TITLE: THE INCIDENCE OF POTENTIAL INSOLATION ON SETTLEMENT DYNAMICS AND SITE LOCATION PREFERENCES: A CASE STUDY FROM THE CANTABRIAN LATE PALAEOLITHIC.

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ABSTRACT: This paper proposes a specific methodology for calculating the potential insolation received by a set of Late Palaeolithic (Upper Magdalenian and Azilian) sites in western Cantabria (northern Iberia). The goal of this study is to test whether insolation is linked to the mobility strategies of foraging communities, and if insolation is a conditioning factor when choosing settlement areas or the season in which they are occupied. The potential insolation at the sites is then compared to the available archaeological evidence in order to test if a correspondence exists between the sites' season of occupation and the insolation they each receive during the year.

KEYWORDS: Late Magdalenian, Azilian, settlement, Cantabria, Geographical Information System, insolation, site location preferences.

1. INTRODUCTION

The choice of a particular place for settlement by a foraging group is conditioned by a wide variety of factors, such as control of strategic points, proximity to resources, living conditions or the symbolic importance of the place (Kellogg 1994; Fano Martínez 1998a; Jones 2010). These factors can vary depending on the specific needs of the group, as well as a result of the function, duration and season of occupation, etc. of the settlement (Eriksen 1997). The analysis of the location and potential habitability characteristics of a given site allows us to get closer to understanding the factors that may influence a group's decision to chose it as a place of settlement, and therefore help us understand its role within hunter-gatherer land-use patterns (García-Moreno and Fano Martínez 2014).

Among the various factors considered desirable in a foragers camp (Kellogg 1994), insolation (receiving a large number of hours of daylight and solar energy) is considered an important one (Fano Martínez 2002). Sunshine is not only enjoyed as natural light, but it also influences the microclimate of a given place and, thus, its habitability conditions. This may have been an important factor when faced the harsh climatic conditions of the European Upper Palaeolithic. Even when Palaeolithic research in northern Iberia began, some authors were already noting the favourable location of some sites thanks to their positioning and high insolation (Sanz De Sautuola 1880: 10; Alcalde Del Río 1906: 44; Vega Del Sella 1916: 11), while Carballo (1933: 16) even speculated on the possible relationship between the seasonal nature of human occupations at El Pendo cave and its changing insolation throughout the year.

The amount of solar radiation received by a site influences both its close environment as well as its habitability conditions, mainly in sites located in caves. The incidence of insolation in sites' surroundings and regional micro-climatology was proved by Duchadeau-Kervazo (1986) in her study of the distribution of Palaeolithic sites in the Dronne basin (France), where she found that most sites were located in areas of high insolation, since the temperature difference compared with shady slopes could reach over 20° C in winter.

In terms of the habitability of caves, besides providing light and heating, insolation can modify air circulation due to the difference in temperature between the outside and inside of the cave (Ramil Rego 1989-1990). On the other hand, sunny vestibules are less humid making them more suitable for habitation, which, in turn, can influence the extent to which some parts of a cave are more heavily occupied than others, as has been suggested for El Mirón Cave (Marín Arroyo *et al.* 2008).

The insolation at an archaeological site, especially those located in caves and rock shelters, is usually related to their aspect; caves or rock shelters oriented towards the south are assumed to receive plentiful insolation, and, as a result, are assumed to represent ideal locations for settlement. However, the insolation received by a site does not only depend on its orientation, especially in mountainous areas where the shadow of landforms can prevent a south-oriented site from receiving strong sunlight (Felicísimo 1994). Despite the long tradition in archaeology of studying the relationship between archaeological sites (mainly built structures) and the sun's position in the sky (Polcaro and Polcaro 2009), the study of potential insolation has rarely been addressed systematically. It has generally been limited to generic observations on the orientation of sites or their position within a sunny area, many times lacking a critical discussion of the factors and issues related to insolation. It is therefore necessary to use specific methodologies to analyse potential insolation, as stated by Hesse (2013), who showed the need for quantitative methods when analysing solar alignments.

A pioneering example of a specific study can be found in the work of Bouvier (1977), who built a model of the area of study with a complex system of gyroscopes, which allowed him to place it at an angle equivalent to that of the Earth's surface with respect to a light source located 1.8m away. This system showed which areas were illuminated and which were in the shade at specific times and dates.

The use of Geographical Information Systems (GIS) allows the analysis of insolation in a specific spot, enabling the calculation of potential insolation by computer simulations (Felicísimo 1994; Mejuto *et al.* 2012). This approach is largely used in disciplines other than archaeology such as ecology, engineering or solar energy. Within archaeology, GIS-based calculations have been applied to Palaeolithic (Garcia Moreno 2008) and Native-American (Schleier 2010; Mignone 2011) settlement location analysis; Neolithic symbolic structures (Mejuto *et al.* 2012); predictive models of site location (Leathwick 2000); and to prehistoric rock wall painting preservation (Díez *et al.* 2006; Aubry *et al.* 2012). Most of these applications share a common methodological background, based on the use of viewshed models to calculate surface insolation (Rich *et al.* 1994). The application of this method largely improves insolation evaluation, from unsystematic observations to quantitative calculations.

Regarding the incidence of sunshine on site location preferences and settlement patterns among Palaeolithic foraging societies, little work has been done up to now. An example of the study of archaeological site insolation through the application of GIS is found in the work of Fano Martínez (1998b), who analyzed the potential insolation received by a large sample of Northern Iberia Mesolithic Asturian shell-middens throughout the year, concluding that their living conditions could vary depending on the amount of sunlight received in each season. His study found a prevalence of sites with high insolation, leading Fano to suggest that this was a conditioning factor in the selection of settlements during the Mesolithic (Fano Martínez 1998a; 2002).

Using a similar approach, García (2008) analyzed the potential insolation received by several Final Upper Palaeolithic sites in the Asón River basin, on the Cantabrian coast. In this case, variations in the insolation received by each site throughout the year were contrasted with their positions along the valley, and more specifically with the distance of each site from the shoreline. It was demonstrated that the settlements located in the coastal area maintained high insolation throughout the year, while those inland displayed a sharp contrast between summer and winter, which was related to the possible mainly summer occupation of inland sites. However, due the limited geographical extension of this work, focused on a single Cantabrian river valley, it was not possible to check whether this same pattern held true for the entire region.

This paper presents an analysis of the potential insolation of 46 Late Magdalenian and Azilian sites in eastern Cantabria, in northern Iberia. This analysis aims to evaluate the possible existence of a pattern of variation of potential insolation received by these sites throughout the year, especially in terms of their distance from the coastline. Within the framework of a seasonal coast-inland mobility settlement pattern (Marín Arroyo 2009, Straus *et al.* 2002), in which the coast is assumed to be more intensively occupied during the winter, while the population, or at least a significant part of it, moved inland during summer, it is hypothesized that, if insolation had an influence on site location preferences, coastal sites should have high insolation during winter, while inland sites would have high insolation during the summer. The goal of this study is thus to analyse whether the insolation may have had some influence on habitat choice at the end of the Palaeolithic, and was therefore one of the factors involved in site location preferences.

2. ARCHAEOLOGICAL BACKGROUND

The Cantabrian coast stretches along the north-western half of the Iberian Peninsula, between the Pyrenees and the Atlantic coast. It is a narrow strip of land about 30 km wide, bounded in the south by the Cantabrian Mountains and in the north by the Bay of Biscay. The proximity of the coastline and the mountain range, whose watershed is at least 1000 m altitude and with peaks above 2000 m, give this region an abrupt relief, configured in three main blocks (García Codrón 2004): the coastal shelf, with a gentle and open relief, and dotted with several bays, estuaries and inlets; the inland valleys, usually separated from the coast by coastal mountains and characterized by a more undulating relief with broad meadows; and finally the high mountains, dominated by glacial landforms. The drainage system consists of short rivers flowing perpendicular to the coast, crossing the strip of land, and forming a succession of parallel valleys separated by mountain ranges.

The study area of this paper focuses on the eastern half of Cantabria, a region that serves as a transition between the Pyrenees and the Picos de Europa massif. This region is characterized by a smoother and more discontinuous relief than its western counterpart, although there are still areas of steep relief. The geographical setting of this region is critical for the analysis of potential insolation, since its steep relief can condition the amount of sunlight received by a given site as a result of topographic shading.

The Cantabrian region hosts a large sample of archaeological sites dating from the end of the Upper Palaeolithic, specifically the Late Magdalenian and/or Azilian (between about 16,200 cal BP and 9800 cal BP) (Fig. 1). This period is characterized by the great climatic instability of the Lateglatial and Early Holocene (Walker *et al.* 1999). A general tendency to warmer conditions can be noted/observed during the Lateglacial Interstadial, when deciduous forest, formed mainly by hazelnut trees oaks, developed in the low lands and mid valleys, displacing pine forest to the mountainous area (Peñalba *et al*. 1997). However, this was not a uniform and continuous process, since that tendency stopped (or at least slowed down) during cold stages, such as the Younger Dryas (Baldini *et al*. 2015).

