Proceedings of the Geologists' Association xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Proceedings of the Geologists' Association

journal homepage: www.elsevier.com/locate/pgeola

Ancient Forests in European drylands: Holocene palaeoecological record of Mazarrón, south-eastern Spain

José S. Carrión[a,*], Elena Fierro[a], Milagros Ros[b], Manuel Munuera[c], Santiago Fernández[a], Juan Ochando[a], Gabriela Amorós[a], Francisca Navarro[d], Tomás Rodríguez-Estrella[e], Saúl Manzano[a], Penélope González-Sampériz[d], Ana Moreno[d]

[a] *Department of Plant Biology (Botany Area), Faculty of Biology, University of Murcia, Campus de Espinardo, 30100 Murcia, Spain*
[b] *Department of Prehistory, Archaeology, Early and Medieval History and Historiographic Sciences and Techniques, University of Murcia, Campus de La Merced, 30001 Murcia, Spain*
[c] *Department of Agricultural Science and Technology, Polytechnic University of Cartagena, 30203 Cartagena, Spain*
[d] *Pyrenean Institute of Ecology-CSIC, Av/Montañana 1005, 50059 Zaragoza, Spain Department of Geography, University of Murcia, Campus de La Merced, 30001 Murcia, Spain*
[e] *Department of Mining, Geological and Cartographic Engineering, Polytechnic University of Cartagena, 30203 Cartagena, Spain*

ARTICLE INFO

Article history:
Received 1 November 2017
Received in revised form 13 May 2018
Accepted 14 May 2018
Available online xxx

Keywords:
Quaternary
Holocene
Palaeoecology
Palaeogeography
Palynology
Historical biogeography
Spain

ABSTRACT

This paper presents a new Holocene palaeoecological record from coastal south-eastern Spain, a region characterised by high plant species diversity, varied physiography, high risk of desertification, and a history of human pressure on the landscape that stretches to antiquity. The pollen sequence shows four main vegetation phases: the first characterised by mixed forests of *Pinus* and evergreen *Quercus* accompanied by broad-leaved mesophilous trees, and a diversity of Mediterranean scrub; the second phase is characterised by mesophytic decline and expansion of *Artemisia;* a third, mid-Holocene phase of thermo-mesophytic maxima with prevalence of forested landscapes; and, finally, the progressive opening of the landscape with sparse pines, halo-xerophytic grasslands and sclerophyllous brushwood. The current treeless situation of south-eastern Spain is a relatively recent feature resulting from a dramatic change in the ecological structure of the regional landscapes. This paper stresses the continued vulnerability of these arid systems in the face of a changing climate. This sequence adds to previous palaeobotanical records (pollen and charcoal) and archaeological reports to suggest that deforestation started earlier in low-elevation areas and river basins than in the inland mountains and platforms, a factor that appears in connection to human exploitation of the natural environment.

1. Introduction

The south-eastern region of the Iberian Peninsula is one of the most arid territories in Europe. At over 13,000 km^2, the Murciano-Almeriense bioprovince (Peinado and Rivas-Martínez, 1987) is particularly well suited for studies addressing diverse environmental and palaeoecological issues due to its high plant-species diversity, varied physiography with abundance of ecotones, high risk of desertification, and a long history of human pressures on the landscape that stretches back to antiquity. As with other dry lands (Horowitz, 1992; Scott and Woodborne, 2007), palynological developments in this region have only become possible after overcoming a multiplicity of methodological difficulties (Carrión et al., 2009). Successful pollen analyses have concentrated on adjacent marine sediments (Magri and Parra, 2002; Parra, 1994; Targarona, 1997), peaty deposits in sub-coastal mountains (Anderson et al., 2011; Carrión et al., 2003a, 2007; Manzano et al., 2016, 2017; Ramos-Román et al., 2016), playa lakes (Burjachs et al., 1997; Giralt et al., 1999), valley-bottom fills in badland areas (Dupré et al., 1996; Nogueras et al., 2000), and prehistoric sites including cave, rockshelters and open-air settlements (Carrión et al., 1995a, 1999, 2003b, 2013; Davis and Mariscal, 1994; Dupré, 1988; Fierro et al., 2011; Fuentes et al., 2005; López-García, 1988; Munuera, 1992; Munuera and Carrión, 1991) (Fig. 1). Investigations in palaeo-lagoons and coastal marshes are limited to a few studies (Carrión et al., 2010a, 2013; Pantaleón-Cano et al., 2003; Yll et al., 1994).

This paper brings new data from a Late Quaternary basin on the coast of south-eastern Iberia, where organic sediments have

---

* Corresponding author.
E-mail address: carrion@um.es (J.S. Carrión).

https://doi.org/10.1016/j.pgeola.2018.05.007
0016-7878/

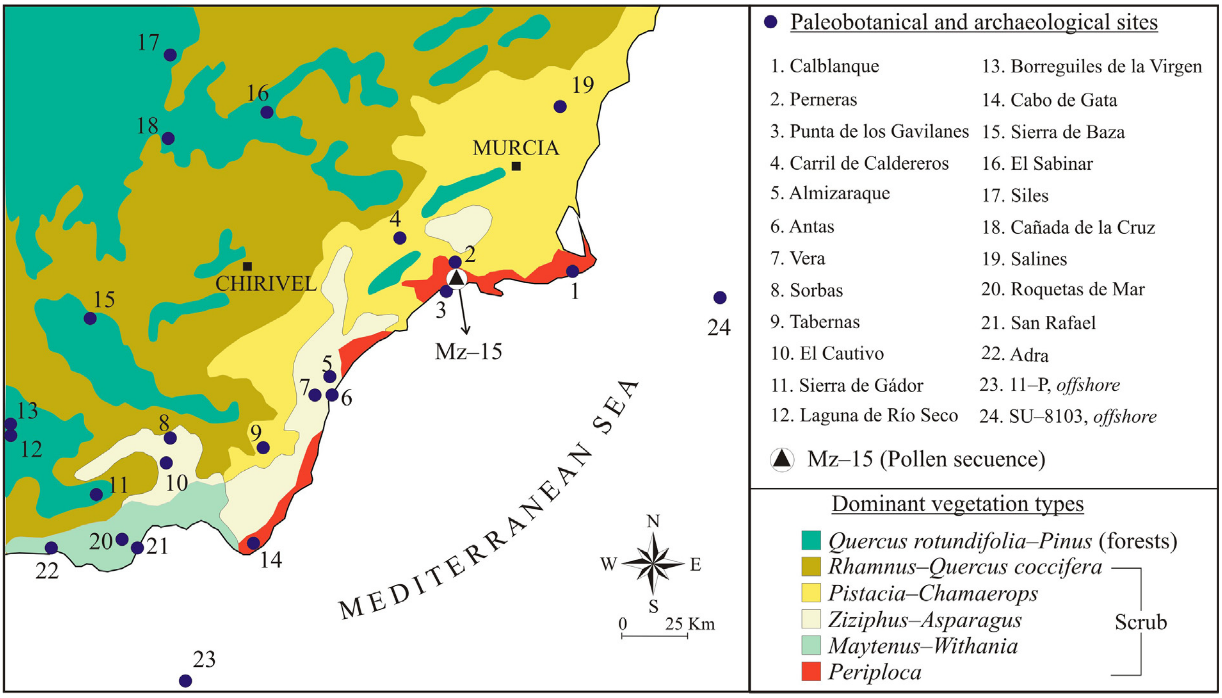

Fig. 1. Location of Mazarrón sequence, and other palaeobotanical and archaeological sites from south-eastern Spain with indication of regional vegetation types. Perneras (Carrión et al., 1995a,b), Punta de los Gavilanes (García-Martínez et al., 2008), Carril de Caldereros (Fuentes et al., 2005), Almizaraque (Davis and Mariscal, 1994), Antas, San Rafael and Roquetas de Mar (Pantaleón-Cano et al., 2003), Calblanque, Vera, Sorbas, Tabernas, and Adra (Castro et al., 2000,Carrión, 2002b), El Cautivo (Nogueras et al., 2000), Sierra de Gádor (Carrión et al., 2003a), Laguna de Río Seco (Anderson et al., 2011), Borreguiles de la Virgen (Jiménez-Moreno and Anderson, 2012), Cabo de Gata (Burjachs et al., 1996), Sierra de Baza (Carrión et al., 2007), El Sabinar (Carrión et al., 2004), Siles (Carrión, 2002a), Cañada de la Cruz (Carrión et al., 2001b), Salines (Giralt et al., 1999, Burjachs et al., 2016), 11P offshore (Targarona, 1997), SU 8103 offshore (Parra, 1994; Magri and Parra, 2002).

become available for pollen analysis. Our goal was to obtain palaeoecological knowledge of an unexplored part of the Mediterranean region that is vulnerable to climate changes, specifically to aridity events and desertification. The novelty of this study site stems from its low altitude, proximity to the coast, and vicinity to an important, long-standing human settlement that started in the Bronze Age (Rodríguez-Estrella et al., 2011; Ros, 2008). In the adjacent mountains, palaeoecological investigations have demonstrated the existence of mixed forests as well as Mediterranean forest and scrub during the middle Holocene (Carrión et al., 2003a), or to present such as in Sierra Nevada (Anderson et al., 2011; Jiménez-Moreno and Anderson, 2012; Ramos-Román et al., 2016). Regarding the coast, there is a gap in our understanding of the palaeofloristic and structural characteristics of Quaternary vegetation, as well as about the chronology and ecology of deforestation in the lowest altitude areas where the current treeless situation is both a striking feature and a research stimulus for biogeographers (Rodríguez-Sánchez et al., 2010) (Fig. 1).

2. Physical setting

The study site (37° 33′ 55′′N, 1° 16′ 31′′W, 0 m a.s.l.) lies within one of the palaeo-lagoonal systems in the Guadalentín river valley, within the littoral zone of Murcia, south-eastern Spain. It is nowadays occupied by the Bahía suburban area of Mazarrón city (Fig. 2). The surrounding orography is made up of the Sierra de la Almenara (882 m a.s.l.), Sierra de las Moreras (545 m a.s.l.), Sierra del Algarrobo (713 m a.s.l.) and Sierra de Lo Alto (540 m a.s.l.) peaks. The former salt flats of Mazarrón belong geologically to the Betic Zone of the eastern Betic cordilleras, in particular to the Nevado-Filábride Tectonic Complex which outcrops underneath the Permo-Triassic Alpujárride Tectonic Complex (Rodríguez-Estrella, 2006). This territory has been unstable since at least the Late Pleistocene because of the existence of faults, as well as fluvio-littoral, and neotectonic movements. The area has been extensively occupied by humans from at least the 2nd millennium BC (García-Martínez et al., 2008). Previously, more disperse settlements correspond to Middle and Upper Palaeolithic groups whose subsistence partly depended on the exploitation of the coastal environment. An example is the underwater site of La Peñica (Montes Bernárdez, 1982) in the fishing port of Mazarrón.

The climate of the study site is typically Mediterranean, with pronounced summer drought and relatively high thermicity. Local mean annual temperature and precipitation are 16–19 °C and 200–300 mm, respectively. Precipitation is yearly and inter-seasonally variable, with rainfall concentrated in autumn and spring, and occasional rainstorms associated with Mediterranean Sea fronts. Winters are absent of freezing days due to the influence of the sea. Bioclimatically, Mazarrón lies in the semiarid thermomediterranean belt (Peinado et al., 1992).

