Title: A spatial connectivity approach to landscapes of conflict: Julius Caesar and the assault to Puig Ciutat (NE Iberian Peninsula)

Authors:

- Xavier Rubio-Campillo – Universitat de Barcelona, Department de Didàctiques Aplicades, Barcelona, Spain / University of Edinburgh, School of History, Classics and Archaeology, Edinburgh, UK (corresponding: xrubio@ub.edu). ORCID: 0000-0003-4428-4335
- Eduard Ble – Universitat de Barcelona, Departament d'Història i Arqueologia, Barcelona, Spain (eble@ub.edu). ORCID: 0000-0002-2931-0454
- Àngels Pujol – GIRA Association, Oristà (Barcelona), Spain (angelspcamps@hotmail.com)
- Roger Sala – SOT Archaeological Prospection, Spain (roger_sala_bar@yahoo.es)
- Robert Tamba – GIRA Association, Oristà (Barcelona), Spain (roberttamba@riseup.net). ORCID: 0000-0001-5896-4492

Abstract

Landscape plays a vital role in the development of military campaigns through the definition of geostrategic landmarks that structure the control of the territory, the imposition of constraints to the movement of armies, and the identification of positions that facilitate defensive tactics against aggressors. These factors are linked to the study of past spatial mobility which is typically performed using Least-Cost Path analysis (LCP). LCP identifies the optimal route that connects any two given points based on minimizing the accumulated cost based on a friction surface map, thus allowing archaeologists to identify the most efficient pathways across a territory. The main challenge of LCP analysis for archaeological regions is that optimal pathways are not well suited to define general mobility patterns within highly uncertain scenarios.

Connectivity modelling based on Circuit Theory (CT) is an alternative approach to the study of mobility. CT does not generate a single path like LCP does; it captures the connectivity of an entire region identifying not only optimal paths, but also bottlenecks, dead-ends and any other spatial feature that may impact movement.

We present here a framework to study landscapes of conflict using connectivity modelling; the framework combines CT, visibility analysis and statistical hypothesis testing to understand the reasons behind the assault and destruction of Puig Ciutat (NE Iberian Peninsula) during Julius Caesar's civil war. Results suggest that the site exerted decisive control over a highly connected area linking two possible logistical bases (Emporion and Massalia) to the armies fighting at Ilerda (49 BC).

Keywords

Conflict archaeology, landscape archaeology, spatial analysis, Julius Caesar, computational archaeology, Ilerda

Declarations

• **Funding**

XRC is funded by the Ramón y Cajal programme RYC2018-024050-I (Fondo Social Europeo – Agencia Estatal de Investigación).

• **Conflicts of interest/Competing interests**

The authors have no competing interests to declare.

• **Availability of data and material**

Dataset is available as Open Data as: Rubio-Campillo, Xavier (2021): Connectivity Modelling Dataset - Puig Ciutat assault. figshare. Dataset. <https://doi.org/10.6084/m9.figshare.14995245.v2>

• **Code availability**

Source code is available as open source from: <https://github.com/xrubio/puigCiutatConnectivity>.

- **Authors' contributions**

Research was conceived by all coauthors. XRC performed the analysis. XRC, RT and AP wrote the paper.

Acknowledgements

The Digital Elevation Model was based on the Global Digital Elevation Model v3 dataset (NASA/METI/AIST/Japan Spacesystems And U.S./Japan ASTER Science Team, 2019). Connectivity modelling was performed using Circuitscape (Anantharaman et al., 2020); further spatial analysis and cartography were performed with QGIS (QGIS Development Team, 2021) and data visualizations were created with R (R Core Team, 2020) and ggplot2 (Wickham, 2016). All source and data is openly available under open licenses. The authors would like to thank everyone that has participated in the archaeological project of Puig Ciutat and Francesc Xavier Hernández for discussions on preliminary results.

1 Introduction

The study of violent conflict through material culture has received a growing interest from archaeological research during the last two decades (Bleed & Scott, 2011; Pollard & Banks, 2005). Conflict archaeology studies the origin, development and consequences of warfare mainly focused on direct engagements such as pitched battles and sieges (Foard et al., 2003; Scott & McFeaters, 2011). Recent works are widening the perspective of the field by integrating additional conflict-related sites and activities such as logistical infrastructures (Tunwell et al., 2015), heritage and memory (Hernández-Cardona et al., 2019), aerial bombings (Moshenska, 2009) or repression events (Jerez Farrán & Amago, 2010).

A common trait of conflict archaeology is a primary focus on historical periods as opposed to the large majority of archaeological research. This trend is explained by the fact that written accounts and other historical sources (photography, cartography, oral memory) are often needed to locate a conflict-related site because the material culture that define a battlefield is difficult to detect without further proxies. This is particularly true for direct engagements; pitched battles seldom generate any kind of structure and the archaeological evidence that can be recovered is composed by small metallic artefacts collected through field surveys using metal detectors (Foard et al., 2003).

Sieges and assaults to fortifications are more easily identified because these violent episodes are linked to settlements and other sites with structures (e.g. walls, forts, pillboxes); even in these cases archaeological work will need support from written accounts because a lack of additional sources inhibits a robust interpretation of the collected evidence: who were the attackers and the defenders? Why was the place attacked? How did the siege develop? Did it succeed? For example, a modern-era European siege is a highly complex event involving thousands of soldiers, trenches, large artillery trains and often civilian population, thus generating a wealth of archaeological, textual, and cartographical evidence with a high degree of detail that allows to track casualties and activities at a daily level (Rubio-Campillo et al., 2015). In contrast, this information is unavailable for prehistorical warfare or historical events that were not considered relevant enough to be mentioned in a written source. As a consequence, the interpretation of conflict-related material culture found on a site is extremely challenging if there are no additional sources of evidence linked to the examined event.

One possible option is to explore to what extent the landscape where a battle took place can provide information on the event (Carman & Carman, 2006). First, the decisions of fighting at a specific location was often explained by the territory as commanders struggled to control key geostrategic locations during a military campaign. Second, the deployment of an army to confront an enemy takes several hours and for this reason the location where a pre-contemporary battle happened was agreed by both sides except for ambushes or small scale skirmishes. Finally, landscape always plays a key role on any violent event by providing defensive positions, generating visual control and mediating the movement of soldiers. As a consequence, a multiscale approach to landscapes of conflict may be useful to strengthen the interpretation of archaeological evidence of violent events without support from other sources (Nolan, 2009; Rubio-Campillo, 2008).

