MEGALITHIC SOCIETIES

OLD QUESTIONS, NEW NARRATIVES

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Front cover: Chan de Castiñeiras 2, the remains of a dolmen from the megalithic complex of Chan de Castiñeiras in Pontevedra, sitting between the municipalities of Vilaboa and Marín. Back cover: Compilation of drawings of the first monument of Forno dos Mouros do Bocelo´s lay-out (by Jadranka Verdonkschot, after Criado-Boado *et al.* 1991).

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Chapter 10

‘Linking megaliths’. A computational approach to the study of movement and mobility in the megalithic complex of Galicia (Northwest of the Iberian Peninsula)

Miguel Carrero-Pazos and Devin A. White

Abstract

In this paper we study the spatial relation of more than 3,000 mounds with the natural movement through the landscape in Galicia (NW Spain). We adopt a computational approach by creating three geospatial models of pedestrian transportation networks in a GIS environment which comprised the creation of almost 19 billion routes in the whole region, taking into consideration as the mobility factors the slope, rivers, and land cover. In a second step, we generated an aggregate viewshed map using a regularly-spaced grid of observers across the region, in order to see if the megaliths are located in areas of high visual prominence. Finally, spatial statistical analyses were applied to see if the sites are situated near places that would naturally channel pedestrian movement at local and regional scales, and areas with high visibility.

The results point out a clear spatial relation of the megalithic monuments with the movement through the landscape, a trend that might be common to the Atlantic façade of Europe. We argue that this relation could be interpreted as a way of connecting the daily lived human landscapes and long-distance routes which not only physically connected the communities but also enabled the expansion of funerary ideas through terrestrial routes.

Keywords: Megaliths, Spain, Least-Cost Path, Viewshed, Geographic Information Systems, Spatial Statistics, Mounds, Geography of movement

Introduction

The megalithic monuments represent the materialisation of one of the social and cultural transformations in Europe during the Holocene, specifically in the Neolithic period. They are among the most common archaeological remains on the Atlantic Façade of Europe. In Western Europe, their chronology is often associated with both the Neolithic and the Bronze Age period. Across this territory, more than 30,000 dolmens, mounds, and other monuments are still preserved, serving as a testament to a number that was likely much higher in the past (Schulz Paulsson 2017). Well-known core areas with a high concentration of sites include regions such as Brittany, central Portugal, the British Isles, and Denmark.

While there is a clear temporal uncertainty behind this number, as the majority of these remains consist of unexcavated mounds, these monuments have been analysed from a broader perspective. The idea is that their significance in the landscape extends beyond their chronology. The Neolithic period witnessed a significant increase in the extent to which humans actively structured and reshaped their landscapes through monuments, essentially transforming natural environments into human-influenced ones (Criado Boado 1989; López-Romero 2005; Schulz Paulsson 2017). Megalithic monuments played a crucial role in this transformative process (Furholt and Müller 2011; Scarre 2005). Essentially, they have been understood as traces of communal possession of the land (Hanks 2008; Saxe 1970), justifying societal cohesion (Chapman 1981; Tilley 1994), or serving as territorial markers to exert control in different parts of the landscape (Lagerås 2002; Last 2007; Thrane 1998: 275; Tilley 2004: 197). Additionally, they are integral to wider cosmological landscapes (Bourgeois 2013), where topographical elements and the presence of other monuments play significant roles as references in culturally and socially humanised landscapes (Criado-Boado and Villoch Vázquez 1998; Cummings and Whittle 2004: 82; Lagerås 2002: 188). The construction of these enduring monuments is seen as a symbolic act, reinforcing the unity and cohesion of groups; indeed, a milestone for society (Delibes de Castro 1991; Renfrew 1976).

Furthermore, the placement of these monuments in the landscape is not random. Various locational patterns in different areas have been identified through fieldwork and modeled with GIS tools. For instance, some proposals suggest that megaliths were strategically placed in zones with topographic prominence, near flooding areas, or near transit paths connecting different parts of the landscape at local and general

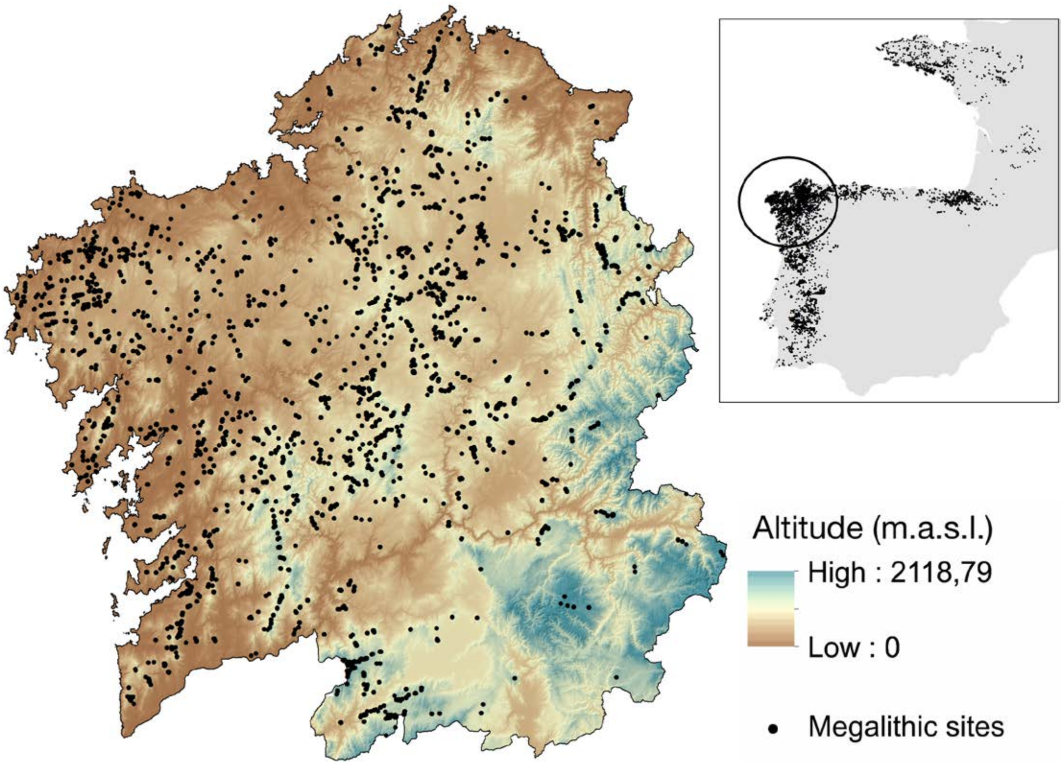

Figure 1. The megalithic phenomenon of Galicia (NW Spain). Data gathered from the megalithic studies group of the University of Santiago de Compostela (currently with 3,305 sites). Upright: The megalithic sites of the Atlantic façade of Portugal, Spain and part of France (data gathered from public sources. © MegaScapes project).

scales. The aim of this paper is to delve into the latter aspect by employing computational approaches.

