



Settlement Organization and Distribution in Bronze Age Sardinia: Utilizing Cumulative Viewshed Analysis and Spatial Statistics in the Sulcis Plain

Miriam Rothenberg, Thomas P. Leppard, Elic Weitzel & Elizabeth A. Murphy

To cite this article: Miriam Rothenberg, Thomas P. Leppard, Elic Weitzel & Elizabeth A. Murphy (2024) Settlement Organization and Distribution in Bronze Age Sardinia: Utilizing Cumulative Viewshed Analysis and Spatial Statistics in the Sulcis Plain, *Journal of Field Archaeology*, 49:5, 356-370, DOI: [10.1080/00934690.2024.2318682](https://doi.org/10.1080/00934690.2024.2318682)

To link to this article: <https://doi.org/10.1080/00934690.2024.2318682>



© 2024 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group



[View supplementary material](#)



Published online: 27 Feb 2024.



[Submit your article to this journal](#)



Article views: 734



[View related articles](#)



[View Crossmark data](#)

Settlement Organization and Distribution in Bronze Age Sardinia: Utilizing Cumulative Viewshed Analysis and Spatial Statistics in the Sulcis Plain

Miriam Rothenberg ¹, Thomas P. Leppard ², Elic Weitzel ³, and Elizabeth A. Murphy ⁴

¹University of Oxford, Oxford, UK; ²International Archaeological Research Institute, Inc., Honolulu, HI, USA; ³University of Connecticut, Storrs, CT, USA; ⁴Florida State University, Tallahassee, FL, USA

ABSTRACT

Nuraghi are ubiquitous in the Bronze Age Sardinian landscape, but the reasons for their distribution and wider function remain poorly understood. Here, we evaluate the argument that these megalithic fortified towers were situated for visual control and thus represent nodes of political or coercive power. Using a dataset of 102 nuraghi, we perform a normalized cumulative viewshed to quantify nuraghe visibility in southwestern Sardinia. We analyze the co-occurrence of highly visible areas with variables pertinent to economic control of the landscape using a model comparison approach. The results suggest that there is no underlying structure to the location of the nuraghi that can be related to visual appreciability of the wider environment, indicating that visual control was not an important consideration during the later 2nd millennium B.C. We consider what the driving rationale may have been behind such a predominant site type that is yet apparently unrelated to political control.

ARTICLE HISTORY

Received 4 October 2023
Accepted 22 January 2024

KEYWORDS

settlement patterns; nuraghi;
Bronze Age; viewshed
analysis; model comparison

Introduction


Sardinia's social and political organization between approximately 1800 and 900 B.C. is imperfectly understood, mainly as a consequence of the inscrutable nature of the island's settlement patterns during this period. The most obtrusive class of settlement site during this phase (i.e., the Middle, Late, and Final Bronze Age)—although not the only type of settlement—comprises the *nuraghi* (s. *nuraghe*). These megalithic towers number roughly 7000 (Lilliu 1959, 1982; Vanzetti et al. 2013; Webster 1996, 2015) and range from the comparatively simple tholos-nuraghi (Webster's [1996, 111–125] Type I, around 5000 sites) through multi-tower complex forms (Type II, around 2000 sites) to the 14 or 15 massive Type III nuraghi, with multiple towers, encircling walls, and extensive extramural settlement.

The distribution, chronology, and archaeology of these sites create challenges for understanding how political power was built and exercised in the landscape. Nuragic architecture—massive, imposing, and with few points of ingress—hints at an interest in defense (e.g., Lilliu 1962; Trump 1992). Conversely, and somewhat paradoxically, the sheer density of the nuraghi (often exceeding 1.5 per km²; Melis 2017) and their likely energetic construction costs suggest a communitarian interest in the construction of fortified sites that probably housed comparatively few people. Moreover, the larger nuraghi display little evidence for elite economic control. Craft production (especially metallurgy) and access to exotica (in particular eastern Mediterranean imports) tend to map onto the distribution of the largest sites only poorly, and there is little evidence for elite control of wealth in the funerary record. As a result of these apparent contradictions, the political

organization of the nuragic landscape has been interpreted widely: either as highly stratified (e.g., Webster 1996, 2015) or markedly egalitarian (e.g., Araque Gonzalez 2019), with a range of intervening positions (see Blake 2014; Perra 2009). The fact that construction of these sites seems to stop at the end of the Late Bronze Age (ca. 1200 B.C.) but that their use—and the evident attraction of ideational structures built around them—continues into the Final Bronze Age and beyond further complicates interpretation.

We aim to contribute to a more robust understanding of the organization of the political landscape of Nuragic Sardinia, analyzing the distribution of nuraghi within a discrete region and whether this distribution relates to environmental specifics or is essentially random. To do this, we bring normalized cumulative viewshed analysis, supported by use of a spatial statistical approach, to bear on a regional dataset—the nuraghi of the Sulcis Plain in southwestern Sardinia. This area has a dense concentration of nuraghi ($n = 102$ in our dataset)—the vast majority of which are the smaller tholos-nuraghi (Webster's Type I)—in a comparatively enclosed landscape that has historically been a focus of agropastoral production (Figure 1). The Sulcis Plain thus represents a viable context in which to analyze whether the spatial organization of these sites can be modeled in terms of the distribution of a series of variables and whether this suggests an underlying cultural or political logic. In particular, we are keen to establish whether local nuraghi were distributed in a manner that is suggestive of an interest in economic or political power via surveillance of the wider landscape. Establishing which of these factors, if any, drove structure in settlement distribution during the Nuragic Bronze Age

CONTACT Miriam Rothenberg  Miriam.Rothenberg@gmail.com  Christ Church, St. Aldate's, Oxford, OX1 1DP.

 Supplementary material for this article is available at: <https://doi.org/10.1080/00934690.2024.2318682>

© 2024 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group

This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (<http://creativecommons.org/licenses/by-nc-nd/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.



Figure 1. View northwest over the Sulcis Plain from Nuraghe Monte Fenugu. Photo: E. Murphy.

in Sulcis likely has wider implications for a more complete understanding of the prehistoric social and political organization of the Sardinian landscape.

Social Organization in the Sardinian Bronze Age

Previous approaches

Although other means exist, the question of how social and political power was assembled and exercised in Nuragic Sardinia is usually approached through the lens offered by the nuraghi themselves. We do not intend to review here the extensive literature on this site type (see Lilliu 1982; Webster 1996, 2015). Instead, we characterize their physical and spatial organization and pertinent aspects of their archaeological record, doing so partly with the aim of demonstrating just how poorly Nuragic settlement fits into received socio-evolutionary models. We then introduce the region of our study, before moving into our methods, results, and a discussion of Sardinian social and political organization between ca. 1800 and 900 B.C.

There are approximately 7000 known nuraghi distributed across Sardinia (Vanzetti et al. 2013), likely representing a major proportion of those originally constructed (not including here the *torri* of southern Corsica, Bronze Age megalithic towers similar to the nuraghi). They have primarily been classified according to size and mode of construction. The earliest forms, from ca. 1800 B.C., are the corridor nuraghe and—slightly later—the much more numerous and canonical tholos-nuraghe. The latter usually take the form of a single megalithic truncated conical tower with interior corbelled spaces, probably reaching between 10 and 20 m, or perhaps three or four storeys, in height. Nuraghi built around a tholos plan can again be subdivided in terms of scale, from the ubiquitous single-tholos (Webster's Type I, around 5000 examples), via complex or multi-tower nuraghi with surrounding non-megalithic architecture (Webster's Type II, around 2000 examples), to

the rare (perhaps 14 or 15 examples; Webster 2015, 97–107) Type III nuraghi. These latter are multi-towered structures enclosed by enceinte walls with their own towers (e.g., Nuraghe Arrubiu or Nuraghe Su Nuraxi [Barumini]). The apogee of nuragic construction appears to be in the period 1500–1200 B.C. (Middle–Late Bronze Age), after which, during the Final Bronze Age, the construction of new nuraghi seems to cease, although there is evidence for subsidiary settlement after this date, sometimes extensive, notably associated with larger nuraghi. Regarding their distribution, nuraghi are common across the island, although with some localized spatial differentiation—they are, for example, very thickly distributed across the central uplands and the Oristanese, but noticeably less so in the Campidano. Type III nuraghi, however, mostly cluster in the south of the island (e.g., Nuraghe Antigori, Nuraghe Serucci, Nuraghe Sirai, and Nuraghe Su Nuraxi).

The evident interest in constructing what appear to be fortified sites, combined with the heterogeneity of both their form and their distribution, has encouraged scholars to interpret Nuragic settlement as hierarchical, with the vertical extent of this hierarchy increasing from the Middle Bronze Age onwards. Webster's model (1996, 130–131), which derives from his attempt to categorize sites based on architectural complexity, has been particularly influential (and the one that we essentially use in this paper; though see also Lilliu 1962). Webster argues for a two-tier settlement hierarchy in the north of the island and a three-tier settlement hierarchy in the south. In this understanding, Type III nuraghi were the locus of emergent chiefdoms, polities that exercised horizontal control over the landscape and thereby political control over smaller nuraghi. While not necessarily endorsing an explicitly chiefly categorization, other scholars have also supposed a more or less hierarchical organization of the nuragic landscape. Blake (1998, 2001) incorporates a temporal dimension, suggesting a transition from Middle Bronze nuraghi controlling their immediate vicinity (yet with such control situated in a wider and

relatively egalitarian framework) to the emergence of social stratification and a restructured, hierarchical landscape in the Late Bronze Age (Blake 1998, 61). Ialongo (2018), noting the apparent preference in nuraghe distribution for productive soils, understands this transition in environmental and human ecological terms, suggesting a saturation of preferred territory leading to a formation of “territorial compounds” (Ialongo 2018, 19) by the Final Bronze Age.

There are several factors that complicate a hierarchical model of the nuragic landscape, however. Most obviously, evidence for material culture or practices associated with a social elite is largely lacking from these sites (Usai 2020; Webster 2001). Equally problematic is relating the supposed chiefly centers to types of economic activity that social elites attempted to control elsewhere in the Bronze Age Mediterranean (e.g., Murray 2023). Sardinia has metal resources that were evidently being exploited during the Bronze Age, although the extent to which the island was directly or indirectly connected to wider Mediterranean exchange systems remains a source of disagreement (Russell and Knapp 2017; Sabatini and Lo Schiavo 2020). Critically, however, this exploitation maps poorly onto the distribution of Type III nuraghi—there is no spatial relationship between oxhide or bun ingot distribution and nuraghe size, for example (Russell 2010). The distribution of imports also frustrates attempts to associate access to exotica with elite control. While the nuraghe complex at Antigori clearly had access to Mycenaean (or Mycenaeanizing; perhaps the majority of the assemblage) ceramics, beyond this site—situated preferentially on the Gulf of Cagliari—there is no evidence to suggest comparable preferential access to off-island materials afforded to Type III sites. Indeed, the overall quantity of later 2nd millennium B.C. ceramic imports to the island is small, with even the nuraghe at Antigori only yielding around 200 sherds in a Late Helladic style (Knapp, Russell, and van Dommelen 2021; Russell 2010).