Spatial analysis offers a toolkit of methods to explore landscape, being the most useful concepts for conflict a) visibility, and b) mobility (see examples in Canosa-Betés, 2016; Murphy et al., 2018; Rubio-Campillo & Hernández, 2015; Sivilich & Sivilich, 2015). Visual control is an essential trait of warfare because armies need constant updates on the position, size and intention of opponents as a means to avoid ambushes while maximising their geographical advantage in case of engagement. The most common approach to visual control is viewshed analysis; this technique quantifies to what extent a location is able to "see" its surroundings (Wheatley, 1995). Conflict archaeology uses techniques such as cumulative viewshed analysis (i.e. combining visibility from multiple locations) and intervisibility analysis (i.e. defining networks of visibility between locations) to identify visual cues that may explain the effectiveness of multiple defensive positions or the visual control from the locations where commanders followed the engagement. A distinctive idea for the use of viewshed analysis within conflict scenarios is that visual control is always subjective and depends on two actors (i.e. both armies); visual control of a battlefield is necessarily linked to the most probable paths

taken by the enemy. There is no point on controlling an entire area where the enemy will never move because a) it is already controlled by friendly units or b) the landscape inhibits movement of military forces. For this reason, visibility analysis of conflict landscapes needs to be integrated with additional parameters if the approach wants to be useful for interpretative activities.

The study of mobility is even more complex than visibility because movement needs to take into account multiple scales beyond the local perspective while the latter is strictly limited by the distance that can actually be observed which will never go beyond a few kilometers (see this diversity in Güimil-Fariña & Parcero-Oubiña, 2015; Murrieta-Flores, 2012; Yubero-Gómez et al., 2015). At a large scale, mobility analysis allows us to understand the challenges of marching large military forces of thousands of soldiers across a region as well as their logistic needs: draught animals, cattle, food and water, and even groups of accompanying civilians. At a small scale, mobility is useful to explore the path followed by the opponents and the way landscape was used to hinder attacks through the choice of optimal defensive positions. The most common tool to assess mobility in archaeological contexts is Least-Cost-Path (LCP) analysis (Verhagen et al., 2019). This technique estimates the optimal route between two given points across a surface of costs that needs to be navigated to move from an origin to a destination. While useful, the optimality of LCP makes the approach open to critique due to the inherent uncertainty of the archaeological record and it may generate weak results where costs are difficult to assess or optimality is not desirable (Herzog, 2014; Supernant, 2017). For example, large pre-contemporary armies split their forces across multiple routes to simplify the logistical challenges of supplying thousands of humans concentrated within a small area. Additionally, the threat posed by the enemy activity may radically change the perception of costs for different paths because the optimal path may be prone to ambushes in narrow passes or it could leave enemy garrisons at the rearguard of the main body, thus putting in danger the umbilical cord linking an army with its supply source.

The use of spatial analysis combining mobility and visibility could help us strengthen our study of conflict sites not present in historical accounts through two main questions: a) why there was a battle at a specific region?, and b) to what extent the choice of battlefield can be explained by its geographical features? However, as mentioned before we would need to integrate the specific dynamics of conflict as opposed to other human activities if we want to develop an effective analytical framework. We present here a novel multiscale analysis to landscapes of conflict used to contextualise a military engagement with very scarce written accounts. The approach is applied to the case study of Puig Ciutat (region of Catalonia, NE Spain) where a Roman army assaulted and destroyed a Roman garrison during the opening movies of Julius Caesar's civil war and probably linked to the campaign of Ilerda (49 BC). The method offers a combined study of visibility and mobility by replacing traditional LCP analysis with a more suitable approach to mobility in the face of uncertainty known as Circuit Theory connectivity (CT).

Next section presents the archaeological site of Puig Ciutat and the challenges posed by a lack of written accounts describing the assault at this location. This is followed by the definition of the materials and methods used in the analysis with an emphasis on the CT algorithm. Section four presents the results of the different analysis while section five discusses these results in the context of the original research objectives. The paper concludes with a summary of the potentials and limitations of this methodology not only for conflict archaeology but also for the general study of archaeological landscapes.

2 Julius Caesar and the assault to Puig Ciutat

The archaeological site of Puig Ciutat (catalan for "*city on the hill*") is located in the area of Lluçanès, 60 km north of Barcelona (NE Spain). The site was already identified in the early 1980s but archaeological works did not start until 21st century. In 2006 a systematic geophysics survey revealed a large urban grid; since 2010 yearly fieldwork activities are being developed to unearth the site (Garcia et al., 2010; Padrós Gómez et al., 2019; Pujol et al., 2019).

Puig Ciutat occupies a 5-hectares plateau at a meander of the Gavarresa river. The main part of the perimeter is formed by steep cliffs except for two areas (E and SW) where walls were built to enclose the plateau; the Eastern section of the defensive wall was partly described by the excavation campaigns

undergone between 2010 and 2014 while the South-Western section was located in a trench excavated during the 2017 summer campaign (see **Figure 1**).

Figure 1: The area covered by the Puig Ciutat site. Excavated buildings are displayed in black while evidence of walls are shown in red

Early geophysics surveys (e.g. Ground Penetrating Radar and magnetic) revealed a complex urban grid affected by widespread fires which were later confirmed by excavations. Both stratigraphy and recovered artefacts suggest that the plateau held an Iberian settlement that was later occupied by a Roman military garrison as a praesidium or castellum (Padrós Gómez et al., 2019). This garrison was assaulted and destroyed by an unknown Roman force as supported by several lines of evidence: a) widespread fires covering the entire final phase of the site, b) a large amount of intact artefacts found in several rooms (e.g. amphorae, tableware, game sets), c) complete cattle and dog remains in anatomic connection, d) human remains in anatomic connection under a collapsed roof, and e) a wide range of Roman military weaponry and equipment (e.g. catapult bolts, slingshots, sandal hobnails, a *pilum* and a *pugio*) found both inside and outside the site's perimeter (Ble Gimeno, 2016, pp. 107–109). The analysis of pottery typologies found at the site suggest that the most probable date of destruction is mid-1st century BC (Padrós et al., 2012); the combination of conflict evidence and the narrow dating indicate that the assault is linked to the early phases of Julius Caesar's civil war and particularly the Ilerda campaign (49 BC).

The Ilerda campaign saw two major armies manoeuvring around the present-day city of Lleida and the lower course of the Ebro river; one was commanded by Julius Caesar while the Pompeian opponent army was led by two legates (Lucius Afranius and Marcus Petreius). The campaign developed at the same time that the Caerian siege of Massalia (present-day Marseille, France); the outcome of these two simultaneous campaigns would determine the control of the Western Mediterranean. At Ilerda both opponents struggled to outmanoeuvre the other army and block its lines of communication and logistics. The written sources

narrating these events as a generalized struggle around Ilerda between Iberian groups gradually shifting supports from Pompeius towards Caesar. The Ilerda campaign concluded without any large engagement as the Caesarian legions managed to isolate the entire Pompeian force, thus forcing its surrender due to the lack of supplies.