This period witnesses several major transformations in Late Palaeolithic societies. Subsistence is based mainly on the massive hunting of one or two species, usually red deer or ibex (Marín Arroyo, 2010), but an increasing diversification in the exploitation of resources, including marine resources, is observed (Marín Arroyo 2009a; Gutiérrez Zugasti 2011; Yravedra Sainz de los Terreros 2002). Similarly, there is also an intensification in the use of local raw materials (Arribas 2004; González Sainz and González Urquijo 2004; Straus 2011).

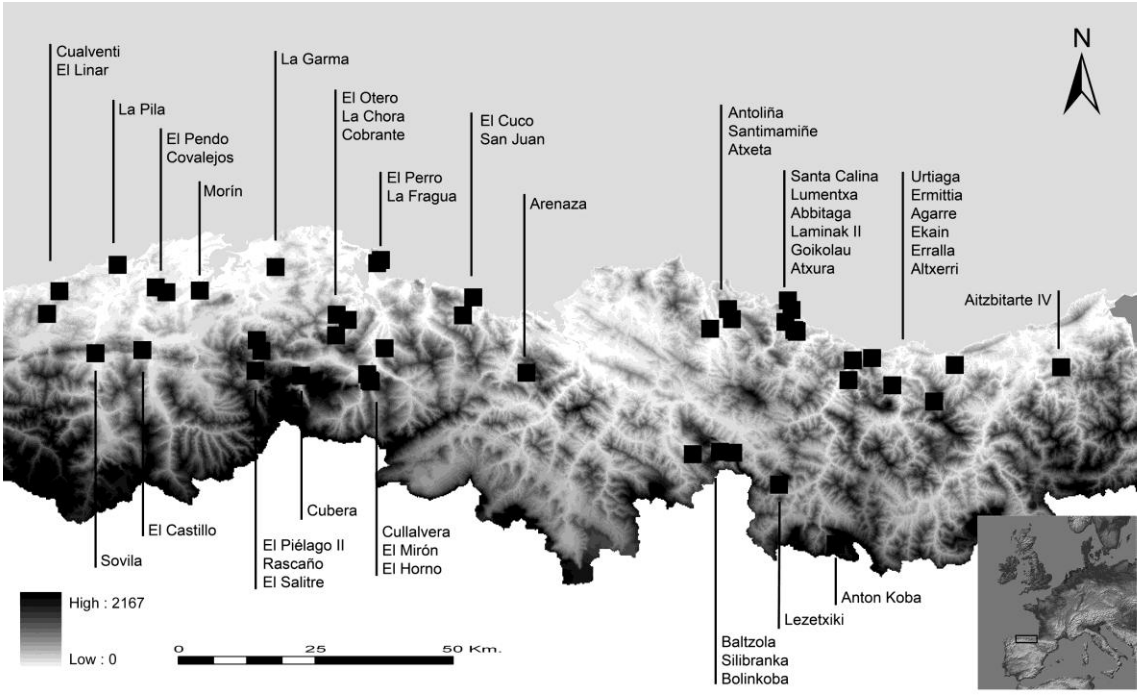

Figure 1. Map of the eastern Cantabrian region (northern Iberia) showing the sites considered in the present study.

In terms of settlement patterns and mobility during this period, a model of mobility between the coastal plain and the interior following the main river valleys is widely accepted (Marín Arroyo 2008), although different dynamics have been suggested to explain it. Originally based on the migratory behaviour of red deer herds (Straus 1977), the mobility between the coast and the interior was supposed to have a functional purpose, with Azilian hunting sites located upvalley and Asturian sites on the coast (Straus 1979). However, stratigraphic and chronological data (González Morales 1982) showed the temporal succession of the Azilian and the Asturian, while seasonality data showed that mobility between the coast and the interior was not strictly seasonal. This led to the proposal of a different coastal-inland mobility model, based on the existence of base camps on the coastal plain and logistical sites along the river valleys (Straus 1986; 1987). Other authors, however, proposed a more flexible model, where mobility also had a role in social organization (Bernaldo De Quirós 1992; González Sainz 1995).

Recent data on seasonality showed that the seasonal mobility model between the coast and the interior is valid, in a broad sense, for the Late Palaeolithic (Marín Arroyo 2009). This model is also consistent with a more intensive occupation of the territory and a settlement pattern based on small, specialized, logistical sites, as proposed for the Cantabrian Late Palaeolithic (Ibáñez and González Urquijo 1997; Terradas *et al.* 2007). However, the appearance of large residential sites inland, like El Mirón cave (Straus 2006), or the occupation of inland sites outside of the warm season (Costamagno and Fano Martínez 2005), points to a more complex and flexible mobility and settlement pattern (García-Moreno 2013b).

3. METHODOLOGY

As a general statement, in northern latitudes insolation is usually linked to a southern orientation; therefore, a first approach to site insolation is the analysis of their orientation. In order to evaluate sites' orientation, aspect of terrain is derived from a Digital Elevation Model (DEM), generated in raster format, with a resolution of 25x25 meters. Despite the fact that this DEM resolution might not be able to accurately represent the exact position of the cave mouths, it was considered good enough to represent the topography of sites' location, and therefore the area affected by solar radiation. The resulting calculation was reclassified into eight categories, corresponding to the eight cardinal directions (North, Northeast, etc.).

However, insolation can be conditioned by topographical shading, especially in regions with steep relief (Felicísimo 1998), and therefore orientation is not an accurate enough method. For that reason, a specific methodology for potential insolation was used, based on the “line of sight” principle (Rich *et al.* 1994). This method is based on the creation of a “virtual” line of sight between the sun’s position (defined by an azimuth and elevation above the horizon) and the terrain; if there is no obstruction between both points, the terrain can be considered to be illuminated.

The potential insolation received by a particular place, i.e. the amount of sunlight received in an ideal situation when clouds are absent for a given time interval depends mainly on two factors: the sun's position with respect to that point, and relief. To study the potential insolation during the late Pleistocene, any variations that both factors may have suffered since that time should be taken into account.

The relief of an area can influence the insolation received due to the topographic effect of concealment, that is, the shadows projected by landforms, mainly the larger entities, such as mountain ranges; on the contrary, small elements or vegetation have less potential impact on sunlight and only affect the immediate area. Local climatology might have had an effect on the insolation received by the archaeological sites, mainly related with the presence, density and periodicity of clouds. Unfortunately, it is difficult to estimate the storminess and cloudiness for this period (Baldini *et al.* 2015; Uriarte 1992) and, therefore, even nowadays it is difficult to estimate their influence on insolation (Pons 1998). For that reason, potential insolation usually refers to an ideal situation of absence of clouds.

A problem derived from using modern cartography it that large geomorphologic changes could have significantly modified the Palaeolithic topography, and therefore limit the calculation of potential insolation. Major geomorphologic processes occur primarily on a geological time scale, and in consequence the general topography of the region have not change significantly since the Late Pleistocene. On the other hand, other processes, such as glacial erosion or Post-Pleistocene sedimentation, might have affected the relief or the region. In the case of the former, glacial processes were already restricted to the eastern Cantabrian mountains at the end of the Pleistocene (Ugarte 1992), and consequently their effect on the regional topography has been restricted ever since. In the case of the sedimentation, it affects mainly the lowlands, such as the coastal plain, and valley bottoms, so its influence on potential insolation is negligible. As a result, the current relief can be considered valid for the study of late Pleistocene sunlight.

In contrast, the relationship between the study area and the position of the Sun may have changed significantly since then due to the astronomical movements of the Earth (Huybers and Wunsch 2005). As a result of these movements, the angle between the Earth and the Sun varies over time, both in terms of the inclination of the terrestrial axis (i.e., the imaginary line through the poles) as well as in the orientation of that axis. First, the angle formed by the Earth's axis to the plane of the ecliptic, called the *obliquity of the ecliptic*, and which currently is about 23.4º, varies between 21.5º and 24.5º in 41,000-year intervals (Uriarte 2003). For the time interval under consideration here, the obliquity of the ecliptic varied between 24.05º (c. 16,500 BP) and 24.11º (9500 BP) (Laskar 1986) (Fig. 2). It is therefore necessary to consider the possible effect that this difference may have had in the number of hours of sunlight received by the study area.