The vegetation of the study basin is dominated by halophytic chenopods such as *Atriplex halimus, Arthrocnemum macrostachyum, Sarcocornia fruticosa, Suaeda vera,* and *Anabasis hispanica*, accompanied by *Phragmites, Tamarix*, and annual species of Lamiaceae, Plantaginaceae, Liliaceae, Poaceae, Cyperaceae, Caryophyllaceae, Plumbaginaceae, and Frankeniaceae. Fruit tree crops surround the area. The adjacent mountains, including Sierra de las Moreras, are characterised by thicket and scrub species such as *Stipa tenacissima, Lygeum spartum, Calicotome intermedia, Lycium intricatum, Chamaerops humilis, Launaea arborescens, Rosmarinus officinalis, Lavandula dentata, Anthyllis cytisoides, Genista umbellata*, several species of *Artemisia,* and *Rhamnus lycioides*, among others. It is worth mentioning the occurrence of Ibero-North African endemics like *Maytenus senegalensis*, *Osyris quadripartita*, *Periploca angustifolia*, *Withania frutescens*, *Ziziphus lotus* and *Tetraclinis*

Please cite this article in press as: J.S. Carrión, et al., Ancient Forests in European drylands: Holocene palaeoecological record of Mazarrón, south-eastern Spain, Proc. Geol. Assoc. (2018), https://doi.org/10.1016/j.pgeola.2018.05.007

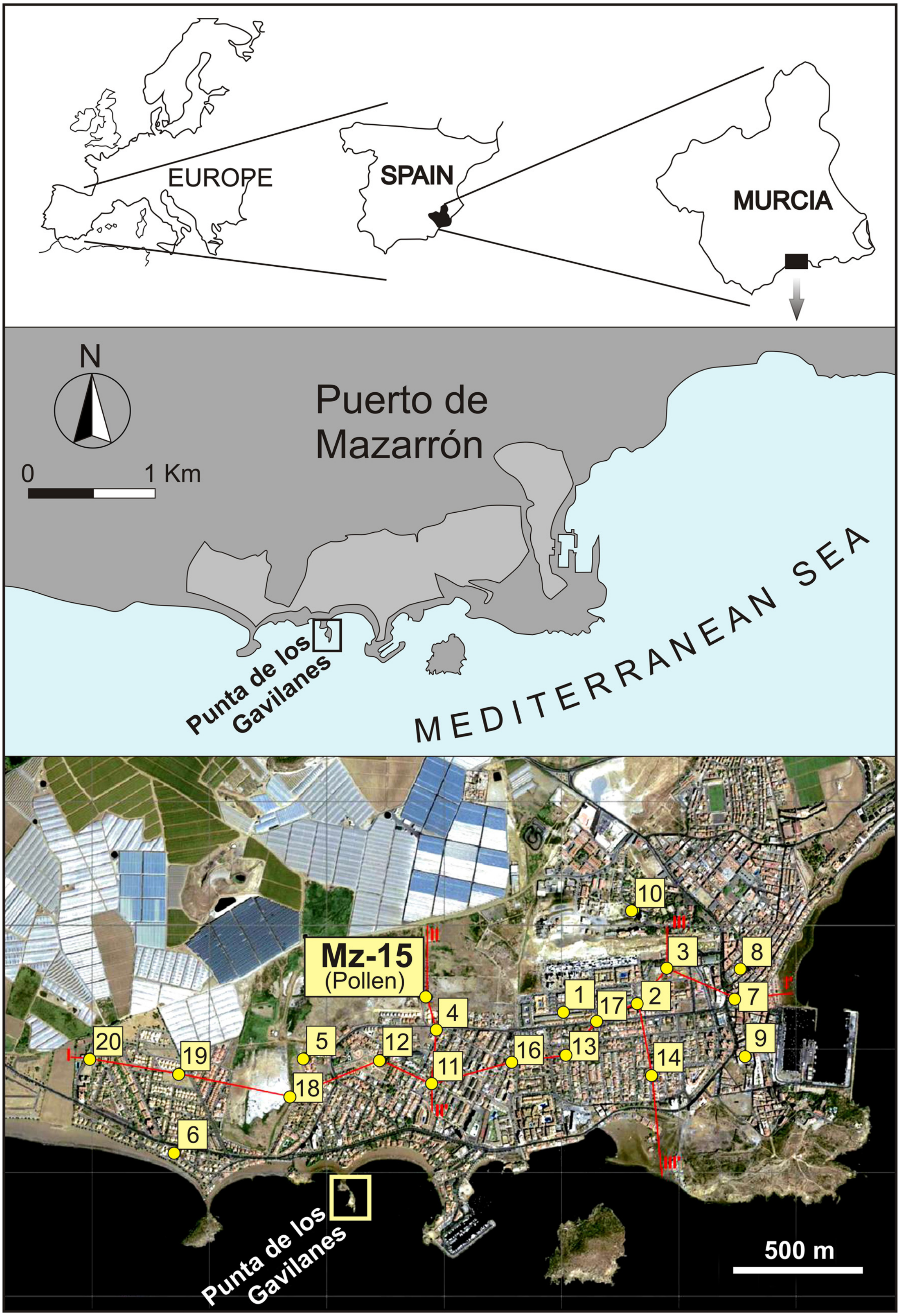

Fig. 2. Location of Maz-15 and other boreholes in the Puerto de Mazarrón area. After Rodríguez-Estrella et al. (2011).

Please cite this article in press as: J.S. Carrión, et al., Ancient Forests in European drylands: Holocene palaeoecological record of Mazarrón, south-eastern Spain, Proc. Geol. Assoc. (2018), https://doi.org/10.1016/j.pgeola.2018.05.007

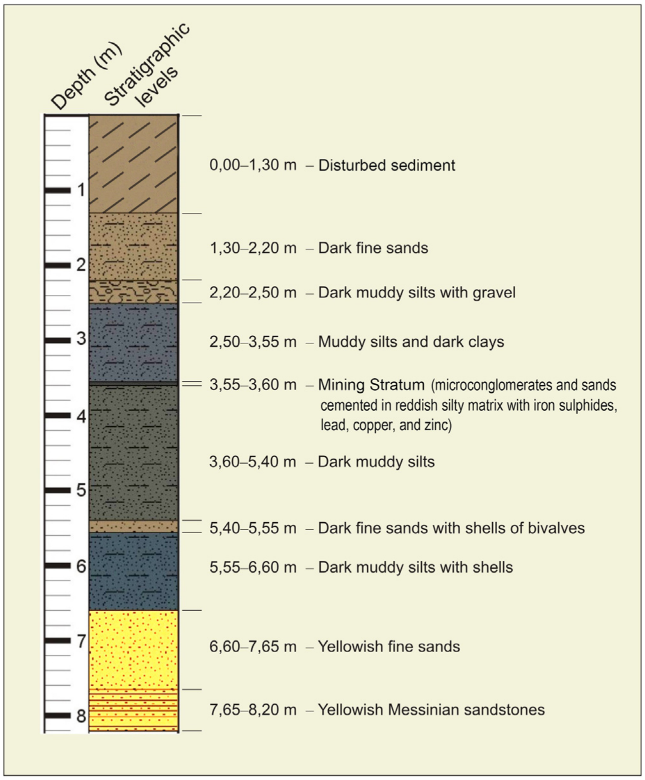

Fig. 3. Litostratigraphy of Maz-15 core. The mining layer is formed by microconglomerates and sands, with dolomitic boulders cemented in reddish silty matrix, and containing the same metallic elements that are captured in the nearby mines of Mazarrón. With evidence of exploitation since at least the beginning of the first millennium BC, up until the 19th century, the mines were located on the left bank of the Las Moreras Boulevard, whose drainage network, in torrential avenues, transported the sterile mined minerals to the marsh area where the MAZ-15 survey is located.

articulata. Trees are characteristically absent from the region, with only some stands of *Pinus halepensis*, the origin of which are unclear (Carrión et al., 2010b).

3. Material and methods

As a part of a broad geological survey (Rodríguez-Estrella et al., 2011), twenty cores were extracted from the basin. We selected this location because the rapid spread of adjacent urban settlement could diminish the future possibility of recovering this unique sedimentary archive (Ortega et al., 2004). From the twenty cores retrieved, three were selected for palynology (boreholes Maz-12, Maz-15 and Maz-16) (Fig. 2). The drilling system was rotary with a piston used to obtain continuous core sections in a liner of 10 cm diameter until a long maximum according to the striking of bedrock. The cores were wrapped in cling-film while still in the field to prevent desiccation, and stored in cool conditions (4 °C) until sampling.

Pollen samples were generally obtained every 2 cm with 1 cm in thickness. Extraction of palynomorphs followed the conventional method of HCl, HF and KOH digestion and mineral separation with heavy liquid density 1.9 g/cm^{3}l, using $ZnCl_2$ (Moore et al., 1991) modified according to Carrión et al. (2008). Initially the samples were dispersed in a pyrophosphate solution (Bates et al., 1978). Exotic *Lycopodium clavatum* tablets of a known concentration of spores (ca. 12,542) were added to each sample at beginning of the treatment to estimate pollen concentrations. After chemical and physical treatment, pollen identification and counting was carried out under a transmitted light microscope by comparison with the reference collection of the Laboratory of Palynology at the University of Murcia. Identification of non-pollen microfossils and the counting of charcoal particles higher than 50 μm were also carried out. In the case of non-pollen palynomorphs (NPPs), their identification was aided by the descriptions and microphotographs of Carrión and van Geel (1999) and van Geel et al. (1981, 1986, 1989). Nomenclature for most fungal palynomorphs follow Elsik (1983). These pollen data will be stored in the European Pollen Database (http://www.europeanpollendatabase.net/index.php).

Samples for pollen in the cores Maz-16 and Maz-12 (Fig. 2) were sterile. This contingency limits the chronological amplitude of the study, because Maz-12 was dated in the Pleistocene between ca. 30,000 and 16,700 cal yr BP (Rodríguez-Estrella et al., 2011). So far, only Maz-15 (total depth 8.2 m) was polleniferous. The uppermost 135 cm of this core corresponds to a disturbed, anthropogenic horizon, and was discarded for pollen counting. A total of 365 samples were studied. Palynological sterility, including samples with a few pollen grains, affected to short intervals in depths 321–323, 328–331, 339–352, 452–454, 539, 546, 585 and 670–820 cm. Pollen diagrams were plotted using *p*-simpoll 4.10 (Bennett, 2002) and edited with Corel Draw X4 (Figs. 4–10). Results are expressed in relative percentages, excluding the pollen sum Chenopodiaceae, hydro- and hygrophytes (Cyperaceae, *Nuphar*, *Typha*, Ranunculaceae, *Epilobium*, *Apium* and *Myriophyllum*), algal (Zygnemataceae, *Rivularia*, *Closterium*), bryophytic (*Riccia*, *Musci*), fungal (Sordariaceae, *Polyadosporites*, *Chaetomium*) and pteridophytic (*Polypodium*, *Selaginella*) spores, indeterminable pollen and other non-pollen microfossils (e.g. Chironomidae mandibles, Oribatidae acari). Charcoal and total pollen abundance are expressed in concentration, calculated with reference to the *Lycopodium* counts. By visual inspection, the pollen diagrams have been divided into pollen zones 1–4, with zone 4 comprising two sub-zones (Figs. 4–10).

4. Results

4.1. Chronology

The Maz-15 pollen record spans from ca. 7617 to 1569 calibrated years BP (cal yr BP) showing several internal inconsistencies due to the occurrence of inverted dates (Table 1). The chronology was established on the basis of 12 dates obtained from bulk sediment using ^{14}C dating of the total organic carbon (TOC) content. Dates were calibrated using CALIB v.7.1 software (Stuiver et al., 2017). The mid-point of 95.4% (2σ probability interval) was selected for these dates (Table 2).

4.2. Palynostratigraphy

4.2.1. Pollen zone 1 (657–615 cm)

Starting at ca. 7617 cal yr BP, this zone is dominated by *Pinus* and evergreen *Quercus*, both reaching high percentages which are nevertheless variable (11–22 and 8–37% respectively). This zone is also characterised by mesophilous tree taxa (deciduous *Quercus*, *Fraxinus*, *Salix*, *Acer*, *Corylus*, *Betula*) and Mediterranean and Ibero-North African woods such as *Pistacia*, *Olea*, *Juniperus*, Thymelaeaceae, Cistaceae, *Phillyrea*, *Erica*, *Arbutus*, *Viburnum*, *Maytenus*, *Calicotome* and *Rhamnus* (Figs. 5 and 6) It is worth emphasising that *Pistacia* attains two maxima, exceeding evergreen oak and pine percentages in the first case. The herbaceous component is dominated by Chenopodiaceae, Asteraceae and Poaceae, the latter exceeding 30% at starting the zone. Other herbs include *Artemisia*, Lamiaceae, *Plantago*, *Limonium* and Apiaceae. The continuous curve of *Equisetum* and the important occurrence of bryophyte spores suggest local colonisation of the lagoon margins. The presence of Zygnemataceae, *Botryococcus*, NPP types 119, 181 and 182, and *Rivularia* indicate palaeolacustrine conditions (Figs. 8 and

Please cite this article in press as: J.S. Carrión, et al., Ancient Forests in European drylands: Holocene palaeoecological record of Mazarrón, south-eastern Spain, Proc. Geol. Assoc. (2018), https://doi.org/10.1016/j.pgeola.2018.05.007

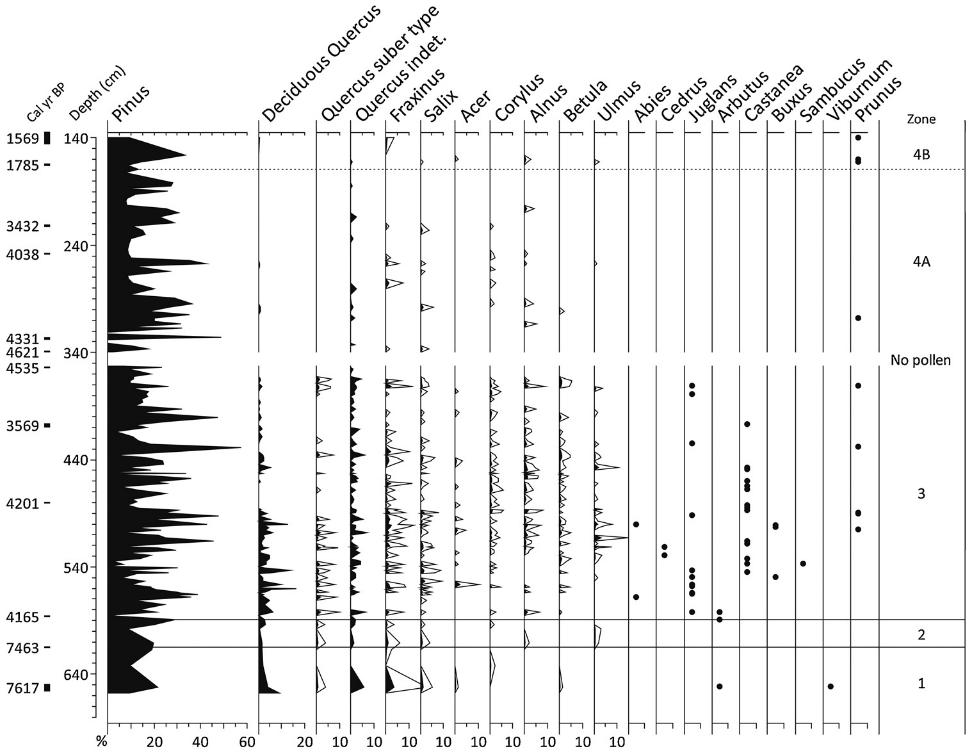

Fig. 4. Maz-15 pollen diagram for trees. Pollen percentages below 2% are represented by dots. Exaggerations x5. Solid horizontal lines indicate pollen zone boundaries, dotted lines mark subzones.

