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RESEARCH

Personal ornament in transition. Final Paleolithic – Mesolithic data from the Iberian Mediterranean Region (16.5 – 7 ky cal. BP)

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Abstract
The present study aims at a better understanding of personal ornaments during the Late Paleolithic and Mesolithic transitions. The approach consists of a combination of the shell beads and pendants from Santa Maira (Alacant) and the information from the Mediterranean façade of the Iberian Peninsula, including the Ebro valley, allowing a systematic evaluation of species richness from a spatio-temporal perspective. An assessment of access to the source and its impact on diversity was also carried out. The results show a continuity between the Late Paleolithic and the Epipaleolithic, as well as a period of cultural break with the Mesolithic. Similar patterns have been documented during the same periods from lithic production studies and may indicate a change in social interactions and/or cultural boundaries.

Keywords Magdalenian · Epipaleolithic · Mesolithic · Ornament · Malacofauna · Iberian Peninsula

Introduction

The study of the personal ornament elements of prehistoric hunter-gatherers-fishers' populations has been the subject of different analyses, providing valuable information on the selection of supports, manufacturing techniques and archaeological contexts (d'Errico et al. 1993; Taborin 1993). Since the latter work, their geographic dispersion has made it possible to investigate questions about the catchment areas of the supports and long-distance exchange and circulation, providing new perspectives on the relationships between groups (Khun and Stiner 2007; Álvarez-Fernández 2006, Álvarez-Fernández and Jöris 2008; Bar-Yosef Mayer and Bosch 2019; Langley 2019), also including their consideration as an expression of an ethnic/ethnolinguistic identity (Newell et al. 1990; Vanhaeren and d'Errico 2005). Likewise, ornaments have been a central aspect in the discussion of early evidence of symbolic behavior among diverse human populations (Kuhn and Stiner 2006; Vanhaeren et al. 2013; Bar-Yosef Mayer and Bosch 2019; Vanhaeren et al. 2019; Shunkov et al. 2020; d'Errico et al. 2021; Martisius et al. 2022; Rigaud et al. 2023). Moreover, their presence in contexts of funerary practices has made it possible to go beyond the scale of group mapping, providing bases for discussion on the treatment related to age, sex, and social position of some individuals (Vanhaeren and d'Errico 2001, 2002, 2005; Grosman et al. 2008; Gravel-Miguel et al. 2023).

This paper analyzes the evolution of personal shell beads and pendants made on malacofauna from the Iberian Mediterranean Region (= IMR) between the Final Paleolithic and the Mesolithic (ca. 16.5—7 ky cal. BP). To establish the study area, the limits of the Eurosiberian and Mediterranean regions proposed by Rivas Martínez (1987) for Iberia have been considered, incorporating the Ebro valley but not the Cantabrian region, considered as Eurosiberian. A considerable part of the known sites in the IMR is caves and rock shelters, formed from recurrent occupations that can be considered palimpsests (Bailey

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2007; Heatherington et al 2019). Data on the production systems of lithic and bone industries indicate the continuity of Magdalenian traditions in the later microlaminar facies, with successive adjustments (Fortea Pérez 1973; Aura Tortosa 1995; Vadillo Conesa 2018; Vadillo Conesa and Aura Tortosa 2019; Román et al. 2021). The data on the subsistence and mobility of human groups show the same, observing the repeated occupation of the Magdalenian sites during the Epipaleolithic (Aura and Pérez Ripoll 1992; Aura Tortosa 2021). For its part, the Mesolithic is considered the end of the Paleolithic-Epipaleolithic traditions according to the known data on production systems, subsistence, and mobility (Alday 2006; Aura Tortosa 2001, 2021). However, in these approaches changes of personal ornaments have so far not been considered.

Based on this evolutionary trajectory, the hypothesis of this work considers that the choice of ornaments is not a functional trait, but is related to a symbolic selection, a more appropriate scope to recognize cultural affinities and chronological changes (Rogers and Ehrlich 2008). So far, the evolution of functional elements (technology, subsistence, and mobility systems) has been involved in the discussion on the continuity and rupture between technocomplexes and archaeological phases, but their evolution has not been compared with the trajectory of ornamental elements (Perlés 2019). Here we study whether the continuity and rupture observed in the functional traits are also manifested in the composition and evolution of the ornaments. Therefore, the aim is to check if the continuity in production systems, subsistence, and mobility between the Upper Magdalenian and the later microlaminar facies is also reflected in the continuity of the ornamentation elements. If so, one would expect a break, or at least a significant variation between the Magdalenian and microlaminar Epipaleolithic assemblages concerning those of the Mesolithic.

To analyze these issues, the data from Santa Maira provides a unique perspective, as it is the only site where all three phases analyzed are available (Aura Tortosa et al. 2014). Likewise, the assemblages and sites of the IMR and Ebro Valley that have data on the ornamental elements between the Upper-Final Magdalenian and Mesolithic are incorporated to have an extended archaeological sample to explore possible changes in the use of shell-beads marine and terrestrial malacofaunal species during the Pleistocene-Holocene transition. In this sense, recent approaches explore the exploitation of malacological resources in the IMR (Álvarez-Fernández 2006; Aura Tortosa et al. 2016; Román et al. 2022; Aguirre-Uribesalgo et al. 2024) or the use as tools (Cuenca-Solana et al. 2021). However, in this work we focus on variation in the species of malacofauna used in the IMR as shell beads.

Material and methods

Les Coves de Santa Maira: a sequence of the Pleistocene-Holocene transition

The IMR is currently one of the warmest regions in Europe and available paleoclimatic data indicate that the changes with the greatest impact on human populations were sea level rise and increased temperature and humidity, with their effect on the expansion of mixed forests and fauna (Carrión 2005; Carrión et al. 2010; Aura Tortosa 2021).

The site of Coves de Santa Maira is in the central area of the IMR, in the municipality of Castell de Castells (Marina Alta, Alacant), about 30 km from the coast. The site is located at an altitude of 600 m above sea level and in a mid-mountain environment. So far it has been excavated in two sectors: the west mouth (SM-W) and the Corral del Gordo (SM-CG). The materials studied in this work come from SM-W, in whose sequence 5 lithostratigraphic units are identified (Fig. 1). Unit SM-5 was formed during GI-1 (15–13 ky cal. BP), and it is a succession of laminations relying on a stalagmitic flow. It includes the occupations of the late Upper Paleolithic, identifying materials characteristic of the Upper and Late Magdalenian. Unit SM-4 is composed of sand, gravel, and small limestone blocks. Its chronology indicates that it was deposited during GS-1 and the Preboreal (12.7—10.4 ky cal. BP) and contains materials of the Epipaleolithic microlaminar facies. Unit SM-3 is bounded by large blocks, in wall and roof, and contains the Mesolithic materials (10.2—8.8 ky cal. BP). Finally, SM-2 includes Neolithic materials and unit SM-1 contains materials related to recent chronologies, even of historical age (Aura Tortosa et al. 2006, 2014).

The anthracological remains (Carrión 2005) have allowed us to know the paleovegetation of the SM-W environment. During the GI-1 *Juniperus* sp. reached an important presence, becoming the main arboreal taxon. In parallel, there is an increase of *Quercus* sp., deciduous and evergreen, during the Preboreal and more marked during the Boreal, coinciding with the Mesolithic technocomplex phase. The mammal fauna has a large presence of lagomorph remains during the Magdalenian and Epipaleolithic periods, thus common species have been identified in sites located in mid-mountain environments: *Capra pyrenaica* and *Cervus elaphus* as the main ungulates, with the occasional presence of *Sus scropha*, *Rupicapra rupicapra*, *Capreolus capreolus*, *Bos* sp., and *Equus* sp. Finally, some carnivores have been identified such as *Cuon alpinus*, *Lynx pardina*, *Felis silvestris,* and *Vulpes vulpes* (Morales Pérez 2015). The marine species provided can be read in paleogeographic terms. Thus, during the GI, GS 1, and Preboreal the bivalve species correspond to a sandy substrate

