RECONSTRUCTING MESOLITHIC SOCIAL NETWORKS ON THE IBERIAN PENINSULA USING ORNAMENTS

Cucart-Mora¹, Carolina; Gómez-Puche, Magdalena¹; Romano, Valéria¹; Fernández López de Pablo, Javier¹; Lozano, Sergi²³

¹Instituto Universitario de Investigación en Arqueología y Patrimonio Histórico (INAPH), Universidad de Alicante, Edificio Institutos Universitarios, 03690 San Vicente del Raspeig, Alicante, Spain.

²Departament d'Història Econòmica, Institucions, Política i Economia Mundial, Universitat de Barcelona, Avinguda Diagonal 690, 08034 Barcelona, Spain

³Universitat de Barcelona Institute of Complex Systems (UBICS), Universitat de Barcelona, Martí Franqués 1, 08028 Barcelona, Spain

Highlights

- Compositions of ornament assemblages were used to reconstruct Mesolithic social networks
- The overall network topology did not change between the Early and Late Mesolithic
- Network analysis suggests that most interactions took place over distances under 300 kilometres
- *Columbella rustica* might have been exchanged through indirect interactions that took place over distances of more than 500 kilometres

Abstract

Archaeologists have been reconstructing interactions among hunter-gatherer populations for a long time. These exchanges are materialized in the movements of raw materials and symbolic objects which are found far from their original sources. A social network, i.e., the structure constituted by these interactions, is a well-established concept in archaeology that is used to estimate the connectivity of hunter-gatherer populations. The heuristic potential of formal network analysis, however, has been scarcely exploited in prehistoric hunter-gatherer archaeology. In this work, we use Social Network Analysis to analyse the interactions among

hunter-gatherers on the Iberian Peninsula in the Early and Late Mesolithic (10,200 to 7,600 cal BP). Ornaments are accepted markers of non-utilitarian mobility and exchange. We thus used ornaments as proxies for social interaction and constructed one network for each phase of the Iberian Mesolithic. We applied three levels of analysis: first, we characterised the overall structure of the networks. Second, we performed node-level analysis to uncover the most relevant nodes in each network. Finally, we conducted an exploratory analysis of the networks' spatial characteristics. No significant differences were found between the overall network topology of the Early and Late Mesolithic. This suggests that the interaction patterns among human groups did not change significantly at a peninsular scale. Moreover, the spatial analysis showed that most interactions between human groups took place over distances under 300 km, but that specific ornament types such as *Columbella rustica* and *Trivia sp.* were distributed over more extensive distances. To summarise, our findings suggest that Iberian Mesolithic social networks were maintained through a period of environmental, demographic, and cultural transformation. In addition, the interactions took place at different scales of social integration.

1.-Introduction

Archaeologists have been studying the interactions among hunter-gatherer populations for a long time. Such exchanges are embodied in the movement of raw materials and symbolic objects that have been found far away from their original sources (Wobst 1974, 1976; Gamble 1998). A social network, i.e., the structure that emerges from those interactions, is a well-established concept in archaeology which allows to estimate connectivity among hunter-gatherer populations. The heuristic potential of formal network analysis, however, has hitherto been scarcely exploited in prehistoric hunter-gatherer archaeology. This paper presents a first approach to the reconstruction and analysis of hunter-gatherer socio-spatial patterns of interaction between the Early Mesolithic (ca. 10,200 – 8,600 cal BP) and Late Mesolithic (8,600 – 7,600 cal BP) on the Iberian Peninsula. Hunter-gatherer (hereafter, H-G) social networks refer

to the structure resulting from inter- and intra-regional interactions within and among H-G regional groups. The function of these interactions, the resources used to maintain them, and their spatial scale all depend on the level of social integration in which they occur (Wobst 1974; Gamble 1998; Whallon 2006). Social interactions were embedded in the activities of all H-G groups, and as such, material culture patterns in the archaeological record are a direct result of these interactions (Coward 2010).

The number of studies on past population social networks has risen sharply in recent years (Peebles 2019), as is visible in the publication of specialised books (Knappett 2011), edited volumes (Knappett 2013; Brughmans et al. 2016), or journal special issues (Collar et al. 2015; Evans and Felder 2016). The potential of this methodological approach is illustrated by the wide range of case studies, topics and research questions to which network analysis has recently been applied: the detection of communities at Çatalhöyük (Mazzucato 2019); the emergence of inequality in Maya settlements (Thompson et al. 2021); the structure of Clovis social networks (Buchanan et al. 2019); or the rates of adoption and diffusion of innovation (Kandler and Caccioli 2016).

Nevertheless, the formal analysis of hunter-gatherer social networks is still very limited (Gjesfjeld 2015; Romano et al. 2020). Only two detailed studies in European Prehistory have been conducted. Riede (2014) modelled long-distance interactions using exotic non-utilitarian objects as proxies, such as ornament shells, amber and zoomorphic figurines made with known raw material sources. He showed that social network breakdowns could explain the reduction in technological complexity observed in southern Scandinavia after the Laacher See eruption (ca. 13,000 years ago). The second case study focused on the reconstruction of Lower Magdalenian social networks in the North of the Iberian Peninsula. Similarities of figurative portable art representations were used as a proxy for social interaction (Gravel-Miguel 2016). Here, the primary goal was to demonstrate that archaeological social networks are better

understood when they are interpreted in relation to their geographical and environmental contexts.

The challenge facing researchers who wish to study hunter-gatherer social networks is that social interactions are not directly preserved in the archaeological record: we thus have to rely on different proxies to approach them. Based on previous ethnographic and archaeological research, we decided to use ornaments as proxies to reconstruct social networks. In ethnographic studies on hunter-gatherer groups, ornaments express group affiliation, personal identity and status; they form a key part of the exchange systems between different groups (Wiessner 1984). In the archaeological record, ornaments have been used as a proxy to reconstruct regional and even linguistic groups on the basis of social identity arising from shared cultural practices (e.g. Newell et al., 1990; Rigaud and Gutiérrez-Zugasti, 2016; Vanhaeren and d'Errico, 2006). Specifically, the geographical distribution of a certain type of ornament, or a collection of ornaments, over specific chronological periods has been used to delineate the geographical reach of these groups. Ornaments are also considered a proxy for interaction between distant groups (e.g. Boric and Cristiani, 2016; Riede, 2014). Concretely, when they are found far away from their raw material source, they are interpreted as a proxy for transport and exchange, associated with the establishment and maintenance of social interactions (Newell et al. 1990; Whallon 2006).

Here, we focus on reconstructing and comparing social networks in the Early and Late Mesolithic on the Iberian Peninsula. This was a period of very significant transformations at the climatic, environmental, demographic, and technological levels. Chronologically, it unfolded (ca.10,200-7,600 cal BP) over the whole Early Holocene Boreal and the onset of the Middle Holocene Atlantic chronozones. These latter periods are characterised by a global trend of stabilisation under warmer and wetter climatic conditions (Cacho et al. 2001), interrupted by several cooling events, the most notable being the 8.2 kya climatic event (López-Sáez et al. 2007). These climatic

changes had a transformative effect on the environment with a sea level rise (Peltier 2002) and the expansion of deciduous and thermophilous forests (Carrión et al. 2010; Gomes et al. 2020). With the onset of the Mesolithic came a shift in subsistence strategies: hunted species diversified and the exploitation of marine resources intensified (Aura et al. 2009; Alday and Soto 2017). From a demographic perspective, according to a logistic model of population growth (Fernández-López de Pablo et al., 2019), the period under study was characterised on the Iberian Peninsula by increasing population levels, subject to different subregional variation patterns. One of such subregional patterns, the Atlantic region of central and southern Portugal, has been recently described (McLaughlin et al. 2021): environmental carrying capacity shifts in estuarine areas were found to be closely linked to an increase in relative population size and settlement nucleation during the Late Mesolithic.