Study area and background research

Up to the north-west of the Iberian Peninsula, Galicia, a region of approximately 30,000km², is characterised by rugged geography with medium-high elevations in the inner parts that are intersected by flattened valleys and lowlands that normally drain to the coast (Figure 1). Galicia shows a very high concentration of unexcavated mounds and megaliths, with more than 3000 sites in our current database, but with possible estimates raised to more than 7,000 sites (data from Xunta de Galicia Government, 2013; Carrero-Pazos 2017). Although this density has proven to be an inherent factor of the Galician megalithic phenomenon—in comparison to other regions (see, e.g. Scarre 2019: 190)—there has also been a great effort by researchers to carry out survey works from the nineteenth century and especially in the last forty years when several projects from universities and the official government ended up with the creation of the official catalog of mounds and megaliths (see, e.g. Rodríguez Casal 1990).

Regarding the relation of megaliths with natural pathways, there is also a long tradition of researching this topic in Galicia, with early researchers stating that 'mounds are built in the bottom of valleys or plains, over the hills (...), and sometimes in tight enclosures' (Martínez de Padín 1849: 231), or that 'mounds were built aligning prehistoric paths' (Maciñeira 1935;1943-44). Later, others stated that megalithic monuments are located near current transit routes but pointed out previous historical pathways built in Neolithic times (Bello Diéguez *et al.* 1982a: 3, 1982b: 117).

These initial interests prompted the analysis of the general spatial patterning of mounds and megaliths, leading to the definition of new horizons in research known as the 'geography of the movement' (Criado Boado *et al.* 1990-1991; Vaquero Lastres 1993-1994; Criado Boado *et al.* 1994) (Figure 2). Subsequent analyses have concluded that there is a spatial relation of megaliths with transit areas throughout the landscape (e.g. Eguileta Franco 1997, 1999, 2000), identifying prehistoric routes using ancient and medieval paths (see, e.g. Martinón-Torres 2001).

Building on these studies, however, in recent years, new analytical approaches have focused on GIS applications and spatial analyses to study the relationship of megaliths with pathways at local scales (Carrero-Pazos and Rodríguez Casal 2019; Llobera 2015; Rodríguez Rellán and Fábregas Valcarce 2015, 2019). Despite being case studies, all these investigations conclude that the spatial relation of megalithic sites with the movement through the landscape could have been a crucial

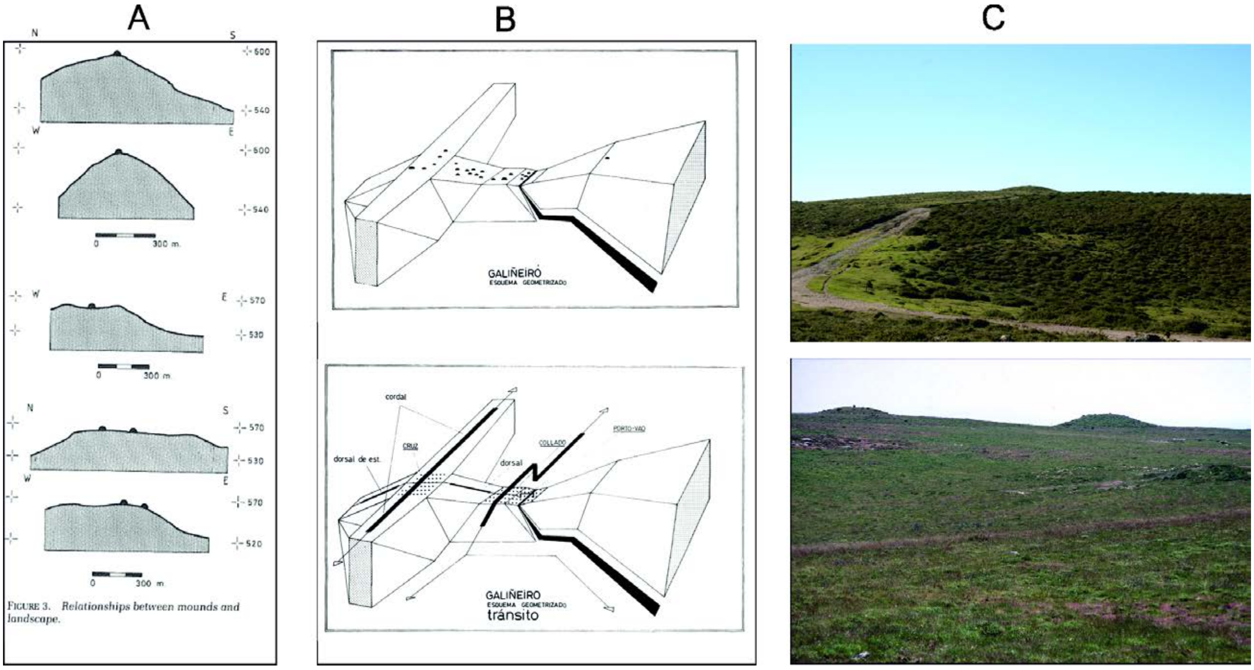

Figure 2. Former (pre GIS) studies about landscape location and the relation of megaliths with the transit through the landscape (A: Criado Boado, Fábregas Valcarce, 1989; B: Vaquero Lastres, 1993-1994). C: Examples of megalithic mounds in Serra do Barbanza (up), and Serra do Leboreiro (down).

factor in choosing their specific settings, along with visibility considerations (see, e.g. Carrero-Pazos, 2018a, b). This paper marks the first attempt in the Iberian Peninsula to examine this locational factor for an area encompassing almost 30,000km².

GIS pedestrian and view shed models

The study of movement and mobility in past landscapes has been a significant focus of GIS applications in archaeology, covering interests ranging from reconstructing trading routes, analysing site location patterns to studying economic networks, among others (see, e.g. Bell and Lock 2000; Carballo and Pluckhahn 2007; Howey 2007; Leary 2014; Sherman *et al.* 2010; Polla and Verhagen 2014). Technically, research has predominantly oriented toward using least-cost paths to reconstruct natural corridors in landscapes or the pathways and roads between specific archaeological sites (see, e.g. Lewis 2024; Llobera 2015; Murrieta-Flores *et al.* 2014; Standley 2015; Van Lanen *et al.* 2015, Wheatley *et al.* 2010; White and Barber 2012; Zakšek *et al.* 2008).

While computational methods have advanced in recent years through high-performance computing (Crabtree *et al.* 2021; Llobera 2020; White and Barber 2012) and advanced spatial statistics (see, e.g. Bevan 2020; Verhagen 2018), some initial and well-known issues of classic approaches, such as the use of different cost surface algorithms, are still under discussion and development (see, e.g. Herzog 2013). New research is now focusing on network analysis (Brughmans 2010) to analyse patterns of communication, introducing variables such as 'the memory of the landscape' (Fovet and Zakšek 2014; Verhagen *et al.* 2013; Verhagen 2018) and how earlier least-cost paths influence the construction of newer ones (Llobera 2020), or incorporating chronological uncertainty (Groenhuijzen and Verhagen 2017; Prignano *et al.* 2019).

In this paper, we develop three pedestrian models to analyse the relationship of megaliths and mounds with natural corridors within the region of Galicia (Table 1). Therefore, the aim of this work is not to reconstruct prehistoric paths but to observe the inherent structure of the mobility through the landscape, using spatial statistics to check if sites are related to areas of potential movement and if those areas maintain high visibility values.

We opted for choosing the FETE approach ('from everywhere to everywhere', many-to-many path relationships) developed by D. White and S. Barber (2012), which generates a network of least-cost paths based on topography and land cover without requiring origin and destination points be supplied in advance (Figure 3).

