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Shellmiddens as landmarks: Visibility studies on the Mesolithic of the Muge valley (Central Portugal)

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ABSTRACT

Recent studies on the Mesolithic shellmiddens of the Muge valley (Central Portugal) indicate that these sites must have had, by their size, aspect and integration in an increasing socially complex cultural system, a major impact on the landscape as monumental anthropogenic features. Their role as landmarks and, most probably, as centers for different social/functional units is expected to be manifested in a considerable visual prominence on the terrain. This paper focuses on the use of geospatial techniques and statistical analysis to assess visibility as a determinant factor for Mesolithic settlement location and social patterns in Muge. Results confirm a considerable importance for features such as visual prominence, intervisibility between several settlements and visual control of the environs. A significant dichotomy in the visibility properties of both riverbanks mirrors differences in the archaeological record of sites and suggest that some of these sites might have been special locales with social impact as cultural landscapes.

1. Introduction

Recent work carried out in the Mesolithic shellmiddens of Muge has allowed us to outline new economic, social and technological paradigms for the communities that inhabited Central Portugal between c. 8200 and 6100 cal BP (Bicho et al., 2011, 2012; Bicho and Gonçalves, in press). This new vision of the westernmost European Mesolithic stands out, particularly by the emphasis given to the diverse evidence of increasing complexity, reflected especially in the realms of symbolic behavior and social and territorial organization (Bicho, 2009; Bicho and Gonçalves, in press; Cummings, 2003; Driscoll, 2009; Zvelebil, 2003).

Estuarine Mesolithic occupations, in particular those in the Muge region, have been interpreted as an adaptive response to environmental modifications occurred during the 8.2 ka cal BP cold event (Bicho et al., 2010), representing a completely different settlement system from the prior Epipaleolithic period in Central Portugal (c. 12500–8000 cal BP). It is hypothesized that declining availability of marine resources, rapid sea level rise, and changes in coastal morphology are among some of the reasons that might have made coastal settings no longer attractive to Epipaleolithic hunter–gatherers. As a consequence, later Mesolithic settlements tend to shift towards estuaries, namely in the Tagus and Sado estuaries (Bicho et al., 2010). Higher concentration of people in these new ecological niches seem to have led to a reorganization of the socio-cultural systems (Bicho and Gonçalves, in press) and, consequently, to the emergence of some specific traits pointing to the advent of an affluent hunter–gatherer–fisher cultural system (as defined by Ames, 2006; Koyama and Uchiyama, 2006; Prentiss and Kuijt, 2004; Price, 1985).

Increasing social complexity is suggested, for example, by the construction of protective cairns at the top of the middens (Bicho et al., in press; Cascalheira and Gonçalves, 2012), the social hierarchical intrasite organization of burials (Bicho and Gonçalves, in press) and the regular distribution of sites at approximately equal distances (c. 750 m) (Gonçalves, 2009).

These examples suggest that, in Central Portugal as well as in other European regions (Driscoll, 2009; Zvelebil, 2003), landscape enculturation begun immediately after the onset of the Holocene and constructed landscapes, as defined by Ashmore and Knapp (1999), started to take form. Human-induced alterations in the territory during this period resulted, most certainly, from changes in the perception of the landscape, and are likely related with the origins of monumentality, as seen in other regions of Atlantic Europe (Cummings, 2003; Driscoll, 2009; Zvelebil, 2003).

Due to their size, aspect and inherent structural/social complexity, the Muge shellmiddens must have had a major impact on the

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landscape. Their role as landmarks and, most probably, as centers for different social/functional units (Bicho and Gonçalves, in press), is expected to be manifested in a considerable visual prominence on the terrain.

Visibility is, in fact, one of the most important features of constructed landscapes (Bongers et al., 2012; Kohler, 1997) and in most cultures, the visual appearance of a site, including visual characteristics like shape, color, among others (Llobera, 2007a), is the most significant impact it has upon any individual's senses (Wheatley and Gillings, 2002).

Visibility analysis have been successfully used in Mesolithic to, for example, argue that campsites were located to afford larger views than other topographically similar non-site locations (Lake and Woodman, 2000), or to check if different site functionality are congruent with different patterns of visibility (van Leusen, 1993). In this study we use Geographical Information Systems (GIS) and statistical analysis to assess visibility as a determinant factor on Mesolithic site location patterns in the Muge River valley. Cumulative viewsheds (Wheatley, 1995) and line-of-sight analyses are undertaken to explore the weight that aspects like landscape visual prominence and intervisibility between sites might have had in the settlement and social dynamics of the Muge hunter–gatherers.

2. The Muge shellmiddens

The Mesolithic in Central Portugal, roughly coincident with the Atlantic climate phase, represents a clear break in the settlement and subsistence patterns as well as technological aspects. It corresponds to a final moment of hunter–gatherer adaptations to the Holocene climate change, right before the advent of the first farming communities in the region. In terms of settlement system, although there are a few sites known in the northern mountains of Estremadura, most sites are shellmiddens that are located in the lower Tagus Valley, around Muge. Lithic materials present at these sites are marked by the disappearance of the previously dominant backed and marginal retouched weaponry, replaced by geometric microliths produced with the microburin technique. Research on diet, health and subsistence practices show that these communities had both a marine and terrestrial animal diet but also showed that plants were an important dietary component. The results from trace elements and isotopic analyses of the human skeletons indicate a wide diversity of resources in the diet within the same site, with marine proteins making up between 70% and 25% of the diet (Umbelino, 2006).

The known 15 shellmiddens forming the Mesolithic complex of Muge are distributed along the banks of three small river tributaries, Magos, Muge and Vale da Fonte da Moça, that flow into the Tagus River from the East (Fig. 1A).

In the particular case of the Muge River valley, seven sites are currently known (Fig. 1B) covering both sides of the valley in a uniform distribution along the margins, thus being most likely representative of the valley landscape setting. Five of them (Moita do Sebastião, Cabeço da Amoreira, Fonte do Padre Pedro, Flor da Beira, Cabeço da Arruda) were identified very early on the investigation history of Muge, and two (ID15 and ID20) were recently revealed by GIS-based predictive modeling (Gonçalves, 2009, in press). The sites are located on the top of the Muge river terraces, in smooth elevations ranging from 14 (north bank) to 24 m (south bank) above present sea level, and at no more than 250 m from the present-day stream. The middens of the Muge valley are characterized by large concentrations of shells up to 70 m in diameter and 5 m tall (Bicho et al., 2011; Roche, 1972, 1989). They are, thus, quite unique sites in western Iberia, very different from the previous Epipaleolithic coastal shellmiddens (Araújo, 2009) and from the coeval sites located in the Sado valley (Arnaud, 1987, 1990).

With the exception of Cabeço da Amoreira and Cabeço da Arruda, all other middens were either totally excavated or destroyed by agricultural activities. Based on the recent work at Cabeço da Amoreira, Bicho et al. (2012, in press) were able to reconstruct the occupational sequence of the site, characterized by: (1) an initial phase with spatially organized, residential features (i.e. pits, hearths, post holes) and human burials attesting to a dichotomous site functionality; (2) a second phase when the dense 2 meter thick shell layers were deposited, with evidence of fire structures and post holes (3) a third moment with the site being used, again, as a burial ground; (4) a fourth phase, with deposition of a compact cap of small pebbles and fire-cracked rocks, placed directly on top of the shells, forming a protective structure defined as a cairn; (5) and a final moment of human activity involving breaking of the cairn surface for the deposition of human bodies, most likely representing a phase of Neolithic use of the site.