The written sources that cover the Ilerda campaign do not mention any assault that could be even directly linked to the conflict event identified at Puig Ciutat. More generally, this identification of violent episodes not covered by written sources is common in conflict archaeology; it generates several interpretative challenges on the causes of these events, on the identity of the opponents, and on the collected archaeological evidence. We focus here on exploring the role played by Puig Ciutat within the Ilerda campaign: was Puig Ciutat a key strategic location to control NW Hispania? Was this military garrison controlling a supply path to Ilerda? Why did a Roman army defend this location against another Roman army? These questions move beyond the site itself because they require additional tools able to analyse the conflict event from a larger perspective.

3 Materials and Methods

3.1 Study region

The area where the Ilerda campaign developed is located around the current city of Lleida (Catalonia), but written sources mention several skirmishes across a larger triangular region defined by the Ebro river, the Pyrenees and the Catalan coast. The study region has been defined by a 100-km buffer beyond this triangle to avoid potential edge-effects bias to planned spatial analysis (see **Figure 2**).

Figure 2: Map of the Western Mediterranean outlining the study region (red area). Five landmarks are also highlighted: Ilerda, Massalia, Puig Ciutat and the two main harbours of the Catalan coast at the time of the Caesarian civil war (Emporion and Tarraco).

A 30 m. resolution Digital Elevation Model (DEM) for this archaeological region was acquired from the current ASTER Global Digital Elevation Model (NASA/METI/AIST/Japan Spacesystems And U.S./Japan ASTER Science Team, 2019). The DEM was then edited to align the Ebro river delta and the Narbonne plain to the

coastline during the Roman period. These modifications were made to improve the accuracy of the topography, but it is worth mentioning that changes in the coastline would not have significant impact on the outcome because both Ilerda and Puig Ciutat were far from the Mediterranean coast. The final DEM was resampled at a 100m. resolution which was deemed high enough to develop large-scale analysis based on previous works in the area while optimizing computational requirements: it generated a raster map of 3840x3677 pixels (see **Figure 3**).

The large size of both armies (at least 40.000 soldiers each) suggested that any spatial analysis should take into account areas instead of specific points of interest; we used this approach to define the region where the two main armies were deployed near Ilerda. It can also be observed that the city of Massalia is far from our study region; the Caesarian force was connected to the besiegers deployed there, so it was decided to define an area of interest covering the path of any road to Massalia (i.e. the current French coast between Montpellier and Béziers); any supply route moving from Massalia to Ilerda would certainly move through the region before crossing the Pyrenees mountain range.

Two additional key locations to consider are the main harbours of the region during this period: Emporion and Tarraco. Emporion (literally market) was a Greek colony founded by the same people that created Massalia (i.e. Phocaeans) and this common origin may suggest that Emporion was probably supporting Pompeius. On the other hand, Tarraco was the earliest Roman settlement in the Iberian Peninsula and its harbour supplied Roman military forces in the region since the Second Punic War. The political position of Tarraco in the civil conflict is difficult to infer but the city probably supported Julius Caesar given the alliances of the Iberian groups living near it.

Figure 3: DEM of the study region highlighting the 4 areas of interest for connectivity purposes: Ilerda, the route to Massalia and the harbours of Emporion and Tarraco. The map also shows in red the perimeter of the region defined for local analysis.

Some research questions focused on the local prominence of Puig Ciutat and for this reason they required a narrower focus. This local region was defined as a 30-km buffer around Puig Ciutat (i.e. the maximum daily

march distance for a Roman military unit). This perimeter covered all the pathways across the region while discarding any mountainous not suitable for military operations as seen in **Figure 4**. This second DEM kept the 30m. resolution used by the original dataset and generated a raster map of 2485x1594 pixels.

Figure 4: Digital Elevation Model for the local study region. The area is characterized by uneven terrain populated by several small hills and river valleys. There are two main pathways: the Vic plain (eastern North-South plateau) and the East-West southern corridor that was used to build a road during the 20th century (identified as C-25).

3.2 Computational approaches to spatial mobility

Current spatial analysis methods offer a diversity of techniques to explore mobility. Present-day movement patterns are commonly studied through graph networks composed by nodes (i.e. cities) and edges connecting them (i.e. roads). While useful, this approach is difficult to apply to study the mobility dynamics of archaeological regions due to inherent uncertainties on the location, dating and even existence of settlements and pathways. The most common alternative to network analysis is offered by Least-Cost Path (LCP) analysis (Conolly & Lake, 2006, pp. 252–255). LCP does not require data for roads or nodes because it is based on a cost surface map defined by the researcher combining variables that may hinder movement (e.g. slope, ruggedness indexes, etc.); LCP uses this cost surface to compute the optimal route that connects any two given points based on its minimal accumulated cost.

One of the challenges of LCP analysis is that the optimality of its pathways are not well suited to study the general mobility of a region because the basic algorithm can only identify one single optimal path between two points. Some variations introduce stochastic processes to add more flexibility to the method (Palmer et al., 2011), but the fact remains that LCP was not designed for the task of analysing regional connectivity at a broader scale because of the assumption of optimality. A possible solution is the analysis of natural corridors:

a set of random points are defined at the perimeter of the archaeological region and then LCP is computed for each possible set of pairs. The final step is to quantify the density of optimal pathways at each cell of the map, thus generating a connectivity map for the region (Murrieta-Flores, 2012; Yubero-Gómez et al., 2015). This approach allows archaeologists to identify the most important pathways independently of the archaeological data, but it still is limited by the optimality of the paths. For example, imagine a location crossed by several suboptimal paths towards the rest of a region; none of the optimal paths will move through this location, even if intuitively we may argue that the spot should have a high connectivity value because it would be an important crossroad for multiple secondary routes. In addition, if the optimal path is not available for any reason (e.g. snow) then the analysis will have to be recreated with a different cost surface map instead of just identifying alternative suboptimal paths.

Connectivity modelling is an alternate approach to spatial connectivity modelling that is widely used in ecological research (McRae et al., 2008). Spatial connectivity is understood as the degree of interaction between areas of a given region; it can be quantified as the chances that an individual moving between two areas will visit any location within a delimited region. A popular approach to connectivity is Circuit Theory modelling (CT) which uses the metaphor of voltage-current relationships to explore the intensity of spatial interactions. The algorithm does not generate a single path like LCP does and for this reason it seems better suited to identify key mobility landmarks, bottlenecks, crossroads and secondary routes because it does not seek optimality. In ecology, the versatility of CT is useful for policy making on wildlife conservation management because it generates an overview of connectivity beyond specific locations (Dickson et al., 2019); it can be argued that this very same versatility should make CT the preferred choice for archaeological studies in regional mobility due to the high uncertainty inherent to past mobility dynamics. In fact, CT has been applied to a number of archaeological case studies (Domingo Ribas, 2018; Howey, 2011; Thayn et al., 2016). The promising results of these works suggest that CT modelling can strengthen traditional LCP-based mobility analysis of past societies thanks to its broader perspective on the connectivity of archaeological regions.