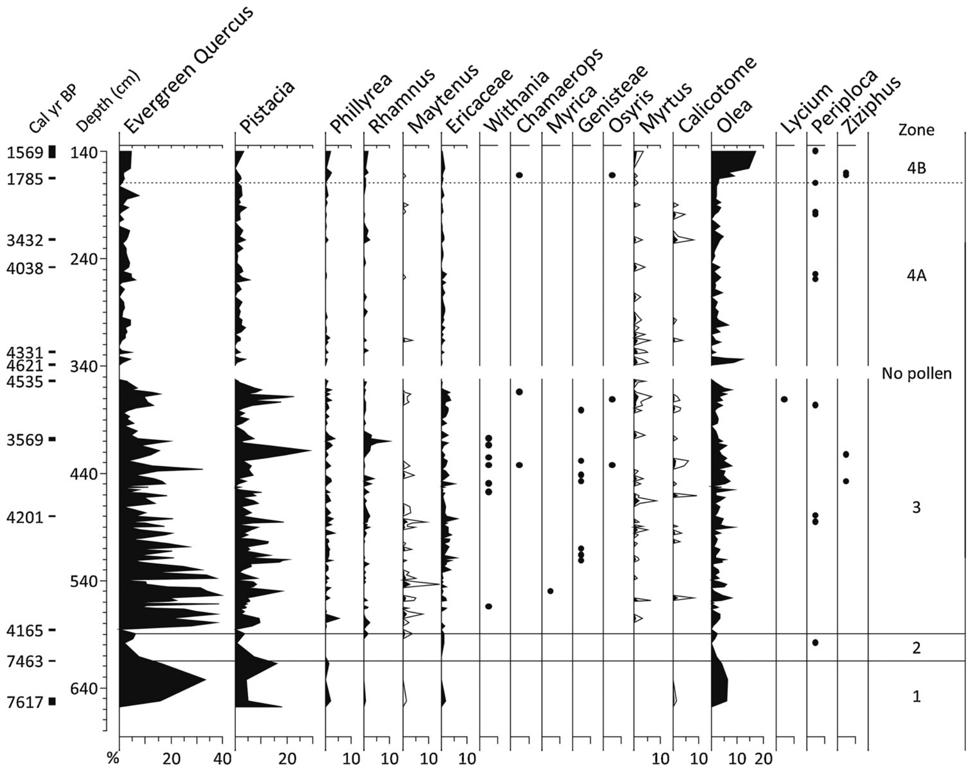

Fig. 5. Maz-15 pollen diagram for thermophilous trees and scrub. The dots indicate pollen frequencies below 2%. Exaggeration x5. Solid horizontal lines indicate pollen zone boundaries, dotted lines mark subzones.

Please cite this article in press as: J.S. Carrión, et al., Ancient Forests in European drylands: Holocene palaeoecological record of Mazarrón, south-eastern Spain, Proc. Geol. Assoc. (2018), https://doi.org/10.1016/j.pgeola.2018.05.007

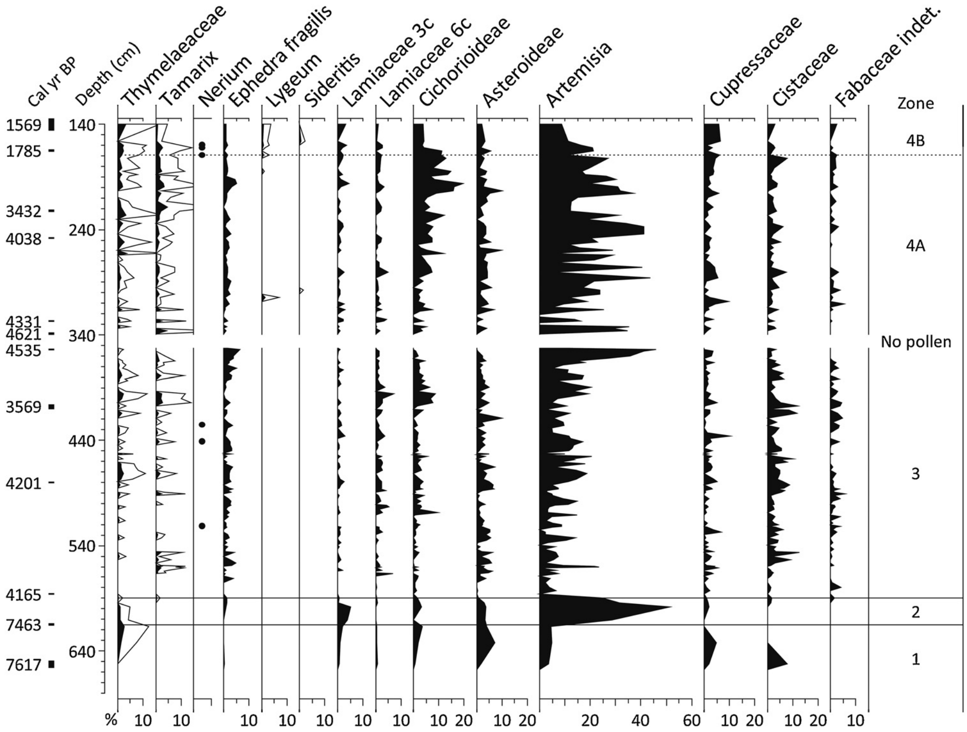

Fig. 6. Maz-15 pollen diagram for Cupressaceae, Cistaceae and other shrubs, as well as *Lygeum* and other herbs in the Maz-15 sequence. The dots indicate pollen frequencies below 2%. Exaggerations x 5. Solid horizontal lines indicate pollen zone boundaries, dotted lines mark subzones. Other (unrepresented) taxa occurring erratically in minor proportions are: *Limonium*, Apiaceae, Urticaceae, *Ononis* type, *Lotus* type, Iridaceae, Malvaceae, *Linum*, *Hypericum*, *Echium*, *Bupleurum*, Caryophyllaceae, *Paronychia*, *Spergularia* type, Rubiaceae, Liliaceae, *Asphodelus*, *Allium*, and Orchidaceae.

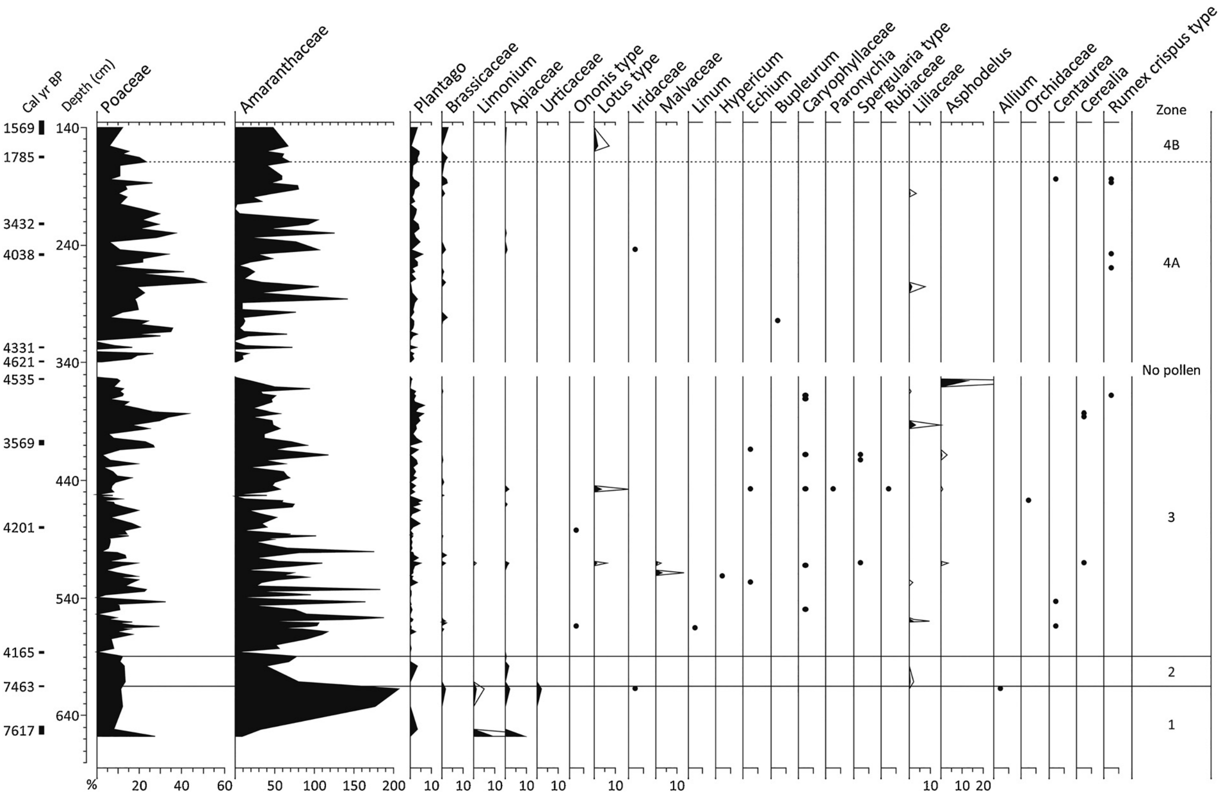

Fig. 7. Maz-15 pollen diagram for Poaceae and other herbs in the Mazarrón sequence. The dots indicate pollen frequencies below 2%. Solid lines indicate pollen zone boundaries, dotted lines mark subzones.

Please cite this article in press as: J.S. Carrión, et al., Ancient Forests in European drylands: Holocene palaeoecological record of Mazarrón, south-eastern Spain, Proc. Geol. Assoc. (2018), https://doi.org/10.1016/j.pgeola.2018.05.007

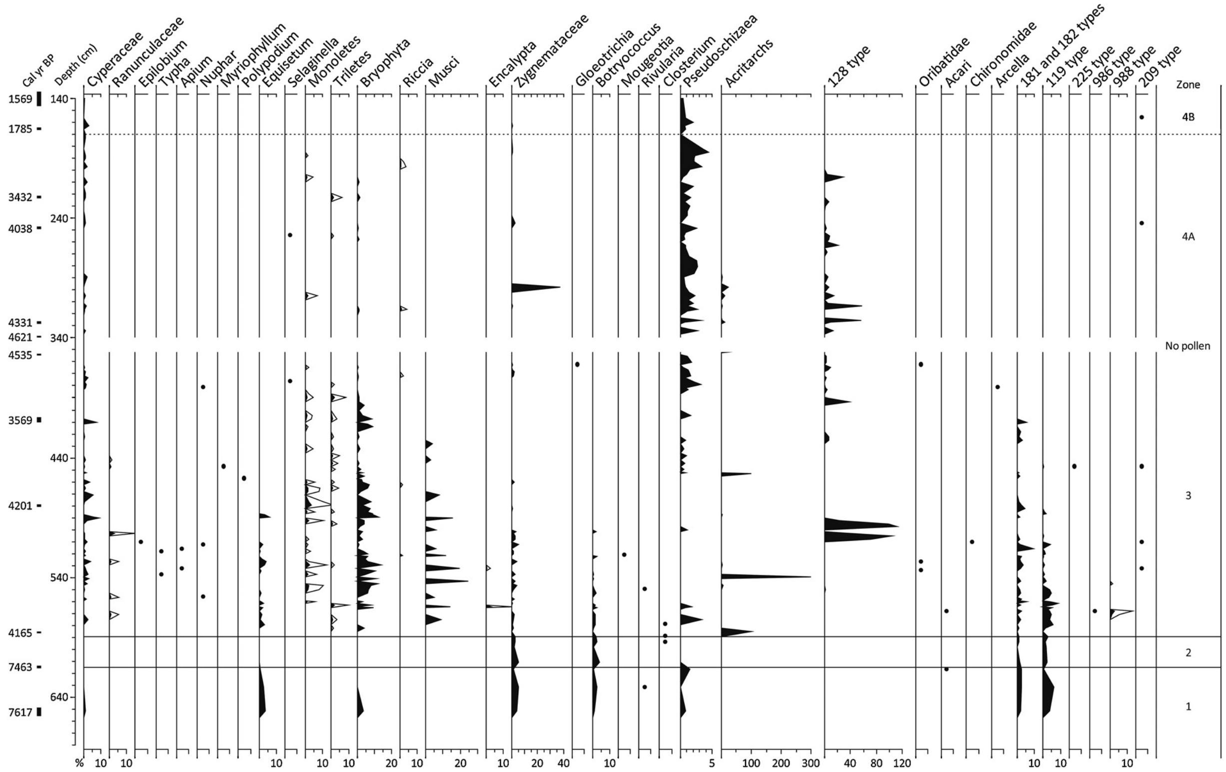

Fig. 8. Maz-15 palynological diagram for hydro- and hygrophytes, cryptogam spores and non-pollen palynomorphs. The dots indicate pollen and spore frequencies below 2%. Exaggerations x 5. Solid lines indicate pollen zone boundaries, dotted lines mark subzones.