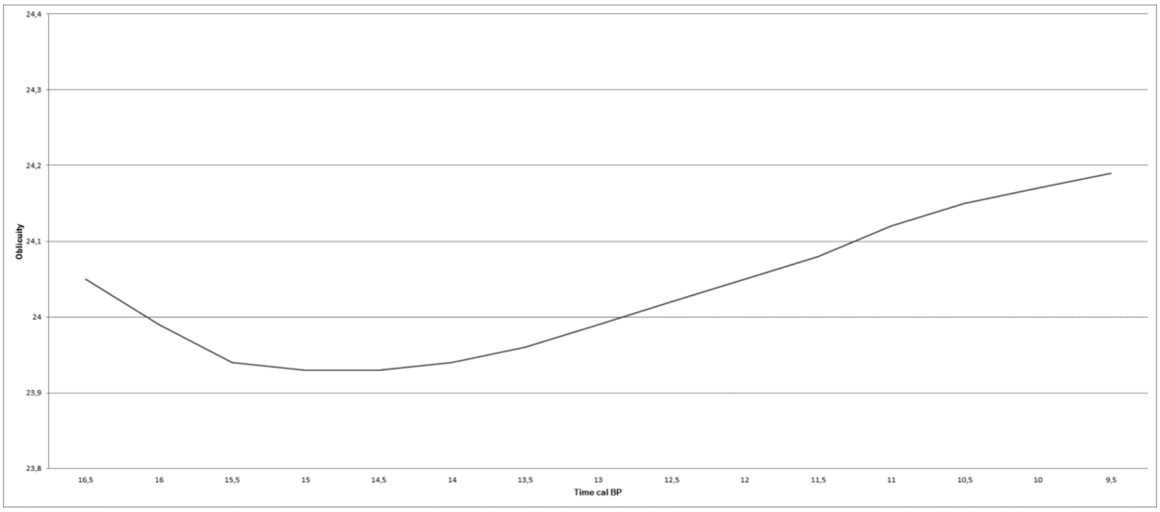

Figure 2. Evolution of the obliquity of the ecliptic during the time interval corresponding to the Upper Magdalenian and Azilian.

Moreover, due to the flattened shape of the Earth and its rotation, the orientation of the Earth's axis with respect to the firmament is also changing in cycles of about 26,000 years, a phenomenon known as *precession of the equinoxes*. During the Late Pleistocene, the Earth's axis was oriented in the opposite direction to its actual position, which caused the perihelion (the closest approach point between the Sun and the Earth) to coincide with summer in the Northern Hemisphere (unlike the current situation), so that the solar radiation received during that season would have been greater than at present, but less in winter (Uriarte 2003). However, the precession of the equinox affects the intensity of solar radiation more than the number of hours of light received (Polcaro and Polcaro 2009).

The Sun's position with respect to a specific point on Earth is defined by two parameters: elevation (or zenith angle), indicated by the angle between the plane of the analyzed surface and the altitude at which the Sun reaches above the horizon; and azimuth, defined as the angle between the meridian passing through the study area with the line that defines the solar path (Felicísimo 1994; Pons 1996). Both parameters, in turn, depend on three elements:

a) The *latitude* of the study area, measured in degrees. The average latitude of the study area used in this work is 43° 20'.

b) *Solar declination*, defined as the angle of the Sun at noon with respect to the Equator. It depends on the ordinal day of the year, and ranges between +23.5° (summer solstice) and -23.5° (winter solstice).

c) The *hour angle*, which measures the movement of the sun throughout the day from east to west on the horizontal plane from sunrise to sunset. In the Northern Hemisphere, the south is at 0° when the sun is at its zenith (12 noon), to the east the degrees are negative (decreasing range), whereas they increase positively towards the west. The increase is 5° for every 20 minutes (15º/h.).

The solar declination depends on the obliquity of the ecliptic, which, as discussed above, was different from the current situation during the late Pleistocene. To verify the possible influence of the change in the calculation of potential insolation with respect to current parameters, a comparative study of the insolation received in a particular area within the study region with two different obliquities was carried out: the current

(23.5°) and the maximum attainable in the late Pleistocene (24.5°). The calculation was performed for the 21st of December, the date corresponding to the winter solstice, when the Sun reaches its lowest altitude above the horizon and thus the shading effect from the topography is more evident.

Once both models of potential insolation were calculated (following the methodology described below), 200 random points within the selected area were generated, from which the number of hours of insolation received for that day in each model was obtained. The mean values obtained in both cases are very similar (23.5º: 3.117±3.47, 24.5º: 3.47±3.138 hours of sunshine) (Fig. 3). In fact, Spearman's Rho correlation analysis shows that there is a strong statistically significant correlation between both samples (rs = 0.988, p = 0.000). It therefore appears that both samples differ very little, which means that the failure to calculate the potential insolation received by the study area with current or late Pleistocene obliquity of the ecliptic values probably does not influence the result significantly. For this reason, the potential insolation of eastern Cantabria was analysed using current astronomical parameters, which would avoid errors resulting from the modification of these parameters, assuming that the result will be similar to that obtained using late Pleistocene values.

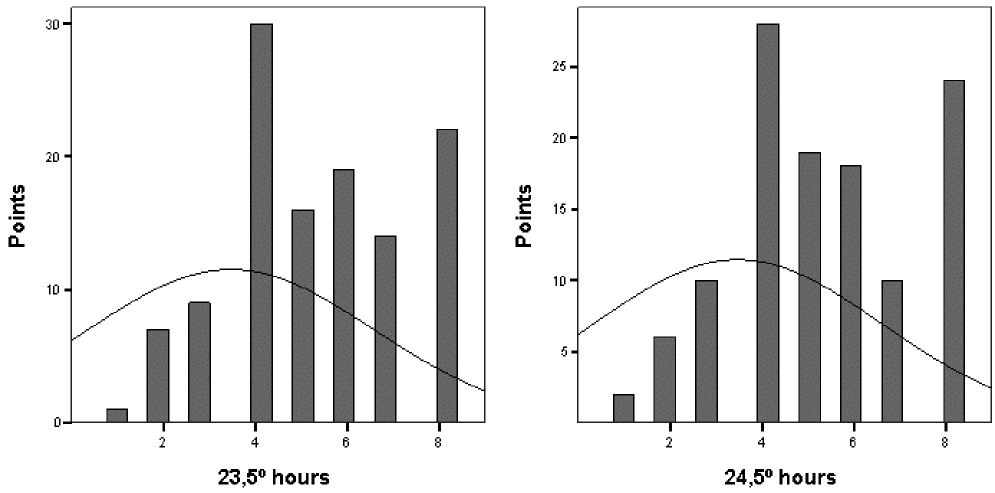

Figure 3. Comparison between two different potential insolation models, taking modern solar declination (left) and maximum solar declination attainable in the late Pleistocene (right) into account.

3.1. Calculation of potential insolation

Having determined the value of obliquity of the ecliptic to be used, the solar declination was calculated. In order to do this, the following formula (Felicísimo 1998) was used:

*D=23.5 * sen [0.986 * (284+d)]*

where *23.5* refers to the angle of obliquity of the ecliptic and *d* is the ordinal day of the year, beginning on the 1st of January and ending in 365, corresponding to the 31st December. For the potential insolation throughout the year, in order not to have to perform the calculation for every single day of the year, 12 different models were calculated, corresponding to the days of daily average insolation which are closest to the monthly average, from January to December: 19, 15, 16, 15, 15, 14, 19, 17, 16, 16, 15, 14 (Pons 1996). These days were considered to accurately represent the mean insolation received during that entire month and are therefore a valid estimation of monthly mean insolation.

In addition, the following formula was used to calculate the hour angle:

$$H = -180 + (15 * h)$$

where *180* represents the maximum angle reached by the Sun in the study area at 12 noon, *h* corresponds to the time of day (expressed in terms of 24 hours) and *15* is the number of degrees the hour angle increases or decreases according to the hour. Thus, for the hours before noon, the resulting product is less than 180, and the hour angle decreases, while growing after 12 noon (Felicísimo 1998).

After obtaining the hour angle and declination of the Sun, it was possible to calculate the position of the sun on any given day at a specific time, expressed in spherical coordinates defined by azimuth and elevation angle above the horizon (Felicísimo 1994, 1998; Pons 1996). The formulae used to carry out these calculations were as follows (Felicísimo 1998):

$$\sin Elevation = (\sin D * \cos L) + (\cos D * \sin L * \cos H)$$

$$\cos Azimuth = [(\cos L * \sin D) - (\cos D * \sin L * \cos H)] / \cos elevation$$

where *L* is the latitude of the area to be tested, *D* is the solar declination and *H* is the hour angle. Finally, in order to calculate the final azimuth and elevation values, the arc sine and arc cosine which concern us here must be obtained.

Using these equations allows us to obtain the position of the Sun with respect to the study area, measured in terms of elevation and azimuth. Its advantage over commercial software, such as the *ArcGIS Solar Analyst*, is that the value of the obliquity of the ecliptic can be modified, and therefore adapted to prehistoric dates, if needed. This allows this method to be applied to any Palaeolithic period, regardless of its chronology.

