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Understanding human movement through spatial technologies. The role of natural areas of transit in the Late Prehistory of South-western Iberia

Entendiendo la movilidad humana mediante tecnologías espaciales: el papel de las áreas naturales de tránsito en el Suroeste de la Península Ibérica durante la Prehistoria Reciente

Patricia Murrieta-Flores (*)

ABSTRACT

Archaeological, historical, and ethnographic research has demonstrated how mountainous environments influence the socio-cultural dynamics of the communities that live in them and in their neighbouring areas. The development of these communities tends to occur at the margins, often far away from centres of political power. This marginality is also extended to movement in these regions, where mountain ranges regularly constitute mighty obstacles on account of their natural configuration which plays a central role in strategy, commerce and travelling. In the case of western Sierra Morena in Spain, its constitution shaped both the ways of transit through the mountains during Later Prehistory and the historical routes of communication that traverse Andalucía. Using a GIS methodology developed specifically to identify particular characteristics of the landscape relevant to human movement, such as passageways, crossing points, and natural areas of transit, we examine the role that natural accessibility had for the late prehistoric societies of this region. We conclude that the location of their habitats and symbolic places are strongly related to corridors, possibly due to an increasing importance of herding activities.

RESUMEN

Investigaciones arqueológicas, históricas y etnográficas han demostrado como los ambientes de montaña tienen una profunda influencia en las dinámicas socioculturales de las comunidades que viven en ellos y en sus áreas vecinas. El desarrollo de estas sociedades tiende a producirse en los márgenes, usualmente lejos de los centros de poder político. Esta marginación se extiende también a la circulación en estas regiones, donde las cordilleras suelen constituir poderosos obstáculos debido a su configuración natural que juega un papel central en sus estrategias, comercio y movimiento humano. Durante la Prehistoria Reciente, la constitución de Sierra Morena Occidental (España) moldeó tanto las vías de tránsito a través de las montañas, como las rutas históricas de comunicación que atraviesan Andalucía. Utilizando una metodología de Sistemas de Información Geográfica diseñada específicamente para identificar características en el paisaje de particular relevancia para el movimiento humano (como corredores naturales, puntos de cruce y áreas naturales de tránsito), se examinó el papel que la accesibilidad del terreno tuvo para las comunidades de esa región durante la Prehistoria Reciente. Mediante este análisis concluimos que la ubicación de sus hábitats y lugares simbólicos se encuentran estrechamente relacionados con corredores naturales, posiblemente debido a una creciente importancia de las actividades de pastoreo.

Key words: Copper Age; Bronze Age; Sierra Morena; GIS; Spatial Analysis; Statistical significance testing; Megaliths; Settlement patterns; Mobility Models; Natural corridors; Mountain environments; Movement; Herding societies; Iberian Peninsula.

Palabras clave: *Edad del Cobre; Edad del Bronce; Sierra Morena; SIG; Análisis espacial; Pruebas de significación estadística; Megalitos; Patrones de asentamiento; Modelos de movimiento; Corredores naturales; Ambientes de montaña; Movimiento; Sociedades pastoras; Península Ibérica.*

1. INTRODUCTION

Iberia is one of the most mountainous regions of Western Europe. Its Central Plateau has an average altitude of 400 m and is surrounded by

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major mountain ranges (Galician Mountains, the Cantabrian Mountains and the Pyrenees to the North, the Iberian System to the East and the Betic and Penibetic Systems to the South). It is also traversed by the Central System and the Toledo Mountains in a NE-SW direction. This geographical configuration can be seen as one the reasons that explains the high fragmentation in ethnic, cultural and linguistic terms that characterised in the past (and still characterises) this vast territory. The importance of the topographic factor in the Iberian Peninsula can be also appreciated in the historical distribution of its population. While there has been a high concentration of inhabitants in regions located close to the sea –i.e. Barcelona, Valencia, Málaga, Sevilla, Lisboa, Faro, Porto, Santander, Bilbao, etc., the centre has been always weakly populated (with the exception of the modern development of Madrid as administrative capital). The restraints on human movement and cultural contact in this highly fragmented territory have generated a remarkable social and cultural variability since Prehistory that favoured, as it has happened in many other regions of the world, the use of inland waterways and the sea as the most prominent ways of communication and transportation.

Taking this into account, it is not surprising that the study of pathways, roads and routes of trade have traditionally occupied an important place in Iberian History and Prehistory. Many studies have attempted to verify to what extent the natural configuration has been a determinant factor in the definition of the road network and how in turn this network has been crucial in the cultural, social, politic and economic structuration of the territory. Faced with the vast literature that has discussed the structure of the Iberian road and path networks during the Middle Ages (Anés and García Sanz 1994; Roda Turón 1996), Antiquity (Blázquez Martínez 1993; Viñas Filloy 1996; Melgar Gil 1996; Franco Maside 2000) or the Iron Age (Berrocal-Rangel 2004; Escacena Carrasco 2007), as we approach Prehistory, this field of research becomes more scarce. This is in no doubt due to the greater difficulty to obtain empirical data and to define appropriate methods of study –see discussion in Muñoz López-Astilleros 2002; Fairén Jiménez *et al.* 2006 (1). Yet, research dealing with natural areas of transit and ways of communication has been present in a number of approaches to the mobility of the Iberian prehistoric societies. Since the mid 1980's an important debate has been carried out on the issue of human movement and natural corridors during the Neolithic and the Copper Age (VI-III millennia cal BC). This debate has had several implications and perspectives. On the one hand, it has been focused on the examination of the spatial association between megalithic monuments and transhumance routes that were used in many regions of Iberia (at least since medieval times), as possible fossilization of prehistoric roads (Chapman 1979; Davidson 1980; Walker 1983; Palomar Macián 1984; Cara Barrionuevo and Rodríguez López 1987; Ruiz-Gálvez Priego and Galán Domingo 1991; Galán Domingo and Martín Bravo 1991-1992; Ruiz-Gálvez Priego 1999; Galán Domingo and Ruiz-Gálvez Priego 2001; Fairén Jiménez *et al.* 2006; Murrieta-Flores 2007; Wheatley *et al.* 2010; Murrieta-Flores 2010). On the other hand, beyond its association with specific transhumance routes, the spatial distribution of the megalithic monuments has often been assessed in terms of landscape markers, associated to crossing points and movement, especially in the Northwest (Criado Boado *et al.* 1990-1991; Criado Boado and Vaquero Lastres 1993; Martinón-Torres and Rodríguez Casal 2000; Martinón-Torres 2001; López Plaza and Salvador Mateos 2002; Murrieta-Flores *et al.* 2011a, 2011b). From a different methodological perspective, mobility during Iberian Late Prehistory has been also approached through geochemical analyses looking at mercury residues in domestic animals (Logemann *et al.* 1995) as well as isotopic analyses of human remains (Díaz-Zorita Bonilla *et al.* 2009).

This article subscribes to a line of research that approaches this problem by analysing (1) the combination between the geographical structure of the landscape, (2) the distribution of prehistoric sites and (3) the available information on prehistoric and historical road networks. Investigating the spatial dimension of the Copper Age and Bronze Age sites of western Sierra Morena this paper addresses the issue of mobility within Iberian later prehistoric societies. By means of a

