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ORIGINAL PAPER

The radiocarbon chronology and temporality of the megalithic cemetery of Los Millares (Almería, Spain)

Gonzalo Aranda Jiménez[1] · Marta Díaz-Zorita Bonilla[2] · Derek Hamilton[3] · Lara Milesi[1] · Margarita Sánchez Romero[1]

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Abstract
In 2012, a radiocarbon dating programme was undertaken to explore the chronology and temporality of megalithic monuments in south-eastern Iberia. After obtaining a new radiocarbon series of 90 dates that have changed many of our current approaches to this phenomenon, we have expanded the radiocarbon programme to one of the most iconic megalithic necropolises in Iberia, the cemetery of Los Millares. The new radiocarbon series modelled in a Bayesian framework was analysed in the context of the site including the settlement and the surrounding "forts". The results led us to four main conclusions: (i) that mortuary activity began in last centuries of the 4th millennium cal BC (3219–3124 cal BC, 68% probability), preceding the settlement foundation by up to 230 years; (ii) that the tombs appear to have been used at different times and with different intensities; (iii) that "forts" were built when most of the settlement was abandoned and only the inner enclosure would remain inhabited; and (iv) that the end of the funerary and housing activities occurred in similar chronological intervals, before ca. 2200 cal BC.

Keywords Copper age · Bayesian modelling · Funerary ritual · Iberian Peninsula · Megalithic phenomenon · Radiocarbon dating

Introduction

In recent decades, chronologies derived from scientific dating have become key to a better understanding of past societies. Methodological advances in radiocarbon measurements and their statistical interpretation have led to a profound change in our perception of temporality (e.g. Buck et al. 1991; Bronk Ramsey 1995, 2013; Bayliss 2009; Scarre 2010; Whittle et al. 2011). The Iberian Peninsula has not benefited from these improvements, as radiocarbon chronology has not been a major concern until very recently. This is the case of megalithic societies of south-eastern Iberia, for which there were just ten radiocarbon dates up to 2012 (Aranda Jiménez 2013). To offset this deficiency, in 2012, we undertook a radiocarbon dating programme aimed at exploring the chronology and temporality of the megalithic phenomenon in this region.

As part of this programme, we focused our attention on several cemeteries that are characteristic of the different types of megalithic tombs known in the study area. They were El Barranquete (Níjar, Almería), a necropolis made up of *tholoi* or tombs with circular chambers covered by false vaults (Aranda Jiménez and Lozano Medina 2014; Aranda Jiménez et al. 2018a); the cemeteries of Las Churuletas, La Atalaya and El Llano de El Jautón (Purchena, Almería), which are characterized mainly by circular chambers without passages, known as Rundgräber (Aranda Jiménez et al. 2017); and finally, the necropolis of Panoría (Darro, Granada), formed by orthostatic tombs with capstone roofs and short passages (Benavides López et al. 2016; Aranda Jiménez et al. 2018b, c). As a result,

✉ Gonzalo Aranda Jiménez
garanda@ugr.es

Marta Díaz-Zorita Bonilla
marta.diaz-zorita-bonilla@uni-tuebingen.de

Derek Hamilton
Derek.Hamilton.2@glasgow.ac.uk

Lara Milesi
lmilesigarcia@gmail.com

Margarita Sánchez Romero
marsanch@ugr.es

[1] Department of Prehistory and Archaeology, University of Granada, Campus Cartuja s/n, 18071 Granada, Spain

[2] Institut für Ur- und Frühgeschichte und Archäologie des Mittelalters, University of Tübingen, Hölderlinstr. 12, 72074 Tübingen, Germany

[3] Scottish Universities Environmental Research Centre, Rankine Avenue, East Kilbride G75 0QF, UK

105 human bone samples were selected and 90 were successfully dated.

This new radiocarbon series modelled within a Bayesian framework proved to be a powerful tool that offered new insights and changed many of our current approaches to the megalithic phenomenon (Aranda Jiménez and Lozano Medina 2014; Aranda Jiménez et al. 2017, 2018a, b; Lozano Medina and Aranda Jiménez 2017, 2018). Nevertheless, it soon became clear that a new phase of the dating programme was needed if we really wanted to base our assessments on more robust chronological foundations. One of the new goals has been to extend the radiocarbon programme to other cemeteries in the region. In this respect, one of the most iconic megalithic necropolises of Iberia, the cemetery of Los Millares, stands out. This paper is specifically aimed at discussing the new ^{14}C dates obtained for this necropolis. In the following sections, the new chronological series will be analysed in a Bayesian framework and their social and cultural implications will be discussed in the context of the site, including the settlement and the surrounding "forts". Firstly, however, we will outline the general background of the Los Millares site.

Archaeological background

Los Millares archaeological site

Los Millares lies on a plain enclosed by the confluence of the Andarax River and the Rambla de Huechar, near the Mediterranean coast (Fig. 1). Discovered in 1891, the cemetery was excavated during different fieldwork seasons between 1891 and 1892 by Luis Siret and his foreman Pedro Flores (Siret 1893) and later published by Leisner and Leisner (1943). Between 1953 and 1956, Martín Almagro and Antonio Arribas excavated the settlement for the first time, although most of the fieldwork focused on the cemetery re-excavation (Almagro Basch and Arribas 1963). Probably the most fruitful research periods were the excavations undertaken between 1978 and 1991 by Antonio Arribas and Fernando Molina, when large areas of Los Millares, plus several of the surrounding small settlements, known as "forts", were systematically excavated (Arribas et al. 1979, 1981, 1983; Arribas and Molina 1984, 1987).

Los Millares can be considered a unique site due to (1) its size, with ca. 19 ha of which six belong to the settlement and 13 to the cemetery; (2) the wealth of the grave goods, including exotic objects such as jet, amber, ostrich eggshell and ivory artefacts; (3) the overall structural complexity, as the settlement was enclosed by three dry-stone walls plus an internal citadel; and (4) the presence of a double line of 13 "forts" in nearby prominent and strategic locations (Fig. 1). The combination of all these features has stimulated different cultural and social interpretations that, leaving aside the early colonial theories, currently range from a kinship-based society (Chapman 1981, 1990; Díaz Del Rio 2011; Ramos Millan 2013) to a class-based form of early state (Molina et al. 2004; Afonso Marrero et al. 2011). As Díaz Del Río (2011: 40) has recently claimed, the social interpretation of Los Millares has climbed all the steps of the neo-evolutionary ladder from equalitarian communities to a tributary state.

Los Millares cemetery

There are at least 80 megalithic tombs in Los Millares cemetery. Typologically, most of them conform to the megalithic classification of *tholoi* or tombs with chambers built using a dry-stone technique and covered by false vaults (Fig. 2). The funerary chambers were entered through passages that were normally divided into equal segments by perforated slabs. Small side chambers in both passages and main chambers were also common. Features such as standing stones and forecourts with stone "baetyls" were also found outside the tombs. These tombs were covered by mounds built of concentric stone walls filled with earth and small stones.

According to the available data (Leisner and Leisner 1943; Almagro Basch and Arribas 1963), human remains were found in chambers, passages and side chambers. The frequent use of these funerary spaces created mortuary deposits characterized by masses of stratified, mixed human bones and grave goods that are found piled on top of each other, overlapping in many cases. Primary depositions have typically been disturbed by later activities, mainly subsequent burials, making finds of articulated or semi-articulated bone remains uncommon. The use of fire inside funerary chambers seems also to have been a widespread practice, given the appearance of burnt or partially burnt bones.

The study of Los Millares cemetery has had to face four main drawbacks. Firstly, most of the tombs cannot be located on the ground. Luis Siret only left a sketch map with the location of 23 tombs within the inner half of the cemetery. After the re-excavation of 44 tombs, Almagro Basch and Arribas (1963) increased this number to 31 tombs, which means that today only 35% of the tombs can be safely located (Chapman 1981). The excavation and recording methods used by Luis Siret and Pedro Flores can be considered a second limitation. They failed to take into account the sequential and spatial arrangements of the different depositional ritual events of skeletal remains and grave goods. This means that all the finds must be considered as a whole for each tomb.

The third drawback is related to the current state of preservation of the anthropological collection. Unfortunately, the skeletal remains found in the re-excavation of 44 tombs are now missing and only an unpublished interim report by the anthropologist Miguel Fusté is preserved.[1] Thus, only the human bones found

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[1] Fuste, M. Nota preliminar sobre los restos humanos procedentes de la necrópolis de Los Millares (Almería). Unpublished report.