Culturally, the Iberian Peninsula Mesolithic is divided into two major cultural phases corresponding to two different technocomplexes. The first, the Early Mesolithic, also called the Notched and Denticulated Mesolithic (ca. 10,200-8,600 cal BP), is technologically characterised by expeditious flake debitage strategies used to produce assemblages dominated by notches, denticulates and scrapers, including macrolithic tools (Alday 2006). During the second phase, the Late Mesolithic or the Geometric Mesolithic (ca. 8,600-7,600 cal BP), debitage systems changed radically towards the production of blades and bladelets, as well as projectiles with geometric microliths, mainly trapezes and triangles, using the microburin technique (Utrilla and Montes 2009).

Studying social networks during this period is relevant for two reasons. First, because SNA allows us to address the impact of demographic changes – recently documented on the Iberian Peninsula (Fernández-López de Pablo et al. 2019; McLaughlin et al. 2021) – on the socio-spatial structure of postglacial populations. Second, SNA enables us to observe whether populations relating to two very different and successive techno-complexes –the Notched and Denticulates

Mesolithic and the Geometric Mesolithic (Alday 2006; Utrilla and Montes 2009) – interacted in different ways.

2.- Data and Methods

2.1.- Data collection

A georeferenced database of ornament assemblages from the Iberian Peninsula dated to the Early and Late Mesolithic was elaborated using specialised publications and grey literature. This database is part of a much more extensive relational database drawn up for the ERC project Paleodem. Table 1 summarises the information recorded in the database (see Supplementary materials S.Tables 1 and 2 for details). The original database contains a total of 106 assemblages from 62 archaeological sites. Considering ornament assemblages by chrono-cultural period, we have a higher number of Late Mesolithic sites compared to Early Mesolithic sites.

	Sites/Assemblages (raw data)	Sites/Assemblages (curated/aggregated)
Early Mesolithic	26/39	25/25
Late Mesolithic	36/67	35/35
Total	62/106	60/60

Table 1. Summary of the information contained in the database.

A data quality control protocol was followed to establish four different levels of chrono-cultural reliability of the ornament assemblages (Supplementary Materials, S.Text.1). We then unified the contexts of the same site that were ascribed to the same Mesolithic phase, either the Early or Late Mesolithic. We referred to periodisation models to establish the chronological limits of both periods (Montes et al. 2006; Martí Oliver et al. 2009; Carvalho 2010; Aura et al. 2011; Bicho and Haws 2012; Soto et al. 2015; Straus 2018). Specifically, the Early Mesolithic included assemblages dated between 10,200 and 8,600 cal BP, while the Late Mesolithic included those between 8,600 and 7,600 cal BP.

Figure 1. Distribution of sites with ornament assemblages used to reconstruct the archaeological networks. Sites are identified by their ID number. The correspondence between IDs and names is detailed in the Supplementary materials S.Tables 1 and 2.

Since our objective was to account for the differences between the two units of the Iberian Mesolithic, we aggregated the levels from the same site which chronologically fell within the same unit – a common practice in the analysis of archaeological networks (Peeples et al. 2016). Once unified, the Early Mesolithic group contained 25 assemblages, and the Late Mesolithic contained 35 (the geographical distribution is illustrated in Fig.1). Worthy of note, these numbers preserve the original archaeological information ratio, in which the Late Mesolithic presents more sites and assemblages than the Early Mesolithic (Table 1). Next, we transformed the raw data to verify the impact of sample biases on ornament assemblages. We generated two file formats: (i) relative frequencies by ornament type; (ii) presence or absence of ornament type per assemblage (Supplementary materials S.Tables 1 and 2).

2.2.- Similarity matrices and network construction

We applied both Brainerd-Robinson's and Jaccard's similarity indexes to construct cultural similarity matrices of ornament assemblages – a step that is widely applied in the construction of archaeological networks (Peeples et al. 2016). Following the recommendations of Prignano

et al. (2017), we first conducted an exploratory analysis to detect which similarity coefficient better represented our dataset. Brainerd-Robinson indices were calculated in R version 4.0.5 (Team 2013), using the script provided in Peeples (2011), including tables with the relative frequency of ornament types. Jaccard indices were calculated using Past statistical software (Hammer et al. 2001) and the tables containing data on the presence/absence of ornament types in each assemblage. We then compared the resulting matrices. As expected (Prignano et al. 2017), Jaccard's coefficient showed to be more sensitive to the presence of the less widespread types in the sample, while Brainerd-Robinson highlighted the most common ones (Prignano et al. 2017). Given the extensive presence of *Columbella rustica* in the Iberian Mesolithic record (Álvarez Fernández 2008), the Brainerd-Robinson coefficient was not appropriate for our dataset. Therefore, we proceeded with matrices based on Jaccard's similarity coefficient.

Similarity matrices were transformed into networks to prepare them for social network analysis (SNA). In this approach, social actors and their interactions are mathematically quantified and graphically represented as nodes and links. SNA offers a rigorous conceptual framework to describe the structure of networks together with methods to analyse and interpret them (Mills 2017). Specifically, we constructed a similarity network for each period of interest on the assumption that ornament assemblage similarities reflect levels of social interaction intensity. In our networks, nodes represent ornament assemblages and links represent a similarity among them. No threshold was imposed to establish links between nodes: a link connected any pair of nodes that showed any level of similarity. These links are undirected since similarity is a non-directed phenomenon. Their weight (i.e., the value quantifying their importance) corresponds to the similarity index. We used igraph R package (Csardi G 2006) to construct and analyse the networks.

As part of the process of network construction, we needed to assess the impact of archaeological data reliability on the network structures. To this end, we constructed and compared several networks, capturing different levels of reliability. First, we constructed one network for each period (the Early Mesolithic and Late Mesolithic) using archaeological contexts that reached the chrono-cultural reliability levels 1 and 2. A second pair of networks was then elaborated by adding the assemblages from level 3 contexts. Assemblages classified as level 4 were not used in any analytical step due to their significant unreliability. Next, we calculated the overall structure of our four networks using density, average degree, weighted average degree, clustering coefficient, and average path length metrics (see S.Table 3 and S.Text 2 in the Supplementary materials for further details). Following a careful comparison of the global metrics of the networks for each period, we concluded that the addition of less reliable information (i.e., level 3) did not alter the overall network topology but did contribute to network completeness. Consequently, we decided that the final networks to be analysed in depth would include all assemblages up to a chrono-cultural reliability level 3, resulting in an Early Mesolithic network of 25 assemblages and a Late Mesolithic of 35 assemblages.