CT analysis requires three main elements: a) sources of energy, b) destinations attracting this energy and c) friction costs of movement between locations. The algorithm simulates a flow of energy moving from the sources towards the destinations, and quantifies the amount of this energy that crosses each area of the region (i.e. every single raster map cell); highly connected spots channelling a large amount of the produced energy will have higher connectivity values while the areas with low values of energy (i.e. cul-de-sacs) will be defined as spatial clusters of low values. CT models have limitations, as any other research tool. The most important issue for archaeological studies is that the output is most useful as a comparative tool within the region; it will allow the researcher to establish areas of higher and lower connectivity, but the outcome is hardly translatable to time or energy. As a consequence, it would be difficult to define absolute values of travel cost or to compare the CT results among multiple different regions.

3.3 Definition of mobility costs

The identification of origin and destination areas is straightforward because it will be decided by each specific hypothesis to assess, but the friction costs also need to be quantified to perform CT analysis. The cost of mobility for this case study has been modelled after the limitations faced by the logistical system of Roman armies. In the absence of maritime and/or riverine transport, food, water, weapons, and the other supplies required by armies were moved by porters, pack-animals and animal-drawn carts such as mules, horses and cattle (Roth, 1999, pp. 198–222). This logistic system was heavily challenged by any terrain beyond roads and plains and for this reason friction costs were derived from slope values. A slope map was computed based on the existing DEM model and then reclassified as seen in **Table 1**; this reclassification heavily penalizes slopes higher than 10 degrees that would render unfeasible the march of large military forces comprising thousands of soldiers, horses, mules and carts.

Slope value (degrees)	Cost
<1°	1
1°-3°	2
3°-5°	3
5°-10°	5
10°-15°	10
15°-30°	15
30°-45°	30
>45°	100

Table 1: reclassification of slope values to mobility costs

Figure 5 shows the cost surface map for the entire region under study. Any N-S path from Massalia to Ilerda is dominated by the Pyrenees mountain range while mobility from the main harbours to the area where both armies were deployed is also spotted with smaller mountain ranges with moderate friction values.

Figure 5: surface cost map for the theatre of operations reclassified from slope values

3.4 Identification of strategic paths

The first research question is aimed at exploring to what extent Puig Ciutat was able to control a natural pathway across the study region. Natural pathways can be defined as the most probable routes to be used for someone moving across a region (Murrieta-Flores, 2012). These routes play a key role in geostrategic connectivity because they are often time-independent at a regional scale: the exact route may vary, but the topographic features that define them (e.g. mountain ranges and valleys) will not change at a human time-scale, thus indicating relevant regional pathways independently from specific phases or sites.

The algorithm used here to identify these natural routes is inspired by previous archaeological research that applied LCP and is defined as follows (based on Yubero-Gómez et al., 2015):

1. define a set of points over the boundaries of the region at regular intervals
2. compute the connectivity raster map using every pair of points as origin/destination and the created friction map
3. create an accumulated connectivity map by adding all connectivity maps produced by step 2

Distance between points was defined at 25 kilometres for a total of 61 points as can be seen in **Figure 6**. This point density was enough to identify the main natural corridors of the region under study while avoiding further computational costs caused by the exponential nature of algorithms performing pairwise calculations.

Figure 6: Boundary points used to identify natural routes displayed here over the surface cost map.

3.5 Tracing supply routes to Ilerda

The second question moved the focus from time-independent geostrategic routes towards the dynamics of the Ilerda campaign. We explored here if the attack to Puig Ciutat could be linked to the supply lines of the armies deployed at Ilerda. Three possible origins were identified for the logistical systems of both forces: the overland route to Massalia, and the harbours of Emporion and Tarraco.

Military control does not only rely on the deployment of garrisons at specific locations but more importantly on the zone of control that these garrisons may exert over the neighbouring territory (i.e. the area where they can identify and intercept enemies). CT models are particularly suited to explore this spatial control because the algorithm quantifies connectivity for each raster cell within a region, thus allowing us to assess whether the area around a point has a higher connectivity than expected. To perform this analysis three buffers around Puig Ciutat were defined at 5, 10, and 20 kilometers, being the rationale that 20 km is a reasonable average daily rate of march for military units since prehistory until twentieth century (Moore, 1960; Neumann, 1971). Effective control would decrease as the distance to the site increases and for this reason we added two smaller buffered areas for the sake of comparison.

For each of the three possible origins (route to Massalia, Emporion, and Tarraco) the following Monte Carlo method was applied to test for high connectivity around Puig Ciutat:

1. compute raster connectivity values from the logistic origin to the area of Ilerda
2. create three circular buffer zones with 5, 10 and 20 km. radius centered at Puig Ciutat
3. Generate four sets of random points with similar density based on a Poisson process (i.e. random spatial coordinates) delimited by: a) the entire region (100k points), b) 5 km. Buffer (1k points), c) 10 km. buffer (1k points) and d) 20 km. buffer (20k points) around Puig Ciutat (see **Figure 7**).
4. Sample the connectivity values from the raster map computed in step 1 for each random point created in step 3.
5. Use null hypothesis significance testing to reject the null hypothesis that the connectivity values within each buffer follow a similar distribution than the rest of the territory.

Figure 7: Example of random points generated by Poisson processes for the different datasets: the entire theatre of operations (white) and the 20 km. buffer around Puig Ciutat (blue). The origin and destination used for this connectivity analysis are color-coded (the origin of Emporion as yellow and the destination of Ilerda as red).

Step 5 used permutation test to assess to what extent the connectivity near Puig Ciutat was higher than it should be expected if the site was not playing a relevant role in the Ilerda campaign. The approach confronted the mean connectivity value within each given radius (5, 10 and 20 km) against 1000 same-sized samples from the Poisson process values; we defined the threshold of significance at the highest 1% quantile of their means. In other words, for each source we would assess if the mean value within the buffer was not higher than 99% of the mean values from the 1000 random sample; if this threshold was not achieved then the connectivity around Puig Ciutat would not be deemed as statistically significant.

3.6 The local dominance of Puig Ciutat

The last question of this work focuses on the local dominance of Puig Ciutat. Two intertwined factors need to be explored here: visibility and mobility. The basic approach to visual control is to compute the viewshed area as seen from the site, its centroid, or its perimeter (Canosa-Betés, 2016; Lake & Ortega, 2013; Murphy et al., 2018; Rubio-Campillo & Hernández, 2015). However, the amount of territory visually controlled by Puig Ciutat is not significant here because the garrison needed to watch over the logistics routes towards Ilerda. Visual control over distant mountain ranges and unconnected valleys would not accomplish much in terms of military control; as a consequence, the size of the viewshed observed from Puig Ciutat would not be a good proxy for visual dominance.