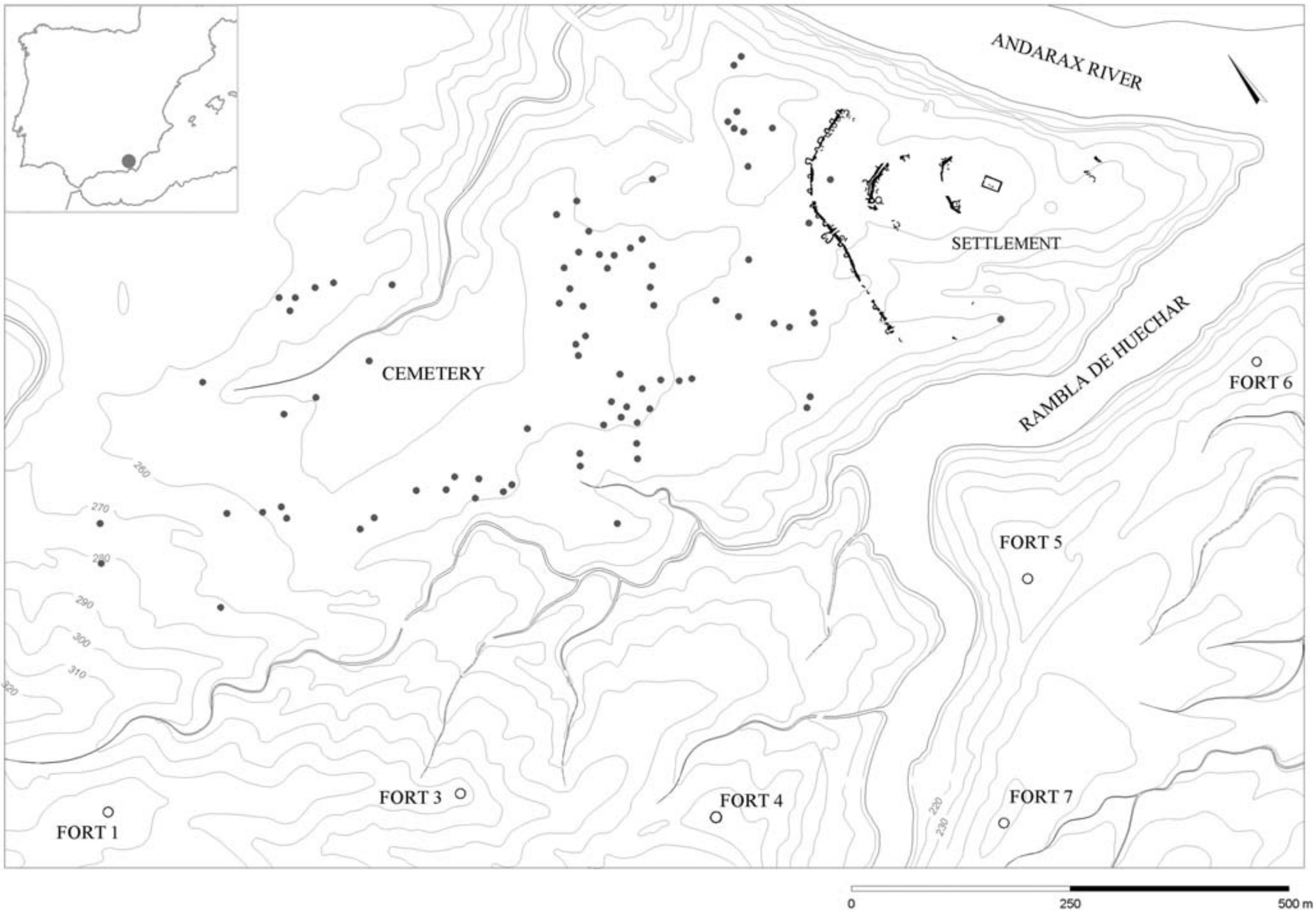

Fig. 1 Map of Los Millares showing the settlement, the cemetery and "forts" (After Arribas Palau et al. 1981, 1983)

by Pedro Flores are available for study. The so-called Siret Collection has been housed at the National Archaeological Museum (MAN) in Madrid since 1934. A recent general overview shows that only 48 tombs preserve anthropological remains, with a surprisingly low minimum number of individuals, ranging in most cases from one to three (Peña Romo 2011). Just seven tombs have an MNI of five or more and in only three cases does it exceed 10 individuals. This situation contrasts sharply with the number of burials identified in each tomb by Pedro Flores. Of the 58 tombs with a known number of burials (Leisner and Leisner 1943), 30 exceed 10 individuals, and in 12 cases, this figure increases to more than 30 people. The reasons behind these differences are unclear. Pedro Flores' lack of anthropological training could have influenced his estimates. Nevertheless, other factors have been put forward to explain this discrepancy. For instance, it has been pointed out that Pedro Flores did not collect all the bone remains found in the tombs, but only a selection (Lorrio Alvarado 2008). Alternatively, it also seems plausible that Luis Siret, as he did with the anthropological collection from sites such as El Argar, collected the most "suitable" skeletal remains to be anthropologically studied, mainly crania and long bones. If this was the case, a large part the original bone assemblage could currently be missing (Peña Romo 2011).

Finally, a fourth limitation is linked to the radiocarbon chronology of Los Millares cemetery. Although this site was pioneering in the use of radiocarbon dating in Iberia, only one date is known so far. In 1956, two samples of charcoal were selected and successfully dated, one from the outer wall of the settlement and another from Tomb 19 (Almagro Basch 1959; Almagro Gorbea 1970). The radiocarbon series for the settlement and the "forts" was subsequently expanded with more measurements (see below), but not for the cemetery. Following the general trend noted previously, Los Millares cemetery is a clear example of how radiocarbon chronology has not been a major concern on Iberian research agendas. It seems clear that the lack of a robust chronological radiocarbon series can be considered an important weakness in the different interpretative proposals that have focused mainly on the variability of grave goods, but not on the timescale and funerary span of the megalithic monuments.

Materials and methods

The dating strategy was based on two main criteria: (1) we focused on human bone remains, as they are short-lived

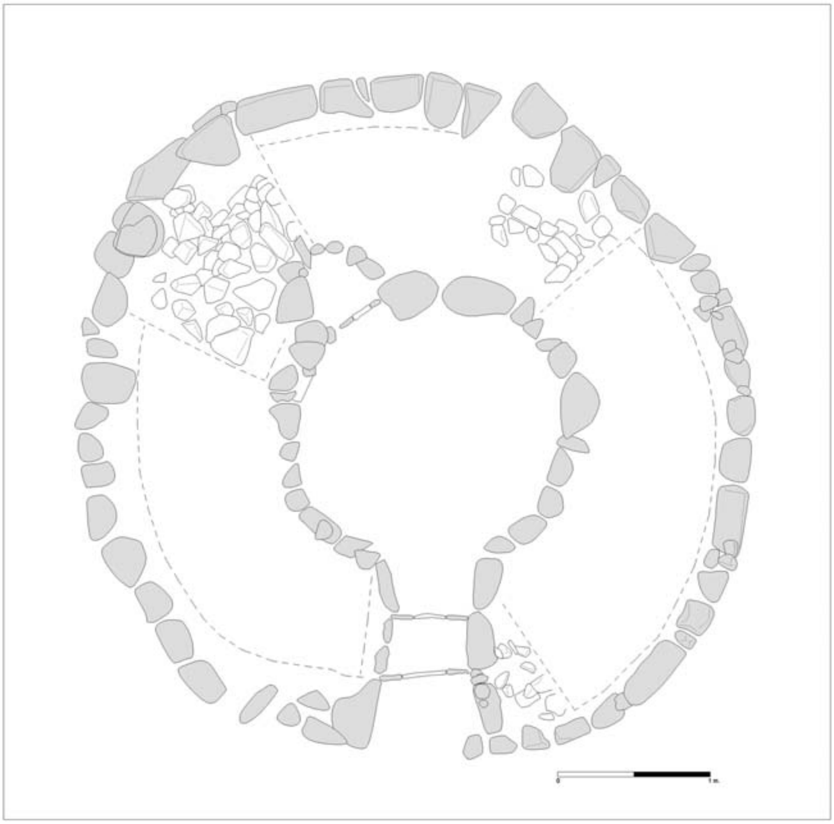

Fig. 2 Plan of the Tomb 71 (after Almagro and Arribas 1963)

samples and the most representative finds of the different ritual practices and depositional events that took place in each tomb; and (2) we decided to date the minimum number of individuals (MNI) as the best way of ensuring that no individual was dated twice. Among the 48 tombs with human bones remains housing at the National Archaeological Museum, we selected those from Tombs 69, 71, 74 and 75 as, according to Peña Romo (Peña Romo 2011: Table 1), they were among the tombs with the largest number of individuals.

