Counting with the invisible record? The role of LiDAR in the interpretation of megalithic landscapes in south-western Iberia (Extremadura, Alentejo and Beira Baixa)

(LiDAR and megalithic landscapes in south-western Iberia)

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Abstract

The megalithic sites from southwest Iberia represent one of the largest clusters of prehistoric monuments in Europe from the Neolithic and Copper Age (5th and 3rd millennia cal BC). Unlike other regions from western Europe, there has not been a recent effort to map the distribution of these kinds of burial across this vast territory. Therefore, this paper aims to collect geographic information from three regions of southwest Iberia (Alentejo and Beira Baixa from Portugal and Extremadura from Spain) and to compare the archaeological evidence between different landscape units. We have mapped already known megaliths (ca. 2000) and settlements (ca. 1500) in this area. Moreover, through the interpretation of LiDAR datasets, we have identified new walled enclosures and megaliths in the Extremadura region (Spain), the only one of the three where LiDAR data are available. The new data reveals new connections between settlements, burials and other archaeological evidence. Finally, we discuss the impact that these new data have on a new overall interpretation of megalithic landscapes from the Iberian Peninsula, stressing also the potential risks that the massive application of remote sensing can have in the production of archaeological knowledge.

Keywords: Neolithic, Copper Age, LiDAR, Iberian Peninsula, Megalithic barrows, Walled enclosures

1. Introduction

Attempting a quantitative estimation of megaliths in Europe comes up against several complications as the result of divergent factors. Among them, the most significant can be the level of research in each country and its historiographic traditions (Furholt et al., 2011; Laporte and Bueno-Ramírez, 2016). This paper will determine the effect that the use of LiDAR can have on the number of records. To do so we have reviewed three of the richest regions in South Europe: Alentejo, Beira Baixa and Spanish Extremadura (Figure 1), where the density of megaliths is remarkable. There are two questions that should be defined regarding these significant concentrations: to what extent does the inventory of known sites recorded through traditional fieldwork methods during the 20th century reflect the reality of the past? And what percentage of these necropolises is associated with ditched, walled and fortified enclosures? It is only by means of these data that we can realistically approach the demography and social processes of southern Europe during Late Prehistory. Moreover, it is now credible to evaluate the locational patterns of both burials and habitats in compact and well-established networks, as has been pointed out for Northern Europe (Andersen, 1988). LiDAR can offer an alternative and novel response to both questions by opening new lines of research that can reveal undetected archaeological evidence.

Extending this approach to other megalithic regions of the European Atlantic façade can contribute to obtaining information for some of the noticeable settlement gaps in some of these regions. Brittany can be a suitable example of this situation due to its impact in research on the Atlantic megalithic sites. As an example of this, it should be considered that both its geological background of schist and granite and some of its best-known megalithic manifestations show similarities with Iberian megaliths. Menhirs and the recent identification of paintings in Breton funerary architectures (dolmens) can be taken as proof of this (Bueno-Ramírez et al., 2015; Cassen and L'Helgouach, 1992; Scarre, 2002). These hypotheses can also be supported by the existence of a “pre-megalithic” Neolithic with equivalent material contexts, especially the presence of personal ornaments found in Breton megaliths and whose origin was the southern Iberian Peninsula (Diniz, 2007; Herbaut & Querré, 2004; Roussot-Larroque & Burnez, 1992). At the beginning of metallurgy, other items linked to bell-beaker pottery reveal ties between Iberia and Brittany, and can be added to the characteristic exchange of metal (copper and gold) in the Atlantic Bronze Age (Fokkens & Harding, 2013; Laporte, 2001).

In a European context, several initiatives have succeeded in detecting prehistoric barrows (or burial mounds) through LiDAR techniques, as the following examples show. Some case studies, like the one performed in the surroundings of Stonehenge more than a decade ago, revealed prehistoric features like fields linked to monuments (Bewley, Crutchley, & Shell, 2005). The analysis of LiDAR-derived images in Ireland has also served to identify an impressive number of new barrows in the archaeological complex of Brú na Boinne (Corns & Shaw, 2013, p. 151). Ongoing work in other megalithic areas, like Brittany, are likely to offer promising results in a near future (Guyot et al.,

2018). In Central Europe the analysis of LiDAR data has also allowed for the detection of groups of prehistoric barrows, and their identification in forested areas is of special interest (Stróżyk, 2016). However, it must be stressed that the difference between our proposal and the aforementioned ones is the scale of our survey. Covering complete regions, as in our case, can be worthwhile to understand the factors and biases that influence the detection of sites through remote sensing.