3.2. Creation of the potential insolation model

The generation of potential insolation models was based on the creation of a series of shading models, one for each hour interval between sunrise and sunset for each of the days selected as being representative of the monthly average. These shading models are based on the principle of sight between two points indicated by the solar position and each DEM cell. Should the case arise that a cell can establish a continuous fictitious line with the position of the sun, this cell will be illuminated for that time slot on that date; if instead the relief stands between the two points, there will topographic concealment and the cell will be not illuminated.

Using the *ArcGIS Surface Analysis - Hillshade* tool, shading models were generated for each date, using the azimuth and elevation values obtained by means of the calculations. The resulting models were reclassified into binary code, assigning a '1' value to the illuminated cells, and a '0' value to those that were in the shade.

Once all shading models for a specific date were created, these were added: since the illuminated cells for each one-hour interval had a '1' value, the number of times this value is repeated in each of the cell represents the number of daily sunlight hours received that day. This model yielded the potential insolation for a day in each month, and, by extension, the monthly average. The annual evolution of potential insolation in the study area was obtained by repeating the same process for the twelve months in the year,. Finally, the values for each archaeological site were extracted.

Lastly, in order to compare whether site insolation is different from a random distribution, a control sample of 50 randomly distributed points was generated. The insolation received by these points was then compared to the archaeological sample.

4. RESULTS

A total of 22 out of the 46 sites have a southern orientation (SW-S-SE) (Table 1), while the dominant orientation is south-east (N=9), followed by south (N=8) and north-east (N=7); according to a Kolmogorov-Smirnov test, this pattern fits a normal distribution ($z = 0.873$, $p = 0.431$), and therefore the sites' orientation is not statistically significant. There is no significant difference in the insolation received by south- and north-oriented sites since both clusters have similar means, especially during the spring and summer; during the autumn and winter (Fig. 4), south-oriented sites receive about one more hour of daily sunlight (see below and Table 2).

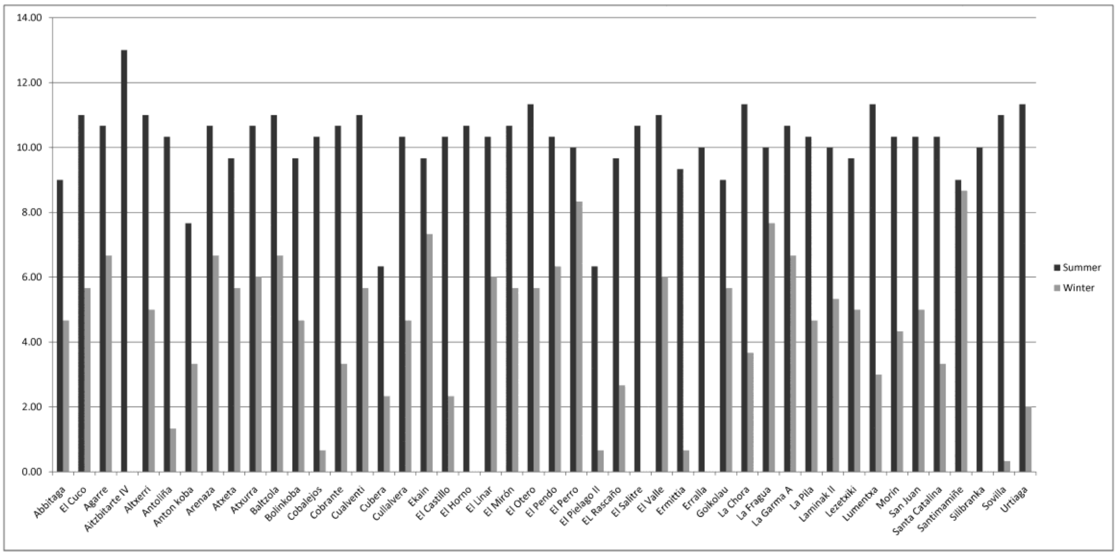

Figure 4. Comparison between summer and winter insolation among the archaeological dataset, measured as mean daily hours of sunlight received by each site.

Table 1 (see separate file)

ASPECT	Annual	Spring	Summer	Autumn	Winter	N
S - SE - SW	7,63±0,31	8,68±0,31	10,21±0,24	6,76±0,38	4,88±0,51	22
N - NE - NW	7,04±0,36	8,26±0,4	10,05±0,22	5,95±0,5	3,92±0,57	13
E	5,87±1,7	6±2	7,66±1,33	5,83±1,83	4±1,67	2
W	6,15±0,70	7,07±0,79	10,81±0,33	4,11±1,03	2,63±0,99	9

Table 2. Annual and seasonal mean insolation of sites according to their orientation.

The calculation of sites' potential insolation (Table 1) indicates that they receive a mean annual sunshine of 7.10 ± 1.65 hours per day. However, there is great variability between the average insolation received during the spring (March, April and May) and summer (June, July and August) compared to that received during the autumn (September, October and November) and winter (December, January and February) (Table 3). In terms of the insolation received by each site throughout the year, almost all of them receive high insolation during summer, and considerably less during the autumn and especially during the winter, although some settlements continue to enjoy plentiful year-round sunshine, such as El Perro, Santimamiñe or La Fragua (Table 1).

	Annual	**Spring**	**Summer**	**Autumn**	**Winter**
Mean	7,10	8,13	10,17	5,97	4,13
Std. Error	1,65	1,82	1,17	2,29	2,50

Table 3. Annual and seasonal mean insolation for the archaeological dataset.

By contrast, the situation is more heterogeneous in the spring, as demonstrated by the Kolmogorov-Smirnov tests, which indicate that the insolation received by the sites during this season does not fit a normal distribution (Table 4) meaning it is not randomly distributed. An analysis of K-means for two clusters can differentiate between those sites with low insolation (e.g. Aiztbitarte IV, Anton Koba, Cubera, El Horno, El Piélago II, Salitre, Ermittia, Erralla and Silibranka), and the rest of the sites that receive significantly higher insolation. Thus, it is during the spring when the two sets of settlements can be more clearly differentiated in terms of the amount of sunshine they receive.

	Annual	**Spring**	**Summer**	**Autumn**	**Winter**
Kolmogorov-Smirnov's K	0,919	1,378	1,245	0,881	1,021
p	0,367	**0,045**	0,09	0,419	0,248

Table 4. Kolmogorov-Smirnov’s test for mean and seasonal sites´ insolation.

Regarding the relationship between the insolation received by the sites and their distance from the coastline, coastal sites (N=30) -those sites located closer than 10 km from modern shoreline (García-Moreno 2013a)- receive higher insolation than their inland counterparts during all four seasons (Table 5). The Pearson correlation analysis shows that there is an inverse relationship between mean annual insolation and distance from shore (r = -0.368, p = 0.018), indicating that the further inland a settlement is, the less insolation it receives. Considering the insolation received during each of the seasons instead of the annual average, it can be observed that this inverse correlation is statistically significant for spring and autumn, while it is not in winter and summer (Table 6). Therefore, it seems that during the spring and autumn, settlements located further inland receive significantly less sunshine than those in the coastal strip, while the difference between them is not relevant during the summer and winter (Fig. 5). The dominant orientation of coastal sites is south-east (N=7; 23.3%), while among inland sites the dominant aspect is west (N=4; 25%) (Table 7). This different orientation pattern, strengthened by topographical shading in some seasons, could explain the differences in insolation between the coastal and inland sites.

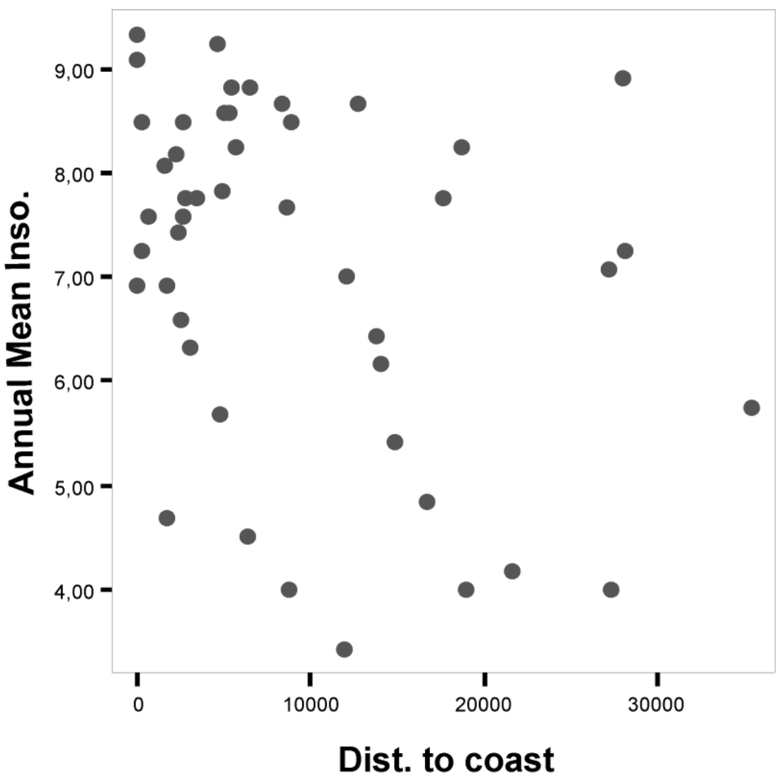

Figure 5. Scatter plot showing the relationship between sites' distance to the coast (in meters) and their annual mean insolation (hours per day).