Subsequently, the first step consisted of the study of the anthropological collection. We analysed 529 human bones and teeth belonging to an MNI of 31. The skeletal remains were from male, female and subadult individuals of all ages, although most of them fit into the adult range. The MNI distribution per tomb was as follows[2]: in Tomb 69, the MNI was calculated on the basis of two left radii. In Tomb 71, the MNI was 10, a figure based on seven adult mandibles plus three skull, radius and tibia samples belonging to infantile I (0–6 years old), infantile II (7–13 years old) and a perinatal, respectively. Tomb 74 comprised an MNI of eight calculated according to six adult mandibles, a perinatal right humerus and a clavicle from a juvenile (14–18 years old). Finally, in Tomb 75, the MNI was 11 of which 10 samples belonged to adult mandibles and one clavicle to a juvenile individual.

As has previously been highlighted, the MNI was the criterion used to select the samples to be dated. Of the MNI of 31, only 29 were sampled. In two cases, no samples were taken in order to maintain the integrity of the collection, as they were small and fragile perinatal bones. Prior to the radiocarbon measurements, elemental analyses ($\%C$ and $\%N$) were performed in the Department of Geosciences at the University of Tübingen in order to understand the carbon and nitrogen content as an indicator of collagen preservation.[3] As a result, samples with an elemental analysis of $\%N < 0.40$ were rejected, which unfortunately meant most of them. In a first attempt, only the three samples with good collagen preservation were dated. In a second stage, we focused on those teeth associated with the mandibles as the best way to eventually increase the number of radiocarbon measurements while maintaining the criterion that no individual could be dated twice. As result, six new dates were obtained. As the samples from teeth showed a better chance of collagen preservation, in a third stage, we expanded the sampling of teeth, obtaining 10 more radiocarbon dates. After several rounds of dating, the final radiocarbon series adds up to total of 19 dates (Table 1).

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[2] Several discrepancies in the MNI were found between our bioarchaeological analysis and that undertaken by Peña Romo (2011), in which only the general figures of the MNI per tomb were published, without any further details.

[3] The carbon and nitrogen elemental composition in whole bone of the samples of $\%N$ ranged from 0.44 to 0.96 and for $\%C$ from 3.22 to 5.45.

Table 1 Radiocarbon dates from Los Millares cemetery including quality markers of the bone collagen

Code	Type of material	Laboratory code	Radiocarbon age (BP)	$\delta^{13}C$ IRMS (‰)	$\delta^{15}N$ (‰)	C:*N*	%*C*	%*N*	Calibrated date (68% confidence) Cal BC	Calibrated date (95% confidence) Cal BC
TOMB 71										
MILL-21	Tooth 36 (Subadult)	SUERC-80508	4106 ± 29	− 19.1	11.9	3.2	31.6	13	2850–2580	2870–2570
MILL-25	Tooth 36 (adult)	SUERC-82840	3961 ± 20	- 19	10.9	3.1	37.9	14.1	2560–2460	2570–2355
MILL-40	Tooth 37 (adult)	SUERC-86917	3938 ± 34	− 1.8	9.6	3.4	43.7	15	2490–2350	2570–2300
MILL-39	Tooth 36 (adult)	SUERC-86913	3883 ± 34	− 18.7	10.2	3.3	44.5	15.7	2460–2310	2470–2210
TOMB 74										
MILL-38	Tooth 72 (Infantile 2)	SUERC-86912	4569 ± 35	− 19	–	–	–	–	3480–3130	3490–3100
MILL-33	Tooth 23 (adult)	SUERC-86907	4466 ± 35	− 19.2	9.5	3.5	43.6	14.6	3330–3040	3340–3020
MILL-34	Tooth 23 (adult)	SUERC-86908	4424 ± 32	− 19.3	10.1	3.2	41.7	15	3260–2940	3320–2920
MILL-31	Tooth 23 (adult)	SUERC-86903	4370 ± 35	− 18.5	13.1	3.4	43.9	15.2	3020–2920	3090–2910
MILL-16	Tooth 46 (adult)	SUERC-80507	4286 ± 33	− 18.2	14.8	3.2	31.6	11.4	2920–2880	3020–2870
MILL-37	Tooth 74 (Infantile 1)	SUERC-86911	4288 ± 35	− 18	12.4	3.4	42.3	14.6	2920–2890	3010–2870
MILL-12	Clavicle (juvenile)	GrM-14657	4198 ± 17	− 18,5	10	3.3	39.6	13.9	2885–2760	2890–2700
MILL-35	Tooth 23 (adult)	SUERC-86909	4136 ± 32	− 17.9	13.4	3.4	44.1	15.2	2860–2630	2870–2600
MILL-13	Jaw (adult)	GrM-14046	4111 ± 16	− 19,9	8.9	3.3	32	11.4	2850–2615	2860–2580
MILL-36	Tooth 23 (adult)	SUERC-86910	4041 ± 34	− 19	–	–	–	–	2620–2490	2830–2470
MILL-17	Jaw (adult)	ETH-89499	3963 ± 27	− 19,5	8.7	3.4	37.7	12.9	2570–2460	2580–2340
TOMB 75										
MILL-3	Tooth 35 (adult)	SUERC-82835	4023 ± 25	− 19,7	11	3.3	40.2	14.4	2580–2490	2620–2470
MILL-7	Tooth 37 (adult)	SUERC-80506	3943 ± 30	− 19,3	8.8	3.2	41.2	14.8	2550–2340	2570–2330
MILL-4	Tooth 34 (adult)	SUERC-82839	3917 ± 25	− 18,9	12.2	3.3	39.1	14	2470–2340	2480–2300
MILL-30	Tooth 37 (adult)	SUERC-86902	3872 ± 32	− 18,9	11.9	3.3	44.2	15.5	2450–2290	2470–2210

All the samples were measured using accelerator mass spectrometry (AMS) in three different labs: the Swiss Federal Institute of Technology (ETH) (Switzerland), the Centre for Isotope Research at the University of Groningen (GrM) (The Netherlands) and the Scottish Universities Environmental Research Centre (SUERC) (Scotland). Radiocarbon dates were calibrated using the internationally agreed atmospheric curve (see below for discussion), IntCal13 (Reimer et al. 2013), and the OxCal v4.3 computer program (Bronk Ramsey 2001, 2009). Calibrated ranges were obtained using the probability method (Stuiver and Reimer 1993) and the endpoints were rounded out by 10 years when the error was equal to or greater than 25 years and by 5 years when the error was less than 25 years (Stuiver and Polach 1977; Millard 2014). The quality of the bone collagen can be checked in Table 1. To study these new radiocarbon series, different Bayesian models were built using the OxCal program v4.3 (Bronk Ramsey 2001, 2009).

When undertaking a radiocarbon dating programme, it is always a very important concern that we base our assessments on solid foundations. One of the basic assumptions when ^{14}C dating humans is that the carbon in the sampled bones was in equilibrium with the atmosphere. Bone collagen from omnivores such as humans may derive from a diet based on marine and freshwater resources, which means that radiocarbon measurements could be strongly influenced by the reservoir effect (Stuiver and Braziunas 1993; Lanting and van der Plicht 1998; Cook et al. 2001a, b). In these cases, the carbon is not in equilibrium with the atmosphere and presents an earlier date than other contemporaneous terrestrial organisms. Assessing the proportions of the individual's diet is consequently a key aspect for the calibration of the radiocarbon age. In order to explore the potential reservoir effect, source-proportional dietary modelling based on δ^{13}C and δ^{15}N stable isotopic values can be used to build a mixed-source calibration model for each individual analysed.

Individual diets were reconstructed using the Bayesian mixing model implemented in the software known as FRUITS (Food Reconstruction Using Isotopic Transferred Signals) (Fernandes et al. 2014). This approach is superior to the linear mixing models often used (Cook et al. 2015), especially when sufficient data is available relating to the isotopic values expected for dietary endmembers of a population. For use in modelling more accurate radiocarbon dates, the approach has been independently validated using burial data that was "sandwiched" between two layers of known-age tephra in Iceland (Sayle et al. 2016).

