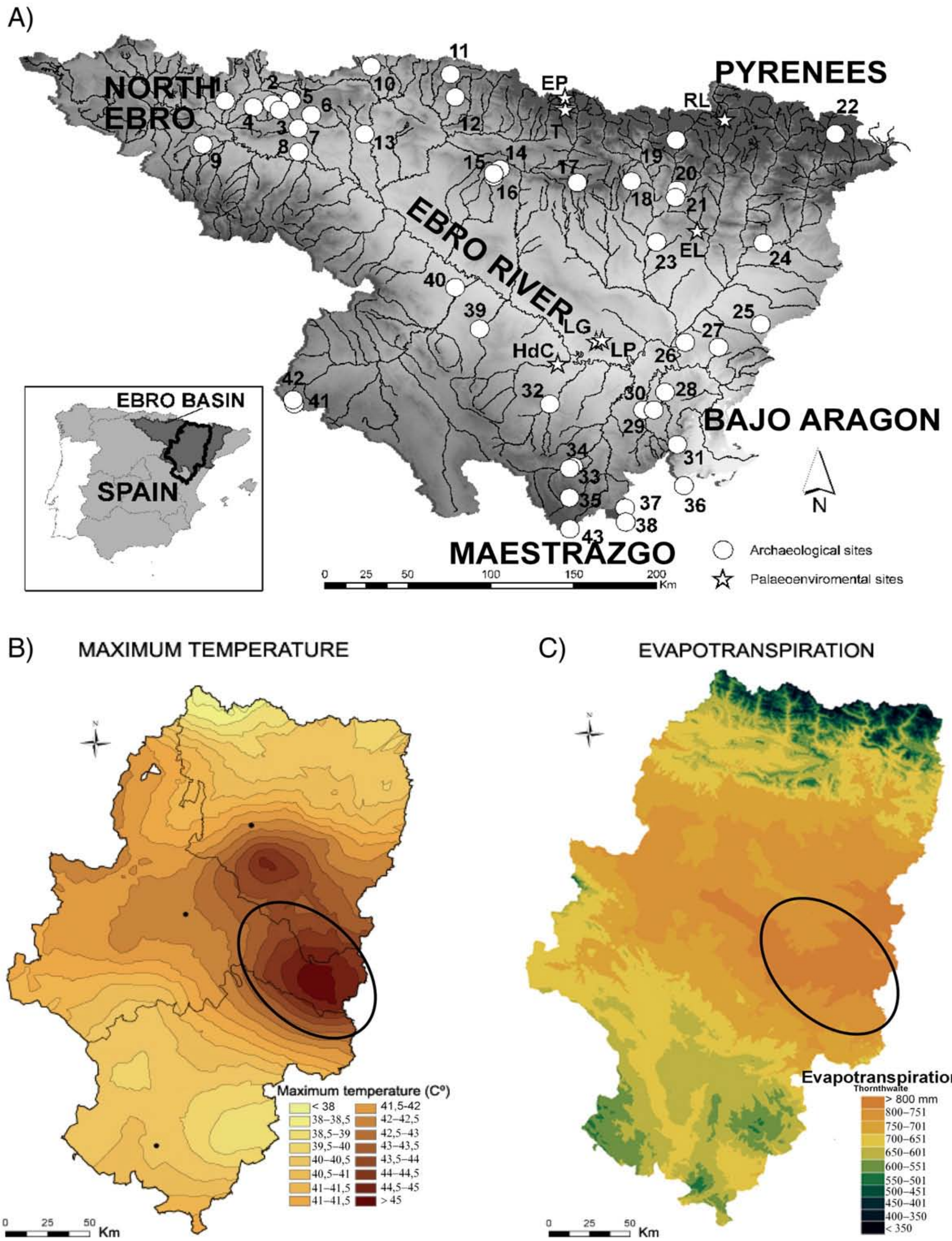

Figure 1. A) Location map of the Ebro Basin with all the archaeological settlements (dots) and palaeoenvironmental sites (stars) cited in the text. Currently, the Bajo Aragón area has a harsh continental climate with: B) the highest absolute maximum temperatures of Aragón region (included in the Ebro Basin), reaching more than 45°C in summer; and C) one of the three highest evapotransipration index areas of the Iberian Peninsula (more than 800 mm). The Bajo Aragón area is encircled in Figures 1B and C. *Archaeological settlements*: 1. Fuente Hoz, 2.Kampanoste, 3. Kampanoste Goikoa, 4. Mendandia, 5. Atxoste, 6. La Peña de Marañón, 7. Peña Larga, 8. Los Cascajos, 9. Cueva Lóbrega, 10. Abauntz, 11. Aizpea, 12. Zatoya, 13. Paternanbidea, 14. Paco Pons, 15. Peña 14, 16. Legunova, 17. Chaves, 18. Huerto Raso, 19. Puyascada, 20. Forcas I, 21. Forcas II, 22. Balma Margineda, 23. Moro de Olvena, 24. Parco, 25. Moli de Salt, 26. Riols, 27. Filador, 28. Costalena, 29. Pontet, 30. Botiquería dels Moros, 31. Vidre, 32. Los Baños, 33. Angel 1, 34. Angel 2, 35. Toros de Cantavieja, 36. Cova de las Bruixes, 37. Cova Fosca, 38. Mas Nou, 39. Cabezo de la Cruz, 40. Cueva del Gato, 41. Lampara, 42. Revilla, 43. Mas Cremat. *Palaeoenvironmental sites*: EP: El Portalet, T: Tramacastilla, RL: Lake Redó, EL: Estanya Lake, LG: Laguna Guallar, LP: La Playa, HdC: Hoya del Castillo.

8.2 ka arid event (Alley et al., 1997) as the main cause for the dramatic cessation of the use of the sites identified at the Bajo Aragón during the end of the Epipaleolithic or Mesolithic culture. The region was not re-occupied intensively until the beginning of the Neolithic, when a new economic activity (agriculture, pastoralism) allowed subsistence there.

Present-day environment: Climate and vegetation

The climate in the Central Ebro River Basin is Mediterranean with strong continental influences resulting in very hot summers, cold and relatively dry winters, strong dry NW winds and low rainfall due to the rain-shadow effect of the Iberian Range (Capel Molina, 1981; García-Vera, 1996). Specifically, this region is the northernmost region of truly semi-arid climate in Europe. In fact, the Bajo Aragón area shows the maximum absolute temperatures in the area with more than 45°C (López-Martín et al., 2007) next to the greatest evapo-transpiration index of the region with an annual water deficit of more than 800 mm and only 300 mm of annual precipitation (Fig. 1A).

