ABSTRACT

Archaeology and the Palimpsest of Landscape: Developing Theoretical Frameworks and Geographic Information Systems Applications Toward Diachronic Landscape Analysis at San Giuliano, Italy

Lauren Sides

Director: Davide Zori, Ph.D.

Landscape archaeology studies past people and their relationship to space by regarding observable modification of the natural environment as a palimpsest recording cultures across time. This study aims to assess the San Giuliano landscape as such a palimpsest through a variety of Geographic Information Systems (GIS) applications. To address criticisms of disjointed landscape archaeological theory, this paper suggests a multi-faceted theoretical framework that draws upon the ideas of Human Behavioral Ecology, Phenomenology, and Spatial Syntax. The utility of this framework is demonstrated using spatial data collected by the San Giuliano Archaeological Research Project. Site suitability models of Southern Etruria are used to evaluate specific environmental variables and their respective weights toward regional site location patterns. Generated experiential models showing intervisibility between the San Giuliano plateau and necropolis demonstrate Etruscan inhabitants' cognition of space. Finally, network analyses of caves comment on social structure during the medieval period. Overall, these applications highlight the strengths of combining processual and post-processual approaches and GIS technology for nuanced interpretations of archaeological landscapes.

APPROVED BY DIRECTOR OF HONORS THESIS:

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Dr. Davide Zori, Baylor Interdisciplinary Core

APPROVED BY THE HONORS PROGRAM:

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Dr. Elizabeth Corey, Director

DATE: ________________________

ARCHAEOLOGY AND THE PALIMPSEST OF LANDSCAPE: DEVELOPING THEORETICAL FRAMEWORKS AND GEOGRAPHIC INFORMATION SYSTEMS APPLICATIONS TOWARD DIACHRONIC LANDSCAPE ANALYSIS AT SAN GIULIANO, ITALY

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Lauren Sides

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Lauren Sides

CHAPTER ONE

Introduction

Until its abandonment before AD 1300, archaeological evidence at the San Giuliano plateau suggests that the site was continuously occupied from the Late Bronze Age onward (Sasso 2005, 88). Even the church of San Giuliano, after which the plateau is named, only fell into disuse sometime during the 16th century (Guerrini 2001, 73). At the height of its occupation during the Etruscan period (800-300 B.C.E.), inhabitants at the San Giuliano plateau constructed hundreds of rock-cut tombs in the surrounding escarpment, effectively creating a “city of the dead” that mirrored their city of the living. However, extensive looting of these tombs since the end of the Etruscan period has made archaeological interpretation of past people at San Giuliano a challenge.

On the modern landscape, the site is located just north of Barbarano Romano in the province of Viterbo. Archaeologists and historians hypothesize that inhabitants of the San Giuliano plateau relocated to Barbarano Romano, where a vibrant community still lives today. However, information about constitutive phases of occupation at the San Giuliano plateau and relocation to Barbarano Romano is limited, with the Barbarano territory at large defined by a lack of historical records until the Early Medieval Period (Guerrini 2003, 131).

Baylor University’s San Giuliano Archaeological Research Project (SGARP) has worked in collaboration with Italian partners since 2016 to survey and excavate at San Giuliano, with the primary goal of “reconstruction of the long-term changes in human occupation from prehistory until the end of the medieval occupation of the site” (Zori

2017, 18). This thesis uses survey data from the 2016-2018 field seasons to contribute to SGARP's aim of diachronic reconstruction using landscape archaeological analysis. Much as the written layers of literal textual palimpsests could not be effectively deciphered without modern innovations in digitization technologies, Geographic Information Systems (GIS) offer the same means of digitizing SGARP's survey data to decipher the landscape's layers of occupation.

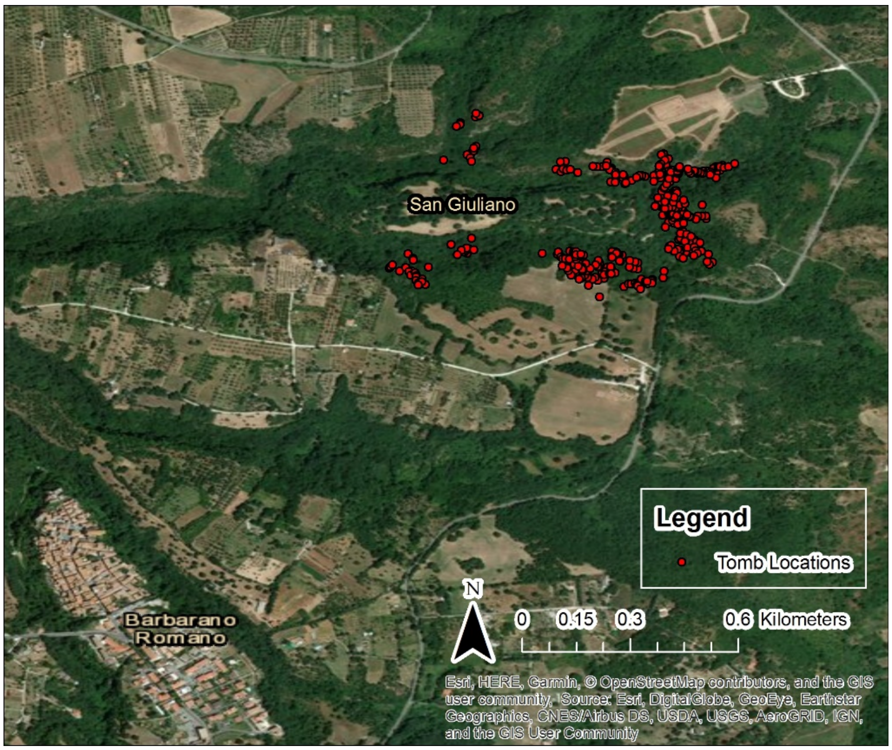


Figure 1. The San Giuliano plateau, which is just north of Barbarano Romano. Each tomb in the necropolis surrounding the plateau is represented in red.