For Los Millares, the dietary endmembers were derived from a number of sources and reduced to four food types: cereals, terrestrial mammals, marine animals and freshwater animals. The mean isotopic values for cereals ($\delta^{13}C = -22.8 \pm 0.1$‰; $\delta^{15}N = +7.8 \pm 0.2$‰) were taken from García Sanjuán et al. (2018) and derived from measurements of archaeobotanical barley and wheat from the Bronze Age site of Terlinques. The terrestrial mammal isotopic values ($\delta^{13}C = -19.7 \pm 0.8$‰; $\delta^{15}N = +7.0 \pm 1.7$‰) were derived from the data collected by Díaz-Zorita Bonilla et al. (2019) belonging to the Neolithic and Chalcolithic sites of Marroquíes, Las Churuletas and El Garcel. Marine fish isotopic values ($\delta^{13}C = -19.3 \pm 0.6$‰; $\delta^{15}N = +11.2 \pm 0.7$‰) were estimated using data provided by Jennings et al. (1997) from fish caught at three sites off the coast of Mallorca. The freshwater isotopic values ($\delta^{13}C = -29.7 \pm 1.3$‰; $\delta^{15}N = +20.9 \pm 1.3$‰) were estimated using data from Soto et al. (2016) that were derived from fish in the Flix reservoir of the lower Ebro river basin in the north-eastern Iberian Peninsula. This is the nearest area with a suitable dataset from freshwater fish. Since these analyses were made on the flesh of the fish, the muscle to bone collagen offset of Bownes et al. (2017) was applied to both the $\delta^{13}C$ (− 2.7‰) and $\delta^{15}N$ (+ 0.4‰) values, while the $\delta^{13}C$ values were further offset by + 0.85‰ to account for the Suess effect (Böhm et al. 2002).

The diet-to-tissue offset used to account for the isotopic fractionation that occurs within the body was taken from the work of Fernandes et al. (2014) and set to 4.8 ± 0.2‰ for $\delta^{13}C$ and 5.5 ± 0.5‰ for $\delta^{15}N$. Lastly, all weights and concentrations were set at 100%.

Results and discussion

Dietary analysis of human remains

The FRUITS program allows the calculations to be constrained by incorporating a priori information from the archaeological record. The consumption of freshwater fish and waterfowl appears very unlikely, given the absence of wetlands in the region and the fact that most of the watercourses are highly seasonal. According to the environmental conditions of south-eastern Iberia, the prior information was to set terrestrial resources in the diet to be greater than the proportion of freshwater protein.

Two mixing models were created using these data. The first model only used isotopic data from cereals, terrestrial protein and marine protein. This dietary Bayesian mixing model suggests a very low-level consumption of marine protein, with an average of 1% (min = 1%; max = 3%). The combined average of cereal and terrestrial animal protein is 99% (min = 97%; max = 99%). The results presented in Table 2 were used to perform a sensitivity analysis on the radiocarbon dating and Bayesian modelling. This chronological model uses the ΔR of Matos Martins and Monge Soares (2013: 1130) which equals + 180 ± 66 years to correct for local variation in the marine carbon reservoir.

Table 2 FRUITS modelling output for the dietary model that includes cereals, terrestrial mammals and marine animals

Code	Cereal (%*C*)	Terrestrial protein (%*T*)	Marine protein (%*M*)
MILL-21	95 ± 9	4 ± 9	1 ± 1
MILL-25	9 ± 8	90 ± 8	1 ± 1
MILL-40	18 ± 8	88 ± 8	2 ± 2
MILL-39	24 ± 17	75 ± 17	2 ± 2
MILL-33	9 ± 7	90 ± 7	1 ± 1
MILL-34	6 ± 6	92 ± 6	1 ± 1
MILL-31	93 ± 5	5 ± 5	2 ± 1
MILL-16	88 ± 12	9 ± 13	3 ± 2
MILL-37	86 ± 9	11 ± 9	3 ± 2
MILL-12	17 ± 14	81 ± 14	2 ± 2
MILL-35	92 ± 6	6 ± 6	2 ± 2
MILL-13	6 ± 6	93 ± 6	1 ± 1
MILL-17	7 ± 6	92 ± 6	1 ± 1
MILL-3	38 ± 42	61 ± 41	1 ± 1
MILL-7	7 ± 7	91 ± 7	1 ± 1
MILL-4	94 ± 15	5 ± 14	1 ± 1
MILL-30	94 ± 7	5 ± 7	1 ± 1

Table 3 FRUITS modelling output for the dietary model that includes the possibility for the consumption of freshwater fish, though this model includes as a prior that this food source is less likely to have been consumed than cereals, terrestrial mammals, and marine animals

Code	Cereal (%*C*)	Terrestrial protein (%*T*)	Marine protein (%*M*)	Freshwater protein (%*F*)	Combined %*M* + %*F* (%)
MILL-21	54 ± 17	43 ± 40	2 ± 2	1 ± 1	3 ± 2
MILL-25	8 ± 6	89 ± 7	2 ± 2	1 ± 1	3 ± 2
MILL-40	14 ± 12	82 ± 12	3 ± 2	1 ± 1	4 ± 2
MILL-39	16 ± 12	80 ± 12	3 ± 2	1 ± 1	4 ± 2
MILL-33	10 ± 8	86 ± 8	2 ± 2	1 ± 1	3 ± 2
MILL-34	6 ± 5	91 ± 5	2 ± 1	1 ± 1	3 ± 2
MILL-31	90 ± 6	6 ± 5	3 ± 2	1 ± 1	4 ± 2
MILL-16	80 ± 10	10 ± 7	6 ± 3	4 ± 3	10 ± 4
MILL-37	83 ± 10	12 ± 10	3 ± 2	1 ± 1	5 ± 2
MILL-12	14 ± 10	81 ± 10	3 ± 2	1 ± 1	4 ± 2
MILL-35	88 ± 6	7 ± 5	3 ± 2	2 ± 1	5 ± 2
MILL-13	6 ± 5	91 ± 5	2 ± 1	1 ± 1	3 ± 2
MILL-17	7 ± 5	90 ± 6	2 ± 1	1 ± 1	3 ± 2
MILL-3	8 ± 7	88 ± 7	2 ± 1	1 ± 1	3 ± 2
MILL-7	7 ± 6	90 ± 6	2 ± 1	1 ± 1	3 ± 2
MILL-4	86 ± 22	12 ± 2	2 ± 1	1 ± 1	2 ± 2
MILL-30	93 ± 5	5 ± 4	2 ± 1	1 ± 1	2 ± 1

A second dietary mixing model included the freshwater fish, although with a prior that cereals, terrestrial and marine protein would all be more likely to be consumed over freshwater protein. This model still indicates that the diet was predominately terrestrial, with an average of 96% (min = 90%; max = 98%) (Table 3). The marine component of the diet increased to an average of 3% (min = 2%; max = 6%) and the freshwater component averaged 1% (min = 1%; max = 4%). The total marine and freshwater component for this model averaged 4% (min = 2%; max = 10%). While there is considerable data for estimating the marine reservoir offset for the southern coast of Spain, there is no direct data from the freshwater systems local to Los Millares, and therefore, the second sensitivity analysis uses the broad ΔR of + 600 ± 100 years,

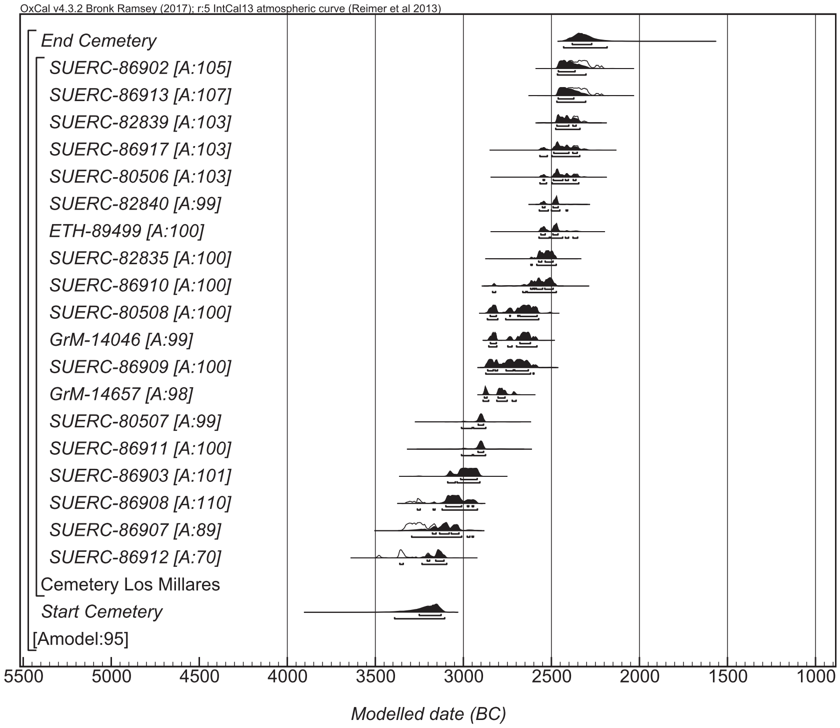


Fig. 3 Probability distribution of dates from the Los Millares cemetery. Each date shows two distributions: light grey represents the radiocarbon calibration and dark grey indicates the result of the Bayesian model (posterior density estimates). Distributions other than those relating to particular dates correspond to aspects of the model. The square brackets down the left-hand side and the OxCal keywords define the overall model exactly