Although some of these features are clearly identified in other sites of the Muge valley (e.g. the residential structures and burial ground in the basal layers of Moita do Sebastião and Cabeço da Arruda) the sequence observed in Cabeço da Amoreira is not common to all middens in Muge. Recent work in both Cabeço da Amoreira and Cabeço da Arruda has revealed very different deposits, particularly in the density of accumulated shells throughout the record. This occurrence suggests the existence of some kind of functional and possibly social diversity between sites within the Muge valley. Some degree of social diversity between sites is also suggested by technological and typological differences in the stone tool production, specifically in the geometrics (Jesus et al., in press; Marreiros et al., in press) as well as in the important variability in dietary habits seen in the isotopic data recovered from the Muge human skeletons (Bicho and Gonçalves, in press; Bicho et al., in press). Both sets of data indicate that the differences among the various sites are not related to chronology (Bicho et al., 2010), as previously thought (Marchand, 2005), but to inter-site social diversity (Bicho et al., 2012). In fact, the Mesolithic occupation in the Muge River valley is solidly clustered in a short period of time of c. 800 years, (between c. 8200 and 7400 cal BP). Notwithstanding, the new social/functional diversity arguments contradict, undoubtedly, the traditional interpretation of the Muge shellmiddens as residential camps with seasonal character, explored by a single homogeneous ethnic group (Arnaud, 1987, 1989; Jackes and Meiklejohn, 2004; Roche, 1972a, 1972b, 1989).

In sum, some facts of great relevance to the visibility analysis here presented should be retained from the current knowledge on the shellmiddens of the Muge River valley as they work as key assumptions for this study: (1) contemporaneity of sites is securely proven by a large set of radiometric dates (Bicho et al., 2010); (2) differences between sites, either in the cultural material or in the sequence and generic characteristics of the deposits, reveal social, functional, or both, diversity within the valley; (3) nonetheless, all shellmiddens were used as burial grounds, forming a mortuary landscape that could have encoded memory and identity claims; (4) finally, patterns of site location are thought to be related not only with straight environmental adaptive behavior but also with unidentifiable cultural factors that may explain, for example, the uniform straight-line distance of 750 meters between middens within the same riverbank (Gonçalves, 2009).

3. Methods

Three null hypotheses regarding the visual properties of the Muge valley landscape were developed for this study, based on all Mesolithic sites known from the Muge River (Fig. 1):

H1. Shellmiddens are distributed regardless the intervisibility with other sites.

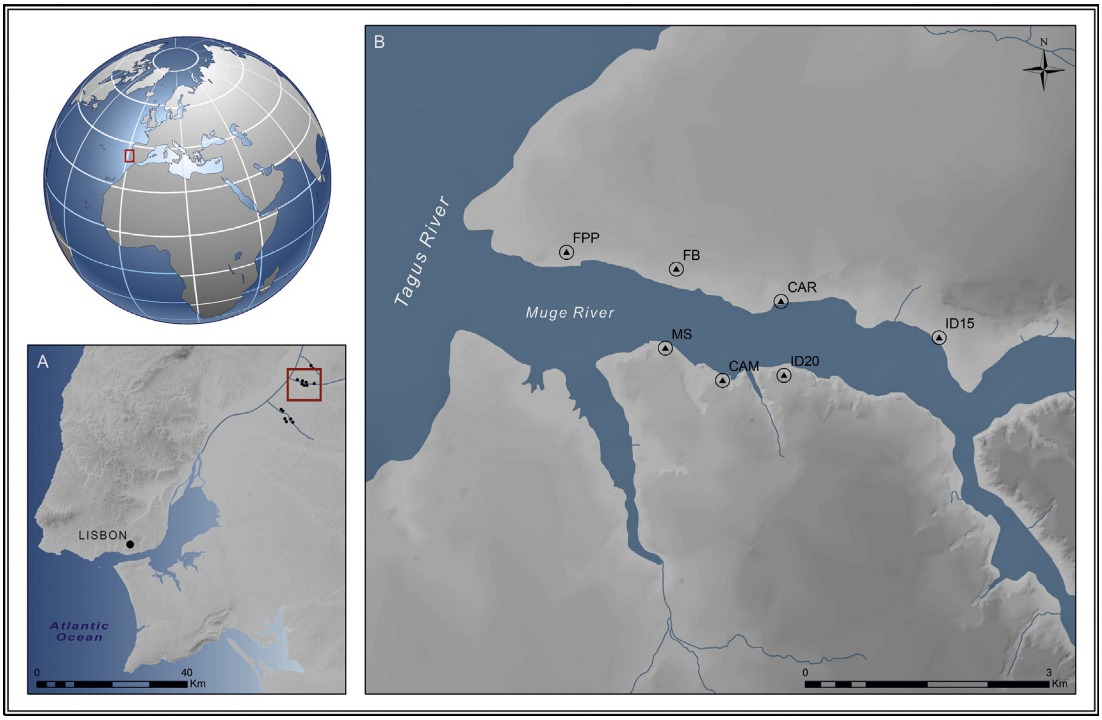

Fig. 1. Location of Muge Mesolithic complex (A) and shellmiddens from the Muge River (B). FPP – Fonte do Padre Pedro; FB – Flor da Beira; CAR – Cabeço da Arruda; MS – Moita do Sebastião; CAM – Cabeço da Amoreira.

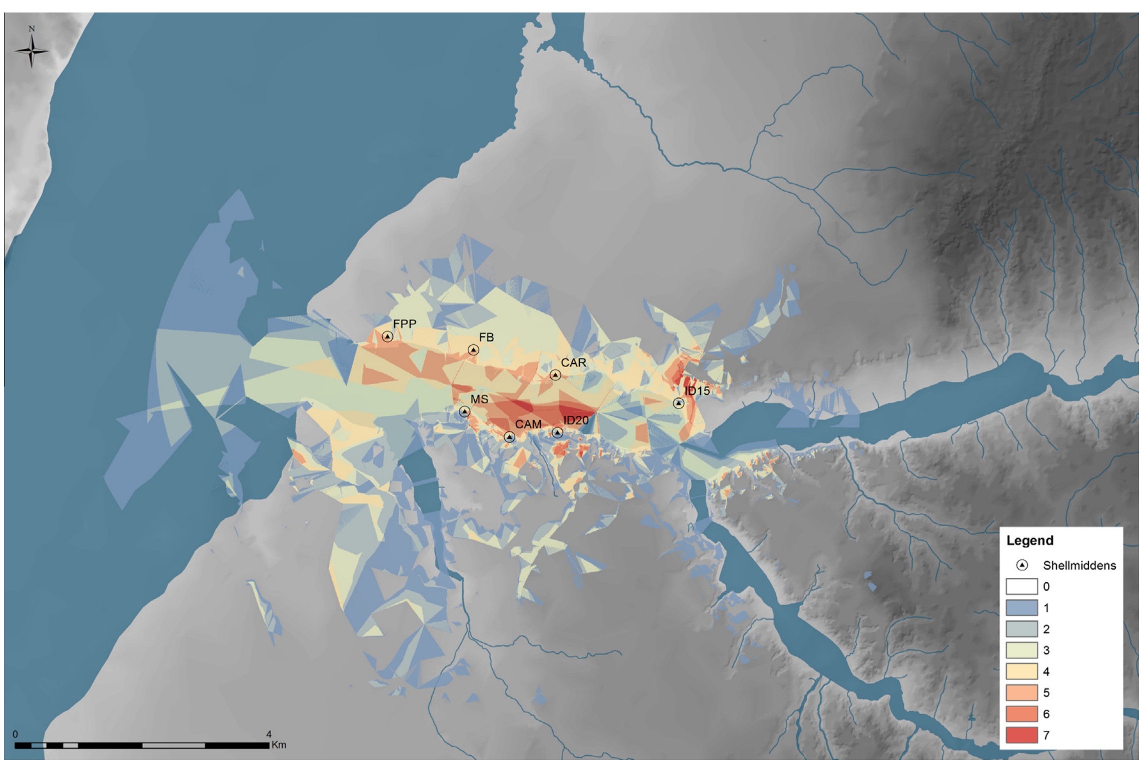

Fig. 2. Cumulative viewshed map for all shellmiddens. Different colors represent the number of shellmiddens that can view that specific area. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

H2. Shellmiddens are distributed regardless their visual prominence in the terrain.