Chapter Two begins with a discussion of landscape archaeological theory, and the limitations of purely positivist or post-processual modes of landscape analysis. Ultimately, a multi-theoretical framework is argued for, as combining theoretical approaches offers the means for a more holistic interpretation of human activity on a landscape at both the societal and individual level. Furthermore, this chapter briefly outlines how the aims of each contributing theoretical framework will be realized using Geographic Information Systems (GIS) visualization and toolsets.

In Chapter Three, the San Giuliano landscape is analyzed in terms of its relationship with the broader region of Southern Etruria. This chapter uses Human Behavioral Ecology as the theoretical approach for this interpretation, compiling regional geological and ecological geospatial information to determine the most significant factors for Bronze Age site location decisions that resonate into the Etruscan period.

Chapter Four employs a Phenomenological approach to the San Giuliano landscape by conducting viewshed analysis between the necropolis and habitation area. This study is purposed to examine how individual visual experience of the landscape can inform conceptions of memory and social organization at San Giuliano throughout the Etruscan period.

Chapter Five uses Spatial Syntax theory to analyze the San Giuliano landscape during the medieval period. Using Guerrini's typology of caves on the plateau, categorization of the cave types' accessibility, symmetry, and distributedness using network analysis informs discussions of the social ordering of space.

Finally, the Conclusion synthesizes the results of analysis using these three approaches to the San Giuliano landscape. This synthesis offers a broader understanding of why the site was first chosen for settlement and how inhabitants experienced their constructed landscape over time.

CHAPTER TWO

Landscape Archaeology: Theory and Methods

"Landscape archaeology" arose as a term in the early 1970s, effectively marking the transition in archaeology from simply recording sites to interpreting the "extensive, chronologically complex cultural landscapes" associated with them (Fleming 2006, 267). The underlying theory of the discipline relied on an understanding of cultural landscape as separate from the natural landscape, a concept first defined by the landscape theorist Carl Sauer (Darvill 2016, 61). Sauer most famously wrote that the cultural landscape acts as a palimpsest of human activity, eternally bearing the resemblances of the cultures that adapted, defined, and co-evolved with the space (Sauer 1969, 333). This idea of interpreting physical space dominated research into the 1980s, during which landscape archaeologists called upon interdisciplinary methods to reconstruct past environmental contexts and social organization, as a means of "systematically addressing human organization and scheduling" in a landscape throughout time (David and Thomas 2008, 28).

Early analytical techniques of landscape archaeology primarily relied on created spatial and temporal models of landscape, which revealed statistically likely patterns of behavior and adaptation (e.g. Judge and Sebastian 1988; Kohler and Parker 1986; Kvamme 1983). Consulting Hawkes' "ladder of inference," which lists in order of increasing difficulty to infer via the archaeological record: "technology," "subsistence-economics," "social/political institutions," and "religious institutions and spiritual life," as observable aspects of human activity, these positivist models were limited to commenting on only the bottom two rungs of the ladder (Hawkes 1954, 161-162). Thus, post-processual landscape archaeology was born from criticisms of how the positivist origins of landscape archaeology restricted archaeologists from asking fundamental questions about the upper rungs of Hawkes' ladder. Post-processual archaeologists argued that predictive models ignored the humans who lived in the landscapes under investigation, leading archaeologists to produce reductive conclusions on human experiences of landscape (e.g. Bender 1993; Thomas 1993; Tilley 1994). This conflict in theory is at the heart of modern landscape archaeology, as the two approaches require distinct methods to achieve their disparate aims in analyzing cultural landscapes.

As "research frameworks are meant to provide the most compelling inferences about the archaeological record," constructing a relevant theoretical framework is "best achieved through the combination of components from multiple theories and methodologies" (Fladd 2017, 127). Thus, the research framework of this study considers the aims of positivism and post-processualism and proposes a unified theoretical framework incorporating both heuristic modeling of and experiential approaches to cultural landscapes. Specifically, this chapter will explore the seemingly incongruent theories of Human Behavioral Ecology and Phenomenology and suggest how Spatial Syntax theory provides a mechanism of bridging the gap between the two and allows for inferences about even the top rungs of Hawkes' ladder. Furthermore, this chapter argues that Geographic Information Systems (GIS) provides the optimal method for achieving these theoretical aims.

Theoretical Research Framework

Human-Behavioral Ecology

Positivism, as the guiding principle of all sciences, maintains that the theory and methods of scientific inquiry must be entirely separated, and that hypotheses posed by practitioners must be testable and predictable (Johnson 1999, 38-39). Given these principles, positivist archaeological interpretation produces deductive generalizations of ideas of human development, which for the most part, can only be made about technological and subsistence behaviors. Thus, one of the most critical modes of positivistic archaeology is Human Behavioral Ecology, which is concerned with interpreting observable adaptive behavior in the archaeological record.

Human Behavioral Ecology assumes that human behavior is normative and functional because it is guided by the evolutionary theories of biological inheritance and natural selection (Bird and O'Connell 2006, 146). Humans will adapt to their environments and pass on adaptive behavioral traits genetically; consequently, technology and subsistence development behaviors that increase fitness are favored and selected, which should be reinforced in the archaeological record (Bird and O'Connell 2006, 147). Archaeological questions can thus be answered by comparing the record to models of optimal behavior in a certain environment (Bird and Codding 2016, 147)

For the most part, archaeologists whose work is guided by human behavioral ecology tend to produce ecological models that show adaptive subsistence and reproductive strategies, which they compare with the archaeological record to deduce general theories of how past humans adapted (Johnson 1999, 173). In landscape archaeology specifically, models of site suitability guided by these same principles of optimality can help determine the importance of certain variables for site selection as well as for predicting where undiscovered sites may exist.