In this paper, we aim to demonstrate that it is feasible to refine our estimation of the number of megaliths on a landscape level scale, which was not conducted in this manner by the prior studies mentioned. Moreover, our research shows that it is also possible to obtain evidence of their relationship with habitats by using a combination of LiDAR technology and fieldwork datasets. Our study contributes to an unpublished georeferenced catalogue of known megaliths in this region of inner Iberia, completed with an important number of new sites and a novel picture of their relationship with fortified and ditched enclosures.

1.1. Quantifying megaliths in south-west Iberia

An accurate quantification of megaliths across the south-western region of the Iberian Peninsula has been a challenge for archaeologists for over half a century. Following the catalogue of G. Leisner and V. Leisner (1956), it was assumed that the Spanish record was marginal and limited. This was explained by a suggested depopulation of this area, which megaliths would have reached in a late stage of their expansion, characterised by structures with a chamber and long passage (Bosch-Gimpera 1932). Archaeological documentation focused on the area of the Spanish-Portuguese border, as it was thought that the expansion of the Portuguese megaliths would have become established in the contact areas (Almagro-Basch 1962). The chronology and changes in the organisation of the monuments were the basic objectives of research, apart from habitation or catchment areas (Arribas-Palau & Molina-González 1984).

A complete quantification of the sites in this region (Figure 2) has never been conducted since the Leisners' catalogue cited above. It has been estimated that there are more than 2000 megaliths in South Portugal (Rocha 2016). In Extremadura about 400 dolmens have been documented, which is similar to the number known in the Central Castilian Plateau (Bueno-Ramírez *et al.* 2016, 158). A small fraction of the evidence comes from local inventories made systematically (Bueno-Ramírez *et al.* 2012; Bueno-Ramírez & Vázquez-Cuesta 2008; Cerrillo-Cuenca *et al.* 2016; Jiménez-Ávila & Barroso-Expósito 2000; Oliveira 1998; Rocha 2015) and most of it is the result of unsystematic research or accidental finds.

LiDAR is a unique tool that can be used to provide new insight towards the level of occupation in one of the areas of interest in European megalithic research. Although this method has been used in research for over a decade, most case studies have concentrated in northern Europe (Bewley, Crutchley, & Shell, 2005), owing to the lack of LiDAR in the south of Europe. However, data has been available for Spain since 2015, and this has allowed a reappraisal of some megalithic territories (Carrero-Pazos, Vilas Estévez, Romaní Romaní, & Rodríguez Casal, 2015; Cerrillo-Cuenca, 2017), but this is not the case of Portugal. The systematic application of photointerpretation is very recent and

has been focused mainly on ditched enclosures (Jiménez-Jáimez, 2015; Valera & Pereiro 2013).

Considering the results of the aforementioned works, the combination of the techniques of photointerpretation and LiDAR has impacted on an updating of the interpretative discourse. This maintains that many of the sites, both habitats and funerary monuments, may form part of a more complex landscape. With the information obtained in Extremadura, the study can be projected towards proximate areas and open new fields in this kind of application. The automatic processing of LiDAR datasets and supercomputing (Cerrillo-Cuenca, 2017) on which the present study is based, means that a larger terrain, with a surface area of over 40,000km², can be covered. This represents one of largest-scale efforts in documenting archaeological evidence through remote sensing techniques in Southern Europe.

2. Methods

LiDAR (Light Detection And Ranging) is a terrain surveying technique with a long tradition in archaeology, as exposed elsewhere (Chase et al. 2011, Crutchley & Crow 2010, Devereux et al. 2005, Doneus et al. 2008, Gallagher & Josephs 2008). LiDAR uses pulsed laser beams to obtain precise 3D information about the terrain. This information is recorded in the form of point clouds, which have been used for the present study.

The LiDAR datasets used in this paper have been obtained through the facilities of the Spanish National Geographic Institute. Each LiDAR tile comprises a surface of 4 sq. km. and an approximate average of 10 million observations (points). Although their resolution might not be optimal for the archaeological recognition of terrain (0.5 points per square metre), it provides enough information to distinguish most prehistoric earthworks, like ditched and walled enclosures, and a significant number of barrows and megalithic structures.

A noticeable novelty in our work is that LiDAR datasets have been massively and automatically processed through an HPC (High-Performance Computing) facility that has reduced the time invested in processing the LiDAR datasets to render cartographic products. Regarding the most technical aspects of LiDAR dataset processing, the software code executed at the HPC facility was written in Python programming language, although it incorporated third-party libraries and binaries.