The FETE algorithm calculates the least-cost paths from all the points in a sampling grid, or specific set of points provided by the user, back to the current origin (see Figure 3D). Then, the locations of the paths are recorded in an accumulative surface, which, in a next step, resembles a road network (as seen in Figure 5A).

PEDESTRIAN MODELS				
	Objective	Characteristics of LCPs	Characteristics of agent	Number of routes generated
Model 1 (male)	To detect natural and general pathways by examining travel across the region	FETE analysis, points derived from vector boundaries of the region, all connected to one another	Male, 165cm tall, 64kg, 25 years old and 4kg of additional load	7,721,312,641
Model 2 (male)	To analyse the relation of sites with pathways by examining travel *within* the region	FETE analysis, regularly spaced grid of points connected to one another, 25-cell spacing	Male, 165cm tall, 64kg, 25 years old and 4kg of additional load	5,585,469,696
Model 3 (female)	To analyse the relation of sites with pathways by examining travel *within* the region	FETE analysis, regularly spaced grid of points connected to one another, 25-cell spacing	Female, 160cm tall, 60kg, 25 years old and 4kg of additional load	5,585,469,696
** Agent characteristics are based on the work of Hermanussen (2003).				

Table 1. Pedestrian models designed for this study.

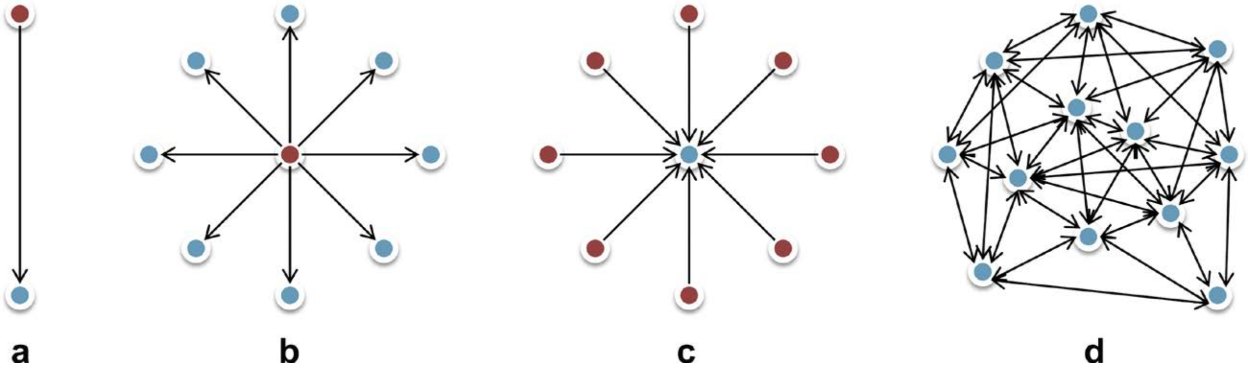

Figure 3. Connectivity options for point travel calculations. A: one-to-one. B: one-to-many. C: many-to-one. D: many-to-many (After White, Barber 2012: 2685).

The FETE algorithm was run over two kinds of procedures. First (Model 1, so-called extents), using the vector limits of the study area as origin and destination points, where the polygon was rasterised to match DEM resolution and only the border cells were used (Figure 4A). Secondly (Models 2 and 3), using a grid of points regularly distributed over the whole study area, every 25 pixels (Figure 4B).

All the analyses were carried out over a 25m DEM (LiDAR based), obtained from the Spanish National Cartographic Service (http://centrodedescargas.cnig.es/CentroDescargas/index.jsp), CC BY 4.0 https://www.ign.es/.

Analysis and results

The FETE models were calculated using a 25m Digital Elevation Model (DEM) with basic land cover data from MODIS MCD12Q1 for 2016. Streams, rivers, and lakes from OpenStreetMap were incorporated as the primary walk impediments. Using the method devised in Crabtree *et al.* 2021, we parameterised the travel function by assuming the least anisotropically 'costly' movement (in terms of caloric expenditure) across the landscape, using, as said before, the streams, rivers and lakes as walk impediments. In the simulations, travellers attempted to move from their origin point to their designated destination while minimizing caloric costs. When estimating the energetic cost of travel from one grid cell to another, the FETE calculates a generalised estimate of walking speed using a scaled version of Tobler's hiking function (see Crabtree *et al.* 2021, 'modelling travel').

We ran the models enough times to generate over 19 billion routes (Table 1), tracking each time a traveller crosses a pixel, thus creating pathways that transect the whole territory. The number of times a pixel was crossed indicates the 'attractiveness' of that cell for the movement. We then applied crossing thresholds to the pathways to identify those in the 1, 5, and 10% attractiveness levels considered across the simulations.

The results generated a total of 18,892,252,033 least-cost paths for the entire region, signifying a substantial advancement in terms of the scale of analysis compared to previous approaches. The creation of nearly 19 billion LCPs was necessary to capture the complexity of the landscape and the multitude of potential routes available, something not approachable from a regional or local point of view. This extensive computational effort allows us to explore not just the most direct or obvious paths, but also less apparent routes that

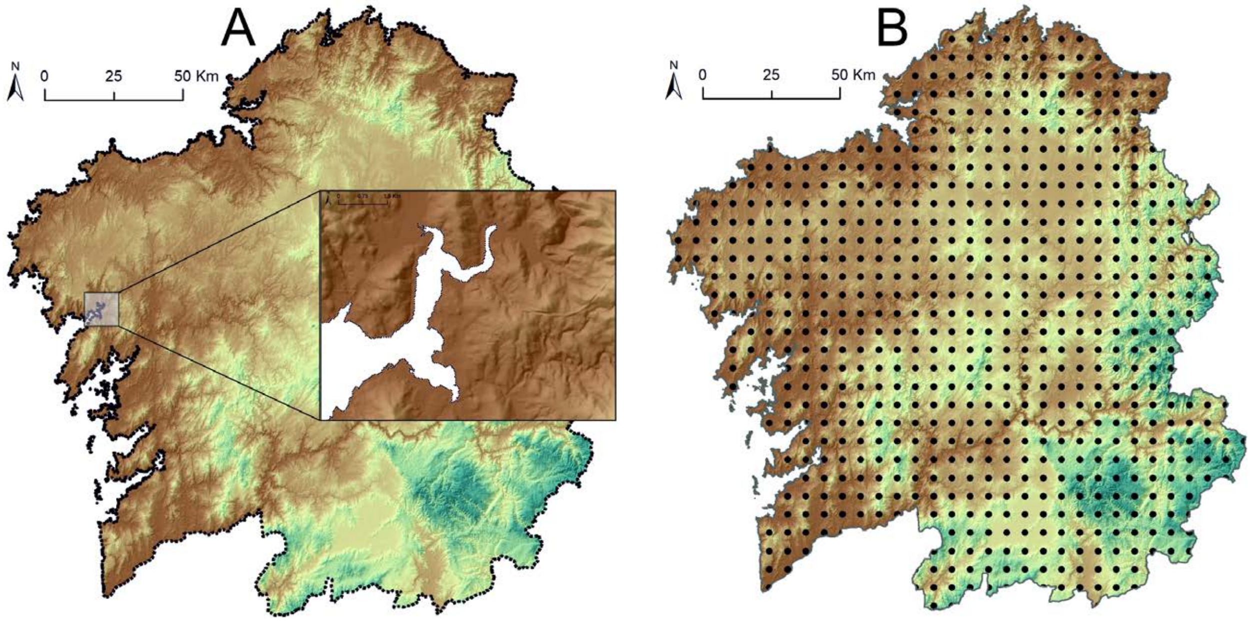

Figure 4. Methodological designs for FETE calculations.
A: Extents (model 1). B: Regular grid (separation of points exaggerated for visualisation purposes) (models 2 and 3).

may have been utilised for various purposes, thereby providing a more comprehensive view of human mobility.