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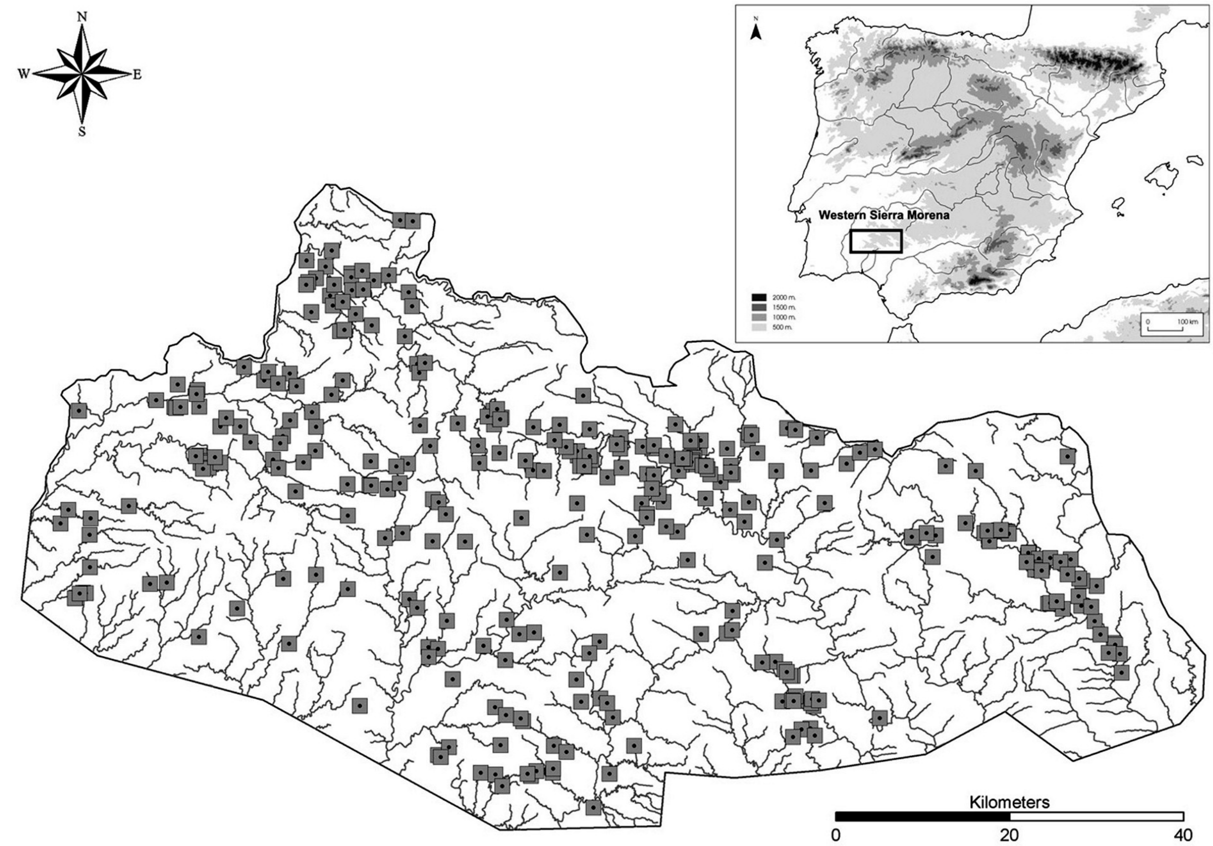

Fig. 1. Location of the study area in the Iberian Peninsula and all the Copper Age and Bronze Age sites analysed in this research.

spatial methodology developed and implemented within Geographic Information Systems (GIS), this research examines particularly the role that natural terrain accessibility might have played within prehistoric herding societies in the location of habitats and symbolic places. The case study involved here is set within the south-western Spanish regions of Sierra de Huelva and Sierra Norte de Sevilla, both referred in this article as western Sierra Morena, where previous research has led to some knowledge about the distribution of archaeological sites of prehistoric date, including settlements, funerary sites and others (Pérez Macías 1987, 1999, 2010; Hurtado Pérez and García Sanjuán 1996; Hurtado Pérez *et al.* 1999; García Sanjuán 1999, 2005; García Sanjuán *et al.* 2004; García Sanjuán and Wheatley 2010) (Fig. 1). The central aim of this paper is to discuss the results of a computational model, which analyses the spatial patterns of these sites in relation to the environmental and archaeological evidence available. From this, we expect to achieve a better understanding of the possible dynamics of movement in this region during Late Prehistory.

2. MODES OF SUBSISTENCE AND HERDING TRADITION IN WESTERN SIERRA MORENA

Sierra Morena is a mountain range of 400 km that crosses from east to west the entire northern extreme of Andalucía (Southern Spain) and constitutes a contact zone between the Spanish Central Plateau and the Betic Depression. Located between two of the most important agricultural river valleys of Iberia (the Guadalquivir and Guadiana), western Sierra Morena presents a peculiar asymmetrical configuration due to the large amount of valleys and ranges interleaving each other. Despite the wealth and variety of its mineral resources, western Sierra Morena is also characterised by the poverty of its soils (Moreno Rey 1998: 19). In addition, the impermeability of the soil and roughness of its terrain have been some of the contributing factors for quick and deep processes of erosion, and ground water represents a limited resource due to a highly developed superficial drainage.

It is probably this difficult environment and the lack of potential for agricultural intensification what makes Sierra Morena a long-established herding region. Thus, the wealth of the cattle-raising economy of the region during the Middle-Age is well known (Carmona Ruiz 1993, 1994a, 1994b). The historical evidence of the pastoral activity in western Sierra Morena and surrounding areas can be traced back at least to the Iron Age, as testified by early literary sources. Roman writer Livy for instance, described how the Phoenicians used local herders of the region as informants during their incursions through the Silver Route. They were considered invaluable not only on account of the information they provided, but also because of their knowledge of the routes to follow, demonstrating with this that towards the Iron Age, there was an already established path network by the pastoralist indigenous populations (Alfaro Giner 2001: 222). Considering the development of such a network, and the fairly organised activity that herding seems to have been during Iron Age in western Sierra Morena, it has been argued that this activity probably has earlier prehistoric roots (Murrieta-Flores 2010).

Various studies have claimed that the prehistoric groups of western Sierra Morena based their subsistence on a combined agropastoral strategy (Pérez Macías 1983, 1987; García Sanjuán 1999; Murrieta-Flores 2010). However, given that few prehistoric sites of this region have been excavated and published extensively (see Hurtado Pérez 2011 for the only exception) and the recovery of faunal evidence is hampered by the high acidity of the soil, there is little hard evidence to go by. This makes the data from the limited excavations, edaphological, palynological and spatial analyses, the only means available at present to understand the possible subsistence modes of the local prehistoric communities. The available pollen studies have suggested that by the IV-III millennium prehistoric societies in Sierra Morena could well have started to develop a *dehesa* ecosystem. As a widespread management method still used nowadays throughout the Sierra and a great part of western Iberia, the *dehesa* constitutes an agrosilvopastoral system whereby dense oak forests are cleared and woody vegetation is controlled in order to create and maintain grassland spaces, achieving a simultaneous and combined production and maintenance of domestic animals as livestock, wild animals as game, wood, firewood, coal and cork (San Miguel Ayanz 1994; Fernández Rebollo and Porras Tejeiro 1998). The earliest evidence of this system comes from paleoenvironmental research, identifying it in a basic form during the Copper Age (c. 3200-2100 BC), and fully developed towards the Iron Age (starting 850 AC) in some parts of south-western Iberia such as Laguna de Las Madres and El Acebrón (Huelva) (Stevenson and Harrison 1992: 243).

Towards the Copper Age the practice of a mixed strategy as subsistence mode (‘agropastoralism’) seems to have been already widely extended throughout south-western Iberia. This is suggested in sites such as Cantarras, Las Viñas and Papa Uvas, where there was an exploitation of the environment with a direct impact on the forest, and presence of grassland of human creation (López Sáez *et al.* 2001: 47; Llergo López and Ubera Jiménez 2008: 2371). This seems to be also supported by other paleoenvironmental research: in the case of Cueva de la Sima (Constantina), Cueva de los Covachos (Almadén de la Plata) and Coudelaria Alto do Chão (Portugal), an increasing use of vegetal species in combination with grassland for herding was already present during this period (Rodríguez Vidal *et al.* 2001; Rodríguez Vidal *et al.* 2003; Duque Espino 2005: 28). The evidence from these settlements suggests that there was an increasing understanding of the exploitation of herding resources in combination with diverse resources product of the *dehesa* environments.

It is difficult to know the extent of these practices without further excavations, although emphasis on one strategy or another (agricultural or pastoral) was probably variable depending on the region. This is evident in the case of western Sierra Morena and the adjacent areas such as the Guadalquivir valley, where the differences concerning access to goods, settlement sizes, resource exploitation and construction of monuments makes it clear that the communities on the sierra lived in different conditions and probably practiced a different strategy to those in the valleys (with more substantial agricultural outputs). Variability in economic practice must have occurred also over time. According to the spatial analyses, the Copper Age societies of this region preferred to establish their settlements in the few areas of the sierra with some agricultural potential in addition to places of long tradition such as caves (García Sanjuán 1999: 148).