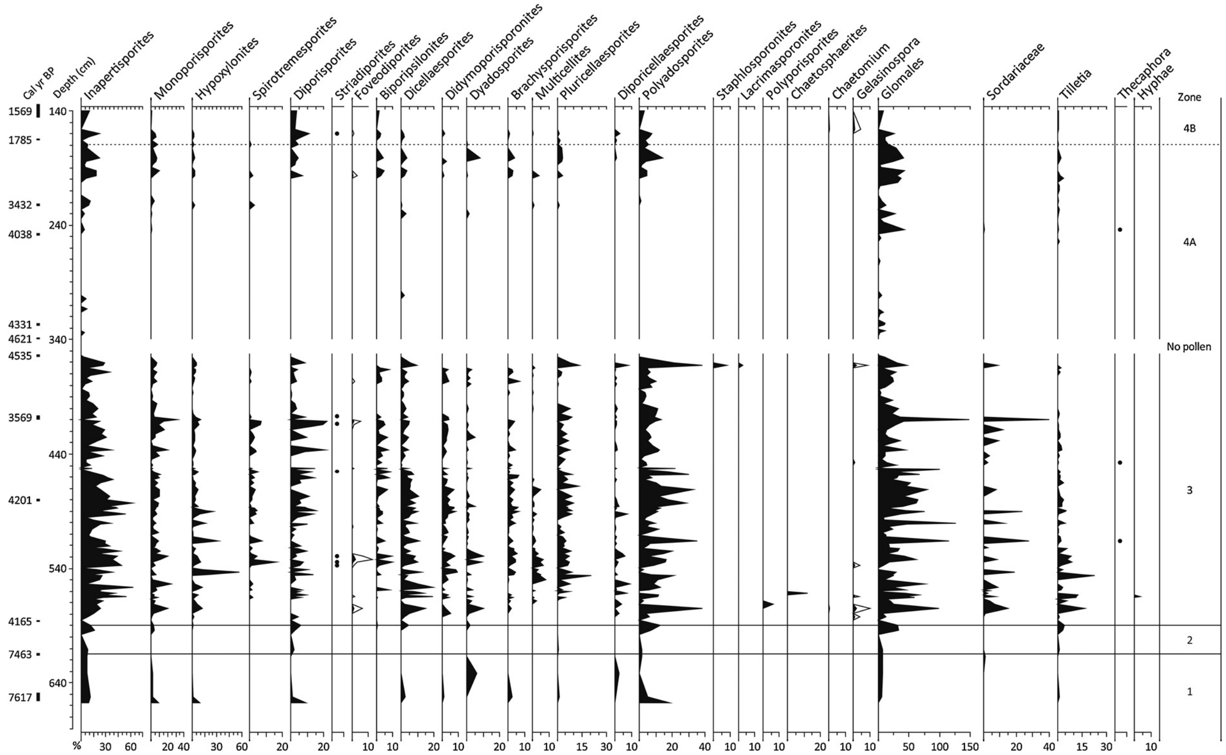

Fig. 9. Maz-15 palynological diagram for fungal spores. Percentages below 2% are represented by dots. Solid lines indicate pollen zone boundaries, dotted lines mark subzones.

Please cite this article in press as: J.S. Carrión, et al., Ancient Forests in European drylands: Holocene palaeoecological record of Mazarrón, south-eastern Spain, Proc. Geol. Assoc. (2018), https://doi.org/10.1016/j.pgeola.2018.05.007

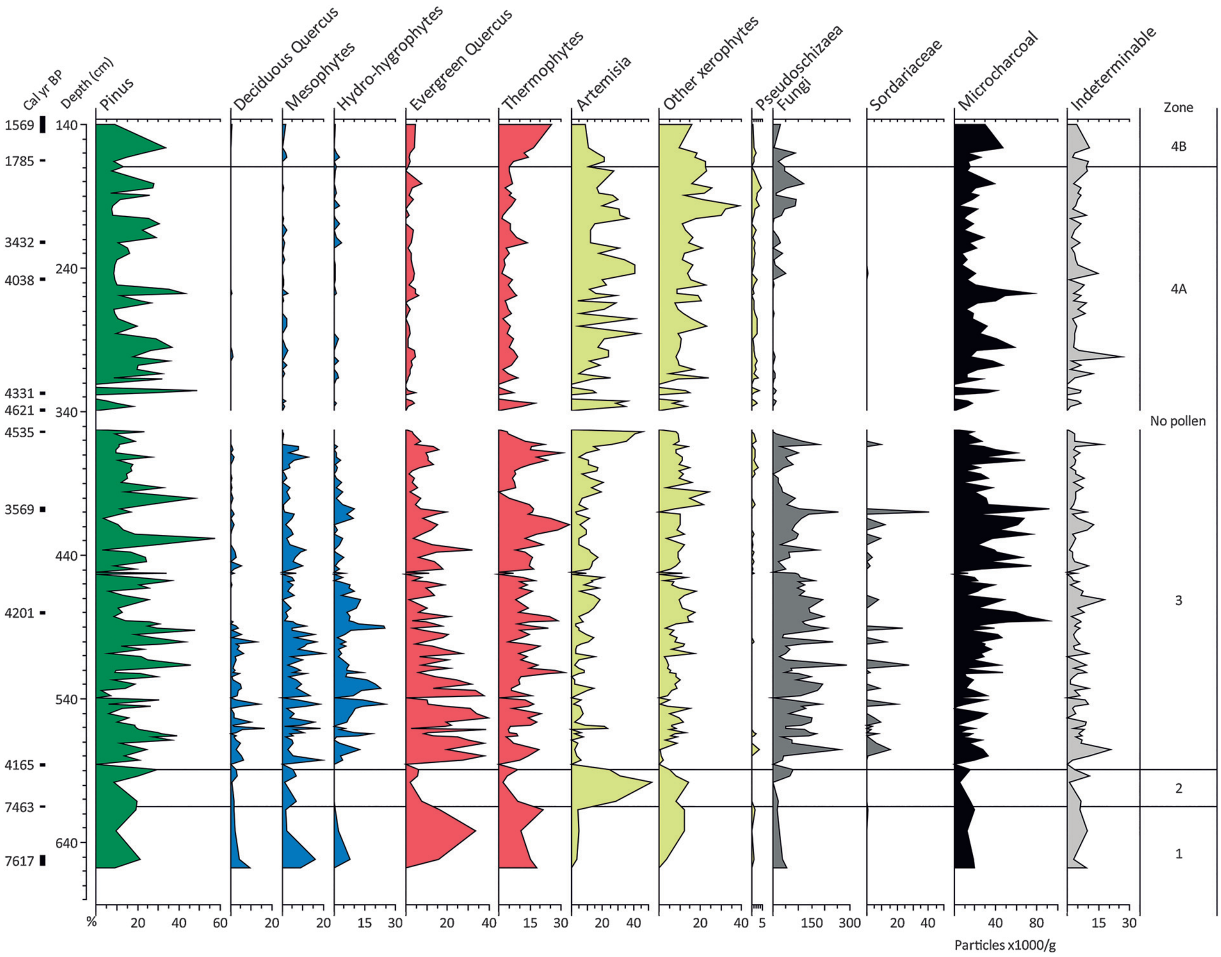

Fig. 10. Synthetic palynological diagram and microcharcoal and pollen concentration variation in the Maz-15 sequence, included the lithostratigraphy. Solid lines indicate pollen zone boundaries, dotted lines mark subzones.

9). *Pseudoschizaea* cysts are episodically detected (Fig. 8). This zone also shows the abundance of fungal spores, especially at the starting of the sequence. Fungal spores are though more abundant and diverse in the uppermost zones. Total pollen concentration is between 647 and 6423 grains/g. Charcoal concentration is between 12,934 and 19,824 particles per gram of sediment (Fig. 10). Lithologically, this zone corresponds to blackish muddy silts.

4.2.2. Pollen zone 2 (615–590 cm)

This zone shows two limiting dates of ca. 7463 and 4165 cal yr BP. *Pinus* prevails in the arboreal component, while broad-leaved trees such as deciduous *Quercus*, *Fraxinus*, *Salix* and *Corylus* maintain their relative frequencies (Figs. 4 and 5). *Acer* and *Betula* are absent. *Alnus* and *Ulmus* are detected for the first time in the sequence. Evergreen *Quercus*, *Pistacia, Olea*, Cupressaceae, Cistaceae and Thymelaeaceae, decline. The North African thermo-xerophyte *Periploca angustifolia* is recorded for the first time, while *Phillyrea*, *Rhamnus*, *Maytenus* and *Calicotome* disappear from the pollen spectra. *Artemisia* increases and becomes a prevailing herbaceous taxon, attaining a sequence maximum of up to 50% at 600 cm depth (Fig. 6). A rise in *Ephedra fragilis* and Lamiaceae tricolpate pollen is also perceptible. The herbaceous vegetation is enriched in Poaceae, Asteraceae, *Plantago*, Apiaceae and Liliaceae. Hydro-hygrophytes are absent, although this zone is also characterised by the occurrence of Zygnemataceae, *Botryoccocus*, *Closterium*, acritarcs, and the aquatic types 181, 182 and 119 (Fig. 8). Fungal diversity and abundance decline with regard to the previous zone. Overall, these findings suggest increasingly lacustrine conditions. This zone is associated with blackish muddy silts with no perceptible variation in relation to zone 1. Average pollen concentration rises and shows a peak of 24,540 grains/g. The concentration of microcharcoal particles is lower than in the preceding zone, suggesting less fire incidence (Fig. 10).

4.2.3. Pollen zone 3 (590–354 cm)

In the pollen zone 3, five sterile samples break the pollen curves at 585, 546, 539, 454 and 452 cm *Pinus* continues to dominate the pollen spectra, although it shows marked fluctuations, with occasional peaks of up to 50%. This zone shows the highest percentages and diversity of deciduous trees and in general, of mesothermophilous taxa. The formerly continuous curve of deciduous *Quercus* is broken at ca. 500 cm, while synchronously, *Quercus suber* becomes more sporadic. *Fraxinus*, *Salix*, *Acer, Juglans, Corylus*, *Alnus* and *Betula* are characteristics of this zone, which also shows punctual occurrences of *Abies*, *Cedrus*, *Buxus*, *Sambucus*, *Arbutus*, *Myrica*, *Osyris*, *Lycium*, *Chamaerops*, *Nerium*, *Periploca* and *Ziziphus* (Figs. 4 and 5). Evergreen *Quercus* and *Pistacia* percentages erratically fluctuate within a range of 2 to 42 and 1 to 33%, respectively. *Olea*, Cistaceae, Cupressaceae, Ericaceae and *Phillyrea* maintain a continuous presence throughout this zone. A high diversity of herbaceous taxa is shown, with the most abundant being Chenopodiaceae, Poaceae and *Artemisia*, this last reaching a peak (~47%) at the bottom of the zone. The joint occurrence of *Plantago*, which shows a continuous curve, and *Centaurea*, Cerealia, *Echium*, *Rumex crispus* type, Malvaceae and *Spergularia*, strongly

Please cite this article in press as: J.S. Carrión, et al., Ancient Forests in European drylands: Holocene palaeoecological record of Mazarrón, south-eastern Spain, Proc. Geol. Assoc. (2018), https://doi.org/10.1016/j.pgeola.2018.05.007

Table 1
Radiocarbon dating for Maz-15 pollen sequence. Ages obtained by analysis of total organic content from bulk sediment. Calibration: CALIB 7.1 (database INTCAL13) (Stuiver et al., 2017).