	Annual	Spring	Summer	Autumn	Winter
Inland	6,19±0,44	7,18±0,52	9,73±0,39	4,87±0,56	2,98±0,58
Coastal	7,58±0,25	8,63±0,27	10,41±0,15	6,55±0,39	4,74±0,44

Table 5. Annual and seasonal mean insolation for coastal and inland sites.

	Annual	Spring	Summer	Autumn	Winter
Pearson's r	-0,347	-0,368	-0,282	-0,297	-0,246
p	0,018	0,012	0,058	0,045	0,099

Table 6. Pearson's correlation test between annual and seasonal mean insolation and distance to the coastline.

	N	NE	E	SE	S
Coastal	2	4	1	7	5
%	6,67	13,33	3,33	23,33	16,67
Inalnd	0	3	1	2	3
%	0	18,75	6,25	12,5	18,75

Table 7. Number of coastal and inland sites according to the orientation categories.

In terms of the randomly generated control sample, annual and seasonal means are similar to the archaeological ones (Table 8). The Kolmogorov-Smirnov test shows that the mean insolation of both annual and seasonal control points fit a normal distribution (Table 9), in contrast with the spring insolation enjoyed by the sites. As a result, it would seem that settlements received a potential insolation similar to a randomly distributed sample. However, when considering settlement location along valleys, the Pearson test shows that there is no correlation between the insolation at the control points and their distance from the coast (Table 10), in contrast with the pattern observed for the archaeological sites, where inverse correlations were found.

	Annual	Spring	Summer	Autumn	Winter
Mean	6,7	7,73	10,39	5,35	3,33
Std. Error	1,6	1,72	1,07	2,28	2,54

Table 8. Annual and seasonal mean potential insolation for the randomly generated sample of control points.

	Annual	Spring	Summer	Autumn	Winter
Kolmogorov-Smirnov's K	0,794	0,905	0,872	1,103	0,936
p	0,553	0,386	0,432	0,175	0,345

Table 9. Kolmogorov-Smirnov's normality test for the annual and seasonal mean insolation received by the randomly generated sample of control points.

	Annual	Spring	Summer	Autumn	Winter
Pearson's r	0,043	-0,052	-0,038	0,056	0,109
p	0,769	0,719	0,796	0,698	0,451

Table 10. Pearson's correlation test between annual and seasonal insolation and distance to modern coastline for the random sample.

5. DISCUSSION

The analysis of potential insolation at Cantabrian Palaeolithic sites shows a clear difference between the amount of sunlight received by the settlements during the spring and summer (8 and 10 hours/ day on average, respectively) and during the autumn and winter (6 and 4 hours/ day on average, respectively). In addition, the average error is higher in the autumn and winter, indicating that there is greater variability during these seasons, whereas during the summer most sites maintain high insolation.

However, these results do not appear to be different from what would be expected if the settlements were randomly distributed. That is to say, the high variability in seasonal insolation seems to be the result of the insolation received by the region as a whole, generally much higher in the summer than during the winter, whatever the location, as indicated by the control sample. This would suggest that high insolation would have not been of special interest when selecting a Palaeolithic settlement location, except maybe during the spring.

However, when considering the relationship between the insolation received by the sites and their distance from the coastline, it is clear that Late Magdalenian and Azilian settlements follow a different pattern from the one expected for a random distribution. Thus, both for the mean annual insolation as well as the spring and autumn mean insolation there is an inverse correlation between the two factors, indicating that the further inland a site is, the less sunlight it receives. However, this pattern is different from that expected if potential insolation was related to the season of occupation of sites, in a context of seasonal mobility between the coast and the interior, as was proposed for the Asón river valley (García-Moreno 2008). Instead, the results suggest that the most appropriate seasons to occupy the coastal zone according to sites insolation would be spring and autumn, while it would make little difference whether the coast or inland were occupied during the summer and winter. In this situation, several hypotheses arise:

First, the simplest explanation would be that potential insolation was not an influencing factor in the choice of settlement location. In this case, even taking into account that high insolation was desirable (as seems to be the case for spring), it may be sacrificed for other factors such as better accessibility to and more direct control of local resources. In that case, settlements would be located in low areas such as valley bottoms and the base of slopes, where they would receive less sunshine due to topographic shading, as has been noted for Cantabrian Late Magdalenian and Azilian sites (García-Moreno 2013a; Straus *et al.* 2002).

Moreover, the analysis of potential insolation could be biased due to differences between modern and Pleistocene insolation, resulting from changes in astronomical parameters, or even as a result of climatic conditions, such as extent of cloud cover. The interpretation of the relationship between insolation and mobility can also be affected by the differential distribution of the sites, since in a few cases coastal and inland sites can be found within the same river valley, as was the case in the Asón river valley.

However, the fact that Late Magdalenian and Azilian sites follow a different pattern to that of the random sample regarding the relationship between potential insolation and distance from the coast, suggests that potential insolation could have played a role in the site-location decision-making process, at least for certain seasons. Therefore, the potential insolation a site received was perhaps only considered during the spring and autumn, because during the summer the entire region would receive high insolation and offer good insolation conditions everywhere, whereas the opposite would be true during the winter.

In contrast, during the spring and autumn, insolation conditions could have influenced the choice of living spaces. During these seasons, coastal settlements would receive greater sunlight than those located further inland, and therefore places with high insolation could be selected when foraging groups moved to -or stayed on- the coastal strip. It has to be noted that Cantabria is a calcareous region with hundreds of caves, and therefore a great variety of spots were available for settlement. This means that, if insolation was a desirable factor when choosing a location, places with high insolation, as well as fulfilling other desirable requirements such as proximity to resources, visibility, etc., could be chosen for settlement. Populations occupying the coast would enjoy good insolation during the cold season, while sites located further up in the valley would receive as much insolation as coastal ones if used during the summer.

This model is broadly consistent with the mobility and occupation patterns proposed for the Late Cantabrian Palaeolithic, in which groups of foragers would travel to the interior of the region during the warm season, whereas they would remain on the coastal strip for much of the rest of the year (González Morales 1995; Straus *et al.* 2002). This model is also consistent with the growing number of specialized logistical settlements during this period, used for the undertaking of specific tasks, and occupied for short periods of time and sporadically (Ibáñez and González Urquijo 1997; Terradas *et al.* 2007).

Unfortunately, archaeological evidence for occupation seasonality is still very elusive, so it is therefore not possible to completely verify the accuracy of this model. The few available data (Costamagno and Fano 2005; Marín Arroyo 2008; 2009b) show how this seasonal mobility model is overall valid, with several coastal sites (Morin, El Pendo, Urtiaga, Ermittia and maybe Santa Catalina) showing evidence of year-round occupation, or at least during several seasons.; on the other hand, inland settlements like Rascaño, El Mirón, Ekain or Erralla would be used mainly during the warm season,. The occupation of La Fragua and El Perro, located on the coast, in autumn and spring respectively, seems to corroborate the permanence of the population along the coast for much of the year.

However, there is also evidence that contradicts this model, such as human presence at El Mirón and Rascaño during the cold season (although less intensely than during the summer), or the occupation of the El Valle and El Horno caves (both inland in the Ason river valley) during the winter; this shows that the land occupation strategies of Late Palaeolithic forager communities were more complex than a coast-winter *versus* interior-summer binary model (García-Moreno 2013b). In any case, the lack of data on seasonality as well as the unequal distribution of the available information prevents us from developing a more accurate approach to the study of Palaeolithic mobility strategies, and how these may be related to/influenced by the insolation received by the settlements.

6. CONCLUSIONS

The study of the potential insolation received by archaeological sites can provide useful information on their potential habitability. However, such analyses require a specific methodology that allows us to quantify the number of daily hours of sunlight that these sites receive throughout the year since seasonal variation in insolation can be useful to understand the mobility and settlement patterns of Palaeolithic groups. An accurate calculation of prehistoric astronomical parameters would improve the assessment of potential insolation, although, having said this, the use of modern parameters does not seem to modify the result significantly.

Moreover, topographic shading can cause sites with a favourable orientation to receive low insolation at certain times during the year, especially in mountainous regions where this kind of effect would be more noticeable.