H3. Shellmiddens are distributed regardless the total area visible from the specific locales where they are located.

Methods used to test these hypotheses have previously been used in GIS-based visibility studies (e.g. Bongers et al., 2012; Fisher et al., 1997; Lake et al., 1998; Wheatley, 1995). Some modifications were made to adapt the methodology to the Muge landscape and archaeological record.

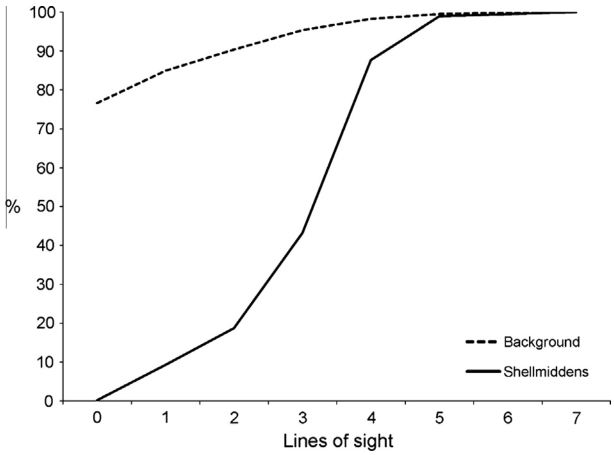

Fig. 3. Cumulative percentages for all shellmiddens viewsheds.

Table 1
Results of the Kolmogorov–Smirnov test.

	dmax	Critical D
Intervisibility	0.50	0.06
Visual prominence (inland)		
Total	0.28	0.06
South	0.60	0.09
North	0.13	0.08
Visual prominence (riverbed)		
Total	0.24	0.06
South	0.05	0.09
North	0.40	0.08

To test visual prominence of the shellmiddens in the landscape, and check for a meaningful distribution with respect to visibility, site locations were compared to a set of 1000 random distributed points that were then separated in: (1) inland – a total of 700 points distributed from the shellmiddens locations towards inland; (2) river – 300 points distributed throughout the Muge river and tributaries. In other studies (e.g., Bongers et al., 2012; Fisher et al., 1997; Fortnam, 2010) authors tend to use, for comparative analysis, either all cells from the study area or random points distributed without any particular spatial partitions. However, the fact that Muge shellmiddens seem to have worked as central units for the exploitation of both terrestrial and aquatic biomes led us to test how visibility patterns changed separately along the two defined areas.

To check for a possible location of middens in locales with strategic commanding views over the landscape, the total area seen by each shellmidden was compared with the total area seen by a set of random points located along the terraces where shellmiddens are located, extracted from the 1000 points set, using a buffer of 250 m from the edge of the terraces towards inland.

Finally, for intervisibility analysis a cumulative viewshed map (Wheatley, 1995) was calculated by determining each of the seven midden viewsheds and summing them together. The calculated surface represents, for each cell within the landscape, the number of sites with a line-of-sight to that cell. In other words, it represents how many sites can see that specific cell-sized locus. In addition, pairwise line-of-sights between shellmiddens were also recorded to check for patterns of preference between sites. All computed viewshed surfaces from the set of generated maps were regarded as a statistical population, allowing the test of apparent differences with a Kolmogorov–Smirnov (K–S) goodness-of-fit test (Wheatley, 1995). According to Kvamme (1990) this non-parametric approach is well-suited for continuous data. In practical terms, the K–S test measures the maximum difference (*dmax*) between the cumulative proportions of the two samples at the point where they are farthest apart (Kay and Sly, 2001). Significance at 0.05 level is achieved if the difference between samples is greater than

$$d = 1.36\sqrt{\frac{n_1 + n_2}{n_1 n_2}}$$

where n_1 is the number of individuals in the background random sample and n_2 is the number of individuals in the sample of archaeological settlements (Shennan, 1997).

Spatial analyses were performed using ArcGIS 10.1 by ESRI® and statistical procedures were done using MS Excel.

Viewshed analysis requires a raster Digital Elevation Model (DEM) of the landscape. For this study, a DEM with a cell size of 5 m was created, based on the 1:25 000 scale regional maps. Site locations were recorded approximately in the center of the midden with a handheld high-precision GPS (less than 5 m error) and implanted into the DEM as (observer) points. In the cases where shellmiddens are still preserved (i.e. Cabeço da Amoreira and Cabeço da Arruda) the total height of the mound was subtracted from the absolute elevation. The assumption was that all points in the landscape were of equal value, and that certain locales were chosen to build the shellmiddens due to their visibility.

For intervisibility and visual prominence analysis we used a 50 m circular buffer from these points considered to be representative of the average minimal dimensions of the shellmiddens. This allowed to check for differences in the visible areas within each site and to use those cells, rather than single points, as a valid statistical population.

Table 2
Intervisibility between north and south bank shellmiddens. Percentages of visibility were calculated based on the total area of 1963 m^2 obtained from the 50 m circular buffer around the sites: *No-visibility: 0%; **Low-visibility: 1–50%; ***High-visibility 51–99%; ****Total-visibility: 100%.

	View direction ↱	North Bank				South Bank		
		FPP	FB	CAR	ID15	MS	CAM	ID20
North Bank	FPP		**	*	*	**	**	**
	FB	*		*	*	**	**	***
	CAR	*	*		**	**	***	***
	ID15	*	*	**		**	*	*
South Bank	MS	****	****	****	**		***	**
	CAM	****	****	****	*	**		*
	ID20	****	****	****	***	***	*	