Lab. code	Sample depth (cm)	years BP	Calibrated years BP	
			Confidence interval (2σ, p = 0,954)	Median
Poz-21033	135–145	1665 ± 35	1420–1693	1569
Poz-28023	165	1850 ± 50	1628–1897	1785
Poz-28025	222	3220 ± 30	3371–3553	3432
Poz-32654	248	3700 ± 35	3927–4149	4038
Poz-32655	327	3900 ± 50	4155–4506	4331
Poz-28026	339	4100 ± 40	4447–4819	4621
Poz-28083	354	4055 ± 35	4424–4687	4535
Poz-21034	407–409	3335 ± 35	3472–3680	3569
Poz-28084	480	3810 ± 35	4087–4402	4201
Poz-28028	586	3785 ± 35	3999–4288	4165
Poz-28029	615	6550 ± 50	7333–7567	7463
Poz-21101	650–655	6760 ± 50	7517–7684	7617

suggest agriculture and ruderalization of the landscape (Fig. 7). Cyperaceae, *Equisetum,* bryophytes, Ranunculaceae, *Epilobium*, *Typha*, *Apium*, *Nuphar*, *Myriophyllum*, *Selaginella*, altogether suggest colonisation of the lake margins. This inference is supported by high occurrence of fungal spores in the palynological assemblages, suggesting increased organic matter decomposition. Zygnemataceae and the pelagic *Botryococcus* decrease with regard to the previous zones (Fig. 8). It is worth mentioning that *Glomus* chlamydospores, and spores of Sordariaceae, *Tilletia* and *Thecaphora* reach their highest values during this interval. The total pollen concentration rises gradually from bottom to top of this zone (Fig. 9). The charcoal concentration curve shows a similar trend, reaching maxima of ca. 53,464 grains/g and 91,713 particles/g, respectively (Fig. 10). At ca. 550 cm, a sedimentological change takes place from blackish muddy silts to dark sands and, at ca. 535 cm, muddy silts (Fig. 3). This zone ends with an oxidized stratum at 360 cm, which precedes a short palynological hiatus between 352 and 336 cm in depth.

4.2.4. Pollen zone 4 (336–140 cm)

During the pollen zone 4, five sterile samples were recorded, two between 320 and 324 cm and three between 328 and 332 cm. The range of values of *Pinus* pollen percentages continues, maintaining the oscillating nature noted in the previous zone. A decrease in the arboreal cover is characteristic of this zone, including the disappearance of *Quercus suber*, *Juglans*, *Arbutus*, *Castanea*, *Buxus*, *Sambucus*, *Viburnum*, *Withania*, Genisteae, *Lycium*, and *Myrica*, as well as declines in deciduous *Quercus*, *Fraxinus*, *Salix*, *Acer*, *Corylus*, *Alnus*, *Ulmus*, evergreen *Quercus*, *Pistacia*, *Phillyrea*, *Maytenus*, Ericaceae, *Calicotome* and Cistaceae (Figs. 4–6). Conversely, Cupressaceae, Thymelaeaceae and *Tamarix* rise. More outstandingly, *Artemisia*, Cichorioideae and Brassicaceae values show increases. The occurrence of *Lygeum* and *Sideritis* is recorded for the first time in the sequence. This zone comprises two subzones. *Olea*, and *Phillyrea* are more frequent in subzone 4B, where *Chamaerops*, *Osyris*, *Ziziphus* and *Nerium* occur. *Artemisia* and Asteraceae are higher in subzone 4A. In addition, zone 4 is characterised by the continuous abundance of *Pseudoschizaea* cysts. Acritarcs and Zygnemataceae reach maxima of ca. 26 and 40% respectively (Fig. 8). Type 128 also shows several peaks at the bottom of the zone, but these are less marked than those at zone 3 (Fig. 8). Fungal spores abound in the uppermost spectra of subzone 4A, and at the bottom of subzone 4B (Fig. 9). The pollen concentration rises gradually from bottom to top, reaching a maximum of ca. 36,445 grains/g at the end of sequence. In this zone, charcoal particles are generally less frequent than in zone 3 (Fig. 10). The greatest lithological changes occur in this zone, with the lithology varying from peaty to more terrigenous sediment (muddy silts, blackish clays-dark sandy silts, gravels-sandy silts).

5. Discussion

5.1. Dating anomalies and assessment by correlation with anthracological data

The sedimentary rate in Maz-15 is relatively low throughout zone 2 and higher between ca. 570 and 200 cm depth. Table 1 shows that the middle part of the pollen sequence lacks a firm chronological control: two dates (ca. 4621 and 4535 cal yr BP) are interbedded in the 3569-3432 interval, thus breaking the temporal sequence. Those two dates limit a palynological hiatus associated with sedimentary disruption, an erosional phase that ended with deposition of a mining stratum, lithologically formed by microconglomerates and sands cemented in reddish silty matrix and containing iron sulphides, lead, copper, and zinc (Fig. 3) (Rodríguez-Estrella et al., 2011). The anomalous dates might result from contamination by old carbon. In any case, dating anomalies from Maz-15 parallel those found in other boreholes of the basin, and reflect a long period (ca.

Table 2
Radiocarbon dating of the anthracological record Punta de los Gavilanes (charcoal and seeds). After García-Martínez et al. (2008), García-Martínez and Ros-Sala (2010). Calibration: CALIB 7.1 (database INTCAL13) (Stuiver et al., 2017).

Lab. code	Archaeological levels	years BP	Calibrated years BP	
			Confidence interval (2σ, p = 0,954)	Median
KIA-32359	GV-III	2380 ± 85	2164–2721	2456
KIA-40415	GV-III	2525 ± 30	2490–2743	2603
KIA-37604	GV-IV	3300 ± 35	3448–3627	3525
KIA-32357	GV-IV	3370 ± 40	3480–3698	3612
KIA-32366	GV-IV	3385 ± 35	3487–3717	3630
KIA-37601	GV-IV	3645 ± 35	3870–4084	3962
KIA-32355	GV-IV	3730 ± 30	3981–4213	4080

Please cite this article in press as: J.S. Carrión, et al., Ancient Forests in European drylands: Holocene palaeoecological record of Mazarrón, south-eastern Spain, Proc. Geol. Assoc. (2018), https://doi.org/10.1016/j.pgeola.2018.05.007

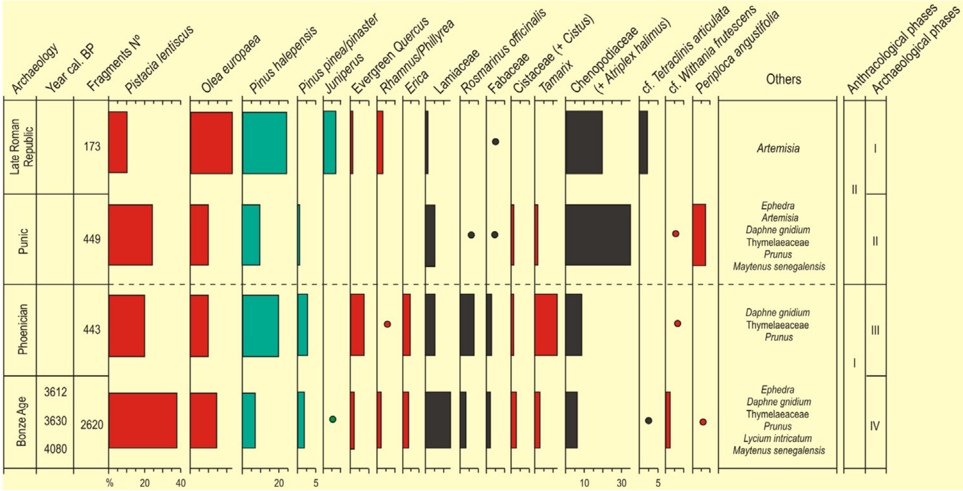

Fig. 11. Anthracological diagram from Punta de los Gavilanes. Redrawn from García-Martínez and Ros (2010). Dots indicate relative charcoal frequencies below 1%.

4400–3500 cal yr BP), of fluvial inflows to the basin under arid climate conditions (Rodríguez-Estrella et al., 2011).

The comparison of the palynological data with the charcoal record from the neighbouring archaeological settlement Punta de Los Gavilanes (37° 33′ 31′′N, 1° 16′ 46′′W) (Fig. 11) allows us to assess the transition from pollen zone 3 to pollen zone 4. The decline of *Pistacia* charcoal after the Bronze Age of Punta de los Gavilanes (Fig. 11) parallels the transition from pollen zone 4 to zone 3, which might have taken place around ca. 3500 cal yr BP where, in addition to *Pistacia* decline, several taxa become absent from the pollen diagram, such as deciduous *Quercus, Quercus suber, Fraxinus, Corylus*, and other broadleaf trees.

5.2. Maz-15: palynological success in sedimentary environment prone to sterility

The sterility of Maz-12 and Maz-16, and the occurrence of non-polleniferous intervals within Maz-15 suggest that pollen corrosion and sedimentary hiatuses may have operated unevenly across the study basin. We cannot rule out the intervention of short events of marine intrusion linked to oxidative processes that would have taken place at the beginning and end of such events. It is also possible that the occurrence of periods of desiccation, caused by high rates of summer evapo-transpiration, would involve cycles of wetting and dehydration that encourage negative effects on the preservation of palynomorphs. Another factor that should not be neglected is the effect that the activity of decomposing bacteria and fungi could have had on the preservation of palynomorph material (Carrión et al., 2009).

In general, the depositional environments of this region are challenging for pollen analysis. Recently analysed peats within the salt flats of Calblanque, in the Murcian coastal zone (nearby Mazarrón) have all been palynologically unproductive. Older, Pleistocene palaeo-lakes equally lack pollen, such as those of Fonelas, Mencal and Orce in the Guadix-Baza basin, Sorbas and Adra sites (Arribas et al., 2001; Calaforra and Pulido-Bosch, 2003; Gibert et al., 1988).

The ecological credibility of the Maz-15 pollen assemblages is supported by significant pollen concentrations, the broad diversity of taxa identified, a relatively low percentage of indeterminable pollen grains, a high degree of internal consistency and a good correlation with the rest of the palynological sequences available for the south-eastern Iberian Peninsula, as we shall see later (Figs. 4–10). The Maz-15 pollen record is still more relevant due to its situation, at very low altitude, in the bioclimatic thermomediterranean belt and next to an important archaeological site of the Bronze Age (Ros, 2008) for which a fine anthracological sequence is available (García-Martínez et al., 2007). This paleoecological record is therefore a unique sequence of lacustrine origin taken from a region where obtaining polleniferous material is largely a matter of luck, pollen analysis in this zone only becoming possible after overcoming many methodological difficulties.

5.3. Thermo-mesophytic mid-Holocene optimum

The pollen record of Maz-15 supports the notion of a wet, mid-Holocene forest optimum with progressive rise in aridity and xerophytization between the mid to late Holocene. This can be deduced from changes observed in floristic composition from zones 1–3 up to zone 4 (Figs. 4–10). Deciduous *Quercus, Quercus suber, Fraxinus, Salix, Acer, Corylus, Alnus, Betula, Ulmus, Juglans, Arbutus, Castanea*, and *Buxus* are more frequent during the zones 1–3, whereas *Tamarix, Lygeum, Artemisia*, and Asteraceae, rise during zone 4. Summer drought was probably characteristic of local climates around ca. 7600 cal yr BP, as shown by the relatively high values of evergreen *Quercus, Pistacia, Ephedra fragilis*, Cistaceae, and *Olea* (Figs. 4 and 5). A critical palaeoclimatic indicator may well be the cyst *Pseudoschizaea* (Fig. 8), which, although being present as early as the beginning of the sequence, becomes particularly abundant during zone 4, suggesting temporal desiccation of the study basin (Carrión, 2002a).