The present landscape in the Central Ebro Basin (including the Bajo Aragón) is an herbaceous-shrubby land, mostly dedicated to agriculture. Steppe vegetation cover is generally open, leaving small patches with xerophyte shrubs, *Pinus halepensis*, *Quercus coccifera* and *Juniperus thurifera* as the main arboreal taxa. Nitrophilous and gypsophilous plants are also abundant (Molero et al., 1986; Longares, 1997). In contrast, the North Ebro area sustains forested landscapes dominated by conifers (*Abies alba*, *Pinus uncinata*, and *Pinus sylvestris*) or broad-leaf angiosperms (*Quercus pubescens*, *Quercus robur*, *Fagus*, *Corylus*, *Betula*, *Acer*, *Tilia*, and *Sorbus*). The Pre-Pyrenean foothills (southeastern of the North Ebro area) and the Iberian Range (Maestrazgo) have a more Mediterranean influence and vegetation is dominated by diverse types of conifers depending the altitude and the substrate and *Quercus ilex-rotundifolia* or *Q. faginea-pubescens* with dense shrub land (Blanco et al., 1997).

Cultural chronology during the Early Holocene

Archaeological information for the Early Holocene in the Ebro Basin shows important population density only in specific areas (Utrilla, 2002, 2005; Montes et al., 2006). For example, 14 archaeological sites are located in the Bajo Aragón during the period known as “Recent Mesolithic” or “Epipaleolithic Geometric culture” (9–8 ka). Despite the high number of settlements known in the whole Ebro Basin, only 40 of them have dated occupation levels between 11,000 and 6500 cal yr BP. For this study we consider the available radiocarbon dates (228) associated with these 40 sites (Tables 1 and 2). The dates have been converted into “calendar” ages using the calibration curve from CalPal-2007-HULU (Weninger et al., 2007; Weninger and Jöris, 2008).

A diagram with the probability of occupation based on the available dates on eight archaeological sites is shown in Figure 2. The settlements located in North Ebro (Axoste, Mendandia and Forcas I and II) do not reflect any occupation change around 8000 cal yr BP. On the contrary, the sites located in the Bajo Aragón (Angel 1 and 2, Los Baños, Botiquería dels Moros and Pontet) were abandoned at this time. The settlement of Mas Nou in Maestrazgo Mountains shows its first occupation just after 8000 cal yr BP. Based on this complete archaeological compilation, a large migration of people from the Bajo Aragón to more humid mountain areas occurred at around 8000 cal yr BP (Figs. 3A and B).

Although erosion of the archaeological record cannot be ruled out as a factor contributing to the observed “silence”, the high number of sites documented in this study, and their location in different geomorphological settings point towards regional-scale processes (migration) more than to site-specific processes (erosion). Besides, the stratigraphy of the sites represented in Figure 2 clearly shows that the intervals without human occupation always correspond to archaeologically sterile levels (without industry, fire, fauna or human traces) but not to hiatus (lack of sediment) as a consequence of erosion processes. The archaeological levels are always *in situ* and, in addition, the abandonment is correctly reflected in the stratigraphy because it is bounded by fertile archaeological levels at top and bottom layers. So, the inherent problem in archaeology that relates erosion and archaeological material displacement known as “apparent archaeological contexts” (Bernabeu et al., 1999) cannot be applied to this area.

Most of the settlements located in the Bajo Aragón were re-occupied after 700 yr (after 7300 cal yr BP) when the Neolithic culture was well-developed in the whole region (Fig. 3C). Nevertheless, one site, Botiquería dels Moros, shows sporadic occupation at 7670 cal yr BP, only 500 yr after the abandonment of the area. However, the archaeological material found in this level (no pottery, mainly lithic industry) is poor, and the cultural adscription is not clear, pointing to a short occupation (only 6–20 cm depth), probably as a knapping site (Utrilla et al., 1998; Barandiarán and Cava, 2000).

Environmental changes during the Early Holocene

Numerous paleoclimate reconstructions show a more positive water balance in the lakes and an increase in forest formations in NE Spain caused by cool temperatures and/or higher precipitation during the Early Holocene (around 11.5 to 7.0 ka) (Montserrat, 1992; Davis, 1994; Valero-Garcés et al., 2000, 2004; González-Sampériz, 2004a; González-Sampériz et al., 2006, 2008; Davis and Stevenson, 2007; Morellón et al; 2008). Higher lake levels observed throughout the Mediterranean region during this period have also been explained as a result of cooler temperatures and/or higher precipitation (Harrison and Digerfeldt, 1993; Roca and Julià, 1997; Giralt et al., 1999; Reed et al., 2001). The vegetation cover of NE Spain during the Early Holocene reflects humid conditions: from maximum of mesophytes in the Pyrenees (i.e., Tramacastilla: Montserrat, 1992; El Portalet: González-Sampériz et al., 2006), Pre-Pyrenees (i.e., Peña 14 archaeological site: González-Sampériz, 2004a; Estanya Lake: Morellón et al., 2008), Iberian Range (i.e., Ojos del Tremedal: Stevenson, 2000) and North Ebro (i.e., Velate: Peñalba, 1989) to more extensive Mediterranean forest formations (coniferous and evergreen *Quercus*) and scarce steppe land proportions in the lowlands of the Central Ebro Basin (i.e., La Playa: González-Sampériz et al., 2008).

Several sedimentary sequences have provided local palaeoenvironmental information about the Early Holocene, although none presents a continuous record up to the Middle Holocene (Valero-Garcés et al., 2000, 2004; González-Sampériz et al., 2008). Most sequences come from archaeological sites with discontinuous records (López-García, 1992; González-Sampériz, 2004b) or playa-lake sediments where *hiati* are common (Davis, 1994; Valero-Garcés et al., 2000, 2004; González-Sampériz et al., 2008). In a recent study, Davis and Stevenson (2007) interpret two playa-lake records from Hoya del Castillo (HdC) and Laguna Guallar (LG) (Fig. 1) as possible candidates for “sedimentary continuity” and “high resolution” pollen analysis. Although the authors claimed that the dating and the resolution are enough to pinpoint the 8.2 ka event, the reconstructions are based on only three radiocarbon dates from HdC, one from LG, and two tie points based on pollen content (*Ephedra* curve) without considering the sedimentation rate differences and pollen-sampling resolution (every 4 cm in LG and every 8 cm in HdC). The chronological model does not seem robust enough to support a centennial-scale reconstruction in these playa-lake records. However, in spite of the limitations, playa-lake records are in some areas the only palaeoclimatological records, although the difficulties to achieve robust chronologies and the inherent problems related to the sedimentation processes (erosion) greatly hamper the identification of short and abrupt events such as at 8.2 ka (González-Sampériz et al., 2008).