In contrast, towards the Early Bronze Age (EBA) (2100-1500 BC), local communities searched for and favoured settlement locations with better defensibility and visual control of their surroundings (García Sanjuán 1999: 141-142). In addition, although some of their sites were still located on soils with better potential for agriculture, the majority seemed to prefer to settle in *dehesa* landscapes such as the case of La Traviesa, El Trastejón and La Papúa (García Sanjuán 1999: 146).

This characteristic seems to be emphasised by the societies of the Late Bronze Age (LBA) (1500-850 BC) that located their settlements not only in areas traditionally used as *dehesas,* woodlands and grasslands, but also predominantly with no agricultural potential and little accessibility (García Sanjuán 1999: 147). Their lack of association to other factors such as visual control, height or other economic resources could lead to their understanding as seasonal camps or herding stations. During this period, diverse important sites of the region with long tradition of occupation such as El Trastejón and La Papúa presented a high level of plants such as: *Erica, Cistus* and *Plantago* (García Sanjuán 1999: 152-158), species that are related to *dehesa* environments and suggestive of exploitation for herding activities. In the case of El Trastejón, the samples recovered suggest that some cultivated species (barley, wheat and lima beans) were consumed but their trace is almost absent from the palynological record. This suggests that either these crops were cultivated near the settlement in small amounts (reason why they were not in the pollen record), or that this site was situated within an exchange network that allowed it to access this kind of resource (García Sanjuán 1999: 70). Moreover, the presence of loom weights at this site indicates the practice of wool processing and textile manufacturing. It is probable that these and other products were exchanged for agricultural resources with communities in the near valleys. In the case of La Papúa cereal crops are under-represented, making improbable the existence of cultivated areas around this settlement. In addition, edaphological analyses have indicated the presence of cattle in this site (García Sanjuán 1999: 154-160).

It can be said that herding has historically been a major resource within the traditional mode of subsistence in western Sierra Morena. Its changing nature has been influenced by diverse factors, but predominantly poor soils shaped its particular development. In this region, it has been demonstrated that none of the plants and types of grass that constitute the diet of ruminants produces enough food for long periods of time (Mora González 2009). In this sense, the historical solution adapted to overcome this situation was transhumance (Fig. 2).

Whether transhumance occurred in Prehistory in a way similar to that documented for historical periods is a matter of debate. However, recent GIS-based studies have emphasised the possible connection between prehistoric monuments, prehistoric pathways and historical transhumance routes (Wheatley *et al.* 2010; Murrieta-Flores *et al.* 2011a, 2011b). The maintenance of large herds was one of the main factors that conditioned historically the practice of transhumance in Iberia. However, this was probably not the case during

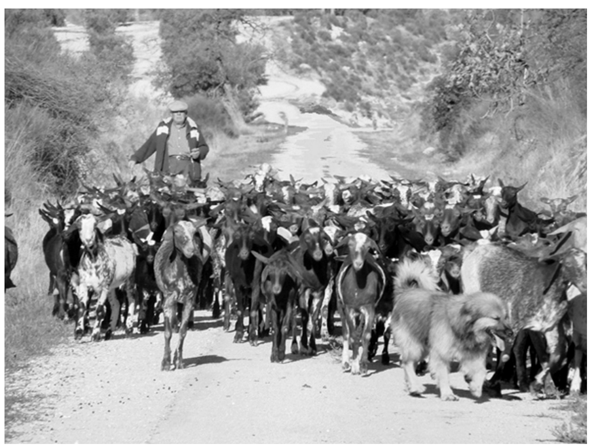

Fig. 2. Herding in Andalucia (photo courtesy of Don Heffernan).

Prehistory where a small amount of animals, might have allowed what is known as short-distance transhumance or trasterminancia. During these journeys, herders carried out local movements looking for pastures in the valleys during the winter and returning to higher altitudes searching for fresher climates during the summer, accomplishing what is spatially known as the 'pastoral orbit'. The pastoral orbit has been described as a conceptual space where transhumant herders carry out movement along a confined 'orbit', visiting a series of places which are not only convenient in terms of resources for their animals but also important in terms of social memory and networks (Frachetti 2008: 133).

Where herding strategies are carried out in mountain environments as is the case of western Sierra Morena, the topographical configuration plays a crucial role in how movement is performed, where herding stations are located, and therefore, in how the pastoral orbit is accomplished. While movement in these environments is frequently localised and accommodated to the nature and steepness of the terrain, travelling through natural passageways and optimal routes such as mountain passes and internal valleys is regular in these regions. Although the optimal employment of the landscape is not always preferred in human societies, in certain special conditions such as these, the search for optimality can have serious advantages. As said, in the case of herding societies while accomplishing the pastoral orbit, natural areas of transit are of vital importance not only in terms of accessibility, but also in the location of seasonal camps and settlements. In this sense, late prehistoric communities of western Sierra Morena may have practiced their herding activities in a similar way.

Taking into account (1) the variability of the settlement pattern, (2) the high number of seasonal habitats (that do not seem to be related to metallurgy or other activity), (3) the lack of potential for agricultural intensification, and (4) the ethnohistorical evidence of a predominant transhumant tradition that is present at least since the Iron Age, it seems fair to suggest that these local communities developed an increasing pastoral strategy. Based on that assumption, the practice of pastoral activity should be reflected at a landscape scale in the spatial distribution of settlements and symbolic places. In order to test this, it becomes necessary to identify specific characteristics of the landscape that are relevant for herding societies and their movement. Thus, a methodology using a combination of GIS methods has been developed in order to recognize important places in terms of movement such as passageways, crossing points and natural areas of transit. The underlying idea of this experiment was to examine the role that natural accessibility might have for these communities in the location of their sites, analysing the possible relationships that might be observed in the spatial layout.

3. IDENTIFYING NATURAL CORRIDORS THROUGH COMPUTATIONAL TECHNIQUES

In the last decade, many interesting computational approaches to past human movement have been developed and important contributions have been made by authors like Llobera (2000), Bell and Lock (2000), Bermúdez Sánchez (2006), Llobera and Sluckin (2007), Frachetti (2008), Herzog (2010) and Mlekuž (2010). In Iberia, the work carried out particularly by Cruz Berrocal (2005), Fairén Jiménez (2004), Fairén Jiménez *et al.* (2006), Fábrega Álvarez (2006) and Fábrega Álvarez and Parcero Oubiña (2007) to mention just few of them, have contributed greatly to the knowledge of movement in Iberian landscapes taking diverse approaches in the analysis of pathways and least cost routes.

In our particular case, the methodology developed had as main goal to identify areas of natural accessibility taking into account the roughness of the terrain and the impediment of crossing certain types of rivers. In order to accomplish this, three particular spatial analyses were combined. Firstly, it was necessary to undertake a 'Morphometric Analysis' of the terrain, identifying the natural passageways into the study area. Once identified, the points from which our study area was accessible were used in a 'Cost Surface Analysis' (CSA) as nodes for the simulation of 'Least Cost Paths' (LCP) crossing the entire region. These were calculated in terms of easiness to walk through diverse slope steepness while travelling. Finally from these results, the number and density of paths in each area was quantified through a 'Line Density Analysis'. The basic assumption that this model made is that the areas through which more paths are accumulated could be considered as the most accessible, and therefore, main natural corridors. The basis for all analyses was a Digital Terrain Model (DTM) with a spatial resolution of 10 m, elaborated by the *Junta de Andalucía* from the 1:20.000 b/w photogrammetric flight of 2000-2002.

With the implementation of the morphometric analysis, the main objective was to classify the landscape in a systematic way dividing it in six morphometric types including planes, channels, ridges, passes, peaks and pits. In order to be able to classify these different features, it is necessary to make a subdivision of all points in the surface represented by the DTM. The terrain model is in raster format, which can be thought of as a grid of cells that store specific values that in this case, consist of coordinates and elevation of the terrain. In this manner, if we represent a determined point in the landscape in the form of cells as it is in an elevation model, we will have that each location (or specific cell) will be always surrounded by eight other cells (Fig. 3). The morphometric features then, can be described by the relationship between the central cell and its adjacent neighbours (Wood 1996: 112) (Fig. 4).