2.3.-Network analysis

Three complementary approaches were used to analyse the networks. All network metrics involved in these three analytical approaches are defined in Table 2. First, we characterised the general structure of both networks using density, average degree, weighted average degree, clustering coefficient and average path length. Second, a node-level analysis was performed to uncover the most relevant nodes in each network (i.e., the most connected nodes or those with the strongest connections). Finally, we evaluated the networks using spatial characteristics. A summary of the methods applied can be found in Table 2.

Specifically, we performed a series of analysis for the spatial characterisation. First, we investigated whether nodes ascribed to the same geographical unit showed connection preference. To do so, we calculated the assortativity coefficient for both networks (Newman 2002). Second, we explored the differences regarding the geographical distances covered by the networks' links for each period. Fig. 5 presents the frequency of links in relation to the distance covered by the links. Although the links reflect a shared cultural practice rather than direct contacts between hunter-gatherer groups, we chose to take the topography into account and adopted a human perspective regarding the distance measurements. We produced a matrix of geodetic distances geodetic, i.e., the shortest distance between each pair of nodes connected through a link, using the XY To Line geoprocessing tool from ArcGIS (ESRI, 2017) considering a 3 arc Digital Elevation Model of the Iberian Peninsula (Instituto Geográfico Nacional, ETRS89, UTM zone 30). Lastly, we examined the relation between the weight of the links and their covered distance using Spearman's correlation test.

Level	Network metrics	Definition	Meaning in the study case	Reference
Network level	Density	Defined as the ratio of the number of links and the number of possible links.	The general level of similarity between the different assemblages in the network. Values range from 0 to 1. High values imply that most nodes present one or a few ornaments in common.	Scott (2017)
	Clustering coefficient	The number of closed triads out of the total in the network, where a triad is set of three nodes with two (open triplet) or three (closed triplet) undirected links between them.	This is a general measure of cohesion. It is based on the existence of triads sharing a similar ornament assemblage.	Scott (2017)
	Average path length	It is defined as the average number of steps of the shortest path for all possible pairs of nodes in the network.	It measures "how far" nodes are from each other and can be used to investigate the efficiency of information transmission within the network for example.	West 1996
	Assortativity coefficient	It measures the level of homophily of the network. It is based on some node labelling or values assigned to nodes. A high coefficient means that connected nodes tend to have the same label or similar assigned values.	This statistic will tell us if the composition of an assemblage is similar to any other assemblage within the same geographical unit. It can be interpreted as regional traditions or common practice among groups.	Newman (2002)

Centrality	Betweenness centrality	This metric measures the number of times a node lies on the shortest path between other nodes.	Identifies the nodes that act as bridges between nodes in the network. High values in our case study would therefore correspond to the assemblages in the network that present unusual combinations of ornament types, making them the bridge between assemblages that have nothing in common.	Freeman (1979)
	Degree	The degree of a node is defined as the number of links connected to a specific node.	Determines which assemblages have more types in common with the nodes in the network. A similarity between nodes can be due to very diverse assemblages or assemblages only containing a type widely present across the nodes.	Freeman (1979)
	Weighted degree	Like the degree, this measure is based on the number of links to a node but pondered by the weights of the links.	Identifies the nodes which have a lot in common with a high number of other assemblages in the network.	Freeman (1979)

Table 2. Definition of network properties and their respective meanings in our case study.

4.-Results

Figure 2. Relative presence of ornament types in each Mesolithic phase on the Iberian Peninsula.

4.1.-Data variability and frequency distribution

We observed geographical and chronological patterns of the taxa used for the elaboration of ornaments. Assemblages were ascribed to one of the five geographical units (i.e. Cantabria, Atlantic, Mediterranean, Interior and Ebro Valley) which are traditionally used by Iberian prehistorians as units of analysis (e.g. Utrilla and Montes, 2009; Álvarez-Fernández, 2006). In

southern Portuguese sites, the most common taxon was *Theodoxus fluviatilis*. In the Cantabrian sites, the most numerous taxa were *Trivia sp.*, followed by *Littorina obtusata*. The Mediterranean record is dominated by *Columbella rustica*. Finally, in the Ebro Valley, we found a mixture of the ornaments documented in the Cantabrian and Mediterranean geographical units.

This representation pattern coincides with the observations made by Álvarez-Fernández (2010; 2011) regarding the Cantabrian and Ebro Valley. Chronologically, we observe that the same taxa were used to make ornaments during both periods. However, we could observe changes in the relative frequencies of some taxa (Fig. 2). For example, although *Columbella rustica* dominates in ornament assemblages in both phases, it is more frequent in the Late Mesolithic. The same pattern can be observed with respect to *Trivia sp.* Conversely, *Nassarius reticulata* is more frequent in the Early Mesolithic than in the Late Mesolithic. Despite the significant presence of region-specific taxa, ornament assemblages still show some inter-regional variability. Network analyses allowed us to use such variability to explore cultural patterns of interaction and potential changes throughout the Iberian Mesolithic.

4.2.- General structure characteristics

Network metric	Early Mesolithic	Late Mesolithic
Num. Nodes	25	35
Num. Links	129	268
Density	0.43	0.45
Clustering coefficient	0.77	0.80
Average path length	1.69	1.57

Table 3. Characterisation of the overall network in the Early and Late Mesolithic.

The results of the general structure analysis for both periods are presented in Table 3 and Fig. 3. Both the Early and Late Mesolithic networks presented density values below 0.5 (i.e., less than half the connections they could have had). Based on our link definition – i.e., connecting any pair of assemblages displaying any level of similarity –, these density values are rather low.

Figure 3. Graphical representation of networks corresponding to the Early Mesolithic (left), and to the Late Mesolithic (right). The graphical representation was based on the Fruchterman-Reingold layout algorithm (Fruchterman and Reingold 1991).

One can observe only a slight difference between the clustering coefficient values and average path length between both networks. A more relevant aspect, however, is the relationship between both metrics. Both networks yielded high clustering coefficient values, and low average path length ones. These results suggest that our two networks present highly similar structures. In other words, no significant changes could be observed between the Early Mesolithic and the Late Mesolithic networks.

4.3.- Centrality metrics

Each node's specific centrality values are listed in the Supplementary material (S.Table 4 and 5). Here, we show their distribution on the Iberian Peninsula, and we refer to nodes with the highest values (i.e., the quarter of the nodes with the highest values for each specific metric).

The highest degree nodes in the Early Mesolithic represent the assemblages from sites located in Alicante, Northern Catalonia, and the upper Ebro Valley (see the network map layout in Fig. 4 a and d), including the sites of Santa Maira, El Collado and Atxoste. In the Late Mesolithic network, the nodes with the highest values in this metric are concentrated within the Mediterranean geographical unit and the lower and upper Ebro River basin, three of which are Fuente Hoz, Aizpea and Pontet, among others. Conversely, the nodes with the lowest values are situated in Portugal and the western half of the Cantabrian region.