The preparation of LiDAR data includes the removal of outlier points from datasets, the filtering of the forest canopies, the generation of terrain models and, finally, the automatic creation of shaded relief images of terrain and the application of algorithms to highlight anomalies (Cerrillo-Cuenca 2017). The outliers were removed by a piece of code that considered the standard deviation of individual points in buffers, whilst the vegetation was classified through a Multiscale Curvature Algorithm (Evans & Hudak, 2007), that has proved extremely efficient in the classification of isolated vegetation as well as denser canopies. In general terms, the usual type of canopy in the region is Mediterranean oak woodland or *dehesas*, which can be accurately filtered by

means of this procedure. In short, this methodology represents a major step forward regarding the limited outcomes of traditional aerial photo-interpretation in South-West Iberia, where the massive extension of oak woodlands did not allow the systematic use of aerial recognition for large areas.

Once filtered, a digital terrain model (DTM) of the naked surface was produced by interpolating the points through an IDW (inverse distance weighted) algorithm. The result was a 1-metre resolution DTM that was converted into shaded relief images (“hillshades”) (Štular, Kokalj, Oštir, & Nuninger, 2012) by applying the conventional parameters of 315° for azimuth and 45° of elevation for an artificial lighting source. However, interpreting certain kinds of terrain might also require the application of additional algorithms (Kokalj et al., 2017). Laplacian of Gaussian (Zhan, Liang, Cai, & Xiao, 2011) and Local Relief Model (Hesse, 2010) algorithms have been the most efficacious in revealing prehistoric features in our case.

The images were automatically uploaded into QGIS desktop software by means of a self-made plugin that directly downloaded the images from the HPC facility into the local computer. This procedure allows us to query for rasters at a given location and recover them in the span of seconds. This approach has allowed us to cover extensive areas of territory that otherwise would have needed a high investment in computational resources and time. The noteworthy reduction in time is also directly related to the surface area covered and the recognition of a high number of archaeological features. A total of 12,000 files have been visually inspected through this system in the last few years.

A main source of information comes from semi-automatic detection of barrows, which is an up-to-date technique (Cerrillo-Cuenca, 2017; Cowley, 2012; Davis 2018; Guyot et al., 2018; Trier, Zortea, & Tonning, 2015). Our method is based on a GEOBIA (GEOgraphic-Object-Based Image Analysis) approach that segments the DTM raster into regions considering specific properties of the terrain. Through this method it is possible to identify barrows in LiDAR datasets by considering the topographic curvature of terrain, elevation, shape and size of suitable locations in DTMs. Once the results obtained for the region described in Cerrillo-Cuenca 2017 had been checked, they were incorporated into the present study.

The results were contrasted with series of historical aerial images available from public web servers in a span of time that extends from 1945 to the present with different resolutions. The mapping of anomalies was performed by using different categories to reflect their correspondence to different types of archaeological sites (dolmen, walled enclosure, etc.) but also their degree of certainty (low likelihood, medium likelihood, high likelihood, and certain) after the evaluation by an expert.

3. The record from Late Prehistory in south-western Iberia

The area of study may be regarded as one of the most intensely occupied in terms of the number and density of megaliths in Europe and it is suggested as the first in which symbolic references (menhirs, steles, decorated rocks in the

open air, painted rock-shelters and decorated megaliths) comprise a record integrated in the megalithic territories (Bueno-Ramírez et al. 2004; Caninas et al. 2016; Oliveira 2000).

The current conception of megalithic architecture in Extremadura is very similar to the Alentejo model of chambers (polygonal) and a short passage in areas near the Tagus and towards the south of the river, as our research has revealed (Bueno-Ramírez 2000, p. 34). Dolmens formed by round chambers and slightly longer passages are distributed across the Beira region and areas near the Spanish border, reaching as far as the inner Tagus valley. These architectonic structures were probably functioning from the last centuries of the fifth millennium and definitely from the start of the fourth millennium cal BC (Boaventura, 2011; Bueno-Ramírez, 2000; Bueno-Ramírez et al., 2005a, 2016).