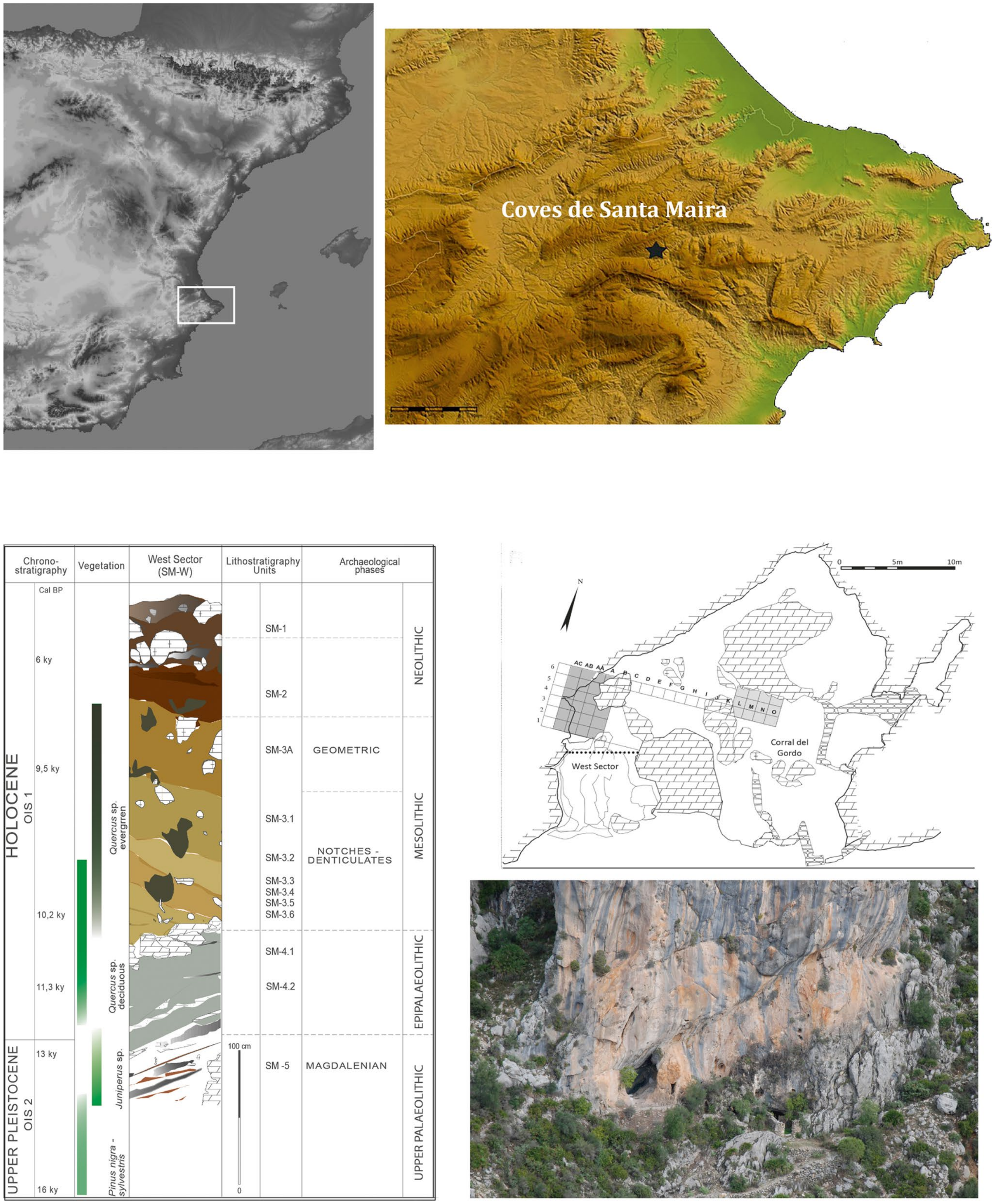

Fig. 1 **A**) Geographical location of Santa Maira. **B**) General view of the cave. **C**) Planimetry of the site with the two sectors. **D**) Schematic table of the stratigraphy of the Site

(mainly scallops and cockles), while those of rocky substrate increase from the Boreal onwards (*Mytilus* sp.). In contrast, the ichthyofauna shows the presence of species linked to estuaries (sparoids and mullets) during the Boreal (Aura Tortosa et al. 2006, 2014).

The ornamental record of Santa Maira

The ornamental assemblage of malacofauna recorded in SM-W was recovered in the excavation of recurrent occupations of the cavity. The first data on the composition of the terrestrial species has already been published (Balcázar and Aura 2021). Regarding the marine malacofauna, preliminary results on the functional analysis have allowed us to identify that certain bivalves were used as tools (Cuenca-Solana et al. 2023).

In this work, we have considered as ornament/pendant elements those remains of marine malacofauna or freshwater species that show evidence of perforation, independently of whether its origin is anthropogenic or natural, mainly because they are not detailed in the different studies. Likewise, in the case of gastropods, we have also counted those unperforated individuals of species that are commonly used as ornaments, small in size, and of null food value, such as *Theodoxus fluviatilis* or *Tritia reticulata*. On the other hand, some remain, basically identified as Glycymeris, Cerastoderma, and Bivalvia indeterminate, have been recognized as tools (Cuenca-Solana et al. 2023), and therefore are not considered shell beads. Of the rest of these bivalves, only perforated shells, infantile individuals and those with ochre remains unrelated to their use as containers have been considered as ornaments. In the case of the scallops, we have only considered those that are perforated, and all the scaphopods have been counted as ornamental elements.

Taxonomical identification and manufacture techniques

For the determination of the different taxa, we used the guides of Poppe and Goto (1991), Giannuzzi-Savelli et al. (1997) and Gofas et al. (2011), as well as the *World Register of Marine Species* (WORMS) for updating the nomenclature. For the analysis of the supports, the following variables have been considered: fracturing, measurements of the individuals, degree of alteration, colorant additions (iron oxides), and those characteristics associated with the perforations: size, manufacturing marks, characterization of the action and marks of use. A Leica M165 C stereomicroscope with a Schott KL 1600 LED cold light source was used for the observation and analysis of the perforations. Finally, a Canon Powershot SX200-IS digital camera was used for photographic recording.

The assemblage is composed of a total of 178 remains, 161 of which have been identified. About their distribution in the sequence of the site, the number of remains attributed to the Magdalenian levels (n = 67), the Epipaleolithic (n = 71), and the Mesolithic contains 40 items (Table 1).

Table 1 Malacofauna assemblage from Santa Maria

Specie	F. Paleolithic	Epipaleolithic	Mesolithic	Total
Antalis sp	2	2	0	**4**
Cerastodema sp	0	3	1	**4**
Cerastodema edule	1	0	0	**1**
Cerastodema glaucum	2	0	1	**3**
Clanculus corallinus	0	2	0	**2**
Columbella rustica	2	1	19	**22**
Clycymeris sp	9	21	3	**32**
Clyciremis glyciremis	0	1	0	**1**
Homalopoma sanguineum	1	0	0	**1**
Melanopsis dufouri	1	0	0	**1**
Mytilus sp	1	0	0	**1**
Ostrea	1	0	0	**1**
Pectinidae	1	0	0	**1**
Spondilus	0	0	1	**1**
Teodoxus fluviatilis	5	6	10	**21**
Trivia monacha	2	0	0	**2**
Tritia sp	1	0	0	**1**
Tritia neritea / pellucida	32	20	3	**55**
Tritia reticulata	0	5	1	**6**
Indeterminate	6	10	1	**17**
Total	**67**	**71**	**40**	**178**

All the elements on malacofauna have been analyzed for the recognition of perforation techniques (abrasion, pressure, percussion, rotation) and the one tooth present has been studied to obtain information on the preparation and perforation technique (scraping, incision, rotation), its location and possible traces of use. It should also be noted that for the analysis of all ornamental material, we have relied on the set of experimental observations made by different authors since the 1990s of the last century (Avezuela Aristu et al. 2011; Balcázar-Campos et al. 2021; Cârciumaru et al. 2019; d'Errico et al. 1993; d'Errico and Vanhaeren 2002; Rigaud 2013; Rigaud et al. 2014, 2017; Soler Mayor 2001a, 2001b; Vanhaeren and d'Errico 2001, 2002, 2005, 2017; White 2007).