This is accomplished in a GIS calculating the morphometric features 'passing' a local window over the DTM, deriving the change in gradient of the central cell in relation to the neighbour cells through a bivariate quadratic function:

$$Z = ax^2 + by^2 + cxy + dx + ey + f$$

Where x, y and z are the local coordinates and a, to f constitute quadratic coefficients (Evans 1972). In order to do this calculation the basic components of morphometric analysis are taken into account. These are the first and second-order derivatives of the DTM such as slope steepness, cross-sectional curvature, maximum and minimum curvature, profile curvature, plan curvature, longitudinal curvature and Gaussian curvature. This was calculated using the method proposed by Wood (1996) as implemented within LANDSERF software.

For this analysis it has to be taken into account that geomorphic phenomena are dependent on scale (Evans 2003). This means that the characteristics observed of determined point or area of the surface will vary when the calculation of the feature is performed with different spatial resolution or spatial extent (Ehsani and Quiel 2009: 336). In this context, spatial resolution refers to the size of one of the cells in the grid, while the spatial extent will constitute the area taken into account to measure the morphometric feature (the size of the window multiplied by the DTM resolution) (Ehsani and Quiel 2009: 336). A channel or a pass then, can be observed at diverse spatial extents ranging from few meters to several kilometres. This will be relevant due to the fact that the calculation of morphometric features will depend precisely on both, the spatial resolution of the terrain model and the spatial extent that we use to identify them.

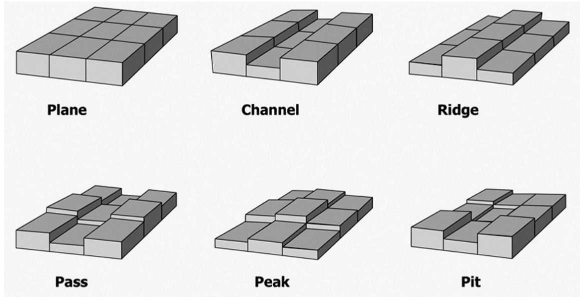

Fig. 4. The morphometric types (after Wood 1996: 112).

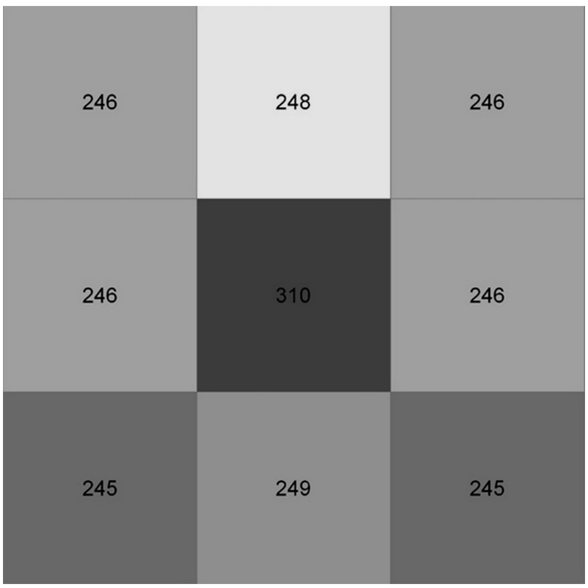

Fig. 3. Representation of a location in the landscape in a Digital Terrain Model and its elevation values.

The spatial resolution of the digital model might not be related to the scale of the morphometric features that we intend to identify, so there is the need to apply a multi-resolution size window instead of a single one (Ehsani and Quiel 2009: 337). This is to say that if we apply a unique window of 3 × 3 to our raster that have for instance, a resolution of 10 m, the only represented features will be the ones covering 30 m on the ground. In this sense, it has been recommended to use windows at diverse sizes in order to identify in a more robust way the desired features (Wood 1996). In this case, because our interest was to identify the morphometric features at a local scale, four local windows were used at sizes of 3 × 3, 5 × 5, 25 × 25 and 65 × 65. These windows represented features covering 30 m, 50 m, 250 m and 650 m. The results from the diverse spatial extents were compared and the locations identified as passes with the windows of 3 × 3, 5 × 5 and 25 × 25 (30-250 m) were used as the points from which our study area can be accessed (Fig. 5). Although in a general sense these are arbitrary sizes, it was considered that they would be wide enough for a comfortable transit with animals, making these zones more likely to be used as 'points of access into the study area'. A total of 36 locations were recorded and then used for the CSA (Fig. 6).

Topography is far from being the only influential factor in human movement and the development of path layouts – for an extensive discussion on this see Murrieta-Flores (2010). Nevertheless, when it comes to mountain environments it is certainly significant. In this case, an anisotropic cost surface analysis was carried out using the method available within IDRISI TAIGA software. The results from physiological experiments in the Middle Mountain environments of Nepal were used (Schneider and Robbins 2009), implementing a simple polynomial equation to calculate the cost of traversing the

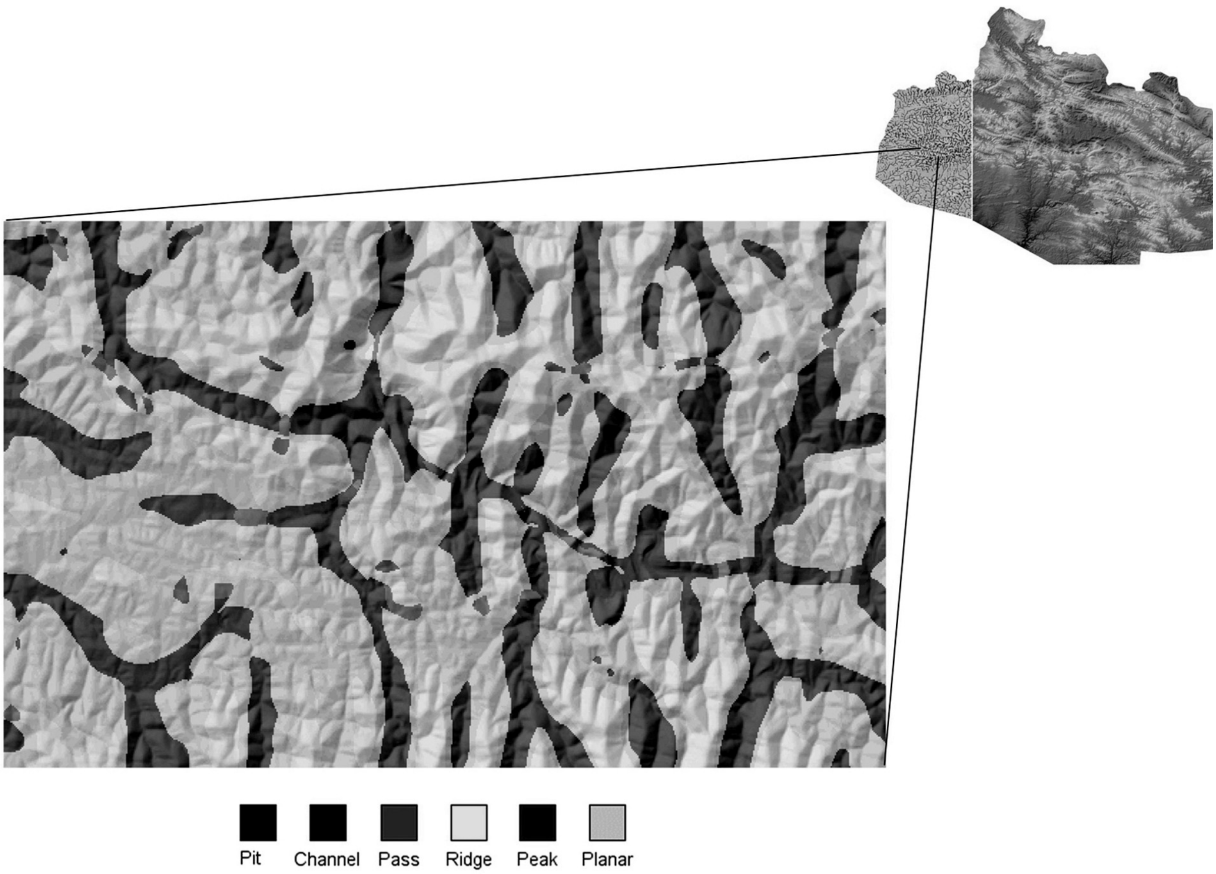

Fig. 5. Example of the morphometric analysis carried out in western Sierra Morena.