The physical distribution of the nuraghi is also somewhat problematic. Ialongo (2018) convincingly shows an interest in productive agricultural soils, yet, as he notes, the density of nuraghi in the Campidano—the richest single crop-and-pasture agroecology on the island—is comparatively low, whereas the density of non-monumental settlement (otherwise quite rare in the Sardinian Middle to Final Bronze, although with some evidence from our own study region) is comparatively high (Webster 2015, 107–109). This necessitates developing an explanation for why an apparently desirable agricultural niche was not directly controlled by the main centers (or was controlled in a manner that is subtle enough to be archaeologically invisible). More generally, the occasionally very dense distribution of tholos-nuraghi is also hard to parse. Comparing the available use-space within corbel-vaulted architecture with the amount of labor likely necessary to complete even a single nuraghe tower intuitively suggests that the structure could only house a fraction of the workforce that completed it. This probably precludes a fragmented landscape characterized by endemic internecine conflict (e.g., Trump 1992; Ugas 2014)—how would a workforce of the necessary size be corralled? It also prompts questions about community organization and kin grouping, such that some scholars have emphasized the communitarian or horizontal aspects of nuragic social organization, with a potential elite exercising only limited control over the wider landscape (e.g., Perra

2009; Usai 2011; see also Araque Gonzalez 2019). Blake (2014) sees this apparently contradictory series of data in terms of a society moving towards state formation, but with elites failing to co-opt control of new economic systems connected to increasingly integrated Mediterranean networks. More recently, noting that previous universalizing explanations remain unsatisfactory, Leighton (2022) has examined the cultic and ritual role of nuraghi, extending arguments for their cultic significance back into the Middle Bronze Age.

This broad diversity of views exemplifies how inappropriate frameworks built around neoevolutionary expectations of trajectories towards statehood are for understanding Nuragic society. This is not the venue to rehearse criticism of this model or series of models—although chiefly definitions of Sardinian political organization may remain popular because of the elasticity of the concept, filling the wide conceptual gulf between egalitarian and state-type societies (Pauketat 2007). Suffice it to say—as Schirru and Vanzetti stress in their recent and authoritative review (2023)—that we do not precisely understand how the Sardinian landscape was politically divided and organized during the nuragic period, how this changed from 1800–900 B.C., and whether the system operated across the island or whether different types of political organization obtained in different areas. Considering the esoteric nature of nuragic settlement archaeology, palaeogenomic evidence that Sardinia has tended to diverge from wider demographic trends (Marcus et al. 2020), and the increasing appreciation of the diversity of political organization in the Mediterranean Bronze Age (e.g., Broodbank 2013), this inexact understanding is regrettable.

Power, space, surveillance

One route into resolving this indeterminacy involves focusing on the spatial organization of the nuragic landscape. It is axiomatic of regional archaeology that settlement distribution displays regularities that in turn reflect wider economic, political, and environmental structures. These regularities can relate to where settlement is physically placed but also to its broader footprint in the landscape, beyond its physical position. In particular, in the tradition of Bentham and Foucault, scholarship has focused on surveillance—the power derived by and exercised through overseeing activity and behavior in a given area. In the archaeological literature, the associated scholarship has often focused on the surveillance of economically important landscapes or resources, attempting to account for the distribution of certain types of sites by the type of landscape or environment over which they exercise visual control. This scholarship has often (but not always; Yekutieli 2006) focused on how sites and infrastructure exercise visual control in state-type societies (e.g. Delle 1998; Leone, Harmon, and Neuwirth 2005; Leone and Hurry 1998; Williams 2017), although an interesting inverse approach interprets activities situated away from or outside surveilled zones as subversive to state institutions (e.g., Given 2004; Hauser 2014). The animating logic of this scholarship is that, cross-culturally, sites associated with social and economic control are often situated to visually survey those parts of the landscape in which their material interests reside.

In the Sardinian Bronze Age, we are not dealing with a centralizing state and its apparatus. However, as we have

seen, nuraghi have often been understood to be implicitly or explicitly connected to landscape control: strongholds that in part manifest social and economic power. Considering the obvious importance of certain types of landforms in agropastoral economies, and previous observations regarding the importance of certain pedological contexts to nuragic settlement (e.g., Ialongo 2018), we want to assess whether visual appreciability from nuraghi was biased towards those parts of the landscape in which we might suppose Bronze Age agropastoralists to have greater economic interest. Specifically, we aim to establish whether certain types of terrain that should be more central to subsistence behaviors and economic exploitation (e.g., well-watered and -drained soils, flatter landforms, areas that have historically been the focus of agropastoral activity, and so on) tend to be subject to surveillance from nuraghi more than other types of landforms. Rather than intuit this, we then aimed to establish whether it would be possible to assert the presence or absence of meaningful trends via robust statistical analysis. To that end, our research question was distilled to: was settlement in the Sulcis Plain in the later 2nd millennium B.C. distributed sensitive to environmental variables (especially those that might impact agricultural potential in a primarily agropastoral economy)? Or were other factors more profoundly influential on settlement distribution? We suggest that establishing whether or not these sites preferentially overlook certain parts of the landscape will contribute to understanding their role and function and thereby to a more robust understanding of Bronze Age sociopolitical organization—more or less centralized, hierarchical, cellular, egalitarian, and so on.

To undertake this assessment, we utilize a case study from the southern half of the Sulcis Plain (Figure 2). This portion of southwestern Sardinia, where the *Landscape Archaeology of Southwest Sardinia* (LASS) Project has been working since 2017 (Murphy et al. 2019), represents an advantageous environment in which to undertake geospatial analysis of this sort. It has dense nuragic settlement—both nuraghi themselves, but also evidence for non-monumental Bronze Age settlement—is essentially self-contained (bounded to the north, east, and south by uplands with much lower density of nuragic settlement), possesses environmental diversity within a limited spatial scale (especially lithologically and pedologically, reflected in diverse modern land use), and has been documented with appropriately high-resolution lidar data. Approximately 102 nuraghi are documented for this part of the Sulcis plain, representing a robust dataset on which to perform cumulative viewshed analysis (Supplemental Material 1).

Cumulative Viewshed Analysis

Previous approaches

Viewshed analysis is one of few GIS-based techniques that, in isolation, can begin to approach an experiential or phenomenological view of the landscape (e.g., Gaffney et al. 1996; van Leusen 1999; Wheatley 1995). While techniques designed to model territoriality or quantify the distance between sites and specific natural resources offer useful information about settlement patterning, they tend to lend themselves to environmentally deterministic interpretations of landscape use (Wheatley and Gillings 2002). Viewsheds, by contrast,

can provide a sense of the experience of being in and moving through a landscape, and they offer an entry point into not only overall patterns of landscape use but also the perspectives of those who engaged with that landscape on a daily basis in the past (e.g., Witcher 1999).

There has been extensive recent work of this type undertaken in Sardinia, often oriented towards understanding the location of nuraghi in terms of visibility and, by extension, defense, movement, and territorial control. (Incidentally, we focus here on visibility, but we note other geospatial approaches taken to assessing landscape control and integration—e.g., Scanu and Podda 2015; Spanedda, Cámara Serrano, and Salaa Herrera 2010—and analyses performed on prehistoric site types other than nuraghi—e.g., Matta 2020). Research by Schirru and colleagues has been especially significant. An investigation of the Marmilla, in south-central Sardinia, showed high degrees of intervisibility between nuraghi (Schirru 2017), supported by an expanded series of case studies—including in the Marmilla, the Sinis peninsula, and the northeast of the island—that again found that views from nuraghi were generally more expansive than views from randomized points (Schirru and Castangia 2022). The authors do, however, note regional differences, especially in terms of visual surveillance possible *from* a nuraghe versus the visibility *of* a nuraghe, the former apparently more evident in the Siniscola and the latter in the Marmilla and Dorgali. This is echoed in a case study from the *giara* (plateau) of Gesturi (Schirru and Vanzetti 2023, 28), which underscored less the role of visual appreciability of the wider landscape from nuraghi and more of Nuragic settlement as an intrinsically visible “statement.” Critically, there was no detectable difference between simple and complex nuraghi in any of these studies, potentially reinforcing a lack of functional distinction between these types.

In a similar vein, Cicilloni and colleagues (2016; Cicilloni and Cabras 2014) evaluated the role of visibility in western Sardinia, in the environs of Mogoro and Monte Arci. Incorporating *tombe di giganti*—Bronze Age megalithic gallery gravesites—and sacred wells into their analysis, they suggest high degrees of intervisibility between sites, which they interpret within a framework of landscape surveillance and territorial control. De Montis and Caschili (2012) also find high degrees of intervisibility on the Pranemuru plateau and suppose a hierarchy within this intervisibility network (although the largest nuraghe in the sample, Arrubiu, has a low topological centrality). Again, the correspondence between size and centrality in the visual landscape is challenged. De Montis and Caschili also entertain the possibility of important factors other than visibility, a position echoed by Stein, Detotto, and Belgiu (2022) in their analysis of clustering within nuraghe distribution.

The general sense that emerges from this scholarship is that, while visual appreciability does play some role in the organization of Bronze Age settlement, there is no clear sense 1) whether this derives from intentionality or simply topographic obtrusiveness of sites of nuragic construction; 2) whether it relates to viewing from or viewing of nuraghi; and, 3) how all these factors might vary regionally.

Technical challenges with modeling landscapes of visibility

These studies have contributed important insights to our understanding of Bronze Age Sardinian landscapes, but

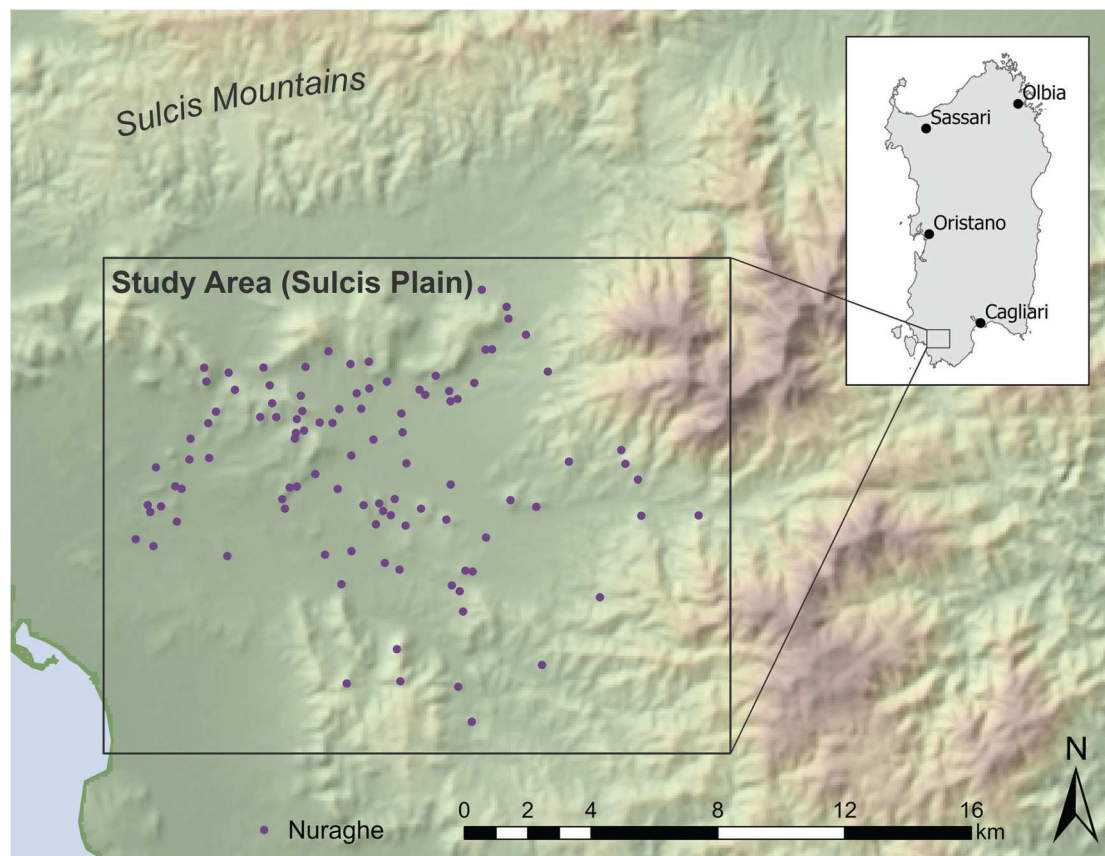


Figure 2. Location of the Sulcis Plain and its nuraghi.

