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Holocene environmental change in a montane region of southern Europe with a long history of human settlement

J.S. Carrión[a,*], N. Fuentes[a], P. González-Sampériz[b], L. Sánchez Quirante[c], J.C. Finlayson[d], S. Fernández[a], A. Andrade[e]

[a]*Departamento de Biología Vegetal (Botánica), Facultad de Biología, Universidad de Murcia, 30100 Murcia, Spain*
[b]*Instituto Pirenaico de Ecología—CSIC, Avenida Montañana 1005, 50059 Zaragoza, Spain*
[c]*Museo Municipal of Baza, Granada, Spain*
[d]*The Gibraltar Museum, 18-20 Bomb House Lane, P.O.Box 939, Gibraltar*
[e]*Departamento de Geología, Universidad de Alcalá, 28871 Alcalá de Henares, Madrid, Spain*

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Abstract

This paper uses a palynological sequence to examine the Holocene (8390–160 cal yr BP) environmental history of the Sierra de Baza (Granada, southeastern Spain) with the goal of establishing the mechanisms exerting control over vegetation change. During the period ca 8390–6320 cal yr BP, *Pinus* dominated the pollen spectra, indicating a forested landscape over the high-elevation areas of the Sierra. From ca 6320–3800 cal yr BP, an expansion of deciduous oaks and other broad-leaf trees took place. After an optimum around 5800–5600 cal yr BP, mesophytes decreased in the 3800–2560 cal yr BP interval while a fire-prone scrub became established. The main loss of forest accompanied the spread of thorny matorral after ca 2560 cal yr BP. Overall, this mountain region has shown itself to be sensitive to a range of influences, among which a continental climate that has become increasingly arid over the last 5000 years, the scarcity of soils suitable for cultivation, a geology that includes sources of copper and other metals and, especially, the incidence of grazing as well as the repeated appearance of fires during the last 4000 years, are highlighted. The history of the vegetation of the Sierra de Baza seems clearly influenced by changes in local economy. Here we discuss how ecological transitions have interacted with cultural changes, with emphasis on the locally highly populated Chalcolithic (5700–4400 cal yr BP) and Argaric (4400–3550 cal yr BP) periods, as well as the Iberian period (3200–2220 cal yr BP). The sierra was abandoned during the Iberian Period which was, paradoxically, when the highest human impact on mountain vegetation is noticeable.

1. Introduction

Although compatible with the influence of millennial-scale climate change, the timing and intensity of disturbances have demonstrated the importance of contingent events on vegetation development in the Iberian Peninsula during the Holocene (Carrión et al., 2001a). The apparently chaotic picture of vegetation dynamics in Mediterranean Spain includes scenarios of inertia and resilience at a palaeoecological scale (Carrión and van Geel, 1999; Carrión, 2002; Franco et al., 2005). Plausibly, in a context of orographic complexity and long history of species interactions due to the persistence of multiple glacial refugia (García-Antón et al., 1990; Peñalba, 1994; Carrión et al., 2003a, Arroyo et al., 2004), subtle differences in initial conditions during glacial times would have tended to cascade and affect the outcome of post-glacial events so that the duplication of the exact sequence of vegetation types at a particular site is highly improbable.

It appears that the patterns of vegetation change reach maximum complexity between the mid- and late-Holocene. Thus, for instance, although an aridification trend over the last five millennia is well-established (Araus et al., 1997; Pantaleón-Cano et al., 2003), the timing of forest decline is spatially uneven and cannot be solely explained by current differences in physical setting (Carrión, 2001). Among the

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*Corresponding author. Tel./fax: +34 968 36 49 95.
E-mail address: carrion@um.es (J.S. Carrión).
URL: http://www.jscarrion.com (J.S. Carrión).

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factors involved, the role of anthropogenic disturbance, which was undoubtedly spatially heterogeneous, should be considered. Burning, pastoralism, and ploughing by agrarian and metallurgic societies, for instance, may have been historically decisive and site-specific.

A pertinent case comes from the Sierra de Gádor palaeoecological sequence (Carrión et al., 2003b), which goes to the heart of the debate about the causes of the Argaric culture termination, sharply about ca 3600 cal yr BP. Was the "Argaric collapse" (ss Lull, 1983) related to any kind of environmental pressure? The timing of environmental and cultural events in the Gádor record supported some causal connection. Around 3900 cal yr BP, this record showed the replacement of a montane forest ecosystem dominated by deciduous oak with high diversity of trees and shrubs, by a scenario where alternation of pines and sclerophyllous oak scrub was controlled by fire disturbance (Carrión et al., 2003b). This was, indeed, a deep change in the ecological structure which might have affected the economy of the local inhabitants. Was this phenomenon observable over the whole area occupied by the Argaric culture or should it be considered merely a Gádor-specific pattern? What can we discern about the remaining, equally interesting, cultural transitions experienced by the agro-pastoral and metallurgic societies in southeastern Spain? Can events synchronous with vegetation changes be identified or can causal links established? Do current models of regional vegetation dynamics fit into the picture of historical influences?

Sierra de Baza (Fig. 1) is well suited to shed light on these questions because it falls within the domain of the same metallurgic societies, principally the Chalcolithic and Argaric (Chapman, 1991; Barandiarán et al., 2002), as those of Gádor. In addition, the Sierra de Baza offers: (i) peaty deposits with palynological potential in high-elevation areas comparable to the Gádor site (Riera et al., 1995); (ii) a number of available archaeological and documentary surveys (Sánchez-Quirante,1998); (iii) a scenario of vegetation landscape with frequent ecotonal conditions (Rodríguez-Sánchez, 1998a), in which forests must have been vulnerable given their location in the centre of semi-arid depressions (Peinado et al., 1992) (Fig. 1); and (iv) the opportunity to contrast historical models with prevailing neontological concepts of vegetation change in a territory in which the highest number of plant endemics of the European continent have been recorded (the Betic chorological province—Mota, 1990; Blanca and Morales, 1991).

This paper uses a palynological sequence, along with archaeological and historical documentary information, to examine the Holocene (8390–160 cal yr BP) environmental history of the Sierra de Baza with the goal of establishing the mechanisms exerting control over vegetation change.

2. Setting and present-day vegetation

The Sierra de Baza is a mountain range, ca 550 km^2 in area, located in the north-east of Granada province, southeastern Spain. It is situated between two extensive plains—Hoya de Baza in the north and Llanos del Marquesado in the south (Fig. 2). Baza joins the Sierra de Los Filabres (Almería Province) to form an 80 × 2.5 km cordillera with prevailing east-west orientation (Fig. 1). Maximum altitude is 2269 m a.s.l. in the Calar de Santa Bárbara, while several other peaks surpass 2000 m a.s.l. A complex fluvial mountain system is connected with the Guadalquivir network.

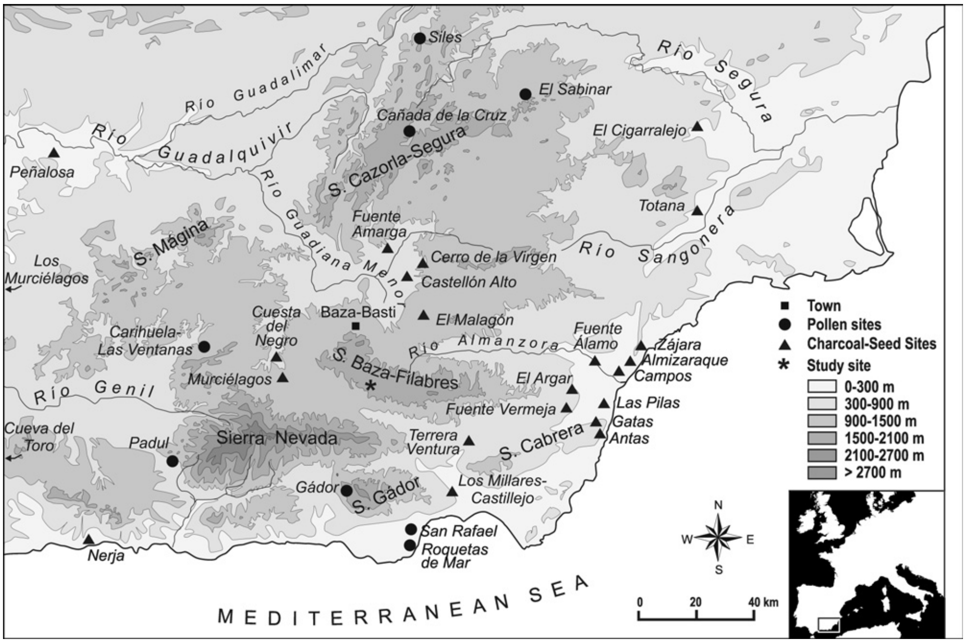

Fig. 1. Location of Baza and other paleobotanical and archaeological sites in southeastern Spain.

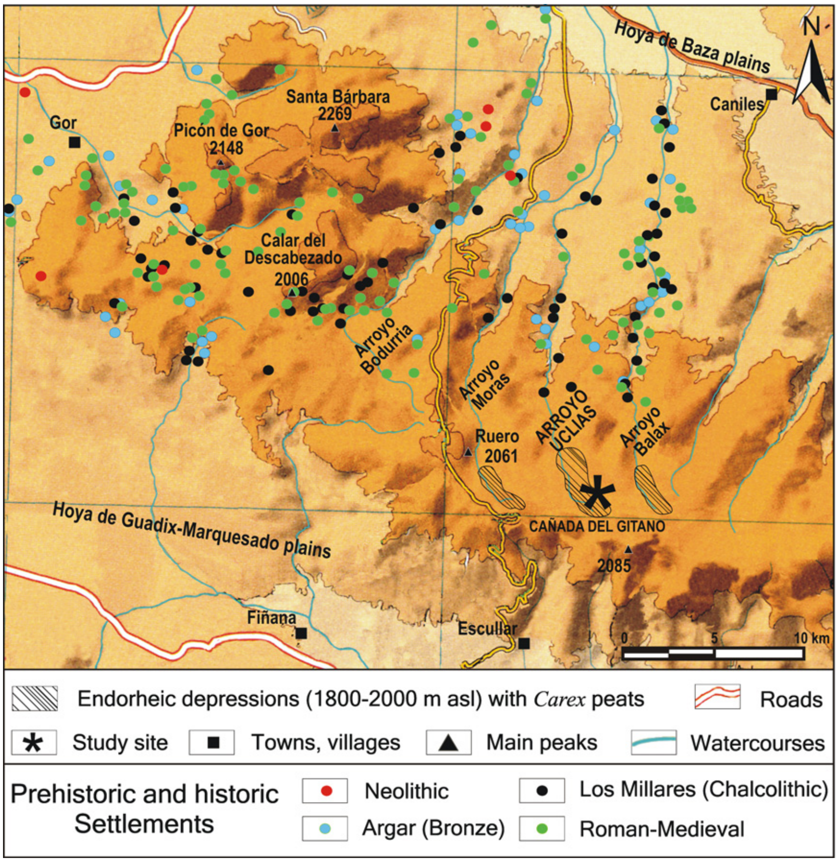

Fig. 2. Location of the study site in Cañada del Gitano, headwall of Arroyo Uclías basin, and distribution of human settlements in Sierra de Baza from Neolithic to Medieval times (synthesis from several archaeological reports, mainly Sánchez-Quirante 1989, 1990, 1991, 1993, 1998).

The study site (37° 14′N, 2° 42′W, 1900 m a.s.l.) is a high-mountain peat deposit, ca $2\,\mathrm{km}^2$, lying in the Cañada del Gitano, one of the headwalls of the Arroyo Uclías (Fig. 2). The nature of the Uclías valley makes it prone to the creation of marsh conditions. The depositional context is silty peat grading into organic silt with clasts overlying a bedrock of schist (Fig. 3). The origin of this peaty sequence must have been connected with some kind of drainage blockage, perhaps associated with increased water input during the early Holocene. Peats accumulate not only in the Uclías but also in the parallel streams (*arroyos*) such as the Moras and Balax (Fig. 2), where trench excavations—probably associated to historical drainage for cultivation—have provoked localised desiccation and erosion.