This mid-Holocene thermo-mesophytic and forest maximum is seen elsewhere in other pollen records of the region (Fig. 1) such as southwards in coastal Antas, Roquetas de Mar, San Rafael (Pantaleón-Cano et al., 2003) and Cabo de Gata (Jalut et al., 2000), upland in Sierra de Gádor (Carrión et al., 2003a), and Sierra de Baza (Carrión et al., 2007), westwards in Carril de Caldereros (Fuentes et al., 2005), and northwards in the Segura Mountains in El Sabinar (Carrión et al., 2004), Siles (Carrión, 2002a), Villaverde (Carrión et al., 2001a), and Cañada de la Cruz (Carrión et al., 2001b). Other studies of palaeoclimatic proxies like the δ^{13}C values of land snail shells from Los Castillejos archaeological site in Montefrío conclude that the mid Holocene was wetter in the region than thereafter during the last millennia (Yanes et al., 2011). Northwards in the Salines playa-lake, the early Holocene shows relatively high amounts of mesophyte pollen from c. 11700 to 8600 cal yr BP, although the palynological sequence does not include the middle Holocene (Burjachs et al., 2016; Giralt et al., 1999). In Sierra Nevada, the high-elevation sites of Laguna de Río

Please cite this article in press as: J.S. Carrión, et al., Ancient Forests in European drylands: Holocene palaeoecological record of Mazarrón, south-eastern Spain, Proc. Geol. Assoc. (2018), https://doi.org/10.1016/j.pgeola.2018.05.007

Seco and Borreguiles de la Virgen show maxima in arboreal pollen, mainly pine, from c. 8200 to 7000 cal yr BP, with episodic evidences of increased aridification thereafter (Anderson et al., 2011; Jiménez-Moreno and Anderson, 2012). None of these records, however, contradict the idea that broad-leaf angiosperms were particularly abundant in south-eastern Spain during the mid Holocene, regardless of the chronology for the onset of the thermo-mesophytic maxima.

5.4. Fire history

In Maz-15, the period corresponding to a relatively high incidence of fire (zone 3 ca. 500 cm up to zone 4 ca. 350 cm depth) (Fig. 11) coincides with the highest amounts of Sordariaceae, *Tilletia*, Glomaceae, Cistaceae, Ericaceae, *Rhamnus* and Genisteae, as well as with the only records of Cerealia, Malvaceae, *Echium*, *Asphodelus*, *Spergularia* and microfossil Type 988, paralleling the beginning of a continuous curve of *Plantago* and the progressive decrease of evergreen *Quercus*. Since they are sometimes indicative of fire occurrence (Carrión et al., 2013), the occurrence of *Centaurea*, *Rumex* type *crispus* (Fig. 7), *Riccia, Chaetomium* and *Thecaphora* (Fig. 9) is also remarkable. The picture resulting from the combination of all these spectra would be one of strong human intervention on the landscape that would include: the use of fire; agricultural activities and grazing involving ruderalization; opening of the landscape at the expense of the oaklands; an increase of thorny scrub and of the scrub associated with early successional stages after forest degradation and soil erosion.

In general, the period from ca. 8000–5000 cal yr BP represents, in Mediterranean Spain, the period of lowest fire activity (Carrión et al., 2007, 2010a; Vannière et al., 2011). The work of Gil-Romera et al. (2010) is pertinent here. Using a high-resolution analysis of fire-vegetation relationships, Gil-Romera et al. noted that, despite discrepancies due to different environmental features, the coastal highlands of south-eastern Spain which were always more populated than the inland, present earlier and more abrupt fire activities. The coastal vegetation would have responded positively to the mid-Holocene increasing rainfall, spreading a mesophilous biomass and therefore fire activity. This could perhaps explain the burning pattern in Mazarrón, with charcoal concentration high during zone 3, probably because in the thermomediterranean belt fuel availability was more a limiting factor than temperature and precipitation in establishing fire regimes.

5.5. Deforestation and the collapse of metallurgic societies

Deforestation may have begun as early as during zone 2, being punctuated throughout zone 3, and sharper across zone 4 after ca. 4000–3500 cal yr BP (Fig. 10). The fluvio-palynological sequence of Carril de Caldereros (Fuentes et al., 2005) shows from c. 4600 years cal. BP the decline of forest taxa. Further north, the Elx sequence (Burjachs, 2012), corresponding to the survey conducted in El Hondo marshlands (near the mouth of the Segura River), reflects a significant decrease in deciduous and sclerophyllous trees in the face of a rise in relative pollen frequencies of chenopods, Poaceae, *Artemisia* and *Tamarix*, around 4500 cal yr BP.

The south-east of the Iberian Peninsula is one of the foci within western Europe where metallurgy was first practiced, in particular ever since ca. 5100 cal yr BP. Data from charcoal analyses at Chalcolithic archaeological sites in Almería (Rodríguez-Ariza, 2000) also report a significant denudation of riparian vegetation during the same period (ca. 4640/4350 cal yr BP). In general, during the Chalcolithic, the archaeological record shows a notorious increase of the demographic pressure in comparison to the Neolithic settlement, which had been dispersed and low in density (Cámalich and Martín Socas, 1999; Chapman, 2008; Nocete et al., 2010; Román Díaz and Martínez Padilla, 1998).

Compared to lowlands, forest degradation began later in the mountains and more continental territories of the south-east. The pollen records suggest a significant transformation of vegetation around 3940–3800 cal yr BP. This consists of the substitution of deciduous *Quercus* and other mesophytes for sclerophylls, in parallel with the progression of open landscapes (Carrión et al., 2003a, 2007). These modifications were preceded by an increase in the frequency of fires (4200-4100 yr cal BP) and ended with a dramatic alteration in the ecological structure preluding the end of the Bronze-age culture in the area; the so-called Argaric collapse.

This mid-Holocene xerophytization is assessed in the Mazarrón area by charcoal analysis in the archaeological settlement Punta de Los Gavilanes (García-Martínez et al., 2013) (Fig. 11). The expansion of heliophytes is noteworthy from about 2nd millennium BP, but it is about c. 2440 yr cal BP when the anthracological sequence highlights a great deforestation which is linked with the local impacts of metallurgy during the period (García-Martínez et al., 2013). Other anthracological data from this region coincide to suggest that clearance started first in low altitude locations, then in mid and high altitudes, especially where human exploitation of the natural environment was more continuous (Badal et al., 1994; Carrión-Marco, 2005; García-Martínez et al., 2007; Rodríguez-Ariza et al., 1995; Rodríguez-Ariza, 1992, 2000).

5.6. Phytogeographical remarks

Charcoal analysis in Punta de Gavilanes allows us to improve taxonomical resolution of the pollen records of Maz-15 and conduct them towards the species level, such as in the case of *Pistacia lentiscus, Pinus halepensis, Pinus pinea, Rosmarinus officinalis* (Lamiaceae), *Atriplex halimus* (Chenopodiaceae), *Daphne gnidium* (Thymelaeaceae), *Withania frutescens, Periploca angustifolia, Lycium intricatum, Atriplex halimus*, and *Maytenus senegalensis* (Fig. 3). Some palaeoecological remarks can be therefore made on floristic affinities of present-day plant communities. It is worth mentioning that the affinities assumed for *Maytenus senegalensis* and *Periploca angustifolia* (Peinado et al., 1992) are not supported by the fossil record, with *Maytenus* more abundant in the lower part of the diagram whereas *Periploca* shows the opposite trend, such as in Gádor (Carrión et al., 2003a). The *Mayteno-Periplocetum* formations could have expanded more as a consequence of human activities than as a direct cause of bioclimatic factors (Carrión et al., 1995b, 2007). Our findings support the ideas asserted by Mota et al. (1996) about the importance of the palaeotropical element in the overall composition of the pre-anthropic shrub communities of the south-eastern coastal mountains.

The pollen sequence and the anthracological results are also in agreement with the abundance of *Pistacia* (*P. lentiscus* according charcoal analysis: García-Martínez et al. (2008) along the coast of Murcia during the study period. *Pistacia* is clearly more frequent here than in other western Mediterranean and Iberian records (Carrión et al., 2013). *Pistacia* is a low pollen producer due to its marked entomophily and, in general, is under-represented in the pollen spectra (Bottema, 1974; Carrión, 2002b). Although, with different species involved (e.g. *Pistacia atlantica*), this extraordinary occurrence of *Pistacia* at Maz-15 only finds counterparts in the eastern Mediterranean basin (Rossignol-Strick, 1999; Willcox, 1999), and especially in Sicily along the thermomediterranean coastal shelves, such as in Lago Preola (Calò et al., 2012), Gorgo Basso (Tinner et al., 2009) and Biviere di Gela (Noti et al., 2009).

The presence of *Abies* during the Middle Holocene, on the coast of Murcia, arouses great interest even though it has only been observed in a couple of samples and with a relative frequency lower than 2% in these cases. There is little history in regional

Please cite this article in press as: J.S. Carrión, et al., Ancient Forests in European drylands: Holocene palaeoecological record of Mazarrón, south-eastern Spain, Proc. Geol. Assoc. (2018), https://doi.org/10.1016/j.pgeola.2018.05.007

palynology (López et al., 1991), but since pollen of *Abies* is very poor in its dispersion (Liepelt et al., 2009), we can discard the idea of a distant contribution and assume its local growing which, although scarce, probably occurred in the more humid biotopes of the adjacent ranges.

5.7. Local extinctions of tree species

It can be concluded that the littoral zone of Murcia has supported phases of forest during the Holocene, and certainly oak forests until very recently. This is a surprising information in the view of current opinions derived from phytosociological models which assume that oak forests do not belong to the natural potentiality of the territory (Loidi, 2017). Unfortunately, the pollen sequence is interrupted at c. 1569 cal yr BP, and we cannot inform about environmental changes that occurred thereafter. Several taxa such as *Abies, Quercus suber, Juglans regia, Myrica, Arbutus unedo, Buxus, and Castanea sativa* might have become extinct long before this date. However, it is clear that, for that time, there were still present several others that are now extinct in the coastal hills and plains such as *Fraxinus, Salix, Acer, Alnus*, and especially evergreen *Quercus*. This accords with historical records and toponimic information suggesting extensive brush, pine and oak forest cover in the mountain systems of Almería and Murcia only three centuries ago. This picture of vegetation is accompanied by animals typical of forest and humid habitats such as bears, wild boars, deer and wolves along with other species such as the common crane and otter (Carrillo et al., 2010; García-Latorre and García-Latorre, 1996, 1997; García-Latorre et al., 2001; Gómez-Cruz, 1991). Altogether, the palaeoecological record suggests that the current treeless situation of this region of southern Europe has been shaped relatively recently, and after millennia of climatic change, it is most likely the ultimate result of pressure placed on the landscape by human activity.

6. Final thoughts

The sequence studied sums up past evidence on the consequences of human disturbances that exceed the vulnerability thresholds of ecosystems that are already fragile due to the physical stress of climate change. Firstly, we can see a dramatic change in the ecological structure that goes hand in hand with a loss of survival resources. Not surprisingly, the Spanish south-east fostered periods of great social prosperity during the Ages of Copper and Bronze, before the Argaric collapse (Carrión et al., 2003a, 2007; Castro et al., 2000; Chapman, 2009). Secondly, we observe the catastrophic loss of biodiversity, in this case forest trees and scrub, accompanied by a cultural and economic change in the communities living in the area. Man is intimately linked to the vegetation landscape so the disappearance of forests usually has a negative impact in the sense of what has come to be called the "extinction of experience" (Miller, 2005; Pyle, 1993).

In these times of global ecocide and uncertainty on the future of humankind, the collapse of the metallurgical communities of south-eastern Iberia has become didactic, providing regional-scale information that could diagnose and forecast the consequences of rupturing the regulating factors within nature. Perhaps, as the French visionary Edgar Morin commented, we need the emergence of a planetary cosmopolitalism, a new philosophical approach capable of embracing both unity and complexity. It is, hence, crucial to examine the art of the palaeoecologist by, say, teaching serendipity: the art of transforming the seemingly insignificant details into clues that can be used to reconstruct a whole history. In the current paradigm, lacking the ability to deal with complexity and historical contingency has brought us to a crisis of paramount importance in all scales.

Acknowledgements

This paper is dedicated to the memory of Dr. Elena Fierro, who tragically passed away shortly after her doctorate. Elena worked hard in the paleoecological sequence of Mazarrón. This work was supported by the Ministerio de Economía y Competitividad [grant numbers CGL-BOS-2012-34717 and CGL-BOS 2015-68604]; and Fundación Séneca [grant numbers 19434/PI/14]. We are grateful to the Editor of PGA, Prof. Malcolm Hart, an anonymous referee, and Prof. R. Scott Anderson for helpful comments to improve the first manuscript. Thank you, as well, to Lara Carrión and James Rudd, who assisted with the English translation and proofreading of this text.

References

Anderson, R.S., Jiménez-Moreno, G., Carrión, J.S., Pérez-Martínez, C., 2011. Postglacial history of alpine vegetation, fire, and climate from Laguna de Río Seco, Sierra Nevada, southern Spain. Quaternary Science Reviews 30, 1615–1629.

Arribas, A., Riquelme, J.A., Palmqvist, P., Garrido, G., Hernández, R., Laplana, C., Soria, J.M., Viseras, C., Durán, J.J., Gumiel, P., Robles, F., López-Martínez, J., Carrión, J., 2001. Un nuevo yacimiento de grandes mamíferos villafranquienses en la Cuenca de Guadix-Baza (Granada): Fonelas P-1, primer registro de una fauna próxima al límite Plio-Pleistoceno en la Península Ibérica. Boletín Geológico y Minero 112, 3–34.