they remain vulnerable to the many critiques of landscape-scale viewshed analysis. One such critique—both of computational viewsheds and of using GIS to model archaeological landscapes in general—is the tendency for these techniques to reduce the landscape into categories of artificial certainty that do not reflect the complexity of the real world as experienced (Wheatley and Gillings 2000). Visibility, for example, is contingent on many factors beyond simply the presence or absence of a direct line-of-sight between two points, including light and atmospheric conditions, time of day, color and contrast, size of the object being observed, and visual acuity. Most computational approaches to viewshed analysis, however, are forced to reduce visibility to a visible/invisible binary, which does not account for this variation. There have been numerous approaches taken to mitigate this limitation, including the use of fuzzy viewsheds (e.g., Fisher 1991, 1992, 1994; Loots, Nackaerts, and Waelkens 1999; Murphy, Gittings, and Crow 2018), total landscape viewshed analysis (e.g., Dungan et al. 2018; Llobera 2003; Llobera et al. 2010; Zamora 2007), and cumulative viewshed analysis (e.g., Fábrega-Álvarez and Parcero-Oubiña 2019; Kay and Sly 2001; Lake, Woodman, and Mithen 1998; Supernant 2014; Wheatley 1995).

Cumulative viewsheds (first described by Wheatley 1995) involve modeling visibility in a landscape by summing together multiple viewsheds generated at specific points of interest. Although the specific methods employed may differ, the goal is the generation of a visibility landscape—rather than simply to display the visibility to/from a few specific points of interest—and they add a degree of complexity to this landscape by moving beyond simply a

visible/invisible binary. Importantly, they do so in a less computationally intense fashion than many of the more detailed and processing-heavy total viewshed approaches (see Schirru and Castangia 2022 and White and Barber 2012 for a similar technique in the realm of cost surface analysis).

Unfortunately, many cumulative viewshed studies overlook the impacts of edge effects on their results. A type of systematic bias, edge effects refer to apparent patterns that are caused by the overlap between the edges of the study area and the extent of the phenomena being studied, rather than genuine patterns based solely on the data (van Leusen 1999; Wheatley and Gillings 2000). Two types of edge effects can impact cumulative viewshed analysis: areas of visibility that may be excluded from the final model because they extend beyond the spatial extent of the study area (Conolly and Lake 2006) and the quasi-arbitrary exclusion of sites outside the study area that nonetheless would have visual appreciability of the study area (van Leusen 1999, 218–219). The former represents missing data but not, in the end, the impact of using a bounded dataset on the quality of the data that are present—a quantitative rather than qualitative error. It can easily be corrected for by extending the processing area beyond the source points. The latter, however, overemphasizes visibility towards the center of the study area and underemphasizes it towards the edges.

This second type of edge effect can be expected whenever a dataset is limited to include only points in a subset of the total area in which a phenomenon occurs—e.g., by looking at only a single valley within a larger region or a study area defined by the restrictions of an archaeological permit.

This is not so much an issue when the totality of a phenomena is spatially bounded, as on an island (e.g., Rothenberg 2021), when phenomena are part of discrete spatial groups (Wheatley and Gillings 2000), or when the research question logically dictates the bounds of the study area (e.g., Earley-Spadoni 2015; Lewis 2020; Schirru and Vanzetti 2023). For all other cases, however, a method of normalization should be applied to account for the problem. Unfortunately, this remains seldom done (e.g., Fábrega-Álvarez and Parcero-Oubiña 2019; Gillings and Wheatley 2020; Murphy, Gittings, and Crow 2018). We demonstrate below how we overcame such edge effects in our own analysis, rendering our method comparatively robust.

Generating a normalized cumulative viewshed

Our study of visibility in the Sulcis Plain relied primarily on two datasets: first, a 10 m resolution bare-earth digital elevation model (DEM; available from the Geoportale Sardegna <https://www.sardegnageoportale.it>) and, second, nuraghe locations compiled from published archaeological literature, the Nurnet geoportal (<http://nurnet.crs4.it/nurnetgeo/>), and surveys completed by the LASS field team, augmented by knowledge from our local collaborators at the Museo Civico Archeologico di Santadi (Table 1). Prior to analysis, the DEM was lightly smoothed to account for data artifacts (including scalloping over an alluvial fan), and the nuraghe dataset was compiled into a single pointfile and all spurious points were removed, resulting in a dataset of 102 points within an area of 310 km², for an overall density of one nuraghe every 3 km². In passing, we note that this is a comparatively large dataset on which to conduct a viewshed analysis in a Sardinian region, although not the largest (Schirru and Castangia 2022).

To generate the initial cumulative viewshed, we followed methods previously developed by Rothenberg (2021) that correspond with widely accepted standards in cumulative viewshed analysis (Wheatley 1995). This involved calculating a viewshed for each site in which “visible” was assigned a value of “1” and “not visible” (NoData) was assigned a value of “0.” These initial viewsheds were generated in ArcGIS Pro, with the nuraghe locations serving as the source points and the DEM as the only other input variable (Supplemental Figure 1). Lacking high resolution information on past land cover and environment, we could not account for the role of vegetation in limiting visibility. The individual viewshed rasters were then summed together to create a cumulative viewshed, with higher values indicating greater overall visibility from the source points (nuraghi in the Sulcis Plain). Given the isotropic nature of viewsheds, the resulting visibility surface equally shows visibility of the nuraghi from

the land surface and visibility of the land surface from the nuraghi.

Initially, we experimented with the parameters of nuraghe height and distance of assumed discernibility for the purposes of generating a reasonable yet conservative cumulative viewshed (i.e., preferring to underestimate rather than overestimate overall visibility). Viewsheds were generated with observer heights of 0 m, 5 m, and 10 m above ground level. These heights correspond to the land surface without the added height of the nuraghi themselves, an average nuraghe height of 10 m (not including the additional height of a human standing atop it), and a midpoint between the two to account for potentially smaller structures. While estimates of typical nuraghe height range from 10–20 m (Schirru and Vanzetti 2023), we opted to model nuraghi at the lower end of this range in line with our conservative approach and to account for the majority of the nuraghi in the Sulcis Plain being single tower tholos-nuraghi (i.e., Webster’s Type I), rather than the more complex—and often taller—Type II and Type III edifices.

In addition to varying observer height, we also experimented with the maximum buffer distance used in the viewshed generation. It is generally understood that there is great variability in maximum visible distance, even within the same physical landscape, based on season, time of day, weather and atmospheric conditions, and the characteristics of the observer. Most notable among the latter is visual acuity, that is, the ability of the human eye/brain to perceive an object of a given size from a given distance. Here, too, there is considerable disagreement. Ogburn (2006, 406) distinguishes between “detection acuity,” “resolution acuity,” and “recognition acuity,” with the latter—“the ability to recognize and identify a target stimulus”—being both the most constrained and the most widely known. He states that humans have visual acuity at a “minimal angle of resolution” of 1’ or 1/60°, although under certain circumstances this threshold can increase to 30” or 1/120°. Determining the maximum lateral distance at which a 10 m high nuraghe could be discerned from the broader landscape under normal conditions, i.e., at 1’, involved the use of simple trigonometry:

$$\text{Tower: } 10 = X * \tan(.0167) \quad X = 34,377 \text{ m}$$

$$\text{Human: } 1.5 = X * \tan(.0167) \quad X = 5157 \text{ m}$$

Following these calculations, visual acuity for a 10 m-high tower is 34.4 km; visual acuity of a human, estimated to be 1.5 m tall, is just over 5 km. Fábrega-Álvarez and Parcero-Oubiña (2019, 61, table 3), however, found significantly reduced maximum distances of visual acuity for viewing humans in the landscape, with 2 km being the distance

Table 1. Data sources used in the analysis.

Dataset	Format	Source	Additional Notes
Nuraghi	Vector file (points)	LASS and Nurnet	Assumed 100% coverage within the study area
Digital Elevation Model	Raster (10 m spatial resolution)	Geoportale Sardegna	Smoothed minimally in ArcGIS before analysis to remove data artifacts. Slope was generated from this layer in ArcGIS
Soils	Vector (polygons)	Geoportale Sardegna	Data from 2019. Divided into five categories: low permeability, medium-low permeability, medium permeability, medium-high permeability, and high permeability
Lithology	Vector (polygons)	Geoportale Sardegna	Data from 2019. Divided into four classes for analysis: igneous, metamorphic, sedimentary, and water
Land Use/Land Cover	Vector (polygons)	Geoportale Sardegna	Data from 2008. Divided into five classes for analysis: settlement, agriculture, forest, freshwater, and saltwater

at which a human first becomes visible in scrubland. With such a large difference in proposed maximum distance of visual acuity between Ogburn's model and Fábrega-Álvarez and Parcero-Oubiña's experimental data, we chose to test three different buffer distances from the nuraghi of the Sulcis Plain: 1 km, 5 km, and 10 km. Overall, the 1 km and 5 km buffers noticeably underestimated—based on observations made in the field—the visibility of the nuraghi in the landscape on days with unremarkable weather and led to an erroneously discontinuous visibility surface (Figure 3). While we did run the normalization and classification on all nine cumulative viewsheds (see below), we therefore chose to perform statistical analysis only on the viewshed generated with a 10 km distance buffer and 10 m observer height to more accurately reflect visibility in this particular landscape, based on experiential observations.