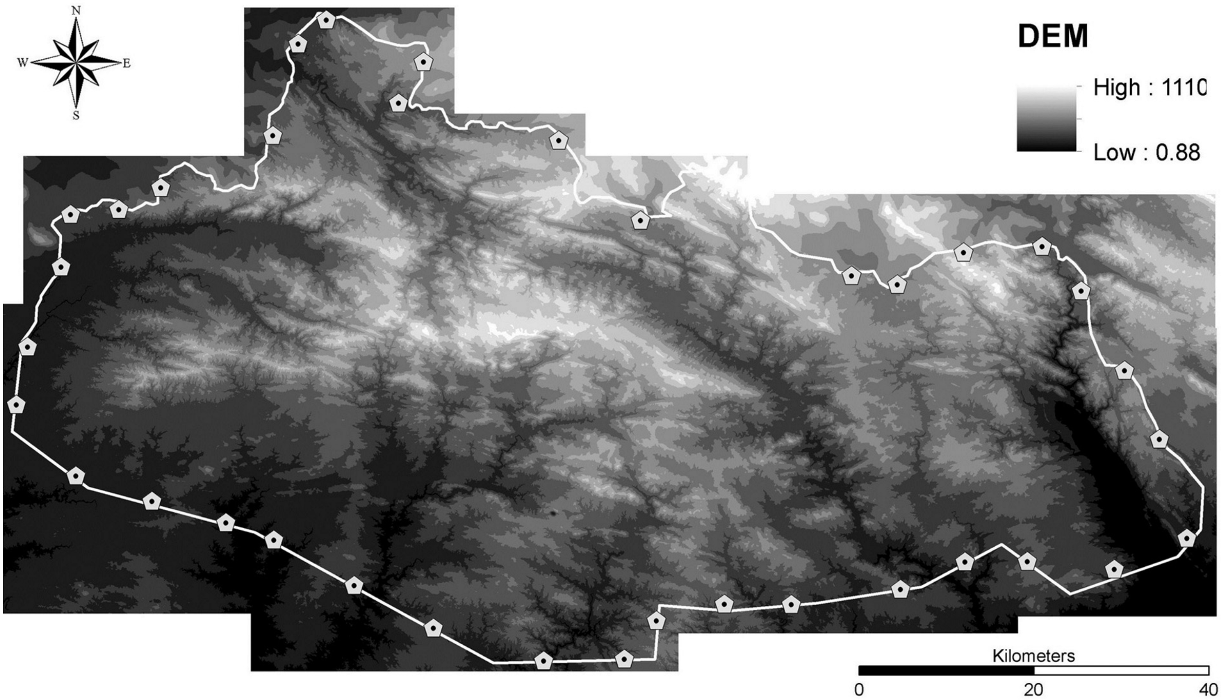

Fig. 6. Defined points of access to the study area. Please see the map in figure 5 for the definition of the study area.

landscape as relative friction. In addition, the rivers of the region were also taken into account as possible obstacles for movement. It is acknowledged that rivers can also act as facilitators for movement, and our study area presents a drainage network constituted mainly by rivers that can be crossed by foot in many parts depending on the season. However, at least three of them are wide and deep enough to become problematic to cross with animals all year round. In order to address this issue in the model, an additional raster layer depicting the cost of crossing rivers was created. Four different relative costs were assigned to the rivers taking into account their volume and width according to the classification given by the Junta de Andalucía from 1 to 4. Classes 1 and 2 are considered seasonal rivers that are easy to cross, so a minimum friction value was assigned to them. Class 3 rivers were assigned a higher value as they are wide and usually deep, while rivers class 4 were given a prohibitive value as they are impossible to cross by foot in any season. Afterwards, this raster and the topographic cost based raster were overlaid to obtain a definitive image for this experiment. This was used as the final friction surface to calculate the cost distance from each node to cross this landscape (Fig. 7). The LCP between the nodes were calculated in the same software (Fig. 8).

The main aim of this experiment is to identify the regions that are more accessible taking into account the variables mentioned above. Following this logic, the most accessible areas would have to be those in which a higher number of paths can be found, or in other words, where there is a denser concentration of them. To identify these areas a grid of cells of 1 km covering all of the study area was created. The number of calculated paths crossing each cell was counted creating a grid depicting the most accessible zones. Additionally, a line density analysis was also performed assigning a search radius of 1.5 km^2 and a cell size of 200 m as parameters in the analysis using the method available in ESRI ArcGIS software. From this, the density of paths in the surrounding of each raster cell was calculated. Finally, through the identification of the most accessible areas in terms of the simulated paths, the record of prehistoric settlements and monuments was analysed in relation to them (Fig. 9).

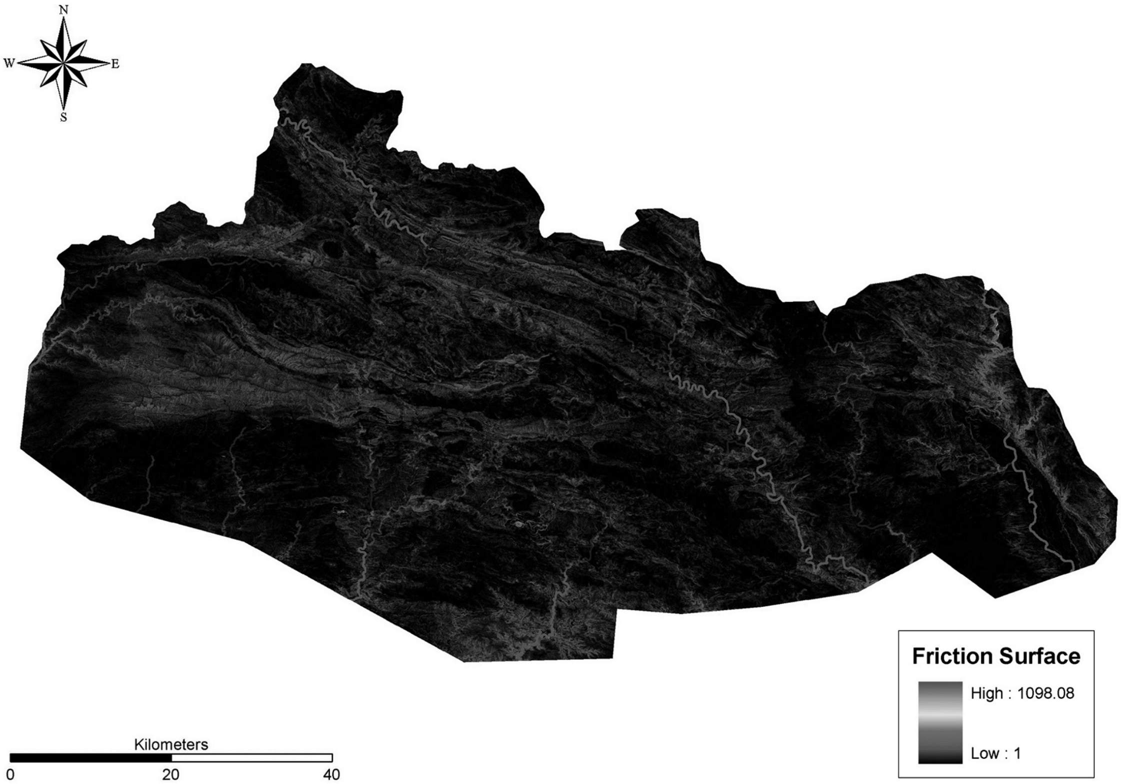

Fig. 7. Friction surface generated from the polynomial equation y=0.031²-0.025x+1, where: y is friction and x is slope.