To analyse the positioning of megaliths, we derived four different versions of each model, representing the full network thresholded to the top 20%, 10%, 5%, and 1% of high-traffic routes, as using the entire raw network became unmanageable for calculations. Additionally, we conducted an aggregate viewshed analysis for the entire Galicia, employing an observer every 10 pixels (resulting in 466,779 regularly-spaced individual viewsheds), to assess whether sites are situated in areas of high visibility.

We calculated the minimum three-dimensional travel distance from each megalith to four versions of each of the three models, representing the full network thresholded to the top 20%, 10%, 5%, and 1% of high-traffic routes (Figure 5). The three-dimensional walking distance refers to the travel distance that accounts for both horizontal movement across the landscape and vertical changes in elevation. Instead of measuring distance in a straight line on a flat surface, it includes the impact of hills, slopes, and other elevation differences that affect the effort or time needed to travel. This is particularly important in archaeological studies, where the complexity of the landscape can significantly influence human mobility. The method is used to assess how close each point on the terrain is to prominent landscape features, considering the terrain's complexity and the effort involved in walking across it (see Crabtree *et al.* 2021 for the technical details of the approach). The raw results for all the cut-offs can be found in the supplementary material under the folder 'Site distances.'

As seen in Figure 6, if we use the 20% cut-off traffic routes, sites are located much closer to the routes, and in the cases of the gridded models, the majority do locate in the near vicinity (50-100 meters). Also, we see that the sex is not introducing any substantial difference on the results.

Utilising the methodology described in Crabtree *et al.* 2021, we then tested the ability of each network thresholded to the top 20%, 10%, 5%, and 1% of routes (12 total) to reproduce the spatial pattern of megaliths by using a multi-staged process. We first calculated the shortest, three-dimensional travel distance from each megalith to each thresholded network, depending on surface elevation, using a standard anisotropic approach for generating a least-cost surface, as mentioned above. Each cell in the resulting grid, which matches the DEM in extents and spatial resolution (25m) represents the shortest travel distance from that location to the thresholded network and we averaged the values for a 100m neighbourhood of cells around each megalith to produce more comprehensive distance estimates. This creates a new coordinate system where the entire thresholded network is represented by the origin (0, 0) as a single point, which allowed us to standardise the distances across varying landscapes, enabling a direct comparison of spatial patterns. In other words, the frame of reference and per-megalith distances from that point can be used as a metric in two standard statistical clustering tests for complete spatial randomness—Kolmogorov-Smirnov (K-S) and Besag's

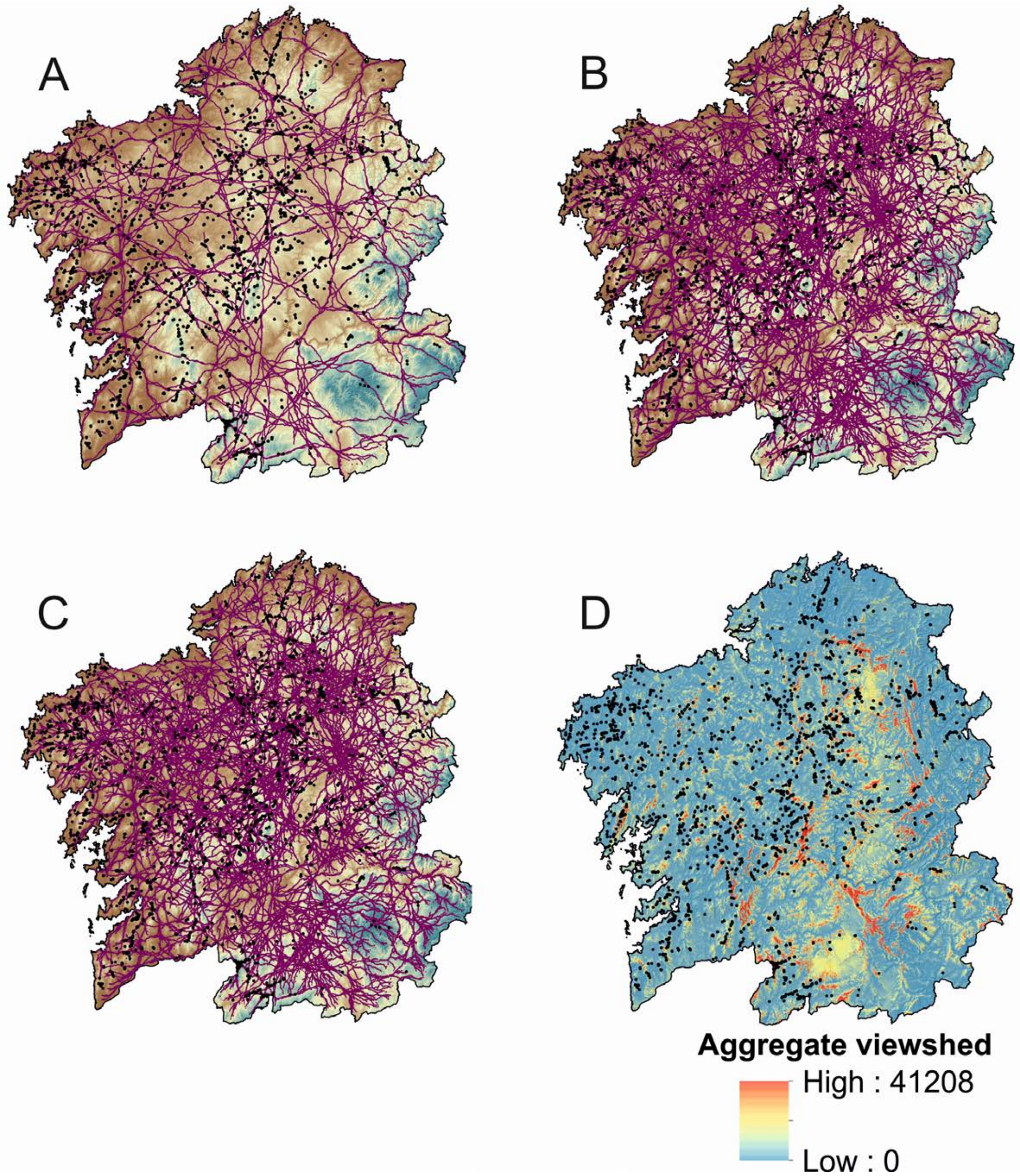

Figure 5. FETE models and aggregate view-shed analysis. A: Model 1, built with origin and destination points from the vector limits of the region (extents) (showing the top 1% of the generated network); B: Model 2, male agent (showing the top 5% of the generated network); C: Model 3, female agent (showing the top 5% of the generated network). D: Cumulative view-shed analysis based on 466,779 regularly-spaced individual viewsheds (observer every 10 pixels).