The impacts of the edge effects on the initial cumulative viewshed were immediately evident, with the most notable—yet erroneous—pattern in visibility being that the center of the study area was more highly surveilled than the edges (Figure 4A). To account for this, we normalized the data to show actual visibility calculated out of the possible visibility of any given pixel. This involved buffering each point, using the “Union” and “Multipart to Singlepart” tools in ArcGIS to cut overlapping buffered areas into distinct polygons within a single layer, and finally, performing a one-to-one spatial join (with the match option set as “ARE_IDENTICAL_TO”)

to link the counts for each polygon with the polygon itself. The resulting layer was snapped to the DEM and rasterized (Figure 4B). We normalized by dividing the cumulative viewshed by the weighted buffer raster using Raster Calculator to receive a visibility value for each pixel between 0 and 1:

Normalized Cumulative Viewshed

$$= \text{float}(\text{Cumulative Viewshed}) / \text{float}(\text{Weighted Buffer})$$

It is important to note, however, that this normalization process necessarily generated its own set of edge effects—the weighted buffer does not take into account the viewsheds of sites located outside of the study area, resulting in low denominators near the edges. This may result in erroneously high values, as is seen in the westernmost portion of our normalized viewshed raster (Figure 4C–D). We were able to account for this by limiting the area investigated statistically to 1 km greater than the maximum X and Y extents of the nuraghe dataset, even though the visual acuity buffer was set to the much larger 10 km. This removed the areas of highest distortion from the quantitative analysis. Overall, collinearity between the normalized and non-normalized viewshed rasters is moderate ($r = 0.469$) and is high when the datasets are spatially clipped ($r = 0.935$). This correlation was much weaker for the viewsheds with smaller buffer areas (see Figure 3), suggesting that normalization has a greater effect on the results when the potential for overlap between individual viewsheds used in the cumulative dataset is lower.

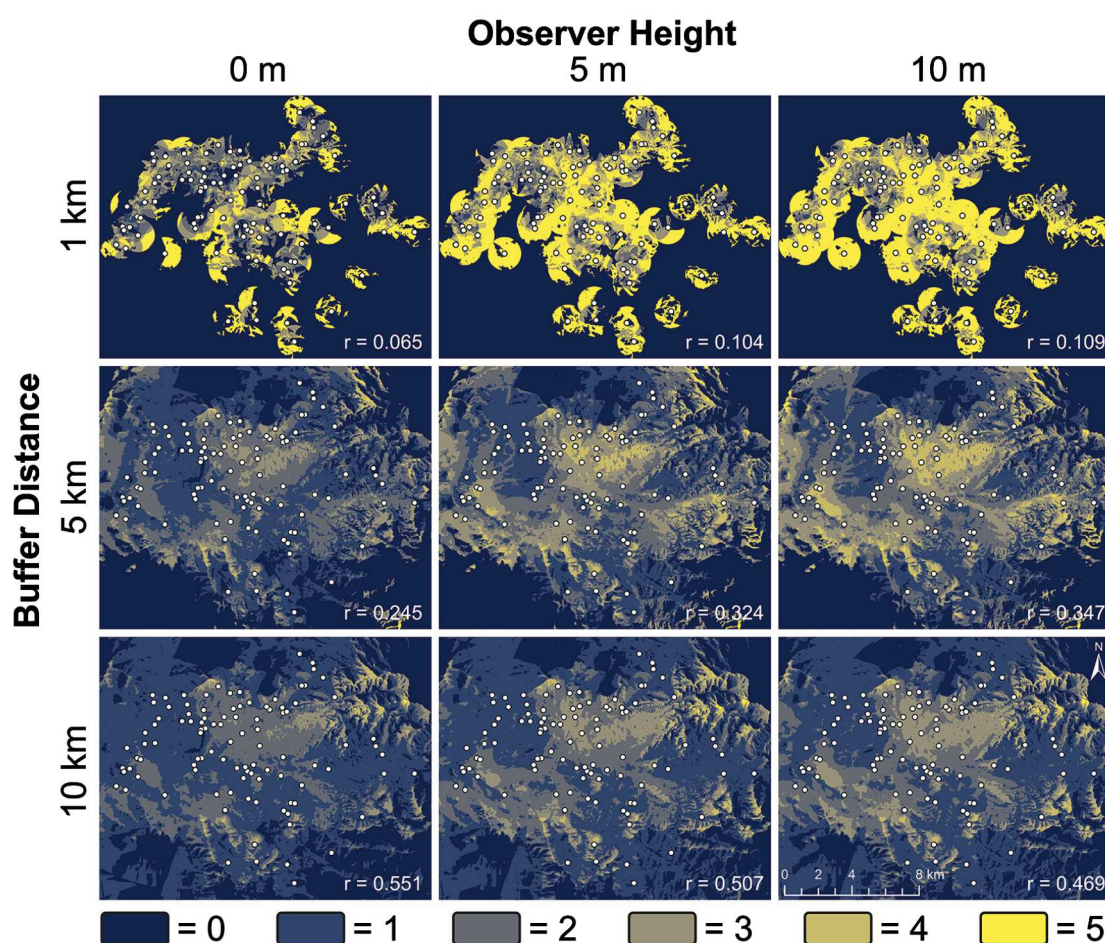


Figure 3. Classified, normalized cumulative viewsheds generated for the study area with nine different combinations of observer height and buffer distance. Correlation coefficients indicate the degree of correlation between the non-normalized raster and the normalized raster (pre-classification). All further statistical analysis was performed on the output that best represented the overall visibility landscape—a 10 km observer height with a 10 km maximum distance, seen here on the bottom right.

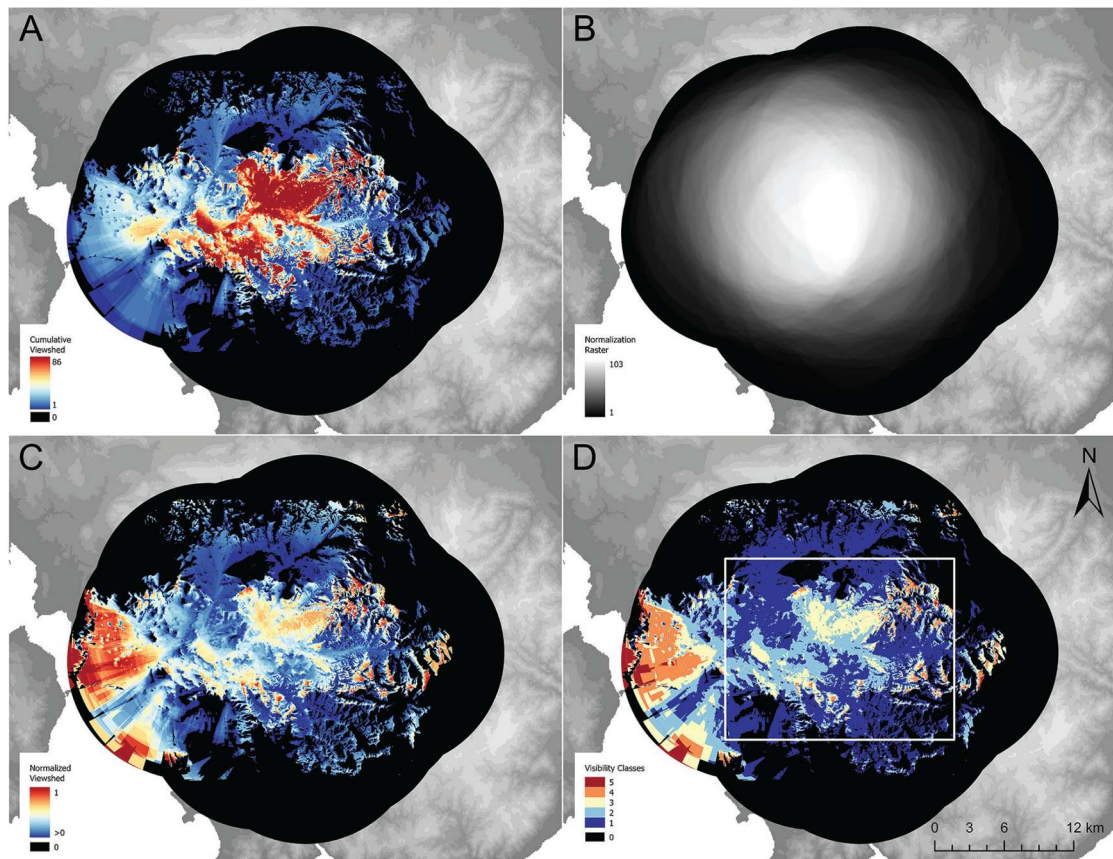


Figure 4. Steps in the cumulative viewshed normalization: A) original cumulative viewshed; B) normalization raster creating by summing the buffers around each nuraghe; C) normalized cumulative viewshed; and, D) reclassified normalized cumulative viewshed (0 = invisible; 1 = 0–.2; 2 = .2–.4; 3 = .4–.6; 4 = .6–.8; and, 5 = .8–1) with the area that was analyzed statistically outlined in white. The normalization corrects for edge effects that overly emphasize the visibility of the center of the image.

The continuous data were reclassified into pentiles with breaks at equal intervals (.2, .4, .6, and .8). The resulting visibility classes, which increased in visibility from *Class 1* (0–.2) to *Class 5* (> .8) and also included *Class 0 = No Data* (i.e., not visible from any points), were of use in qualitatively comparing visibility with various landscape features. Unsurprisingly, topographic prominence plays an important role in overall visibility. Highly visible pixels (classes 5 and 4) represent either mountain peaks or areas towards the edge of the study area whose visibility values are erroneously high from being divided by very low denominators during the normalization process. The latter—a new edge effect—was compensated for by limiting the quantitative analysis to an area defined as 1 km greater than the extent of the complete nuraghe dataset. Visibility class 3, however, appears to represent comparatively flat topography that is, nonetheless, extensively cumulatively visible. Classes 2 and 1 are successively less visible, and class 0 denotes areas that are not visible from any of the nuraghi in the Sulcis Plain.

Statistical analysis of surveillance

Having developed a general sense of cumulative visibility in the landscape by examining the visibility classes, we turned to statistical analysis to approach this problem quantitatively. Using the continuous (i.e., unclassified) normalized data, we attempted to relate areas of greater and lesser cumulative visibility to other environmental factors that can also be expressed as spatially continuous data; specifically, factors that might be supposed to render a given portion of the

environment more or less attractive for agropastoral cultivation. These factors included elevation (certain cultivars prefer particular elevation ranges), slope (lower is better for non-terraced agricultural systems), soil permeability (common cultivars in the area prefer well-draining soils), lithology (impacts the pH and the available mineral nutrients), and modern land use/cover—the latter of these as an admittedly imperfect proxy for ancient land use/cover in the absence of detailed paleoenvironmental data for the region (Figure 5). Rather than simply demonstrating overlap, we aimed to evaluate which combination of these variables best predicted visibility. In order to do so, we laid a grid of points spaced to 100 m across the study area ($n = 31,086$) and used this to sample each of the variables of interest at the same locations, thus allowing the dataset to be analyzed as discrete datapoints.