Interestingly, most high weighted degree nodes did not in fact correspond to the nodes that yielded the highest degree values in both networks (see the network map in Fig. 4 b and e). In the Early Mesolithic network, these nodes represent sites located in Alicante and the lower and upper Ebro valley, such as the sites of Angel 1, Arenal de la Virgen, Costalena or Kanpanoste Goikoa. In turn, the nodes which yielded the highest weighted degree values are located in Alicante, the lower Ebro Valley and the western Pre-Pyrenees, including El Esplugón, Costalena or Casa Corona. All these nodes, in both networks, share a common feature: they represent assemblages composed of a single ornament type: *Columbella rustica*.

Early Mesolithic 10200 - 8600 cal BP

Late Mesolithic 8600 - 7600 cal BP

Figure 4. Network layout representing nodes/assemblages located according to their site coordinates. The colour represents the degree of each node: the darkest the colour, the higher its value. Each node is identified by its ID, see Table 1 and 2 for the ID's corresponding names. The existence of a link between two nodes indicates some degree of assemblage similarity. a) Early Mesolithic network node colour according to their degree; b) Early Mesolithic network node colour according to their weighted degree; c) Early Mesolithic network node colour according to their betweenness centrality; d) Late Mesolithic network node colour according to their degree; e) Late Mesolithic network node colour according to their weighted degree; f) Late Mesolithic network node colour according to their betweenness centrality. The figures were elaborated using Visone 2.20 (Brandes and Wagner 2004).

Lastly, the nodes presenting the highest betweenness (see the network map layout in Fig. 4 c and f) in the Early Mesolithic are located at four different ends of the peninsula: southern Portugal, the Cantabrian strip, the Lower Ebro Valley, and Alicante. Some of these nodes represent the assemblages from Barranco das Quebradas, Santa Maira, Balma Margineda or Atxoste. In turn, in the Late Mesolithic network, nodes with the highest values in this metric are in the Cantabrian strip, the Upper and Lower Ebro Valley and central Valencian Region. These nodes correspond to sites such as Benàmer, Los Baños, Aizpea and la Braña. Contrary to what we observed in the case of nodes with a high weighted degree, those with a high betweenness represent assemblages composed of various types of ornament.

4.4.- Spatial analysis

Figure 5. Distribution of the number of links according to the distance they cover. Early (upper) and Late (lower) Mesolithic networks. The red colour indicates the links established between sites where *Columbella rustica* is present.

Assortativity is a measure of homophily: it is positive when nodes tend to group together based on some shared characteristic (in our case, the geographical unit they belong to) and negative otherwise. The coefficient for the early Mesolithic network was 0.0836, while for the Late Mesolithic, it was 0.143. We observe a weak tendency for the geographical units in the Late Mesolithic network to be more connected than those in the Early Mesolithic network.

Fig. 5 shows the frequency distributions of geographic distances covered by links in each network. In both cases, the number of links were found to decrease as the covered distances increased. This finding was quantitatively supported by the results of several Spearman's correlation tests, showing a moderate negative correlation for both the Early Mesolithic (Rho=0.3304, $p=5.2442E-05$) and Late Mesolithic (Rho = - 0.29854, $p=1.461E-06$) networks. Moreover, both histograms presented a drop in link counts for distances greater than 300 km. In the Early Mesolithic network (upper panel), links covering distances below 300 km accounted for 55.56% of the total, and in the Late Mesolithic network (lower panel), the percentage rises to 66.93%. These results agree with the increasing regionalisation observed above.

Histograms in Fig. 5 also allow us to assess the maximum range of the interactions according to the type of ornament. Specifically, we were interested in the distribution of ornaments made with Cantabrian or Mediterranean endemic species outside their areas of origin, and whose occurrence could be interpreted as the result of the interaction and exchange between distant groups (Newell et al. 1990; Whallon 2006; Riede 2014). The interactions involving *Columbella rustica* (Fig. 5, in red) ranged from 100 to 500 kilometres during the Early Mesolithic, and from 100 to 550 kilometres during the Late Mesolithic. For their part, the interactions involving Cantabrian taxa (i.e., *Littorina obtusata* and *Trivia* sp.) suggest a smaller range of interactions. More concretely, the maximum range of distribution of *Littorina* in the Late Mesolithic is a little over 170 kilometres connecting the Cantabrian to the upper Ebro Valley. The maximum range of interaction involving *Trivia* would be almost 500 kilometres, from Asturias to Zaragoza. This

does not imply that a specific ornament travelled those distances during a single “interaction event”. Specifically, it means that within this range, interactions and exchanges took place in which these ornaments had a symbolic meaning. Lastly, the Spearman’s correlation test used to analyse the correlation between the weight of the links and the distance they covered showed a moderate negative correlation for both the Early Mesolithic ($p = -0.3304$, $p=5.2442E-05$) and Late Mesolithic ($p = -0.29854$, $p=1.461E-06$) networks.

Finally, to further explore these spatial observations, we divided the links into three groups according to their weight: low weighted links (values from 0.1 to 0.39), middle weight (from 0.4 to 0.69) and high weight (from 0.7 to 1). The distribution of the distances covered by the links in each group is illustrated in Fig. 6. The boxplots corresponding to the Early Mesolithic links (left) show a clear pattern: links with a low weight cover greater distances than those with a high weight, which thus cover the shorter distances. The pattern is not so clear for the Late Mesolithic links (right). As we can see in Fig. 6, there is an overlap between the distances covered by links included in groups 1 and 2.

5.- Discussion

5.1.-Evaluation of the method against the representativeness of the Iberian Mesolithic record: problems and corrective strategies

Figure 6. Distribution of distances covered by links in each similarity group.

The present study aimed at characterising and comparing the patterns of interaction among human groups during both phases of the Iberian Mesolithic. Because the use of SNA is still incipient in prehistoric archaeology, it was necessary, first, to evaluate the potential and the limitations of this methodological approach to understand Mesolithic social networks. Recent studies have discussed the potential problems of applying SNA to the H-G archaeological record, including: (i) the impact of taphonomic processes on the preservation of the material record – especially considering the sort of activity residues and the palimpsest nature of most archaeological deposits (Gravel and Coward in press); (ii) the so-called fragmentation problem (Gjesfjeld 2015) – concerning the representativeness of the archaeological record regarding different types of sites and research biases; (iii) the multi-scalar nature of social network structures (Hamilton et al. 2007) and its translation into specific network boundaries; and (iv) the difficulty of assessing contemporaneity among different archaeological contexts in the reconstructed networks (Gjesfjeld 2015).