In the case of the Cantabrian Late Magdalenian and Azilian, the analysis of site potential insolation has shown that it does not seem to have been a conditioning factor in the selection of settlements, although it may have been the case that during certain seasons sites with high insolation were preferred among those meeting other essential criteria. However, it seems that other factors played a greater role in the decision-making process behind site-location choice, some of them maybe at the cost of good insolation.

In any case, the application of a specific methodology for potential insolation evaluation provides alternative information as well as an interesting perspective on settlement patterns, while the possibility of calculating the astronomical parameters for different latitudes and time periods makes it possible to apply it to different archaeological contexts. The improvement of such a methodology and the combination of its results with archaeological data on seasonality or site function will allow us to attain a better understanding of prehistoric settlement patterns.

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Table 1

NAME	ASPECT	DIST	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	SPRING	SUMMER	AUTUMN	WINTER
Abbitaga	SE	2483.07	5	5	6	7	8	10	9	8	7	5	5	4	6.58	7.00	9.00	5.67	4.67
El Cuco	NE	200.00	5	7	9	10	11	11	11	11	10	7	5	5	8.50	10.00	11.00	7.33	5.67
Agarre	SW	5481.79	7	7	9	10	11	11	11	10	10	7	7	6	8.83	10.00	10.67	8.00	6.67
Aitzbitarte IV	W	6393.45	0	0	0	1	13	15	15	9	1	0	0	0	4.50	4.67	13.00	0.33	0.00
Altxerri	SE	1627.88	5	6	8	9	11	11	11	11	10	6	5	4	8.08	9.33	11.00	7.00	5.00
Antoliña	S	5929.80	0	4	6	7	11	11	11	9	9	6	2	0	6.33	8.00	10.33	5.67	1.33
Anton koba	NE	35471.13	3	4	6	6	8	8	8	7	7	5	4	3	5.75	6.67	7.67	5.33	3.33
Arenaza	SW	8332.24	7	7	8	10	11	11	11	10	9	7	7	6	8.67	9.67	10.67	7.67	6.67
Atxeta	N	9824.97	5	7	8	9	10	10	10	9	9	7	5	5	7.83	9.00	9.67	7.00	5.67
Atxurra	W	2635.93	6	7	9	9	11	11	11	10	10	7	6	5	8.50	9.67	10.67	7.67	6.00
Baltzola	SW	28044.26	7	7	9	9	11	11	11	11	10	8	7	6	8.92	9.67	11.00	8.33	6.67
Bolinkoba	SE	27191.40	5	5	6	7	10	10	10	9	8	6	5	4	7.08	7.67	9.67	6.33	4.67
Cobalejos	N	4718.58	0	2	5	7	11	11	11	9	8	4	0	0	5.67	7.67	10.33	4.00	0.67
Cobrante	NE	12086.20	3	4	6	7	11	11	11	10	9	5	4	3	7.00	8.00	10.67	6.00	3.33
Cualventi	W	2198.01	6	6	7	10	10	12	11	10	9	6	6	5	8.17	9.00	11.00	7.00	5.67
Cubera	E	21689.59	2	3	2	4	6	7	6	6	6	3	3	2	4.17	4.00	6.33	4.00	2.33
Cullalvera	NW	17673.00	4	6	8	10	10	11	10	10	9	6	5	4	7.75	9.33	10.33	6.67	4.67
Ekain	NE	6555.34	7	8	9	10	9	9	10	10	11	8	8	7	8.83	9.33	9.67	9.00	7.33
El Castillo	NE	13835.51	2	3	6	9	10	11	11	9	8	4	2	2	6.42	8.33	10.33	4.67	2.33
El Horno	W	18950.23	0	0	0	4	11	13	11	8	1	0	0	0	4.00	5.00	10.67	0.33	0.00
El Linar	SE	5663.76	6	7	8	9	10	11	11	9	10	7	6	5	8.25	9.00	10.33	7.67	6.00
El Mirón	W	18757.42	5	7	8	10	11	11	11	10	9	7	5	5	8.25	9.67	10.67	7.00	5.67
El Otero	W	8810.36	5	7	9	9	11	12	11	11	10	7	5	5	8.50	9.67	11.33	7.33	5.67
El Pendo	S	4989.11	6	7	9	9	11	11	11	9	10	7	7	6	8.58	9.67	10.33	8.00	6.33
El Perro	SE	25.00	8	9	9	10	10	10	10	10	11	9	8	8	9.33	9.67	10.00	9.33	8.33
El Pielago II	S	11912.21	0	2	3	3	5	8	6	5	5	3	1	0	3.42	3.67	6.33	3.00	0.67
EL Rascaño	SW	14031.79	3	4	5	7	10	10	10	9	8	4	3	1	6.17	7.33	9.67	5.00	2.67
El Salitre	W	16769.32	0	0	2	5	11	12	11	9	8	0	0	0	4.83	6.00	10.67	2.67	0.00
El Valle	SE	12726.20	6	7	9	10	11	11	11	11	10	7	6	5	8.67	10.00	11.00	7.67	6.00
Ermittia	W	1755.71	0	2	3	5	9	10	9	9	7	2	0	0	4.67	5.67	9.33	3.00	0.67
Erralla	N	8802.88	0	0	1	3	9	11	10	9	5	0	0	0	4.00	4.33	10.00	1.67	0.00
Goikolau	E	2586.62	5	7	7	8	9	9	9	9	9	8	6	5	7.58	8.00	9.00	7.67	5.67
La Chora	SE	8640.38	3	6	8	10	11	12	12	10	9	6	3	2	7.67	9.67	11.33	6.00	3.67
La Fragua	SE	125.00	8	8	10	10	10	10	10	10	11	9	6	7	9.08	10.00	10.00	8.67	7.67
La Garma A	S	5299.17	6	7	8	8	11	11	11	10	9	8	7	7	8.58	9.00	10.67	8.00	6.67
La Pila	S	602.08	4	6	7	9	10	11	11	9	9	6	5	4	7.58	8.67	10.33	6.67	4.67
Laminak II	NW	2840.88	5	6	8	9	9	10	11	9	9	6	6	5	7.75	8.67	10.00	7.00	5.33
Lezetxiki	S	28256.61	5	5	6	9	10	10	10	9	8	5	5	5	7.25	8.33	9.67	6.00	5.00
Lumentxa	SE	212.13	2	5	7	10	11	12	12	10	9	5	2	2	7.25	9.33	11.33	5.33	3.00

Morín	NW	2402.60	4	6	7	9	10	11	11	9	9	6	4	3	7.42	8.67	10.33	6.33	4.33
San Juan	NE	3465.54	5	6	7	9	10	11	11	9	9	7	5	4	7.75	8.67	10.33	7.00	5.00
Santa Catalina	NE	25.00	3	5	7	9	10	11	11	9	8	5	3	2	6.92	8.67	10.33	5.33	3.33
Santimamiñe	S	4649.26	9	9	10	9	9	9	9	9	11	10	9	8	9.25	9.33	9.00	10.00	8.67
Silibranka	W	27450.10	0	0	0	3	10	11	11	8	5	0	0	0	4.00	4.33	10.00	1.67	0.00
Sovilla	S	14824.49	0	1	3	7	11	12	11	10	9	1	0	0	5.42	7.00	11.00	3.33	0.33
Urtiaga	SW	1706.60	1	5	7	9	11	12	12	10	8	5	3	0	6.92	9.00	11.33	5.33	2.00

Table 1. Orientation (aspect), distance to coast (in meters), annual, monthly and seasonal mean potential insolation for the Late Palaeolithic sites considered in this paper.

Table 2

ASPECT	Annual	Spring	Summer	Autumn	Winter	N
S - SE - SW	7,63±0,31	8,68±0,31	10,21±0,24	6,76±0,38	4,88±0,51	22
N - NE - NW	7,04±0,36	8,26±0,4	10,05±0,22	5,95±0,5	3,92±0,57	13
E	5,87±1,7	6±2	7,66±1,33	5,83±1,83	4±1,67	2
W	6,15±0,70	7,07±0,79	10,81±0,33	4,11±1,03	2,63±0,99	9

Table 2. Annual and seasonal mean insolation of sites according to their orientation.

Table 3

	Annual	Spring	Summer	Autumn	Winter
Mean	7,10	8,13	10,17	5,97	4,13
Std. Error	1,65	1,82	1,17	2,29	2,50

Table 3. Annual and seasonal mean insolation for the archaeological dataset.

Table 4

	Annual	**Spring**	**Summer**	**Autumn**	**Winter**
Kolmogorov-Smirnov's K	0,919	1,378	1,245	0,881	1,021
p	0,367	**0,045**	0,09	0,419	0,248

Table 4. Kolmogorov-Smirnov’s test for mean and seasonal sites´ insolation.