To determine the best predictors of cumulative visibility, we employed a model comparison approach (Burnham and Anderson 2004) in which we built several candidate models with different combinations of our five predictor variables and used Akaike's Information Criterion (AIC) to determine the best model of the candidate set. To our knowledge, this is the first time that such an approach has been utilized within a cumulative viewshed analysis framework, at least in the Mediterranean. Using the predictor variables of elevation, slope, land use, permeability, and lithology, we constructed 31 candidate models by identifying all possible combinations of these five covariates. The response variable was visibility—in this case, a proportion—and thus our models were binomial family generalized

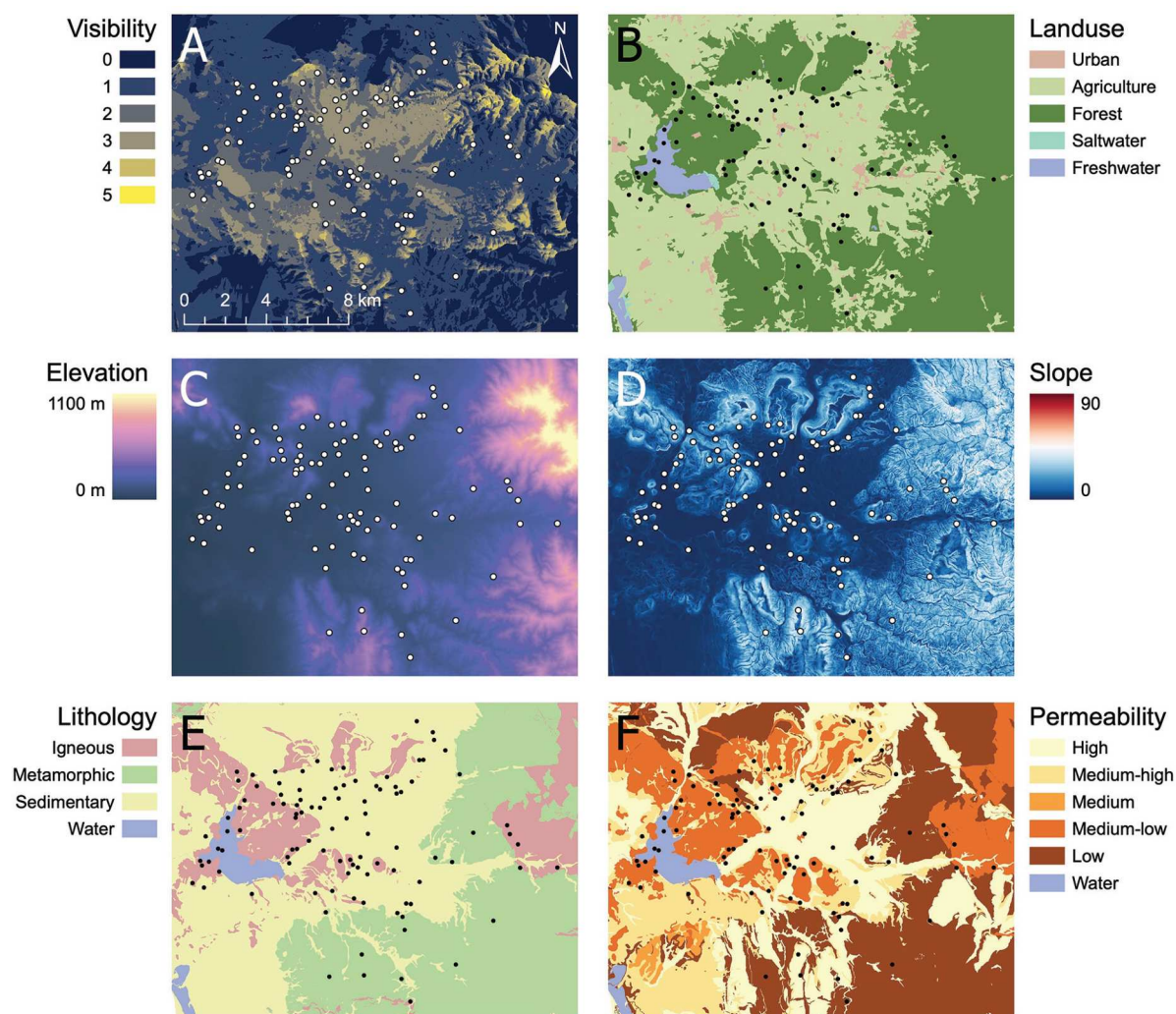


Figure 5. The A) classified normalized cumulative viewshed juxtaposed with the five predictor variables used in the GLMs: B) modern land use/cover, C) elevation, D) slope, E) geology, and F) soil permeability. Points indicate nuraghe locations.

linear models (GLMs) with canonical logit link functions. All statistical analyses were conducted in R (R Core Team 2023).

With the candidate model set constructed, we used the corrected Akaike's Information Criterion (AICc) to assess which model was best (Burnham, Anderson, and Huyvaert 2011). AICc accounts for both goodness of fit and model parsimony, but the values have no meaning independent of the candidate model set: all AICc values are relative to the data and model structure being used. The lowest AIC value represents the best model of the candidate set. Our results suggest that Model 17 is the best model of the set, which includes the predictor variables of elevation, slope, and permeability. Elevation and permeability have positive effects on visibility, while slope has a negative effect (Supplemental Material 2). The next best model was over five units away, suggesting that Model 17 was strongly superior. This was also supported by the high AIC weight of 0.937 compared to the next best model weight of 0.063 (Table 2).

While the model with elevation, slope, and permeability as predictor variables performed best, our model comparison approach can only identify the best model of those in the candidate set. It does not indicate whether a model actually has explanatory power or not. To accomplish this, we calculated the D-squared (deviance squared) statistic: an analogous measure to the more familiar R-squared, but able to

be used with GLMs (Guisan and Zimmerman 2000). Interestingly, the D-squared of our best-performing model was only 0.02, suggesting that only 2% of the deviance in our best model could be explained by the inclusion of these three predictor variables.

To assess the best possible goodness of fit obtainable using these five predictor variables, we built an overfitted model with all variables and all possible interaction effects. This model is a poor model given the lack of parsimony, but it is useful for understanding 1) how important interaction effects may be and 2) what the maximum attainable goodness of fit is for these variables. Even for this maximally overfitted model, the D-squared value was only 0.029, meaning that even with all possible predictors and interaction effects, these five variables can only account for 2.9% of the deviance, leaving over 97% unaccounted for.

This analysis demonstrates that elevation, slope, land use, permeability, and lithology are poor predictors of cumulative visibility. While the model including elevation, slope, and permeability performed best, it is simply the best of a bad candidate set of models that are incapable of explaining nuraghe placement across the landscape. None of these geographic variables predict cumulative visibility, but other important factors outside of those evaluated here may. This negative finding is nonetheless important, as we go on to discuss in the next section.

Discussion

Methodological limitations

Before we can consider the meaning of our results, it is important to indicate the interpretive limitations of this study. One such limitation results from the exclusion of any sort of site hierarchy among our corpus. The vast majority of nuraghi within our dataset are single tower tholos-nuraghi. As a result, each nuraghe is treated similarly in the analysis, without evaluation of whether larger and more complex nuraghi—whose function could conceivably have differed from the single-tower tholos nuraghi—might have been overlooking a different portion of the landscape than the ubiquitous Type I nuraghi (Schirru and Castangia 2022). Relatedly, while recognizing that nuraghi do not exist as floating points in space, but are instead structures of varying sizes and shapes, offering different visualscapes from various places on their surfaces, we have opted to treat them as points due to a lack of information on their individual dimensions (cf. Brughmans and Brandes 2017).

We also have not compared our cumulative viewshed with an independently generated total viewshed, prominence raster, or other assumed control raster, as is standard practice (Kvamme 2020; Schirru and Castangia 2022). To create a normalized total viewshed of the Sulcis Plain with a degree of spatial resolution that would make it meaningfully comparable with the cumulative viewshed required more computing power than that to which we had access. Topographic prominence is determined mainly on the basis of elevation (Kirmse and de Ferranti 2017; see Llobera 2001 for topographic prominence in archaeology), which was also one of the variables we tested against the cumulative viewshed. Because elevation was found not to contribute significantly to the differential visibility of some areas above others, it did not make sense to compare the visibility

landscape with a computationally generated prominence layer based solely on that variable.

A conceptual challenge to the sort of analysis we attempt here—although one common to much spatial analysis of settlement patterns—involves our inability to establish synchronicity, or not, of site occupation. While it is possible to grossly periodize nuraghi based on mode of construction, lack of excavation means that we have very little chronological resolution in our dataset beyond the half-millennial scale. Certainly, some nuragic villages show intermittent occupation, but whether this same temporal pattern of use can be extended to the towers themselves remains unclear—both because of the limited stratigraphic data available for the towers and because of the ambiguous nature of those data which do exist (e.g., Michels and Webster 1987, 19, 105; Webster 1988, 467–469). As we cannot establish that all the nuraghi in our dataset were in use simultaneously, 102 may be an overestimation of the number of sites within, for example, the visual network for the Sulcis Plain in the Bronze Age. This is not fatal for our analysis, however, as we are less interested in the evolution of settlement structure (impossible in any case, without high resolution dates from excavation) and more in the analysis of a quasi-artificial moment of maximum occupation of the landscape at ca. 1200 B.C. That is, assuming that a nuraghe was constructed to be occupied or used at a given point, it not being used in that manner at another arbitrary point during the Late Bronze Age does not indicate it was not constructed with the same underlying principles as those contemporaneously in use. Finally, in this vein, the issue of contemporaneity of settlement of course affects all viewshed analysis; indeed, any geospatial analysis in which contemporaneity of occupation is assumed and not formally demonstrated by radio-carbon assays.

Table 2. Model comparison results.

Model Name	K	AICc	Delta AICc	Model Likelihood	AICc Weight	Log Likelihood	Cumulative Weight	D2
Mod17	4	15084.420	0.000	1.000	0.937	-7538.210	0.937	0.020
Mod26	8	15089.830	5.408	0.067	0.063	-7536.910	1.000	0.020
Mod19	7	15106.860	22.433	0.000	0.000	-7546.430	1.000	0.019
Mod28	6	15107.260	22.833	0.000	0.000	-7547.630	1.000	0.020
Mod31	10	15107.620	23.193	0.000	0.000	-7543.800	1.000	0.021
Mod8	3	15113.310	28.892	0.000	0.000	-7553.660	1.000	0.018
Mod29	9	15139.200	54.774	0.000	0.000	-7560.600	1.000	0.019
Mod21	5	15154.170	69.752	0.000	0.000	-7572.090	1.000	0.018
Mod4	2	15239.090	154.663	0.000	0.000	-7617.540	1.000	0.017
Mod15	4	15246.200	161.774	0.000	0.000	-7619.100	1.000	0.018
Mod25	8	15275.020	190.597	0.000	0.000	-7629.510	1.000	0.018
Mod24	5	15289.940	205.514	0.000	0.000	-7639.970	1.000	0.018
Mod13	6	15291.000	206.573	0.000	0.000	-7639.500	1.000	0.018
Mod30	9	15297.890	213.463	0.000	0.000	-7639.940	1.000	0.019
Mod11	3	15308.330	223.909	0.000	0.000	-7651.170	1.000	0.018
Mod22	7	15317.700	233.279	0.000	0.000	-7651.850	1.000	0.018
Mod16	7	15839.890	755.471	0.000	0.000	-7912.950	1.000	0.009
Mod18	6	15853.790	769.370	0.000	0.000	-7920.890	1.000	0.010
Mod6	3	15855.440	771.019	0.000	0.000	-7924.720	1.000	0.007
Mod27	10	15857.510	773.087	0.000	0.000	-7918.750	1.000	0.010
Mod7	6	15885.740	801.315	0.000	0.000	-7936.870	1.000	0.006
Mod20	9	15906.670	822.248	0.000	0.000	-7944.330	1.000	0.008
Mod9	5	15916.760	832.338	0.000	0.000	-7953.380	1.000	0.006
Mod1	2	15949.830	865.412	0.000	0.000	-7972.920	1.000	0.001
Mod3	5	15980.630	896.205	0.000	0.000	-7985.310	1.000	0.006
Mod5	4	16006.220	921.796	0.000	0.000	-7999.110	1.000	0.006
Mod14	8	16036.720	952.299	0.000	0.000	-8010.360	1.000	0.007
Mod2	2	16042.040	957.617	0.000	0.000	-8019.020	1.000	0.006
Mod10	6	16053.400	968.980	0.000	0.000	-8020.700	1.000	0.007
Mod12	5	16062.420	978.001	0.000	0.000	-8026.210	1.000	0.007
Mod23	9	16070.060	985.637	0.000	0.000	-8026.030	1.000	0.007