As regards point (i), issues of site taphonomy regarding the preservation of material culture are indeed ubiquitous in the archaeological record. Their impact in the present study, however, was minimised due to the extensive use of all the available information on ornament assemblages, including different site types (open-air, caves and rock shelters) from a period that has in fact been intensively investigated over the past two decades (Alday and Cava Almuzara 2006; Utrilla and Montes 2009). In terms of the data's geographic representativeness (problem ii), the distribution maps of the analysed assemblages (Fig.1) reflect an evident lack of ornament assemblages from Andalusia and the Iberian interior. In Andalusia, the long stratigraphic sequences of Nerja and Bajondillo caves, on the Malaga coast, and Cueva del Nacimiento, in Jaén, were the only sites to yield a very limited lithic industrial evidence of trapezes dated to the Late Mesolithic (Cortés Sánchez 2007; Aura Tortosa et al. 2009). No ornament assemblages, however, have been published for those sites. With respect to the Iberian interior (referring to the North and South Iberian Plateaux), the lack of ornament assemblages is more clearly

associated with an almost total absence of Mesolithic sites. Over the past two decades, Iberian prehistorians have discussed whether this pattern of 'Mesolithic emptiness' reflects a reorganisation of the settlement distribution in favour of coastal regions, forced by a carrying capacity reduction due to the very dense development of thermophilus forests (Zilhão 2001; Fernández-López de Pablo and Gómez-Puche 2009); or, on the contrary, whether it results from chronological and research biases (Arias Cabal and Fano 2009). While such a discussion is beyond the scope of this study, we believe that the archaeological patterns observed in the Iberian interior reflect a significantly lower and chronologically discontinuous settlement density during the Early Mesolithic and an absence of reliable Late Mesolithic sites. In this respect, it is worth noting that commercial archaeology operations have been taking place on major motorway and wind farm infrastructure sites for over three decades. They supposedly provide chronologically unbiased evidence. Yet the documentation of open-air Mesolithic sites, such as Parque Darwin in Madrid (Escobar, 2010), remains an exception compared to both older (Cacho et al. 2010), and more recent prehistoric periods (Balsera et al. 2015).

Concerning the contemporaneity problem of the assemblages included in each network, we opted for chronological aggregation in two broads, but taxonomically relevant time slices of 1,600 and 1,100 years each. Such a chronological scale allows capturing the aggregated record resulting from persistent patterns of social interactions within the two major and successive Mesolithic taxonomic units derived from lithic typology. In addition, these chronological aggregation intervals are comparable to other SNAs recently applied to the Palaeolithic archaeological record, with 1,000-3,000 year ranges (Gravel-Miguel and Coward; Coward 2010; Rivero and Sauvet 2014).

Finally, regarding the problem of translating network boundaries into the geographic space (problem iii), in this case study, we decided to set the whole Iberian Peninsula as an analytical unit. The Iberian Peninsula has very well defined physical geographic boundaries and a *cul-de-*

sac position at the southwestern tip of the Eurasian continent. In addition, from a biogeographic perspective, a major divide between the Euro-Siberian and Mediterranean regions can be recognised. In conjunction with geographic physical barriers, the divide allows us to explore some regional and subregional variation patterns in the archaeological record in terms of social interactions.

5.2.-Main findings and prospective research

Our study focused on ornament assemblage similarities to reconstruct social interaction patterns. Using this archaeological proxy, we assumed that ornament assemblage similarities would positively correlate with interactions among different social groups sharing similar cultural practices (i.e., the greater the similarity, the greater the probability of social interaction). The reconstructed social networks were thus analysed and compared following a threefold investigation: general structural characteristics, nodes centrality and spatial distribution.

As far as social networks based on ornament assemblage similarity were concerned, our general structure analysis did not reveal any significant differences between both networks. One exception was the higher number of nodes and links for in the Late Mesolithic compared to the Early Mesolithic. This absence of difference suggests that populations interacted creating the same global patterns. This is a relevant finding considering the notable differences in lithic technology between the Early and Late Mesolithic. From a large-scale perspective, the continuity observed in ornament assemblage networks has also been recognised in other cultural domains such as settlement patterns, funerary practices based on individual burials (Gibaja et al. 2015), and foraging strategies. In turn, the similarity of the global interaction patterns suggests that Early Mesolithic social networks may have played a significant role in the transmission process, revealed by the appearance of trapeze microliths and bladelet debitage systems at the beginning of the Late Mesolithic. Testing such a hypothesis, however, would

require a finer grained chronological resolution and more sophisticated spatio-temporal network analyses (Lozano et al. 2020).

The greater number of nodes and links observed during the Late Mesolithic may reflect an increase in population densities regarding the previous Early Mesolithic, a pattern that has been consistently documented at both Iberian and subregional scales (Barton et al. 2018; Fernández-López de Pablo et al. 2019; McLaughlin et al. 2021). Our study was able to capture this overall trend. It lacked, however, the chronological resolution required to address the socio-ecological impacts on social networks of the Early Holocene episodes of rapid climatic change, such as the 10.2, 9.2, the 8.6 and the 8.2 kya climatic events (González-Sampériz et al. 2009; Fernández-López de Pablo and Jochim 2010; Bicho and Haws 2012; García-Martínez de Lagrán et al. 2014).

The analysis of the spatial properties of both networks led to some interesting observations. First, the assortativity coefficient showed that interactions among nodes were slightly more frequent within each regional unit than between nodes in different regions. This metric might reflect the sort of nested social organisation in which these connectivity patterns were embedded: interactions among individuals, families and bands from the same regional group were more common than among those from different regions (Newell et al. 1990). This finding leaves room for future studies to focus on identifying regional groups using multi-proxy evidence and other network methods (e.g., modularity, community detection).

Second, the comparison of the frequency distributions of the link distances between the Early and Late Mesolithic networks reveals different spatial scales of social interaction. As presented earlier, in order to explore the spatial extension, i.e., the whole range of possible interactions within each network, we did not establish any threshold in terms of distances or similarity between ornament assemblages. The resulting frequency distributions of link distances that we observe in these unconstrained networks ranged from 0 up to a maximum of 900 km in the Early Mesolithic, and to 800 km in the Late Mesolithic. In both networks, the highest frequency

distributions were clearly below 300 km with a progressive decrease for longer distances, i.e., in those ranging from 300 km to 900 km. The exploration/visualisation of the frequency distribution densities of the *Columbella rustica*, ornament provided a more robust proxy for the spatial scales of social interactions. As seen in Fig.5 (in red), the maximum distribution range was 0-500 km in the Early Mesolithic, and 0-600 km in the Late Mesolithic, with the highest distribution densities below 300 km. As from 300 km onwards, there is an evident a decline in the distribution frequencies. In addition, the decline seems more pronounced in the Late Mesolithic network than in the Early Mesolithic network, where the density is more sustained. Such differences might reflect different scales of interaction within and among different social integration units.

Other Mesolithic case studies have used shell ornaments as a proxy for social interaction. They provide a frame of reference to interpret the results of our own analysis even though these works did not apply the same methodology. In Southwestern Germany, according to the heuristic model proposed by Whallon (2006), decorative shells over distances ranging from 150 km to 250 km became very common during the Early Mesolithic, the ornament assemblages reflecting interactions within the same maximal band. In contrast, shell ornaments found between 250 to 400 kilometres would correspond to social interactions between adjacent maximal bands, and those over 600 km beyond adjacent maximal bands. In the Balkans, *Columbella rustica* shells have been documented over distances up to 100 km away from the shorelines during the Mesolithic (Boric and Cristiani 2016), and the same range is documented for the *Columbella rustica* in the Dolomites (Italy) (Álvarez Fernández 2008). Our results fall within the variability range of the cited examples, which, adopting the Whallon's model, would correspond to interactions taking place within minimal bands (distances up to 28km), within maximal bands (up to distances of 123 km) and, to a lesser extent, between different maximal bands (up to 325 km). The extent to which links above 325 km do represent interactions beyond

adjacent maximal bands remains to be further investigated, using additional and more accurately traceable raw material evidence.