Only regional lacustrine archives of the Ebro River Basin may provide the needed high-resolution reconstructions. Lake Redó (RL),

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Table 1
Early Holocene available radiocarbon dates (11,000–6500 cal yr BP) from archaeological settlements of the North Ebro area (NE Spain)

Archaeological site Level	Ref. Lab.	Radiocarbon date ^{14}C yr BP	σ	Calibrated date cal yr BP	σ	Culture	Remain
Abauntz							
2r	GrN-21010	5820	40	**6620**	**60**	N	C
c	I-11537	6910	450	**7770**	**430**	NA	hh
d	Ly-1964	9530	300	**10860**	**410**	Mag/Az	hh
Peña de Marañón							
d inf.	BM-2363	7890	120	**8760**	**170**	MG	H
Aizpea							
III (b alt)	GrN-18421	6370	70	**7310**	**80**	NA	hh
II (b med/alt.)	GrA-799	6600	50	**7500**	**50**	MG	H
II (b med/alt.)	GrN-16622	6830	70	**7680**	**70**	MG	hh
I (b med.)	GrN-16621	7160	70	**7990**	**70**	MG	hh
I (b bas.)	GrN-16620	7790	70	**8580**	**90**	MG	hh
Atxoste							
IIIb1	GrN-9789	6220	60	**7130**	**90**	NA	H
IIIb2	Sin datos	6710	50	**7580**	**50**	MG	H
IIIb2	GrA-13415	6940	40	**7770**	**50**	MG	H
IV	Sin datos	6970	40	**7810**	**60**	MG	H
IIIb2	Sin datos	7140	50	**7960**	**40**	MG	H
IV	GrA-13418	7340	50	**8150**	**80**	MG	H
IV	GrA-13469	7480	50	**8290**	**70**	MG	H
V	GrA-13447	7810	40	**8590**	**40**	MD	H
V	GrA-13472	7830	50	**8630**	**70**	MD	H
V	GrA-13448	8030	50	**8900**	**100**	MD	H
IV	Sin datos	8080	50	**8980**	**110**	MD	H
VI	GrA-15700	8510	80	**9500**	**50**	MD	H
VI	GrA-15699	8760	50	**9770**	**110**	MD	H
VI (Hogar)	GrA-13473	8840	50	**9950**	**150**	MD	H
E2	Sin datos	9510	150	**10840**	**230**	Em	H
VII	GrA-15858	9550	60	**10910**	**140**	Em	H
E	Sin datos	9650	150	**10970**	**210**	Em	H
E2	Sin datos	9820	150	**11270**	**300**	Em	H
Balma Margineda							
3a (f1)	Ly-3288	6640	160	**7520**	**140**	NA	C
3b (f3)	Ly-2839	6670	120	**7550**	**90**	NA	C
3/4	Ly-3290	6820	170	**7690**	**150**	NA	C
3b (f3)	Ly-3289	6850	160	**7720**	**140**	NA	C
4 sup.	Ly-3291	8210	180	**9130**	**250**	MD	C
4 sup.	Ly-2840	8390	150	**9330**	**170**	MD	C
4 base	Ly-2841	8530	420	**9560**	**540**	MD	C
4/5	Ly-3892	8850	120	**9920**	**200**	MD	C
5/6	Ly-4402	8960	120	**10030**	**180**	Em	C
4 base	Ly-4401	8970	120	**10040**	**180**	MD	C
6 sup.	Ly-2842	9250	160	**10480**	**200**	Em	C
6L	Ly-3884	9900	110	**11430**	**180**	Em	C
Chaves							
Ia	CSIC-381	6120	70	**7020**	**110**	NA	C
b (muerto)	GrA-26912	6230	45	**7140**	**90**	NA	H
Ia	CSIC-379	6230	70	**7130**	**100**	NA	C
Ia	GrN-13603	6260	100	**7160**	**130**	NA	C
Ia	GrN-13605	6330	70	**7270**	**80**	NA	C
Ia	GrN-13602	6330	90	**7260**	**110**	NA	C
Ia	GrA-28341	6380	40	**7330**	**60**	NA	B
Ib	CSIC-378	6460	70	**7370**	**60**	NA	C
Ib	GrN-13604	6490	40	**7400**	**50**	NA	C
Ib	GrN-12683	6650	80	**7530**	**60**	NA	C
Ib	GrN-12685	6770	70	**7630**	**50**	NA	C
Filador							
2	AA-13411	8150	90	**9130**	**120**	MD	C
2	OxA-8658	8515	50	**9510**	**30**	MD	C
7	ICEN-495	9130	230	**10280**	**330**	Em	C
4	UBAR-284	9460	190	**10770**	**280**	Em	C
5/6	AA-13412	9988	97	**11520**	**190**	Em	C
7	UBAR-257	9830	160	**11290**	**310**	Em	C
4	AA-8647	10020	80	**11550**	**180**	Em	H
Forcas I							
VII	GrN-17784	9360	140	**10630**	**230**	Az/Em	C
IX	GrN-17785	9715	75	**11050**	**150**	Az/Em	C
Forcas II							
VIII	GrN-22689	6680	190	**7560**	**170**	NA	C
VI	GrN-22688	6900	45	**7740**	**50**	NA	C
V	GrN-22687	6970	130	**7810**	**120**	NA	C
V	Beta 60773	6940	90	**7790**	**90**	NA	C
IV	Beta 59995	7090	340	**7950**	**320**	MG	C

Table 1 (*continued*)