L-function (a normalisation of Ripley's K function) —to determine how well each thresholded network explains megalith locations. The stronger the clustering, the stronger the relationship.

Both clustering tests require the comparison of megalith distances to those obtained from the same number of randomly generated points—a process that is generally repeated many times to estimate an empirical value; for this analysis we selected 10,000 trials. The Kolmogorov-Smirnov test is straightforward and indicates whether two samples are drawn from the same distribution. If a large enough number of the comparisons between megalith distances and those for random points pass the test, which is based on a standard uniform distribution probability, complete spatial randomness cannot be ruled out and the thresholded network in question is declared uninformative.

If enough simulated estimates do not pass the Kolmogorov-Smirnov test, indicating that megalith locations are not random with respect to a thresholded

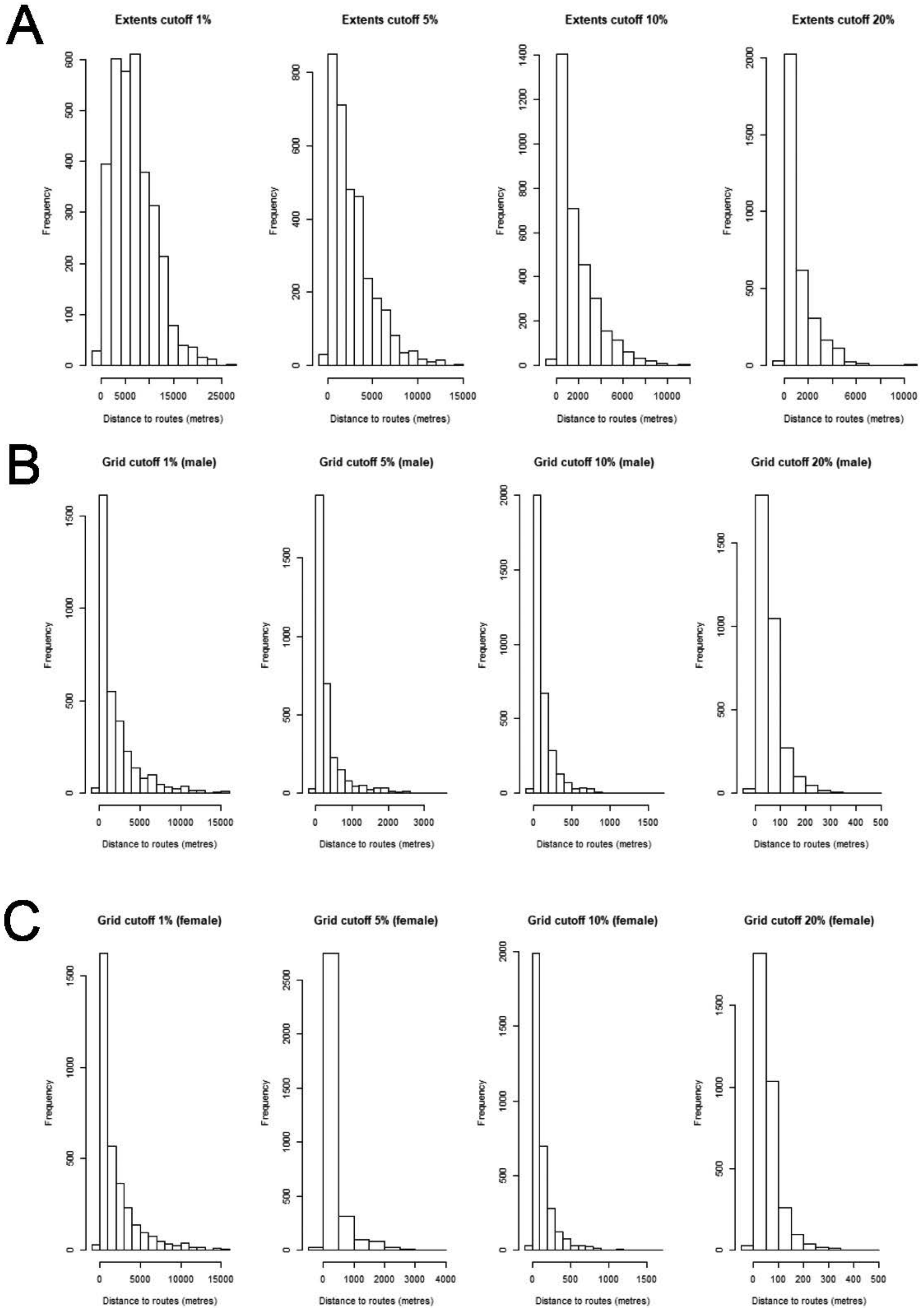

Figure 6. Histograms of distance to routes from megaliths.
A: Extents model; B: Male model; C: Female model.

Model 1		Top 1%		Top 5%		Top 10%		Top 20%	
Extents	**Alpha**	**K-S**	**L**	**K-S**	**L**	**K-S**	**L**	**K-S**	**L**
	0.001	Not Random	Partial Pass	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass
	0.005	Not Random	Partial Pass	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass
	0.025	Not Random	Partial Pass	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass
	0.050	Not Random	Partial Pass	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass
	0.100	Not Random	Partial Pass	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass
Model 2		**Top 1%**		**Top 5%**		**Top 10%**		**Top 20%**	
Male Grid	**Alpha**	**K-S**	**L**	**K-S**	**L**	**K-S**	**L**	**K-S**	**L**
	0.001	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass
	0.005	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass
	0.025	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass
	0.050	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass
	0.100	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass
Model 3		**Top 1%**		**Top 5%**		**Top 10%**		**Top 20%**	
Female Grid	**Alpha**	**K-S**	**L**	**K-S**	**L**	**K-S**	**L**	**K-S**	**L**
	0.001	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass
	0.005	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass
	0.025	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass
	0.050	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass
	0.100	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass	Not Random	Full Pass

Table 2. Summary of the K-S and L tests for all thresholded models.

network, Besag's L-function evaluates how resilient the relationship is by examining it at multiple spatial scales. The greater the number of scales where it passes, the stronger the explanatory power. Instead of comparing megalith distances to each set of randomly generated points, we use all sets of randomly generated points to create a single empirical estimate of randomness against which the set of megaliths can be compared at a series of distances (1-26km, in 1km increments). The test was limited to a distance of 26km because that is the maximum distance travellers can be from any megalith in the region or from the borders of the region, based on least-cost, three-dimensional travel distance. We then pooled results across all distances to create a single probability estimate for each thresholded network. The *L*-function can test for either clustering or dispersion with respect to a given frame of reference. For this analysis, we considered clustering.

Table 2 contains the results of all tests on all 12 thresholded networks. With respect to the K-S test, all networks had non-random spatial relationships with all megaliths in the region, and all but the top 1% network for Model 1 fully passed the L test for resiliency at all distances. The top 1% network for Model 1 passed at all distances except for the first few kilometres, so it recorded as a partial pass. The raw results of each are included in the supplementary materials.