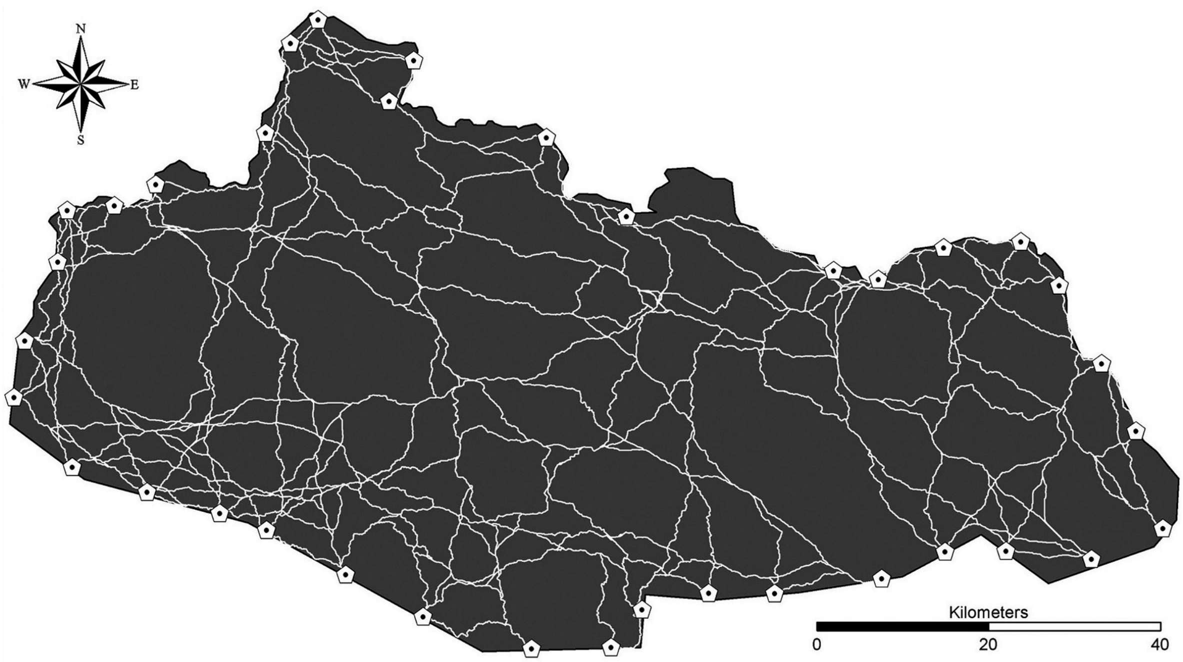

Fig. 8. The Least Cost Paths calculated from the cost surface analysis.

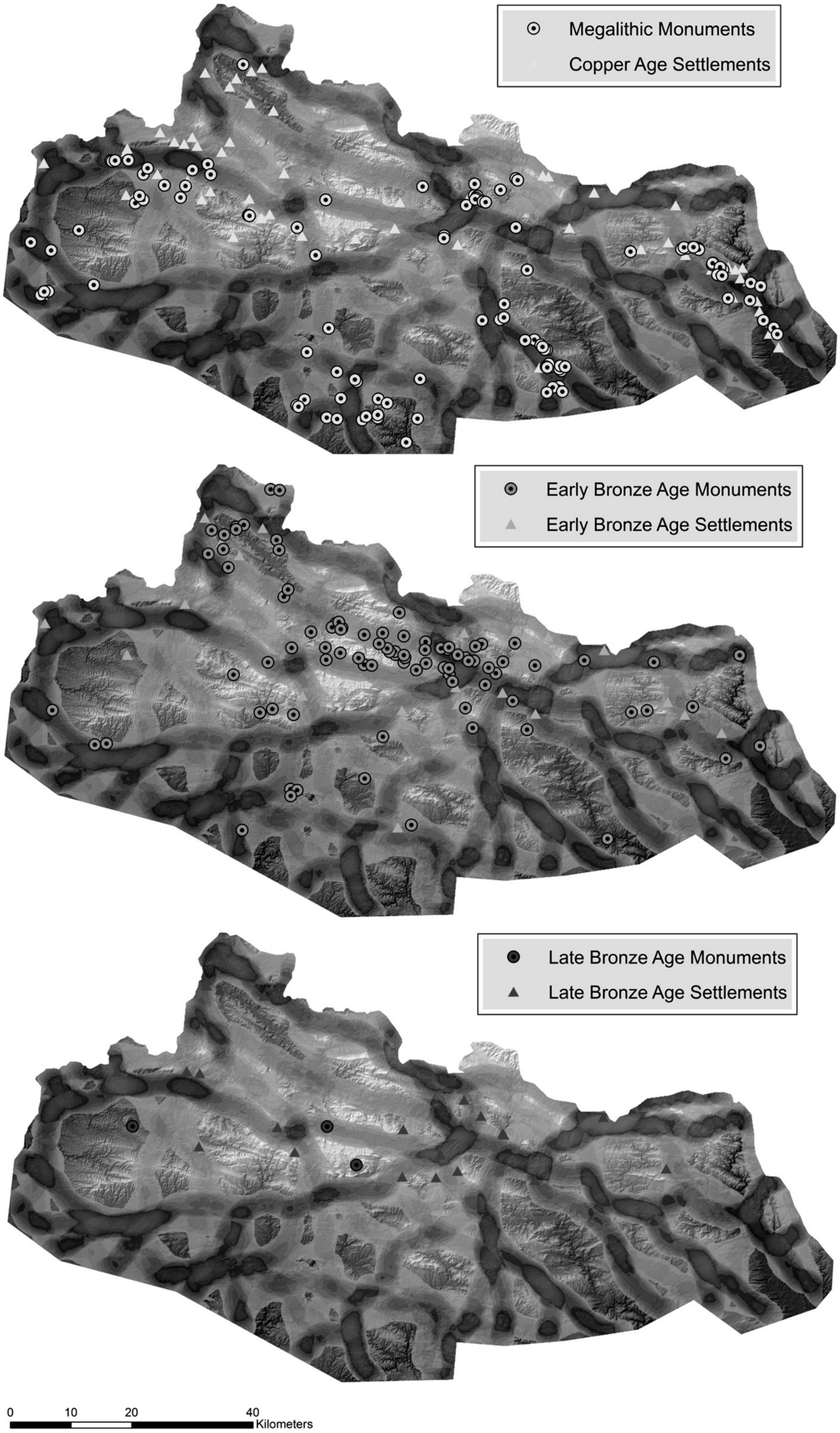

Fig. 9. The results of the Line Density Analysis depicts the most accessible zones in the study area. The monuments and settlements from the late prehistoric communities were spatially analysed in relation to the defined natural corridors.

4. DISCUSSION

Although the limitations of the available archaeological record must be taken into consideration, it is interesting to note that natural corridors in this region seem to have been heavily used during Prehistory. This is reflected in the results from the analysis that suggests that the majority of sites and monuments, regardless of their chronology, fall within the areas identified as natural corridors. In order to test this observation and to examine the possible role that natural accessibility may have played in the location of habitats and symbolic places of late prehistoric societies, we carried out statistical tests of significance. By these means, the spatial relationship between settlements or symbolic monuments and natural corridors was investigated, clarifying whether these sites are closer to the natural corridors than it could be expected by matter of chance alone. The statistical analysis used was the non parametric Kolmogorov-Smirnov test of one sample, which is appropriated for analysing two sets of observations. The general purpose of this test is to determine whether a difference between the means of two samples is statistically significant. In this manner, the test is based in the maximum difference between two cumulative distributions (sample and population) that determine by its significance if the sample deviates noticeably from the population. In other words, it allows us to know if the relationship between them is random or not, and therefore, if there is something to explain (Corder and Foreman 2009: 26).

The procedure followed for these analyses with the aid of GIS was to establish a distance index from the natural corridors identified creating buffers each 500m, observing how many archaeological elements occurred within each index. From this, the areas calculated are taken as the background population and the cumulative frequency is derived, while the cumulative frequency of the number of archaeological cases per index is also derived. Finally the maximum differences (Dmax) between both cumulative frequencies are calculated. The maximum value is compared with a given critical value that is determined depending on the level of significance established. If Dmax exceeds the critical value, the null hypothesis proposed can be rejected (i.e. 'Ho = The Copper Age settlements are randomly distributed with respect to the natural corridors').