Mean annual temperature and precipitation at these altitudes are about 4–8 °C and 500–600 mm, respectively, with about 2 months of heavy snowfall (Rodríguez-Sánchez, 1998b). As in most eastern Iberian mountains, precipitation in the Sierra de Baza is distributed unevenly due to elevation gradients and localised rain shadow effects. Thus, precipitation increases with altitude, exceeding 600 mm above 1400 m, but drops to below 350 mm along the southern slopes (Gómez-Mercado and Valle, 1988).

Local vegetation on the waterlogged soils of the Cañada del Gitano is characterised by hygrophilous communities with sedges (*Carex leporina*, *C. nigra*, *C. mairii*, *Eleocharis quinqueflora*) and several *Juncus* species. Downstream along the watercourse, riverine trees, like *Salix* (*S. alba*, *S. fragilis*, *S. purpurea*, *S. caprea*), *Populus* (*P. alba*, *P. nigra*, *P. tremula*, *P. canescens*), and *Ulmus* (*U. minor*, *U. pumila*), grow.

The Sierra de Baza comprises a complex mosaic of plant formations. Tree vegetation includes pine, oak, and mixed pine–oak woodlands (Gómez-Mercado and Valle, 1988). The timber line, above 1700–1800 m a.s.l., is featured by open vegetation with stands of *Pinus sylvestris* subsp. *nevadensis* and *P. nigra* subsp. *salzmannii*, a basal layer of hard-leaf grasses (*Festuca hystrix*, *Poa ligulata*, *Koeleria vallesiana*), and a cushion matorral of junipers (*Juniperus communis* subsp. *hemisphaerica*, *J. sabina*), Genisteae (*Erinacea anthyllis*, *Genista versicolor*, *Echinospartum boissieri*), and other thorns like *Berberis hispanica*, *Vella spinosa*, *Ptilotrichum spinosum*, *Bupleurum spinosum*, *Daphne oleoides*, *Dianthus subacaulis*, among others.

Deciduous oak forests are restricted to the most humid biotopes on high ground. These are dominated by *Quercus faginea*, occasionally accompanied by *Acer granatense*. The holm oak (*Q. ilex* subsp. *ballota* = *Q. rotundifolia*) does not form closed forests as it does in other regions of Andalucía, but is relatively abundant above 1000 up to 1800 m, mixed with pine species (*Pinus pinaster*, *P. halepensis*) and scrub of

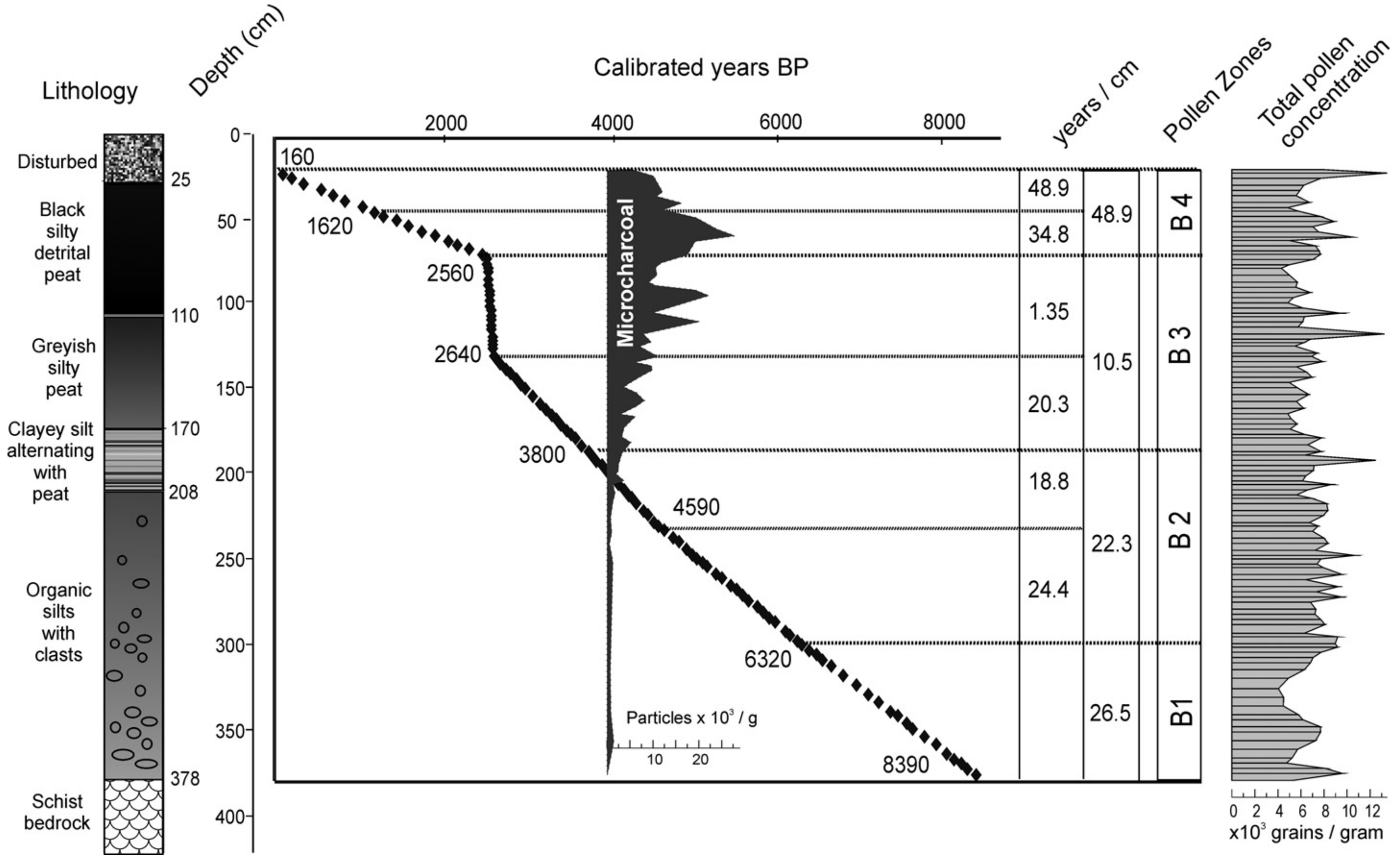

Fig. 3. Sediment depth, litho- and pollen stratigraphy, and microcharcoal concentration to radiocarbon age relationships from the Baza section. Lines connecting each plotted point are interpolated sediment-accumulation rates.

Crataegus monogyna, *Berberis hispanica*, *Prunus ramburii*, *Cytisus reverchonii*, *Adenocarpus decorticans*, *Genista cinerea* subsp. *speciosa*, *G. scorpius*, and *G. umbellata*. It is generally believed that the holm oak communities, either on calcareous (*Paeonio coriaceae*-*Quercetum rotundifoliae*, *Berberido hispanicae–Quercetum rotundifoliae*, or siliceous substrates (*Adenocarpo decortinanti–Quercetum rotundifoliae*) represent the remnants of a potential vegetation developed on the supra- and meso-Mediterranean belts (Gómez-Mercado and Valle, 1988). Thermophilous *Quercus coccifera*, *Pistacia lentiscus*, and *Phillyrea angustifolia* understorey communities are characteristic of the lower, more xerophytic, territories. Despite the evident deforestation, the Baza-Filabres cordillera represents a kind of ‘‘bioclimatic island’’, as it is currently bordered by areas of cultivars, and unproductive, treeless matorral, mainly on marls and gypsic dry substrates (Peinado et al., 1992; Mota et al.,1997).

3. Methods

Two sediment cores were collected from the head of the Cañada del Gitano Basin during late spring (2000) using a 6-cm diameter piston sampler. Coring was stopped at 417 and 378 cm on reaching bedrock. The 417 cm-deep core, quite detritic, was discarded because of its poor pollen content and sterility in several beds. The present study refers to the 378 cm-deep core which was fully polleniferous. Macrofossils were not discerned throughout the core. The uppermost 25 cm of this core, a disturbed horizon with sedges roots, was not considered for pollen analysis (Fig. 3).

In the laboratory, sub-samples (2–4 cm thick) were taken contiguously in order to obtain sufficient sediment for pollen and radiocarbon dating analyses. Extraction of palynomorphs followed the standard procedure described in Moore et al. (1991). Mineral separation with heavy liquid density 2.0 was used for all the samples. Exotic *Lycopodium* tablets of a known concentration were added to calculate pollen concentrations. Palynological identification and counting was aided by the reference collection of the Laboratory of Palynology at the University of Murcia.

Pollen diagrams (Figs. 4–6) were constructed using the computer program p-simpoll (Bennett, 2000). Hydroseral pollen (Cyperaceae, *Typha*, *Apium*, *Myriophyllum*), algal (Zygnemataceae), fern spores, bryophytic (*Riccia*), and fungal spores (Sordariaceae, *Puccinia*, *Tilletia, Glomus*), and other non-pollen palynomorphs (Type 128, *Pseudoschizaea*) were excluded from the pollen sum. The delimitation of Baza (B) pollen assemblage zone boundaries was obtained from a visual inspection of the pollen stratigraphy.

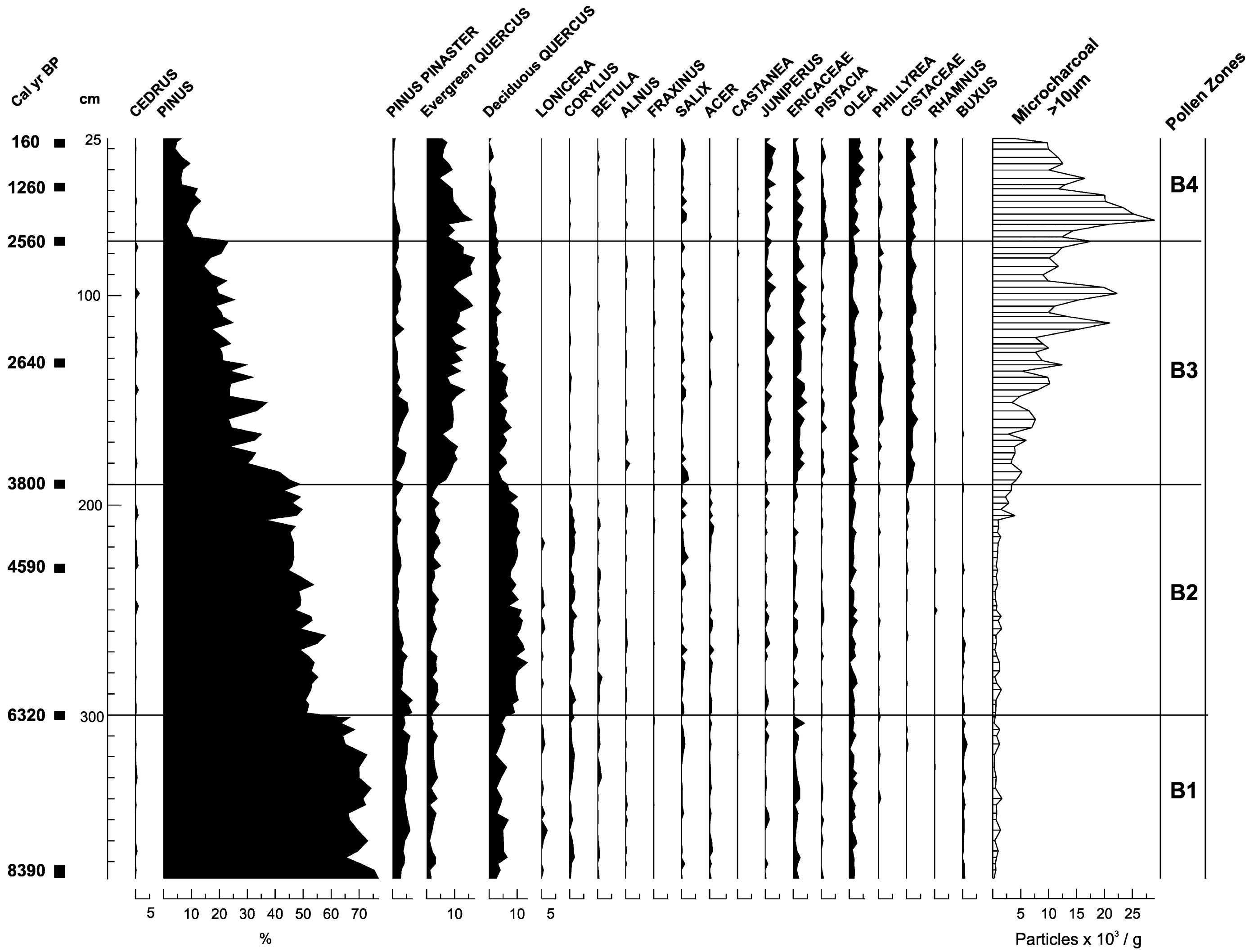

Fig. 4. Pollen diagram for trees and shrubs, and microcharcoal variation in the Baza sequence.