The diachronicity in these architectures is firm evidence of constructive specialisations of an identitarian nature, as has been observed in other parts of Europe (Furholt et al., 2011). This is the case of the larger chambers and longer passages that appear in the construction systems in Beira, Portugal, and which have also been documented in the east of Extremadura and on both plateaus in inner Spain (Bueno-Ramírez et al., 2016, p. 161). Alentejo, Beira Baixa and Spanish Extremadura share an abundant number of anthropomorphic representations made on sandstone or schist plates that reveal a highly-coded system of association between burial deposits and human representations (Bueno-Ramírez 2010).

The high point in the construction of necropolises with a large number of dolmens was reached in the time from the late fourth millennium to the mid-third millennium cal BC. A series of more “mechanical” mortuary solutions was superimposed over a background of architectures with a long tradition, and these expanded across the whole Iberian Peninsula. They included corbel-roofed tombs, hypogea and cemeteries with small monuments that emulated the classic forms of passage graves, just as occurred in other parts of southern Iberia (Aranda-Jiménez & Lozano-Medina, 2014; Bueno-Ramírez et al. 2012; Rocha, 2016; Valera, 2016).

The association between the megaliths in the region and the lithology has disproved the hypothesis that connected granite with large constructions in areas of farming potential and schist with small monuments built by groups that did not practise agriculture (Oliveira, 1998). Systematic analysis of the contents of pottery found in megaliths on slate has shown that they used cereals and additionally their grave goods include prestige objects such as gold, in a sector where the wealth of gold has been demonstrated (Bueno-Ramírez, Barroso-Bermejo, & Balbín-Behrmann, 2008).

The relationship between habitation areas and megaliths is confirmed by stratigraphies with continuous sequences with occupations and megalithic constructions (Oliveira, 1998; Zapatero-Magdaleno & Delibes-de-Castro, 1996). Similarly, the large concentrations of megaliths are associated with ditched or walled enclosures.

The availability of radiocarbon dates in the whole of western Iberia is still too limited to be able to design demographic models like those that have been

developed from absolute dates in other parts of Europe (Timpson et al., 2014), but some trends can be described. As in any historical process, it seems realistic to consider that the intensity of the occupation of the territory during Neolithic and Copper Age should have been variable and discontinuous. Thus, during the fifth millennium cal BC and the first half of the fourth millennium, the record of habitation sites is especially poor in both Alentejo and Extremadura (Cerrillo-Cuenca, 2005; Diniz, 2007), which contrasts with the larger number of dates for different types of graves, particularly for those dated in the area of study from the late fifth millennium onwards. There must be many causes for this, but the most recent studies in the Plateau suggest that the oldest dolmens "conceal" previous habitats (Bueno-Ramírez et al., 2016). It is, therefore, possible that the numbers of this type of site will increase when excavations in western Iberia uncover sequences underneath the barrows. In contrast, more habitation sites are known for the second half of the fourth millennium and the third millennium cal BC. This is also seen in most of the continent and attests more complex population dynamics (Díaz-del-Río, 2008; García-Sanjuán et al., 2017; Parkinson and Duffy, 2007). Sites covering several hectares are known in both Extremadura and Alentejo, some of them including sepulchres (Odriozola-Lloret & Hurtado-Pérez, 2009; Valera, 2016).

4. Results: adding sites with LIDAR.

LiDAR has been used to identify 236 new barrows, distributed unequally throughout the basins of the Rivers Tagus and Guadiana in Spain (Figure 3). Nearly 80 new ditched or walled enclosures have been documented. Such increases are hard to find in other studies in Europe and justify the methodology that has been applied.

Barrows are detected with a degree of uncertainty, and therefore their identification is accepted only after review of the "false positives" that are common with manual or automatic method of detection (Cerrillo-Cuenca, 2017, p. 143; Inomata et al., 2018, p. 2). Many factors can hamper the recognition of funerary mounds in LiDAR-derived images, among the most obvious are the size and preservation of the mounds, but also the resolution of the original LiDAR datasets. The identification of walled and fortified enclosures is less difficult as their morphology in the form of concentric enclosures is easily recognisable and less prone to false positives. However, by relying only on LiDAR for the detection of settlements we are probably increasing the number of walled enclosures, but underestimating the role that less visible evidence (i.e. ditched enclosures or non-enclosed sites) might have in prehistoric landscapes.