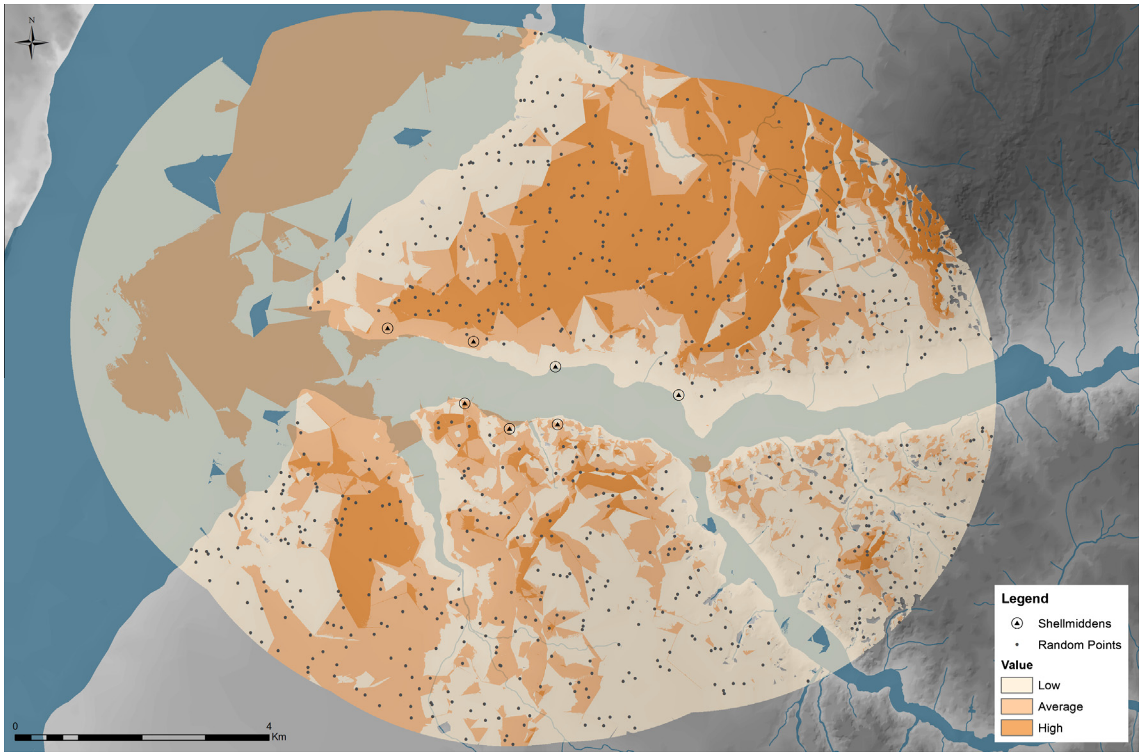

Fig. 4. Visual prominence of the shellmiddens from inland random points. Darker colors indicate that more points can view that areas. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Within the DEM we recreated the early Holocene shore and water surface of the Muge River, using altimetric parameters, aerial photographic resources based on van der Shrieck (2004, 2007) data on the geomorphology of the valley. Those fluvial features roughly correspond to the modern surface of the alluvial plain.

Earth curvature and refraction were automatically corrected in ArcGIS but two other variables had to be taken into account: (1) the height of the viewer – viewer's eyes were placed at 1.5 m from the ground, a value based on the average height of the Mesolithic adult skeletons recovered from the Muge shellmiddens (Umbelino, 2006); (2) and the maximum radius of the viewshed calculation: given that human eye can generally distinguish things as small as 1 arc minute (1/60th of a degree) (Bongers et al., 2012). A 5000 m buffer zone of each site or random point location was used, in order to reduce the impact of edge-effects (Fortnam, 2010). Finally, despite the very significant efforts in recent years to incorporate vegetation in GIS-based visibility analysis (e.g. Llobera, 2007b; Dean, 1997) this factor was not taken into account in our study. For some tests, like intervisibility between banks, vegetation is not a real issue due the presence of the river. However, the possible effects of vegetation on visibility should be considered when evaluating the significance of results reported hereafter.

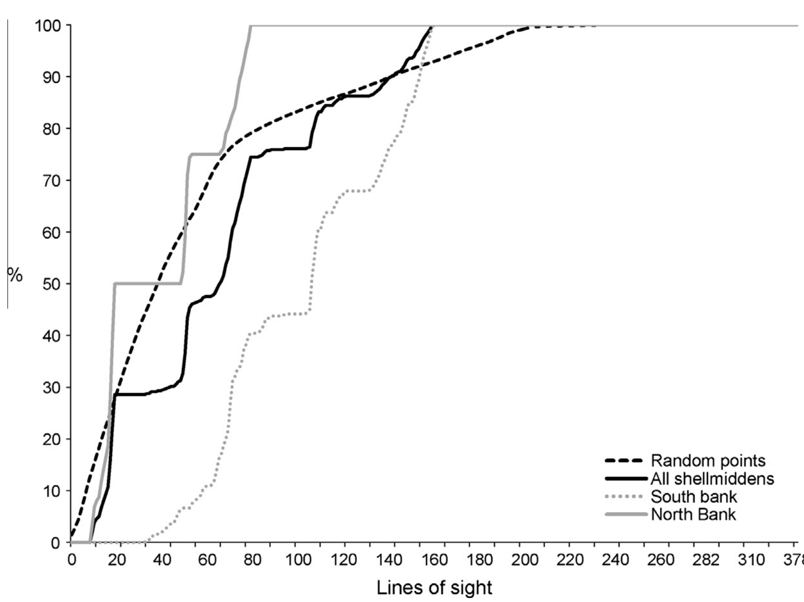

Fig. 5. Cumulative percentages for the visual prominence from inland.

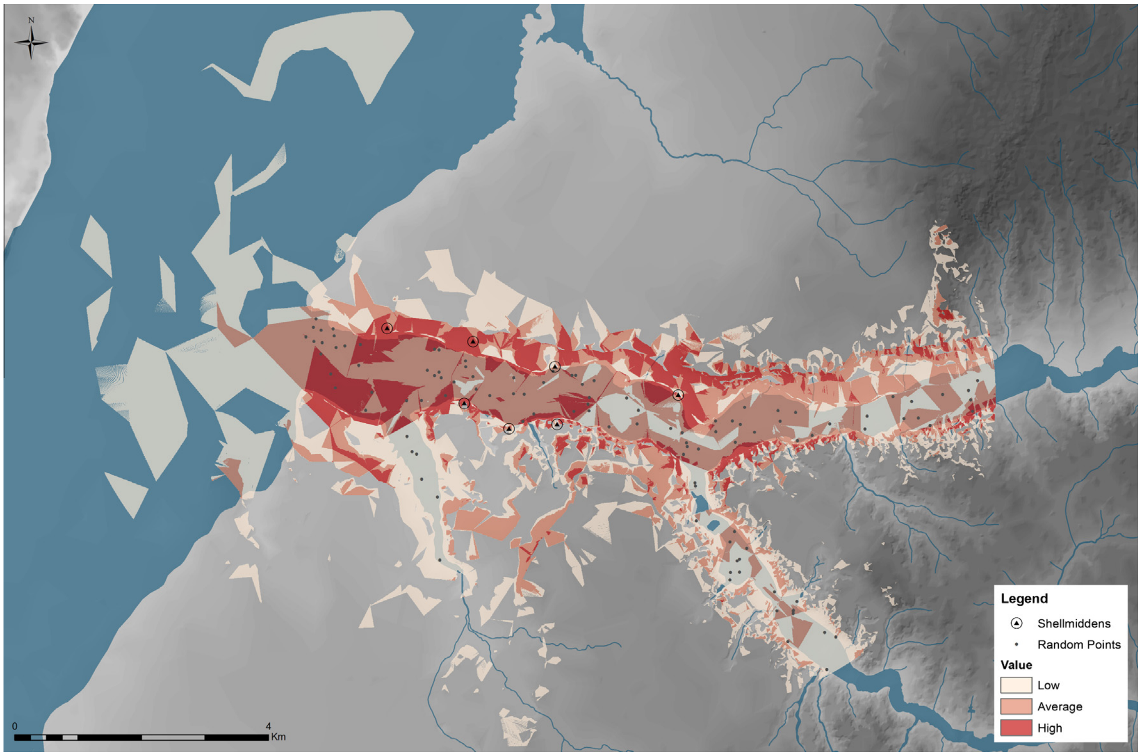

Fig. 6. Visual prominence of the shellmiddens from river random points. Darker colors indicate areas viewed by more points. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

4. Results

4.1. Site intervisibility

The cumulative viewshed map presented in Fig. 2 illustrates the areas with higher (7) to lower (0) lines-of-sight from the middens. Only small portions of the river and of the upper hills in the East can be seen concurrently from all seven shellmiddens. In fact, close to 25% of the total area is not visible from a single site. In contrast, all middens are seen by at least one other site, and an important percentage of the areas occupied by them (c. 44%) are simultaneously visible from four different sites. When compared with the background cumulative visibility curve (Fig. 3) the middens generally occur in locations with more lines-of-sight than expected, indicating that intervisibility was an important factor for deciding where to construct the middens. The statistical significance of these results is attested by the values provided by the K–S test, whose maximum difference (*dmax*) between the background and site samples (0.50) is much higher than the value *d* obtained from the sample size (0.06) (Table 1).