Another question that we want to analyse is if these transit areas have also visual relations with the sites. A positive confirmation would suggest that megaliths functioned, to some extent, as landmarks, as theorised. If so, are the sites strategically situated in the most visible areas of the landscape when viewed from these paths?

To address this question, we initially extracted the visibility values (the raster file is available in the supplementary material) and compared the resulting trend with 999 Monte Carlo simulations. These simulations utilised an equivalent number of points spread across the study area (Figure 7A). Additionally, we conducted a cumulative viewshed analysis from the pathways (thresholded to the top 10% cut-off), as using the entire network again became unmanageable. We employed the QGIS plugin 'Visibility Analysis' created by Z. Cuckovic (http://www.zoran-cuckovic.from.hr/QGIS-visibility-analysis/). In technical terms, we calculated a cumulative viewshed analysis using 6,459,029 observer points taken from the routes (Figure 7B), using 1km as the maximum viewshed distance.

From Figure 7, we observe that megaliths are not situated in the most visible parts of the landscape, whether considering the general cumulative viewshed approach (representing the background) or using the routes as observers. Instead, they are positioned in areas with medium visibility levels, indicating that other parts of the landscape offer higher visibility. This observation extends to the visibility from transit routes. However, this does not diminish the importance of that locational criteria. The trend depicted by the monuments in both Monte Carlo simulations (Figure 7A, below) suggests that the viewsheds of megaliths differ from those of

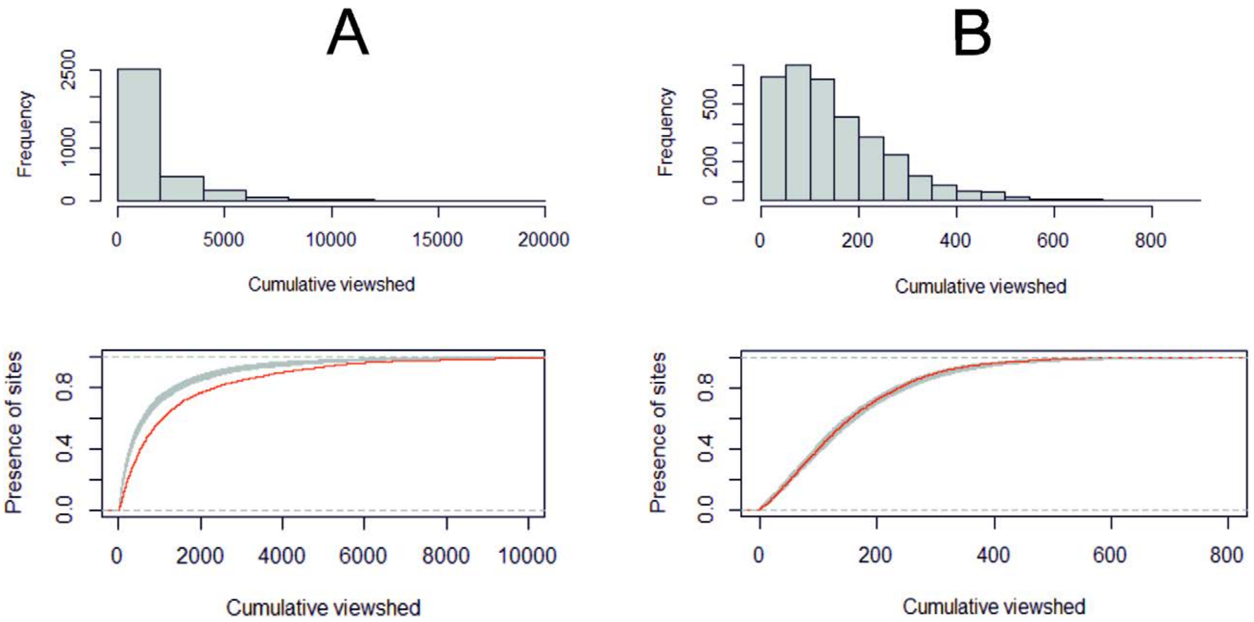

Figure 7. A. Histogram with site's values (up) and Monte Carlo Simulation (down) for the regularly-spaced grid cumulative viewshed approach. B. Histogram with site's values (up) and Monte Carlo Simulation (down) for the cumulative viewsheds with the pathways as observers.

the random background population. As highlighted in other research (see Carrero-Pazos 2021), it is plausible to conclude that the visibility is a significant locational factor, especially when considering sites with restricted views.

Discussion

The implementation of the FETE models in this study represents a significant advancement in our understanding of the spatial role of megalithic monuments and their relationship with natural transit routes in Galicia. By employing a quantitative approach, we contribute to a body of research which is exploring how prehistoric societies interacted with their regional landscapes. The integration of movement studies into archaeological research offers a robust framework for examining the human behaviour in relation to environmental factors. In the context of megalithic monuments, understanding how people moved through the landscape can illuminate the social and cultural significance of the underlying social structures. This study has focused on least-cost paths to provide a tangible means of exploring how megalithic sites were built in relation to natural transit routes, suggesting that the sites were not merely isolated markers but strategically positioned to facilitate movement and communication among communities.

The FETE models allowed us to create, for the first time, the most detailed network of natural transit (least coast path density) in Galicia. A simple density analysis indicates those areas which present high traffic natural routes (high frequency) versus those with low frequency (Figure 8).

Following the works of A. Bevan (*et al.* 2013; Bevan 2020), we further inspected this by comparing the location of the 3305 megaliths with 999 random samples (each one composed by 3305 points) spread across the entire study area, in order to build a 95% confidence envelope. The results, depicted in Figure 8 (graphs), reveal that the positioning of megalithic monuments deviates from randomness. Although not absolute, it is evident that there is a discernible correlation between megaliths and areas that guide the pedestrian movement through the landscape. While a broad view (e.g. map in Figure 8A) may suggest that a significant number of monuments are not situated in potential transit areas, a closer examination reveals that many of them form linear concentrations precisely along transit routes (Figure 9). Unlike previous methods that often relied on simple proximity measures, our approach utilises a network analysis framework to assess the role of megaliths within broader landscape dynamics. This methodology is consistent with contemporary research trends in archaeological science, which emphasise the importance of spatial analysis and modelling to understand ancient human behaviour (see e.g. Lewis 2024).

The non-random distribution of megalithic sites suggests a conscious effort by Neolithic societies to integrate these structures into their daily life and movement patterns. The evidence indicating that