4.1. New settlements

The first result of this study is the demonstration of the close relationship between dolmens and these sites. The percentage of habitats with megaliths in their proximity has been calculated with the available sample, considering linear distances as the basic measure for a general estimate. In this way, 68% of the known habitats have megaliths in an area 5 km in radius around them. This relationship of proximity shows that, however biased the sample might be, the location of habitats and graves seems to follow a similar pattern. To take this a

little further, the distribution of megaliths and settlement may in general terms be considered a consequence of similar patterns of landscape occupation and can be seen as a first approach to evaluate the intensity of land use. Therefore, the distribution of barrows can be understood as an indirect measure of human activity across different kinds of landscapes. This reasoning can be useful to obtain a regional picture of the distribution of Neolithic and Chalcolithic sites, which unequivocally need to be completed with detailed local studies, whose scope is beyond the aim of this paper.

In Extremadura, the only walled enclosures that were known previously are in Plasenzuela, Jaraíz de la Vera and several sites in the Guadiana basin (Bueno-Ramírez et al., 2000; González-Cordero et al., 1991; Hurtado-Pérez & Mondéjar-Fernández-de-Quincoces, 2009) (Figure 1). These are now joined (Figure 4) by the walled enclosure associated with the two corbel-roofed graves in Colada de Monte Nuevo (Schubart, 1973), formed by at least 4 walls that cover an area of 6 ha (Figure 5). Its detection should force a reconsideration of the alleged hierarchy of settlement in the neighbouring area, dominated by such well-known sites as Perdigões, Porto Torrão, or San Blas, besides the flow of goods distribution (Odriozola-Lloret & Hurtado-Pérez, 2009). Other examples are La Corona (Figure 6) next to the megaliths of Barcarrota (Enríquez Navascués & Duque Espino, 2015; Leisner & Leisner, 1956), which will require further defined and localized studies, the concentration of villages and necropolises composed by several dolmens in the south-east of the region and the necropolis and walled enclosure near the paintings at Monfragüe (Figure 7). These are large areas delimited by walls, some of them over 1 ha, linked to necropolises and graphic markers (e.g. at Monfragüe), or situated in areas with good potential for copper ore (e.g. the Azuaga area). Third millennium cal BC chronologies are repeated in the sites near Perdigões, San Blas (Hurtado, 2004) or La Pijotilla, where the tombs are located inside the ditched enclosures, or at the village of Charneca do Fratel in the Portuguese Tagus International (Soares, 2016). The comparison with the necropolis of Los Millares, a fortified site with an organised necropolis and decorated rock-shelters in its surroundings, seems convincing (Martínez-García 1981).

4.2. *A global picture of old and new megaliths*

An assessment of the increase in the numbers of megaliths includes accepting the difficulties in identifying barrows, as mentioned above, and interpreting their detection in relation to the different types of landscape and lithologies in the region (Figure 8). This aspect requires detailed analysis. Therefore, a first approach is proposed here. The lithology has been classified in very general categories based on the OTALEX.C spatial data infrastructure (Batista et al., 2013). A brief analysis of the variables produces the results expressed in the total inventories presented in Table 1.

Table 1. Quantification of known sites in relation to the lithology in Portugal (PT) and Spain (ES).

Lithology	Known sites (PT)	Known sites (ES)	Total
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Alluvial and colluvial	482 (29.88%)	37 (8.83%)	519 (25.54%)
Limestones	27 (1.67%)	12 (2.86%)	39 (1.92%)
Quartzites	14 (0.87%)	8 (1.9%)	22 (1.08%)
Dunes	2 (0.12%)	-	2 (0.0009%)
Granites and other plutonic rocks	880 (54.56%)	153 (36.51%)	1033 (50.84%)
Schists	208 (12.89%)	209 (49.88%)	417 (20.52%)
Total	1613	419	2032

Table 2. Quantification of possible sites grouped according to the lithology in Spain (ES).

Lithology	New LiDAR data (ES)
Alluvial and colluvial	40 (16.88%)
Limestones	3 (1.26%)
Quartzites	12 (5.06%)
Dunes	0
Granites and other plutonic rocks	40 (16.88%)
Schists	142 (59.91%)
TOTAL	237

Granite areas, to which the metamorphic and plutonic areas can be added, represent a large part of the dataset, distributed in an irregular way. In Portugal, areas like Central Alentejo have one of the highest densities of megaliths in Western Europe. A GIS-based calculation, performed in a 10 x 10 km grid, reveals densities of more than 0.4 megaliths per square kilometre for the surroundings of Évora and the Reguengos areas. Although no systematic surface surveying has been carried out on the large areas of granite in the central parts of Extremadura, slightly lower densities are found in certain areas in this region, like Valencia de Alcántara.