By these means, the spatial relationship between settlements and monuments of each period and the natural corridors was investigated, clarifying whether these sites are closer to the natural corridors than it could be expected by matter of chance alone. This was done at a landscape scale considering a study area of 5,261 km^2 and a total of 398 archaeological sites ranging from Copper Age to LBA. The spatial association was investigated at a significance level of 0.05 and the null hypotheses in all cases were rejected with the exception of the LBA funerary monuments, which sample is too small to obtain a robust result from any statistical test (Tabs. 1-5).

For each other period the results show a pronounced association that is statistically significant, concluding that settlements and funerary sites tend to occur close to the corridors. In fact, while 73.33% of the Copper Age settlements occur in areas of natural transit, in the case of the Bronze Age this coincidence is even greater, (81.25% for the EBA and 87.5% for the LBA). In the case of funerary places this relationship seems to shift. For the Copper Age the association between natural corridors and the megalithic monuments is emphasised with 88.24% of them falling within the areas of transit, while in the case of the EBA the coincidence between funerary sites and corridors is of 75% and for the LBA is only of 33%. Despite this, it has to be taken into account that for the LBA this figure might be the result of the rather small archaeological record. However, in the case of the Cooper and EBA these figures are very meaningful in terms of modes of subsistence, social interaction and movement. A high coincidence between settlements and corridors was an expected observation in general, as it is likely that human societies will locate their settlements within reach of communication networks. However, these results are consistent with the observations made by other scholars in terms of the differences observed between the Copper Age and Bronze Age settlement patterns (García Sanjuán 1999; Pérez Macías 2010: 275-276).

The comparatively weaker association between natural corridors and Copper Age habitats might be explained through a comparison of their distribution patterns to those of the Bronze Age. The association to land historically used for pas-

T.1 SITE TYPE	**CASES**	**CRITICAL V**	**DMAX**				**NULL HYPHOTESIS**
Copper Age Settlements	60	0.175	0.193				REJECTED
	Background Population			**Archaeological Cases**			
Distance Index	Area km2	Area%	Cum%	Cases	Cases%	Cum%	**Dmax**
0	9	0	0	0	0	0	0
1	579.237	15.83458396	0.15834584	7	11.666667	0.1166667	0.041679173
2	489.646	13.38543756	0.29220022	12	20	0.3166667	0.024466452
3	414.272	11.32494085	0.40544962	13	21.666667	0.5333333	0.12788371
4	382.73199	10.46273257	0.51007695	10	16.666667	0.7	0.189923051
5	347.80499	9.507934256	0.60515629	5	8.3333333	0.7833333	0.178177041
6	309.133	8.450759261	0.68966388	6	10	0.8833333	**0.193669449**
7	279.27701	7.634586986	0.76600975	1	1.6666667	0.9	0.133990246
8	257.72501	7.045420628	0.83646396	0	0	0.9	0.063536039
9	227.21201	6.211287691	0.89857684	3	5	0.95	0.051423162
10	197.959	5.411599061	0.95269283	1	1.6666667	0.9666667	0.013973838
11	173.052	4.730717172	1	2	3.3333333	1	0

T.2 SITE TYPE	**CASES**	**CRITICAL V**	**DMAX**				**NULL HYPHOTESIS**
EBA Settlements	32	0.234	0.274				REJECTED
	Background Population			**Archaeological Cases**			
Distance Index	Area km2	Area%	Cum%	Cases	Cases%	Cum%	**Dmax**
0	0	0	0	0	0	0	0
1	390.052	11.97800146	0.11978001	5	15.625	0.15625	0.036469985
2	376.29099	11.55541832	0.2353342	8	25	0.40625	0.170915802
3	366.884	11.26654161	0.34799961	6	18.75	0.59375	0.245750386
4	351.38501	10.79058731	0.45590549	4	12.5	0.71875	0.262844513
5	343.51501	10.54890961	0.56139458	3	9.375	0.8125	0.251105417
6	330.90399	10.1616412	0.663011	4	12.5	0.9375	**0.274489005**
7	307.57001	9.445084317	0.75746184	1	3.125	0.96875	0.211288162
8	285.67999	8.772869609	0.84519053	0	0	0.96875	0.123559466
9	261.90601	8.042800882	0.92561854	0	0	0.96875	0.043131457
10	242.216	7.438145686	1	1	3.125	1	0

T.3 SITE TYPE	**CASES**	**CRITICAL V**	**DMAX**				**NULL HYPHOTESIS**
LBA Settlements	24	0.269	0.275				REJECTED
	Background Population			**Archaeological Cases**			
Distance Index	Area km2	Area%	Cum%	Cases	Cases%	Cum%	Dmax
0	0	0	0	0	0	0	0
1	366.604	14.93886797	0.14938868	4	16.666667	0.1666667	0.017277987
2	355.35001	14.4802754	0.29419143	7	29.166667	0.4583333	0.1641419
3	339.76599	13.845237	0.4326438	6	25	0.7083333	**0.275689529**
4	323.19101	13.16981765	0.56434198	2	8.3333333	0.7916667	0.227324686
5	280.33099	11.42330048	0.67857499	0	0	0.7916667	0.113091682
6	507.18399	20.66740861	0.88524907	4	16.666667	0.9583333	0.073084262
7	281.60199	11.47509288	1	1	4.1666667	1	0

Tables 1-3. Kolmogorov-Smirnov test of the relationship between Copper, Early, and Late Bronze Age settlements and corridors.

T.4 SITE TYPE	**CASES**	**CRITICAL V**	**DMAX**			**NULL HYPHOTESIS**	
Copper Age Funerary	119	0.124	0.375			REJECTED	
Monuments	**Background Population**			**Archaeological Cases**			
Distance Index	Area km2	Area%	Cum%	Cases	Cases%	Cum%	**Dmax**
0	0	0	0	0	0	0	0
1	782.63098	15.336098	0.15336098	43	36.134454	0.3613445	0.207983558
2	662.79999	12.98794177	0.2832404	32	26.890756	0.6302521	0.347011703
3	585.495	11.47310664	0.39797146	17	14.285714	0.7731092	**0.37513778**
4	517.875	10.14805439	0.49945201	6	5.0420168	0.8235294	0.324077404
5	466.49899	9.141312328	0.59086513	4	3.3613445	0.8571429	0.266277726
6	309.133	6.057636489	0.6514415	7	5.8823529	0.9159664	0.26452489
7	412.74899	8.088050589	0.732322	4	3.3613445	0.9495798	0.21725783
8	327.18701	6.411415056	0.79643615	2	1.6806723	0.9663866	0.169950402
9	276.75201	5.423112622	0.85066728	1	0.8403361	0.9747899	0.124122637
10	234.377	4.592750264	0.89659478	1	0.8403361	0.9831933	0.086598496
11	193.34399	3.788685157	0.93448163	1	0.8403361	0.9915966	0.057115006
12	334.353	6.551837	1	1	0.8403361	1	0

T.5 SITE TYPE	**CASES**	**CRITICAL V**	**DMAX**			**NULL HYPHOTESIS**	
EBA Funerary	92	0.141	0.22			REJECTED	
Monuments	**Background Population**			**Archaeological Cases**			
Distance Index	Area km2	Area%	Cum%	Cases	Cases%	Cum%	**Dmax**
0	0	0	0	0	0	0	0
1	566.76001	12.63699256	0.12636993	22	23.913043	0.2391304	0.112760509
2	531.77698	11.85697936	0.24493972	17	18.478261	0.423913	0.178973324
3	507.02499	11.30508665	0.35799059	12	13.043478	0.5543478	0.19635724
4	477.51599	10.64712736	0.46446186	12	13.043478	0.6847826	**0.220320749**
5	458.048	10.21305149	0.56659237	9	9.7826087	0.7826087	0.216016321
6	433.84698	9.673443716	0.66332681	5	5.4347826	0.8369565	0.17362971
7	408.37299	9.105452651	0.75438134	3	3.2608696	0.8695652	0.115183879
8	386.93301	8.627407512	0.84065541	6	6.5217391	0.9347826	0.094127196
9	366.29599	8.167265894	0.92232807	4	4.3478261	0.9782609	0.055932798
10	348.353	7.767192799	1	2	2.173913	1	0

Tables 4-5. Kolmogorov-Smirnov test of the relationship between Copper and Early Bronze Age funerary monuments and corridors.

turage and herding activities is of 25% for Copper Age settlements and 65.6% for EBA settlements (García Sanjuán 1999). This suggests not only that Bronze Age groups were looking more regularly for spaces that were suitable for herding, but also that they were performing seasonal movements and therefore, we observe a stronger relationship between their habitats and natural corridors.