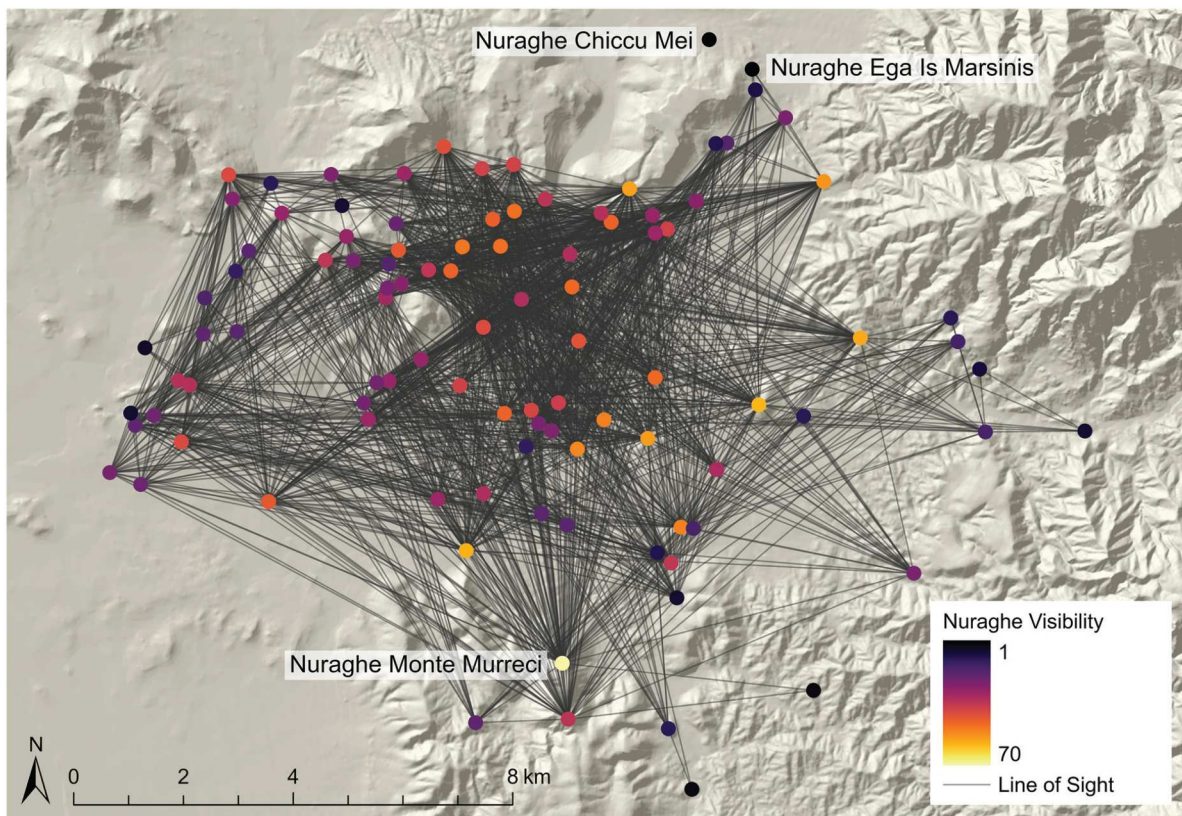


Figure 6. Lines of sight between the nuraghi of the Sulcis Plain. Each line of sight represents visibility in at least one direction. The nuraghi are color-coded by the number of other nuraghi that can be seen from them, an anisotropic measure.

Finally, one avenue we opted not to go down in this paper was formal network analysis of intervisibility (see Brughmans and Brandes 2017). Where network analysis has been employed before with regard to visibility in archaeological landscapes, it has generally been for the purpose of evaluating proposed communication or signaling networks (Brughmans et al. 2018; De Montis and Caschili 2012; Earley-Spadoni 2015; Rawat et al. 2021). The density of nuraghi in the Sulcis Plain is such that intervisibility is the norm, rather than a feature that must be deliberately sought out. While a few of the nuraghi located towards the edges of the study area and in steep terrain were mostly not visible from the other nuraghi, only Nuraghe Chiccu Mei in the extreme north was completely visually isolated from the others and neighboring Nuraghe Ega Is Marsinis could not be seen by any others in the set (but could see four itself). The rest of the sample could all be seen by between one and 69 other nuraghi—Nuraghe Monte Murreci was the most visible site and also the one from which the most others could be seen (82)—often in a mutual relationship. On average, each nuraghe could be seen by 28 other members of the group (mean = 28.3; median = 28). Thus, with such a high degree of intervisibility, we did not find it worthwhile to attempt to tease out distinct clusters of nuraghi or communication routes (Figure 6).

Interpreting settlement and settlement patterns in Nuragic Sardinia

Beyond these methodological challenges, we can turn to more substantive interpretive issues. Let us assume that our analysis indicates that visual appreciability of certain types of environments was not an important factor in the

selection of sites for nuraghe construction in the Sulcis Plain. This does not preclude that visibility of the wider environment was not a structuring factor in the distribution of nuraghi; it could be the case that visual appreciability of a type of environmental variable that we have not considered was important. For example: it could be that visual communication between nuraghi and Chalcolithic chamber tombs was a significant factor in settlement distribution. There are reasons to suppose this is intrinsically unlikely, but on the basis of our analysis we cannot exclude it. What we can exclude is that the nuraghi in the Sulcis Plain were constructed with the primary aim of overlooking certain parts of the landscape in which conditions were especially conducive to agropastoral production. In essence, our results are negative, in that our statistical parsing of Nuragic site distribution (in a sample size that should lend our analysis mathematical robusticity) fails to show any overarching pattern or trend.

Our findings parallel other attempts to analyze the spatial structure of Bronze Age settlement (e.g., De Montis and Caschili 2012; Schirru 2017; Schirru and Castangia 2022) in that there seems to be no grand underlying logic to the distribution of nuraghi, either in Sulcis or at an island-wide scale. While they may tend to be situated such that the area visible from them is greater than from a random point in the landscape, this is not to such a degree that a case can be made for territorial control via visibility of that territory. Indeed, in a context in which there is only inconclusive evidence for societal elites or the capacity to project power horizontally, we might wonder more generally how any degree of territorial control could in fact be established via simple surveillance. The potency of surveillance lies in the power of institutions to act on the resulting information;

institutions with that capacity are hard to find in the archaeological record of prehistoric Sardinia.

Rather, we would suggest that the inability to account for the distribution of nuraghi with a single model reflects one of two possible, and possibly complementary, reasons. First, we might suppose that lack of regularity in their distribution reflects that the nuraghe represents a multipurpose type of settlement. Perhaps interpretation has been led astray by the comparative uniformity of nuragic architecture, and it is possible that this uniformity masks plasticity of use. Nuraghi could have assumed varying roles depending on the location of each. Or, perhaps, an individual site's role could have differed seasonally or several roles could have been performed by a single site simultaneously. In Sulcis, we could quite reasonably posit that nuraghi were farmhouses, watchtowers, strongholds of individual lineages, centers of cult, storehouses (and perhaps corrals?), and decision-making spaces. This proliferation of roles would militate against any overall spatial pattern emerging. The few excavated assemblages from single tower tholos-nuraghi (as opposed to the larger examples) arguably support a multi-use model (Usai 2020; Webster 2001).

Second, we can build on this position by proactively inverting some of the assumptions central to viewshed analysis and spatial analysis of settlement distributions more generally. We have been operating on the tacit assumption that the form of the nuraghe is somehow where the social or symbolic content of this distinctive architecture lies; that nuraghi were *for* something and that their construction was a necessary means to a more important end (see discussion in Leighton 2022). This assumption may be unjustified. Considering the likely energetic needs and technical specifics of nuraghe construction (on which see Cappai 2003; Cavanagh and Laxton 1987)—especially in terms of person hours—their proliferation, evident rebuilding and expansion at a subset of them, increasing interest in their iconography in the period 1200–900 B.C., and lack of any obvious spatial rationale in their distribution, it may be that the process of construction was the location of social meaning, not the finished outcome. In tangential support of this might be the observation that visual appreciability *of*, not from, nuraghi, may be more important in terms of their distribution in Gesturi (Schirru and Vanzetti 2023). It may be the case that the construction of nuraghi instantiated community cohesion or cooperation and that visible appreciation of that tangible outcome of that cooperation was somehow significant. Perhaps—and here we admittedly enter a deeply speculative vein—construction happened at moments of formal social change: the establishment of a newly independent household, perhaps, or when bringing a new area under cultivation. We might envisage such activity as deeply prosocial: a nuraghe as necessary for a group (perhaps a family, perhaps another form of group) to function as a unit within the wider society but impossible to construct without dependance on that wider community, a process creating strong ties of social obligation.

Conclusion

In this paper, we have undertaken a formal analysis of the spatial distribution of 102 nuraghi in the Sulcis Plain in southwestern Sardinia. In this analysis, we aimed to establish whether these sites were situated such that they offered visual

appreciability of certain parts of this historically agropastorally productive landscape—specifically, those areas in which we might suppose Bronze Age communities to have the greatest economic interest. We derived a cumulative viewshed from publicly available lidar data, mitigated digital artifacts and edge effects, and computed discrete classes of visibility from this viewshed. We evaluated the co-occurrence of these classes against five variables that might be supposed to bear on agropastoral productivity. Specifically, we used a model comparison approach to assess which of these variables, in which combination, best predicted visibility.

The outcome is essentially negative—no model consisting of the five variables considered here is particularly effective at predicting visibility—but this in itself is of fundamental interest in attempting to unpick the logic behind the placement of nuraghi in the Sulcis Plain and more widely. The physical form of nuraghi, and the right-tailed shape of their size versus frequency (many small ones and fewer large ones), have nudged interpretation towards defense, coercion, and resource-and-access control. Increasingly powerful computational assessment of the distribution of these sites has, so far, largely failed to support this; nuraghi do not really seem to be positioned in a manner that maximizes control over human movement through or behavior within the landscape. This finding essentially parallels inferences drawn from excavated assemblages—that the nuraghi do not seem to be centers of political or social power or even necessarily implicated in defense in any conspicuous form. Our conclusions are, by and large, in agreement with this body of literature, albeit for an area of the island that had not previously been subject to analysis of this type.