Archaeological site Level	Ref. Lab.	Radiocarbon date ^{14}C yr BP	σ	Calibrated date cal yr BP	σ	Culture	Remain
Forcas II							
II	GrN-22686	7240	40	**8070**	**60**	MG	C
Ib	CAMS-5354	8650	70	**9650**	**90**	MD	C
Fuente Hoz							
II (lecho 16)	I-12084	6120	280	**6970**	**310**	NA	C
III (lecho 23)	I-12778	7140	120	**7980**	**130**	MG	C
III (lecho 21)	I-12083	7840	130	**8710**	**190**	MG	C
III (lecho 23)	I-13496	7880	120	**8750**	**170**	MG	C
III (lecho 28)	I-12985	8120	240	**9020**	**310**	MD	C
Huerto Raso							
b (base)	GrA-21360	6310	60	**7240**	**60**	NA	C
Kanpanoste							
Lanhs	GrN-22440	7620	70	**8440**	**70**	MD	hh
Lanhi (base)	GrN-22442	7920	100	**8790**	**150**	MD	hh
Lanhi (med.)	GrN-22441	8200	70	**9180**	**110**	MD	hh
Kanpanoste Goikoa							
III	GrN-20214	6360	70	**7300**	**80**	MG	hh
III	GrN-20289	6550	260	**7410**	**250**	MG	hh
III inferior	GrN-20215	7620	80	**8440**	**70**	MD	hh
III inferior	GrN-20455	7860	330	**8780**	**380**	MD	hh
Legunova							
1	GrA-24292	8200	50	**9160**	**90**	MD	C
1	GrA-22086	8250	60	**9240**	**110**	MD	C
2	GrA-24294	8800	60	**9890**	**160**	MD	C
Los Cascajos							
Estructura 183	Ua-16024	6185	45	**7090**	**70**	NA	H
Estructura 497	Ua-24426	6230	50	**7140**	**90**	NA	H
Estructura 551	Ua-24428	6435	45	**7360**	**50**	NA	C
Mendandia							
I	GrN-22740	6440	40	**7370**	**40**	NA	hh
II	GrN-22741	6540	70	**7450**	**70**	NA	hh
III sup	GrN-22742	7180	45	**8000**	**40**	NA	hh
III sup	GrN-19658	7210	80	**8050**	**80**	NA	hh
III inf.	GrN-22743	7620	50	**8440**	**50**	MG	hh
IV	GrN-22745	7780	40	**8550**	**50**	MD	hh
IV	GrN-22744	7810	50	**8600**	**60**	MD	hh
V	GrA-6874	8500	60	**9500**	**40**	Em	hh
Molí del Salt							
Sup	Beta-173335	8040	40	**8910**	**100**	MD	H
Moro de Olvena							
Cámara superior	GrN-12119	6550	130	**7440**	**110**	NA	C
Paco Pons							
2	GrA-19294	6010	45	**6860**	**60**	NA	C
2	GrA-19295	6045	45	**6900**	**60**	NA	C
Parco							
IAB-40	CSIC-279	5790	190	**6630**	**220**	N	hh
EE1	GrN-20058	6120	90	**7010**	**130**	NA	C
IAB-39	CSIC-281	6170	70	**7070**	**90**	NA	cc
IAB-38	CSIC-280	6450	230	**7300**	**240**	NA	hh
Paternanbidea							
Enterramiento 2 (A)	GrA-13675	5960	40	**6800**	**60**	NA	H
Enterramiento 1	GrA-13673	6090	40	**6970**	**60**	NA	H
Peña 14							
a	GrN-25094	7660	90	**8470**	**80**	MG	C
b	GrN-25999	8000	80	**8850**	**130**	MD	C
b	GrN-25998	8000	90	**8850**	**140**	MD	C
b	GrN-25097	8340	130	**9300**	**150**	MD	C
b	GrN-25098	8780	110	**9860**	**200**	MD	C
Peña Larga							
IV	I-14909	5830	110	**6640**	**130**	NA	hh
IV	I-15150	6150	230	**7010**	**260**	NA	hh
Puyascada							
II	CSIC-384	5930	60	**6770**	**80**	N	C
Riols							
a1	GrN-13976	6040	100	**6920**	**140**	N	C
Zatoya							
I	Ly-1397	6320	280	**7160**	**290**	NA	hh
Ib	Ly-1398	8150	220	**9060**	**300**	E	C
Ib	Ly-1457	8260	550	**9270**	**670**	E	C

(0=AD 1950). *P* (68%). CalPal 2007, HULU curve.
Archaeology: Mag/AZ, Magdalenian/Azilian; Em, Epipalaeolithic microlaminar; MD, Mesolithic with Denticulates; MG, Mesolithic Geometric; NA, Ancient Neolithic; N, Neolithic.
Dated material: B, Acorn; C/cc, Charcoal; Cl, Cerealia seed; H/hh, Bones.

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Table 2
Early Holocene available radiocarbon dates (11,000–6500 cal yr BP) from archaeological settlements of the South Ebro area (NE Spain)

Archaeological site Level	Ref. Lab.	Radiocarbon date ^{14}C yr BP	σ	Calibrated date cal yr BP	σ	Culture	Remain
Abrigo de Ángel 1							
10 sup (<8b)	GrA-21555	5820	110	**6630**	**130**	NA	H
8c (U28)	GrA-27274	7435	45	**8270**	**60**	MG	C
U8	Unknown	7950	300	**8870**	**360**	MG	Unknown
8c (U8-11)	GrA-27278	7955	45	**8830**	**120**	MG	C
8d (U8 inf.)	GrN-15518	8060	270	**8970**	**330**	MD	C
U8	Unknown	8070	160	**8970**	**240**	MD	Unknown
8d (U13)	GrN-15520	8150	170	**9070**	**250**	MD	C
8d (U13)	GrN-15519	8210	210	**9120**	**280**	MD	C
8d	GrA-22826	8390	60	**9400**	**70**	MD	C
9 (U13)	GrA-27275	9200	50	**10380**	**80**	Unknown	C
Abrigo de Ángel 2							
2b	GrN-22836	8310	60	**9310**	**100**	MD	C
Botiqería dels Moros							
6	GrA-13268	6040	50	**6890**	**70**	NA	H
8	GrA-13270	6240	50	**7150**	**90**	NA	H
4	GrA-13267	6830	50	**7670**	**50**	EG/NA	H
2	Ly-1198	7550	200	**8370**	**210**	MG	cc
2	GrA-13265	7600	50	**8410**	**40**	MG	H
Bruixes (C. de les)							
III	Ly-4269	6460	140	**7360**	**130**	NA	C
Cabezo de la Cruz							
UE 1351	GrN-29134	7130	130	**7960**	**140**	MG	C
UE 1397	GrN-29135	7150	70	**7970**	**70**	MG	C
Costalena							
C3 (med/alt.)	GrA-10949	6310	170	**7270**	**260**	NA	hh
C3 (alt.)	GrN-14098	6420	250	**7270**	**260**	NA	hh
Cova del Vidre							
II hogar	Beta-58934	6180	90	**7080**	**120**	NA	C
Cova Fosca							
Z: −9 a −15	Beta-148993	5820	40	**6620**	**60**	NA	C
Z: −34 a −48	Beta-148996	5850	70	**6660**	**90**	NA	C
Z: −45 a −57	Beta-148997	5870	80	**6690**	**100**	NA	C
Z: −15 a −41	Beta-148994	5980	70	**6830**	**90**	NA	C
Z: −45 a−83	Beta-148999	5980	70	**6830**	**90**	NA	C
Z: −118 a −120	Beta-149005	6070	80	**6960**	**130**	NA	C
Z: −49 a −78	Beta-149000	6080	80	**6970**	**130**	NA	C
Z: −120 a −130	Beta-149007	6130	60	**7040**	**90**	NA	C
Z: −65 a −79	Beta-149001	6140	90	**7030**	**120**	NA	C
Z: −111 a −120	Beta-149004	6150	70	**7050**	**100**	NA	C
Z: −119	Beta-149006	6250	80	**7150**	**110**	NA	C
Z: −135	Beta-149009	6390	40	**7340**	**60**	NA	C
Z: −180	CSIC-356	7100	70	**7920**	**70**	–	C
Z: −182	CSIC-357	7210	70	**8050**	**80**	–	C
Z: −184	CSIC-353	7640	110	**8450**	**100**	–	C
Z: −270	I-9868	8880	200	**9950**	**250**	Em/MD	C
Z: −278	I-11313	9460	160	**10780**	**260**	Mag/AZ	C
Cueva del Gato							
S.I	GrA-22525	6240	50	**7150**	**90**	N	C
Cueva Lóbrega							
N. III	GrN-16110	6220	100	**7120**	**120**	N	hh
Lámpara							
Hoyo 1	KIA 6789	6033	34	**6880**	**50**	NA	hh (human)
Hoyo 11	KIA 21348	6125	33	**7050**	**80**	NA	H
Hoyo 1	KIA 6790	6144	46	**7060**	**80**	NA	H (human)
Hoyo 9	KIA 21352	6280	33	**7220**	**40**	NA	H
Hoyo 1	UtC-13346	6280	50	**7210**	**50**	NA	Cl
Hoyo 1	KIA 4780	6390	60	**7330**	**60**	NA	C
Hoyo 18	KIA 21347	6407	34	**7350**	**50**	NA	H
Hoyo 13	KIA 16571	6608	35	**7510**	**40**	NA	C
Hoyo 9	KIA 16579	6610	32	**7510**	**40**	NA	C
Hoyo 13	KIA 16574	6729	45	**7600**	**40**	NA	C
Hoyo 9	KIA 16575	6744	33	**7610**	**30**	NA	C
Hoyo 13	KIA 16566	6835	34	**7670**	**30**	NA	C
Hoyo 9	KIA 21350	6871	33	**7710**	**40**	NA	H
Hoyo 18	KIA 16577	6915	33	**7750**	**40**	NA	C
Hoyo 9	KIA 16569	6920	50	**7760**	**60**	NA	C
Hoyo 18	KIA 16570	6956	39	**7790**	**50**	NA	C
Hoyo 9	KIA 16578	6975	32	**7810**	**50**	NA	C
Hoyo 9	KIA 16580	6989	48	**7830**	**70**	NA	C
Hoyo 9	KIA 16568	7000	32	**7850**	**50**	NA	C
Hoyo 18	KIA 16581	7075	44	**7910**	**50**	NA	C
Hoyo 16	KIA 16573	7108	34	**7930**	**40**	NA	C
Hoyo 9	KIA 16576	7136	33	**7970**	**30**	NA	C