Table 4 Posterior density estimates of Bayesian models discussed in the text

Cluster criteria	Parameter	Posterior density estimate (68% of probability cal BC)	Posterior density estimate (95% of probability cal BC)
Cemetery (preferred model) (Figs. 3 and 4)			
Cemetery	Boundary start	3255–3125	3390–3105
	Boundary end	2385–2270	2430–2180
	Span	775–965	715–1120
Tomb 74	Boundary start	3255–3125	3415–3110
	Boundary end	2550–2415	2565–2280
	Span	625–845 years	580–1045 years
Tomb 71	Boundary start	2765–2500	3030–2490
	Boundary end	2450–2305	2465–2150
	Span	160–490 years	40–795 years
Tomb 75	Boundary start	2580–2475	2735–2465
	Boundary end	2460–2335	2475–2200
	Span	1–245 years	1–480 years
Settlement + forts (Fig. 6)			
Whole radiocarbon series	Boundary start	3155–2975	3345–2935
	Boundary end	2305–2115	2380–1955
	Span	670–885 years	585–1050 years
Enclosure Wall IV (citadel)	Boundary start	3050–2930	3170–2905
	Boundary end	2455–2265	2545–2155
	Span	530–770 years	420–940 years
Enclosure Wall II	Boundary start	3015–2910	3125–2885
	Boundary end	2845–2445	2860–2320
	Span	95–565 years	60–710 years
Enclosure Wall I	Boundary start	3020–2770	3110–2670
	Boundary end	2810–2475	2860–2320
	Span	15–400 years	1–665 years
Differences between enclosures	Difference start wall IV & start wall II	−95 and 45 years	−225 and 135 years
	Difference start wall IV & start wall I	−220 and 20 years	−380 and 110 years
	Difference start wall II & start wall I	−195 and 45 years	−345 and 155 years
	Difference end wall IV & end wall II	65 and 435 years	−100 and 595 years
	Difference end wall IV & end wall I	85 and 440 years	−105 and 585 years
"Fort 1"	Boundary start	2590–2465	2690–2360
	Boundary end	2450–2260	2460–2190
	Span	25–275 years	0–440 years
Differences between enclosures and "Fort 1"	Difference end wall I& start Fort 1	−265 and 75 years	−375 and 290 years
	Difference end wall II & start Fort 1	−255 and 105 years	−380 and 285 years
	Difference end wall IV & start Fort 1	50 and 295 years	−65 and 470 years
Settlement + forts + cemetery (Fig. 7)			
Whole Radiocarbon Series	Boundary start	3420–3145	3775–3120
	Boundary end	2350–2065	2390–1390
	Span	790–950 years	735–1080 years
Cemetery	Boundary start	3220–3125	3330–3100
	Boundary end	2390–2295	2435–2230
	Span	720–835 years	675–925 years
Settlement	Boundary start	3090–2955	3190–2925
	Boundary end	2515–2365	2560–2270
	Span	440–615 years	375–715 years
"Forts"	Boundary start	2510–2380	2580–2350
	Boundary end	2420–2290	2455–2215
	Span	0–125 years	0–260 years
Differences between cemetery, settlement and "forts"	Difference start cemetery & start settlement	−235 and −55 years	−340 and 45 years
	Difference start Settlement & start forts	−655 and −480 years	−770 and −400 years
	Difference end settlement & start forts	−70 and 115 years	−155 and 240 years

which was used by García Sanjuán et al. (2018) to correct the combined marine and freshwater reservoir for each individual. The percentages of marine and marine + freshwater diet were used to calculate a "personal" calibration curve for each individual using the Mix_Curves command in OxCal.

The radiocarbon chronology of Los Millares cemetery

As has been previously noted, the unknown sequential order in the funerary depositions of the human remains prevents the use of this information for calculating a shorter probability distribution for every radiocarbon date. Then, all the finds in each tomb must be considered as a whole. A first Bayesian model follows a simple bounded phase, as described in Hamilton and Kenney (2015), which assumes no stratigraphic relationships between any of the samples. The primary model assumes no dietary reservoir offset to the dates (Fig. 3 and Table 4). This model has good agreement ($A_{\text{model}} = 95$) and

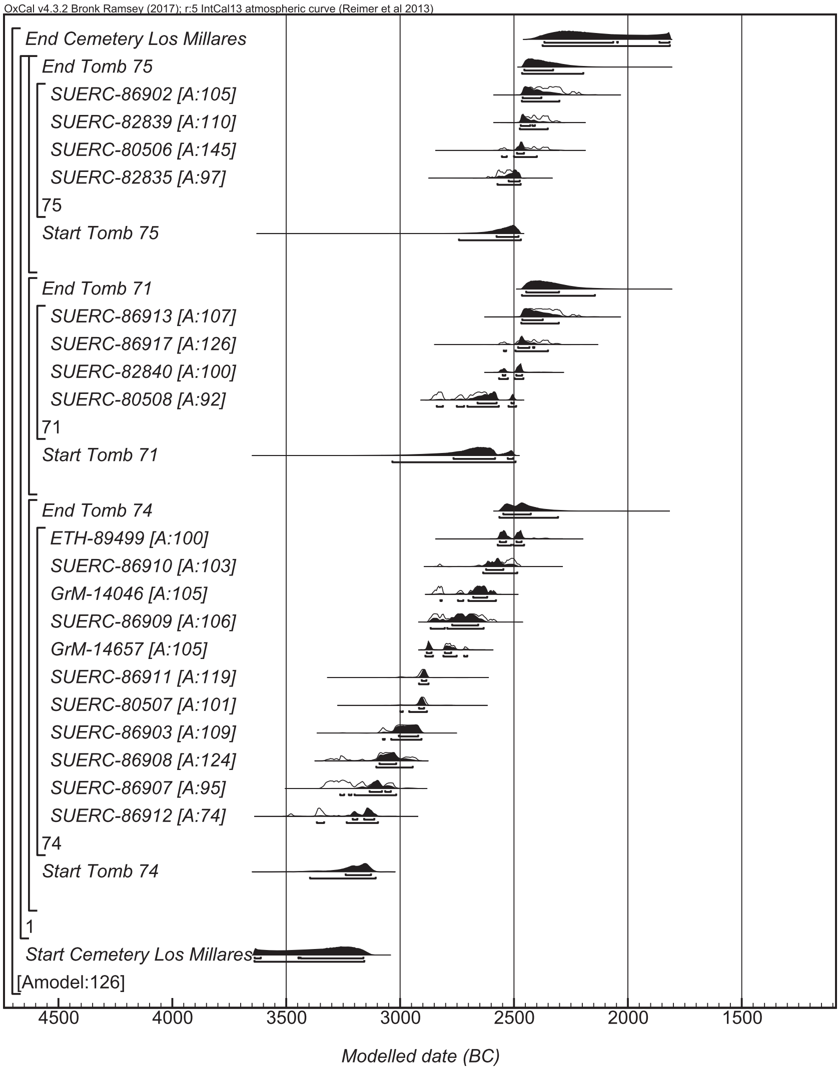


Fig. 4 Probability distribution of dates from Tombs 71, 74 and 75 at Los Millares cemetery. The format is identical to that in Fig. 3

estimates that burials at Los Millares began in 3390–3105 cal BC (95% probability; Fig. 3; start: Los Millares) and probably 3255–3125 cal BC (68% probability). The burial activity is estimated to have ended in 2430–2180 cal BC (95% probability; Fig. 3; end: Los Millares) and probably in 2385–2270 cal BC (68% probability), which implies a long period of use, between 775 and 965 of calendar years (68% probability span).

For the sensitivity analyses, the two results with assumed $\delta^{13}C$ values (SUERC-86910 and SUERC-86912) were modelled using the average dietary amounts for the remaining 17 individuals, 1 ± 1% in Model 1 and 4 ± 2% in Model 2.

Sensitivity Model 1 has good agreement ($A_{\text{model}} = 88$) and estimates that burials at Los Millares began in 3385–3105 cal BC (95% probability; start: Los Millares (Marine)) and probably 3250–3125 cal BC (68% probability). The burial activity is estimated to have ended in 2420–2170 cal BC (95% probability; end: Los Millares (Marine)) and probably in 2375–2260 cal BC (68% probability).