The total number of microcharcoal particles larger than 10 µm in diameter was counted on the slides prepared for pollen analysis and their concentrations calculated with reference to the *Lycopodium* counts (Figs. 3, 4, 7). The number of charcoal particles can be taken as an indication of regional fire occurrence (Carcaillet et al., 2002). Because of the many problems inherent to the taphonomy of charcoal in these depositional environments (Tinner and Hu, 2003), details on the geographical extent of fire events in the Baza sequence cannot be provided. A synthetic diagram, including selected pollen and microfossil curves and microscopic charcoal abundance, is shown in Fig. 7. In this diagram, "mesophytes" include deciduous *Quercus*, *Corylus*, *Betula*, *Alnus*, *Fraxinus*, *Salix*, *Acer*, and *Castanea*. "Xerophytes" include *Artemisia*, other Asteraceae, Chenopodiaceae, Lamiaceae, and *Ephedra*.

4. Chronology

The pollen record can allow insights into the vegetation history of the high- and mid-elevation areas of Sierra de Baza from ca 8390 to 160 cal yr BP (Figs. 4–7). The chronology was established on the basis of eight radiocarbon dates (Table 1). Samples consisted of bulk organic sediment, dated by the AMS method where necessary (basal sample) because of relatively low organic content in the organic extract. Dates were calibrated using the program CALIB Rev. 4.4.2 (Stuiver et al., 1998). Calibrated ages BP were taken as the mid-points of the 95% (2σ) probability intervals. An age–depth model, based on interpolated ages between adjacent pairs of dates, was obtained (Fig. 3). Sediment-accumulation rates are such that 1 cm represents, on average, 26.5 years for zone B1, 22.3 years for zone B2, 10.5 years for zone B3, and 48.9 years for zone B4.

5. Pollen stratigraphy and palaeoecological sequence

5.1. Ancient pine forests in the high Sierra de Baza (ca 8390–6320 cal yr BP)

During the zone B1 (ca 8390–6320 cal yr BP), *Pinus* dominated the pollen spectra, with amounts from ca 75%

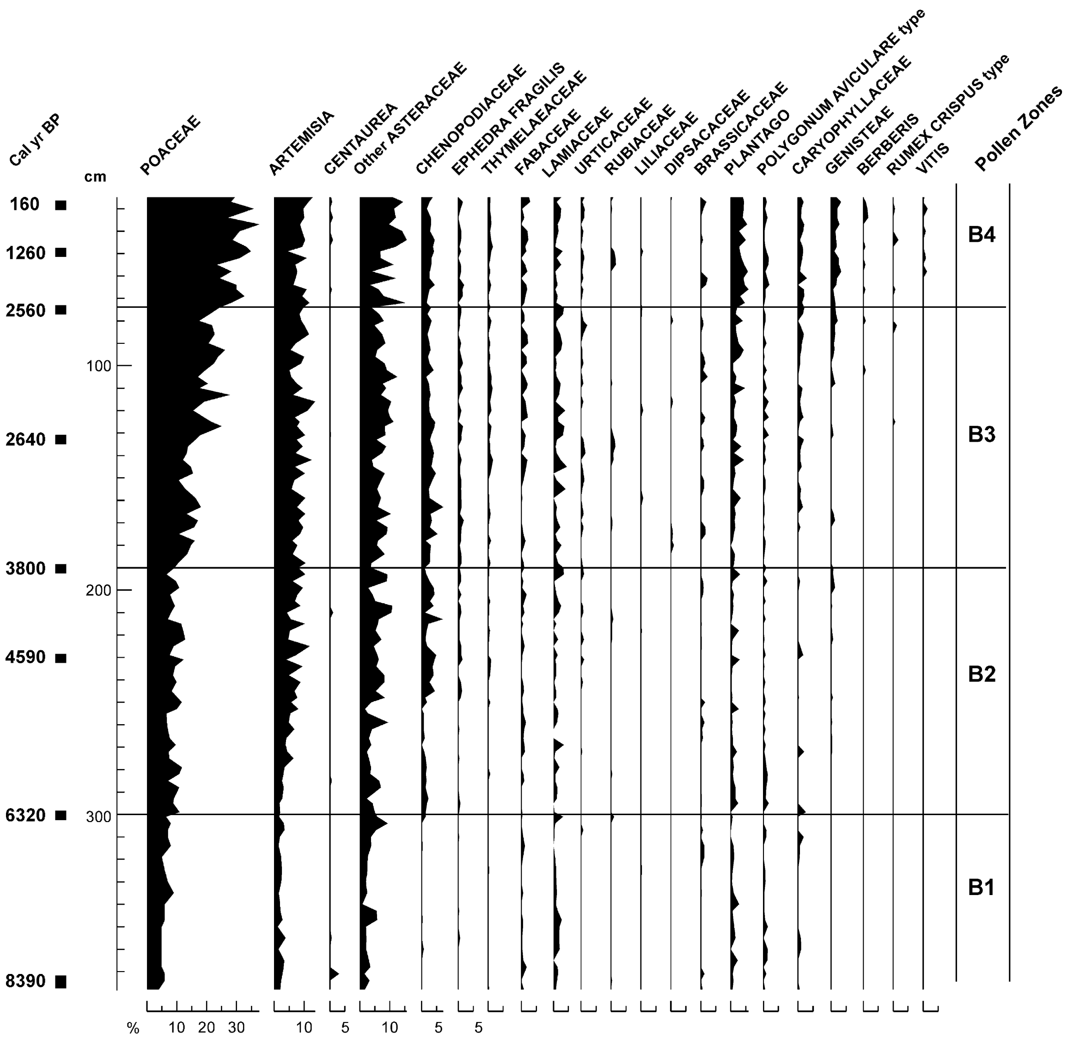

Fig. 5. Pollen diagram of Baza for Poaceae and other herbs, xerophytes, thorny scrub, and anthropogenic indicators.

to 60%, thus indicating a forested landscape at least over the oro-Mediterranean belt of Baza above 1700–1800 m a.s.l. (Andrade et al., 1994). Considering their present-day distribution, *Pinus nigra* and *P. sylvestris* are the most likely pine pollen-producing species at these altitudes (Blanca and Morales, 1991; Morente, 1998), although some contribution of *P. halepensis* from lower-altitude areas is also possible. This zone is also characterised by continuous pollen curves (with occurrences below 10% in all cases) of *Pinus pinaster*, deciduous and evergreen *Quercus*, and to a lesser extent, *Corylus*, *Betula*, *Salix*, *Acer*, Cupressaceae, Ericaceae, *Pistacia*, and *Olea*. *Buxus* and *Lonicera* attain their maxima in this zone. Other taxa, such as *Alnus*, *Fraxinus*, and *Castanea*, occur episodically. *Phillyrea*, Cistaceae, and *Rhamnus* appear in the uppermost pollen spectra above 350 cm depth. The diversity and frequencies of mesothermophilous arboreal pollen taxa are relatively high, which supports the view that the site is a well-sited catchment for pollen from supra- (1400–1800 m a.s.l.) and meso-Mediterranean (800–1400 m a.s.l.) oak, pine, and mixed woodlands. The herbaceous component, dominated by Poaceae, *Artemisia*, other Asteraceae, Chenopodiaceae, and *Plantago*, shows its lowest amounts in this zone.

The combination of Cyperaceae, *Typha*, and *Myriophyllum* pollen and Zygnemataceae spores, and the microfossil Type 128 (Van Geel et al., 1989) suggest the existence of a semi-permanent body of shallow water with marginal vegetation (Van Geel et al., 1989). The occurrence of fungal spores suggests a certain degree of organic decomposition, including faecal material if the continuous presence of Sordariaceae spores is taken into account. The joint occurrence of *Riccia* and Sordariaceae may well be indicative of grazing in the lake catchment (Carrión, 2002), a feature constant throughout the sequence (Figs. 6 and 7).

5.2. Expansion of deciduous oaks and the onset of xerophyte spread (ca 6320–3800 cal yr BP)

During the zone B2 (ca 6320–3800 cal yr BP), pine forests continue to be the dominant vegetation on high ground, although with reduced cover (49–59%), probably to the benefit of local heliophytic communities. Deciduous *Quercus* expanded their range, as did components of other

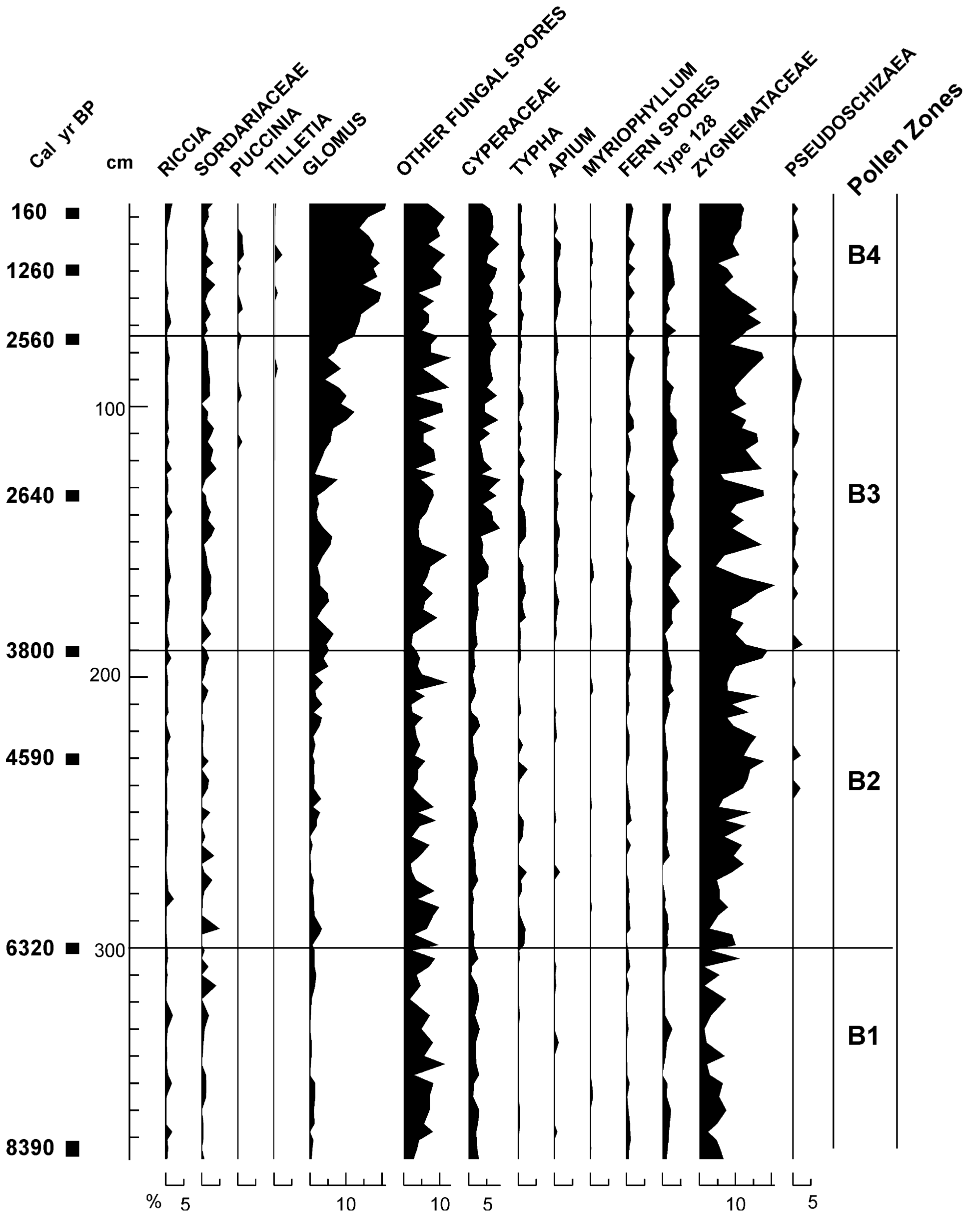

Fig. 6. Pollen diagram of Baza for marginal vegetation, cryptogam spores, and non-pollen palynomorphs.

broadleaved trees such as *Corylus*, *Betula*, *Salix*, *Acer* and *Alnus*, lianas (*Lonicera*), and sub-Mediterranean shrubs (*Buxus*). This zone includes a mesophytic maximum around 5600–5800 cal yr BP and the onset of xerophyte spread from ca 5000 cal yr BP onwards (Figs. 5 and 7).