However, these models have been criticized as limited in explanatory power, especially as the results of these models can only comment on nomothetic laws for human behavior and ignore the contextual and structural influences on site selection and development. Additionally, human behavioral ecology as a whole has been criticized as environmentally deterministic, regarding cultures solely as "functions of, or shaped by, environmental pressures" (Gaffney and Leusen 1995, 368). As such, these models write off the "ritual and cognitive aspects of site location" entirely (Gaffney and Leusen 1995, 368).

Thus, while predictive models through human behavioral ecology provide a means of rigorous scientific analysis of a broad landscape, presenting interpretations through this approach as indiscriminate truth promotes with false certainty results that ignore the complex factors introduced by humans as agents on a landscape. While archaeologists should be mindful of impressing modern ideas of social or political structure and cognition of space on archaeological phenomenon, models of cultural landscapes through human behavioral ecology do not even attempt to comment on individual experience of the landscape, and thus cannot wholly communicate an authentic past.

Phenomenology

While human behavioral ecologists are certainly correct in asserting that environmental variables significantly impact the shaping of cultural landscapes, many archaeologists choose to study landscape through a phenomenological approach. Phenomenology embraces a "belief in the importance of people's thoughts and symbolism, and with this a belief that cultures could not be viewed purely as adapting to an external environment" (Johnson 1999, 103). Thus, some of the cultural factors analyzed by phenomenologists range from sensory experience of the landscape to even the experience of the spiritual or supernatural, in liminal spaces that have been called "spiritscapes" (McNiven 2003, 335).

Ultimately, this range of factors can all fall under the umbrella of phenomenological theory because the approach developed in rejection of the positivist mandate of separating theory and method. Consequently, phenomenology is inherently interpretative, focusing on the cultural context and the role of the individual in shaping the archaeological record. The method for conducting this interpretation of the cultural landscape is through "embodiment" in which information is collected and analyzed "through perceptual experience of them [landscapes] from the point of view of the subject" (Tilley 2016, 271). Embodiment acknowledges the agency of individuals, while stressing the "materiality" of the landscape, which is experienced sensorially and temporally (Tilley 2016, 271-2). However, embodiment also requires an understanding of the "representations" that are present on the landscape, such as perceived place and paths, which can only be approached through contextual knowledge of the culture (Tilley 2016, 271-2).

Criticisms of phenomenology are that the theories and methods are "uncorroborated," "untestable," and "want verification" (Fleming 2006, 268). Embodiment as a method has none of the rigor of predictive modeling, and as such, allows for unchecked inductive reasoning and confirmation bias. However, without phenomenological theory in landscape archaeological analyses, “processes of social power,” cosmological understandings.” “memory and remembrance,” and “religious beliefs that concern the soul” and afterlife are all untouchable (David et al. 2016, 158-159). Thus, both positivist and post-processual modes of analysis must be used to interpret a cultural landscape, weighing their mutual criticisms to approach a more balanced understanding of the multitude of variables that constitute a cultural landscape.

Spatial Syntax

Spatial syntax theory is a relational framework developed by Hillier and Hanson (1984) for understanding architecture on a landscape, based on how spatial order can inform social order. This theory focuses on architecture in space in terms of dispersion and accessibility to make inferences about social stratification, as “the ordering of space influences modes of social interaction, [and] buildings have sociological meaning” (Ferguson 1996, 11). As the spatial syntax analyses involve representing architectural features and their relationships on a landscape, the strengths of this method are that it allows for interpretation considering both how architecture and the larger environment shape cultures, “while simultaneously allowing for the agency of individuals and their ability to alter the imposed structure” (Fladd 2017, 129).

The power of spatial syntax lies in its methodology, which classifies all space semiotically via morphic language, the syntax of which defines the structure of architectural features, their relations, and the space in between (Ferguson 1996, 12). According to this morphic language, “axial” space represents space that has related features or paths, and “convex” space represents the space in between (Hanson and

Hillier 1984, 16). Architectural features are represented as a cell or node, and the axes between them demonstrate relationships, which are further classified based on relational symmetry and distributedness (Ferguson 1996, 13). Symmetry indicates that a relationship between nodes is “equivalent and direct,” while asymmetry indicates that there is intervening space between the two nodes (Ferguson 1996, 13). Distributedness indicates “the presences of more than one nonintersecting route between spaces,” while nondistributedness defines “only a single nonintersecting route” (Ferguson 1996, 13).

Ultimately, as the strengths of spatial syntax lie in its method of classification, underlying spatial syntax theory leaves plenty of room for interpretation from outside anthropological and sociological theory. Hillier and Hanson suggest a general theory for interpreting spatial syntax classification in a way that aligns closely with a Durkheimian understanding of solidarity. They choose to interpret the presence of multiple pathways as an indication of inequality between cultural sub-groups, such as economic classes or genders, suggesting that multiple pathways evidence “differential forms of solidarity and different degrees of access” (Hillier and Hanson 1984, 257). However, many other landscape archaeologists have used spatial syntax in ways that closely resemble the aims of both Human Behavioral Ecology and Phenomenology.

Ultimately, spatial syntax offers a comprehensive framework for classifying space in terms of relationships between archaeological features to inform spatial and social order. Where Human Behavioral Ecology leaves off in addressing culture in its models, spatial syntax picks up by suggesting “a relationship between settlement form and social forces” (Hillier and Hanson 1984, 82). This social relationship can further be analyzed according to the sites known context to inform phenomenological interpretations further up Hawkes' ladder, such as religious institutions and cognitive experience.