Numerous dolmens are located on the Pre-Cambrian substrate, especially in the Tagus International (Figure 9, Figure 10), where they are organised in well-structured necropolises on each side of the border (Bueno-Ramírez et al. 2004; Cardoso 2008; Oliveira 1998; Scarre et al. 2011). Despite the presence of alluvial materials on the northern edge, the Pre-Cambrian substrate in both

areas means that slate is the main building material used in the megaliths, which form a compact group in their distribution. Thus, for the first area, the alluvial plains, the density of megaliths rises to approximately 0.2 per square kilometre, whilst for the southern edge, the density has been determined to be nearly half that, considering only the previous existing archaeological data. This can reflect the effect of both Spanish and Portuguese research tendencies and feasibly different preservation issues. Noticeable concentrations of megaliths on schists have also been recorded in the surroundings of the granite areas with a denser concentration of monuments, but also a similar pattern of ungrouped megaliths can be observed here.

In the Tierra Barros area, in Spanish Extremadura, the terrain was densely occupied, as a dense settlement network proves (Odriozola-Lloret & Hurtado-Pérez 2009). However, the valleys of the main rivers have revealed few corbel-roofed graves (Blasco-Rodríguez & Ortiz-Alesón 1991; Hurtado-Pérez et al. 2000). The simplest explanation is that the deep Tertiary soils do not provide the right materials for the construction of large chambers with consistent slabs. It is possible that other forms of burial will be discovered in the future, such as the hypogea that are already known in Alentejo and the interior of the Iberian Peninsula.

Quartzite lithologies are not dominant, but barrows are found in the geological contact zones between quartzite and slate or granite, within a pattern in which the tombs are located at the foot of the quartzite hills and more rarely in higher positions. This model can be seen in both Portugal and Spain. The data in the watershed between the river basins of the Guadiana and the Tagus are indicative of the model, in an area where new megaliths have been detected through LiDAR datasets.

This can reveal two tendencies in the distribution of megalithic sites in southwest Iberia on an overall scale. The first one is that the dissemination of megaliths in the landscape is relatively uniform in areas with different geological backgrounds, making it feasible to question the alleged differences between the groups who built their megaliths in schist or granite areas. A relatively uniform density over extensive areas denotes a constant occupation of territory, whilst areas with higher density of megaliths do exist in Central Alentejo, representing the second tendency. Therefore, it is plausible to consider a “constant” or “uniform” megalithic appropriation of the landscape in different types of natural environments together with compact areas characterised by a reiterated aggregation of monuments.

On a regional scale, the distributions can be understood in two ways. The most obvious is that the areas where a certain density of megaliths were already known are more prone to new discoveries, which indicates that perhaps surveying has not covered the whole terrain systematically. Thus, the information from the border zone of the Tagus International has balanced the number of tombs known on each side of the border, which has confirmed our hypothesis that areas that are very similar in the characteristics of their landscape would probably support similar population densities in the Neolithic and Chalcolithic. In short, we can expect that the gaps in distribution maps are just liable to render low densities of megalithic sites.

The second interpretation confirms the role played by geomorphology in the detection of sites, even though the degree of conservation of the megaliths is the most important factor. Excessive altimetric variations are an impediment to the detection of barrows on the different cartographic products that are generated, especially in the case of the rounded and irregular relief of granite areas. The finds are usually made in the contact of different lithologies, with some very clear examples in the Tagus basin, where the megaliths were built on flat land a few metres from granite outcrops. Table 2 shows that the percentages of barrows recorded by traditional methods in the granite substrate are nearly twice as high in Extremadura as those located by means of LiDAR remote sensing. This difference can possibly be explained by the difficulties in identifying megaliths in granite landscape through LiDAR, since the presence of numerous outcrops hinders the identification of barrows. The same relationship rises to three and a half in Portuguese regions, where it should be noticed that the exceptional concentration of megaliths around the granite outcrops of Central Alentejo in Portugal varies significantly the percentage between both regions (Figure 11).

As shown in Table 2, flat land offers the best possibilities for the location of new sites using LiDAR. Slate plains or flat alluvial land are the ideal topography allowing the visual contrast between the terrain and the barrows in the shaded DEMs. This is the explanation for the large number of potential barrows located on those types of geomorphology, which are the most extensive at a regional scale.

5. Discussion and perspectives

5.1. Mapping sites, revealing tendencies

The quantification of megaliths along the western façade of Iberia has been a pending task which can now be approached thanks to a systematic coverage of terrain through data repositories and remote sensing techniques. This new opportunity has let us map a significant quantity of barrows and settlements that represent the first overview in decades of the geographic distribution of Late Prehistory sites in this region of the Iberian Peninsula.