A change in the sediment takes place in the uppermost zone B2 from 208 to 170 cm depth, where organic silts with clasts are replaced by a bed of clayey silt alternating with greyish fine-textured peat (Fig. 3). This change towards a more peaty environment coincides with the onset of an increasing trend of microcharcoal concentration about 4100 cal yr BP (Fig. 4). The microfossil *Pseudoschizaea*, whose first records are about 4700–4800 cal yr BP, suggests the installation of temporal desiccation phases in the marshland (Scott, 1992).

5.3. Mesophyte decline and establishment of fire-prone scrub (ca 3800–2560 cal yr BP)

The zone B3 (ca 3800–2560 cal yr BP) is characterised by the synchronous declines of deciduous *Quercus*, *Corylus*, *Betula*, and *Acer*, together with the disappearance of *Buxus* and *Lonicera* from the pollen record at 3400 and 4300 cal yr BP, respectively. Pine pollen percentages experience a decreasing tendency, now more pronounced (ca 50–17%) than in the previous zone. In contrast, evergreen *Quercus* progressively increase, reaching 17% at the end of the zone. In addition to Poaceae and *Juniperus*, several scrub taxa, such as Cistaceae, Ericaceae, *Pistacia*, and *Phillyrea*, show more or less raised curves (Fig. 4). Caryophyllaceae starts a continuous curve at ca

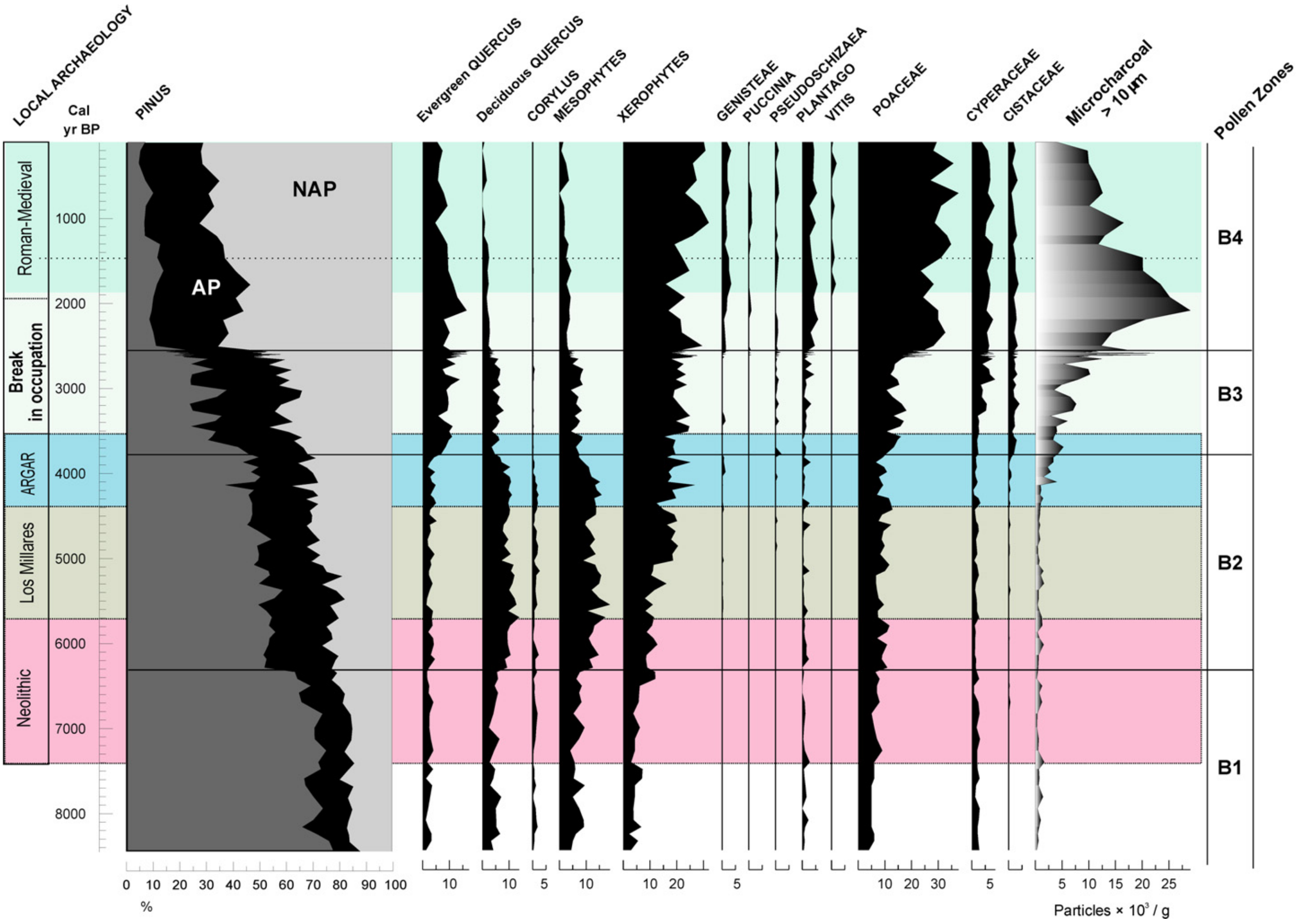

Fig. 7. Synthetic pollen diagram and microcharcoal variation in the Baza sequence.

Table 1
Radiocarbon ages of bulk sediment samples from Sierra de Baza (ages calibrated using the program CALIB Rev. 4.4.2 (Stuiver et al., 1998)

Lab. ref.	Depth (cm)	Conventional age (^{14}C yr BP)	Calibrated BP age ranges	Calibrated age years BP	Analysis
Pta-9156	25–27	180 ± 80	0–323	160	Conventional
Pta-9149	47–49	1320 ± 25	1228–1292	1260	Conventional
Pta-9142	72–74	2520 ± 40	2363–2747	2560	Conventional
Pta-9150	131–133	2590 ± 110	2353–2917	2640	Conventional
Pta-9154	188–190	3520 ± 50	3685–3913	3800	Conventional
Pta-9160	229–231	4060 ± 90	4352–4828	4590	Conventional
Pta-9139	299–301	5530 ± 30	6281–6357	6320	Conventional
GrA-24386	374–378	7595 ± 45	8328–8454	8390	AMS

The calibrated age BP was taken as the mid-point of the 95.4% (2σ) probability interval. Calibration data set: intcal98.14c, Copyright 1986–2004, M. Stuiver and P.J. Reimer.

3500 cal yr BP. Between ca 2620 and 2580 cal yr BP, this zone shows the first pollen records of the thorn *Berberis* and the anthropophyte *Rumex crispus*, and the first spore records of *Tilletia* and *Puccinia*, which are often regarded as indicators of agriculturisation (Carrión and van Geel, 1999; Carrión et al., 2001a).

Together with the expansion of Mediterranean scrub, the charcoal record envisages a picture of progresive fire incidence. Thus, the concentration of microcharcoal particles continues to increase, reaching maximum values at the end of this zone (ca 2590–2620 cal yr BP) (Figs. 4 and 7), in coincidence with a change in the sediment-accumulation rate from 20.3 to 1.3 yr cm^{-1}. The increases of Cyperaceae, *Glomus* and other fungal spores, and a more continuous presence of *Pseudoschizaea* (Fig. 6) suggest a denser littoral vegetation than in the previous zone, with phases of basin desiccation.

5.4. Main forest depletion and spread of thorny matorral (ca 2560–160 cal yr BP)

Sharply during the zone B4 (ca 2560–160 cal yr BP), *Pinus* decreases, and Poaceae becomes dominant, showing maxima (37–38%) after ca 1500 cal yr BP. Other taxa that increase include Genisteae, *Plantago, Olea*, *Polygonum*, Asteraceae, and *Rhamnus*. *Corylus* disappears after ca 1600 cal yr BP. Evergreen *Quercus* continue to be relatively abundant, while deciduous *Quercus* and *Pinus pinaster* descend below 5%. This zone also shows the first pollen records of *Vitis* (ca 1700 cal yr BP) and the almost continuous presence of *Berberis, Puccinia* and *Rumex*, together with slight increases of Sordariaceae spores. Cerealia pollen type was not observed.

Zone B4 marks the establishment of the current landscape in the high-altitude areas of Sierra de Baza, characterised by grazed areas dominated by spiny shrubs (*Erinacea, Genista, Echinospartum, Rhamnus, Berberis, Ptilotrichum, Vella*, etc), grasses, junipers, and sparsely pine stands. Although there is no great variation in the microfossil assemblages, the limnological environment might be more terrigenous than during the preceding phase, as suggested by the *Glomus* sequence maxima. The sediment-accumulation rates return to relatively low values (34.8–66.4 yr cm^{-1}), although erosive hiatuses, especially above 50 cm depth, cannot be discarded. This zone is also characterised by high values of microcharcoal concentration, reaching a peak at ca 2000 cal yr BP. Overall, this is the most xerophytic and pyrophytic phase of the Baza record, as well as the period where the indicators of anthropogenic disturbance are most visible (Fig. 7).

6. Environmental and cultural changes in the Sierra de Baza in a regional context

The Sierra de Baza has a long history of human occupation, with phases in which settlements proliferated alternating with episodes of abandonment. Without doubt, under the influence of climate change and ecological interactions, the perturbations associated with human activity would have affected the changing landscape at different temporal and spatial scales. There is then the question of the degree to which cultural transitions and changes in socio-economic systems could have been ecologically driven. These issues will be addressed through an explanatory model of the Late Quaternary vegetation and cultural history of these mountains, taking into account the information derived from the palynological sequence, the archaeological record and historical documentation. The latter, though as usual vague and fragmentary (Oldfield, 2005), allows us to establish some of the most recent circumstances that have influenced the present-day distribution of vegetation communities in the region and to make certain inferences concerning the prehistoric processes of exploitation and adaptation to the natural environment by its inhabitants.

6.1. Palaeolithic landscape diversity and hunter-gatherers in southeast Iberia

Even though there is insufficient evidence of human presence in the Sierra de Baza during the Palaeolithic, dispersed settlements in Filabres, to the east, are known (Sánchez-Quirante, 1998). It is probable that groups of hunter-gatherers living in lower ground along river courses or tablelands (Barandiarán et al., 2002) would have periodically ascended to hunt or collect plant resources, taking shelter in some of the caves in the area.