GIS Methods and Theory

Geographic Information Systems (GIS) allows for users to map spatially referenced data for ease of visualization and analysis. It is a powerful tool of organization that, when used to aggregate data, produce models, and calculate relevant spatial statistics, can falsify or verify archaeologists' hypotheses about cultural landscapes. In addition to hypothesis testing and model building, visualization of geological, climatological, and other landscape data in ArcGIS can allow for the reconstruction of past landscapes so archaeologists can discuss landscape changes over time. This can be done through statistical modeling of natural processes on a landscape, such as erosion (Ducke 2008, 15). The importance of this reconstruction is that it provides the means for deducing trends and correlations that may go unnoticed on the modern natural landscape, and furthermore, gives rise to meaningful diachronic study of cultural landscapes as palimpsests.

Ultimately, digitizing spatial archaeological data in GIS provides the perfect canvas for conducting theoretical analyses through this study's proposed research framework. From the perspective of human behavioral archaeology, predictive models can analyze the multivariate environmental influences on landscape development and speak to a site in relation to its broader region. GIS also provides a powerful tool for embodiment by presenting statistical viewsheds that can comment on the sensorial experience of an individual on a specific landscape. Viewshed results can be paired with a study of the contextual structural influences on individual agency to produce site-specific interpretations of spatial patterning. Finally, spatial syntax using GIS allows for ease of visualizing classified and relational space, and through cluster and network analyses, speak to nodal symmetry and distributedness to make claims about social structure at a site.

Human Behavioral Ecology

As the aim of human behavioral ecology archaeology is to use optimal models against the actual archaeological record as the arbiter for cultural landscape analyses, GIS programs, such as ArcGIS, feature analytical tools perfectly suited for model building. While patterns and environmental variables for settlement patterns may seem evident when visualizing regional spatial data, ArcGIS' wide array of spatial statistical toolsets allows for generating quantitative data for "identifying multivariate patterning" and the relative contributions of environmental and cultural variables (Conolly and Lake 2006, 181). This is because predictive models generated in ArcGIS determine statistical significance of site distribution across the landscape so that researchers can reject the null hypothesis, that spatial data is organized on a landscape without any relationship to one or more variables, with statistically significant certainty (Conolly and Lake 2006, 145-146).

The first step for building a predictive model is to gather appropriate attributive data for the region of study. Potentially relevant primary data can include aerial or satellite imagery, historical maps, digital elevation models, or other survey data. Furthermore, available open source datasets that contain landscape attribute information on regional vegetation, land use, hydrology, soil types, and geology are necessary (Conolly and Lake 2006, 145). These primary datasets allow for secondary datasets relevant toward predictive modeling to be generated in ArcGIS, such as slope, aspect, watershed, distance to water sources, soil productivity, erodibility, exposure, and solar angles (Conolly and Lake 2006, 182).

In order to conduct relevant spatial analyses, an optimality framework developed from a Site Suitability Index must be generated (Issa and Saleous 2018). Best practice for generating this index include looking at the contemporary landscape alongside ethnographic and literary sources on the area to determine optimal adaptive solutions for site selection in the region of study. This Site Suitability Index will list different environmental variable optimal values and their weights according to determinant importance (Issa and Saleous 2018).

Within ArcGIS, this collected spatial data can be organized within a geodatabase for spatial analysis. Each data layer should be combined and according to multivariate analysis techniques, such as “Weighted Overlay” using the Spatial Analyst toolset functions in ArcGIS (Conolly and Lake 2006, 145). Weighted overlay analysis generates a single multiband raster output from combined primary and derived datasets to show frequency of intersections between optimal variables from the Site Suitability Index. This suggests areas most suitable for site development according to human behavioral ecology optimality theory, which can be compared with the actual location of sites in the area.

Ultimately, predictive models generated in ArcGIS through this method should reveal “the extent to which a site location may have been influenced by a complex interaction of environmental factors,” and subsequently, which environmental factors have the most influence (Conolly and Lake 2006, 180). Results from these regional analyses can also determine the role that a specific site plays in its larger regional network, according to model-revealed environmental factors that carried the most weight for site location (Woodman 2000, 453).

Phenomenology

Landscape analysis in accordance with the aims of phenomenology can also be conducted in ArcGIS by generating experiential variables, such as viewshed, or visibility models (Rennell 2012, 513). Visibility models can inform the interpretation spatial patterns that are the result of individual experience of landscape, as “visual qualities are linked with cognitive, perceptual and symbolic associations and provide alternative to previous economic and environmentally dependent explanations” (Rennell 2012, 513). Thus, these models provide quantitative data for the discussion of agency in shaping a landscape, which is even more powerful when paired with contextual information about the social, political, or religious institutions that inform the structures of a culture.

Similar to predictive modeling, the first steps for phenomenological analysis in ArcGIS is data collection. However, the primary means of acquiring relevant phenomenological data is through pedestrian survey that achieves the aims of embodiment by recording sensorial quantitative attributes of the landscape (Tilley 2016, 271). The quantitative landscape attributes necessary for viewshed analysis are a digital elevation model of the area, along with the georeferenced locations where an observer of the landscape would stand (Wheatley 1995, 172).

Viewsheds are generated in ArcGIS using 3D Analyst tools, in which one can use observer locations and heights to determine a total viewshed or a cumulative viewshed of the landscape. In a total viewshed map, binary values are assigned to raster cells, with “0” indicating that a cell is not visible and “1” indicating that the cell is within the line of sight from any defined observer point, effectively demonstrating intervisibility between two areas (Wheatley 1995, 173). However, in a cumulative viewshed map, cells are assigned values ranging from "0" to *n*, in which *n* is defined by the number of observer points being analyzed. Consequently, a cumulative viewshed model will show areas of higher and lower visibility "in order to explore how monumental buildings might be experienced from the surrounding landscape" (Rennell 2012, 521).