Table 2 (*continued*)

Archaeological site Level	Ref. Lab.	Radiocarbon date ^{14}C yr BP	σ	Calibrated date cal yr BP	σ	Culture	Remain
Los Baños							
2b3sup	GrA-21550	7350	60	**8170**	**90**	MG	C
2b3inf	GrA-21551	7550	50	**8360**	**40**	MG	C
2b3 general	GrN-24300	7570	100	**8370**	**110**	MG	C
2b1	GrA-21552	7740	50	**8520**	**60**	MG	C
2b1	GrN-24299	7840	100	**8710**	**170**	MG	C
2b1	GrA-21556	8040	50	**8900**	**100**	MD/MG	C
Mas Nou							
1	Beta-136678	6560	130	**7450**	**110**	NA	C
2b	Beta-170713	6760	40	**7620**	**30**	NA	H
1	Beta-136676	6800	70	**7650**	**60**	NA	H
1	Beta-136677	6900	70	**7750**	**70**	NA	H
3	Beta-170715	6920	40	**7760**	**50**	MG	H
3	Beta-170714	6910	40	**7750**	**50**	MG	H
fosa	Unknown	7010	40	**7860**	**60**	MG	H
Pontet							
c inf.	GrN-14241	6370	70	**7310**	**80**	NA	C
e	GrN-16313	7340	70	**8170**	**100**	MG	C
Revilla							
Estructura 8	KIA 13943	5642	96	**6450**	**110**	NA	C
Estructura 4	UtC-13348	6120	60	**7030**	**100**	NA	Cl
Estructura 12	KIA 21353	6156	33	**7070**	**70**	NA	H (dom.)
Estructura 12	KIA 21349	6158	31	**7070**	**60**	NA	H
Estructura 13	KIA 21354	6177	31	**7080**	**60**	NA	H (dom.)
Estructura 2	KIA 21346	6202	31	**7100**	**60**	NA	H (dom.)
Estructura 2	UtC-13350	6210	60	**7120**	**90**	NA	Cl
Estructura 13	KIA 21355	6230	30	**7150**	**80**	NA	H
Estructura 16	UtC-13294	6240	50	**7150**	**90**	NA	Cl
Estructura 4	KIA 21359	6245	34	**7180**	**60**	NA	H
Estructura 12	UtC-13295	6250	50	**7160**	**80**	NA	Cl
Estructura 2	UtC-13269	6250	50	**7160**	**80**	NA	Cl
Estructura 14	KIA 21357	6271	31	**7210**	**40**	NA	H
Estructura 4	KIA 21351	6289	31	**7220**	**40**	NA	H
Estructura 9	UtC-13347	6313	48	**7240**	**50**	NA	Cl.
Estructura 4	KIA 13936	6335	46	**7270**	**60**	NA	C
Estructura 4	KIA 21356	6355	30	**7290**	**30**	NA	H (dom.)
Estructura 14	KIA 21358	6365	36	**7320**	**50**	NA	H
Estructura 2	KIA 13932	6385	35	**7340**	**50**	NA	C
Estructura 4	KIA 13937	6405	36	**7350**	**50**	NA	C
Estructura 4	KIA 13942	6415	36	**7360**	**50**	NA	C
Estructura 8	KIA 13945	6446	39	**7370**	**40**	NA	C
Estructura 5	KIA 13948	6449	37	**7370**	**40**	NA	C
Estructura 4	KIA 13938	6449	42	**7370**	**40**	NA	C
Estructura 2	KIA 13933	6468	40	**7380**	**40**	NA	C
Estructura 4	KIA 13940	6568	37	**7480**	**30**	NA	C
Estructura 14	KIA 13946	6691	48	**7560**	**40**	NA	C
Estructura 4	KIA 13939	6755	57	**7620**	**40**	NA	C
Estructura 2	KIA 13934	6772	47	**7630**	**40**	NA	C
Estructura 14	KIA 13947	6809	37	**7650**	**30**	NA	C
Estructura 4	KIA 13935	6983	45	**7830**	**70**	NA	C
Estructura 8	KIA 13944	7014	37	**7870**	**50**	NA	C
Estructura 4	KIA 13941	7165	37	**7990**	**30**	NA	C
Toros de Cantavieja							
a1	GrA-24791	5880	50	**6710**	**50**	NA	H

(0=AD 1950). *P* (68%). CalPal 2007, HULU curve.
Archaeology: Mag/AZ, Magdalenian/Azilian; Em, Epipalaeolithic microlaminar; MD, Mesolithic with Denticulates; MG, Mesolithic Geometric; NA, Ancient Neolithic; N, Neolithic.
Dated material: B, Acorn; C/cc, Charcoal; Cl, Cerealia seed; H/hh, Bones (human, dom-animal).