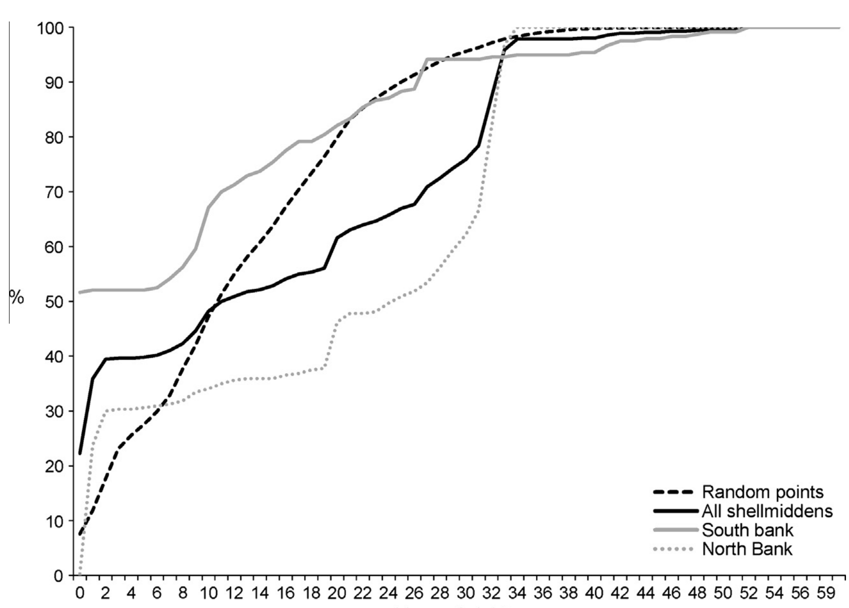

Fig. 7. Cumulative percentages for the visual prominence from the river.

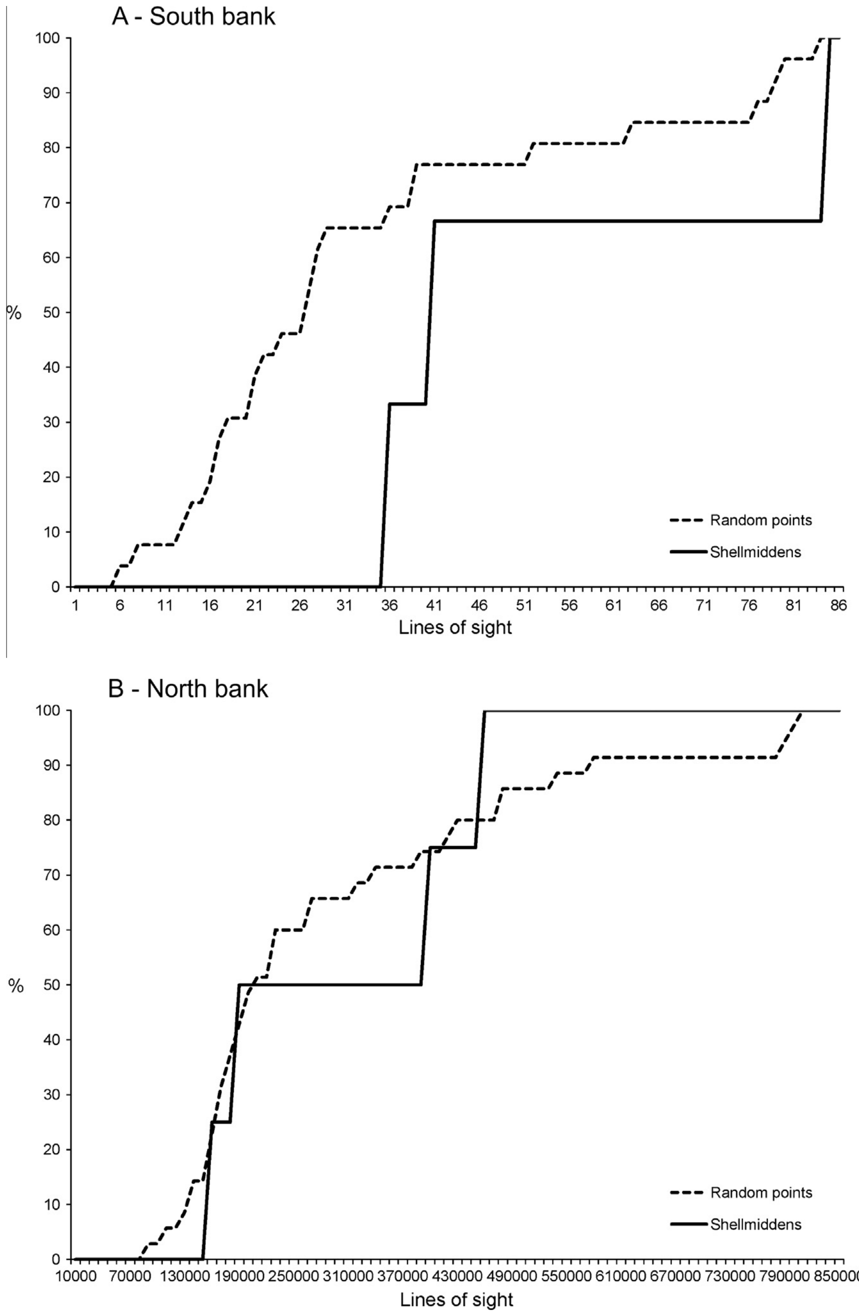

Fig. 8. Cumulative percentages for the total area seen from the south bank (A) and north bank (B) shellmiddens and correspondingly random points.

Differences in the intervisibility between the north and south banks are also evident, as shown in Table 2. While middens located in the south bank have direct visibility over most of sites' areas located in the north bank, the opposite is not true. Only partial, sometimes very small, areas of Moita do Sebastião ($x = 23\%$), Cabeço da Amoreira ($\bar{x} = 38\%$) and ID20 ($\bar{x} = 36\%$) are in the range of vision of the remaining middens. This non-reciprocal visibility pattern is, most probably, related with terrain geomorphological characteristics and differences in the height of the terraces where shellmiddens are located.

Within the same bank, intervisibility is also very poor, the only exceptions being the sites of Cabeço da Amoreira and Moita do Sebastião of which more than 80% of the areas are seen from Moita do Sebastião and ID 20, respectively.