Malacological assemblage on a regional scale

The data obtained in Santa Maira need to be evaluated based on a larger archaeological/regional sample to explore whether it is possible to recognize evolutionary trends in the use of marine and terrestrial malacofauna species over the time interval studied. For this reason, the sample used has been expanded to different regions of the Mediterranean façade of the Iberian Peninsula. The choice of ornaments elaborated on malacofauna is based on it allowing us to have a reference on their catchment area, especially in the case of marine species. In contrast, freshwater species (*cf. Theodoxus*) are more difficult to identify their origin because they could have been collected in any local stream or from ancient lagoons. Between ca. 16.5—7 ky cal. BP, several technocomplexes and phases are recognized in the Iberian Mediterranean region and the Ebro Valley, which we have simplified into three major horizons:

- o The final Paleolithic, which includes the Upper and Final Magdalenian (MSF), is perhaps the entity with the most consensus regarding its denomination, characteristics, and chronology (16.5 – 13.5 ky cal. BP).
- o Epipaleolithic, which includes microlaminar facies that receive different denominations in the analyzed territories. Microlaminar Epipaleolithic, Epimagdalenian, and even Azilian (13.5 – 10.5 ky cal. BP). The relationship of the Sauveterrian and Sauveterroid with these facies is under discussion from technological perspectives and their relation to the early Mesolithic (so-called Notched and Denticulated Mesolithic).
- o Mesolithic, assessing the technological rupture that involved the replacement of microlaminar productions to configure first a flake industry and second a composite trapezoidal arrowhead (Fortea Pérez 1973; Aura Tortosa 2001; Martí et al. 2009). In this analysis, the Early (Notched and denticulated Mesolithic) and the Later Mesolithic (trapezial arrowheads) are analyzed jointly (10.5 – 7 ky cal. BP).

The three phases under consideration are of comparable duration each, *ca*. 3000 years, but with very unequal samples in number and objects (see electronic material). For these chrono-cultural phases, 52 ornamental malacofaunal assemblages have been collected from 49 sites (including Santa Maira) located throughout the IMR region and the Ebro Valley (Fig. 2). The materials analyzed were obtained from excavations carried out over the last 100 years, so there are methodological differences and possible biases, as already mentioned (Cucart-Mora et al. 2022). The dispersion of the archaeological sites is unequal, and for geographical reasons, we have split it into four sub-regions. Three of them correspond to the Mediterranean façade: Northeast (between the Pyrenees and the Ebro); Eastern (between the Ebro and the Vinalopó River); and Southeastern (between the Vinalopó River and Gibraltar). The fourth region corresponds to the Ebro Valley.

The final count represents a total of 1270 objects, not including the few items made from mammal teeth (see electronic material). The taxonomic identifications and archaeological attributions to each horizon have been made based on the proposals of the researchers who have analyzed the different assemblages. We need to note that some of these works only those species that are perforated and/or have not recognized food value are considered as ornaments. Likewise, most of the malacofaunal remains come from shelter and cave contexts, with a few exceptions. Other common elements are that they correspond to habitat sites, and they have been recovered in occupations that can be considered palimpsests. This origin gives them a certain unity for comparison, but prevents any analysis regarding individual identities (age, sex, position), since no information is available on their association with burials.

Statistical approach

There are different approaches to exploring species diversity and richness broadly defined and used by Ecology (Roswell et al. 2021). In this paper, we have decided to explore ornament diversity from a diachronic perspective applying the Shannon–Weaver H index (Shannon and Weaver 1949). This index is designed to measure diversity among different groups of population (archaeological sites in our case). Although it is particularly sensitive to gaps in information within the sample (Magnussen and Boyle 1995), the data used in this work have been published systematically, so we consider the H index to be appropriate. In parallel to the examination of diversity, a hierarchical cluster analysis (Johnson 1967) was carried out to determine which archaeological sites have common ornamental characteristics according to the species' habitat type (rocky, muddy, or fluvial). In our case, it has been decided to use Ward's algorithm (1963), as it allows us to minimize the total variance within the cluster. This makes it possible to combine clusters whose merger produces the minimum loss of information.

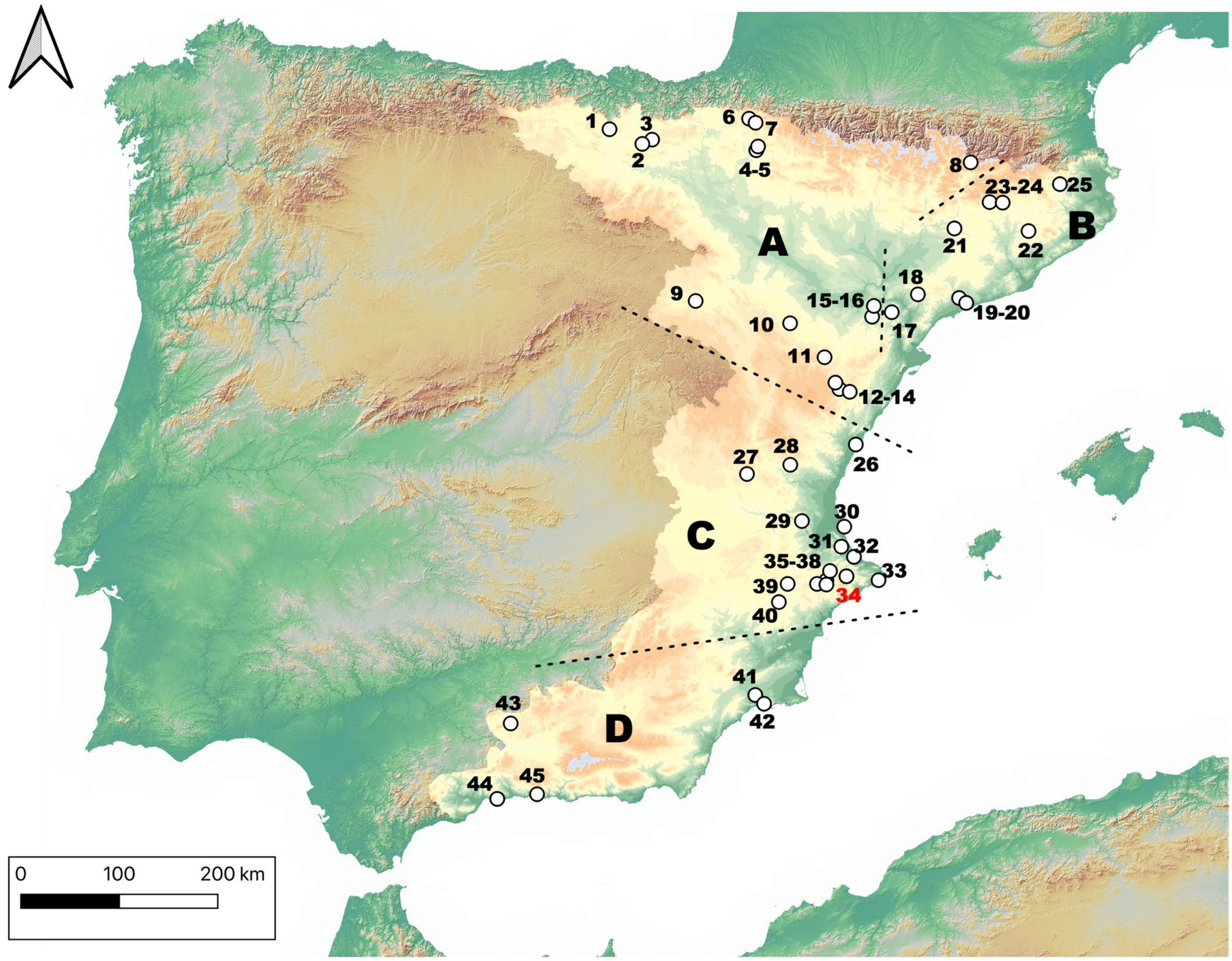

Fig. 2 Map with archaeological sites explored in this paper. Ebro Valley (**A**): 1. Fuente Hoz, 2. Mendandia, 3. Atxoste, 4. Kampanoste, 5. Kampanoste Goikoa, 6. Aizpea, 7. Zatoya, 8. Balma Margineda, 9. Peña Diablo, 10. Costalena, 11. Abrigo del Ángel 1, 12. Mas Cremat, 13. Barranc de la Fontanella, 14. Cova Fosca d'Ares, 15. Boquitería dels Moros, 16. El Pontet. Northeastern (**B**): 17. Abric del Filador, 18. Hort de Boquera, 19. Molí del Salt, 20, La Cativera, 21. Cova del Parco, 22. Balma del Gai, 23. Balma Guilanyà, 24. Font del Ros, 25. Serrat del Pont. Eastern (**C**): 26. Assut d'Almassora, 27. Covacha de Llatas, 28. Mangranera, 29. Cueva de la Cocina, 30. Volcán del Faro, 31. Cova del Parpalló, 32. El Collado, 33. Cova de les Cendres, 34. Coves de Santa Maira, 35. Tossal de la Roca, 36. Benàmer, 37. Penya del Comptador, 38. Abric de la Falguera, 39. Casa Corona, 40. Cueva del Lagrimal. Southeastern (**D**): 41. Algarrobo, 42. Caballo, 43. El Pirulejo, 44. Cueva Victoria, 45. Cueva de Nerja

Finally, to discern whether the distribution of malacofaunal remains is affected by the distance to the source of origin, we have decided to perform a Pearson correlation between the Shannon index and the distance to the Mediterranean Sea for each archaeological site. In this sense, the calculation of the distance to the coastline has been carried out by applying three reference levels from the radiometrically calibrated SPECMAP time scale: −75 m, −43 m and −23 m (Thompson and Goldstein 2006) which are consistent with the marine terraces described by Hernández-Molina (1994) in Málaga and which have already been used as a reference in other works (Jordá Pardo et al. 2011).