The approach developed here computes the visual control of highly connected areas (i.e. visual control of strategic routes) and it is also inspired by previous works using LCP (Canosa-Betés, 2016; Wilson-Daily et al., 2018). The method is defined by 3 processes; first, a connectivity map is calculated for the local region based on the work developed for the first question:

1. define a set of regularly spaced points covering the boundary of the local region around Puig Ciutat. The distance between points was defined at 5 km for a total of 44 points.

2. compute a raster map of connectivity between every pair of points
3. create an accumulated connectivity map by adding all connectivity maps produced by step 2

Second, viewshed analysis was used to assess the visual control from Puig Ciutat using Monte Carlo:

1. generate a sets of 100 random points inside the perimeter of Puig Ciutat
2. compute a binary viewshed from each point of step 1. The viewshed was performed at an added height of 3 meters over the DEM elevations to account for the existence of walls and watchtowers. The output will be a binary raster map where cells will have a value of 1 (i.e. it can be seen from the point) or 0 (i.e. it cannot be seen from the point). Maximum visibility distance was fixed at 10 km. because a larger distance would render control ineffective due to weather, vegetation and other unaccountable factors.
4. Create a combined visibility map by performing a logical AND operation on the 100 binary viewsheds computed at step 2. The result is a raster map where each cell has a value of 1 if it was observed by at least 1 point and a value of 0 if it was not observed by any point within Puig Ciutat.

Finally another Monte Carlo simulation similar to the one designed to answer the second question was used here to assess whether Puig Ciutat controlled areas with high connectivity values (either by distance or visibility):

1. generate three sets of 1000 random points based on Poisson processes: a) the entire region, b) visible points within 10 km of Puig Ciutat, and c) non-visible points within 10 km of Puig Ciutat
2. sample the connectivity values from the previously computer raster map for each random point of the three sets
3. use significance testing to quantify differences between the distribution of connectivity values amongst the three datasets

The boundaries for the region, the 10 km. buffer and the perimeter of the site can be seen in **Figure 8**.

Figure 8: Analysis of local dominance for Puig Ciutat. The red line defines the boundary of the local region while white points display the locations used to create the pairwise CT model. The shaded circle is the 10 km buffer around Puig Ciutat used to perform viewshed analysis

Step 3 used the non-parametric Kolmogorov-Smirnov test because it allows us to reject the null hypothesis that two distributions were generated by the same process (i.e. there is the same level of connectivity inside and outside Puig Ciutat's control).

It is worth noting that the final parameter values used for the three analysis were informed by a parameter space exploration designed to assess the sensibility of the algorithms to the different variables. Specifically, different reclassification tables were developed for the cost map, including a linear option and a plain-based friction model with heavy penalties to any slope higher than 5 degrees. Other explorations focused on the impact of larger buffer radius and the sample size of the Poisson processes. The results of this exploration of the parameter space is not presented here due to space but readers interested on the experiment design may use the open source code and datasets provided with this manuscript to explore the analysis at will. Ultimately, outcomes proved to be robust to changes on parameter values as natural pathways, logistic routes and statistical results were consistent across parameter values.

4 Results

We present here the results generated by the three analysis using the algorithms and parameters defined in the previous section.

4.1 Strategic paths

The CT model of natural pathways across the region can be seen in **Figure 9**; the colour gradient of the map has been defined to highlight regions with particularly low or high connectivity. It can be observed that the main natural pathway is a North-South corridor near the Mediterranean coast which would be used later to build the most important Roman road in Hispania: the Via Augusta (and the current AP-7 highway). A second highly connected areas extends on a West-East axis from the central coast towards Ilerda (covering the route of the current A-2 motorway).

Figure 9: cumulative current map for the theatre of operations. The colour gradient is divided in 10%, 25%, 50%, 75% and 90% quantiles; the same gradient of relative values has been applied to the rest of the connectivity maps to facilitate comparison

The lowest tail of the distribution of connectivity values is displayed at the Pyrenees. The area also shows a few highly connected passes which were also used to build past and current roads (from west to east: La Cerdanya, Coll d'Ares, and Coll del Pertús). These three mountain passes channel the energy flow across the Pyrenees and for this reason they have always been key geostrategic locations for any military conflict linked to the Pyrenees including Roman civil wars, modern conflicts between Spain and France or the Republican retreat at the end of the Spanish Civil War.

The map reveals that Puig Ciutat is not located near any natural pathway. There are a small number of highly connected clusters around this location, but they are not particularly relevant at this scale because they are isolated from both the main pathways and the Pyrenees corridors.

4.2 Supply routes to Ilerda

Results for the second analysis explored to what extent the assault could be linked to the control of supply lines as seen in **Figure 10**. Puig Ciutat does not seem to be located around the most highly connected areas, but significant differences appear between the distinct outputs generated from the three origins.

Figures 10a, 10b, 10c: cumulative current map to Ilerda from the three defined origins: a) the path to Massalia, b) Tarraco, and c) Emporion. All maps show the 20-km buffer around Puig Ciutat used for the algorithm

The path from Massalia to Emporion is constrained by the few possible passes of the Pyrenees. The energy flow as generated by the algorithm is spread over the three main passes. The eastern pass of Pertús shows a higher intensity due to its proximity to the coastal area and a wider corridor than the other passes. A smaller percentage of the flow crosses the other passes (Cerdanya and coll d'Ares) and moves near Puig Ciutat, thus suggesting that its garrison may exert a significant control over some of the secondary routes. The second output shows that easier terrain between Tarraco and Ilerda would make Puig Ciutat irrelevant as no supply line from Tarraco to Ilerda would remotely move near the site. Finally, the location of Puig Ciutat seems more relevant if the logistic source was the harbour of Emporion as explored by the third map. This output shows two routes moving from Emporion towards Ilerda: a) the North-South corridor linked to the Via Augusta and b) a network of secondary flows crossing the area controlled by Puig Ciutat on a East-West general direction.

The previous maps are complemented by **Figure 11**. The relative connectivity of the random points generated by the Poisson process (i.e. null hypothesis) is compared to the connectivity values sampled within 20km of Puig Ciutat using Monte Carlo methods.

Figure 11: Boxplot of connectivity values sampled from random points and points at 5, 10 and 20 km. from Puig Ciutat for the three origins

We cannot confidently reject the null-hypothesis for the Tarraco and Massalia scenarios because the area around Puig Ciutat does not exhibit significant higher connectivity values than the ones sampled from the Poisson process. In contrast, in the CT model with Emporion as origin the connectivity values around Puig Ciutat are much higher than the ones provided by the Poisson distribution. These results suggest that a supply base at Emporion would be the option where the attack on Puig Ciutat may be more justified by the logistical needs of the Ilerda campaign.