Sensitivity Model 2 also has good agreement ($A_{\text{model}} = 101$) and estimates that burial at Los Millares began in 3360–3045 cal BC (95% probability; start: Los Millares (M/FW)) and probably 3240–3110 cal BC (68% probability). The burial activity is estimated to have ended in 2400–2140 cal BC (95% probability; end: Los Millares (M/FW)), and probably in 2355–2240 cal BC (68% probability).

The dietary modelling demonstrates the potential for significant variation in the diets of the individuals buried at Los Millares. However, any differences in the diet and the associated reservoir have no appreciable impact on the resulting chronological modelling. The very low, even occasional marine and freshwater protein consumption is also supported by the faunal assemblage found in the settlement and "forts" of Los Millares. Of the more than 28,000 faunal bone remains studied, only eight fish bones from four different species have been identified so far (Peters and Von den Driesch 1990). According to these data, the initial model with no dietary correction (Fig. 3) was chosen as the

Table 5 Radiocarbon dates from Los Millares settlement and "forts"

Laboratory code	Type of material	Single entity	Feature	Context	Radiocarbon age (BP)	Calibrated date range (68% confidence) cal BC	Calibrated date range (95% confidence) cal BC	Reference
Beta-124532	Charcoal	Unknown	Enclosure wall IV (Citadel)	Earliest deposits (Phase 1)	4410 ± 60	3270–2920	3340–2910	Molina et al. (2004)
Beta-124531	Charcoal	Unknown		Deposit under hut (Phase 6)	4200 ± 60	2890–2680	2910–2600	
Beta-124529	Charcoal	Unknown		Habitation level of a hut (Phase 7)	4020 ± 60	2620–2470	2860–2350	
Beta-124530	Charcoal (*Populus*)	Unknown		Corridor collapse (Phase 9)	3900 ± 60	2470–2300	2570–2200	
Beta-124527	Charcoal (*Olea europea, P. halepensis, Q. ilex-coccifera* and others)	Mixture	Enclosure wall III	Habitation level (Metal workshop)	4220 ± 70	2910–2480	3010–2580	
Beta-124528	Charcoal (*Olea europea* and others)	Mixture		Hut collapse	4030 ± 130	2860–2350	2900–2210	
Beta-124524	Charcoal (*Olea europea* and others)	Mixture	Enclosure Wall II	Hut foundation	4420 ± 70	3320–2920	3340–2910	
Beta-124523	Charcoal (*Q. ilex-coccifera* and others)	Mixture		Hut foundation	4220 ± 70	2910–2680	3010–2580	
BM 2343	Charcoal (different fragments)	Mixture		Post (collapse of the wall)	4150 ± 40	2870–2670	2880–2620	Arribas and Molina (1987)
Beta-124522	Charcoal	Mixture		Tower collapse	3990 ± 60	2620–2410	2840–2300	Molina et al. (2004)
H 204–247	Charcoal	Single entity	Enclosure Wall I (outer wall)	Post (between Wall I and the inner enforcement)	4295 ± 85	3090–2710	3320–2630	Almagro (1959)
Beta-124526	Charcoal (*Olea europea* and others)	Mixture		Bastion X, inner deposit	4220 ± 70	2910–2680	3010–2580	Molina et al. (2004)
BM 2344	Charcoal	Mixture		Habitation level, contemporary with the barbican	4110 ± 110	2870–2510	2920–2350	Ambers et al. (1987)
Beta-124525	Charcoal (*Olea europea* and others)	Mixture		Tower XI floor	4040 ± 60	2830–2480	2870–2460	Molina et al. (2004)
Beta-125862	Charcoal (*P. halepensis*)	Single entity?	Fort 1	Bastion XI Post hole	4000 ± 70	2830–2370	2860–2300	
Beta-125861	Charcoal (*Tarae* and others)	Mixture		Inner enclosure (habitation level)	3980 ± 40	2570–2470	2620–2350	
Beta-125860	Charcoal (*Olea europea*)	Single entity?		Inner enclosure (habitation level)	3950 ± 40	2560–2350	2570–2310	
BM 2536	Charcoal	Unknown		Tower IX (habitation level)	3920 ± 50	2480–2310	2570–2210	Ambers et al. (1991)
BM 2537	Charcoal	Unknown		Tower XI Habitation level	3880 ± 50	2460–2300	2470–2200	Molina et al. (2004)
Beta-125859	Charcoal (*P. halepensis*)	Single entity?		Inner enclosure (habitation level)	3880 ± 60	2460–2290	2560–2150	Molina et al. (2004)
BM 2345	Charcoal (different fragments)	Mixture		Bastion V (collapse level)	3820 ± 40	2340–2200	2460–2140	Arribas y Molina (1987)
Beta-135,669	Charcoal (*P. halepensis*)	Single entity?	Fort 4	Interior enclosure fire	3830 ± 70	2450–2150	2470–2050	Molina et al. (2004)
Beta-135670	Charcoal		Fort 5	Interior enclosure fire	3840 ± 50	2430–2210	2470–2150	

Table 5 (continued)

Laboratory code	Type of material	Single entity	Feature	Context	Radiocarbon age (BP)	Calibrated date range (68% confidence) cal BC	Calibrated date range (95% confidence) cal BC	Reference
	(*Populus*)	Single entity?						
Beta-135871	Charcoal (*Populus* and *Olea europea*)	Mixture		Interior enclosure fire	3840 ± 70	2450–2200	2480–2050	
KN 72	Charcoal (different fragments)	Mixture	Tomb 19	Funerary chamber	4380 ± 120	3330–2890	3490–2680	Almagro (1970)

preferred model, which means that the radiocarbon in dated samples was in equilibrium with the contemporary atmosphere at the time of death.

The new radiocarbon series can also be modelled according to the three dated tombs. This Bayesian model has good agreement ($A_{\text{model}} = 126$) (Fig. 4 and Table 4) and shows