All statistical analyses and visual outputs were performed with R in its version 4.3.1 (Core Team 2023) using several packages such as *cluster* (Maechler et al. 2022), *vegan* (Oksanen et al. 2012), FactoMineR (Lê et al. 2008), *factoextra* (Kassambara and Mundt 2020) and *patchwork* (Pedersen 2023). Following the open science policy and the criteria of transparency and reproducibility (Marwick 2017; Pardo-Gordó and Cortell-Nicolau 2023), all the information necessary to replicate this work is available in the repository Zenodo (https://doi.org/https://doi.org/10.5281/zenodo.10883001).

Fig. 3 Shell beads from Santa Maira collection, sector W. From bottom to top: Final Paleolithic (Upper-Final Magdalenian) beads: *Columbella rustica*; *Trivia monacha*; *Tritia* sp.; *Theodoxus fluviatilis*; *Homalopoma sanguineum*; *Trita neritea*; *Ostrea* sp. and *Pectinidae*. Epipaleolithic: *Clanculus corallinus*; T*heodoxus fluviatilis*; T*rita neritea*; *Glycimeris* sp. Mesolithic: *Columbella rustica*

Results

Santa Maira's ornament taxa

The ornaments analyzed were made from three types of phylum Mollusca (Fig. 3):

a) Gastropoda: *Tritia* is the most abundant taxon in the whole sequence (n = 56) and almost 50% of the sample are fractured pieces and fragments. In the case of SM-W it has not been possible to identify, in most cases, whether it was *Tritia neritea* (Linnaeus 1758) or *Tritia pellucida* (Risso 1826). Therefore, we have opted for the double denomination. As for their distribution in the sequence, they are numerous in the Magdalenian and Epipaleolithic, while in the Mesolithic they decrease drastically. *Theodoxus fluviatilis* is morphologically like the *Tritia* explained above, but they have a fluvial origin. It is the 4th most common taxon represented throughout the sequence (n = 21), and always below the *Tritia* assemblage. Likewise, its presence at Santa Maira is lower in relation to its documentation in other Mediterranean sites. The remain of *Homalopoma sanguineum* (Linnaeus 1758) appear in Magdalenian layers. This specie had so far only been documented south of the Ebro in the Cova de les Cendres (Villaverde et al. 2019). This scarcity in the central-southern region contrasts with its numbers in the north and northeast of the Iberian Peninsula and Europe (Álvarez-Fernández 2002; Cârciumaru et al. 2019; Peresani et al. 2019). The two individuals of *Clanculus corallinus* (Gmelin 1791) documented correspond to the first evidence of this species in the malacofaunal record of this region. The two pieces retain much of their striking coloration and have been documented in an Epipaleolithic context. Finally, *Columbella rustica* (Linnaeus 1758) appears constantly in the infralittoral along the coast and almost every type of seafloor. It is present in the Magdalenian and Epipaleolithic with a scarce representation (n = 3) that will be multiplied exponentially in the Mesolithic (n = 19).
b) Bivalvia: *Glycymeris* sp. (Lamarck 1789) is documented in both the Mediterranean and the Atlantic and the case of Santa Maira is present in the entire sequence studied (n = 33), with a maximum occurrence during the Epipaleolithic (n=21). *Cerastoderma* sp. is usually a species well represented as an ornament in other regional sites throughout the Paleolithic sequence, in our site it has a limited presence (n = 8). Finally, other species such as *Mytilus* sp. and *Ostrea* sp., have a scarce presence as ornament whereas *Pectinidae* only one fragment shows a clear anthropic perforation.
c) Scaphopods: The presence of *Dentalium* (Linnaeus 1758) / *Antalis* (Adams & Adams 1854) is scarce in this sector (n = 4), and this is also noteworthy given that it is one of the recurrent elements in all the ornamental assemblages of the Mediterranean Paleolithic.

Production techniques and functional observations

As far as perforation techniques are concerned, no technique is exclusive to a specific support (Taborin 1974). However, Santa Maira repeats the patterns known in most of the deposits of the Mediterranean Paleolithic sequence, which, without being decisive, shows a trend characterized using a single technique to drill the support. For example, abrasion is mainly documented in species *Glycymeris* sp. and *Tritia reticulata*. Rotation is only associated with one scallop fragment. On the other hand, pressure/percussion is associated with *Tritia neritea* and *Theodoxus fluviatilis*. It should be noted perforation is associated with numerous bivalves, although some show signs of erosion which may be attributed to the fact that they were collected with natural perforations. Finally, the complexity of determining percussion and pressure techniques is a constant. The reason lies in the fact that both show stigmata on the surface of the shells, and they can be confused because these technical actions produce similar traces: the orifices have a similar morphology using both indirect percussive technique and pressure (Tátá et al. 2014).

Concerning use wear, we were only able to detect a few very subtle traces of wear on the edges of the perforations (Fig. 4). A smoothing can be seen at the edge of the perforation in one part of the hole. This could be due to the constant rubbing of a suspension wire, as described in some experimental and archaeological works. (d'Errico et al. 1993; Avezuela Aristu et al. 2011; Vanhaeren et al. 2013; Álvarez-Fernández et al. 2022).

Regional variations in species diversity during the Pleistocene-Holocene transition

A diachronic analysis of the diversity of species has been carried out, to appreciate changes in the choice of species for the elaboration of the beads-pendants. In this sense, diversity could be indicative of both changes in species availability and/or intentional selection by socio-cultural decisions. The diversity scores do not show variation in the three phases analyzed in Santa Maira (1.52, 1.38, 1.38), but if we explore the number of taxa in absolute values, we observe that between the Final Paleolithic and Mesolithic periods, the number of taxa is reduced by half. The most significant changes occur in the substitution of the majority species in each of the periods. Thus, in the Final Paleolithic and the Epipaleolithic, the most common gastropod was *Triria neritea / pellucida*, while the *Columbela rustica* was