Badal, E., Bernabeu, J., Vernet, J.L., 1994. Vegetation changes and human action from the Neolithic to the Bronze Age (7000-4000 BP) in Alicante, Spain, based on charcoal analysis. Vegetation History and Archaeobotany 3, 155–166.

Bates, C.D., Coxon, P., Gibbard, P.L., 1978. A new method for the preparation of clay-rich sediments samples for palynological investigation. New Phytologist 81, 459–463.

Bennett, K., 2002. Documentation for Psimpoll 4.10 and Pscomb 1.03. C Programs for Plotting Pollen Diagrams and Analysing Pollen Data. University of Cambridge, Cambridge, pp. 125.

Bottema, S., 1974. Late Quaternary vegetation history of northwestern Greece. Thesis. University of Groningen, The Netherlands, pp. 190.

Burjachs, F., Giralt, S., Riera, S., Roca, J.R., Julià, R., 1996. Evolució paleoclimática durante el ultimo ciclo glaciar en la vertiente mediterránea de la Península Ibérica. Notes de Geografia Física 25, 21–39.

Burjachs, F., Giralt, S., Roca, J.R., Seret, G., Julià, R., 1997. Palinología holocénica y desertización en el Mediterráneo Occidental. In: Ibáñez, J.J., Valero, B.J., Machado, C. (Eds.), El paisaje mediterráneo a través del espacio y del tiempo. Implicaciones en la desertificación. Geoforma ediciones, , pp. 379–394 Logroño.

Burjachs, F., Jones, S.E., Giralt, S., Fernández-López de Pablo, J., 2016. Lateglacial to Early Holocene recursive aridity events in the SE Mediterranean Iberian Peninsula: the Salines playa lake case study. Quaternary International 403, 187–200.

Burjachs, F., 2012. Elx, Alicante. In: Carrión, J.S. (Ed.), Paleoflora y Paleovegetación de la Península Ibérica e Islas Baleares: Plioceno-Cuaternario. Ministerio de Economía y Competitividad, , pp. 647–648 Madrid. Chapter 14.

Cámalich, M.D., Martín Socas, D., 1999. El territorio almeriense desde los inicios de la producción hasta fines de la antigüedad. Un modelo: la Depresión de Vera y Cuenca del Río Almanzora. Arqueología, Monografías. Junta de Andalucía, Sevilla, pp. 435.

Calò, C., Henne, P.D., Curry, B., Magny, M., Vescovi, E., La Mantia, T., Pasta, S., Vannière, B., Tinner, W., 2012. Spatio-temporal patterns of Holocene environmental change in southern Sicily. Palaeogeography, Palaeoclimatology, Palaeoecology 323–325, 110–122.

Calaforra, J.M., Pulido-Bosch, A., 2003. Evolution of the gypsum karst of Sorbas (SE Spain). Geomorphology 50, 173–180.

Carrión, J.S., van Geel, B., 1999. Fine-resolution Upper Weichselian and Holocene palynological record from Navarrés (Valencia, Spain) and a discussion about factors of Mediterranean forest succession. Review of Palaeobotany and Palynology 106, 209–236.

Carrión, J.S., Dupré, M., Fumanal, M.P., Montes, R., 1995a. A palaeoenvironmental study in the semiarid south-eastern Spain: the palynological and sedimentological sequence at Perneras Cave (Lorca, Murcia). Journal of Archaeological Science 22, 355–367.

Carrión, J.S., Munuera, M., Dupré, M., 1995b. Estudios de Palinología arqueológica en el sureste ibérico semiárido. Cuaternario y Geomorfología 9, 17–31.

Carrión, J.S., Munuera, M., Navarro, C., Burjachs, F., Dupré, M., Walker, M.J., 1999. The palaeoecological potencial of pollen records in caves: the case of Mediterranean Spain. Quaternary Science Reviews 18, 1061–1073.

Carrión, J.S., Andrade, A., Bennet, K.D., Navarro, C., Munuera, M., 2001a. Crossing forest thresholds: inertia and collapse in a Holocene sequence from south-central Spain. The Holocene 11, 635–653.

Carrión, J.S., Munuera, M., Dupré, M., Andrade, A., 2001b. Abrupt vegetation changes in the Segura Mountains of southern Spain throughout the Holocene. Journal of Ecology 89, 783–797.

Carrión, J.S., Sánchez-Gómez, P., Mota, J.F., Yll, R., Chaín, C., 2003a. Holocene vegetation dynamics, fire and grazing in the Sierra de Gádor, southern Spain. The Holocene 13, 839–849.

Please cite this article in press as: J.S. Carrión, et al., Ancient Forests in European drylands: Holocene palaeoecological record of Mazarrón, south-eastern Spain, Proc. Geol. Assoc. (2018), https://doi.org/10.1016/j.pgeola.2018.05.007

Carrión, J.S., Yll, E.I., Walker, M.J., Legaz, A., Chaín, C., López, A., 2003b. Glacial refugia of temperate, Mediterranean and Ibero-North African flora in south-eastern Spain: new evidence from cave pollen at two Neanderthal man sites. Global Ecology and Biogeography 12, 119–129.

Carrión, J.S., Yll, E.I., Willis, K.J., Sánchez, P., 2004. Holocene forest history of the eastern plateaux in the Segura Mountains (Murcia, south-eastern Spain). Review of Palaeobotany and Palynology 132, 219–236.

Carrión, J.S., Fuentes, N., González-Sampériz, P., Sánchez Quitante, L., Finlayson, J.C., Fernández, S., Andrade, A., 2007. Holocene environmental change in a montane region of southern Europe with a long history of human settlement. Quaternary Science Reviews 26, 1455–1475.

Carrión, J.S., Finlayson, C., Fernández, S., Finlayson, G., Allué, E., López-Sáez, A., López-García, P., Fuentes, N., Gil, G., González-Sampériz, P., 2008. A coastal reservoir of biodiversity for Upper Pleistocene human populations: palaeoecological investigations in Gorham's Cave (Gibraltar) in the context of the Iberian Peninsula. Quaternary Science Reviews 27, 2118–2135.

Carrión, J.S., Fernández, S., González-Sampériz, P., Leroy, S.A.G., López-Sáez, J.A., Burjachs, F., Gil-Romera, G., Rodríguez-Sánchez, E., García-Antón, M., Gil-García, M.J., Parra, I., Santos, L., López-García, P., Yll, E.I., Dupré, M., 2009. Quaternary pollen analysis in the Iberian Peninsula: the value of negative results. Internet Archaeology 25. http://intarch.ac.uk/journal/issue25/5/toc.html.

Carrión, J.S., Fernández, S., Jiménez-Moreno, G., Fauquette, S., Gil-Romera, G., González-Sampériz, P., Finlayson, C., 2010a. The historical origins of aridity and vegetation degradation in south-eastern Spain. Journal of Arid Environments 74, 731–736.

Carrión, J.S., Fernández, S., González-Sampériz, P., Gil-Romera, G., Badal, E., Carrión-Marco, Y., López-Merino, L., López-Sáez, J.A., Fierro, E., Burjachs, F., 2010b. Expected trends and surprises in the Lateglacial and Holocene vegetation history of the Iberian Peninsula and Balearic Islands. Review of Palaeobotany and Palynology 162, 458–475 Special issue: Carrión, J.S., Leroy, S. (Eds), Iberian Floras through Time: Land of Diversity and Survival.

Carrión, J.S., 2002a. Patterns and processes of Late Quaternary environmental change in a montane region of southwestern Europe. Quaternary Science Reviews 21, 2047–2066.

Carrión, J.S., 2002b. A taphonomic study of modern pollen assemblages from dung and surface sediments in arids environments of Spain. Review of Palaeobotany and Palynology 120, 217–232.

Carrión, J.S., et al. (Ed.), 2013. Paleoflora Ibérica: Plioceno-Cuaternario, 2 vols. Ministerio de Economía y Competitividad, Madrid. Universidad de Murcia y Fundación Séneca, Murcia.

Carrión-Marco, Y., 2005. La vegetación mediterránea y atlántica de la Península Ibérica: nuevas secuencias antracológicas. Trabajos Varios de S.I.P. (Servicio de Investigación Prehistórica). Diputación Provincial de Valencia, Valencia, pp. 314.

Carrillo, A.F., Carrión, J.S., Fernández, S., Román, J.L., 2010. Toponimia y biogeografía histórica de plantas leñosas ibéricas Servicio de Publicaciones de la. Universidad de Murcia, Murcia, pp. 246.

Castro, P., Gili, S., Lull, V., Mico, R., Rihuete, C., Risch, R., Chapman, R., 2000. Archaeology and desertification in the Vera Basin (Almería, South-East Spain). European Journal of Archaeology 3, 147–166.

Chapman, R., 2008. Producing Inequalities: Regional Sequences in Later Prehistoric Southern Spain. Journal of World Prehistory 21, 195–260.

Chapman, R., 2009. Emerging complexity. The later prehistory of south-east Spain, Iberia and the west Mediterranean. New Studies in Archaeology. Cambridge University Press, Cambridge.

Davis, O.K., Mariscal, B., 1994. A comparison of archaeological palynology of Almería, Spain, and coastal southern California, U.S.A. In: Davis, O.K. (Ed.), Aspects of archaeological palynology: methodology and applications, AASP Contributions Series, 29, 75–82.

Dupré, M., Fumanal, M.P., Martínez Gallego, J., Pérez Obiol, R., Roure, J.M., Usera, J., 1996. The Laguna de San Benito (Valencia, Spain): palaeoenvironmental reconstruction of an endorheic system. Quaternaire 7, 177–186.

Dupré, M., 1988. Palinología y paleoambiente. Nuevos datos españoles. Servicio de Investigación Prehistórica. Diputación provincial de Valencia. Serie de Trabajos Varios, Valencia, pp. 160.

Elsik, W.C., 1983. Annotated glossary of fungal palynomorphs. AASP Contributions Series, pp. 11.

Fierro, E., Munuera, M., Fernández, S., Arribas, A., Carrión, J.S., 2011. Upper Pleistocene and Holocene vegetation changes in the Andalusian region. Menga. Journal of Andalusian Prehistory 2, 15–33.

Fuentes, N., García-Martínez, M., González-Sampériz, P., Fernández, S., Carrión, J.S., Ros, M., López-Campuzano, M., Medina, J., 2005. Degradación ecológica y cambio cultural durante los últimos cuatro mil años en el sureste ibérico semiárido. Anales de Biología 27, 69–84.

Gómez-Cruz, M., 1991. Atlas histórico-forestal de Andalucia. Siglo XVIII. Servicio de Publicaciones de la. Universidad de Granada, Granada, pp. 73.

García-Latorre, J., García-Latorre, J., 1996. Los bosques ignorados de Almería. Una interpretación histórica y ecológica. In: Sánchez-Picón, A. (Ed.), Historia y medio ambiente en el territorio almeriense. Servicio de Publicaciones. Universidad de Almería, Almería, pp. 99–126.

García-Latorre, J., García-Latorre, J., 1997. Efectos de la sobreexplotación de los recursos naturales en la vegetación: los madroñales del sureste árido español. V Jornadas de la Asociación Española de Ecología Terrestre. Área de Ecología de la Universidad de Córdoba, Córdoba, pp. 112.

García-Latorre, J., García-Latorre, J., Sánchez-Picón, A., 2001. Dealing with aridity: socio-economic structures and environmental changes in an arid Mediterranean region. Land use Policy 18, 53–64.

García-Martínez, M.S., Ros, M.M., 2010. Gestión del combustible leñoso e impacto medioambiental asociados a la metalurgia protohistórica de Punta de los Gavilanes (Mazarrón, Murcia). Trabajos de Prehistoria 67, 545–559.

García-Martínez, M.S., Grau Almero, E., Ros Sala, M.M., 2007. Paisaje y gestión de los recursos vegetales en la costa de Mazarrón (Murcia), según el antracoanálisis de Punta de los Gavilanes. In: Lario, J., Silva, P. (Eds.), Contribuciones al estudio del período Cuaternario. AEQUA, Ávila, pp. 107–108.

García-Martínez, M.S., Grau, E., Ros, M.M., 2008. El paisaje vegetal pre- y protohistórico de la costa de Mazarrón (Murcia) según el antracoanálisis de Punta de los Gavilanes. Cuaternario y Geomorfología 22, 107–120.

García-Martínez, M.S., Grau Almero, E., Ros Sala, M.M., 2013. Woody plants in semi-arid south-eastern Iberia during the Bronze Age: charcoal analysis from Punta de los Gavilanes (Mazarrón, Murcia, Spain). In: Damblon, F. (Ed.), Proceedings of the Fourth International Meeting of Anthracology. BAR International Series 2486, , pp. 103–112.