The centrality analysis of our networks allowed us to relate assemblage composition to the interaction structures. In particular, assemblages sharing a very similar composition with many other assemblages in the network presented higher degree and weighted degree centralities. Conversely, nodes with high betweenness corresponded to assemblages with uncommon ornament combinations, thus becoming the bridges towards assemblages that had nothing in common.

Specifically, we found that in the Late Mesolithic network, the nodes with the highest betweenness drew an arc connecting the Mediterranean sites, through the Ebro Valley to the Cantabrian sites. This suggests that sites in the Ebro Valley may have bridged indirect interactions between Mediterranean and Cantabrian groups, in agreement with a common conception of the Ebro Valley as a communication route between these two regions. Nevertheless, such an interpretation should be treated with caution, because centrality measures generally (and betweenness, in particular) are known to be affected by record incompleteness (Peeples et al. 2016). The Iberian Peninsula has been researched to such an extent that we can assume that information gaps actually reflect population gaps. It is also true that open air settlements and certain mobility strategies leave small traces in the archaeological record. The potential influence of these information voids is thus also very difficult to quantify. However, based on all the above, given that our results do not contradict previously found evidence and interpretations, we believe that they can be cautiously accepted.

Researchers in archaeology are aware of the limitations of the application of SNA to archaeological studies. Different approaches have been designed to overcome them. Most of these approaches are devoted to quantifying the extent to which missing data affects the network analysis (e.g. Gjesfjeld, 2015), or to designing procedures that may help identify missing

links within networks (Tsirogiannis and Tsirogiannis 2016). To our mind, the best course of action to pursue the line of investigation inaugurated in the present work is to incorporate geographical and environmental information into the network analysis. More concretely, the approach applied by Gravel de Miguel (2016) to the study of Cantabrian Magdalenian social networks would lead to a more accurate interpretation of the networks, without the need for additional cultural information.

Conclusions

Our primary objective was to reconstruct and analyse the interaction patterns among groups in the Iberian Mesolithic. For this, we constructed and analysed socio-spatial networks using ornaments as a proxy for human interactions. Moreover, this case study was an opportunity to evaluate the potential of SNA in prehistoric hunter-gatherer research.

Our findings suggest that despite climatic, cultural, and population transformations, general patterns of human interactions remained unaltered between the two culturally different phases of the Iberian Mesolithic. We also observed the emergence of spatial patterns of interaction, in which most interactions potentially took place within a radius of 300 km. Based on Whallon's (2006) heuristic model of the spatial organisation of band-level foraging groups, we believe that these findings have captured the interactions that took place mainly within maximum bands, and between groups belonging to different maximum bands.

We also encountered a few limitations to the research approach applied, which are not exclusive to our case study. Indeed, they derive from the specific nature of archaeological information and can only be overcome by additional archaeological information, or the development of specific analysis methods that apply to this sort of data. The present case study not only demonstrates the potential of applying SNA to the interaction patterns of Iberian Mesolithic human groups, but it also indicates the direction to follow within this line of research.

BIBLIOGRAPHY

- Alday A (2006) El Mesolítico de muescas y denticulados en la cuenca del Ebro y el litoral mediterráneo peninsular: síntesis de los datos. In: Alday A (ed) Mesolítico de muescas y denticulados en la cuenca del Ebro y el litoral mediterráneo peninsular. Diputación Foral de Álava, departamento de Cultura, pp 303–317
- Alday A, Cava Almuzara A (2006) La unidad de Muecas y Denticulados del Mesolítico en el País Vasco: la formalización de un modelo cultural. In: Alday A (ed) El mesolítico de muescas y denticulados en la cuenca del Ebro y el litoral mediterráneo peninsular. Diputación Foral de Álava, Departamento de Cultura, pp 223–300
- Alday A, Soto A (2017) La Sociedad Mesolítica de la Península Ibérica. In: Pérez-Díaz S, Ruiz-Fernández J, López-Sáez J-A, García-Hernández C (eds) Cambio climático y cultural en la Península Ibérica: una perspectiva geohistórica y paleoambiental. Universidad de Oviedo, Oviedo, pp 75–91
- Álvarez-Fernández E (2006) Los objetos de adorno-colgantes del Paleolítico superior y del Mesolítico en la Cornisa Cantábrica y en el Valle del Ebro: una visión europea. Universidad de Salamanca
- Álvarez-Fernández E (2010) Shell beads of the Last Hunter-Gatherers and Earliest Farmers in South-Western Europe. *MUNIBE (Antropología-Arkeología)* 61:129–138
- Álvarez Fernandez E (2011) Personal Ornaments Made from Mollusc Shells in Europe during the Upper Palaeolithic and Mesolithic:: News and Views. In: Cakirlar C (ed) *Archaeomalacology Revisited*. Oxbow Books, pp 1–8
- Álvarez Fernández E (2008) The use of *Columbella rustica* (class: gastropoda) in the Iberian peninsula and Europe during the Mesolithic and the early Neolithic. *IV Congr del Neolítico Penins* 2:103–111

- Arias Cabal P, Fano MÁ (2009) ¿Mesolítico geométrico o Mesolítico con geométricos? El caso de la región cantábrica. In: Utrilla P, Montes L (eds) El Mesolítico geométrico en la Península Ibérica. Universidad de Zaragoza, Departamento de Ciencias de la Antigüedad, Zaragoza, pp 69–91
- Aura JE, Jordá JF, Montes L, Utrilla P (2011) Human responses to Younger Dryas in the Ebro valley and Mediterranean watershed (Eastern Spain). *Quat Int* 242:348–359.
<https://doi.org/10.1016/J.QUAINT.2011.01.023>
- Aura JE, Jorda Pardo JF, Morales J V, et al (2009) Economic transitions in finis terra : the western Mediterranean of Iberia. *Before Farming* 2:1–17
- Aura Tortosa JE, Jordà Pardo FJ, Pérez M, et al (2009) Epipaleolítico y Mesolítico en Andalucía Oriental primeras notas a partir de los datos de la Cueva de Nerja (Málaga, España). In: Utrilla P, Montes L (eds) El Mesolítico geométrico en la Península Ibérica. pp 343–360
- Balsera V, Díaz-del-Río P, Gilman A, et al (2015) Approaching the demography of late prehistoric Iberia through summed calibrated date probability distributions (7000–2000 cal BC). *Quat Int* 386:208–211.
<https://doi.org/https://doi.org/10.1016/j.quaint.2015.06.022>
- Barton CM, Aura Tortosa JE, Garcia-Puchol O, et al (2018) Risk and resilience in the late glacial: A case study from the western Mediterranean. *Quat Sci Rev* 184:68–84.
<https://doi.org/https://doi.org/10.1016/j.quascirev.2017.09.015>
- Bicho N, Haws J (2012) The Magdalenian in central and southern Portugal: Human ecology at the end of the Pleistocene. *Quat Int* 272–273:6–16.
<https://doi.org/https://doi.org/10.1016/j.quaint.2012.02.055>
- Boric D, Cristiani E (2016) Social Networks and Connectivity among the Palaeolithic and Mesolithic Foragers of the Balkans and Italy. In: Krauss R, Floss H (eds) Southeast Europe