Although this seems contrary to the traditional argument that in southern Iberia, with an increasing social inequality, the desire to settle in places with better defensibility might have increased towards the Bronze Age, it offers a new alternative interpretation where it is argued that the settlements seem to be in rather accessible locations. In the specific case of western Sierra Morena with a subsistence mode related to pastoralism, it is probable that many of the sites identified as temporal camps or settlements were related to their pastoral orbit and therefore, they had a stronger relationship with natural corridors. This might have been the case in the selection of some caves as shelters such as Cueva de la Mora de la Umbría (Aracena). This cave apparently served as a permanent settlement during the EBA and towards the LBA, it became a sporadic or maybe seasonal shelter (Martínez Rodríguez and Lorenzo Gómez 1992: 198). This kind of use has also been observed in other mountain environments, where the combined use of caves as pens for sheep and residence for herders during Late Prehistory has been documented (Palomar Macián 1984; Mlekuž 2005). Although excavations are needed, it is important to note that those cases are regularly related to pasturage. In addition, in comparison with the rest of Andalucía, the caves of Sierra de Huelva seem to have significant occupation during the Bronze Age (Martínez Rodríguez and Lorenzo Gómez 1992: 199), which could be related to the increase in herding activities and seasonal mobility.

Also of note is the fact that in the case of an important natural corridor with prehistoric settlements such as the Múrtigas River Valley, settlements were not reused after the Copper Age despite their location in places with good agricultural soil (Pérez Macías 2010: 274). This seems to emphasize further the economic change towards the Bronze Age, and possibly the increasingly specialised pastoralist strategy. Although more paleoenvironmental research is needed, several EBA sites are associated to soils that have been traditionally used for pasturage. This is the case of El Trastejón, Puerto Moral, La Grama, Santa Catalina and Cerro Librero I, located within the Rivera de Huelva River valley, one of the most important passageways in this area and the main natural corridor leading from the Guadalquivir River into the 'inner' part of the Sierra de Huelva.

It is also interesting to note that recent analyses carried out in western Sierra Morena looking at the evidence available regarding the exploitation of metals have concluded that for the Copper Age, there is no evidence of metallurgic activity or metal artefacts for this period, with the exception of the funerary site of La Zarcita (Santa Bárbara de Casas, Huelva) (Costa Caramé 2011: 324). Despite this, towards the Early and Late Bronze Age this seems to change. Although the evidence points to the idea that the exploitation of metals in this region is very low in comparison with adjacent areas such as the Guadalquivir valley, there seems to be an diachronic increment in the linear distance between settlements and places of metallurgic activity in general (Costa Caramé 2011: 274). This change between periods might be connected to an increase in the mobility of these societies and is possibly associated to herding activities. In this manner, the rising importance of commerce during this period, the potential proliferation of herding activities and the enterprises that come with them, might be some of the factors explaining why during the Bronze Age, a larger number of settlements and seasonal camps were located near natural corridors.

In relation to the funerary sites, two remarkable results emerge from this analysis: firstly, the hypothesis expressed several decades ago pointing to a relationship between megalithic monuments and natural corridors (Chapman 1979; Galán Domingo and Martín Bravo 1991-1992; Criado Boado and Vaquero Lastres 1993; López Plaza and Salvador Mateos 2002) can be finally accepted for western Sierra Morena. Secondly, that the relationship with funerary sites and natural corridors seems to hold also true for later periods, at least for the EBA.

While the possible reasons for these relationships are still under investigation and have been explored elsewhere (Murrieta-Flores 2007; Wheatley *et al.* 2010; Murrieta-Flores *et al.* 2011a, 2011b), it is important to note that the majority of megalithic monuments are located within a range of 500-1000 m of the calculated corridors. The strong spatial relationship recognised for the megaliths seems to be consistent with the idea that they are often located in visible and traversable areas, and it also emphasises their possible role as landscape markers (Murrieta-Flores *et al.* 2011a, 2011b). In the case of the EBA funerary places, they are located even closer in a range of 0-500 m. This could be related to the role that burials play as spatial markers for herding societies while performing the pastoral orbit and it could be interpreted as a possible continuation in the symbolic role of funerary monuments for these communities.

Related also to this is the remarkable coincidence between historical paths and natural corridors. As it was mentioned at the beginning of this paper, there is a long-standing debate on whether Iberian prehistoric monuments were associated to historical routes such as droveways. What is clear from this experiment is that the monuments are definitively associated with areas of natural transit. Although it is still necessary to analyse in depth what is the logic behind the layout of the historical routes, their connection to funerary monuments may be due to the fact that some parts of these paths follow the most accessible areas in the landscape. Therefore, what we might be observing is in reality the relationship of the monument 'with' the natural corridor which happens to be used by the historical route. This might be the explanation why in some cases a spatial relationship between historical routes and funerary monuments can be confirmed and in some others not (Wheatley *et al.* 2010). In this sense, in the context where the spatial relationship with historical paths has been impossible to establish, it would be useful to test if the monuments are related to natural corridors instead. In this case it must be taken into account that although there are many variables and factors that influence the establishment of path layouts, in mountain environments these options are relatively more constrained. Therefore, is not surprising that the historical routes follow at least in some sections natural corridors, and that these may have been used by earlier societies. This specific relationship is currently under investigation.

Finally, an interesting perspective derived from all these observations is that places where natural corridors, historical paths and prehistoric monuments converge, they constitute parts of the landscape that are highly likely to have been used by prehistoric communities and therefore, they could be targeted for archaeological investigation. Because it has been a usual practice for all societies to reuse the already established paths, the presence of these three elements may be indicative of the possible fossilization of a route, at least in those specific segments. It can be argued that historical transhumance routes had a specific purpose, so their layout must have been quite unique to the social and economic needs of the societies that created them. However, in this case there are many segments where the roads tend to follow the natural corridors, and if in these parts the monuments are strongly associated to them, it is possible to think that these segments might be part of older paths.

5. CONCLUSION

The research about the mobility and daily life aspects of the prehistoric communities of this region is far from concluded. The results from this analysis offer further support to the scarce archaeological evidence available of western Sierra Morena, suggesting that its societies favoured (over time) habitats located close to natural corridors. This has opened a series of interesting questions. While it has been argued that this relationship might be in connection to the growing economic weight of pastoral practices towards the Bronze Age, the spatial association between megalithic monuments and corridors remains to be further investigated. In relation to this, their possible use as landscape markers and their potential role in territoriality is currently under examination. In addition, ideas of permanence concerning sacred and/or symbolic places and their materialization in the landscape are still to be identified. In the case of western Sierra Morena, there is also the need to think of the implications that these results have within a larger frame. In this sense, the possible relationships and interaction between the communities of this mountain range and the adjacent valleys have to be researched.

Regarding the methodological aspect, computational approaches allow us to test hypotheses and to explore at a landscape scale the spatial characteristics of archaeological sites that are denotative of past social aspects. However, it must be acknowledged that models of movement are usually far from perfect. The results depend (among many other things), on the spatial resolution of the terrain model used, the equations employed to calculate the costs to traverse it, and the algorithms used to calculate the LCP. Moreover, there are many variables, both physical and social, that can influence how people move and the paths they follow. In this sense, it is acknowledged that the results presented here constitute a starting point for the formulation of additional archaeological questions and also of methodological improvements in mobility models. Nevertheless, it is believed that the method used has proven to be not only a robust way to investigate past landscapes, but also an innovative approach in movement models, combining well grounded tools like LCP and morphometric analysis.

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