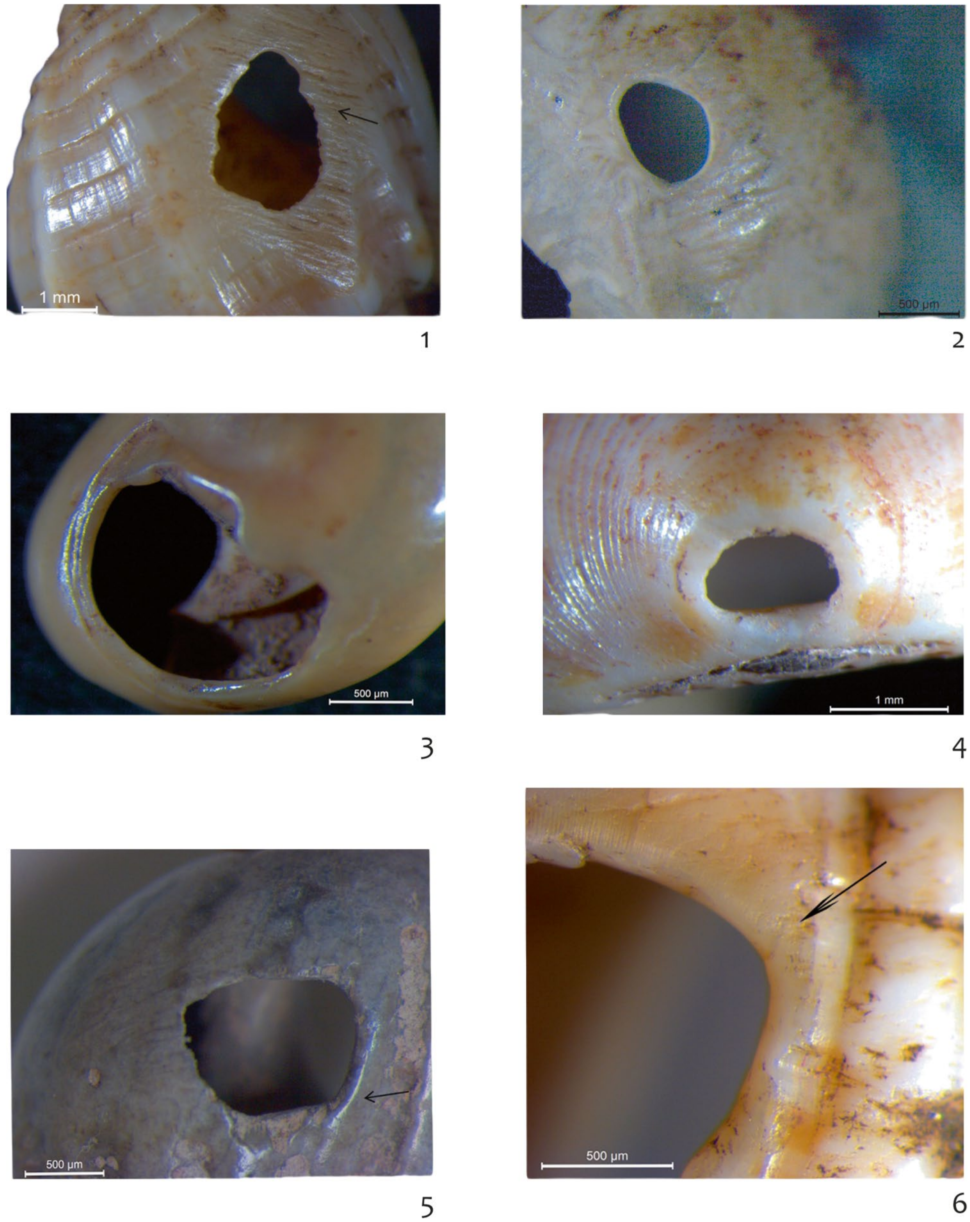

Fig. 4 Drilling techniques identified in Santa Maira collection, sector W. 1, Abrasion (*Tritia reticulata*); 2, abrasión (Glycimeris sp.); 3, pressure-percussion (*Tritia neritea*); 4, non anthropogenic perforation (*Glycimeris* sp.); 5, use wear (*Tritia* sp.); 6, use wear (Tritia reticulata, see item nr 1)

the most popular in the Mesolithic. The Epipaleolithic phase shows an increase of perforated bivalves as a characteristic feature, mainly *Glycimeris* sp., but keeps continuity with the Final Paleolithic. If we explore the evolution of diversity at the regional scale (Fig. 5) we observe that, regardless of the archaeological sample used (all species, removing freshwater species and those sites with a minimum number of archaeological remains), the diversity gradually decreases (Table 2).

Results are of special interest because, as has been pointed out in the archaeological literature, there was a clear trend toward an increase in marine resources at the end of the Pleistocene in Southern Iberia (Aura Tortosa 2001, 2016), expanding this evidence to the entire Mediterranean coastal region during the Mesolithic (Aguirre-Uribesalgo et al. 2024; Román et al. 2022; Fernández-López de Pablo 2016). In this way, the results show that an increase in the exploitation of malacofaunal resources associated with consumption is not related to an increase in the selection of species (diversity) for the elaboration of symbolic items/ornaments.

From the species' habitat type and species' distribution, can regional groups be established?

Once the diversity has been explored, we have made an approximation of the species' habitat and distribution to be able to identify possible forms of catchment and circulation between regional entities. At first glance of the clusters (Fig. 6) indicate that the geographical proximity between sites may help to

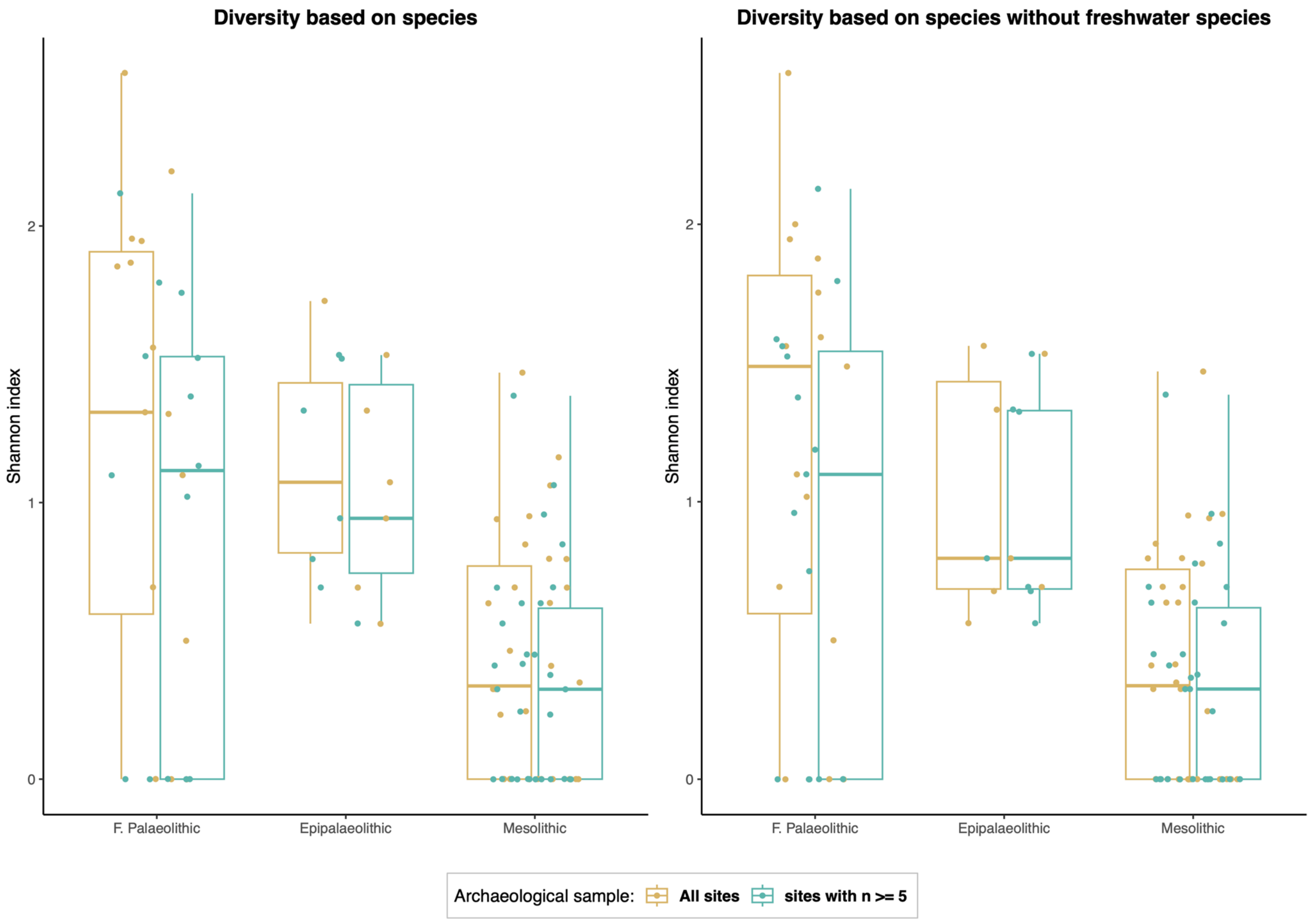

Fig. 5 Boxplot comparing diversity by period using the total sample (brown) and those sites with remains greater than 4 (cyan). The graph on the right refers to the same analysis but excluding species of fluvial origin (see online version for color identification)

understand the generated groups. Thus, in the Final Paleolithic (Fig. 6A) the only site located in the northeastern (Cova del Parco) is differentiated from the rest of the clusters. The next group (n = 5) includes all the sites located in the southeast of the peninsula except for HC-Volcán, which is in the eastern of Iberia site. The last two groups correspond, although we could consider them as a single cluster, to the settlements located in the eastern peninsular. More specifically, the cluster formed by Cendres and Parpalló is coherent because both sites are located close to the coastline and share an ecological niche. In the last cluster, the grouping of the two eastern peninsular sites (Santa Maira and Tossal de la Roca) is coherent not only by geographic location but also by ecology and distance from the coastline. However, this cluster includes the site of Cueva de Nerja, which is in the southeast region, and which always remained very close to the coastline. These groupings become more nuanced if we process only the shell beads made on marine species (Fig. 6D), but the general pattern is the same.

Moving on to the Epipaleolithic, the results show the best fit with the data, both in the analysis based on the total objects and in the analysis restricted to marine species (Fig. 6B & E). The clusters considered are defined by geographical variables and ecological contexts, but it is worth noting that Santa Maira is the only site located in the East of the Iberia, which appears individualized in a cluster of its own.