Gibert, J., Martínez, B., Caporicci, C., Jiménez, C., Ferrández, C., Ribot, F., Soria, F., Pérez-Cuadrado, J.L., Arribas, A., Canals, J., García-Targa, J.M., Iglesias, A., Romero, R., 1988. Resumen de las investigaciones paleoantropológicas y arqueológicas de Orce (Granada) y Cueva Victoria (Cartagena). Coloquios de Paleontología 42, 11–60.

Gil-Romera, G., Carrión, J.S., Pausas, J., Fernández, S., Burjachs, F., 2010. Holocene fire activity and vegetation response in South-Eastern Iberia. Quaternary Science Reviews 29, 1082–1092.

Giralt, S., Burjachs, F., Roca, J.R., Julià, R., 1999. Late Glacial to early Holocene environmental adjustment in the Mediterranean semi-arid zone of the Salines playa-lake (Alacant, Spain). Journal of Paleolimnology 21, 449–460.

Horowitz, A., 1992. Palynology of Arid Lands. Elsevier, Amsterdam.

Jalut, G., Esteban, A., Bonnet, L., Gauquelin, T., Fontugne, M., 2000. Holocene climatic changes in the western Mediterranean from south-east France to south-east Spain. Palaeogeography, Palaeoclimatology, Palaeoecology 160, 255–290.

Jiménez-Moreno, G., Anderson, R.S., 2012. Holocene vegetation and climate change recorded in alpine bog sediments from the Borreguiles de la Virgen, Sierra Nevada, southern Spain. Quaternary Research 77, 44–53.

López, P., Riviera, D., Obón, C., Morales, A., Cereijo, M.A., Moreno, R., 1991. Las transformaciones del ecosistema: análisis paleobotánicos y paleontológicos. In: López, P. (Ed.), El cambio cultural del IV al II milenios a.C. en la comarca del noroeste de Murcia, Volumen I. Consejo Superior de Investigaciones Científicas, Madrid, pp. 213–237.

López-García, P., 1988. Estudio polínico de seis yacimientos del sureste español. Trabajos de Prehistoria 45, 335–345.

Liepelt, S., Cheddadi, R., de Beaulieu, J.L., Fady, B., Görmöry, D., Hussendörfer, E., Konnert, M., Litt, T., Longauer, R., Terhürne-Berson, R., Ziegenhagen, B., 2009. Postglacial range expansion and its genetic imprints in Abies alba (Mill.): A synthesis from palaeobotanic and genetic data. Review of Palaeobotany and Palynology 153, 139–149.

Loidi, J. (Ed.), 2017. The vegetation of the Iberian Peninsula. 2 vols. Springer, Berlin.

Magri, D., Parra, I., 2002. Late Quaternary western Mediterranean pollen records and African winds. Earth and Planetary Science Letters 200, 401–408.

Manzano, S., Carrión, J.S., Munuera, M., González-Sampériz, P., Fernández, S., Jiménez-Moreno, G., Anderson, S., Ramos, M.J., Camuera, J., Jiménez Espejo, F., García Murillo, P., Martínez Ruiz, F., Fierro, E., Pardos, M., Rodríguez Vidal, J., Ruiz Muñoz, F., Cáceres, L.M., Abad, M., 2016. Resiliencia y umbrales de vulnerabilidad de la vegetación en dos territorios ibéricos de alta diversidad biológica y fisiográfica: Doñana y Sierra Nevada. Revista OAPN (Proyectos de Investigación en Parques Nacionales, monográfico 2011-2014). , pp. 157–175.

Manzano, S., Carrión, J.S., López-Merino, L., González-Sampériz, P., Munuera, M., Fernández, S., Martín-Lerma, I., Gómez Ferreras, M.C., 2017. Mountain strongholds for woody angiosperms during the Late Pleistocene in SE Iberia. Catena 149, 701–712.

Miller, J.R., 2005. Biodiversity conservation and the extinction of experience. Trends in Ecology and Evolution 20, 430–434.

Montes Bernárdez, R., 1982. El ciclo transgresión-regresión y hundimientos costeros en el Sureste español. Su influencia en asentamientos pleistocénicos, VI Congreso Internacional de Arqueología Submarina, Cartagena, pp. 99–110.

Moore, P.D., Webb, J.A., Collinson, M.E., 1991. Pollen analysis, second edition Blackwell Scientific Publications, Oxford, pp. 216.

Mota, J.F., Peñas, J., Castro, H., Cabello, J., 1996. Agricultural development vs biodiversity conservation: the Mediterranean semiarid vegetation in El Ejido (Almería, south-eastern Spain). Biodiversity and Conservation 5, 1597–1617.

Munuera, M., Carrión, J.S., 1991. Palinología de un depósito arqueológico en el sureste ibérico semiárido: Cueva del Algarrobo (Mazarrón, Murcia). Cuaternario y Geomorfología 5, 107–118.

Munuera, M., 1992. Análisis polínico de la Cueva del Algarrobo (Mazarrón, Murcia) Tesis de Licenciatura. Universidad de Murcia.

Nocete, F., Lizcano, R., Peramo, A., Gómez, E., 2010. Emergence collapse and continuity of the first political system in the Guadalquivir Basin from the fourth of the second millennium BC: The long-term sequence of Úbeda (Spain). Journal of Anthropological Archaeology 29, 219–237.

Nogueras, P., Burjachs, F., Gallart, F., Puigdefàbregas, J., 2000. Recent gully erosion in the El Cautivo badlands (Tabernas, SE Spain). Catena 40, 203–215.

Noti, R., van Leeuwen, J.F.N., Colombaroli, D., Vescovi, E., Pasta, S., La Mantia, T., Tinner, W., 2009. Mid- and late-Holocene vegetation and fire history at Biviere di Gela a coastal lake in southern Sicily, Italy. Vegetation History and Archaeobotany 18, 371–387.

Please cite this article in press as: J.S. Carrión, et al., Ancient Forests in European drylands: Holocene palaeoecological record of Mazarrón, south-eastern Spain, Proc. Geol. Assoc. (2018), https://doi.org/10.1016/j.pgeola.2018.05.007

Ortega, M., Velasco, J., Millán, A., Guerrero, C., 2004. An ecological integrity index for littoral wetlands in agricultural catchments of semiarid Mediterranean regions. Environmental Management 33, 412–430.

Pantaleón-Cano, J., Yll, E.I., Pérez-Obiol, R., Roure, J.M., 2003. Palynological evidence for vegetational history in semi-arid areas of the western Mediterranean (Almería, Spain). The Holocene 13, 109–119.

Parra, I., 1994. Quantification des précipitations à partir des spectres polliniques actuels et fossiles: du Tardiglaciaire à l'Holocène Supérieur de la côte méditerranéene espagnole Ph.D. thesis. Université de Montpellier, Francia, pp. 217.

Peinado, M., Rivas-Martínez, S., 1987. La vegetación de España. Servicio de publicaciones de la Universidad de Alcalá de Henares. España 544.

Peinado, M., Alcaraz, F., Martínez-Parras, J.M., 1992. Vegetation of south-eastern Spain. J. Cramer, Berlín, pp. 487.

Pyle, R.M., 1993. The thunder tree: lessons from an urban wildland. Houghton Mifflin, Boston, MA.

Ramos-Román, M.J., Jiménez-Moreno, G., Anderson, R.S., García-Alix, A., Toney, J.L., Jiménez-Espejo, F.J., Carrión, J.S., 2016. Centennial-scale vegetation and North Atlantic Oscillation changes during the Late Holocene in the western Mediterranean. Quaternary Science Reviews 143, 84–95.

Rodríguez-Ariza, M.O., Ruiz Sánchez, V., Buxó, R., Ros Mora, T., 1995. Palaeobotany of a Bronze Age community. Castellón Alto (Galera Granada, Spain). Actes du Colloque d'Archéométrie 1995 de Périgueux. Revue d'Archéometrie 191–196.

Rodríguez-Ariza, M.O., 1992. Human plant relationships during the Copper and Bronze Ages in the Baza and Guadix basins (Granada, Spain). Bulletin de la Société Botanique de France 139, 451–464.

Rodríguez-Ariza, M.O., 2000. El paisaje vegetal de la Depresión de Vera durante la Prehistoria reciente: Una aproximación desde la antracología. Trabajos de Prehistoria 57, 145–156.

Rodríguez-Estrella, T., Navarro, F., Ros, M., Carrión, J.S., Atenza, J., 2011. Holocene morphogenesis along a tectonically instable coastline in the Western Mediterranean (SE Spain). Quaternary International 243, 231–248.

Rodríguez-Estrella, T., 2006. Geología de la Región de Murcia. In: Conesa García, C. (Ed.), El medio físico y Natural de la Región de Murcia. Servicio de Publicaciones de la Universidad de Murcia, Murcia, pp. 11–45.

Rodríguez-Sánchez, F., Hampe, A., Jordano, P., Arroyo, J., 2010. Past tree range dynamics in the Iberian Peninsula inferred through phylogeography and palaeodistribution modelling: A review. Review of Palaeobotany and Palynology 162, 507–521 Special issue: Carrión, J.S., Leroy, S. (Eds.), Iberian Floras through Time: Land of Diversity and Survival.

Román Díaz, M.P., Martínez Padilla, C., 1998. Aproximación al estudio de las transformaciones históricas en las sociedades del VI al III milenio a.C. en el sureste peninsular. Trabajos de Prehistoria 55, 35–54.

Ros, M.M., 2008. La Punta de Los Gavilanes: un asentamiento en el tiempo en el litoral de la Bahía de Mazarrón (Murcia). Memoria Arqueológica de las campañas de trabajo 1998-2004. Dirección General de Bienes Culturales y Museos de la CARM, Murcia.

Rossignol-Strick, M., 1999. The Holocene climatic optimum and pollen records of sapropel 1 in the eastern Mediterranean, 9000-6000 BP. Quaternary Science Reviews 18, 515–530.

Scott, L., Woodborne, S., 2007. Vegetation history inferred from pollen in Late Quaternary faecal deposits (hyraceum) in the Cape winter-rain region and its bearing on past climates in South Africa. Quaternary Science Reviews 26, 941–953.

Stuiver, M., Reimer, P.J., Reimer, R., 2017. Calib 7.1 [WWW program] at http://calib.org, accessed 2017-10-19.

Targarona, J., 1997. Climatic and oceanographic evolution of the Mediterranean Region over the last Glacial-Interglacial transition. A palynological approach. Utrecht: LPP Contribution Series, Utrecht, The Netherlands, pp. 155 (No. 7).

Tinner, W., van Leewen, J.F.N., Colombaroli, D., Vescovi, E., van der Knaap, W.O., Henne, P.D., Pasta, S., D'Angelo, S., La Mantia, T., 2009. Holocene environmental and climatic changes at Gorgo Basso a coastal lake in southern Sicily, Italy. Quaternary Science Reviews 28, 1498–1510.

Vannière, B., Power, M.J., Roberts, N., Tinner, W., Carrión, J., Magny, M., Bartlein, P., Colombaroli, D., Daniau, A.L., Finsinger, W., Gil-Romera, G., Kaltenrieder, P., Pini, R., Sadori, L., Turner, R., Valsecchi, V., Vescovi, E., 2011. Circum-Mediterranean fire activity and climate changes during the mid-Holocene environmental transition (8500-2500 cal. BP). The Holocene 21, 53–73.

van Geel, B., Bohncke, S.J.P., Dee, H., 1981. A palaeoecological study of an Upper Late Glacial and Holocene sequence from De Borchert, The Netherlands. Review of Palaeobotany and Palynology 31, 367–448.

van Geel, B., Klink, A.G., Pals, J.P., Wiegers, J., 1986. An upper Eemian lake deposit from Twente, eastern Netherlands. Review of Palaeobotany and Palynology 46, 31–61.

van Geel, B., Coope, G.R., Van der Hammen, T., 1989. Palaeoecology and stratigraphy of the Lateglacial type section at Usselo (The Netherlands). Review of Palaeobotany and Palynology 60, 25–129.

Willcox, G., 1999. Charcoal analysis and Holocene vegetation history in southern Syria. Quaternary Science Reviews 18, 711–716.

Yanes, Y., Romanek, C.S., Molina, F., Cámara, J.A., Delgado, A., 2011. Holocene paleoenvironment (~7200-4000 cal. BP) of the Los Castillejos archaeological site (SE Spain) inferred from stable isotopes of land snail shells. Quaternary International 244, 67–75.

Yll, E.I., Roure, J.M., Pantaleón-Cano, J., Pérez-Obiol, R., 1994. Análisis polínico de una secuencia holocénica en Roquetas de Mar (Almería). In: Mateu, I., Dupré, M., Güemes, J., Burgaz, M.E. (Eds.), Trabajos de Palinología básica y aplicada. Universitat de València, Valencia, pp. 189–198.

Please cite this article in press as: J.S. Carrión, et al., Ancient Forests in European drylands: Holocene palaeoecological record of Mazarrón, south-eastern Spain, Proc. Geol. Assoc. (2018), https://doi.org/10.1016/j.pgeola.2018.05.007