Over 2000 megaliths (Table 1) and over 1500 potential sites have been considered for the whole region, to which the number detected by LiDAR can be cautiously added. Although it must be admitted that some archaeographic problems exist, such as the over-representation of megaliths and enclosures in areas of most archaeological activity, the volume of data allows a first approach to the quantification of megaliths in the whole Portuguese-Spanish sector and to their distribution in the territory. With the application of remote sensing techniques, the apparently marginal areas in the interior of the Iberian Peninsula in Late Prehistory reveal a picture that is similar the one that began to be perceived in the first studies carried out in the north of Europe, which discovered repeated associations of habitats and monuments (Andersen, 2011). In this sense, an interesting field of research might be to propose similar studies in areas with cultural and geological affinities, like Brittany, where numerous megaliths (more than 1000 dolmens and 6000 menhirs, after Giot,

2007) are known but few settlements are related to them. The overall picture obtained in this paper for southwest Iberia is also coincident with the one depicted in classic megalithic areas on the Atlantic façade, where concentrations of monuments, like Brittany, are coeval with a looser distribution of monuments in surrounding areas.

In general terms, with the new data from remote sensing, we can expect to find a closer relationship between different kinds of archaeological evidence that have been recursively presented and analysed as disconnected phenomena. This disconnection, taken by some authors as a cultural pattern (i.e. Jiménez-Jáimez & Márquez-Romero, 2016), has had a clear impact on the way that the discourse of Late Prehistory in South Iberia has been built. The debate is definitely not new, and it can also be found in the literature of other European countries and in more recent prehistoric periods.

Despite the increase in archaeological information, it does not seem probable that all the existing "gaps" in the interpretation of cultural sequences in south-western Iberia can find an unequivocal solution in LiDAR remote sensing. For some periods, like the Middle or Late Neolithic (5th and 4th millennia cal BC), the detection of settlements is a pending task, as mentioned above. Recent finds of ditched enclosures linked to barrows in neighbouring regions like Toledo province (Schmitt, 2017) are certainly very promising. They may decidedly vary the current picture of Neolithic settlement patterns, but unfortunately, a considerable proportion of sites are actually undetectable in LiDAR datasets. On the contrary, it is worth noting that very recent studies have revealed a significant concentration of Chalcolithic ditched enclosures in our study area using the methods described here and a limited use of photo-interpretation (López-López, 2016). Although these outcomes might be encouraging, we should acknowledge that it is an exceptional situation in LiDAR remote sensing. New data from aerial photo-interpretation is revealing its effectiveness in detecting ditched enclosures (García-García 2013; López-López 2016; Valera & Pereiro 2013) and can complement the data gathered from LiDAR datasets.

On the whole, these new data support the classic and widespread idea that from the last quarter of the fourth millennium cal BC south-western Iberia would have undergone demographic intensification, whose outcome would have been the increase in the number and size of settlements (García-Sanjuán & Murillo-Barroso 2013, 119).

The results gain in significance for the understanding of settlement during the third millennium cal BC. From the data here presented it can be inferred that the number of walled and fortified sites may be larger, enriching perhaps some regularities that some authors have noticed over the past decades (Odrizola-Lloret & Hurtado-Pérez 2009). Apparently marginal areas can count now on new densities of settlements that, in short, can reveal a more intensive strategy of land use. Additionally, the smaller concentrations of detected settlements might uncover different intensities and local strategies of landscape occupation, revealing unpredicted territorial behaviours and non-linear social and demographic processes.

5.2. Future perspectives on the use of LiDAR in the Iberian Peninsula

As in many large scale regional projects, to create an accurate interpretative model for the entire region considered in this paper is unrealistic. The biases in the creation of site databases are present and cannot be ignored since they have a decisive effect on the construction of cultural interpretations (see Attema *et al.* (2010) for a discussion). Aspects such as historic land use, intensities of surveys, different criteria of scholars (Cowley, 2016, p. 150) might have had a decisive effect on the overall picture of megaliths that we currently possess. Among these factors the difference in research traditions between Portugal and Spain appears to alter drastically the inventory of megaliths and other prehistoric evidence. With the availability of LiDAR data for Portugal, we can probably detect the importance of some of these research biases by producing a more balanced cartography of sites.