4.3 Puig Ciutat local control

The third set of results assesses the local prominence of Puig Ciutat. **Figure 12** portrays the cumulative current map generated by the CT model of natural routes. The sites does not seem to be located at a particularly connected area as compared to the N-S corridor traversing the eastern area or the E-W corridor at the southern border.

Figure 12: cumulative current map for the local region around Puig Ciutat. The map also displays in white the 10km. buffer used for viewshed analysis

The second component required by this analysis is the binary viewshed computed from points within the site's perimeter (see **Figure 13**). The outcome does not reveal a particularly exceptional viewshed from the assaulted site beyond the valleys adjacent to the plateau where it is located.

Figure 13: Binary viewshed analysis performed within a 10 km. buffer from Puig Ciutat

Three Monte Carlo simulations were ran to compare connectivity values between visible, non-visible and the baseline of a Poisson process (see **Figure 14**).

Figure 14: The Monte Carlo method required generating three random sets of points to sample the connectivity values for: a) points visible from Puig Ciutat within 10-km radius (blue), b) points not visible from Puig Ciutat within 10-km radius (red), and c) complete random points (white).

The distribution of connectivity values sampled for these three groups can be seen in **Figure 15**.

Figure 15: Density plot of cumulative current values samples from sampled points: a) points visible from Puig Ciutat within 10-km radius (blue), b) points not visible from Puig Ciutat within 10-km radius (red), and c) complete random points (white)

Kolmogorov-Smirnov was finally computed to complement this visualization with null-hypothesis significance testing. Results were adjusted for multiple hypothesis testing with Bonferroni correction and revealed statistically significant for the two groups within 10-km of Puig Ciutat versus the random points (p -value <0.001 for both tests) while the null hypotheses of identical distribution could not be rejected for visible vs non-visible points (p -value=1). The outcome indicates that the locations near Puig Ciutat had higher connectivity values than the average on the region independently of their visual control from the site.

5 Discussion

The result of these three analysis are interpreted here in the context of the assault to Puig Ciutat and its potential role within the Ilerda campaign. First, the CT model of natural routes suggest that the PC does not exert any geostrategic control over the key routes crossing the NE Iberian Peninsula. This negative result is strengthened by the fact that the area where the site is located (i.e. Lluçanès) has seldom been particularly relevant for other historical conflicts. The few cases where the region saw military operations are associated with asymmetric warfare where Catalan guerilla or light infantry units faced an invading army (Spanish or French). A good example of these dynamics is the epilogue of the War of the Spanish Succession (1713-1714). In this campaign a joint French-Spanish besieged Barcelona while a Catalan army commanded by the marquis de Poal moved across this territory to harass the lines of the communication of the invading army using specialized light infantry military units known as *miquelets* (see an example in Rubio-Campillo, 2008). Overall, this lack of geostrategic relevance of PC suggests that the importance of PC was linked to the Ilerda campaign.

The outcome of the second analysis reveals that PC could have exerted control over lines of communication from Ilerda to the coast and particularly to the Greek colony of Emporion. If this harbour was supplying one of the armies deployed at Ilerda then PC would have become a key location dominating a network of secondary routes crossing the region with a W-E direction; this location would be even more relevant if the enemy blocked the main communication route from the coast towards Ilerda that followed the Via Augusta and then turned towards the West. This scenario (i.e. one side controlling the main path and forcing the other one to rely on secondary routes) seems plausible due to the shifting alliances of the local population between both Roman military forces. These outputs can be combined with the information provided by the written account of Julius Caesar to argue that the garrison defending Puig Ciutat was part of the Pompeian army while the assaulting force was Caesarian; the rationale behind this is the fact that the Pompeian commanders sent

garrisons to protect the Pyrenees passes which were defeated by Caesar, thus granting him control of the northern area. The assault to Puig Ciutat fits this Caesarian decision to control the lines of communication around the region while there is no mention to Pompeian forces moving from the coast towards Ilerda.

Finally, these results explain why the control of the Lluçanès area could have been an operational goal for both Roman armies; but why was PC chosen as the key location of the region? Archaeological evidence tells us that one side deployed a sizeable garrison at this hill while the other side invested a considerable amount of time, resources and soldiers to assault the position. The outcome of the third analysis does not reveal PC as a particularly dominant location within the region so the question on why the garrison was assaulted remains open. The simplest answer is that PC offered some defensive benefit beyond its location. Two hypotheses can be suggested here: a) the plateau of PC was the only one large enough to host a large military garrison, and b) the garrison occupied a previously fortified settlement.

This spatial analysis highlights some additional ideas relevant to the assault to PC. First, the lack of visibility suggests that any garrison deployed in PC would need additional detachments and infrastructure across the territory to create a network of posts that enabled a more effective visual control of the region. Second, while fieldwork has found evidence of earlier settlements there is still no clear evidence of its size or activity. PC hosted a fortified Iberian settlement, but we still do not know whether it was abandoned at the time of the Ilerda campaign; the Roman garrison could have occupied and extended the abandoned fortifications or expelled the Iberians living there as a means to use a fortified and easily defensible perimeter. Finally, additional field surveys beyond the plateau may reveal other archaeological sites linked to the battle of Puig Ciutat; these smaller sites may include temporary camps built by the attackers during the assault as well as watchtower or small posts linked to the defensive perimeter. From this perspective, the information generated by this work will be used to inform further fieldwork activities designed to test these hypotheses.

Beyond the case study of PC, the multiscalar analysis presented here shows how CT modelling may be useful to a number of research questions where archaeologists have previously applied LCP-based approaches. The most relevant benefit of CT is the definition of a general perspective on the connectivity of an archaeological region beyond optimal paths. This is particularly useful for cases such as the one explored here because the optimality assumption may not be assumed in the context of violent conflict between two forces. Furthermore, the fact that optimality is not required by CT may be interesting to cases with high levels of uncertainty; in these instances, the binary nature of LCP may be too sensitive to take into account this uncertainty while the continuous outcome generated by CT models seems more flexible and prone to robust archaeological interpretation. CT is also computationally less expensive than adaptations of LCP to general connectivity analysis (e.g. identification of natural corridors) because the algorithm integrates parallelism thus mitigating the exponential increase of CPU requirements that is required for pairwise analysis.

As any other method, CT has also some limitations. Most of them are common to other spatial analysis approaches such as sensibility to changes on the definition of the friction costs. While this sensitivity is an issue, it can be mitigated by the analysis of multiple possible surface cost maps (which was done in this research) to assess to what extent results depend on specific friction values. Additionally, CT explores general connectivity instead of single optimal paths and for this reason it is less sensitive to slight variations in parameter values. If we focus on the outcome of the algorithm then the most relevant trait to take into account is that the values generated by the CT algorithm are better understood as relative connectivity values within the region. It is difficult to transform CT results to an estimate of time, energy, or other absolute meaningful cost for mobility; as a consequence, if absolute estimates and minimum cost are relevant for the research question then LCP is still the best existing technique to be applied within archaeological contexts (Rosenswig & Martínez Tuñón, 2020).