Table 5

	Annual	**Spring**	**Summer**	**Autumn**	**Winter**
Inland	6,19±0,44	7,18±0,52	9,73±0,39	4,87±0,56	2,98±0,58
Coastal	7,58±0,25	8,63±0,27	10,41±0,15	6,55±0,39	4,74±0,44

Table 5. Annual and seasonal mean insolation for coastal and inland sites.

Table 6

	Annual	Spring	Summer	Autumn	Winter
Pearson's r	-0,347	-0,368	-0,282	-0,297	-0,246
p	0,018	0,012	0,058	0,045	0,099

Table 6. Pearson's correlation test between annual and seasonal mean insolation and distance to the coastline.

Table 7

	N	**NE**	**E**	**SE**	**S**
Coastal	2	4	1	7	5
%	6,67	13,33	3,33	23,33	16,67
Inalnd	0	3	1	2	3
%	0	18,75	6,25	12,5	18,75

Table 7. Number of coastal and inland sites according to the orientation categories.

Table 8

	Annual	Spring	Summer	Autumn	Winter
Mean	6,7	7,73	10,39	5,35	3,33
Std. Error	1,6	1,72	1,07	2,28	2,54

Table 8. Annual and seasonal mean potential insolation for the randomly generated sample of control points.

Table 9

	Annual	Spring	Summer	Autumn	Winter
Kolmogorov-Smirnov's K	0,794	0,905	0,872	1,103	0,936
p	0,553	0,386	0,432	0,175	0,345

Table 9. Kolmogorov-Smirnov's normality test for the annual and seasonal mean insolation received by the randomly generated sample of control points.

Table 10

	Annual	Spring	Summer	Autumn	Winter
Pearson's r	0,043	-0,052	-0,038	0,056	0,109
p	0,769	0,719	0,796	0,698	0,451

Table 10. Pearson's correlation test between annual and seasonal insolation and distance to modern coastline for the random sample.

FIGURE CAPTIONS

Figure 1. Map of the eastern Cantabrian region (northern Iberia) showing the sites considered in the present study.

Figure 2. Evolution of the obliquity of the ecliptic during the time interval corresponding to the Upper Magdalenian and Azilian.

Figure 3. Comparison between two different potential insolation models, taking modern solar declination (left) and maximum solar declination attainable in the late Pleistocene (right) into account.

Figure 4. Comparison between summer and winter insolation among the archaeological dataset, measured as mean daily hours of sunlight received by each site.

Figure 5. Scatter plot showing the relationship between sites’ distance to the coast (in meters) and their annual mean insolation (hours per day).

Figure 1

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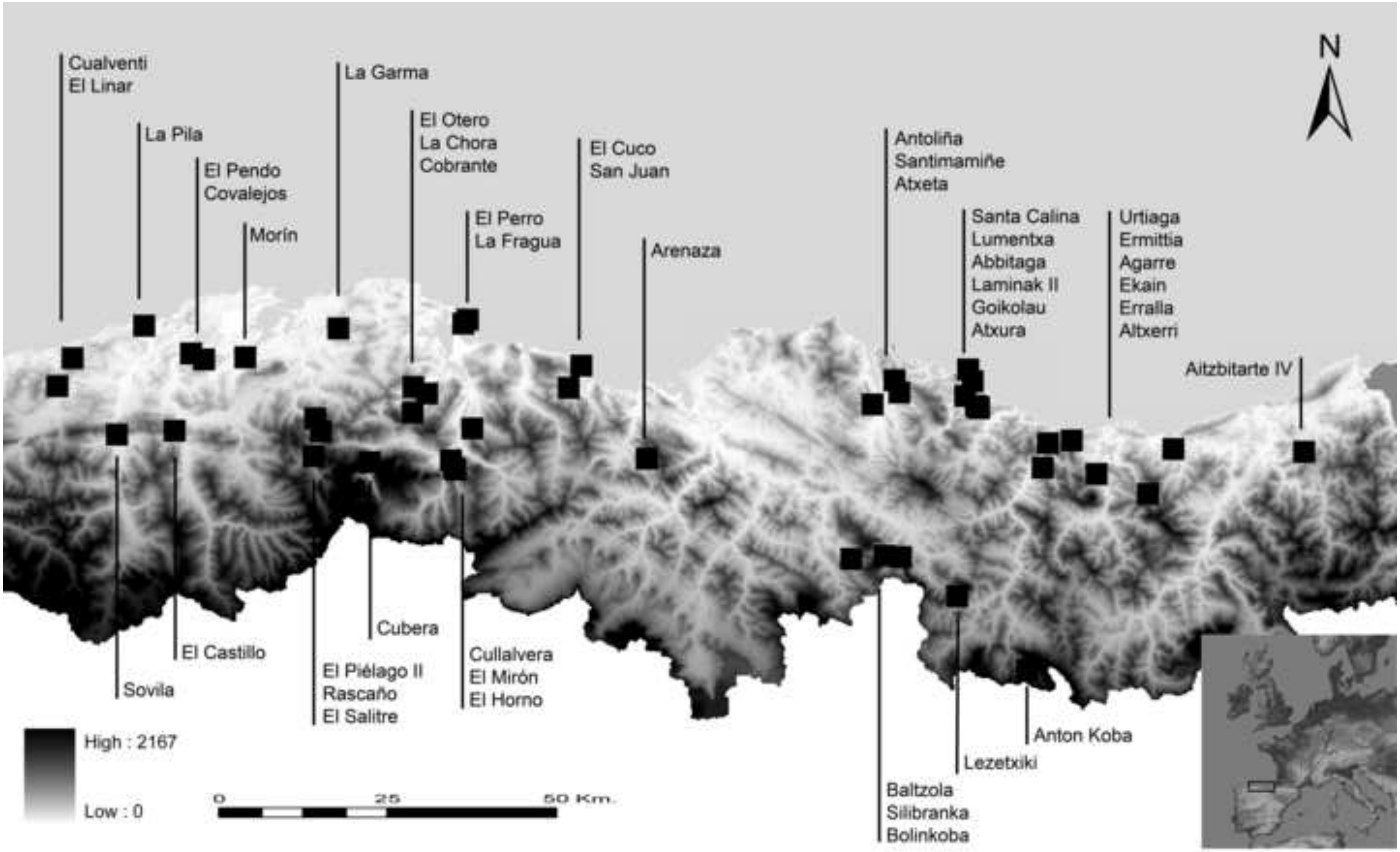

Figure 2
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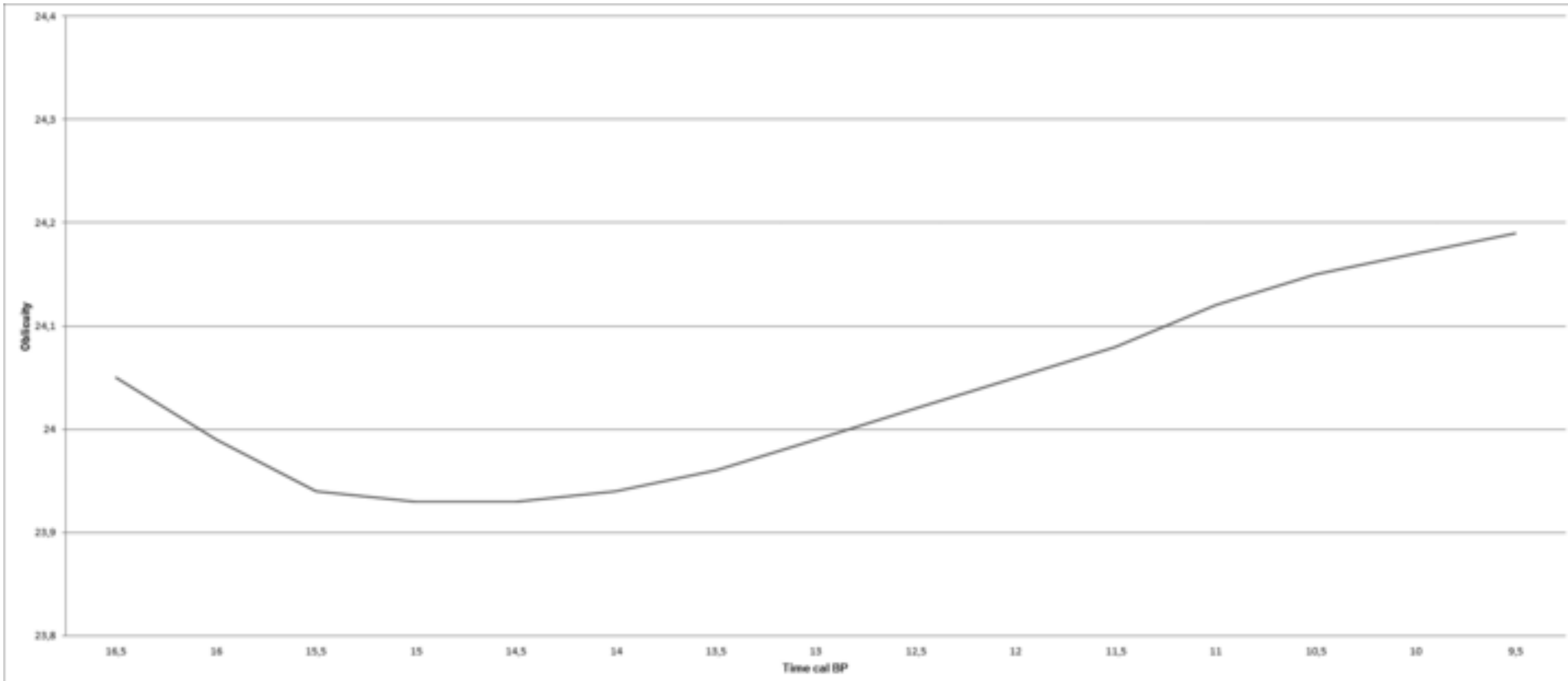