Finally, as far as the Mesolithic period is concerned, results vary considerably depending on the type of sample used. Thus, exploring all information (Fig. 6A) we observe four clusters with an unequal number of archaeological sites. The first group is based on the geographical component since 9 of the 11 observations correspond to sites located along the Ebro Valley. Analyzing the taxa, this group is characterized by the variability of

Table 2 Global diversity index by period and sample used

Period	All species	Freshwater	All species (n > 4)	Freshwater (n > 4)
F. Palaeolithic	1.25	1.20	1.05	0.98
Epipalaeolithic	1.12	1.02	0.99	0.93
Mesolithic	0.43	0.40	0.35	0.33

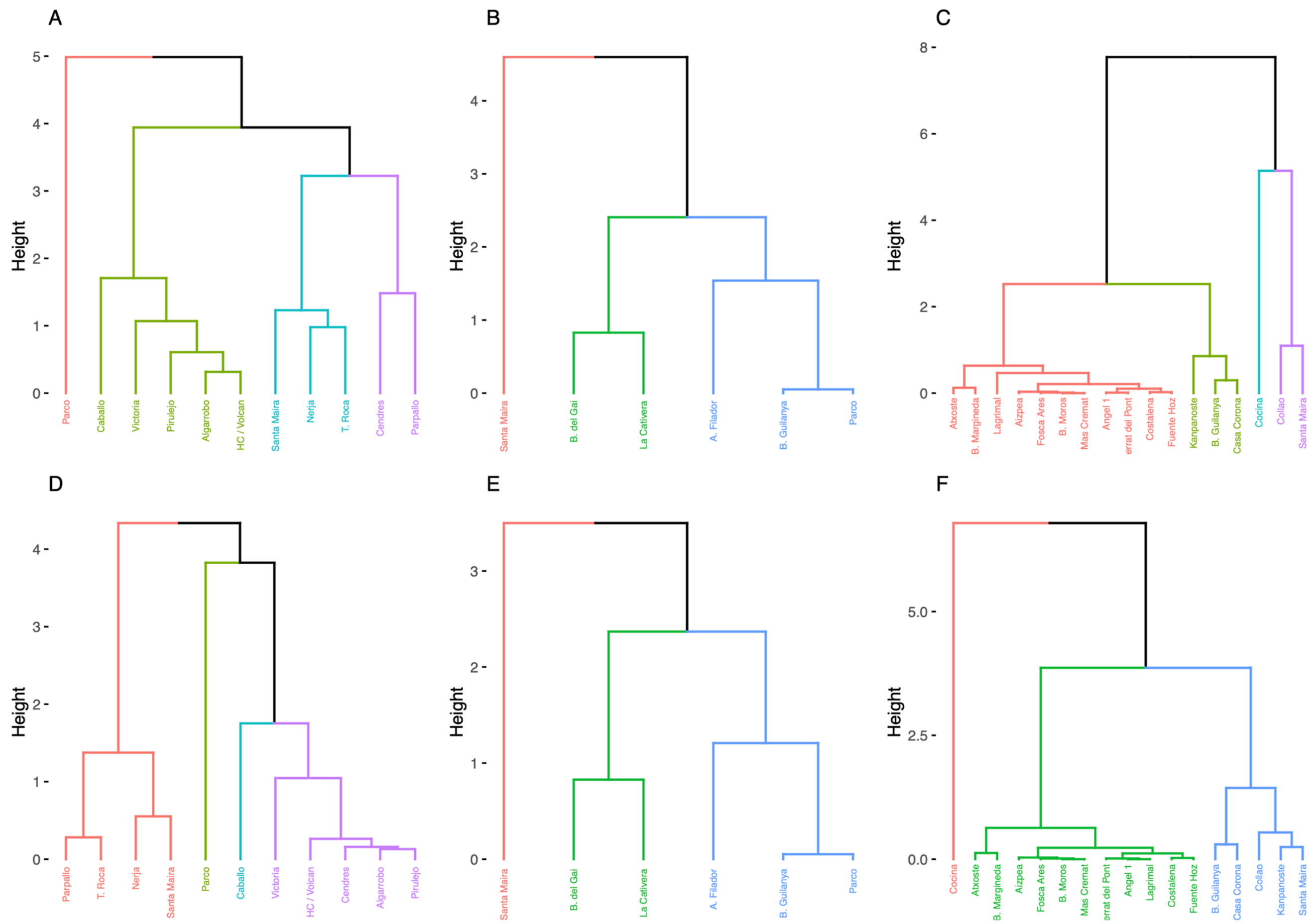

Fig. 6 Clusters made on archaeological sites with ornament items >4. The upper line corresponds to all species from Paleolithic (**A**), Epipaleolithic (**B**), and Mesolithic (**C**) sites. The bottom line refers to the sample without accounting for freshwater species from Paleolithic (**D**), Epipaleolithic (**E**), and Mesolithic (**F**) sites

species used (n = 11), but with reduced presence (< 10 remains), except for *Columbella rustica*, which is the most common in most of the sites. It should be noted that most of the species associated with this group come from sandy-bottom habitats. The second group is characterized by three observations, one per geographical region. Exploring the species information we observe that the number used is lower than in the previous cluster (5), although both *Columbella rustica* and *Tritia reticulata* present values higher than 15 items. The following group is explained both by geography and functionality since they are in the eastern of Iberia and both are funerary necropolises sites (Gibaja et al. 2015; Morales-Pérez et al. 2017), but we do not have detailed data on their association with burials. Also, the two sites share 3 species in common (*Collumbella rustica*, *Tritia reticulata,* and *Antalis*). Finally, the last group corresponds to the Cueva Cocina site, which is characterized by the presence of more than 300 *Collumbella rustica* remains. These groupings become more nuanced if we process only the shell beads made on marine species (Fig. 6F). First, it should be noted that Cocina continues to be individualized concerning the rest of the archaeological sites. The next corresponds to the grouping of two clusters differentiated in Fig. 4C. This corresponds to sites from the eastern peninsular (Santa Maira, Collado, and Casa Corona) together with several from the Ebro and northeast (B. Guilanyà and Kampanoste) and all the species (except *Collumbela rustica*) correspond to sandy-bottom species. Finally, the last and most extensive grouping is the same as when the totality of species has been analyzed.

Can a relationship be observed between distance of access to the source and species diversity?

Finally, we have attempted closely to explore whether the degree of diversity documented in each archaeological site is influenced by the distance to the source of supply. *Columbella rustica* is the only species that is certainly of Mediterranean Sea origin. Therefore, in the assemblages in which this species is identified, the distance to the sea refers to the Mediterranean coasts, although