El Portalet (EP) and Estanya Lake (EL) cores represent, at this moment, the only three long sequences in the region (Fig. 1) with a robust chronology based on ten radiocarbon dates from RL, 13 from EP and 17 from EL and they have been analysed following a multiproxy approach that could show the effects of the 8.2 ka event in climate, palaeohidrology and vegetation at a regional scale (Plá and Catalán, 2005; González-Sampériz et al., 2006; Morellón et al., 2008).

Lake Redó crysophyte cysts altitude anomaly curve shows a warming trend during the Early Holocene interrupted by a cold spell around 8200 cal yr BP (Plá and Catalán, 2005). Although this event appears embedded in a warm, local fluctuation, the age matches the cold 8.2 ka event in the GISP2 record (Figs. 4B and G). El Portalet pollen record shows a rapid *Juniperus* response–a decrease in the pollen percentages indicative of more arid conditions–to all abrupt changes identified during the Lateglacial and the Early Holocene, including the 8.2 ka event, (Fig. 4C) (González-Sampériz et al., 2006). The mesophytes pollen curve of this site, mainly composed by *Betula* and *Corylus*, also reflect a decreasing trend after its maximum development during the Early Holocene. The Estanya Lake record clearly shows an increase in water availability during the Early Holocene, after 9500 cal yr BP. In addition, an increase in water salinity represented by higher sulphur values (gypsum deposition) (Fig. 4D) occurred around 8200 cal yr BP (Morellón et al., 2008).

Other continental records in Spain also reflect the 8.2 ka event. Fluvial deposits in several Iberian watersheds document large floods between ca. 11,200 and 9000 cal yr BP and a period without floods between ca. 8400 and 7600 cal yr BP (Benito et al., 2003, Macklin et al., 2006; Thorndycraft and Benito, 2006) in agreement with the more humid conditions of the Early Holocene and the aridity crisis related to the 8.2 ka event (Fig. 4E).

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Available western Mediterranean marine records also show a distinctive Early Holocene signature. The geochemical composition of the IMAGES core (MD99-2343) located offshore Menorca (Balearic Islands) points to abrupt events during the Holocene related to the intensity of Mediterranean deep water formation and the amount of particles derived from fluvial transport (Frigola et al., 2007). The percentage of *K* as an indicator of clays transported by the rivers clearly decreases from 9500 to 7700 cal yr BP, reaching the minimum at the 8.2 ka event (Fig. 4F). In addition, the Si/Al ratio, considered a proxy for deep currents intensity, marks the

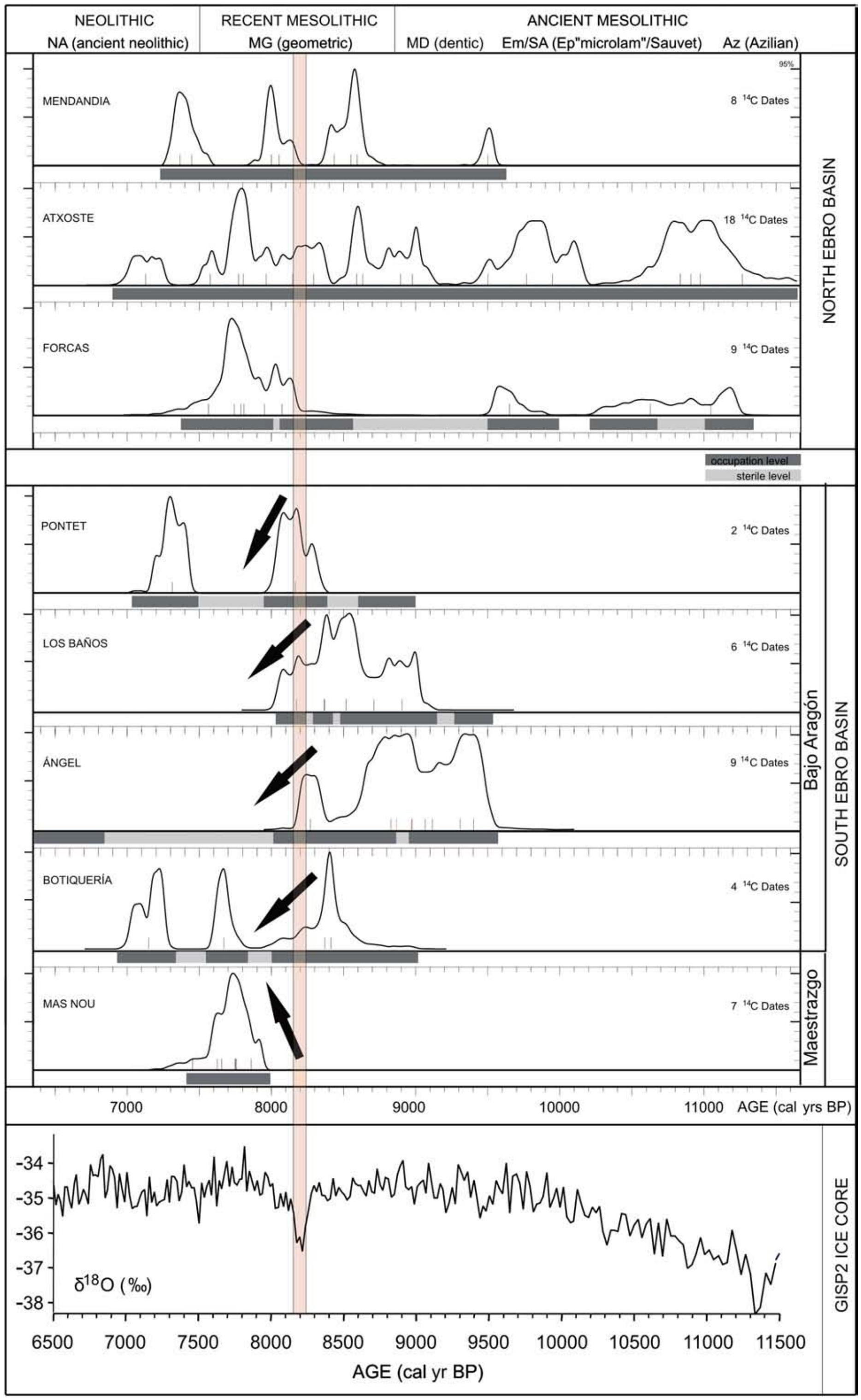

Figure 2. Diagram of calibrated dates for eight selected archaeological sites from North Ebro (Mendandia, Axoste and Forcas) and South Ebro Basin (grouped in Bajo Aragón - Pontet, Los Baños, Ángel and Botiquería dels Moros- and Maestrazgo areas—Mas Nou) between 11,500 and 6500 cal yr BP. The settlements of the Bajo Aragón are affected by a dramatic abandonment marked by the band at 8.2 ka referenced at the GISP2 ice core (Grootes and Stuiver, 1997). The Mas Nou site, in the Maestrazgo Mountains (Iberian Range), shows its first occupation when the Bajo Aragón is abandoned. The fertile (occupation) and sterile (abandoned) archaeological levels of every settlement are also indicated by a grey band below each site. The corresponding cultural adscription is shown at the bottom of the diagram (*Ancient Mesolithic*: Az—Azilian, Em/SA—Epipalaeolithic microlaminar or Sauveterrian, MD—Mesolithic with Denticulates; *Recent Mesolithic*: MG—Mesolithic with geometrics; and Neolithic: NA—Ancient Neolithic).