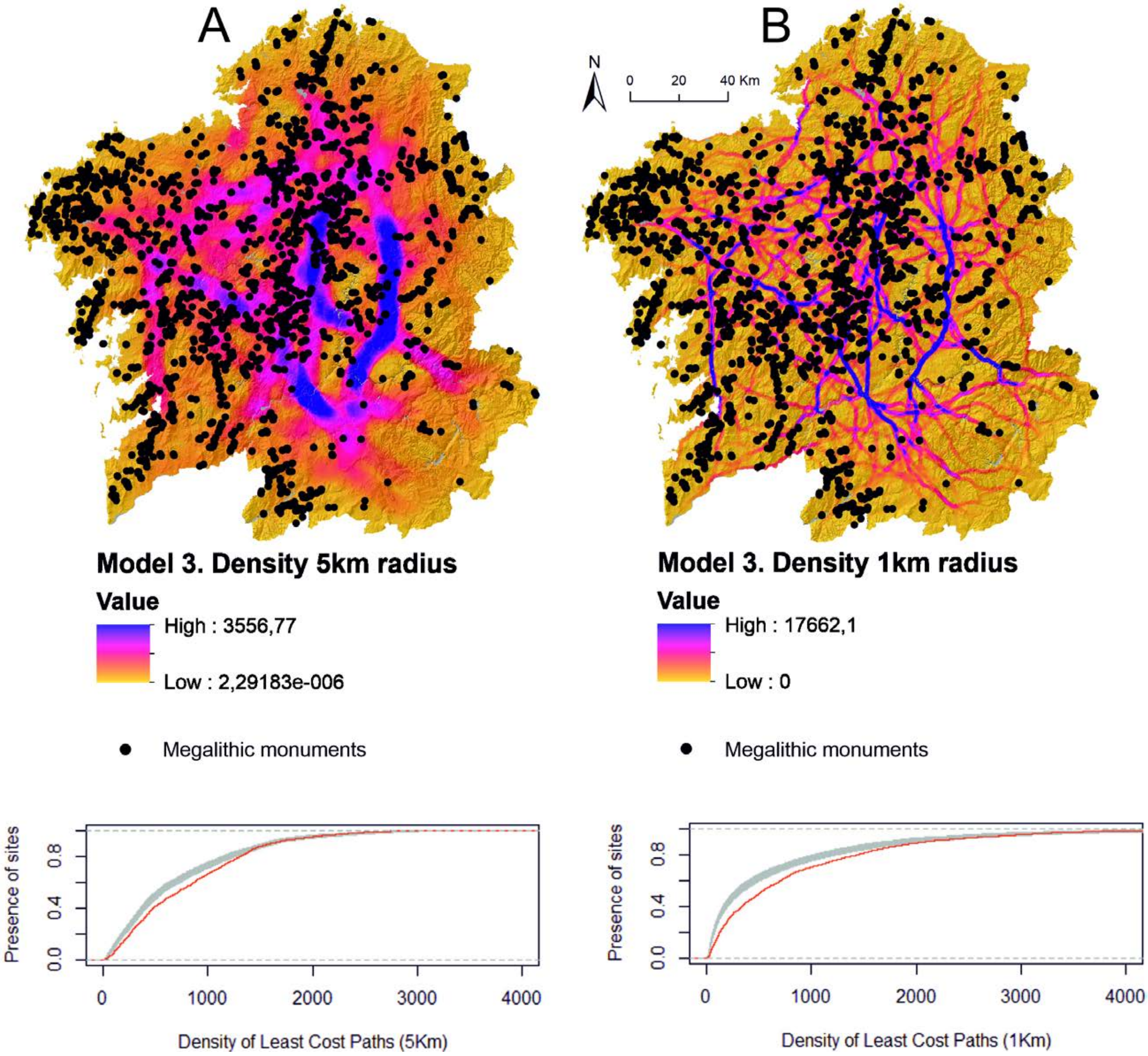

Figure 8. Density of the generated Least-Cost Paths (full network, model 3), and Monte Carlo Simulation for conditional random simulation (results reduced to 4000 cells for visualisation purposes).
A: Density calculated with 5km radius; B: Density calculated with 1km radius.

megaliths are located along high-density transit routes implies that these monuments played a vital role in the social landscape, possibly serving as focal points for community gatherings, rituals, and the delineation of territories. This perspective enhances our understanding of megaliths as not just funerary sites but as vital components of a larger social network.

Comparative visibility analyses help reinforcing this idea. The observed tendency for monuments to be located in areas with medium visibility—rather than high visibility—suggests that these structures may not have aimed to visually dominate the landscape. Instead, they may have been intended to serve as more nuanced markers of transit routes, allowing visibility only from specific vantage points or routes, reinforcing their presence to those traversing particular paths rather than the entire region. This finding would suggest a more nuanced visibility framework, where megalithic monuments could be strategically placed to control or demarcate specific areas without necessarily aiming to stand out prominently across the entire landscape, as stated for specific areas (e.g. Carrero-Pazos 2021). This selective placement may have served to reinforce social identities and facilitate the communication between groups, ideas that have been also suggested in regional approaches (see e.g. Eguileta Franco 1999).

All this raise questions about the role of megaliths in cultural memory and the formation of social identities, suggesting that these structures may have acted as social markers (Renfrew 1976), guiding both physical and cultural movement across the landscape. Moreover, the clustering tests, particularly the Kolmogorov-

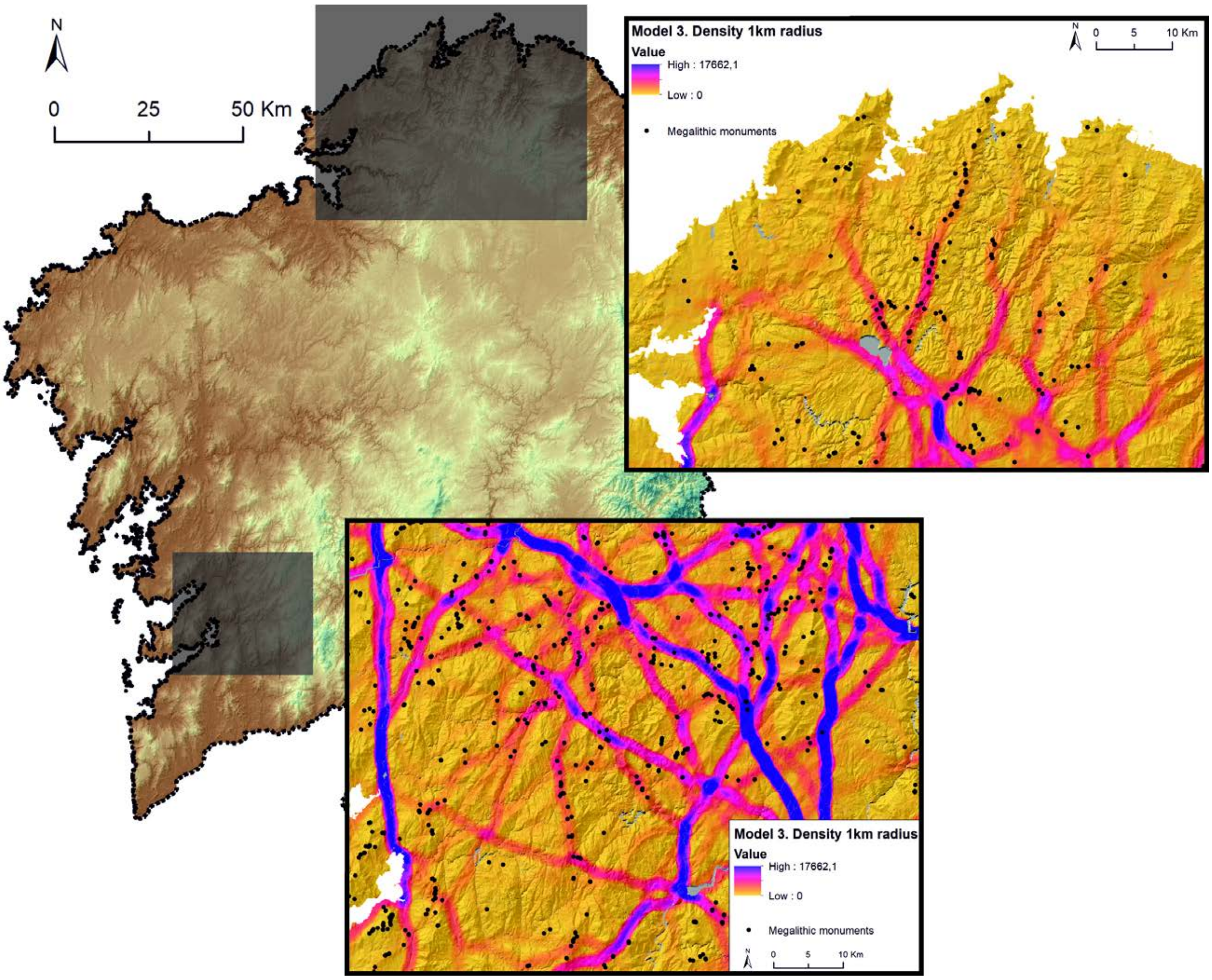

Figure 9. Closer looks to examine the location of megaliths in areas of traffic density.