The adjacent regions are full of palaeontological sites dating from the Plio–Pleistocene, in many cases produced by the activity of hyaenids, but also by hominins since at least 1.2 million years ago (Oms et al., 2000; Arribas et al., 2004). During the greater part of the early Quaternary, if account is taken of the biogeochemistry and ecomorphology of the large mammal assemblage, we can infer that the landscape of the Baza–Guadix Depression would have been characterised by the presence of shallow lakes with swampy marginal zones and extensive areas of savannah with tall grass and shrubs (Palmqvist et al., 2003).

The pollen sequence presented in this paper does not go back into the Pleistocene but, as in other places in southeast Spain, the predominance of high mountain steppes, pine woods in mid-altitudes and a diversity of woody plants of the present-day meso-Mediterranean, during the post-Cromerian glacial phases is most likely. This is at least what can be inferred by comparison with the final Pleistocene record of Siles in the Segura Mountains (Carrión, 2002). In the wide mountain tablelands to the west, the pollen records of Carihuela, Las Ventanas and Padul, reveal an alternation between pine woods and open vegetation with the continuous presence of mesothermophilous taxa during stadials as well as sequences of *Quercus* and other trees during OIS 3 (48–26 ka BP). This is especially the case after 15 cal ka BP suggesting the presence of forest formations entrenched in adjacent mountains, for example Sierra Nevada, Arana, and Magina (Pons and Reille, 1988; Carrión et al., 1999, 2001c) (Fig. 1). The existence of a diversity of biotopes is supported by the rodent fauna (Ruíz-Bustos, 2000).

The pleniglacial vegetation of the coastal thermo-Mediterranean was sparser, although it also included deciduous trees and an elevated number of woody species, as can be seen in the marshland of San Rafael (Pantaleón-Cano et al., 2003) and in some Mousterian cave sites such as Perneras (Carrión et al., 1995). The marine pollen sequences from Alborán and the Atlantic coasts of southern Iberia support this picture of regional pollen rain with curves that, though oscillating, indicate a continuous presence of humid, temperate and Mediterranean taxa (Sánchez-Goñi et al., 1999, 2002).

In general, palaeobotanical information for Mediterranean Iberia supports the view that the region, especially the south, was suitable for the survival of temperate elements during full-glacial stages (Dupré, 1988; García-Antón et al., 1990; Burjachs and Julià, 1994; Carrión et al., 1995, 2003b; Carrión, 2002, Figueiral and Terral, 2002; González-Sampériz, 2004; Finlayson and Carrión, 2007), a picture that fits into the spatial genetic structure of woody plant populations (Arroyo et al., 2004; Hewitt, 2004; López de Heredia et al., 2007). It is plausible that this scenario of elevated phytodiversity permitted the settlement and survival of human populations, including the Neanderthals, which appear to have survived particularly late in southern Iberia (Finlayson, 2004; Fernández et al., 2007; Finlayson et al., 2006).

6.2. Early Holocene forests and the Neolithic settlement

As is the case with the Baza sequence, the pollen diagrams that cover the first half of the Holocene in central and eastern Iberia often show the continuity or expansion of pine forests that characterise the mountain landscapes of the end of the Pleistocene (Carrión and van Geel, 1999; Stevenson, 2000) which, given the undoubted climatic amelioration (Bradley, 1999), suggests a multimillennial inertia for established populations in the mountains (Case, 1990). Alternatively, as in some parts of the eastern Mediterranean, it may reflect the prevalence of arid conditions under particular geomorphological conditions (Eastwood et al., 1999; Roberts et al., 2004). In the case of Baza, altitude appears as a first-order factor when explaining the predominance of *Pinus nigra–sylvestris*. Nevertheless, both oaks and other broad-leaved trees, together with the cluster pine (*Pinus pinaster*), are present in this pollen record already since ca 8390 cal yr BP (Figs. 4 and 7), suggesting the existence of mesic oak and mixed forests below 1700 m a.s.l.

As in many other regions of the Iberian Peninsula, there is no evidence of Mesolithic communities in the Sierra de Baza. These nevertheless appear in the neighbouring Sierras de Segura (Cueva del Nacimiento) and Cazorla (Valdecuevas), as well as in Málaga Bay (Nerja) and Sierra Morena, and on the coasts of Murcia and Almería (Barandiarán et al., 2002). Between ca 7400 and 5700 cal yr BP, Neolithic humans left their signs in many caves in the limestone sectors of the Sierras de Baza y Filabres: Castillico de Cobdar, Cueva del Cristal, Sima Blanca, Cueva del Palo, Cueva de la Pastora, and Cueva de Cerro Morente are some of the most significant sites (Sánchez-Quirante et al., 1995) (Fig. 2). We stress that the excavated sites represent only a small fraction of those discovered, there being indications of Neolithic open-air sites. With regards to tools, in addition to the usual stone axes, ceramics, bracelets and other adornments in slate and marble, and animal and human bone remains, there is evidence of agriculture.

These findings agree with the localisation of a number of Neolithic sites in the Sierra de Baza close to alluvial soils with potential for cultivation, such as the sites close to Bodurria or Gor (Fig. 2). In others, it seems clear that communities seeking high mountain pastures also hunted or fished. Such is the case of the settlements situated close to Calar del Descabezado or the Picón de Gor, above 1600 m (Fig. 2). These are cases of relatively unspecialised communities that developed exploitation strategies of a diverse physical environment close to resources (Sánchez-Quirante et al., 1995). Such strategies would have been based in the seasonal alternation of the use of mountain pastures in the summer, leaving fallow lower areas in the winter, and agriculture where it could be carried out the year round. Without doubt, agricultural-farming activities would have been combined with the gathering of wild plants, as is shown by the palaeocarpology of adjacent sites (Buxó, 1997).

The Baza pollen diagram does not contain irrefutable evidence of agriculture in the Neolithic (Figs. 5, 7, 8). Evidently, a pollen sequence need not leave evidence of agricultural activity on the vegetation landscape, unless it had a significant spatial magnitude. Nevertheless, the behaviour of *Plantago*, *Polygonum aviculare*, Caryophyllaceae, Brassicaceae, Urticaceae, and Fabaceae, which are present throughout zones B1 and B2, and continue to increase in B3 and B4 (Fig. 5), could be linked to an early transformation of the mountain landscape. These pollen types may be more indicative of pastoral activity than agriculture. In the first place, given the physical characteristics of the area surrounding the site—abrupt orography—but above all because it has to be borne in mind that, since zone B1, spores of sordariaceous fungi are found associated with *Riccia*. Therefore, the Sierra de Baza could have suffered from overgrazing of mountain pastures since before the Neolithic, without discarding the alternative or complementary impact from wild ungulates (Carrión, 2002).

It is worth considering the transition between zones B1 and B2 from the point of view of factors controlling vegetation change. In the first place, how can the apparent paradox of the synchronous increase of mesophytes and xerophytes be explained? A question underlines the uncertainty associated with the geographical origin of any pollen spectrum (it is not particularly suited to detect species areas), but, in any case, it must be taken into account that (i) the palaeoecological significance of the group known as "xerophytes" in an altitudinal sequence is vague; (ii) given a greater opening of the oro-Mediterranean pine woodland the supply of pollen to the catchment area from zones below could have been more efficient; (iii) given a hypothetical increase in aridity with expansion of xerophytes in the meso-Mediterranean, the populations of deciduous trees could have survived in valleys and gulleys close to the timberline as occurs in other mountain systems (Carrión et al., 2001a, b); and (iv) given a hypothetical increase in rainfall and temperature which would facilitate the altitudinal rise of angiosperm forests, the number of months of the year with snow would be reduced, permitting the increasing impact of deforestation on the original pine woodland related to pastoral activity. Together with the greater competitive potential of oaks, hazels and other deciduous trees given climatic amelioration, the pine tree density would be reduced.

This last option is parsimonious because the mid-Holocene declines of *Pinus*, synchronous with spreads of deciduous *Quercus*, are quite common in the region suggesting an influence of the thermo-pluviometric maximum which is recorded in southwest Europe and North Africa between ca 7500 and 5000 cal yr BP (Jalut et al., 2000). The transition B1–B2 in Baza cannot, nevertheless, be simply interpreted as a response to climate change. It is necessary to take into account the complexity of interactions of climate, humans, vegetation, and long-term trends as well as other small-scale factors. It should be noted that, regionally, the replacement of pines by oaks is not synchronous. Thus, while in Baza and Gádor (1530 m a.s.l.) the change is dated at 6320 and 6060 cal yr BP, respectively, in Siles (1320 m a.s.l.) it is at ca 7260 cal yr BP, in Villaverde (870 m a.s.l.) at ca 5940 cal yr BP (Carrión, 2002), in El Sabinar at ca 6640 cal yr BP (Carrión et al., 2004) and in Navarrés (225 m a.s.l.) at ca 5930 cal yr BP (Carrión and van Geel, 1999). In some localities of the southeast coast of Spain (Levante) what is observed at the end of the Neolithic in some anthracological records is an increase of evergreen oaks to the detriment of deciduous oaks, pines being scarce from Mesolithic to Bronze Age times (Carrión-Marco, 2002).

Looking further at this scenario, can the decrease in montane pine cover be considered the result of agro-pastoral impact? There are elements that suggest pastoral activity and its early impact over the environment of the Sierra de Baza. In the first place, it is worth noting that unlike Baza, after its first Holocene regression, *Pinus* increases temporarily again from ca 3940 cal yr BP in Gádor (Fig. 8), as from ca 3470 cal yr BP in Villaverde (Carrión et al., 2001a), from ca 5100 cal yr BP in Siles (Carrión, 2002) and from ca 4500 cal yr BP in Navarrés (Carrión and van Geel, 1999). The Baza sequence resembles some of the Levantine and Andalucian thermo-Mediterranean sequences in that tree cover irreversibly decreases throughout the entire Holocene, irrespective of whether *Pinus* or *Quercus* is the dominant element of the AP. The anthropic impact that starts to become manifest in the thermo-Mediterranean from the Neolithic adds critically to the aridification that sets in from ca 4700–5300 cal yr BP (Carrión, 2002). This leads to the progressive extension of garrigues, depending on locality, to the detriment of pines and arboreal oaks (Badal et al., 1994; Burjachs and Riera, 1995; Carrión et al., 2003b; Pantaleón-Cano et al., 2003).

Comparison of anthracological sequences suggests that a large-scale degradation of vegetation began in the Middle Neolithic (seventh millennium BP) along the coast, whereas in the interior it may have begun early in the fourth millennium BP, or even later (Bernabeu et al., 1993; Rodríguez-Ariza, 1995, 2000a). Some pollen diagrams of short sequences in archaeological sites, as in the Cueva del Calor (López-García, 1988), indicate the presence of cereal pollen already at this time. Noteworthy among the fauna are species associated with pastoral activity, especially ovicaprids (*Ovis aries*, *Capra hircus*), but also wild animals, such as red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), wild boar (*Sus scrofa*), aurochs (*Bos primigenius*), ibex (*Capra pyrenaica*), and lagomorphs (*Oryctolagus, Lepus*) that suggest an important hunting element. In some sites close to Baza, such as Carihuela, the remains from hunting account for 25% of the fauna, with 60% being ovicaprids. Here, charred wheat and barley are abundant throughout the Neolithic (Wigand, 1978).

The pollen record of Carihuela (1020 m a.s.l.) is particularly pertinent to this discussion. Holocene pollen zones 20–21 (Fernández et al., 2007), dated between ca 8400 and 6300 cal yr BP, are characterised by arboreal types with dominance of broad-leaved species within a mixed oak forest ecosystem. Poaceae already show an increasing trend, however, that culminate with values of 48%. After 6300 cal yr BP, in the Neolithic and Bronze pollen zone 22, a significant decrease in tree pollen occurs while Poaceae reaches persistently high percentages of around 30–33%, with increases in *Juglans*, Genisteae, Chenopodiaceae, and *Olea*. This zone is also characterised by the exclusive occurrence of *Vitis*, Cerealia, and *Polygonum aviculare* type, as well as maximum values of *Plantago*. It is perhaps significant that, in Carihuela and Baza, an opening of the landscape is observed within the Neolithic, irrespective of the dominant tree species. The faunal record and seed remains in Neolithic Carihuela also suggest agriculture and animal domestication since the Neolithic, although not as extensive as later on. The abundance of post-Neolithic settlements around Iznalloz, Huelago, Campotejar, Sierra Arana, Río Fardes, and Laborcillas (Pellicer, 1964a, b; Wigand, 1978; Nocete, 2001) supports the idea that human impact upon the landscapes may have been relatively intense in the lowlands since ca 5200–5000 cal yr BP.