Future work on this problem would clearly be of benefit if we want to better understand the esoteric nature of 2nd millennium B.C. Sardinian political organization—and, indeed, forms of political and social power in the western Mediterranean more widely, considering the extent to which they deviate from contemporary eastern Mediterranean forms. Network analytic approaches, and analyses focused on architectural energetics, might be supposed to be likely productive avenues of investigation. More generally, however, we may have to be more creative in attempts to understand what types of behaviors, assumptions, and symbolic systems nuraghi instantiate. If attempts to find evidence in support of a Hobbesian or Foucauldian dystopia continue to founder, it may be more productive to focus on new models: potentially, those that emphasize plasticity of use, prosociality, and communitarian behavior.

Acknowledgements

We are grateful for the guidance and expertise of Massimo Botto, Livia Tirabassi, Giacomo Paglietti, and Stefano Crispù, and all the staff at the Museo Civico di Santadi. We also thank Christina Luke and the two anonymous reviewers for their feedback.

Notes on Contributors

Miriam A. W. Rothenberg (Ph.D. 2021, Brown University) is a Junior Research Fellow in Archaeology at Christ Church, University of Oxford. Her research focuses on landscape, memory, and environmental hazards in the historical Caribbean and the ancient Mediterranean, drawing on landscape archaeology and spatial analysis; trauma, dark heritage, and ruination; geoarchaeology; and digital archaeology.

Thomas P. Leppard (Ph.D. 2013, Brown University) is an archaeologist with International Archaeological Research Institute, Inc. (IARII). He is broadly interested in how human behavior and human environments have co-evolved, especially but not only on islands, and has undertaken fieldwork in the Mediterranean, Caribbean, and Pacific.

Elic M. Weitzel (M.S. 2016, University of Utah) is a PhD Candidate in Anthropology at the University of Connecticut. A human ecologist, anthropologist, and archaeologist interested in how people adapt to, exploit, and shape their environments—whether those environments be natural or social—he takes a quantitative, ecological, and evolutionary approach to understanding human behavior and ecology in both the past and the present.

Elizabeth A. Murphy (Ph.D. 2014, Brown University) is an Assistant Professor of Classics at Florida State University and director of the Landscape Archaeology of Southwest Sardinia Project (LASS). An archaeologist specializing in the study of the Mediterranean during the Roman Imperial and Late Antique periods, her work focuses on the history and archaeology of labor, production, and technology, with complementary interests in ancient urbanism and the Roman military.

ORCID

Miriam Rothenberg  <http://orcid.org/0000-0002-3740-9649>

Thomas P. Leppard  <http://orcid.org/0000-0002-4803-4061>

Elic M. Weitzel  <http://orcid.org/0000-0001-5214-8451>

Elizabeth A. Murphy  <http://orcid.org/0000-0002-6817-1987>

References

- Araque Gonzalez, R. 2019. "Anarchy in the Bronze Age? Social Organisation and Complexity in Sardinia." In *Alternative Iron Ages: Social Theory from Archaeological Analysis*, edited by B. X. Currás, and I. Sastre, 74–94. London: Routledge.
- Blake, E. 1998. "Sardinia's Nuraghi: Four Millennia of Becoming." *World Archaeology* 30 (1): 59–71.
- Blake, E. 2001. "Constructing a Nuragic Locale: The Spatial Relationship Between Tombs and Towers in Bronze Age Sardinia." *American Journal of Archaeology* 105: 145–161.
- Blake, E. 2014. "Late Bronze Age Sardinia: Acephalous Cohesion." In *The Cambridge Prehistory of the Bronze & Iron Age Mediterranean*, edited by A. B. Knapp, and P. van Dommelen, 96–108. Cambridge: Cambridge University Press.
- Broodbank, C. 2013. *The Making of the Middle Sea: A History of the Mediterranean from the Beginning to the Emergence of the Classical World*. London: Thames and Hudson.
- Brughmans, T., and U. Brandes. 2017. "Visibility Network Patterns and Methods for Studying Visual Relational Phenomena in Archaeology." *Frontiers in Digital Humanities* 4: 17.
- Brughmans, T., M. S. de Waal, C. L. Hofman, and U. Brandes. 2018. "Exploring Transformations in Caribbean Indigenous Social Networks Through Visibility Studies: The Case of Late Pre-Colonial Landscapes in East-Guadeloupe (French West Indies)." *Journal of Archaeological Method and Theory* 25: 475–519.
- Burnham, K. P., and D. R. Anderson. 2004. *Model Selection and Multi-Model Inference: A Practical Information-Theoretic Approach*. New York: Springer.
- Burnham, K. P., D. R. Anderson, and K. P. Huyvaert. 2011. "AIC Model Selection and Multimodel Inference in Behavioral Ecology: Some Background, Observations, and Comparisons." *Behavioral Ecology and Sociobiology* 65: 23–35.
- Cappai, S. N. 2003. "A Hypothesis on a Building Technique to Determine the Shape of the Nuragic Tholoi." In *Proceedings of the First International Congress on Construction History*, edited by S. Huerta, 535–544. Madrid: Reverte.
- Cavanagh, W., and R. Laxton. 1987. "An Investigation Into the Construction of Sardinian Nuraghi." *Papers of the British School at Rome* 55: 1–74.
- Cicilloni, R., and M. Cabras. 2014. "Aspetti insediativi nel Versante Orientale del Monte Arci (Oristano - Sardegna) tra il Bronzo Medio e la Prima età del Ferro." *Quaderni* 25: 81–107.
- Cicilloni, R., G. Ragucci, M. Cabras, and A. Mossa. 2016. "New Approaches in Landscape Analysis of the Bronze Age in Central-Western Sardinia: The Area of Mogoro (Oristano - Italy)." *Landscape Archaeology Congress Proceedings* 2014: 1–12.
- Conolly, J., and M. Lake. 2006. *Geographical Information Systems in Archaeology*. Cambridge: Cambridge University Press.
- De Montis, A., and S. Caschili. 2012. "Nuraghes and Landscape Planning: Coupling Viewshed with Complex Network Analysis." *Landscape and Urban Planning* 105: 315–324.
- Delle, J. 1998. *An Archaeology of Social Space: Analyzing Coffee Plantations in Jamaica's Blue Mountains*. New York: Plenum.
- Dungan, K. A., D. White, S. Déderix, B. J. Mills, and K. Safi. 2018. "A Total Viewshed Approach to Local Visibility in the Chaco World." *Antiquity* 92 (364): 905–921.
- Earley-Spadoni, T. 2015. "Landscapes of Warfare: Intervisibility Analysis of Early Iron and Urartian Fire Beacon Stations (Armenia)." *Journal of Archaeological Science: Reports* 3: 22–30.
- Fábrega-Álvarez, P., and C. Parceró-Oubiña. 2019. "Now You See Me: An Assessment of the Visual Recognition and Control of Individuals in Archaeological Landscapes." *Journal of Archaeological Science* 104: 56–74.
- Fisher, P. F. 1991. "First Experiments in Viewshed Uncertainty: The Accuracy of the Viewshed Area." *Photogrammetric Engineering and Remote Sensing* 57 (10): 1321–1327.
- Fisher, P. F. 1992. "First Experiments in Viewshed Uncertainty: Simulating Fuzzy Viewsheds." *Photogrammetric Engineering and Remote Sensing* 58 (3): 345–352.
- Fisher, P. F. 1994. "Probable and Fuzzy Models of the Viewshed Operation." In *Innovations in GIS: Selected Papers from the First National Conference on GIS Research UK*, edited by M. F. Worboys, 169–184. London: Taylor and Francis.
- Gaffney, V., K. Ostir, T. Podobnikar, and Z. Stančić. 1996. "Spatial Analysis, Field Survey, Territories and Mental Maps on the Island of Brač." *Archeologia e Calcolatori* 7: 27–41.
- Gillings, M., and D. Wheatley. 2020. "GIS-based Visibility Analysis." In *Archaeological Spatial Analysis: A Methodological Guide*, edited by M. Gillings, P. Hacıgüzeller, and G. Lock, 313–332. London: Routledge.
- Given, M. 2004. *The Archaeology of the Colonized*. London: Routledge.
- Guisan, A., and N. E. Zimmerman. 2000. "Predictive Habitat Distribution Models in Ecology." *Ecological Modelling* 135 (2): 147–186.
- Hauser, M. 2014. "Blind Spots in Empire: Plantation Landscapes in Early Colonial Dominica (1763–1807)." In *The Archaeology of Slavery: A Comparative Approach to Captivity and Coercion*, edited by L. W. Marshall, 143–165. Carbondale, IL: Southern Illinois University Press.
- Ialongo, N. 2018. "Crisis and Recovery: The Cost of Sustainable Development in Nuragic Sardinia." *European Journal of Archaeology* 21 (1): 18–38.
- Kay, S., and T. Sly. 2001. "An Application of Cumulative Viewshed Analysis to a Medieval Archaeological Study: The Beacon System of the Isle of Wight, United Kingdom." *Archeologia e Calcolatori* 12: 167–179.
- Kirmse, A., and J. de Ferranti. 2017. "Calculating the Prominence and Isolation of Every Mountain in the World." *Progress in Physical Geography* 41 (6): 788–802.
- Knapp, A. B., A. Russell, and P. van Dommelen. 2021. "Cyprus, Sardinia and Sicily: A Maritime Perspective on Interaction, Connectivity and Imagination in Mediterranean Prehistory." *Cambridge Archaeological Journal* 32 (1): 79–97.
- Kvamme, K. L. 2020. "Analysing Regional Environmental Relationships." In *Archaeological Spatial Analysis: A Methodological Guide*, edited by M. Gillings, P. Hacıgüzeller, and G. Lock, 212–230. London: Routledge.
- Lake, M. W., P. E. Woodman, and S. J. Mithen. 1998. "Tailoring GIS Software for Archaeological Applications: An Example Concerning Viewshed Analysis." *Journal of Archaeological Science* 25: 27–38.
- Leighton, R. 2022. "Nuraghi as Ritual Monuments in the Sardinian Bronze and Iron Ages (Circa 1700–700 BC)." *Open Archaeology* 8: 229–255.
- Leone, M. P., J. M. Harmon, and J. L. Neuwirth. 2005. "Perspective and Surveillance in Eighteenth-Century Maryland Gardens, Including William Paca's Garden on Wye Island." *Historical Archaeology* 39 (4): 138–158.
- Leone, M. P., and S. D. Hurry. 1998. "Seeing: The Power of Town Planning in the Chesapeake." *Historical Archaeology* 32 (4): 34–62.