- before neolithisation. Proceedings of the International Workshop within the Collaborative Research Centres sfb 1070 “RessourcenKulturen”, Schloss Hohentübingen, 9th of May 2014. Universität Tübingen, pp 73–112
- Brandes U, Wagner D (2004) Analysis and visualization of social networks. In: Graph Drawing Software. Springer, pp 321–340
- Brughmans T, Collar A, Coward F (2016) The Connected Past Challenges to Network Studies in Archaeology and History. Oxford University Press, Oxford
- Buchanan B, Hamilton MJ, David Kilby J (2019) The small-world topology of Clovis lithic networks. *Archaeol Anthropol Sci* 11:3537–3548. <https://doi.org/10.1007/s12520-018-0767-7>
- Cacho C, Martos JA, Jordá Pardo J, et al (2010) El Paleolítico superior en el interior de la Península Ibérica. Reflexión crítica y perspectivas de futuro. In: Mangado X (ed) El Paleolítico superior peninsular. Novedades del siglo XXI. Monografies del Seminari d’Estudis i Recerques Prehistòriques, 8, Barcelona, pp 75–96
- Cacho I, Grimalt JO, Canals M, et al (2001) Variability of the western Mediterranean Sea surface temperature during the last 25,000 years and its connection with the Northern Hemisphere climatic changes. *Paleoceanography* 16:40–52. <https://doi.org/https://doi.org/10.1029/2000PA000502>
- Carrión JS, Fernández S, González-Sampériz P, et al (2010) Expected trends and surprises in the Lateglacial and Holocene vegetation history of the Iberian Peninsula and Balearic Islands. *Rev Palaeobot Palynol* 162:458–475. <https://doi.org/https://doi.org/10.1016/j.revpalbo.2009.12.007>
- Carvalho AF (2010) Chronology and geography of the Mesolithic-Neolithic transition in Portugal. In: Armbruster T, Hegewisch M (eds) On Pre- and Earlier History of Iberia and

- Central Europe Studies in honour of Philine Kalb. Studien Tuden zur Archäeology, Europas 11. Dr. Rudolf Habelt GmbH, Bonn, pp 45–62
- Collar A, Coward F, Brughmans T, Mills BJ (2015) Networks in Archaeology: Phenomena, Abstraction, Representation. *J Archaeol Method Theory* 22:1–32.
<https://doi.org/10.1007/s10816-014-9235-6>
- Cortés Sánchez M (2007) Cueva Bajondillo (Torremolinos). Secuencia cronocultural y paleoambiental del Cuaternario reciente de la bahía de Málaga. Servicio de Publicaciones y Divulgación Científica de la Universidad de Málaga
- Coward F (2010) Small Worlds, Material Culture and Ancient Near Eastern Social Networks. In: Dunbar R, Gamble C, Gowlett J (eds) *Social Brain, Distributed Mind*. Oxford University Press, Oxford, pp 453–483
- Csardi G NT (2006) The igraph software package for complex network research
- Escobar Requena A (2010) Tras las huellas del cambio en el centro peninsular. La industria de muescas y denticulados del yacimiento Parque Darwin (Madrid) en el contexto del IX milenio BP. Universidad Autonoma de Madrid
- Evans S, Felder K (2016) Introduction: Making the connection: Changing perspectives on social networks. *Archaeol Rev from Cambridge* 29:9–17
- Fernández-López de Pablo J, Gómez-Puche M (2009) Climate change and population dynamics during the Late Mesolithic and the Neolithic transition in Iberia. *Doc Prehist* 36:67–96
- Fernández-López de Pablo J, Gutiérrez-Roig M, Gómez-Puche M, et al (2019) Palaeodemographic modelling supports a population bottleneck during the Pleistocene-Holocene transition in Iberia. *Nat Commun* 10:1872. <https://doi.org/10.1038/s41467-019-09833-3>

- Fernández-López de Pablo J, Jochim MA (2010) The impact of the 8,200 Cal BP climatic event on human mobility strategies during the Iberian Late Mesolithic. *J Anthropol Res* 66:39–68
- Freeman LC (1979) Centrality in social networks conceptual clarification. *Soc Networks* 1:215–239. [https://doi.org/10.1016/0378-8733\(78\)90021-7](https://doi.org/10.1016/0378-8733(78)90021-7)
- Fruchterman TM., Reingold E. (1991) Graph Drawing by Force-directed Placement. *Software-Practice Exp* 21:1129–1164
- Gamble C (1998) Palaeolithic society and the release from proximity: A network approach to intimate relations. *World Archaeol* 29:426–449.
<https://doi.org/10.1080/00438243.1998.9980389>
- García-Martínez de Lagrán I, Rojo-Guerra MA, Iriarte E, et al (2014) Paleoambiente y cambios culturales en los inicios del Holoceno: el abrigo de Artusia (Unzué, Navarra). *Trab Arqueol Navarra* 26:7–98
- Gibaja JF, Subirà ME, Terradas X, et al (2015) The Emergence of Mesolithic Cemeteries in SW Europe: Insights from the El Collado (Oliva, Valencia, Spain) Radiocarbon Record. *PLoS One* 10:1–18
- Gjesfjeld E (2015) Network Analysis of Archaeological Data from Hunter-Gatherers: Methodological Problems and Potential Solutions. *J Archaeol Method Theory* 22:182–205. <https://doi.org/10.1007/s10816-014-9232-9>
- Gomes SD, Fletcher WJ, Rodrigues T, et al (2020) Time-transgressive Holocene maximum of temperate and Mediterranean forest development across the Iberian Peninsula reflects orbital forcing. *Palaeogeogr Palaeoclimatol Palaeoecol* 550:109739.
<https://doi.org/10.1016/j.palaeo.2020.109739>
- González-Sampériz P, Utrilla P, Mazo C, et al (2009) Patterns of human occupation during the

early Holocene in the Central Ebro Basin (NE Spain) in response to the 8.2 ka climatic event. *Quat Res* 71:121–132.

<https://doi.org/https://doi.org/10.1016/j.yqres.2008.10.006>

Gravel-Miguel C (2016) Using Species Distribution Modeling to contextualize Lower Magdalenian social networks visible through portable art stylistic similarities in the Cantabrian region (Spain). *Quat Int* 412:112–123.

<https://doi.org/https://doi.org/10.1016/j.quaint.2015.08.029>

Gravel-Miguel C, Coward F Palaeolithic Social Networks and Behavioural Modernity

Hamilton MJ, Milne BT, Walker RS, et al (2007) The complex structure of hunter–gatherer social networks. *Proc R Soc B Biol Sci* 274:2195–2203.