With a few exceptions like the Ronda Depression, Málaga (Rodríguez-Ariza, 1992a), the majority of anthracological and palaeocarpological works in archaeological excavations in eastern Andalucía have produced results that are coincident with agricultural development and landscape alteration since the Neolithic in lowlands and mid-altitude plateaux (Rodríguez-Ariza, 1995; Buxó, 1997). Thus, in the Cueva de Nerja on the Malaga coast, the last anthracological phase, equivalent to the Middle Neolithic (ca 7300 cal yr BP), demonstrates the increase of matorral species. In this and other sites (Cueva del Toro, Los Murciélagos, Campos, Cerro de la Virgen) the gathering of olive, walnut, stone pine seeds, and brambles (*Rubus ulmifolius*, *R.idaeus*) and acorns, as well as the cultivation of *Triticum aestivum/durum*, *Lathyrus cicera*, *Pisum sativum*, *Vicia faba*, *Lens culinaris* and *Papaver somniferum* (Bernabeu et al., 1993; Buxó, 1997) is confirmed. To these have to be added carpological remains such as *Plantago lanceolata*, *Trifolium*, *Melilotus*, *Medicago sativa*, *Atriplex*, *Chenopodium album*, *Malva sylvestris*,

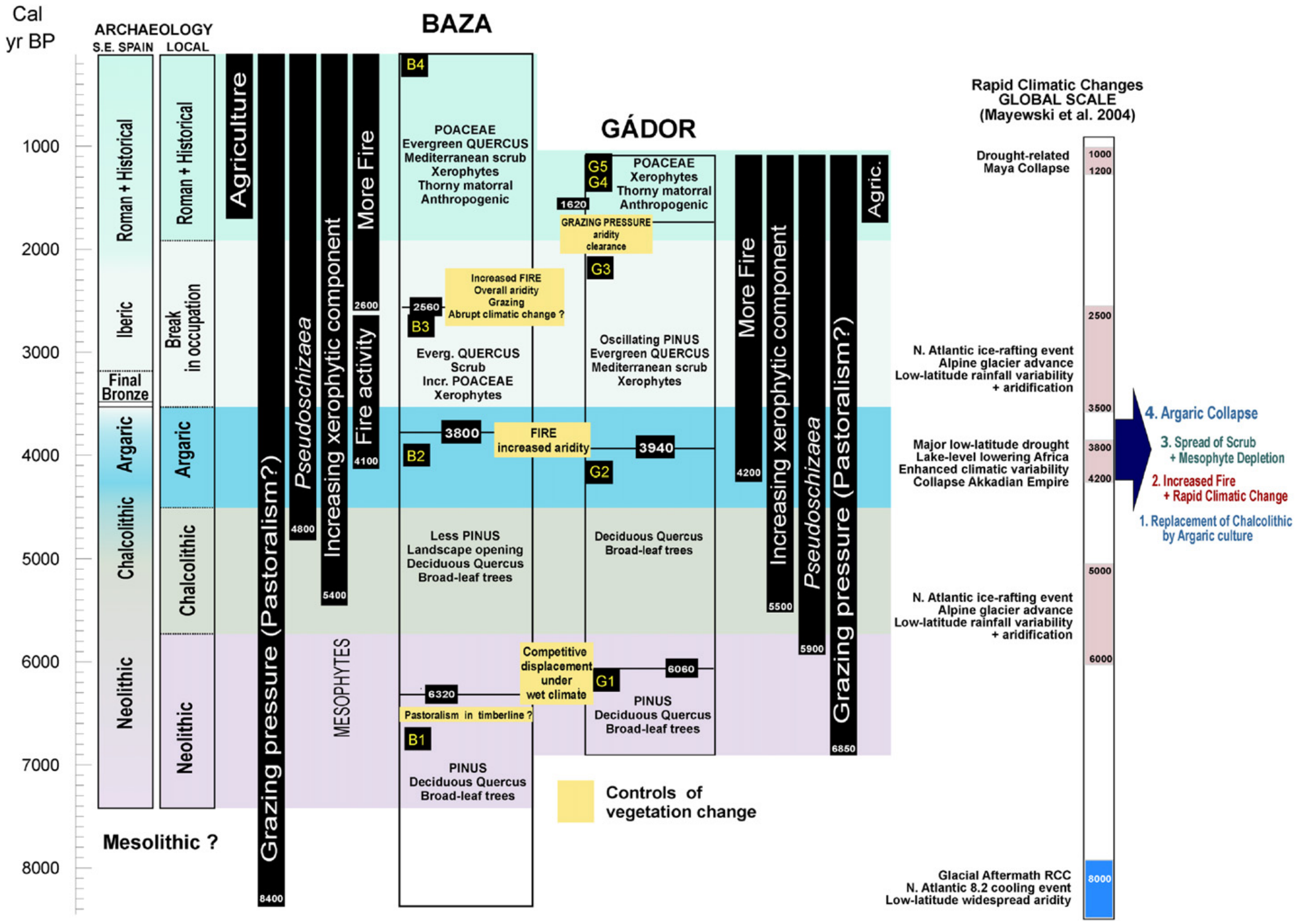

Fig. 8. Patterns and processes of vegetational developments in the Baza and Gádor sequences and correlation with patterns of human settlement, and regional and extra-regional environmental records.

Agropyron repens and *Sherardia arvensis* (Buxó, 1997). In reality, the debate remains open with regards to whether Neolithic humans could have interfered with the vegetation changes that took place in the mid-Holocene in Mediterranean Iberia and it seems increasingly clear that the impact was particularly heterogeneous.

6.3. Chalcolithic landscapes

The southeast of the Iberian Peninsula is one of the zones in western Europe in which metallurgy was first practised. Even though there are strong discrepancies in the chronologies of the different sites, and the transition from the Neolithic is not abrupt (Hernando, 1999), the majority of Chalcolithic settlements of the region occur between ca 5000–4900 and 4400–4200 cal yr BP (Delibes, 1988; Castro et al., 1999; Nocete, 2001). The southeast Iberian Chalcolithic (copper culture known as "Los Millares") consists of small settlements on hills above river sources and arid river valleys, made up of clusters of circular huts with stone walls and covered with mud and branches. With regards to mining activity it is true that activity, compared with the next stage, was not very intense. There are few tools and trenches are small. It would have been mining on a local scale.

In the Sierra de Baza, copper mineralises into micaceous schists and quartzites, contrary to what occurs in adjacent plains, and is found in marls and conglomerates. Locally, the Millares culture can be dated initially to around the interval between 5700–5600 and 4500 cal yr BP (Sánchez-Quirante, 1998). The settlements on the sierra clearly follow the networks of the rivers Valcabra, Uclías, Moras, Bodurria, and Balax (Fig. 2). Two settlements, El Tesorero and Los Moralicos, are in fact found on the plains of the Uclías. In any case, one of the best preserved sites (with evidence of fortification) is the Loma del Colmenar in the Arroyo Balax. In general, these are areas that are topografically abrupt and unsuitable for cultivation.

The vegetation of the Sierra de Baza was not altered substantially during the Chalcolithic phase so that forests with pines and deciduous oaks, together with *Corylus* and other broad-leaf trees, continue to dominate the local landscapes. An increase in the percentage of xerophytic pollen is observed in any case from 5400 cal yr BP and especially after 5000 cal yr BP. Since there are no other indicators of vegetation change, especially among woody plants, and taking into account that a similar process is observed in the Sierra de Gádor from 5500 cal yr BP (Fig. 8), it seems plausible that the increase in xerophytic pollen might reflect an opening of the landscape of the adjacent high plains, probably influenced by a general process of climate change. In the northern hemisphere, the 6000–5000 cal yr BP rapid climatic change intervals feature North Atlantic ice-rafting events, alpine glacier advances and strengthened westerlies over the North Atlantic and Siberia (Mayewski et al., 2004). At lower latitudes, the 6000–5000 interval marks the end of the early to mid-Holocene humid period in tropical Africa, beginning a long-term trend of increasing rainfall variability and aridification (Mayewski et al., 2004).

This global climatic phenomenon clearly conditions the vegetation change of the thermo- and meso-Mediterranean bioclimatic stages of the region in which an opening of the landscape and an ecological degradation are observed with local loss of woody taxa, especially mesophytes (Burjachs et al., 1997). In the pollen record of the San Rafael marshland in the Almería littoral, a clear trend towards the development of shrublands (with expansion of communities of *Artemisia* and chenopods) is evident from the mid-Holocene from 5500 cal BP (Pantaleón-Cano et al., 2003). The same occurs in Roquetas del Mar and, further north, in the catchment of the Río Antas (Yll et al., 1994; Pantaleón-Cano et al., 2003). Geomorphological studies confirm a gradual erosive degradation of many river catchments in the southeast from the Chalcolithic (Calmel-Avila, 2000).

This scenario is confirmed by studies of archaeological charcoal. In general, if in the initial and full Chalcolithic there was a well-developed riparian vegetation, with alder, ash, willow, and poplar, this became progressively denuded in the river valleys and their immediate surroundings. During the Chalcolithic, *Olea europaea*, *Pinus halepensis*, *Pistacia lentiscus*, *P. terebinthus* and, at times, *Tamarix* were abundant in the anthracological spectra, with marked presence of *Pinus pinaster*, *Ephedra, Phillyrea, Quercus ilex–coccifera*, *Rosmarinus officinalis*, *Cistus*, *Fraxinus*, *Sambucus*, *Populus*, and *Salix* (Grau, 1990; Rodríguez-Ariza and Vernet, 1991; Rodríguez-Ariza, 1992a, b, 1995, 2000a; Cámalich and Martín, 1999; Castro et al., 1999). The palynology of some archaeological sites confirms a certain rural trend in the landscape with indicators of agriculture (*Vitis* and Cerealia principally) (López-García, 1988, 1991; Davis and Mariscal, 1994).

The Millares culture included numerous sites within the provinces of Almería, Granada, Málaga and Murcia in southeast Spain. A model of polarised settlement around specific sites of importance and a certain degree of permanent urbanisation, from which the exploitation of respective territories is centred, is observable: los Millares in the Río Andarax, Almizaraque in the lower Almanzora, Terrera Ventura in the Tabernas area, El Malagón in the high plain of Chirivel (Delibes and Fernández-Miranda, 1993) (Fig. 1). A notable population increase is observable when compared to the Neolithic. Chapman (1991) has estimated no fewer than 10,000 inhabitants on average. Archaeological research has demonstrated that the majority of settlements in the lower areas were agricultural, although some represent pastures or sites of control of access into the mountains. Palaeocarpology indicates an agricultural economy based on wheat and barley, together with beans and lentils, indicating the importance of crop rotation. An intensification of agricultural activity with respect to the Neolithic cannot be confirmed but the existence of a well diversified environment from the point of view of resources, with the inclusion of species such as *Lathyrus sativa*, *Stipa tenacissima* (basketry), and *Linum usitatissimum* (oil and fibre) (Rivera and Obón de Castro, 1987; Buxó, 1997) is clear.

The faunal remains in archaeological sites show a decrease in the proportion of ovicaprids—the cheapest and quickest meat to produce—in proportion to the large bovids and horses that were sacrificed at advanced ages, which suggests that they were utilised as draft animals before being sacrificed (Barandiarán et al., 2002). There is also a large consumption of meat derived from hunting, especially red deer, wild boar, ibex, rabbit, aurochs, and birds.