Smirnov (K-S) and Besag's L-function, confirm the significance of natural transit paths in the spatial distribution of megalithic sites. The K-S test results indicate that the arrangement of megaliths does not match a pattern of complete spatial randomness, while the L-function shows clustering across multiple spatial scales, affirming the durability of this spatial relationship. This result implies a robust connection between the megalithic placement areas and the transit routes, possibly suggesting that the monument construction was influenced by not only accessibility but also by the need to reinforce certain social pathways or boundaries. Such interpretations align with the views of e.g. P. Murrieta-Flores (2012a, b) for similar areas in the south of the Iberian Peninsula, who argue that megalithic monuments often marked significant places in landscapes shaped by the movement.

Conclusions

In historical terms, the megalithic monuments interact with a humanised natural landscape from the moment architecture arises, with natural conditions actively shaping the choices of Neolithic societies, especially in selecting specific sites for tombs. The natural spaces transform into monumental and, consequently, social entities with visual interactions extending to their immediate surroundings. These interactions are linked not only to the tombs themselves but also to mobility across the territory.

While it is widely acknowledged that megalithic monuments had functions beyond funerary purposes, such as marking communal land possession or acting as territorial milestones in Neolithic landscapes, contemporary computational approaches provide an opportunity to revisit these ideas more formally and quantitatively.

This paper has examined the significance of proximity to natural routes as a locational factor for megaliths in Galicia. Similar importance of this locational factor has been observed in other Iberian and European regions (e.g. Andrés Ruperez 1999; Cabras 2018; Carrero-Pazos 2021; López Plaza 2000; Murrieta-Flores 2012a, b; Murrieta-Flores *et al.* 2014). However, this paper, for the first time, quantitatively assesses this relationship with more than 3,000 sites in a region spanning over 30,000km^2. This suggests that the connection of megalithic sites with natural transit through the landscape, whether understood from a local or regional perspective, may be a common feature in broader contexts, such as the Atlantic façade of Europe. The presence of a shared spatial pattern along the Atlantic façade hints at the potential of an overarching cultural strategy across distant regions. The structural similarity of the landscape use in Galicia to patterns observed in other areas, such as the southern part of Iberia, suggests that the megalithic sites may have been part of a larger network of symbolic or territorial markers in the Neolithic. This shared locational strategy could reflect a broader cultural phenomenon where the monument location was something intended to manage not only immediate social territories but also a broader landscape control. Such a perspective opens avenues for future studies to explore this concept of a 'transit-oriented' spatial strategy across the European megalithic landscapes.

This research has enhanced our understanding of megalithic landscapes in the broader Atlantic context and highlights the importance of natural routes in shaping spatial practices in the Neolithic. While further studies are needed to extend these findings, this approach provides a model for quantitatively assessing the relationship between ancient monuments and natural transit networks. The big scope adopted in this paper offers a promising context for researching the underlying social and spatial logics that governed the megalithic placement in prehistoric Europe.

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Supplementary material and replicability

The data used in this paper is available in a *Zenodo* public repository (https://zenodo.org/records/14036933; https://doi.org/10.5281/zenodo.14036933). We emphasise that the data is released under the CC-BY4.0 license, and we are sharing the FETE extracted routes for the models defined in this work in shapefile format. These pedestrian models have significant potential for reuse in other archaeological studies in Galicia. The baseline methodology for FETE is not reproducible in this paper, but it can be accessed through the paper by White and Barber (2012), with additional modifications applied in Crabtree *et al.* (2021) (see https://github.com/dawhite/sfa). We refer the reader to those papers for a detailed explanation of the FETE methodology used here. The code for reproducing the K-S and L tests can also be accessed in the GitHub public repository: https://github.com/dawhite/sfa.

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Shining a light on some of the most interesting research results on megalithic cultures, as well as their contemporaries, these 16 papers from the European Megalithic Studies Group symposium (Santiago de Compostela, Spain), cover monuments from Scandinavia, moving down the Atlantic Facade, across to Ireland, and then back to the Western Mediterranean. Key issues under discussion include temporality and mobility (both at the broad scale and at the local scale), social organisation and settings, and external relationships. The methods used to investigate these themes are various: bio-molecular and isotopic analyses, typo-chronology, targeted excavations and radiocarbon dating, material cultural analyses, 3D models, ceremonial and funerary/burial practices (including osteometrics), and large-scale prospection. New methods researching the materiality and symbolism of monuments are also presented; some incorporate the role of the natural world. Alongside them are other contributions focusing on the key characteristic of megalithic monuments – the skilful and purposeful arrangement of large blocks of stone – and their interpretation. Discoveries include the intriguing return of large and complex ceremonial timber circles in active megalithic areas, presenting a significant contrast to what was considered the main funerary expressions in South Portugal. Ultimately, through the application of new, or differently applied, technologies and ways of thinking, this volume offers a series of studies that remove some of the mystery that surrounds these mementos of another time.

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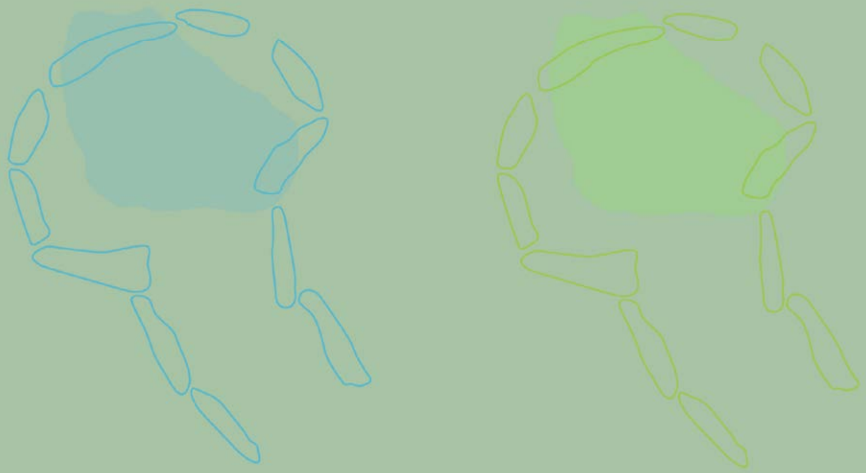

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