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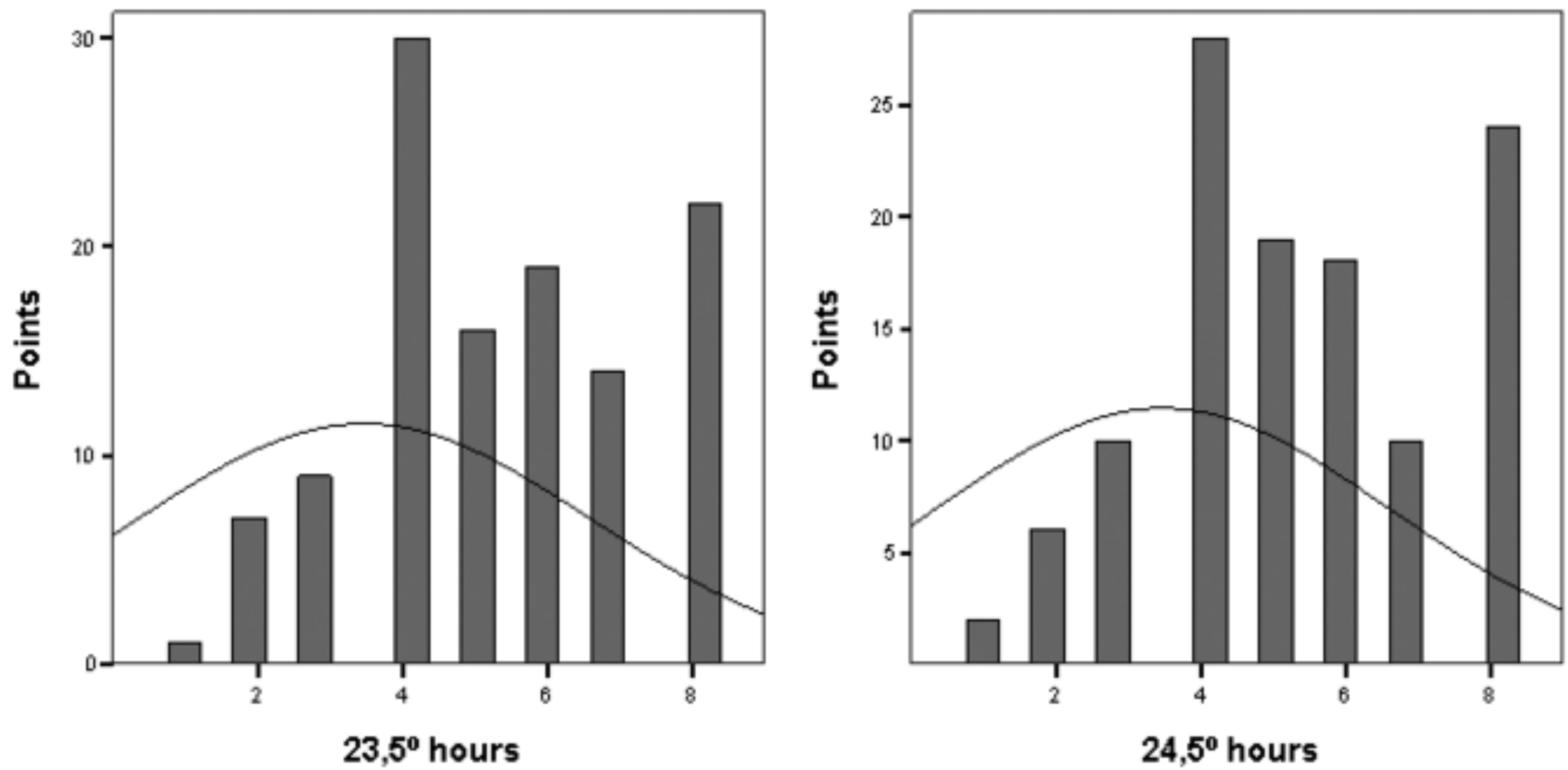

Figure 4

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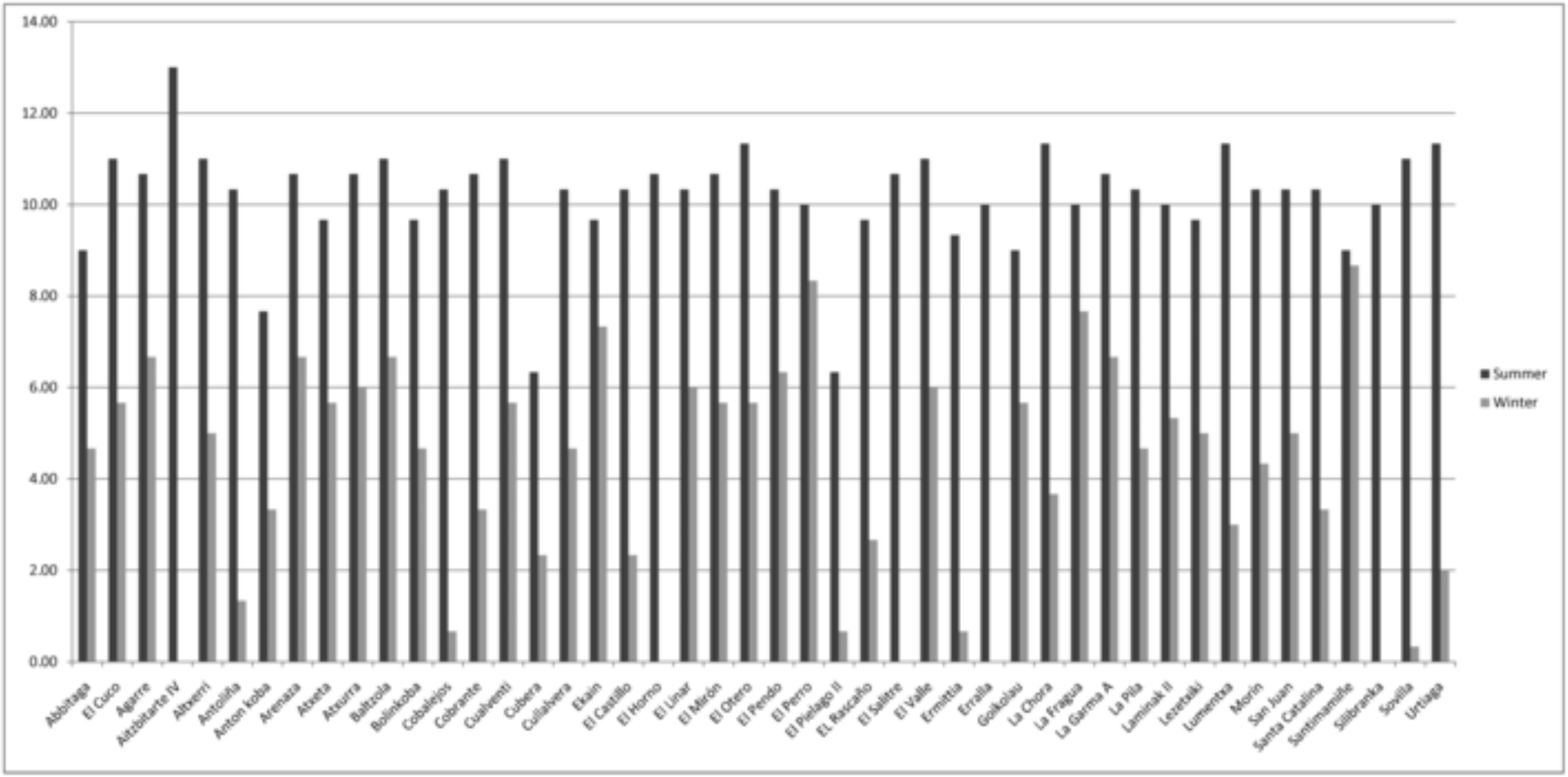

Figure 5
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