However, as viewsheds are purposed to generate experiential data for an environment that may be drastically different from the modern environment in terms of vegetation, erosion, or land use, probabilistic modeling and fuzzy viewsheds provide a means of interpolating visibility models with higher statistical certainty (Fisher 1991, 1321). In these probabilistic models, uncertainty of surface elevation values is increased by introducing Root Mean Square Error (RMSE) to the model. Consequently, the visibility results in the probabilistic models show the sum of probabilities that a cell is visible to an observer so intervisibility can be discussed with statistical certainty (Fisher 1991, 1323). Thus, the criticism that methods of analysis in phenomenology lack rigor can be effectively addressed by employing the theory in conjunction with ArcGIS methods of analysis.

While there are certainly limits to what viewsheds and intervisibility can reveal about individual experience of a landscape, viewshed models "provide a baseline" upon which other agent-based data and interpretation can stand on (Rennell 2012, 523). Ultimately, it is the contextualization of this data that is most important for phenomenological interpretation, as understanding of cultural structures that affect agents on a landscape allows archaeologists to consider social, ceremonial and ritual, and spiritual experience on a landscape alongside statistically rigorous models of experience (Llobera 2007, 67).

Spatial Syntax

Alongside the morphic language and traditional graphical representation inherent to spatial syntax approaches to landscape, ArcGIS can incorporate georeferenced relational models with network and cluster analysis to bolster conclusions about social relationships reflected in the landscape. Using ArcGIS, architecture or features are recorded by GPS location and digitized as nodes, which have the capacity to be topographically related to other nodes via network routes (Conolly and Lake 206, 247). Additionally, within the geodatabase storing these nodes, qualitative attribute data can be added to characterize each node, such as architectural features and chronology. Relationships between nodes are thus defined by conducting cluster analysis through Ripley's K Means to assess statistically likely related structures based on all available information.

Following cluster analysis, ArcGIS's Network Analyst toolset allows for routes to be created between nodes (Abubakar and Aina 2006). These routes are determined according to their viability as a most likely path, which are those paths that incur the least cost in terms of defined environmental attributes, such as distance or slope of the path (Conolly and Lake 2006, 252). After these network nodes and paths are defined, accessibility scores can be generated for each network across the landscape using the Network Analyst Accessibility Index tool (Abubakar and Aina 2006). Noted differences in accessibility can inform discussions of function, organization, or diachronic change in the landscape. Thus, spatial syntax revealed through cluster and network analysis in

ArcGIS on architecture in a landscape has important implications for studying landscape as a palimpsest.

Ultimately, especially when recalling Sauer's conception of landscape as a palimpsest of the multitude of cultures and agents interacting with a landscape, congruence in interpretation through all three theoretical and methodological approaches is necessary for balanced approaches to each rung of Hawkes' ladder of archaeological inference. Predictive modeling through human behavioral archaeology allows for analysis of a site in an environmental and economic context, while phenomenology takes the opposite approach by using specific contextual details to support claims about individual experience and agency in a cultural landscape. Spatial syntax theory balances between the two, using optimal clustering and network analyses to make claims about individual experience of accessibility and the social structures represented by those relational networks. In combination, this theoretical framework fills in the holes left by purely positivist or post-processual modes of landscape archaeological analysis, and effectively communicates the multitude of influences that make up cultural landscapes.

CHAPTER THREE

Site Suitability Modeling in Southern Etruria

The Southern Etruria landscape has been occupied by humans since the Neolithic period, with the earliest concrete archaeological evidence of settlement near San Giuliano being pottery fragments dating to the Early Bronze Age (Sasso 2005, 88). Regionally, the sites occupied during the Late Bronze Age and Proto-Villanovan periods (1300-700 B.C.E.) eventually become larger village centers during the Villanovan period (900-700 B.C.E.) and urban centers during the Etruscan period (700-300 B.C.E.) (Steingräber 2008, 13). At the end of the Villanovan period, five major settlement centers emerge: Caere (Cerveteri), Veii, Tarquinia, Vulci, and Volsinii (Orvieto) (Steingräber 2008, 13). Interactions between these urbanizing centers and their surrounding hinterlands ultimately pave the way for Etruscan development and urbanization across the region, at which time smaller sites like Norchia, Blera, San Giovenale, and San Giuliano become incorporated into the Etruscan cultural and economic network.

From a Human Behavioral Ecology (HBE) perspective, these site locations remain from the Pre-Villanovan period to the Etruscan period because they are optimally adapted to the environmental factors that define and constrain the landscape. Otherwise, site selection behavior at locations that are not optimal for human occupation would have been selected against according to evolutionary theory. This chapter seeks to analyze the San Giuliano landscape and the broader region of Southern Etruria from this perspective, with an understanding of a landscape as the environmental variables that spatially constrain an individual's reproductive fitness (Bird and Codding 2016, 296).