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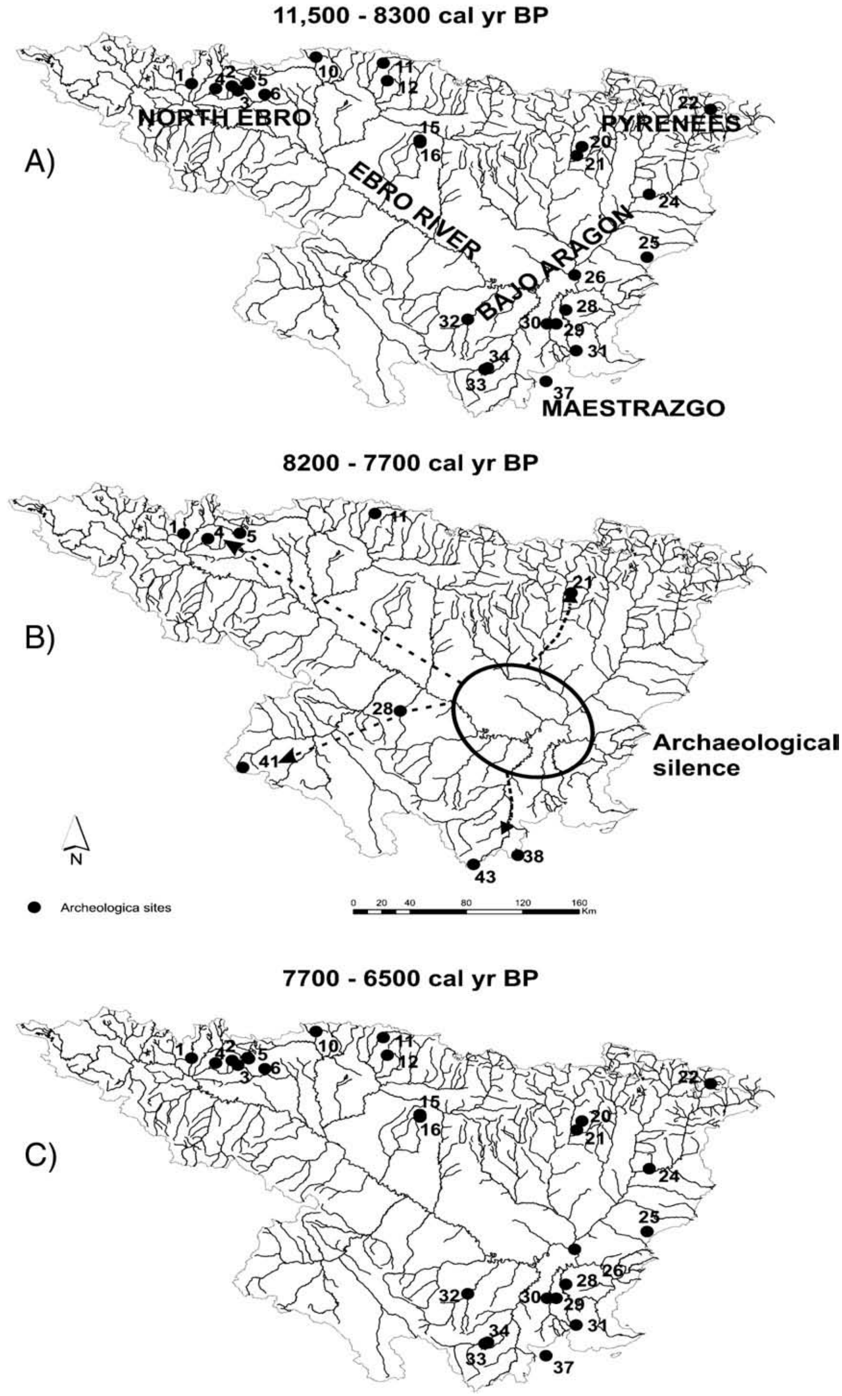

Figure 3. Chronological and cultural periods in the Ebro Basin (modified from Utrilla and Martínez-Bea, 2006): (A) between 11,000 and 8200 cal yr BP (dense human occupation); (B) between 8200 and 7700 cal yr BP (abandonment of the Bajo Aragón: "Archaeological Silence"; continuous occupation in North Ebro areas and onset of the occupation in the Maestrazgo Mountains); (C) between 7700 and 6500 cal yr BP (re-occupation of the Bajo Aragón and new development overall the Ebro Basin).

most prominent peak of the last 11,500 yr at the 8.2 ka event (Fig. 4F).

Therefore, the globally cold 8.2 ka event (GISP2 ice core, Fig. 4E) appears in northeastern Spain as a cold, short phase at altitude (RL) and as a dry event in most records from the whole studied area (EP, EL, MD99-2343).

Climate and humans during the 8.2 ka event in the Central Ebro Basin

Abrupt climate changes conducive to large changes in water availability have caused a concomitant reduction of archaeological sites in several regions. Thus, Lateglacial and Holocene human occupation of the Puna de Atacama Desert in Chile follows the alternation of dry/wet periods (Núñez et al., 2002). Particularly significant is the "silencio arqueológico," a period without human occupation that has been related to the well-documented Mid Holocene aridity crisis in the Chilean Altiplano (Grosjean et al., 2005). In Europe, the transition between the Bronze-Iron Age in the Netherlands was associated to a cold and humid period around 2650 cal yr BP that also caused an important migration to higher altitudes due to the expansion of wetlands in low areas (Van Geel et al., 1996).