4.2. Visual prominence

In order to determine whether the position of the shellmiddens was the result of a preference for locations highly visible from inland, the cumulative viewshed of a set of random points was used (Fig. 4). As shown in Fig. 5 the comparison between 'random points vs. sites' cumulative distributions clearly reveals that when grouped together, shellmiddens generally occur in areas, with more lines-of-sight than the background viewshed population. The K–S test indicates that there is a significant statistical difference, at a 0.05 confidence level, with the *dmax* value of 0.28 clearly exceeding the critical *d* (Table 1). These data seem to support the fact that site location is not random and middens were located and distributed based on the visual prominence from inland. How-

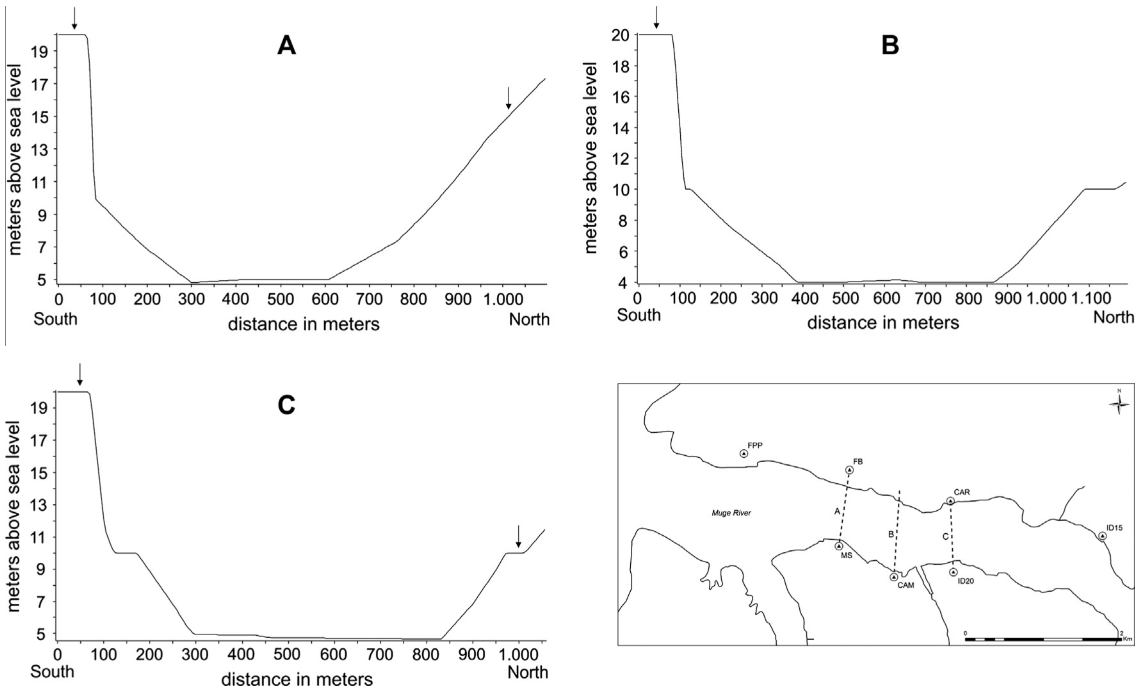

Fig. 9. Topographic cross profiles of the Muge River valley. Arrows indicate the approximate location of shellmiddens.

ever, when analyzed as separated populations, the cumulated frequencies of north and south bank middens appear to disclose very different patterns (Fig. 5). While south bank middens are clearly different from the background population, north bank sites tend to occur in locales with fewer lines of sight than the random points. Oddly, statistics indicate that both sets provide significant values that permit to reject the null hypothesis that shellmiddens are located in randomly chosen areas regarding visibility from inland (Table 1).

Using the same procedure to test the visual prominence of the sites from the river (Fig. 6), the non-randomness of the site location pattern is also very marked, at least for the sample that includes all middens (Fig. 7). A *dmax* value of 0.24 guarantees the statistical significance of the graphical results (Table 1). This pattern, however, seems to be masked by the clustering of all sites as one singular sample. Splitting the model into northern and southern sites provides, in fact, a very different scenario. Shellmiddens located in the south riverbank exhibit very low values with respect to visible areas from the river. In this case, the results from the K–S test clearly reject the hypothesis that shellmiddens in the south bank are located in areas with higher visibility from the river. On the other hand, data from the north bank present a very different pattern with sites being located in areas with more visibility from the river.

4.3. Commanding views

The final proposed hypothesis intended to test whether shellmiddens were located in areas with stronger commanding views over the surrounding landscape when compared with a set of random points distributed across the riverbanks. Fig. 8 shows the cumulative frequencies of random points and sites separately from north (A) and south banks (B). Although the small number of sites (here working as observer points and not observed areas) does not permit the application of a significance test in this specific analysis, visual comparison of the four distributions suggests that relevant differences exist between sites and the randomly generated points, but that they are much less evident for the northern than for the southern bank.

Thus, Moita do Sebastião, Cabeço da Amoreira and ID20 cannot be considered to represent a sample drawn at random from the background population. In practical terms this means that, at least for these middens, significant differences exist regarding the areas visible from the locales where shellmiddens are and any other random spot along the same riverbank.

5. Discussion and conclusions

The analyses reported here suggest a considerable importance for visibility in the choice of settlement location for the Muge Mesolithic hunter–gatherers. The most relevant result observed seems to be the detected difference between riverbanks concerning the tested hypotheses. The limited visibility of southern bank shellmiddens from the river and from the mounds located in the northern bank contrasts, indeed, with their high visual prominence from inland and the high visual dominance over the surrounding landscape. This is undoubtedly related with the altimetric profile of the southern bank, 10–15 m higher than the northern bank. In addition, the pattern obtained for the visual prominence of Moita do Sebastião, Cabeço da Amoreira and ID20 can also be masked by the fact that the areas defined for the analysis do not, in all cases, exactly meet the terrace's scarp, but are located slightly inland.

Fig. 9 presents three different cross-sections of the valley, and the altimetric relation between the alluvial floodplain and the south and northern terraces, showing very clearly why a large percentage of the south bank middens were most probably not seen from the river and opposite bank.

Nonetheless, it cannot be dismissed that the spots where shellmiddens are located could have had some kind of visual marker in order to identify sites from the water and the opposite bank. Also, the dimension and brightness of the shell concentrations, stoutly contrasting to the landscape, may have had a major visual impact, even at very long distances and from unlikely positions. For this reason the general impact of vegetation in the visual prominence of shellmiddens should have been minor. Moreover, according to regional pollen data (van der Shrieck, 2004) and site's charcoal analysis (Monteiro, 2012) the vegetation was essentially similar to the current setting, marked by a Mediterranean woodland open landscape with more abundant unforested than arboreal areas.

Still, one of the possible visual markers from the river would be, for instance, the existence of anchorage spots for boats, since the location of all sites is associated with the existence of small bays that would have worked as good natural shelters for boat anchoring, including protection from winds as well as wave action coming from the wide open estuary side. In fact, although the location of shellmiddens along the riverbanks certainly reveals the necessity of close distance to the high-ranked subsistence aquatic resources, it does not necessarily imply that this was the main reason behind the original choice of the specific locales for site implantation (as it seems to be indicated by the standard distance of c. 750 m between sites). Given that the first occupation, at least in Cabeço da Amoreira and Moita do Sebastião, was of residential and funerary nature, from where very few shells were recovered, the preference for the initial settlement on those spots may have been related with other reasons beyond aquatic subsistence practices. The immediacy with the river is, for example, easily explained by the proximity with, in all likelihood, the most important route for communication and transportation during Mesolithic times.