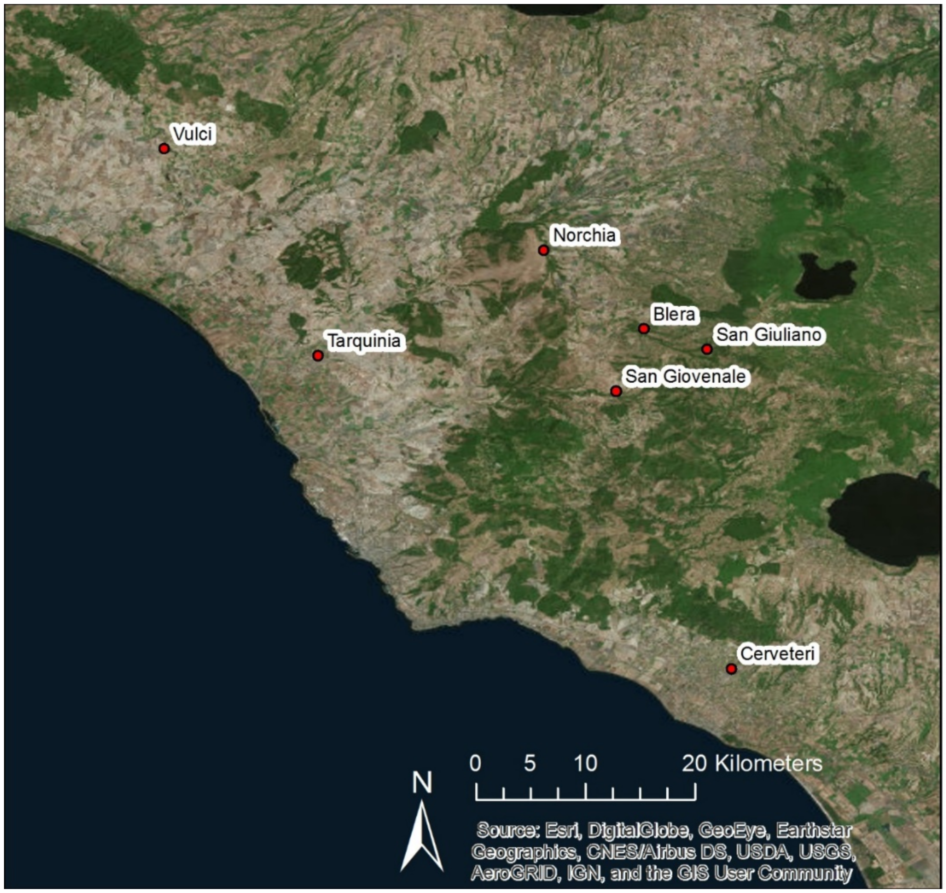


Figure 2. Representation of several prominent Etruscan centers in Southern Etruria, which will be particularly relevant for this study. Basemap imagery from Esri DigitalGlobe.

Following previous HBE modeling studies, predictive modeling of the landscape was carried out in four stages: data acquisition, site suitability indexing (SSI), modeling in ArcGIS, and interpretation of weighted analysis (Conolly and Lake 2006, 181). The purpose of the model is to test the hypothesis that there is a relationship between the optimal environmental variables in Southern Etruria and the presence of archaeological sites. The hypothesis further considers the relative weights of determinant landscape variables by comparing the optimal locations modeled on the landscape with the actual location of archaeological sites, with optimality assessed according to SSI values. The SSI is generated independently based on which environmental factors are emphasized in geological and ecological scholarship and literature about the region for the Late Bronze Age to Villanovan periods.

Geological and ecological data requested from Geoportale Nazionale, Open Data Lazio, and additional European GIS databases were compiled in ArcGIS for an overall understanding of the makeup of the landscape. Further data, such as slope and aspect, were developed mathematically in ArcMap. Weighted overlay of the multitude of layers in accordance with the constructed site suitability index reveals areas of high, medium, and low suitability.

Models that best fit the true archaeological record offer a baseline for discussion of the most important environmental variables for settlement in this area, which is especially important given the lack of written record about the inhabitants of Southern Etruria until the area is conquered by the Roman Empire. Temporally and spatially patterned behavior of site location decisions in the Southern Etruria region can reveal insight into the economic relationships between sites in the region, as well as comment on San Giuliano's role in the larger network of settlements leading into the Etruscan period.

Geological and Ecological Overview

Regional Geology

The most significant influence on the formation of the region of Southern Etruria was the Vico volcanic events of the Pleistocene (Perini et al. 1997, 140). There are three distinct periods of eruption and lava flow from 419 kya to 95 kya, which make up the Vicano chronostratigraphic system (Perini et al. 1997, 142). Archaeologically, this volcanic geological profile is a noteworthy environmental factor for site settlement, as the Vico eruptive events deposited layers of consolidated tuff across the region. Tuff's relative softness means that it has been easily eroded by rivers and streams on the landscape, which Guerrini says would have created natural pathways through valleys that prehistoric peoples would have followed (Guerrini 2003, 127).

