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Reconstruction of LGM faunal patterns using Species Distribution Modelling. The archaeological record of the Solutrean in Iberia

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A B S T R A C T

This paper focuses on analyzing the links between archaeological sites and their environments by calculating the catchment areas of Solutrean sites in Iberia and the habitat suitability for the different hunted species in each site. This research uses Geographic Information Systems (GIS) for calculating the catchment areas and Species Distribution Modelling (SDM) for reconstructing potential distributions of prey species. The results of this modelling for the Solutrean sites were then compared to a database on faunal remains. The SDM results show differences between northern and southern Iberia in the habitat suitability for some species. There are also visible differences between the faunal record and in the subsistence strategies in both areas, which can be linked to the climatic and topographic conditions inferred by means of site catchment analysis and the SDM.

1. Introduction

The Iberian Peninsula is a perfect framework to analyze the relationships between environment, climate and human behaviour because of its geographic and climatic variety (Aura Tortosa et al., 2002; Schmidt et al., 2012; Straus et al., 2000). In this sense, this paper represents an attempt to better determine the potential distribution of the ungulates relevant to the diet of hunter-gatherers and establish a link between the catchment areas and the hunting patterns revealed through the faunal record documented for the Solutrean sites in Iberia, the chronological framework of which encompasses the Last Glacial Maximum (LGM). The spatial behaviour of hunter-gatherers is shaped by the landscape and the available resources in their catchment area (e.g. Bettinger, 1991), and in the last decades, researchers have made efforts to link the archaeological records (lithic raw materials, exotic materials, shells …) with the site's environment because hunter-gatherer groups depended on the resources' distribution in the landscape (Kelly, 2013) and because understanding human behaviour is a primary goal of archaeological studies.

Most analyses on human mobility and procurement of resources are performed simply by analyzing the acquisition of raw materials. However, over the last years, there have been more attempts to link the hunted species present in the archaeological record to a site's environment, because it could provide useful information (Banks et al., 2008a, 2008b). Some researchers establish the links by using a weighted values method (Dalla Bona, 2001; Ríos and García-Moreno, 2015), but the most used method is predictive modelling (in our case Species Distribution Modelling –SDM-), which is a powerful tool to test archaeological hypotheses. The results of an SDM analysis depend on the quality of the available data and the variables introduced for the modelling (Verhagen, 2008). In our analysis, climate is the most important variable in reconstructing potential species distribution because it is one important factor that limits the geographic range of different species.

Solutrean period covers mainly the LGM, when climatic changes occurred and there was an increase in the development of woodlands and semi-arid vegetation in Iberia, findings confirmed both in the palynological studies conducted in the MD95-2043 core (Sánchez-Goñi and D'Errico, 2005; Fletcher and Sánchez-Goñi, 2008; Fletcher et al., 2010) and in the small mammals assemblages (Bañuls-Cardona et al., 2014). Surprisingly, the climate of Iberia was colder and drier than other areas in Europe (Carrión

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et al., 2010; Bernat-Rebollal and Pérez-González, 2008; Domínguez-Villar et al., 2013; Fletcher and Sanchez-Goñi, 2008). Recent studies on climate simulations for this period also show an increase in daily precipitation amounts (Burke et al., 2014; Ludwig et al., 2016), evidence of a very humid climate.

2. Materials and methods

The methodology used for this analysis consists of two parts. The first part focuses on Solutrean sites with well-preserved and published faunal records, including the Minimal Number of Individuals (MNI). In addition, we select Solutrean sites that have radiocarbon datings, clear diagnostic findings and undisturbed Solutrean contexts. The study is based on a literature review, which provided a sample of 31 sites with 67 levels where there are studies related to the faunal record of the site (25 sites in the north of Iberia: Cueva Oscura de Perán, El Cierro, Cova Rosa, El Buxu, Coberizas, Cueto de la Mina, La Riera, Balmori, Chufín, Altamira, Hornos de la Peña, El Castillo, La Pasiega, El Ruso, Cueva Morín, Arlanpe, Bolinkoba, Lezetxiki, Atxeta, Santimamiñe, Ermittia, Urtiaga, Amalda, Aitzbitarte IV, Peña Capón; and 6 in the south: Mallaetes, Parpalló, Ambrosio, Nerja, El Pirulejo, Higueral de Motillas). We differentiate between northern and southern Iberia by dividing the peninsula along the 40° N latitude. This limit is suggested by the distribution of sites and environmental data such as ombrotype maps (Rivas-Martínez et al., 2004) and has been previously used for research purposes (Schmidt et al., 2012). Table 1 shows the list of sites and levels analysed and Fig. 1 shows the spatial distribution of our sample. This dataset, which contains more sites in the north than in the south, contrasts with the general outlook for the Solutrean in Iberia, where an increase in the number of sites in the south is evident (Schmidt et al., 2012). This probable bias in site number can be explained by poorer faunal preservation in the south and more intensive research in faunal assemblages in the north.