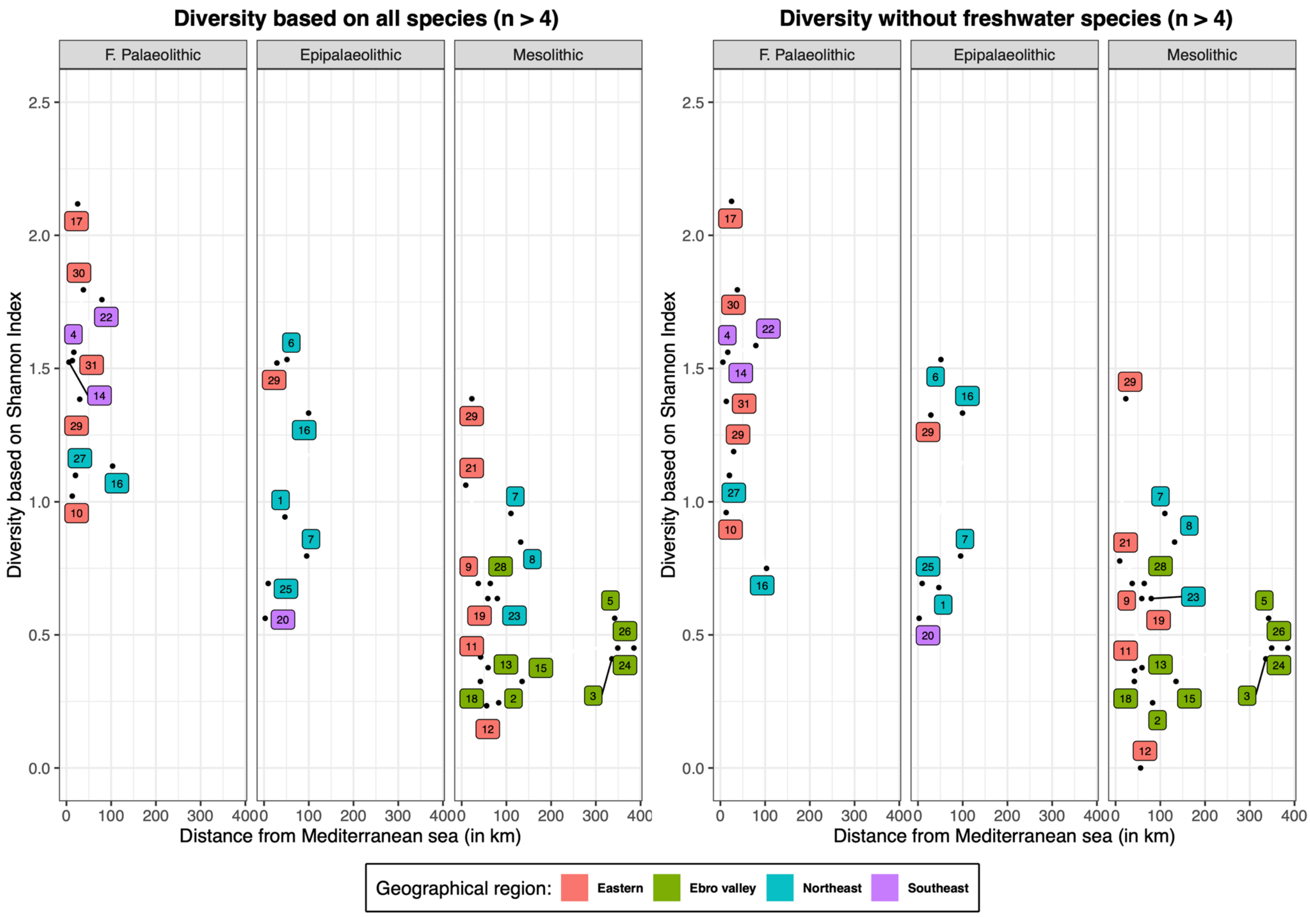

Fig. 7 Scatterplot relating the distance from the site to the coastline and the diversity score. The left plot corresponds to the diversity using all species, while the right section does not consider the freshwater species

the Cantabrian coast is closer to the upper Ebro valley sites. At first glance, we can indeed see a reduction in diversity over time (Fig. 7) as noted in Section 3.2. Nevertheless, if we examine the sample closely, we can see that regardless of the sample used (with/without fluvial elements) the settlements show the same behavior and can be grouped as follows:

- During the Final Paleolithic, the sites in southeastern Iberia present similar diversity values. However, it should be highlighted that Cueva de Nerja and Cueva de la Victoria, located less than 8 km from the coast, have a diversity value of zero (Table 3). This pattern is also observed in the deposits of northeastern Iberia. Here, we document neighboring sites with divergent diversity values; while Moli del Salt (no.27) shows a diversity close to 1, other sites such as Hort de Boquera or La Cativera have a calculated diversity of 0. For sites located in eastern Iberia, diversity values are > 1, regardless of their distance from the coastline. Finally, if we explore the diversity without freshwater species, the pattern is the same except for Cova del Parco (no.16) which reduces the diversity score in this case.
- According to the Epipaleolithic data, we observe that sites present lower diversity than in the previous period. Analyzing the plot in more detail, it should be noted that the site of Santa Maira during this cultural period presents the highest diversity score of the whole sequence analyzed. Nevertheless, if we focus on the northeastern sites, which correspond to many of the cases, only Abric del Filador (no.1) shows a reduction in diversity value when freshwater samples are discarded.
- As far as the Mesolithic is concerned, an important part of the archaeological sample presents diversity values of 0 and covers all the geographical regions considered (Table 3). Nevertheless, Santa Maira (no.29) and Collao (no.21) have a diversity index higher than 1 when all species are explored. This trend does not hold if freshwater species are discarded since the diversity value for El Collao goes from 1.06 to 0.77. For the rest of the sites, the diversity index shows small fluctuations, although it is worth mentioning the case of Cueva del Lagrimal (no.12) where de diversity score is 0 when removing species of freshwater origin. Finally, although it is observed throughout the diachronic analysis

Table 3 Diversity results associated with archaeological contexts with a minimum number of 5. Archaeological sites with a diversity value of 0 in both columns have not been represented in Figure 5. Likewise, the numbers in the ID column refer to the identification of the sites in the corresponding figure

Id	Site	Geographical Area	Period	Diversity	Diversity Freshwater
1	A. Filador	Northeast	Epipalaeolithic	0.943	0.678
2	Angel 1	Ebro valley	Mesolithic	0.245	0.245
3	Aizpea	Ebro valley	Mesolithic	0.410	0.410
4	Algarrobo	Southeast	F. Palaeolithic	1.561	1.561
32	Assut Almassora	Eastern	Mesolithic	0.000	0.000
5	Atxoste	Ebro valley	Mesolithic	0.562	0.562
6	Balma del Gai	Northeast	Epipalaeolithic	1.533	1.533
7	Balma Guilanya	Northeast	Mesolithic	0.956	0.956
7	Balma Guilanya	Northeast	Epipalaeolithic	0.796	0.796
8	Balma Margineda	Northeast	Mesolithic	0.849	0.849
33	Barranc Fontanella	Ebro valley	Mesolithic	0.000	0.000
9	Benamer	Eastern	Mesolithic	0.693	0.693
34	B. Moros	Ebro valley	Mesolithic	0.000	0.000
10	Cendres	Eastern	F. Palaeolithic	1.021	0.960
11	Cocina	Eastern	Mesolithic	0.417	0.366
12	Lagrimal	Eastern	Mesolithic	0.234	0.000
13	Mas Cremat	Ebro valley	Mesolithic	0.377	0.377
14	Caballo	Southeast	F. Palaeolithic	1.523	1.523
35	Casa Corona	Eastern	Mesolithic	0.000	0.000
15	Costalena	Ebro valley	Mesolithic	0.325	0.325
16	Parco	Northeast	Epipalaeolithic	1.332	1.332
16	Parco	Northeast	F. Palaeolithic	1.133	0.750
17	Parpallo	Eastern	F. Palaeolithic	2.118	2.128
18	Fosca Ares	Ebro valley	Mesolithic	0.325	0.325
19	Llatas	Eastern	Mesolithic	0.637	0.637
20	Nerja	Southeast	F. Palaeolithic	0.000	0.000
36	Victoria	Southeast	F. Palaeolithic	0.000	0.000
21	Collao	Eastern	Mesolithic	1.063	0.778
22	Pirulejo	Southeast	F. Palaeolithic	1.758	1.586
37	Falguera	Eastern	Mesolithic	0.000	0.000
23	Font Ros	Northeast	Mesolithic	0.637	0.637
24	Fuente Hoz	Ebro valley	Mesolithic	0.451	0.451
38	H. Boquera	Northeast	F. Palaeolithic	0.000	0.000
39	Kanpanoste	Ebro valley	Mesolithic	0.000	0.000
40	K. Goikoa	Ebro valley	Mesolithic	0.000	0.000
25	La Cativera	Northeast	Epipalaeolithic	0.693	0.693
25	La Cativera	Northeast	F. Palaeolithic	0.000	0.000
41	Mangranera	Eastern	Mesolithic	0.000	0.000
26	Mendandia	Ebro valley	Mesolithic	0.451	0.451
27	Moli del Salt	Northeast	F. Palaeolithic	1.099	1.099
42	P. Diablo	Ebro valley	F. Palaeolithic	0.000	0.000
43	P.Comptador	Eastern	Mesolithic	0.000	0.000
44	Padre Areso	Ebro valley	Mesolithic	0.000	0.000
28	Pontet	Ebro valley	Mesolithic	0.693	0.693
29	Santa Maira	Eastern	Epipalaeolithic	1.520	1.325
29	Santa Maira	Eastern	F. Palaeolithic	1.384	1.188
29	Santa Maira	Eastern	Mesolithic	1.386	1.386
45	Serrat del Pont	Northeast	Mesolithic	0.000	0.000
30	Tossal de la Roca	Eastern	F. Palaeolithic	1.795	1.795
31	HC / Volcan	Eastern	F. Palaeolithic	1.529	1.376

Table 3 (continued)

Id	Site	Geographical Area	Period	Diversity	Diversity Freshwater
46	Zatoya	Ebro valley	Mesolithic	0.000	0.000

(Fig. 7), it is during the Mesolithic where the non-existence of a relationship between diversity score values and distance to the coastline is most clearly observed, since sites with geographical distance < 50 km from the sea have similar diversity values to sites located more than 350 km away.