European archaeologists are realistic about the capabilities of LiDAR in archaeological practice, stressing that remote sensing cannot be the only resource to interpret archaeological landscapes (Crutchley, 2006; Verhoeven, 2017). Certainly, some aspects of the diversity of elements comprising a prehistoric landscape in our region cannot always be detected with LiDAR, such as mortuary sites partially excavated in the ground (simple chambers, hypogea, corbel-roofed graves) and natural caves. These all play an important role in the dynamics of the definition of a territory (Araújo, Lejeune, & Santos, 1995; Cerrillo Cuenca & González Cordero, 2007). Similarly, such important parts of the graphic record as menhirs and decorated panels and rock-shelters can only be detected by conventional archaeological surveying. It should also be remembered that a large proportion of dolmens and settlements that have been published are not visible with LiDAR and, at the same time, systematic surface surveying is documenting large populated areas in territories with abundant megaliths (Bueno-Ramírez, Balbín-Behrmann, Barroso-Bermejo, & Carrera Ramírez, 2011; Cerrillo Cuenca *et al.*, 2016).

The combination of different detection techniques, as discussed here, and the systematic exploration of the territory will have to define the future research agenda, as some authors have expressed elsewhere (Inomata *et al.* 2018; Fernandez-Diaz *et al.* 2014; Magnoni *et al.* 2016; and see Cowley 2016 and Verhoeven 2017 for a well-addressed discussion about biases in remote sensing in archaeology). For instance, Magnoni *et al.* (2016) have stated that only between 20 and 40% of the already recorded archaeological features were recognisable in their LiDAR datasets.

The most apparent and positive point is that the application of LiDAR is able to generate in a simple way a volume of data that significantly expands our knowledge of certain cultural dynamics in Late Prehistory. The combination of systematic surface survey and LiDAR analysis seems a reliable strategy for filling the gap between the traditional archaeological record and the new results from remote sensing procedures. Otherwise, it is quite possible that the new documentation obtained will contribute to the over-representation of a clearly visible archaeological record in the data obtained by LiDAR, to the detriment of less visible evidence, only identifiable by surface surveying. Complacently assuming that documentation by LiDAR will end up reducing the bias in current archaeological information in Western Iberia will only perpetuate the belief that weighed down the interpretation of megalithic territories in past decades, when

it was thought that general trends could be proposed from the analysis of the data representing the reality known at that time.

In sum, a more complete interpretation of megalithic occupations can be obtained than had been perceived until now in an isolated way, even at local scales. The present challenge is to contribute towards a general picture of the different cultural processes in the Iberian Peninsula in recent prehistory by integrating the singularities that these local realities have revealed.

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Conflict of interest

The author declares no conflict of interest.

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Figure 1. Sites documented in Extremadura, Beira Baixa and Alentejo. A. Known fortified sites (including those in the Tagus Estuary). B. Known ditched enclosures. Data from Endovélico, Hurtado & Mondejar 2009; González Cordero 2012; Valera 2016.

Figure 2. Densities of known megaliths in the area of study.

132x92mm (300 x 300 DPI)

Figure 3. The contribution of LiDAR to the documentation of landscapes at local scales (10 x 10km squares).

Figure 4. Distribution of the fortified enclosures detected and interpreted with LiDAR, indicating those that are cited in the text and in the figures.

Figure 5. The site of Colada de Monte Nuevo (Olivenza, Spain). The visualisation by LiDAR is able to identify up to four lines of walls (6 ha.) which are associated with two corbel-roofed graves excavated by Schubart (1973) (Fig. 4, 1)

132x108mm (300 x 300 DPI)

Figure 6. Walled enclosure of La Corona (Barcarrota, Spain) and its relationship with the megalithic monuments in the surrounding area. The fortification (7.5 ha.) has three lines of walls, identified by LiDAR (Fig. 4, 2).

413x661mm (72 x 72 DPI)

Figure 7. Fortified sites identified with LiDAR in Spain. A. Pedra Toro (Fig. 4, 3). B. Las Labores (Fig. 4, 6). C. Berzalejos (Fig. 4, 5). D. Cabezas (Fig. 4, 4).

132x113mm (300 x 300 DPI)

Figure 8. Densities of probable megaliths detected by LiDAR in Extremadura (Spain).

132x93mm (300 x 300 DPI)

Figure 9. Area of the Tagus International with the position of the known megaliths in Spain and Portugal (black dots) and possible new sites detected by LiDAR in Spain (red dots).

132x74mm (300 x 300 DPI)

Figure 11. Approximate densities of megaliths classified by their lithology.

132x114mm (300 x 300 DPI)