6 Concluding remarks

Conflict archaeology is an emerging field of studies that often combines archaeological evidence with written and cartographical sources. If these sources are available then it is common that archaeological activity is guided by records and maps describing the battle under study. This focus on historical conflicts means that

our understanding of violent conflict will mostly be based on the materiality of renowned battles and sieges covered by historical sources. In fact, conflict archaeology may tend to overlook prehistoric warfare beyond the excavation of fortified sites and mass graves displaying evidence of violent trauma. As a consequence, we should be cautious in our efforts to understand past warfare and avoid a biased perspective suggesting that prehistorical chronologies saw less intense conflict activities.

Beyond this intensity bias, another consequence is that conflict archaeology is focused on large events while minimizing the relevance of activities other than pitched battles and long sieges. Examples of these key activities would be reconnaissance, logistics and supply, pre- and post-battle skirmishes and pursuits, field hospitals and a long list of additional processes required by armies of all periods. Some of these tasks are very difficult to observe in the archaeological record, but in other cases a conflict archaeology perspective may be particularly useful given the lack of alternative sources to materiality.

In both cases the study of landscape on spatial analysis and hypothesis testing may allow us to quantify to what extent working hypotheses at different scales are plausible even when the events were not recorded by any written source. However, the study of landscapes of conflict has some unique traits that make this type of analysis different to the rest of landscape studies such as the existence of two actors or the logics of military operations. From this perspective, conflict archaeologists should not rely on embracing common analytical tools used in site-based studies; the interpretation of conflict landscapes needs alternate approaches more suitable to the challenges posed by the study of warfare. At the same time, some of the challenges of conflict studies are shared by other archaeological cases and for this reason we hope that the exploration of less well-known methods such as Circuit Theory connectivity modelling may also be adopted by landscape archaeologists studying other dimensions of the human past.

7 References

- Anantharaman, R., Hall, K., Shah, V. B., & Edelman, A. (2020). Circuitscape in Julia: High Performance Connectivity Modelling to Support Conservation Decisions. *Proceedings of the JuliaCon Conferences*, 1(1), 58. <https://doi.org/10.21105/jcon.00058>
- Ble Gimeno, E. (2016). *Guerra y conflicto en el nordeste de Hispania durante el período romano republicano (218—45 a.C). La presencia del ejército romano a partir de sus evidencias arqueológicas metálicas* [PhD Thesis, Universitat de Barcelona]. <http://hdl.handle.net/10803/398391>
- Bleed, P., & Scott, D. D. (2011). Contexts for Conflict: Conceptual Tools for Interpreting Archaeological Reflections of Warfare. *Journal of Conflict Archaeology*, 6(1), 42–64. <https://doi.org/10.1179/157407811X12958860458497>
- Canosa-Betés, J. (2016). Border surveillance: Testing the territorial control of the Andalusian defense network in center-south Iberia through GIS. *Journal of Archaeological Science: Reports*, 9, 416–426. <https://doi.org/10.1016/j.jasrep.2016.08.026>
- Carman, J., & Carman, P. (2006). *Bloody meadows: Investigating landscapes of battle*. The History Press.
- Conolly, J., & Lake, M. (2006). *Geographical information systems in archaeology*. Cambridge University Press.
- Dickson, B. G., Albano, C. M., Anantharaman, R., Beier, P., Fargione, J., Graves, T. A., Gray, M. E., Hall, K. R., Lawler, J. J., Leonard, P. B., Littlefield, C. E., McClure, M. L., Novembre, J., Schloss, C. A., Schumaker, N. H., Shah, V. B., & Theobald, D. M. (2019). Circuit-theory applications to connectivity science and conservation. *Conservation Biology*, 33(2), 239–249. <https://doi.org/10.1111/cobi.13230>
- Domingo Ribas, G. (2018). *A QGIS plugin to explore landscape connectivity through least-cost path networks and circuit theory* [MSc]. University of Edinburgh.
- Foard, G., Sutherland, T. L., Schmidt, A., Pollard, T., & Newman, M. (2003). Battlefields. *Landscapes*, 4(2), 5–43. <https://doi.org/10.1179/lan.2003.4.2.5>
- Garcia, E., Gómez, C. P., Pujol, À., Sala, R., & Tamba, R. (2010). Resultats preliminars de la primera campanya d'excavació al jaciment de Puig Ciutat (Oristà, Osona). *Ausa*, 24(166), 685–714.
- Güimil-Fariña, A., & Parceró-Oubiña, C. (2015). “Dotting the joins”: A non-reconstructive use of Least Cost Paths to approach ancient roads. The case of the Roman roads in the NW Iberian Peninsula. *Journal of Archaeological Science*, 54, 31–44. <https://doi.org/10.1016/j.jas.2014.11.030>
- Hernández-Cardona, F. X., Rubio-Campillo, X., Besolí, A., Íñiguez, D., & Sospedra, R. (2019). Forgotten Pilots, Airfields and Aircraft: A Transdisciplinary Approach to the Memory of the Republican Air Force During the Spanish Civil War (1936–39). *Public Archaeology*, 18(1), 3–27. <https://doi.org/10.1080/14655187.2019.1784664>
- Herzog, I. (2014). A review of case studies in archaeological least-cost analysis. *Archeologia e Calcolatori*, 25, 223–239.
- Howey, M. C. L. (2011). Multiple pathways across past landscapes: Circuit theory as a complementary geospatial method to least cost path for modeling past movement. *Journal of Archaeological Science*, 38(10), 2523–2535. <https://doi.org/10.1016/j.jas.2011.03.024>
- Jerez Farrán, C., & Amago, S. (Eds.). (2010). *Unearthing Franco's legacy: Mass graves and the recovery of historical memory in Spain*. University of Notre Dame Press.
- Lake, M., & Ortega, D. (2013). Compute-intensive GIS visibility analysis of the settings of prehistoric stone circles. *Computational Approaches to Archaeological Spaces*, 213–242.
- McRae, B. H., Dickson, B. G., Keitt, T. H., & Shah, V. B. (2008). Using circuit theory to model connectivity in ecology, evolution and conservation. *Ecology*, 89(10), 2712–2724. <https://doi.org/10.1890/07-1861.1>
- Moore, J. G. (1960). Mobility and strategy in the Civil War. *Military Affairs*, 68–77.
- Moshenska, G. (2009). Resonant Materiality and Violent Remembering: Archaeology, Memory and Bombing. *International Journal of Heritage Studies*, 15(1), 44–56. <https://doi.org/10.1080/13527250902746062>
- Murphy, K. M., Gittings, B., & Crow, J. (2018). Visibility analysis of the Roman communication network in southern Scotland. *Journal of Archaeological Science: Reports*, 17, 111–124. <https://doi.org/10.1016/j.jasrep.2017.10.047>