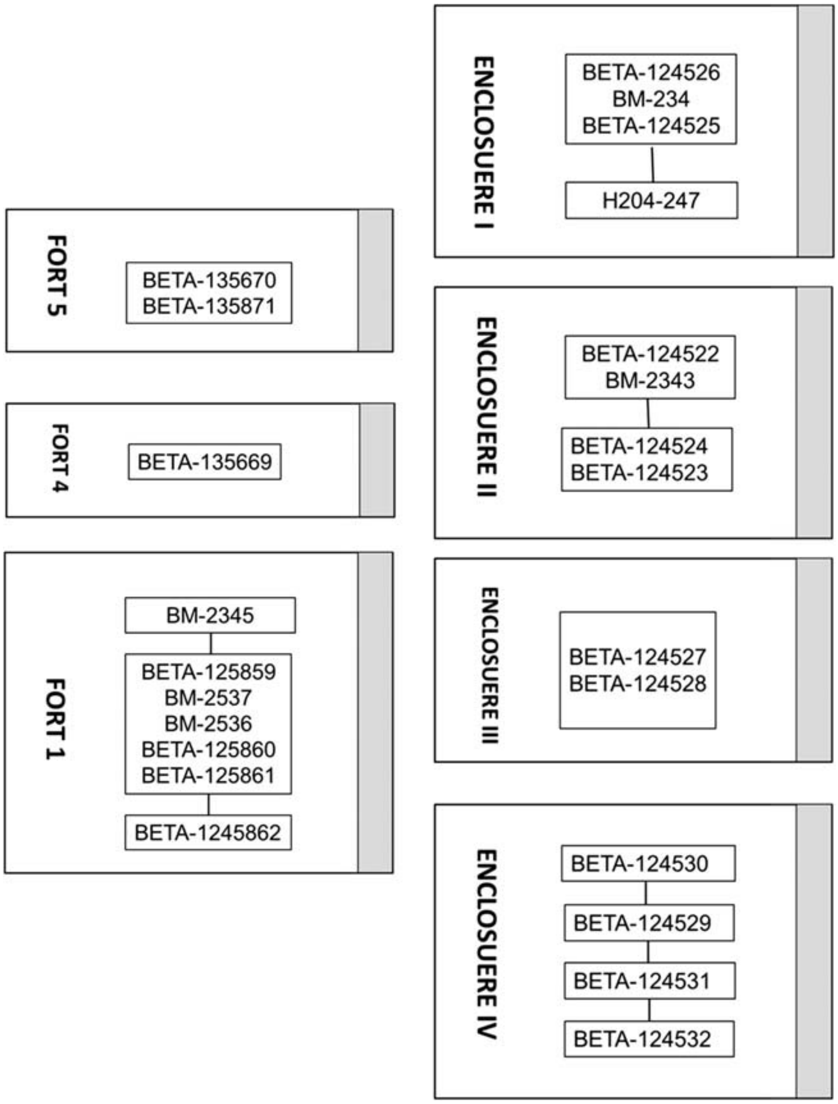
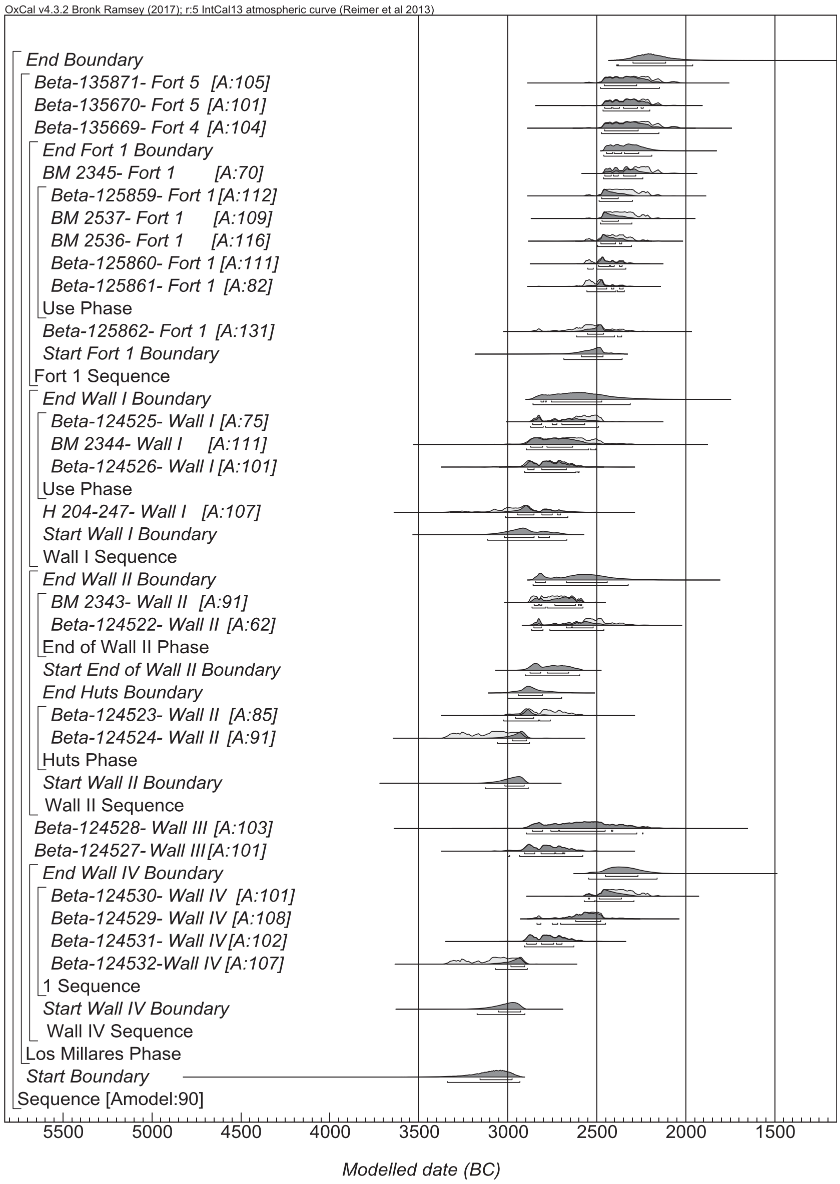


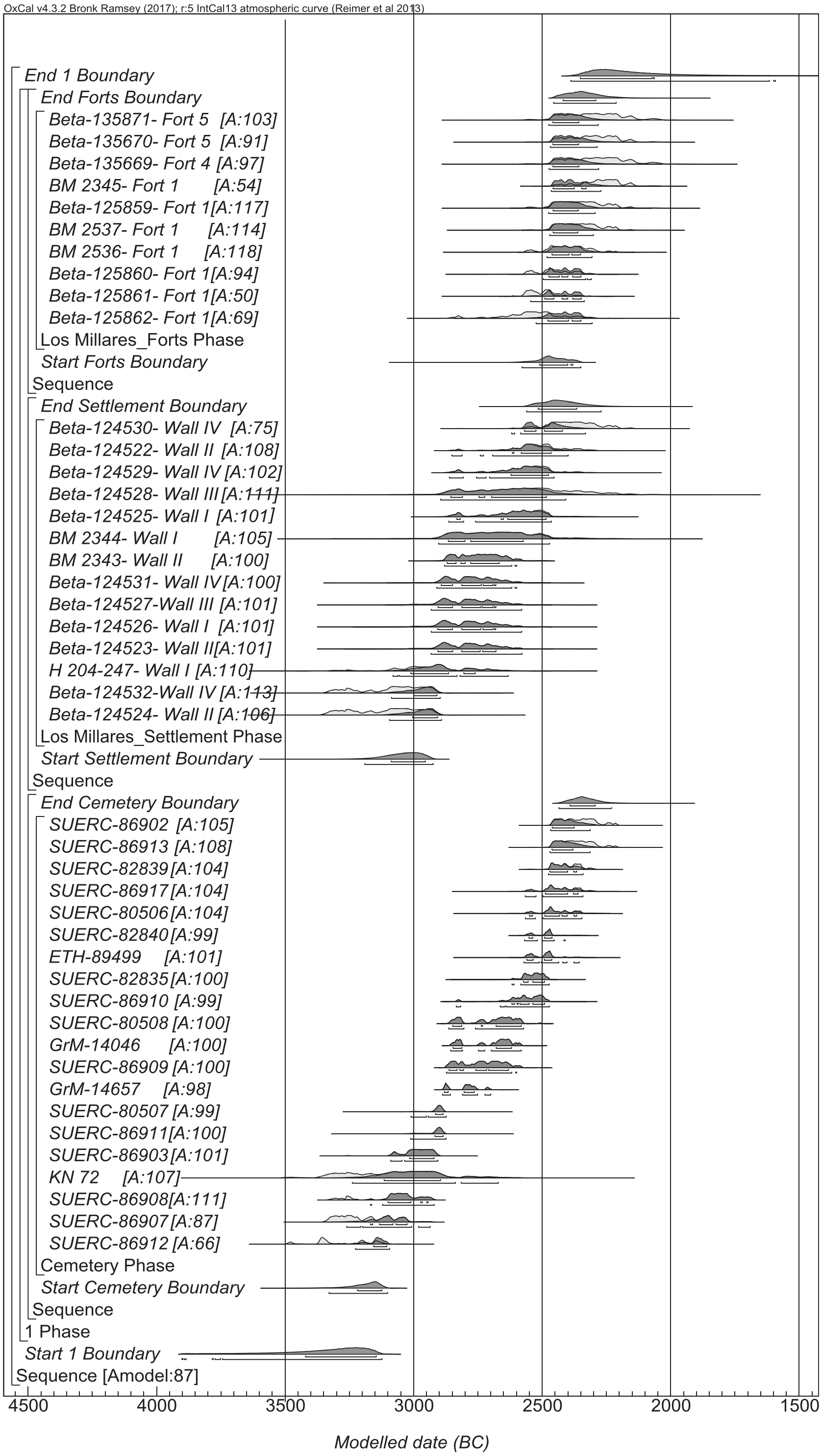
Fig. 5 Prior information incorporated in the Bayesian model shown in Fig. 6. Within boxes, the stratigraphic relationships are shown with the earliest at the bottom. Grey bars represent uniformly distributed phases of activity

Fig. 6 Probability distribution of dates from the settlement and "forts" at Los Millares site. The format is identical to that in Fig. 3



remarkable differences in the period of use between the tombs, which appear to have been built at different times and used on different temporal scales. If we assume that mortuary activity began just after their construction, Tomb 74 was probably built in the last centuries of the 4th millennium (3255–3125 cal BC at 68% probability, Fig. 4, start Tomb 74), which means several centuries before the first interments were placed in Tomb 71 (2765–2500 cal BC at 68% probability, Fig. 4, start Tomb 71). Especially noticeable are the differences between Tombs 74 and 75. The end of the funerary activity in Tomb 74 (2550–2415 cal BC at 68% probability, Fig. 4, end Tomb 74) matches the beginning of human bone deposition in Tomb 75 (2580–2475 cal BC at 68% probability, Fig. 4, start Tomb 75). The coexistence, if it existed, was during a short period of up to 150 years (− 30 and 150 years, difference end Tomb 74 & start Tomb 75; 68% probability). Although these data must be handled with caution because of the small number of radiocarbon dates in Tombs 71 and 75, this scenario is consistent with the chronological differences found between tombs in megalithic cemeteries such as El Barranquete, La Atalaya and Panoría (Aranda Jiménez et al. 2017, 2018a, c; Lozano Medina and Aranda Jiménez 2018). Although it is plausible that these tombs were built at different times and used with different intensities, other explanations for these chronological differences cannot be ruled out. It is also possible that the bone assemblage formation was not only the result of primary depositions disturbed by subsequent burials but also of the removal of skeletal remains. If this was the case, the radiocarbon chronology would not capture the whole use-life of the tombs and, consequently, it could not be associated with construction events. The drawbacks

Fig. 7 Probability distribution of dates from the settlement, "forts" and cemetery at Los Millares site. The format is identical to that in Fig. 3



previously highlighted prevent us from properly exploring the bone assemblage formation of these tombs.