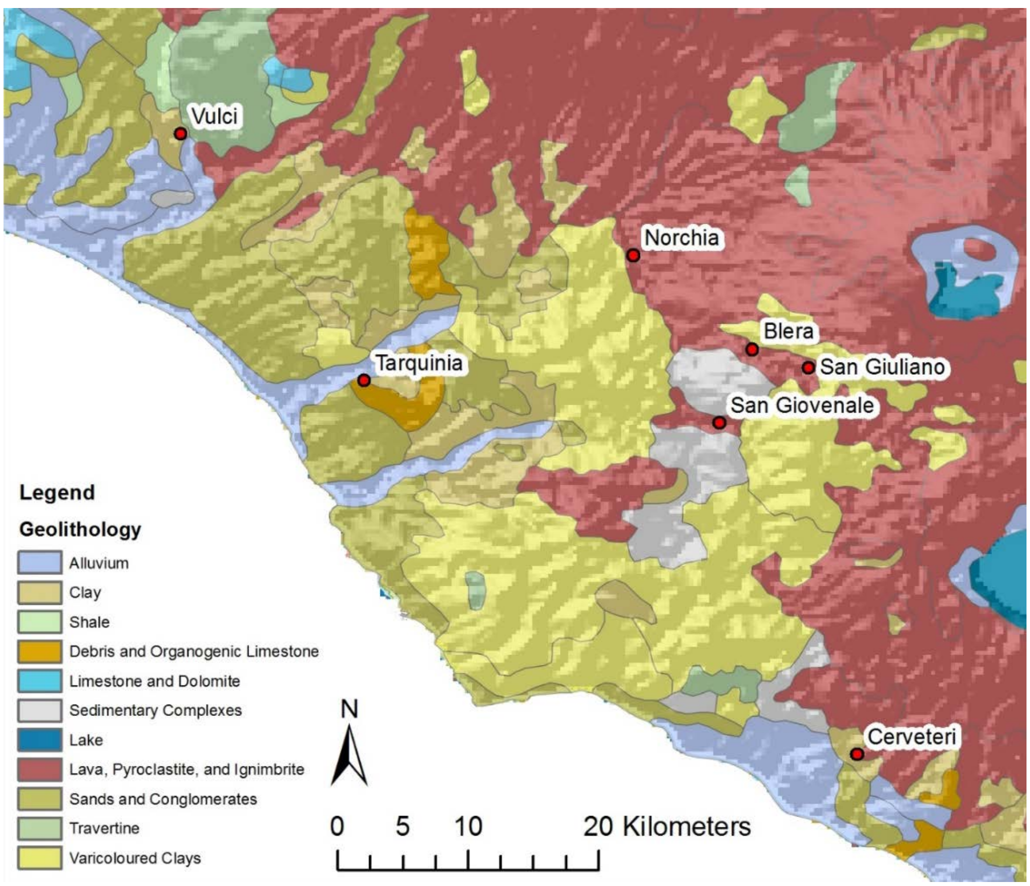


Figure 3. This map shows the primary geological makeup of the San Giuliano region, with volcanic flow indicated in red. This geological information was acquired with permission from Geoportale Nazionale.

The erosion of the landscape via fluvial channels also meant that the Southern Etruria landscape was rife with natural water resources in the forms of streams and rivers (Stoddart 2015, 50).

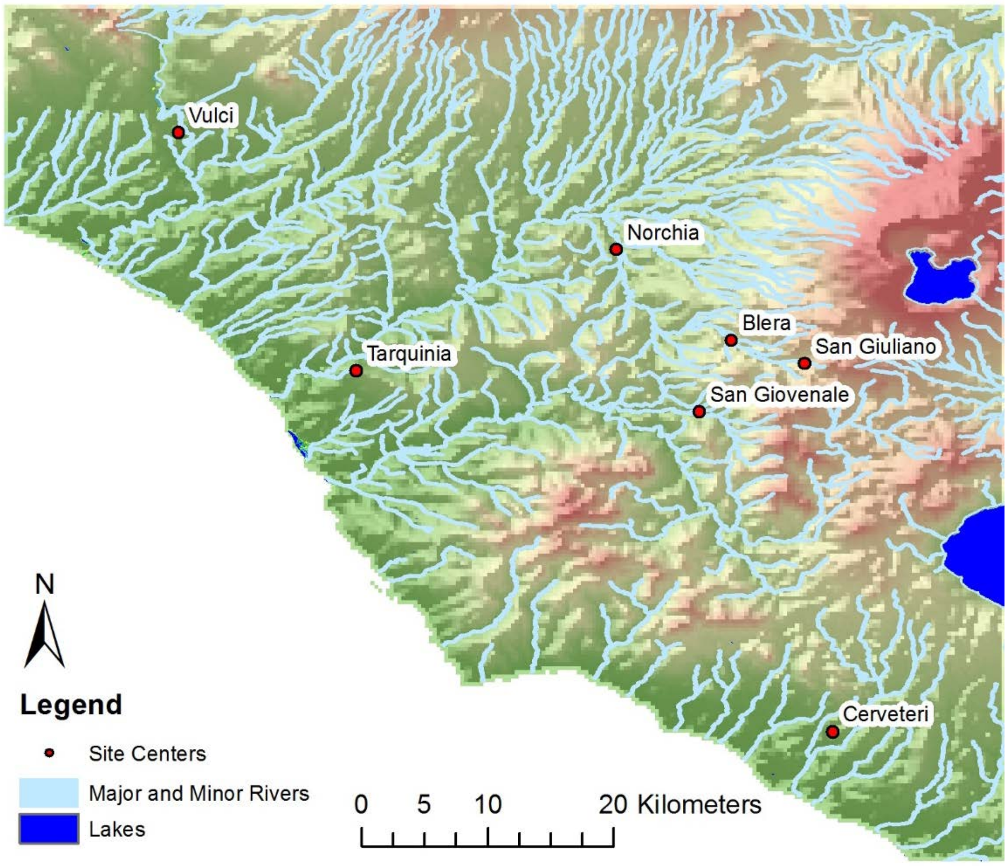


Figure 4. Image showing elevations and rivers. Digital elevation model taken from Open Data Lazio with permission. Elevation is represented along a green (low) to red (high) gradient. Water data is also taken with permission from Open Data Lazio.

Additionally, erosion of these volcanic depositional environments created natural divisions in the terrain that only allowed for certain areas of the landscape to be occupied successfully (Stoddart 2015, 51). Numerous plateaus were formed in the region, which acted as space for easily defensible habitation zones (Stoddart 2015, 52). The larger of these plateaus were often inhabited, while smaller surrounding plateaus offered high mineral concentration soils that supported sustainable agriculture (Stoddart 52). These volcanic soils of the region are predominantly andisols, with high water retention capacity and high levels of nutrients and humus, which are optimal for intensive agricultural activity (Magri and Sadori 1999, 248).