Concerning the recent interpretations on social and cultural dynamics of the Muge shellmiddens, the differences detected in the altimetric location of the sites, and consequent variation of the visibility patterns are noteworthy. Based on the evidence presented by Bicho and Gonçalves (in press) incipient social hierarchy, based on clan and lineage organization, has been hypothesized for the Muge valley during Mesolithic times. Site location patterns suggest that the distance between sites is not the sole result of physical landscape characteristics, but the outcome of decisions based on the economic division of land and sense of social ownership, as a form of enculturation of the regional Mesolithic landscape (Driscoll, 2009; Zvelebil, 2003). Adding the visibility, which is often argued as being instrumental in the definition of territories (Fortnam, 2010; Llobera, 2003), and altitudinal data to this proposal can offer a new perspective to a hypothetical hierarchical allotment between riverbanks. Most likely, and although all mounds were likely used as territorial markers, the south bank sites could have had a different role within the valley, probably with a more monumental character. This is attested by, for example, the density of the shell layers and the presence of the symbolic protective cap of small pebbles at the top of Cabeço da Amoreira. High visual prominence and great commanding views over the surrounding landscape from the south bank may have, indeed, provided the perfect spots for the construction of monumental sites with a strong socio-cultural significance.

Some of the Muge mounds constitute thus, in our perspective, evidence for a continuation of social and symbolic practices that surpasses the straight economic strategies and adaptation. The accumulation of the dense packed shell layers magnify those purposefully chosen locales in the sense that it amplifies their symbolism and enlarge their monumental impact on the landscape, just as argued for the intentional Late Archaic shell rings constructions in southeastern United States (Kohler, 1997; Claassen, 1991). Contrary to the shell rings example, that seem to demonstrate a collaborative (through feasting) construction of those monumental sites (Saunders and Russo, 2011), the case of Muge seems, although no feasting evidence are available, to point in an opposite direction. Differences detected in the cultural material of each shellmidden together with the visibility patterns just presented indicate the presence of some kind of segmented social environment that translates into the implementation of strong territorial markers which may be used for example, as is well-known in hunter–gatherer societies where 'ownership' of land is rarely recognized, to signal their users the right to accomplish certain functions at those specific locations (Grøn, in press). This, in turn, clearly fits in with the argument of a changing ideology concerning landscape that implicates the application of a new perspective to the territory and the purposefully construction of locales with characteristics of monumentality. A pattern that is now suggested to emerge during the Mesolithic (Bicho et al., in press; Cummings, 2003) and not in the Neolithic as previously thought (Bradley, 1998; Sherratt, 1996; Thomas, 1988), and that may have been the main influence to the advent of the so-called Neolithic and Calcolithic landscapes of death.

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References

Ames, Kenneth M., 2006. Thinking about household archaeology on the northwest coast. In: Sobel, A., Gahr, A., Ames, K. (Eds.), Household Archaeology on the Northwest Coast. International Monographs in Prehistory, Ann Arbor, pp. 16–36.

Araújo, A.C., 2009. Hunter–gatherer adaptations during the Pleistocene/Holocene transition in Portugal: data and explanatory models. In: McCartan, S., Schulting, R., Warren, G., Woodman, P. (Eds.), Mesolithic Horizons. Papers Presented at the Seventh International Conference on the Mesolithic in Europe. Oxbow Books, Oxford, pp. 533–540.

Arnaud, J., 1987. Os concheiros Mesolíticos dos Vales do Tejo e Sado: semelhanças e diferenças. Arqueologia 15, 53–64.

Arnaud, J., 1989. The mesolithic communities of the sado valley, Portugal, in their ecological setting. In: Bonsall, C. (Ed.), The Mesolithic in Europe. John Donald, Edinburgh, pp. 614–631.

Arnaud, J., 1990. The mesolithic communities of the Sado valley, Portugal, and their ecological setting. In: Bonsal, C. (Ed.), The Mesolithic in Europe. Papers Presented at the Third International Symposium. John Donald Publishers, Edinburgh, pp. 614–631.

Ashmore, W., Knapp, A.B. (Eds.), 1999. Archaeologies of Landscape: Contemporary Perspectives. Blackwell Publishers, Malden, Mass.

Bicho, N., 2009. Sistemas de povoamento, subsistência e relações sociais dos últimos caçadores-recolectores do Vale do Tejo. Estud. Arqueol. Oeir. 17, 133–156.

Bicho, N., Gonçalves, C., in press. Back to the past: the emergence of social differentiation in the Mesolithic of Muge, Portugal. In: Proceedings from the Eighth International Conference on the Mesolithic in Europe.

Bicho, N., Umbelino, C., Detry, C., Pereira, T., 2010. The emergence of the Muge Mesolithic shellmiddens (central Portugal) and the 8200 cal yr BP cold event. J. Island Coast. Archaeol. 5, 86–104.

Bicho, N., Cascalheira, J., Marreiros, J., Pereira, T., 2011. The 2008–2010 excavations of Cabeço da Amoreira, Muge, Portugal. Mesol. Misc. 21 (2), 3–13.

Bicho, N., Cascalheira, J., Marreiros, J., Gonçalves, C., Pereira, T., Dias, R., 2012. Chronology of the Mesolithic occupation of the Muge valley, central Portugal: the case of Cabeço da Amoreira. Quatern. Int. 308–309, 130–139.

Bicho, N., Pereira, T., Umbelino, C., Jesus, L., Marreiros, J., Cascalheira, J., Gonçalves, C., Detry, C., in press. The construction of a shellmidden: the case of Cabeço da Amoreira, Muge (Portugal). In: Proceedings from the Eighth International Conference on the Mesolithic in Europe.

Bongers, J., Arkush, E., Harrower, M., 2012. Landscapes of death: GIS-based analyses of chullpas in the western Lake Titicaca basin. J. Archaeol. Sci. 39 (6), 1687–1693.

Bradley, R., 1998. The Significance of Monuments: On the Shaping of Human Experience in Neolithic and Bronze Age Europe. Routledge, London and New York.

Cascalheira, J., Gonçalves, C., 2012. Spatial density analysis and site formation processes at the Mesolithic shellmidden of Cabeço da Amoreira (Muge, Portugal). In: Cascalheira, J., Gonçalves, C. (Eds.), Actas das IV Jornadas de Jovens em Investigação Arqueológica. Promontoria 16. NAP, Faro, pp. 75–82.

Claassen, C., 1991. Gender, shellfishing, and the shell mound archaic. In: Gero, Joan M., Conkey, Margaret W. (Eds.), Engendering Archaeology: Women and Prehistory. Basil Blackwell, Cambridge, pp. 276–300.