The numerical chronology of the los Millares site

The new radiocarbon series has also been analysed from a comparative perspective to explore how it fits into the general chronology of the site, including the settlement and the surrounding "forts". For this purpose, all dates were compiled to give a radiocarbon series of 24 dates (Table 5). They were all obtained from charcoal, mostly from wooden posts linked to different construction events. This kind of sample was probably affected by the so-called old wood effect, which means that if a wood sample is not from the bark or the final ring of the post, the radiocarbon measurement will be earlier than the death of the organism, in some cases even several centuries (Waterbolk 1971; Bowman 1990). The use of long-lived samples is combined with other important drawbacks as in most cases the samples came from a mixing charcoal, which would also imply the mixture of different ages-at-death. The radiocarbon measurements of this kind of sample do not date any particular archaeological event and must be handled with caution (Ashmore 1999). Nevertheless and according to the contextual provenance of the samples, it seems that at least the mixed materials came from the well-defined events of deposition and not from many different features or events.

Bearing in mind all these restrictions, the evaluation of the dates context-by-context make it possible to produce Bayesian models based on the stratigraphic relationships of the samples or alternatively on the sequence of building events (foundations, rebuilding, use and collapse). In accordance with this prior information (Fig. 5), a Bayesian model was built for the different areas of the site: the citadel, the three walling enclosures and the surrounding "forts" (Fig. 6). The model has good overall agreement between the radiocarbon dates and the underlying modelling assumptions ($A_{\text{model}} = 90$).

According to this model (Fig. 6 and Table 4), four main aspects can be highlighted: (1) Los Millares (settlement and "forts") started in 3345–2935 cal BC (95% probability), probably between 3155 and 2975 cal BC (68% probability) and ended in 2380–1955 cal BC (95% probability), possibly around 2305–2115 cal BC (68% probability); (2) the posterior probability estimates for the beginning of the walling enclosures show very similar intervals which means that they were built at the same time or with a difference of just a few decades between them (see Table 4 for the start differences between enclosures). Whatever the case, at the beginning of the 3rd millennium, the settlement of Los Millares would have reached the height of its expansion; (3) the probability estimates for the walling enclosure ending show similar intervals, except for Enclosure IV or the Citadel, which occurred in 2455–2265 cal BC (68% probability; Fig. 6; end: enclosure IV), between 85 and 440 years later (68% probability; difference between the end of Wall IV and Walls I–II*)*; and (4) in comparison with the settlement, "Fort 1" began very late, in 2590–2465 cal BC (68% probability; Fig. 6; start Fort 1), ending in the same chronological interval as Enclosure IV, between 2450 and 2260 cal BC (68% probability; Fig. 6; end Fort 1). "Fort 1" only shows a reliable period of coexistence with Enclosure IV.

To explore more accurately this comparative approach, radiocarbon dates were modelled according to their contextual provenance, the cemetery ($n = 20$),[4] the settlement ($n = 14$) and the "forts" ($n = 10$). The Bayesian model was built taking into consideration all dates in phases of continuous activity (Fig. 7 and Table 4). This model has good agreement ($A_{\text{model}} = 87$) and estimates that mortuary activity first began (3330–3100 cal BC; Fig. 7; 95% probability; start cemetery) between 55 and 235 years earlier than the settlement (68% probability, difference start cemetery & start settlement). The foundation of the settlement occurred in the transition between the 4th and the 3rd millennia (3090–2955 cal BC; Fig. 7; 68% probability; start settlement), several centuries before the appearance of the nearby "forts", between 480 and 655 years (68% probability, difference start settlement & start forts*)*. In fact, when the "forts" were built, between 2510 and 2380 cal BC (Fig. 7; 68% probability; start forts), only the inner enclosure or citadel remained inhabited. According to the Bayesian model, the coexistence between the "forts" and the settlement could only have occurred during a short period, of not more than a century (− 70 and 115 years, difference end settlement & start forts; 68% probability). The end of the funerary and housing activities occurred in similar chronological intervals, before the ca. 2200 cal BC traditionally considered as a benchmark for the end of the Copper Age.

Conclusions

For the first time, we have a coherent radiocarbon series with which to discuss the chronology and temporality of Los Millares cemetery. Although the new chronological series can be considered a remarkable improvement, we are still far from fully understanding the chronological complexity of the site. Therefore, the following cultural evaluations must be considered as a first approach.

The Los Millares radiocarbon series stresses a long period of use that began in the last centuries of the 4th millennium cal BC and ended with the appearance of the Early Bronze Age societies ca. 2200 cal BC (Aranda Jiménez et al. 2015). Nevertheless, not all features—the cemetery, the settlement and the "forts"—coexisted during the entire period; quite the opposite in fact, as there are important chronological differences between them.

Remarkably, mortuary practices preceded the first evidence of housing activity by up to 230 years. It seems that the location of the settlement could have been determined by the very special symbolic and sacred significance of the site. This scenario is also consistent with the nearby cemetery of El Barranquete and the associated settlement of El Tarajal. In that case, funerary activity also began between one and five centuries prior to the settlement foundation (Lozano Medina and Aranda Jiménez 2018). Could megalithic landscapes be considered a key aspect for understanding the location of settlements? In other words, could the sacred significance of megalithic cemeteries such as El Barranquete and Los Millares

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[4] In this case, we have also included in the model the old radiocarbon dates KN-72 from Tomb 19 (4380 ± 120 BP, 3490–2680 cal BC at 95% of probability).

explain the desire of different social groups to be closely connected to these meaningful gathering places? This is a very stimulating hypothesis that also finds support in the chronological differences reported at other enclosures such as Valencina de la Concepción, a key site located in southwestern Iberia. The large radiocarbon dating programme undertaken there recently also showed that mortuary activity preceded the appearance of other kinds of production, storage and housing facilities. As happened in Los Millares, mortuary rituals in the form of collective burials began in Valencina de la Concepción at the end of the 4th millennium, several centuries before the first non-funerary dated evidence (García Sanjuán et al. 2018).

At Los Millares, as in other cemeteries in the region, such as El Barranquete and Panoría, the tombs appear to have been built at very different times and used on different timescales. In these cemeteries characterized by long periods of ritual activity, it seems that their final configuration was more the result of tomb aggregation, in which their temporal differences emerge as a main aspect for a better understanding of the social dynamics traditionally analysed only on the basis of grave goods variability.

The foundation of the Los Millares settlement occurred in the transition between the 4th and the 3rd millennia cal BC when the walling enclosures that shape the inhabited area were built over a short period of time. Soon after their foundation, the settlement of Los Millares reached its largest expansion at the beginning of the 3rd millennium. It is at the end of the housing activity that important chronological differences are found. According to the Bayesian models, most of the settlement was abandoned prior to ca. 2500 cal BC. Only the inner enclosure or citadel remained inhabited, probably until the end of site's occupation in around ca. 2200 cal BC. It was at that time when the small settlements known as "forts" were built and inhabited. As has been suggested by different authors (Castro et al. 1996, 2006; Chapman 2008; Díaz Del Rio 2004, 2011; Lull et al. 2010), the coexistence of the inner enclosure and the "forts" occurred only during a short period. According to the probability estimates previously discussed, this would have been no more than a century.

These temporal differences show the importance of a robust chronology. The new radiocarbon dates from the cemetery, together with the Bayesian modelling of whole Los Millares series, have revealed a complex temporality of coexistences and successions. It seems clear that only through refined chronologies will it be possible to reveal more accurately the complex web of interactions that produced a unique and multi-composited site such as Los Millares.

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