From the above it is worth emphasising that the ecological structure of the Sierra de Baza seems to have been resistant to an important episode of global change and to human activities derived from an intensive occupation of the sierra. The question remains open as to whether the Chalcolithic economy was not sufficiently aggressive on the landscape to leave a mark on the pollen landscape, or whether the forest ecosystem was able to absorb both types of stress during this interval. From the point of view of the impact of the Chalcolithic economy, more projects and studies are needed that target the question. In the southwest of the Iberian Peninsula, the extraordinary intensity of archaeological work has recently allowed clear processes of ecological degradation to be detected from the Chalcolithic (Nocete et al., 2005). In the beginning of the third millennium BC, the Iberian Pyrite Belt of southwestern Spain developed a sudden territorial occupation structured around intensive copper mining and smelting. It was of great magnitude and provoked systematic deforestation and increased erosion and the beginnings of heavy metal pollution in the estuaries of Tinto and Odiel rivers (Gulf of Cádiz). Based on a temporal correlation between the developments and dismantling of territorial networks, Nocete et al. (2005) have inferred a direct link to the development and collapse of the inter-social body of core/periphery relationships during this cultural period.

6.4. *Environmental changes during the Argaric period*

The Argaric Bronze period is found in the Sierra de Baza between 4400–4300 cal yr BP and 3600–3500 cal yr BP.

The Argaric settlements follow the fluvial networks noteworthy among which, within Uclías, are the sites of Cortijo del Carnicero, Las Juntas de Morax and Barranco de San Sebastián (Sánchez-Quirante, 1998). The settlements show some degree of urban planning, with streets and passages between houses which, opposed to the previous phase, are of rectangular or irregular plan. In some cases, as in the settlements of the watershed of the Balax, there seems to be an absence of concern over defence, as they are located in areas of easy access (in that sense they would not be typically Argaric).

An important environmental change is observed during the Argaric period in Baza (pollen transition B2–B3), which implies a general reduction in arboreal cover, with an increase in grasses, as well as an expansion of evergreen oaks and associated Mediterranean sclerophyllous scrub to the detriment of *Pinus*, deciduous oaks, and other mesophytes. The control over change appears to be linked to an increase in fires and the frequencies of microcharcoal increase around 4100 cal yr BP, just before the pollen transition around 3800 cal yr BP. The main question would be if this increase in fires is anthropogenic, climatically induced, or the result of the interaction of the two.

It is open to question whether the increase in xerophyte pollen and *Pseudoschizaea* from ca 5400 and 4800 cal yr BP, respectively (Figs. 6 and 7) are somewhat related to climate change. The pollen sequences of lower altitudes in southeastern Iberia irrefutably show a change towards aridity since at least 5500 cal yr BP (Yll et al., 1994; Jalut et al., 2000; Pantaleón-Cano et al., 2003). At a broader scale, a steep fall in carbonate percentage in a marine sediment record from the Gulf of Oman, representing a major episode of dust deposition, is directly linked to drought conditions associated with the demise of the Akkadian civilisation around 3800–4200 cal yr BP (Cullen et al., 2000; deMenocal et al., 2000).

The climatic influence is therefore a definite possibility. There are, nevertheless, elements suggestive of an acceleration of the process of deforestation due to human activities, especially through activities associated with mining and grazing. With respect to agriculture, the local impact was not important in the typically mountainous areas of Baza and Filabres, not only because there are no indisputable pollen indicators of agriculture, but especially because the meadows with good soil are scarce, narrow, and small. This has always made rotation complicated, at least much more so than in the fertile meadows of the lowlands. The density of population during the Argaric continues to be relatively high, but is restricted to small settlements whose distribution can only be explained by their orientation towards metallurgic exploitation of copper, an abundant resource accessible to a poorly evolved technology (Sánchez-Quirante, 1998).

It seems probable, therefore, that grazing combined with mining activity accelerated and exacerbated the establishment of a new ecological system better adapted to a situation of greater summer drought: a sclerophyllous vegetation that would periodically catch fire, in some cases due to the direct action of humans, in others because of the inherent flammability of the invasive species (*Q. ilex–coccifera*, *Erica*, *Pistacia lentiscus*, *Phyllirea angustifolia*, and especially, *Cistus*).

It is worth asking, therefore, whether the end of the Argaric period (ca 3500 cal yr BP) had an environmental conditioning. The idea of the Argaric collapse was principally put forward by Lull (1983), who always suggested that this culture would have suffered a socioeconomic debacle due to the persistence of a pastoral–agricultural system based on the degradation of vegetation and soils. The role of metallurgy, as an activity requiring large amounts of natural fuel which would have favoured deforestation, would have been prominent in this collapse. The crisis would have occurred when the available resources became insufficient to maintain the volume of pastoral–agricultural elements distributed politically in secondary production and the labour force. Having reached a threshold level (in which we imagine an important reduction in vegetation cover), the decline of the southeastern societies would have caused an economic collapse in a few years with the consequent massive depopulation.

The technical difficulties in establishing a causal nexus between cultural and environmental changes in this period is understandable given the imprecise chronologies available, the fragmentary character of the palaeoecological information and the lack of recent studies specifically orientated towards this problem. Clearly, the hypothesis of an environmentally induced cultural termination is parsimonious with the sequence of observed events in Baza and Gádor (where ecological change takes place around 3900 cal yr BP (Fig. 8). In both cases, fire appears as a direct conditioning factor in vegetation change; in both cases there are indicators of climate change more than a millennium earlier; in both cases the trend in vegetation change is the same.

In general terms, the Argaric period of the southeast suggests continuity in many settlements, in some territories the increase in their number and size as well as the organisation of the territory, probably more structured in accordance with economic, political, and strategic functions. There is also an intensification and diversification in metallurgic production (Eiroa, 1989; Barandiarán et al., 2002). In this sense, a general increase in the number of metallic objects recovered in necropolis and settlements is detected as well as a greater typological diversity which encompasses utensils, weapons, and adornments. Apart from the mining settlements, there is a good number with pastoral–agricultural orientation while the great centres are linked to arable land; these could have had a central function over the control of the territory. The area occupied by the Argaric culture has been estimated at around 45,000 km^2, according to Chapman (1991), with settlements of an area of up to 3.5 ha in La Bastida de Totana (Murcia) and 0.13 ha in Picacho de Oria. In terms of number of inhabitants, the estimates are of between 40 and 1200, which would give mean population densities of 3.13 inhabitants/km^2 (there are many settlements to be discovered so these may be underestimates). Nocete (2001) has suggested a state political organisation for this period along with a spatial specialisation related to the transformation, production, and storage of cattle and cereals.

In general terms, in comparison with the Chalcolithic, the same cereals as in the preceding period are documented with a greater presence of leguminous plants (bean, lentils, peas) and flax (Netolizsky, 1935; Stika, 1988; Hopf, 1991; Peña Chocarro, 1995), in a diversified agricultural framework, with the presence of millet (*Panicum miliaceum*), figs (*Ficus carica*), olive, and adventitious plants such as *Lolium perenne/rigidum* and *Polygonum* (Buxó, 1997). The prevalence of irrigation is not clear in this period as there is anthracological evidence that riparian woodland was better developed than today (Carrión Marco, 2004); in other words, the greater activity of tributary streams would make possible the hypothesis that agriculture was practised without need of irrigation infrastructure, ground liable to flooding being that only utilised. In addition, analysis of carbon isotope discrimination in cereal and faba bean seeds from archaeological sites fails to support the existence of irrigation practices during this period (Araus et al., 1997). In terms of animal species, the same are recorded as in the preceding period but at different frequencies: ovicaprids and pig continue to be important, but there is an increase in bovids and horse (Barandiarán et al., 2002).

In general, the anthracological analyses in the meso- and thermo-Mediterranean of the southeast show a landscape that is more forested than at present, but already clearly degraded, with abundance of lentisc, wild olive, rosemary, *Quercus coccifera*, *Rhamnus*, *Phyllirea*, leguminous plants, heathers, labiates, low presence of *P. pinaster*, *P.halepensis*, *Olea*. *Tamarix*, *Salix*, and *Populus* would have been abundant along river margins (Grau, 1990; Cámalich and Martín, 1999). Together, archaeological charcoal and pollen support Lull's (1983) hypothesis regarding the insufficiency of the environment to meet the needs of a social entity as key factor in terms of explaining the disappearance of basic features of the Argaric society. The causes, as indicated by Castro et al. (1999) would not just be metallurgy but also pastoral–agricultural activity and Argaric manufacture. Grazing would have to be added as an important factor in degradation at an important scale along with the exigencies of food production (especially cereals) and fuel use. It must not be forgotten that we are in a context of slow soil regeneration.

6.5. Break in occupation and impacts from lowland Iberian settlements

The Sierra de Baza became depopulated after the Argaric occupation. Unlike other areas of the southeast, there are no final Bronze Age settlements in Baza (Fig. 8). There are, nevertheless, vestiges of lower-Imperial Roman and Arab occupation, always in direct relationship with mines and other metallic deposits, which indicate a revaluation of the mining tradition of the sierra, perhaps through the search for iron oxides (Sánchez-Quirante, 1993) (Fig. 2). It would not have been, in any case, a systematic occupation as in the Chalcolithic and Argaric periods, but one of miners and shepherds with few agricultural enclaves.

The pollen transition B3–B4 at 2560 cal yr BP falls within the Iberian period of southern Spain (ca 3200–2200 cal yr BP). While the Mediterranean scrub component remains, zone B4 indicates a major forest regression, greater mesophyte depletion including the disappearance of *Corylus*, the appearance of palynological indicators of agriculture (*Vitis*, *Puccinia*) and other human activities, probably grazing (increased *Plantago*, *Rumex crispus*, *Polygonum aviculare*), and the expansion of thorny scrub of Genisteae, *Dianthus subacaulis*, *Berberis*, etc, as well as the clogging of the bog by sedges with an increase in organic sedimentation (fungal spores) and terrestrialisation of the former swampy vegetation (*Glomus*) (Fig. 3).

The B3–B4 transition is again preceded by increases in the concentrations of microcharcoal around 2620–2590 cal yr BP, which suggests a degree of perturbation as in the B2–B3 transition although even more pronounced if we take the relative microcharcoal concentration into account (Figs. 4 and 7). A previous pollen study in the Cañada Larga del Cerro del Sotillo (Arroyo Moras, 1890 m a.s.l.) reveals an increase in the concentration of microcharcoal from 2678 cal yr BP, with a peak around 2384 cal yr BP, preceded by an increase in Cyperaceae, grasses, and *Plantago* (Riera et al., 1995). In this sequence, the percentage differences of some pollen types can be observed, for example the rock roses (*Cistus laurifolius* is very abundant even today in the upper course of the Arroyo Moras). Other differences between the two records could be marked by differences in the local extent of hygrophytic Cyperaceae. The general trends are otherwise similar for the past 2600 years.

It appears striking at first sight that the B3–B4 transition, so important in the vegetation sequence from the point of view of indicators of human impact, should happen during a period when the Sierra de Baza was unoccupied (Fig. 8). It is, nevertheless, not at all surprising if we consider the immediate geographic context. The depopulation of the sierra coincided with the development of the Iberian culture in the lowlands (ca 3200–2220 cal yr BP), which had a crucial importance in the economic development of the region. Just 3 km from the present city of Baza is the Cerro Cepero, the site of the ancient Ibero–Roman city of Basti (Fig. 1). This was one of the principal fortified Iberian cities of the entire country, to the point that it gave its name to an extensive region, Bastetania, which included the whole of present-day eastern Andalucía and even part of Albacete and Murcia, according to contemporary Graeco–Latin sources (Almagro, 1986). It was possibly founded in the eighth century BC and reached its maximum splendour during the fifth to first centuries BC. This city was occupied later by the Visigoths and Byzantines and was abandoned later still at the beginning of the Medieval period. There is an important necropolis, Cerro Santuario, close to Basti where the Dama de Baza (the best example of funerary statue of the entire Iberian art) was found.