Cummings, V., 2003. Mesolithic world-views of the landscape in western Britain. In: Larsson, L., Kindgren, H., Knutsson, K., Leoffler, D., Åkerlund, A. (Eds.), Mesolithic

on the Move: Papers Presented at the Sixth International Conference on the Mesolithic in Europe, Stockholm. Oxbow, Oxford, pp. 74–81.
Dean, D., 1997. Improving the accuracy of forest viewsheds using triangulated networks and the visual permeability method. Can. J. Forest Res. 27, 969–977.
Driscoll, K., 2009. Constructing later mesolithic landscapes. In: Finlay, N., McCartan, S., Milner, N., Wickham-Jones, C. (Eds.), From Bann Flakes to Bushmills: Papers in Honour of Professor Peter Woodman, Prehistoric Society Research Papers, vol. 1. Oxbow, Oxford, pp. 97–108.
Fisher, P., Farrelly, C., Maddocks, A., Ruggles, C., 1997. Spatial analysis of visible areas from the bronze age cairns of mull. J. Archaeol. Sci. 24, 581–592.
Fortnam, S., 2010. The Applicability of Geospatial Techniques to Analyze Visibility as a Determinant of Late-Woodland Settlement Patterns in Southwestern Pennsylvania. Unpublished M.A. thesis. Indiana University of Pennsylvania.
Gonçalves, C., 2009. Modelos preditivos em SIG na localização de sítios arqueológicos de cronologia mesolítica no Vale do Tejo. Unpublished M.A. thesis. Universidade do Algarve.
Gonçalves, C., in press. GIS as a predictive tool for the location of new Mesolithic sites in the Tagus Valley (Portugal). In: Proceedings from the Eighth International Conference on the Mesolithic in Europe.
Grøn, O., in press. Territorial infrastructure, markers and tension in Late Mesolithic hunter–gatherer societies: an ethnoarchaeological approach. In: Proceedings of the Muge 150th meeting. Salvaterra de Magos, Portugal.
Jackes, M., Meiklejohn, C., 2004. Building a method for the study of the Mesolithic–Neolithic transition in Portugal. Document. Praehist. 31, 89–111.
Jesus, L., Marreiros, J., Cascalheira, J., Gibaja, J., Pereira, T., Bicho, N., in press. Occupation, functionality and culture. Preliminary results from microliths technology and use-wear analysis of Cabeço da Amoreira (Muge, Portugal). In: Proceedings from the Eighth International Conference on the Mesolithic in Europe.
Kay, S., Sly, T., 2001. An application of cumulative viewshed analysis to a medieval archaeological study: the beacon system of the Isle of Wight, United Kingdom. Archeol. Calcol. 12, 167–179.
Kohler, T., 1997. Public architecture and power in pre-Columbian North America. In: International Symposium ''Power, Monuments, and Civilization'' Nara, Japan, December 1997.
Koyama, S., Uchiyama, J., 2006. Why ''Beyond Affluent Foragers''? Looking back at the original affluent foragers concept. In: Grier, C., Kim, J., Uchiyama, J. (Eds.), Beyon Affluent Foragers: Rethinking Hunter. Gatherer Complexity. Proceedings of the 9th Conference of the International Council of Archaeozoology, Durham, August 2002. Oxbow Books, Oxford, pp. 1–3.
Kvamme, K., 1990. One-sample tests in regional archaeological analysis: new possibilities through computer technology. Am. Antiquity 55 (2), 367–381.
Lake, M.W., Woodman, P.E., 2000. Viewshed analysis of site location on Islay. In: Mithen, S. (Ed.), Hunter–Gatherer Landscape Archaeology: The Southern Hebrides Mesolithic Project, 1988–98, Archaeological Fieldwork on Colonsay, Computer Modelling, Experimental Archaeology, and Final Interpretations, vol. 2. The Mcdonald Institute for Archaeological Research, Cambridge, pp. 497–503.
Lake, M., Woodman, P., Mithen, S., 1998. Tailoring GIS software for archaeological applications: an example concerning viewshed analysis. J. Archaeol. Sci. 25, 27–38.
Llobera, M., 2003. Extending GIS-based visual analysis: the concept of visualscapes. Int. J. Geograph. Sci. 17 (1), 25–48.
Llobera, M., 2007a. Reconstructing visual landscapes. World Archaeol. 39, 51–69.
Llobera, M., 2007b. Modeling visibility through vegetation. Int. J. Geograph. Inform. Sci. 21 (7), 799–810.
Marchand, G., 2005. Interpretar as mudanças dos sistemas técnicos do Mesolítico final em Portugal. O Arqueól. Port. Sér. IV 23, 171–195.
Marreiros, J., Jesus, L., Cascalheira, J., Pereira, T., Gibaja, J., Bicho, N., in press. ''Shell we move?'' New technological approach to Mesolithic settlement patterns at Muge (Portuguese Estremadura). In: Proceedings from the Eighth International Conference on the Mesolithic in Europe.
Monteiro, P., 2012. Woodland exploitation during the Mesolithic: anthracological study of new samples from Cabeço da Amoreira (Muge, Portugal). CKQ 2, 33–47.
Prentiss, W.C., Kuijt, I. (Eds.), 2004. Complex Hunter–Gatherers; Evolution and Organization of Prehistoric Communities on the Plateau of Northwestern North America. University of Utah Press, Salt Lake City.
Price, T.D., 1985. Affluent foragers in Mesolithic south Scandinavia. In: Price, T.D., Brown, J. (Eds.), Prehistoric Hunter–Gatherers. Academic Press, pp. 341–363.
Roche, J., 1972a. Les amas coquilliers (concheiros) mésolithiques de Muge (Portugal). Fundamenta 3, 72–107.
Roche, J., 1972b. Les amas coquilliers de Muge (Portugal). In: ĹEpipaléolithique Méditerranéen. Colloque international, Aix-en-Provence, 1972. CNRS, Paris, pp. 79–81.
Roche, J., 1989. Spatial organization in the Mesolithic sites of Muge, Portugal. In: Bonsall, C. (Ed.), The Mesolithic in Europe. Third International Symposium. John Donald, Edinburgh, pp. 607–613.
Saunders, R., Russo, M., 2011. Coastal shell middens in Florida: a view from the Archaic period. Quatern. Int. 239, 38–50.
Shennan, S., 1997. Quantifying Archaeology. University of Iowa Press, Iowa.
Sherratt, A., 1996. Instruments of conversion? The role of megaliths in the Mesolithic/Neolithic transition in north-western Europe. Oxford J. Archaeol. 14, 245–260.
Thomas, J., 1988. Neolithic explanations revisited: the Mesolithic–Neolithic transition in Britain and south Scandinavia. Proc. Prehist. Soc. 54, 59–66.
Umbelino, C., 2006. Outros sabores do passado. As análises de oligoelementos e de isótopos estáveis na reconstrução da dieta das comunidades humanas do Mesolítico Final e do Neolítico/Calcolítico do território português. Unpublished Ph.D. dissertation, Universidade de Coimbra.
van der Shrieck, T., 2004. Holocene Environmental Change and the Alluvial Geoarchaeology of Mesolithic Settlement-Subsistence in the Muge and Magos Valleys, Lower Tagus Basin, Portugal. Unpublished Ph.D. dissertation, University of Newcastle upon Tyne.
van der Shrieck, T., 2007. The palaeogeography of Mesolithic settlement-subsistence and shell midden formation in the Muge valley, Lower Tagus Basin, Portugal. Holocene 17 (3), 369–385.
van Leusen, P.M., 1993. Cartographic modelling in a cell—based GIS. In: Andresen, J., Madsen, T., Scollar, I. (Eds.), Computing the Past: Computer Applications and Quantitative Methods in Archaeology. Aarhus University Press, Aarhus, pp. 105–123.
Wheatley, D., 1995. Cumulative viewshed analysis: a GIS-based method for investigating intervisibility, and its archaeological application. In: Lock, G., Stancic, Z. (Eds.), Archaeology and Geographical Information Systems: A European Perspective. Taylor & Francis, London, pp. 171–186.
Wheatley, D., Gillings, M., 2002. Spatial Technology and Archaeology: The Archaeological Applications of GIS. Taylor & Francis, New York.
Zvelebil, M., 2003. Enculturation of mesolithic landscapes. In: Larsson, L., Kindgren, H., Knutsson, K., Leoffler, D., Åkerlund, A. (Eds.), Mesolithic on the Moved: Papers Presented at the Sixth International Conference on the Mesolithic in Europe. Oxbow, Oxford, pp. 65–73.