In a second step, we calculate the catchment area of these sites using ArcGIS 10.3.1 and the ASTER GDEM V2 (NASA JPL, 2015) Digital Elevation Model (DEM) and model the potential distribution of the prey species for every catchment area. For the calculation of the catchment area of coastal sites, we use the bathymetric data provided by GEBCO (IOC et al., 2003; http://www.gebco.net/). Furthermore, we use the bathymetric data from EMODnet (http://www.emodnet-bathymetry.eu) to compute the most representative sea level curves from SPECMAP (Thompson and Goldstein, 2006) which cover the time span of the Solutrean period (Samples 10 209, 925, 9155, RFG9-13-3). The last step is comparing the MNI of the species to the mean of the potential occurrence of every species in the catchment area during the Solutrean.

2.1. Site catchment analysis and modelling

The concept on which site catchment analysis (SCA) is based was first used in 1970 by Vita-Finzi and Higgs. In the model, a site's catchment describes the territory frequently exploited by human groups for procuring resources. It is based on the principle that the farther one moves, the greater the amount of energy that must be expended for the procurement of natural resources. Based on the habitants of a site covering the distances to exploit the resources of an area by walking, it assumes that the size of the catchment area is defined by the time it takes to walk it. Subsequently, to avoid confusion with the concept of defended territories, other researchers suggested the term Site Exploitation Territory (SET) (Bailey and Davidson, 1983).

SCA is performed on an exploited territory related to a time limit. The time boundary, which has been established as 2 h (Lee, 1976; Vita-Finzi and Higgs, 1970), can be represented in maps by an isochrone. The model assumes that human groups periodically returned to a central place (Wobst, 1974; Orians and Pearson, 1979; Whallon, 2006), and it has been applied to Solutrean contexts in Iberia to analyse the raw material procurement (Andrés-Herrero et al., 2017; Aubry et al., 2012, 2015). Furthermore, Cannon (2003) formulated the model of central place forager prey choice as applied to faunal remains, which has also been used for Lateglacial contexts in Iberia (Marín-Arroyo, 2008, 2009). In line with the criteria from Marín-Arroyo (2009), the maximum duration of a trip for hunting red deer is around 8 h, but, after taking into account the processing and handling times, this time gives a maximum distance of 2.15 h for travelling, which would take about 4.3 h travel time in total (there and back). This time distance is the distance used in this research to calculate the boundary of the catchment areas.

Similar to other archaeological research, we analysed the SDM using catchment areas rather than using exact coordinates (Gravel-Miguel, 2016) because the prey species that appeared in the archaeological records were not hunted in the sites, but in their surroundings, as shown in ethnographic studies (Binford, 1980; Kelly, 2013). Catchment areas allow calculation of the possibility of occurrence of every prey species in an area that spans over 2.15 h walking time from the site. We use ArcGIS software and the DEM provided by ASTER to model the catchment areas. Furthermore, we used the bathymetric data provided by GEBCO to calculate the areas in coastal sites. Tobler's Hiking Function (Tobler, 1993), which has been used in similar studies (Wheatley and Gillings, 2002; Verhagen et al., 2014), was applied to calculate the speed at which hunter-gatherers moved. The calculation results in a cost raster that is applied in ArcGIS's *cost distance* tool to produce an accumulated cost raster that is then used to create the 2.15 h isochrones. The application of cost distance analysis to investigate the mobility patterns of hunter-gatherer groups in Palaeolithic times is based in the hunter-gatherers' necessity to optimize the energy and time they spent in acquiring biotic and abiotic resources (Surface-Evans and White, 2012).

2.2. Species distribution modelling

To generate faunal palaeodistribution data, species distribution modelling (SDM) is applied, utilizing openModellers (Muñoz et al., 2009) MaxEnt implementation. Some previous work in this area also refers to SDM or similar approaches as ecological niche modelling (ENM), and the exact terminology is still being debated and may sometimes be used inappropriately. Elith and Leathwick (2009) argued for a neutral terminology, here SDM, to describe species distributional models, terminology that is in line with that behind the openModeller (SPDM) in the related publication (Muñoz et al., 2009) and the assessments by Soberón and Peterson (2005). The key assumption of these approaches is the dependence of a species's distribution on the environment, as specific environmental variables allow long-term survival of a species. The modelling algorithm applied was MaxEnt (Maximum Entropy), which was originally a general-purpose statistical method for making predictions from incomplete information. MaxEnt estimates a target distribution by finding the distribution of maximum entropy (i.e. the closest to uniform), subject to the appropriate constraints. In the context of ENM or SPDM, these constraints consist of the environmental data, while the occurrence data of a species serve as the sample points (Townsend Peterson et al., 2007). The goal is the modelling of species' potential palaeodistributions, and for this appropriate environmental data is required. This data is available in the form of present and palaeo climate data that is used to project present species occurrences to past potential distributions.

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