- Lewis, J. 2020. "Visibility of the Gask Ridge Road from Simulated Watchtowers: A Monte Carlo Testing Approach." *Journal of Archaeological Science: Reports* 33: 102482.
- Lilliu, G. 1959. "The Nuraghi of Sardinia." *Antiquity* 33: 32–38.
- Lilliu, G. 1962. *I Nuraghi: Torri Preistoriche di Sardegna*. Cagliari, Italy: Edizioni La Zattera.
- Lilliu, G. 1982. *La Civiltà Nuragica*. Sassari: Delfino.
- Llobera, M. 2001. "Building Past Landscape Perception with GIS: Understanding Topographic Prominence." *Journal of Archaeological Science* 28: 1006–1014.
- Llobera, M. 2003. "Extending GIS-Based Visual Analysis: The Concept of Visualscapes." *International Journal of Geographical Information Science* 17 (1): 25–48.
- Llobera, M., D. Wheatley, J. Steele, S. Cox, and O. Parchment. 2010. "Calculating the Inherent Visual Structure of a Landscape (Inherent Viewshed) Using High-Throughput Computing." In *Beyond the Artefact: Digital Interpretation of the Past: Proceedings of CAA2004, Prato, 13–17 April 2004*, edited by F. Niccolucci, and S. Hermon, 146–151. Budapest: Archaeolingua.
- Loots, L., K. Nackaerts, and M. Waelkens. 1999. "Fuzzy Viewshed Analysis of the Hellenistic City Defence System at Sagalassos, Turkey." In *Archaeology in the Age of the Internet. CAA97. Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 25th Anniversary Conference, University of Birmingham, April 1997*, edited by L. Dingwall, S. Exon, V. Gaffney, S. Laflin, and M. van Leusen, 82–1–82–9. Oxford: Archaeopress.
- Marcus, J. H., C. Posth, H. Ringbauer, L. Lai, R. Skeates, C. Sidore, J. Beckett, A. Furtwängler, A. Olivieri, C. W. K. Chiang, H. Al-Asadi, K. Dey, T. A. Joseph, C.-C. Liu, D. Der Sarkissian, R. Radzevičiūtė, M. Michel, M. Giuseppina Gradoli, P. Marongiu, S. Rubino, V. Mazzearello, D. Rovina, A. La Fragola, R. Maria Serra, P. Bandiera, R. Bianucci, E. Pompianu, C. Murgia, M. Guirguis, R. Pla Orquin, N. Tuross, P. van Dommelen, W. Haak, D. Reich, D. Schlessinger, F. Cucca, J. Krause, and J. Novembre. 2020. "Genetic History from the Middle Neolithic to Present on the Mediterranean Island of Sardinia." *Nature Communications* 11: 939.
- Matta, V. 2020. "Sanctuaries in the Sardinian Bronze Age and Early Iron Age Landscape (1200–700 BC): Network Analysis and GIS Approach." *Layers - Archeologia Territorio Contesti* 5: 109–124.
- Melis, P. 2017. "I Nuraghi." In *Corpora Delle Antichità Della Sardegna, La Sardegna Nuragica, Storia e Monumenti*, edited by A. Moravetti, P. Melis, L. Foddai, and E. Alba, 29–53. Sassari: Delfino.
- Michels, J. W., and G. S. Webster. 1987. *Studies in Nuragic Archaeology: Village Excavations at Nuraghe Urpes and Nuraghe Toscono in West-Central Sardinia*. BAR International Series 373. Oxford: British Archaeological Reports.
- Murphy, K. M., B. Gittings, and J. Crow. 2018. "Visibility Analysis of the Roman Communication Network in Southern Scotland." *Journal of Archaeological Science: Reports* 17: 111–124.
- Murphy, E. A., T. P. Leppard, A. Roppa, E. Madrigali, and C. Esposito. 2019. "The Landscape Archaeology of Southwest Sardinia Project: New Data and Method from the Insular Mediterranean." *Journal of Field Archaeology* 44 (6): 367–382.
- Murray, S. C. 2023. "Eastern Mediterranean Bronze Age Trade in Archaeological Perspective: A Review of Interpretive and Empirical Developments." *Journal of Archaeological Research* 31: 395–447.
- Ogburn, D. E. 2006. "Assessing the Level of Visibility of Cultural Objects in Past Landscapes." *Journal of Archaeological Science* 33: 405–413.
- Pauketat, T. R. 2007. *Chiefdoms and Other Archaeological Delusions*. Lanham, MD: AltaMira Press.
- Perra, M. 2009. "Osservazioni Sull'evoluzione Sociale e Politica in età Nuragica." *Rivista di Scienze Preistoriche* 52: 355–368.
- R Core Team. 2023. R: A Language and Environment for Statistical Computing. Version 4.3.0. Vienna, Austria.
- Rawat, N. S., T. Brughmans, V. Nautiyal, and D. D. Chauniyal. 2021. "Networked Medieval Strongholds in Garhwal Himalaya, India." *Antiquity* 95 (381): 753–772.
- Rothenberg, M. A. W. 2021. "Wind-Powered Sugar Mills as Constructions of Control in Colonial Montserrat." *International Journal of Historical Archaeology* 25 (1): 144–169.
- Russell, A. 2010. "Foreign Materials, Islander Mobility and Elite Identity in Late Bronze Age Sardinia." In *Material Connections in the Ancient Mediterranean: Mobility, Materiality, and Identity*, edited by P. van Dommelen, and A. B. Knapp, 106–126. London: Routledge.
- Russell, A., and A. B. Knapp. 2017. "Sardinia and Cyprus: An Alternative View of Cypriotes in the Central Mediterranean." *Papers of the British School at Rome* 85: 1–35.
- Sabatini, S., and F. Lo Schiavo. 2020. "Late Bronze Age Metal Exploitation and Trade: Sardinia and Cyprus." *Materials and Manufacturing Processes* 35 (13): 1501–1518.
- Scanu, G., and C. Podda. 2015. "Contributo Alla Definizione del Numero dei Nuraghi Della Sardegna: Quando la Carta Storica e Rivisitata in Ambiente GIS." *ASITA* 2015: 731–742.
- Schirru, D. 2017. "Nuraghi with a View: Understanding Visualscapes in Nuragic Marmilla (South-Central Sardinia, Italy)." *Journal of Archaeological Science: Reports* 11: 106–114.
- Schirru, D., and G. Castangia. 2022. "All Along the Watchtower: Visibility Analysis on Bronze Age Sardinian Megalithic Landscapes." *Journal of Archaeological Science: Reports* 43: 103437.
- Schirru, D., and A. Vanzetti. 2023. "Climbing the Giara: A Quantitative Reassessment of Movement and Visibility in the Nuragic Landscape of the Gesturi Plateau (South-Central Sardinia, Italy)." *PLoS ONE* 18 (8): e0289023.
- Spanedda, L., J. A. Cámara Serrano, and F. E. Salaa Herrera. 2010. "Bronze Age Settlement Patterns in Dorgali Municipality (Sardinia)." *Rivista di Scienze Preistoriche* 60: 283–306.
- Stein, A., C. Detotto, and M. Belgiu. 2022. "A Spatial Statistical Study of the Distribution of Sardinian Nuraghes." *Annals of GIS* 28 (3): 245–261.
- Supernant, K. 2014. "Intervisibility and Intravisibility of Rock Feature Sites: A Method for Testing Viewshed Within and Outside the Socio-Spatial System of the Lower Fraser River Canyon, British Columbia." *Journal of Archaeological Science* 50: 497–511.
- Trump, D. H. 1992. "Militarism in Nuragic Sardinia." In *Sardinia in the Mediterranean: A Footprint in the Sea. Studies in Sardinian Archaeology Presented to Miriam S. Balmuth*, edited by R. H. Tykot, and T. K. Andrews, 198–203. Sheffield: Sheffield Academic Press.
- Ugas, G. 2014. "La Sardegna Nuragica. Aspetti Generali." In *Corpora Delle Antichità Della Sardegna, La Sardegna Nuragica, Storia e Materiali*, edited by A. Moravetti, E. Alba, and L. Foddai, 11–34. Sassari: Delfino.
- Usai, A. 2011. "La Civiltà Nuragica, dai Nuraghi a Mont'e Prama." In *La Pietra e gli Eroi. Le Sculture Restaurate di Mont'e Prama*, edited by M. Minoja, and A. Usai, 9–16. Sassari: H-Demia.
- Usai, A. 2020. "Il Nuraghe Bingia 'e Monti (Gonnostramatza - OR), Scavi 1983–1993." In *Quaderni del LaPARS 4. Omaggio a Enrico Atzeni. Miscellanea di Paleontologia*, edited by M. G. Melis, 343–373. Sassari: Università degli Studi.
- van Leusen, M. 1999. "Viewshed and Cost Surface Analysis Using GIS (Cartographic Modelling in a Cell-Based GIS II)." In *New Techniques for Old Times—CAA98—Computer Applications and Quantitative Methods in Archaeology: Proceedings of the 26th Conference, Barcelona 1998*, edited by J. A. Barceló, I. Briz, and A. Vila, 215–223. Oxford: British Archaeological Reports.
- Vanzetti, A., G. Castangia, A. Depalmas, N. Ialongo, V. Leonelli, M. Perra, and A. Usai. 2013. "Complessi Fortificati Della Sardegna e Delle Isole del Mediterraneo Occidentale Nella Protostoria." *Scienze dell'Antichità* 19: 83–123.
- Webster, G. 1988. "Duos Nuraghes: Preliminary Results of the First Three Seasons of Excavation." *Journal of Field Archaeology* 15 (4): 465–472.
- Webster, G. 1996. *A Prehistory of Sardinia, 2300–500 BC (Monographs in Mediterranean Archaeology 5)*. Sheffield: Sheffield Academic Press.
- Webster, G. 2001. *Duos Nuraghes. A Bronze Age Settlement in Sardinia (BAR International Series 949)*. Oxford: Archaeopress.
- Webster, G. 2015. *The Archaeology of Nuragic Sardinia (Monographs in Mediterranean Archaeology 5)*. Sheffield: Equinox.
- Wheatley, D. 1995. "Cumulative Viewshed Analysis: A GIS-Based Method for Investigating Intervisibility, and its Archaeological Application." In *Archaeology and GIS: A European Perspective*, edited by G. Lock, and Z. Stančić, 171–185. London: Taylor and Francis.
- Wheatley, D., and M. Gillings. 2000. "Vision, Perception and GIS: Some Notes on the Development of Enriched Approaches to the Study of Archaeological Visibility." In *Beyond the Map: Archaeology and Spatial Technologies*, edited by G. Lock, 1–27. Amsterdam: IOS.

- Wheatley, D., and M. Gillings. 2002. *Spatial Technology and Archaeology: The Archaeological Applications of GIS*. London: Taylor and Francis.
- White, D. A., and S. B. Barber. 2012. "Geospatial Modeling of Pedestrian Transportation Networks: A Case Study from Precolumbian Oaxaca, Mexico." *Journal of Archaeological Science* 8: 2684–2696.
- Williams, J. 2017. *The Archaeology of Roman Surveillance in the Central Alentejo, Portugal*. Berkeley: California Classical Studies.
- Witcher, R. 1999. "GIS and Landscapes of Perception." In *Geographical Information Systems and Landscape Archaeology*, edited by M. Gillings, D. Mattingly, and J. van Dalen, 13–22. Oxford: Oxbow.
- Yekutieli, Y. 2006. "Is Somebody Watching You? Ancient Surveillance Systems in the Southern Judean Desert." *Journal of Mediterranean Archaeology* 19 (1): 65–89.
- Zamora, M. 2007. "Total and Cumulative Viewshed: An Application in the Genil River Valley." In *The World is in Your Eyes. CAA2005. Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 33rd Conference, Tomar, March 2005*, edited by A. Figueiredo, and G. L. Velho, 313–318. Tomar, Portugal: CAA Portugal.