- Murrieta-Flores, P. (2012). Understanding human movement through spatial technologies. The role of natural areas of transit in the Late Prehistory of South-western Iberia. *Trabajos de Prehistoria*, 69(1), 103–122.
- NASA/METI/AIST/Japan Spacesystems And U.S./Japan ASTER Science Team. (2019). *ASTER Global Digital Elevation Model V003* [Data set]. NASA EOSDIS Land Processes DAAC. <https://doi.org/10.5067/ASTER/ASTGTM.003>
- Neumann, C. (1971). A note on Alexander's march-rates. *Historia: Zeitschrift Für Alte Geschichte*, H. 2/3, 196–198.
- Nolan, T. J. (2009). Geographic Information Science as a Method of Integrating History and Archaeology for Battlefield Interpretation. *Journal of Conflict Archaeology*, 5(1), 81–104. <https://doi.org/10.1163/157407709X12634580640290>
- Padrós, C., Pujol, A., & Sala, R. (2012). El jaciment tardorepublicà de Puig Ciutat (Oristà, Osona): Nous mètodes aplicats a l'arqueologia de recerca. *Tribuna d'Arqueologia*, 2013, 100–120.
- Padrós Gómez, C., Pujol, À., Sala, R., & Tamba, R. (2019). Puig Ciutat (Cataluña). Localización, excavación y museización de un castellum romano republicano en el nordeste peninsular. *Bellón, JP; Rueda, C.; Vallori, B., Accampamenti, Guarnigioni e Assedi Durante La Seconda Guerra Punica e La Conquista Romana (Secoli III-I AC): Prospettive Archeologiche. Quasar*, p. 83-96., 83–96.
- Palmer, S. C. F., Coulon, A., & Travis, J. M. J. (2011). Introducing a 'stochastic movement simulator' for estimating habitat connectivity: *Perceptual range limits habitat connectivity. Methods in Ecology and Evolution*, 2(3), 258–268. <https://doi.org/10.1111/j.2041-210X.2010.00073.x>
- Pollard, T., & Banks, I. (2005). Why a Journal of Conflict Archaeology and Why Now? *Journal of Conflict Archaeology*, 1(1), iii–vii. <https://doi.org/10.1163/157407705774929024>
- Pujol, À., Fernández-Götz, M., Sala, R., Padrós, C., Ble, E., Tamba, R., & Rubio-Campillo, X. (2019). Archaeology of the Roman Civil Wars: The destruction of Puig Ciutat (Catalonia, Spain) and Caesar's campaign in Ilerda (49 BC). In *Julius Caesar's Battle for Gaul. New Archaeological Perspectives* (pp. 227–240). Oxbow Books.
- QGIS Development Team. (2021). *QGIS Geographic Information System*. QGIS Association. <https://www.qgis.org>
- R Core Team. (2020). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. <https://www.R-project.org/>
- Rosenswig, R. M., & Martínez Tuñón, A. (2020). Changing Olmec trade routes understood through Least Cost Path analysis. *Journal of Archaeological Science*, 118, 105146. <https://doi.org/10.1016/j.jas.2020.105146>
- Roth, J. P. (1999). *The logistics of the Roman army at war (264 B.C.-A.D. 235)*. Brill.
- Rubio-Campillo, X. (2008). An Archaeological Study of Talamanca Battlefield. *Journal of Conflict Archaeology*, 4(1–2), 23–38. <https://doi.org/10.1163/157407808X382746>
- Rubio-Campillo, X., Cardona, F. X. H., & Yubero-Gomez, M. (2015). The Spatiotemporal Model of an 18th-Century City Siege. *Social Science Computer Review*, 33(6), 749–765. <https://doi.org/10.1177/0894439314558559>
- Rubio-Campillo, X., & Hernández, F. X. (2015). Combined Arms Warfare in the Spanish Civil War: The Assault on the Republican Defence Line at Fatarella Ridge. *Journal of Conflict Archaeology*, 10(1), 52–69. <https://doi.org/10.1179/1574077315Z.00000000043>
- Scott, D. D., & McFeaters, A. P. (2011). The Archaeology of Historic Battlefields: A History and Theoretical Development in Conflict Archaeology. *Journal of Archaeological Research*, 19(1), 103–132. <https://doi.org/10.1007/s10814-010-9044-8>
- Sivilich, E. D., & Sivilich, D. M. (2015). Surveying, Statistics, and Spatial Mapping: KOCOA Landscape Analysis of Eighteenth-Century Artillery Placements at Monmouth Battlefield State Park, New Jersey. *Historical Archaeology*, 49(2), 50–71. <https://doi.org/10.1007/BF03377139>
- Supernant, K. (2017). Modeling Métis mobility? Evaluating least cost paths and indigenous landscapes in the Canadian west. *Journal of Archaeological Science*, 84, 63–73. <https://doi.org/10.1016/j.jas.2017.05.006>
- Thayn, J. B., Sampeck, K., & Spaccapaniccia, M. (2016). Refining Hernando de Soto's route using electric circuit theory and Circuitscape. *The Professional Geographer*, 68(4), 595–602.

- Tunwell, D. C., Passmore, D. G., & Harrison, S. (2015). Landscape Archaeology of World War Two German Logistics Depots in the Forêt domaniale des Andaines, Normandy, France. *International Journal of Historical Archaeology*, 19(2), 233–261. <https://doi.org/10.1007/s10761-015-0287-4>
- Verhagen, P., Nuninger, L., & Groenhuizen, M. R. (2019). Modelling of Pathways and Movement Networks in Archaeology: An Overview of Current Approaches. In P. Verhagen, J. Joyce, & M. R. Groenhuizen (Eds.), *Finding the Limits of the Limes* (pp. 217–249). Springer International Publishing. https://doi.org/10.1007/978-3-030-04576-0_11
- Wheatley, D. (1995). Cumulative viewshed analysis: A GIS-based method for investigating intervisibility, and its archaeological application. *Archaeology and GIS: A European Perspective*. London: Routledge, 171–186.
- Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York. <https://ggplot2.tidyverse.org>
- Wilson-Daily, A. E., Kemmelmeier, M., & Prats, J. (2018). Intergroup contact versus conflict in Catalan high schools: A multilevel analysis of adolescent attitudes toward immigration and diversity. *International Journal of Intercultural Relations*, 64, 12–28. <https://doi.org/10.1016/j.ijintrel.2018.03.002>
- Yubero-Gómez, M., Rubio-Campillo, X., López-Cachero, F. J., & Esteve-Gràcia, X. (2015). Mapping changes in late prehistoric landscapes: A case study in the Northeastern Iberian Peninsula. *Journal of Anthropological Archaeology*, 40, 123–134.