In Bastetania, there was a system of territorial organisation based on cities that were strategically situated close to fertile meadows in the intersection of commercial routes. We are talking of cities of the order of 2000–5000 inhabitants coexisting with scattered villages. The Iberian period represents, in the region, an enormous advance in agriculture: irrigation as well as the cultivation of the vine, fig, and almond became widespread. Coinage also became common as means of payment and richness was converted into currency that separated social classes.

The anthracological (e.g. sites of Fuente Amarga and Los Baños) and archaeological pollen studies suggest a landscape strongly altered by human activity close to rivers and in meso-Mediterranean valleys (Rodríguez-Ariza and Ruíz Sánchez, 1993; Rodríguez-Ariza, 2000b). Zones of natural vegetation appear dominated by *Quercus rotundifolia*, *Q. coccifera*, and *Pinus halepensis*, which progressively decreased in favour of *Retama* and other shrubby elements. From these studies and from numerous excavations it can also be deduced that, for the Iberians, the forest was an essential resource: rotation for pastures, bee keeping and hunting, wood collection for fuel in the houses, hearths, ceramic and smelting ovens, as charcoal, as construction material, as protection for buildings, for domestic use, agricultural tools, weapons, and ritual objects (Ruíz and Rodríguez-Ariza, 2002).

The Iberian period is the one in which *Hordeum vulgare nudum* was substituted by *Hordeum vulgare*, a process that started in the Copper–Bronze transition. *Triticum dicoccum* was also substituted by *T. durum aestivum*, although in this case the change was more gradual. Buxó (1997) interprets that this change was associated with the specialisation of wheat as a human dietary product to the detriment of barley which became an animal fodder. There was also the consumption of millet, which became the third cereal product. To this we must add the regular consumption of peas (*Pisum sativum*) and beans (*Vicia faba* var. *minor*), lentil (*Lens culinaris*) and chick pea (*Cicer arietum*). To the importance of agriculture in the lowlands, we must also add the existence of a notable cattle element, as demonstrated by palaeo-faunal studies at nearby sites (Riquelme, 1992). All this speaks in favour of an important human intervention over the plant resources of the Sierra de Baza and justifies a landscape change through clearance.

Climatic changes should not be disregarded when interpreting the controls over vegetation change during this phase. Around 2760 cal yr BP, a sudden and sharp rise in the atmospheric ^{14}C content (probably caused by a reduction in solar activity) has been found to be contemporaneous with an abrupt and global climate change. At middle latitudes of the northern hemisphere, this led to a cooler and wetter climate; in the tropics it was a drier climate, as shown by both archaeological and palaeoecological data (van Geel and Renssen, 1998). It is not possible with the available information, however, to establish a direct link between this rapid climatic change at the global scale and the vegetation changes observed in Baza.

6.6. Roman and historical records of human impact on the vegetation of Sierra de Baza

The mountain landscape in zone B4 is dominated, at the expense of the former mixed forests with abundance of pines and broad-leaf deciduous trees, by evergreen oaks and pines together with Mediterranean scrub with widespread grasslands and thorny dwarf matorral in the high-elevation areas (Fig. 7). This vegetation would have been largely influenced by episodic fires, tree cutting, pastoralism, and a continental Mediterranean climate.

Palaeobotanical studies in the lowlands surrounding Sierras de Baza and Gádor support a regional picture of progressive deforestation, loss of tree diversity and expansion of heliophytes, spiny shrubs, and ruderals (Rodríguez-Ariza and Ruíz Sánchez, 1993). Attention should be drawn to the anthracological study of Castillejo de Gádor (Almería, very close to Los Millares, on the thermo edge of the Río Andarax, west of the Sierra de Gádor) (Rodríguez-Ariza, 2001). In reality, this sequence shows the evolution of woody types from the Argaric to the Medieval. During the Argaric, the presence of *Populus*, *Alnus*, and *Salix*, together with different species of pines (*P. nigra–sylvestris*) and oaks (*Q. faginea*, *Q. suber*, *Q. ilex–coccifera*) is noteworthy. The landscape progressively became deforested and there was an expansion of *Nerium*, Genisteae, and *Cistus*, with cultivated plants such as vines, almond, olive, and walnut during the Medieval Period.

A problem when developing a picture of the vegetation changes emerges from the use of a single sequence, even if the resolution is relatively high. Nevertheless, historical and geographical elements can be used to better understand the controls of current vegetation in Sierra de Baza and the possible impacts of man on the vegetation during the last two millennia. Those elements are abundant in the Sierra de Baza and immediate surroundings. The Roman occupation, for instance, meant the maintenance, even expansion, of the agricultural settlement which had started in adjacent valleys (Almanzora, Vera Depression, etc.) during the Iberian period, especially in the fifth century BC. The existence of important metallurgical sites of copper, silver, iron and lead in the Sierras de Filabres, Almagrera, Herrerías, Almagro, and Cabrera was the essential engine that gave impulse to the Romans to occupy and exploit the territory (Fig. 1).

The settlement of Baza and Filabres throughout prehistory and recent history can only be well explained by taking mining into account. There are historical records that indicate that the watershed of the Uclías suffered a population avalanche during the nineteenth century because low altitude mines had been exhausted (Sánchez-Quirante, 1998). It seems clear, on the other hand, that in the late Roman world and the High Medieval Period, mining became intense after a long depopulation since the late Bronze Age. It is significant that the majority of settlements during the Chalcolithic of, for example, the Bodurria stream are on the left bank, in direct contact with the phyllites that offer copper mineralisation in the form of carbonates (Sánchez-Quirante, 1998).

Exploitation of domestic animals must have been carried out for many millennia. The tracks and trails of the sierra are very abundant and there is archaeological evidence of pastoral activity in many shelters and caves that were used to keep animals (Sánchez-Quirante, 1998). During the sixteenth, seventeenth, and eighteenth centuries the sierra was utilised for summer pastures (goats and sheep) by farmers from Almería, Granada, and even Guadalajara (central Spain).

High altitude zones have been more exploited for pastures until recent years. If the distribution of farms is observed, it is clear that nearly all are on the high zones of the Uclías, Balax, and Moras. High altitude pastoral activity has left its mark in the architecture, the use of schist slices for hut roofs being noteworthy, as in the Cañada del Gitano, a few hundred metres from the study site (Sánchez-Quirante, 1998). Currently, the greater part of the high mountain range is uninhabited but there are ruins of numerous farms, stables, and sheepfolds for cattle, which were used between late spring and autumn in search of summer pastures.

With respect to the exploitation of wood, this is recorded since the fifteenth century with use for firewood, charcoal, construction of churches, convents, public buildings, and houses. There are also texts that testify to the frequency of fires and the use of wood for fortifications in Oran (Algeria) and for the Invincible Armada. In the records of the Marqués de la Ensenada (1753), a concession for use of wood is described. In these records, there is mention of the abundance of holm oaks (*Q. rotundifolia*): more than 12,000 censused in the margins of the Uclías, some 14,000 in the Balax, and some 22,000 in the Moras. Having benefited from protective legislation for centuries, many of these oak woods of the meso-Mediterranean, as well as poplar woods of the supra-Mediterranean, were cut down *en masse* during the second half of the twentieth century due to the shortages after the Spanish Civil War. There is evidence also of massive rotations of deciduous oaks, pines, and holm oaks during the sixteenth, seventeenth, and nineteenth centuries, and pine afforestation during the twentieth century (Rodríguez-Sánchez, 1998b; Gómez-Cruz, 1991).

The historical data suggest, in any case, that there were still enclaves with dense forests, of oaks, pines, and mixed forests at the end of the Medieval Period (Madoz, 1846; Bauer, 1980; García-Latorre and García-Latorre, 1996). It is evident from our study that deforestation in the oro and supra-Mediterranean stages took place, but it is possible that lower belts had a certain capacity for the retention of forest ecosystems even after the strong mining and pastoral intervention. Not in vain, even today, the Sierra de Baza is a Natural Park which, because of its wide geo-biological diversity, is protected by legislation. Bear and wolf were frequent even in historical times (Torres, 1998).

The agricultural impact does not explain the vegetation changes observed in Baza. Along the rivers and streams there are many orchards, relics of a mountain agriculture with diversified Mediterranean cultivation. But the agricultural settlement has always been marginal, in low zones and linked to periods of crises. The massive rotations of the sixteenth, seventeenth, and late nineteenth and early half of the twentieth centuries were not very profitable due to the poor soils, even after the great efforts of terracing and the large scale cutting of forests in flatter areas. The depressions of Baza and Caniles were more appropriate in covering subsistence deficiencies.

7. Final remarks

This paper provides a record of environmental change for the greater part of the Holocene in a mountain system surrounded by high plains and river valleys in a semi-arid context within the extreme southeast of the Iberian Peninsula. Contrasting with other mountain and plateaux systems of continental Iberia, in which pine woods predominate for the greater part of the Holocene (Franco et al., 2005), the high mountain vegetation of the Baza-Filabres mountain block has been subjected to important changes during the Holocene and, though there appear phases of resilience, it has shown itself to be sensitive to a range of influences, namely a continental climate that has become increasingly arid over the last 5000 years, a broken relief, the scarcity of cultivable soils, a geology that includes sources of copper and other metals and, the incidence of grazing as well as the repeated appearance of fires during the last 4000 years.

There are no historical elements in Baza that allow us to uphold phytosociological models of vegetation dynamics based on present-day floral characteristics (e.g. Peinado et al., 1992). Very especially, the data suggest that the present-day holm oak woods (*Paeonio–Quercetum*, *Berberido–Quercetum*, *Adenocarpo–Quercetum*) are not formations strictly conditioned by climate, but that they are the result of the combined action of climate and human activities that have favoured trends towards xerophytic vegetation.

The history of the vegetation of the Sierra de Baza seems clearly influenced by changes in local economy, but direct relationships between human occupation maxima and stages of greatest ecological degradation cannot be established. A main reason for this is that the Sierra was surely affected by human communities settled out of the geographical limits of the Sierra. The successive archaeological survey seasons, one of which is situated along the

Arroyo Uclías in the vicinity of the study bog, have indicated three periods of occupation: between the fourth and second millennia BC, in the late Roman–high medieval period, and from the sixteenth to the last third of the twentieth century. From the fourth to the first half of the third millennium, the economy was a subsistence one based on mixed pastoral–agricultural strategies. From the third millennium, the systematic exploitation of a specific non-subsistence resource—copper—is recorded. It is a first-order factor that explains the population increase between the third millennium and throughout the greater part of the second millennium BC. It is the starting point for the first metallurgic communities of the southeastern Iberian Peninsula: the cultures of Los Millares and El Argar. From the end of the second millennium to the late Roman–High Medieval period, there was a depopulation that coincided with the disappearance of the Argaric world and copper–bronze–arsenic metallurgy.

The crucial question of whether Sierra de Baza was at this time abandoned because of human impact on the environment or because of increased aridity therefore arises in this connection. Considering the strong similarities found between Holocene successions at the Sierra de Baza and the nearby Sierra de Gádor, we prefer the view that the Sierra de Baza was abandoned for both and even more reasons. The story is one of great complexity. Over the course of Chalcolithic and Argaric periods, the human population and its demands on the Sierra de Baza's environment would have been growing while resources declined. Local people could have come to be living increasingly close to the limits of what the environment could support, in a certain sense close to the edge. Through palaeoecological, combined with historical, information we observe ecological degradation, landscape opening, fires, pastoralism, and perhaps tree cutting for mining, as the proximate causes of abandonment. But the real connection between climate, fire, vegetation, and palaeoeconomy is far from understood. If we consider the last-century trend of human occupation in the semi-arid southeastern region of Spain (in this case caused by tourism and immigration), it is clear that this debate is pertinent in the political sphere. Dramatically, we could be dealing with a similar story of resource exhaustion in a particularly sensitive region, which—like today, but never before so intensely in historical times—was densely populated during the mid-Holocene.

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