In the Bajo Aragón the influence of climatic conditions on human occupation appears as a very plausible explanation for the

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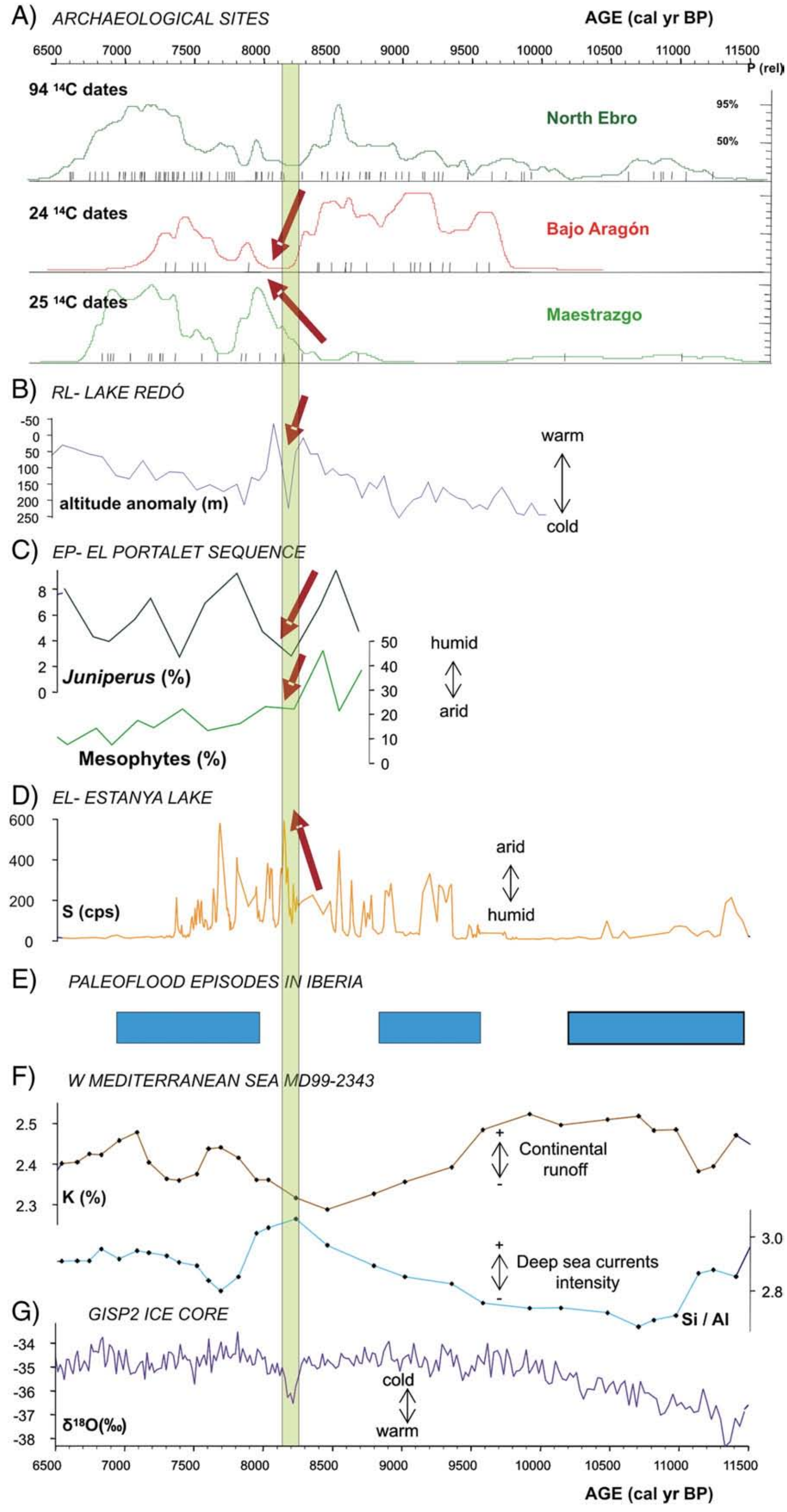

Figure 4. Interval 11,500 to 6500 cal yr BP comparison between:—A) probability curves of Archaeological Occupation (%) for Northern Ebro Basin, Bajo Aragón and Maestrazgo regions (this study) and—a suite of regional palaeoenvironmental records: B) *RL-Lake Redó* record of crysophytes altitude anomaly (meters) (Plá and Catalán, 2005); C) *EP-El Portalet* Peatbog record *Juniperus* and Mesophytes pollen percentages (%) (González-Sampériz et al., 2006); D) *EL-Estanya Lake* record Sulphur (S) content (counts per second, cps) (Morellón et al., 2008); E) *Paleoflood episodes* in the Iberian Peninsula (based in Thorndycraft and Benito, 2006); F) Minorca Drift record (*Core MD99-2343*, Mediterranean Sea) Potassium (K) percentage (%) and Silicon/Aluminium (Si/Al) ratio (Frigola et al., 2007) and G) *Greenland GISP2* ice core oxygen isotope curve (Grootes and Stuiver, 1997). A grey band marks the 8.2 ka event as referenced at the GISP2 ice core (Grootes and Stuiver, 1997).

'archaeological silence' between 8000 and 7300 cal yr BP. On the other hand, the settlements located in the North Ebro persisted, likely due to more favourable conditions. In addition, new occupations occur in the Maestrazgo area at about this time (Olaria et al., 2005; Fernández-López de Pablo, 2006) supporting the hypothesis that Bajo Aragón hunter-gatherers migrated to more humid habitats in the southern Iberian Range mountains. The existence of an exclusive style of "Levantine rock art" in the Maestrazgo, that it is exactly the same as in the Bajo Aragón (Utrilla, 2005; Utrilla and Martínez Bea, 2006), supports the migration and cultural connections from both areas.

The Bajo Aragón was definitively re-occupied during the Neolithic, after 7300 cal yr BP. The new Neolithic Culture permits a better "adaptation" to the ecologically fragile environment with the use of fire and deforestation practices to facilitate agriculture expansion and grazing. However, despite the proliferation of settlements over all the Ebro Basin, population density in the Bajo Aragón was lower than during the Early Holocene.

Conclusions

Following a dramatic abandonment of archaeological settlements in the Bajo Aragón (NE Spain), people migrated to more humid areas (North Ebro and Maestrazgo) between ca. 8190 and 7670 cal yr BP. The reduced extent of human settlements around 8000 cal yr BP is synchronous with the sharp transition from wet-temperate to more arid climate identified as the 8.2 ka event. The impact of this short and abrupt climate change in the population of these environmentally fragile areas was large enough to cause the abandonment of the region until Neolithic times. This collapse of widespread occupation ("archaeological silence") reflects environmental stress and likely caused human migrations, changes in habitat types and in the economy. An important decrease in water availability affected the vegetation resources and led to subsequent animal migration, degrading basis for the hunter-gatherer type of life. During that time, people occupied alternative habitats or refugia where appropriate resources for them remained available in the overall harsh environment.

As in other historic or prehistoric times in different geographic locations, this period of abrupt climate change which occurred during the Early Holocene forced the hunter-gatherer human communities of the Central Ebro Basin to look for new habitat areas and to change their subsistence patterns and culture.

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