Discussion

The results section notes three potential biases that may affect the available data. The first issue pertains to the differences in recovery techniques used in the compared collections. Some of the collections were excavated almost a century ago, such as the Parpalló assemblage (Pericot 1942; Soler Mayor 1990; Vidal López 1947;). Additionally, the biometric data of Santa Maira indicate that recent collections contain ornaments with dimensions less than 5 mm, which were impossible to recognize in the earlier collections (Soler Mayor and Aura Tortosa 2021). The second issue pertains to the varying levels of representation across sites and phases. The Ebro Valley and IMR-southeast regions being the least represented. The third issue concerns the number of assemblages and objects available for each phase, revealing a greater number of objects for the extreme phases (Final Paleolithic and Mesolithic) compared to the middle phase (Epipaleolithic).

These situations are the result of different regional research traditions. We understand the data to be significant of the composition of pendant-ornaments assemblages in the IMR and Ebro valley throughout the three chrono cultural phases. Studies on the shell beads of the Hunter-gatherer-fishers of the IMR have been limited to specific sites, archaeological phases, or subregions. For example, some researchers have conducted their work on a specific site (Jordá Pardo 1986; Soler Mayor 1990, 2015; Aura Tortosa et al. 2006; Soler Mayor et al. 2013; Avezuela Aristu et al. 2011; Lloveras et al 2019; Soler Mayor and Aura Tortosa 2021; Pascual-Benito and García-Puchol 2021) or on a specific archaeological phase (Avezuela Aristu and Álvarez-Fernández 2012), while Álvarez-Fernández (2006), Estrada (2009) and Martínez (2015) studied regions. It is important to expand the scope of these studies to gain a more comprehensive understanding of the topic. In this sense, a comparative study between the Paleolithic and Mesolithic ornament assemblages of the Eastern and Southeast subregions of the IMR (Cotino Villa and Soler Mayor 1999) suggested that the greatest similarities were internal, at the level of each site, and at the level of each subregion. Likewise, In the Ebro valley, there are studies with a diachronic perspective that analyze the relationships of the remains with the the Cantabrian region (Álvarez-Fernández 2006). Finally, a paper of the geographic and chronological patterns of taxa used for Mesolithic ornament has been published for Iberia, applying a Social Network Analysis perspective (Cucart-Mora et al. 2022).

Despite the above, the evidence of our results suggests that there are clear diachronic changes in the composition of the assemblages. This evolution could have been influenced by changes in species availability due to sea level rise or cultural decisions.

- Regarding the environmental hypothesis, changes in the position of the coastline between the end of the Late glacial and the Early Holocene flooded an uneven extension of low-lying beaches (Jordá Pardo et al. 2011; Aura et al. 2019). This process coincides with a halving of objects made on sandy-muddy bottom species and a three-fold increase of rocky substrate objects in the Mesolithic phase compared to the Magdalenian phase. In the Mesolithic period, the presence of objects made from fluvial species (*Theodoxus fluviatilis*) doubled, possibly due to both inland movement of coastal bars and lagoons (Carmona et al. 2016) as well as increased rainfall, indicated by the expansion of mixed forest (Carrión 2005). These changes at the SM site may be linked to the various catchment areas of the nearby coast, which were located between 30 and 23 km during the analyzed phases and included estuaries, coves, and cliffs.
- When considering the cultural motivation behind changes in species selection, it is important to consider all available regional data. Diversity indices reveal significant differences between phases, particularly when comparing the oldest and most recent phases. Furthermore, the Epipaleolithic phase exhibits similar indices to those of the Final Paleolithic phase (see Table 3). The table illustrates a clear trend over time towards a reduction in diversity across all groups analyzed, including assemblages of both more and less than four objects, as well as shell beads assemblages containing marine and fluvial species, or exclusively marine species. This indicates that the loss of diversity is a widespread and consistent feature, observed in sites both near and far from the present-day coast. The Final Paleolithic phase had sites on the coast, such as Cueva de Nerja or Cueva Victoria, with diversity indices equal to zero in two locations that offer marked differences in the species exploited for their consumption (Álvarez-Fernández et al. 2022). However, the Ebro valley during the Mesolithic phase had sites like Aizpea and Fuente Hoz, located several hundred kilometers away, with higher diversity indices than the

previous ones. This suggests that the sites located on the coast during the Final Paleolithic phase had the lowest diversity indices, despite being from the phase with the highest average diversity indices.

These results raise questions about whether the selection of marine species is primarily influenced by the accessibility of their direct catchment areas, as distance from the coast does not create clear distinctions between coastal and inland sites. Under these circumstances, it could be expected that the assemblages would exhibit a regional clustering tendency due to the closer relationships between the nearest hunter-gatherer-fishers groups. However, the results of the cluster analysis are partially inconclusive. In the different groupings by phases, deposits from other regions are included in mostly regional groups. For example, HC-VF is included in the group of Final Paleolithic deposits of the Southeast subregion, and Cueva de Nerja is included in the Eastern subregion.

The distance of the shell beads recovered from the archaeological sites concerning their catchment areas allows some assessment of their circulation. The only ubiquitous species for all sites is *Theodoxus fluviatilis*, as it is accessible to both inland and near-shore sites. Marine species, on the other hand, allow measurement of the distance between their catchment area and their 'dispersal' point. In this case, their choice can be related not only to their ecological availability, as in the case of coastal sites, but also to the mechanisms of interaction between regional groups.

Material evidence of this connection between sites, regions, and groups has been pointed out from the dispersal of a Mediterranean marine species, such as *Columbella rustica*, identified both in the Ebro Valley, the Cantabrian Sea, and more continental regions. (Álvarez Fernández 2008). Probably, the collection of local species was influenced by the ecological conditions around the sites. For its part, long-distance, transferred circulation requires a socio-cultural perspective (Rigaud 2011). In a certain sense, this double strategy would be the result of the interaction between ecological factors and cultural decisions.

On the other hand, the diachronic changes observed in the diversity of the assemblages, the preference for certain taxa and their circulation at distances greater than 300 km from their catchment areas could be indicative of changes in social boundaries and a more rigid normativity in the Mesolithic compared to previous phases. This phenomenon is not only observed in the generalization of *Columbella rustica* as the dominant taxon, which coincides with processes observed in Mediterranean regions (Álvarez-Fernández 2008; Bertolini et al. 2016; Boric & Cristiani 2016), but also in the identification of changes in other variables of the archaeological record, such as the lithic productions. In the field of lithic industry, there is evidence of a transition from microlaminar production systems to a flake industry. Following this, a highly standardized blade industry emerged in the central-western Mediterranean to produce geometric arrowheads.

Concluding remarks

This work has focused on the exploration of the continuity and rupture trends between the Final Paleolithic and the Mesolithic from the information recovered in the west mouth of Santa Maira. The results conclude the existence of a continuity between the Late Paleolithic and the Epipaleolithic and the existence of a break with the Mesolithic. Therefore, the evolution of the shell beads and pendants reinforces the phyletic relationship between the Final Paleolithic and Epipaleolithic phases, considering non-functional variables, deepening the techno-economic differences already described concerning the Mesolithic (Aura et al. 2006), without forgetting that between the two phases there are differences but also signs of continuity (Soto et al. 2023).

Likewise, from the Santa Maira sample, a regional approach has been made, although most of the data and interpretation possibilities are concentrated on the comparison between the phases of its extremes, which has allowed us to reinforce their differences. These have been observed at the taxonomic level allowing us to identify a gradual reduction in species diversity and to analyze it both about the catchment habitats and, above all, with the distance of each assemblage from the coastline.

Most of the Late Paleolithic, Epipaleolithic, and Mesolithic ornaments were made on malacofauna in the study area. This selection defines the strategies of regional collection and circulation. A general feature is that Gastropoda is the preferred class for making the ornament compared to Bivalvia and Scaphopods. A few gastropod species concentrate most of the shell beads: *Columbella rustica* during the Mesolithic and *Triria neritea / pellucida* during the Late Paleolithic and Epipaleolithic. Fluvial species, mainly *Theodoxus fluviatilis*, account for just over 7% of the total. Other species are located with low values such as *Tritia reticulata, Homalopoma sanguineum* or *Trivia* sp. This distribution undergoes diachronic changes, but these are its basic characteristics.

Finally, further research focused on both the evaluation of the representativeness of the sample to the volume of the excavation as well as analysis on a macro-regional (Mediterranean) scale will be necessary to conclude whether the changes in social boundaries and the standardization observed with the Mesolithic identified in this work are confirmed and, above all, whether they can be traced in the Mediterranean.

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Data availability All the information necessary to replicate this work is available in the repository Zenodo: https://doi.org/https://doi.org/10.5281/zenodo.10883001.

Declarations

Competing interest The authors declare no competing interests.

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