<https://doi.org/10.1098/rspb.2007.0564>

Hammer Ø, Harper DAT, Ryan PD (2001) Past: Paleontological statistics software package for education and data analysis

Kandler A, Caccioli F (2016) Networks, Homophily, and the Spread of Innovation. In:

Brughmans T, Collar A, Coward F (eds) *The Connected Past. Challenges to Network Studies in Archaeology and History* 2. Oxford University Press, Oxford, pp 175–199

Knappett C (2011) *An archaeology of interaction. Network perspectives on material culture and society*. Oxford University Press, Oxford

Knappett C (2013) *Network Analysis in Archaeology. New Approaches to Regional Interaction*. Oxford University Press, Oxford

López-Sáez J-A, López-Merino L, Pérez Díaz S (2007) Crisis climáticas en la Prehistoria de la Península Ibérica: el Evento 8200 cal. BP como modelo. In: Salvador Rovira L, Heras GM, Moret Gener M, Ruiz Montero I (eds) *Actas VII Congreso Ibérico de Arqueometría (Madrid)*. Consejo Superior de Investigaciones Científicas (España, Madrid, pp 77–86

- Lozano S, Prignano L, Gómez-Puche M, Fernández-López de Pablo J (2020) Early Holocene Socio-Ecological Dynamics in the Iberian Peninsula: A Network Approach. In: Verhagen H, Borit M, Bravo G, Wijermans N (eds) *Advances in Social Simulation*. Springer, pp 287–290
- Martí Oliver B, Aura Tortosa JE, Juan Cabanilles J, et al (2008) El Mesolítico Geométrico de tipo “Cocina” en el País Valenciano. In: *El mesolítico Geometrico en la Península Iberica*, Monografía. Zaragoza-Jaca, pp 205–258
- Mazzucato C (2019) Socio-Material Archaeological Networks at Çatalhöyük a Community Detection Approach. *Front Digit Humanit* 6:8. <https://doi.org/10.3389/fdigh.2019.00008>
- McLaughlin TR, Gómez-Puche M, Cascalheira J, et al (2021) Late Glacial and Early Holocene human demographic responses to climatic and environmental change in Atlantic Iberia. *Philos Trans R Soc B Biol Sci* 376:20190724. <https://doi.org/10.1098/rstb.2019.0724>
- Mills BJ (2017) Social Network Analysis in Archaeology. *Annu Rev Anthropol* 46:379–397. <https://doi.org/10.1146/annurev-anthro-102116-041423>
- Montes L, Utrilla P, Mazo C (2006) El Epipaleolítico macrolítico en Aragón en el contexto del valle del Ebro y la Cataluña costera. In: *El mesolítico de muescas y denticulados en la cuenca del Ebro y el litoral mediterráneo peninsular*.
- Newell RR, Kielman D, Constandse-Westermann TS, et al (1990) *An Inquiry into the ethnic resolution of Mesolithic regional groups : the study of their decorative ornaments in time and space*, E.J. Brill. E.J. Brill, Leiden
- Newman MEJ (2002) Assortative Mixing in Networks. *Phys Rev Lett* 89:208701. <https://doi.org/10.1103/PhysRevLett.89.208701>
- Peebles MA (2019) Finding a Place for Networks in Archaeology. *J Archaeol Res* 27:451–499. <https://doi.org/10.1007/s10814-019-09127-8>

Peeples MA (2011) R Script for Calculating the Brainerd-Robinson Coefficient of Similarity and Assessing Sampling Error

Peeples MA, Mills BJ, Haas RW, et al (2016) Analytical Challenges for the Application of Social Network Analysis in Archaeology. In: Brughmans T, Collar A, Coward F (eds) The Connected Past. Challenges to Network Studies in Archaeology and History. Oxford university Press, Oxford, p 200

Peltier WR (2002) On eustatic sea level history: Last Glacial Maximum to Holocene. *Quat Sci Rev* 21:377–396

Prignano L, Morer I, Diaz-Guilera A (2017) Wiring the Past: A Network Science Perspective on the Challenge of Archeological Similarity Networks. *Front Digit Humanit* 4:13. <https://doi.org/10.3389/fdigh.2017.00013>

Riede F (2014) Eruptions and ruptures – a social network perspective on vulnerability and impact of the Laacher See eruption (c. 13,000 BP) on Late Glacial hunter-gatherers in northern Europe. *Archaeol Rev from Cambridge* 29:67–102

Rigaud S, Gutiérrez-Zugasti I (2016) Symbolism among the last hunter–fisher–gatherers in northern Iberia: Personal ornaments from El Mazo and El Toral III Mesolithic shell midden sites. *Quat Int* 407:131–144. <https://doi.org/10.1016/J.QUAINT.2015.10.029>

Rivero O, Sauvet G (2014) Defining Magdalenian cultural groups in Franco-Cantabria by the formal analysis of portable artworks. *Antiquity* 88:64–80. <https://doi.org/DOI:10.1017/S0003598X00050225>

Romano V, Lozano S, Fernández-López de Pablo J (2020) A multilevel analytical framework for studying cultural evolution in prehistoric hunter–gatherer societies. *Biol Rev*. <https://doi.org/10.1111/brv.12599>

Scott J (2017) Social Network Analysis

- Soto A, Alday A, Montes L, et al (2015) Epipalaeolithic assemblages in the Western Ebro Basin (Spain): The difficult identification of cultural entities. *Quat Int* 364:144–152
- Straus LG (2018) Environmental and cultural changes across the Pleistocene-Holocene transition in Cantabrian Spain. *Quat Int* 465:222–233.
<https://doi.org/https://doi.org/10.1016/j.quaint.2016.10.005>
- Team RC (2013) R: A language and environment for statistical computing. R Foundation for Statistical Computing
- Thompson AE, Feinman GM, Lemly M, Prufer KM (2021) Inequality, networks, and the financing of Classic Maya political power. *J Archaeol Sci* 133:105441.
<https://doi.org/https://doi.org/10.1016/j.jas.2021.105441>
- Tsirogiannis C, Tsirogiannis C (2016) Uncovering the hidden routes: algorithms for identifying paths and missing links in trade networks. In: Brughmans T, Collar A, Coward F (eds) *The Connected Past. Challenges to Network Studies in Archaeology and History*. Oxford University Press, Oxford, pp 103–122
- Utrilla P, Montes L (2009) *El Mesolítico geométrico en la Península Ibérica*. Universidad de Zaragoza, Departamento de Ciencias de la Antigüedad, Zaragoza
- Vanhaeren M, d’Errico F (2006) Aurignacian ethno-linguistic geography of Europe revealed by personal ornaments. *J Archaeol Sci* 33:1105–1128.
<https://doi.org/https://doi.org/10.1016/j.jas.2005.11.017>
- Whallon R (2006) Social networks and information: Non-“utilitarian” mobility among hunter-gatherers. *J Anthropol Archaeol* 25:259–270.
<https://doi.org/https://doi.org/10.1016/j.jaa.2005.11.004>
- Wiessner P (1984) Reconsidering the behavioral basis for style: A case study among the Kalahari San. *J Anthropol Archaeol* 3:190–234.

[https://doi.org/https://doi.org/10.1016/0278-4165\(84\)90002-3](https://doi.org/https://doi.org/10.1016/0278-4165(84)90002-3)

Wobst HM (1976) Locational relationships in Paleolithic society. *J Hum Evol* 5:49–58.

[https://doi.org/https://doi.org/10.1016/0047-2484\(76\)90099-3](https://doi.org/https://doi.org/10.1016/0047-2484(76)90099-3)

Wobst HM (1974) Boundary Conditions for Paleolithic Social Systems: A Simulation Approach.

Soc Am Archaeol Am Antiq 39:147–178

Zilhão J (2001) Radiocarbon evidence for maritime pioneer colonization at the origins of farming in west Mediterranean Europe. *Proc Natl Acad Sci* 98:14180 LP – 14185.

<https://doi.org/10.1073/pnas.241522898>