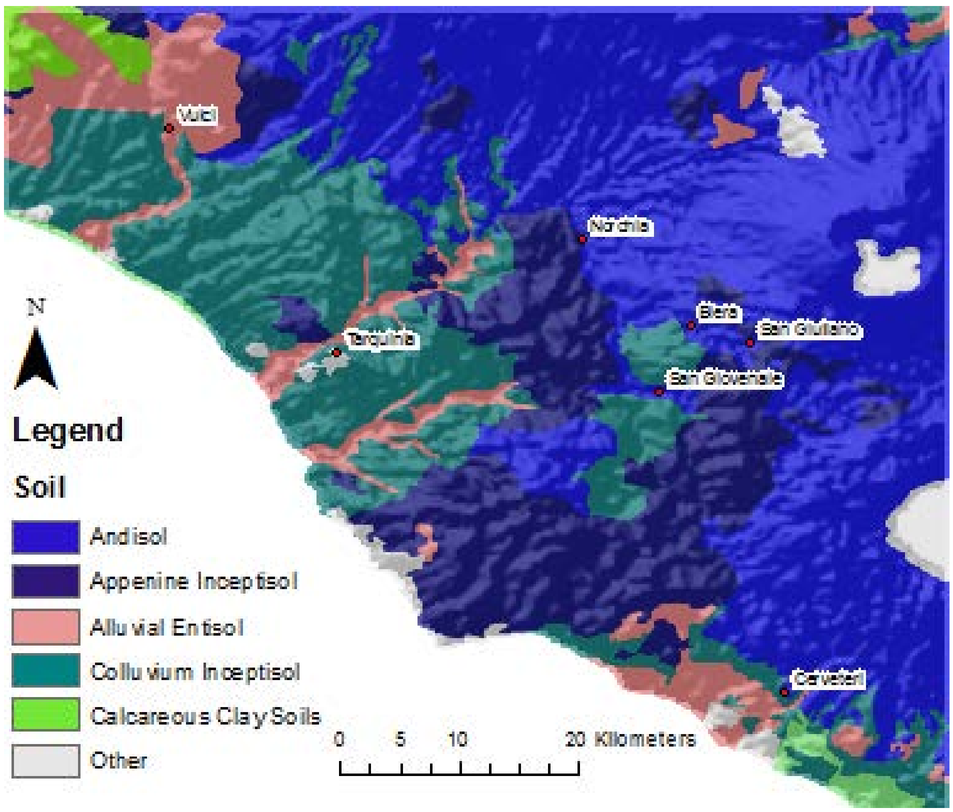


Figure 5. Map of the soil content of the San Giuliano landscape. Data taken from Geoportale Nazionale with permission.

Furthermore, Guerrini argues that tuff stone environments were specifically sought out by past people because structures could be excavated into the tuff itself using relatively simple equipment, and stone blocks could be quarried for the construction of structures (Guerrini 2003, 128). Etruscan populations specifically capitalized on the geological makeup of the region by using tuff as the primary material for architectural construction and by excavating tombs directly into the tuff available around their habitation zones (Barker and Rasmussen 1988, 34).

Regional Climatology and Ecology

Sediment records from the Vico volcanic lake act as a climate proxy for the Southern Etruria region, indicating that the landscape began to experience increased aridity and degradation of vegetation coverage beginning in the Bronze Age and culminating in the Roman periods (Narcisi 2001, 253). This loss of vegetation coverage is likely from human clearance of the landscape, as pollen from these sediments remains in low concentration until Late Antiquity (Magri and Sadori 1999, 258).

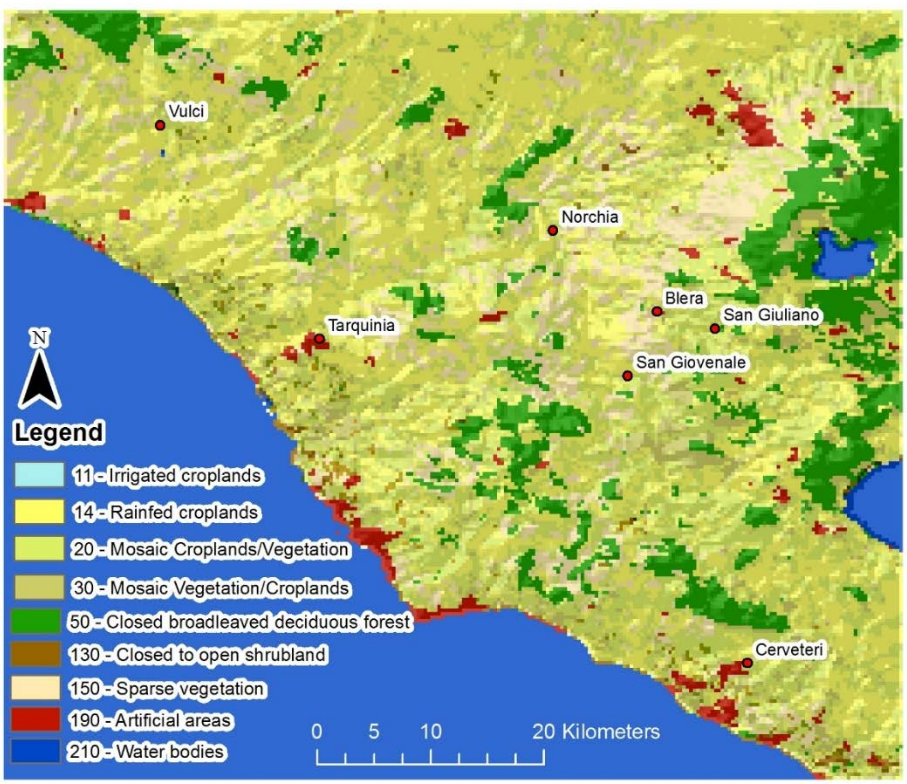


Figure 6. Modern regional land use map created from CORINE Land Cover data used with permission from Copernicus Land Monitoring Services.

Additionally, the presence of *Castanea, Olea* and cereal pollen appear after 2630±95 B.P., further evidencing this assessment of human activity and demonstrating the agricultural practices occurring on the landscape (Magri and Sadori 1999, 258).

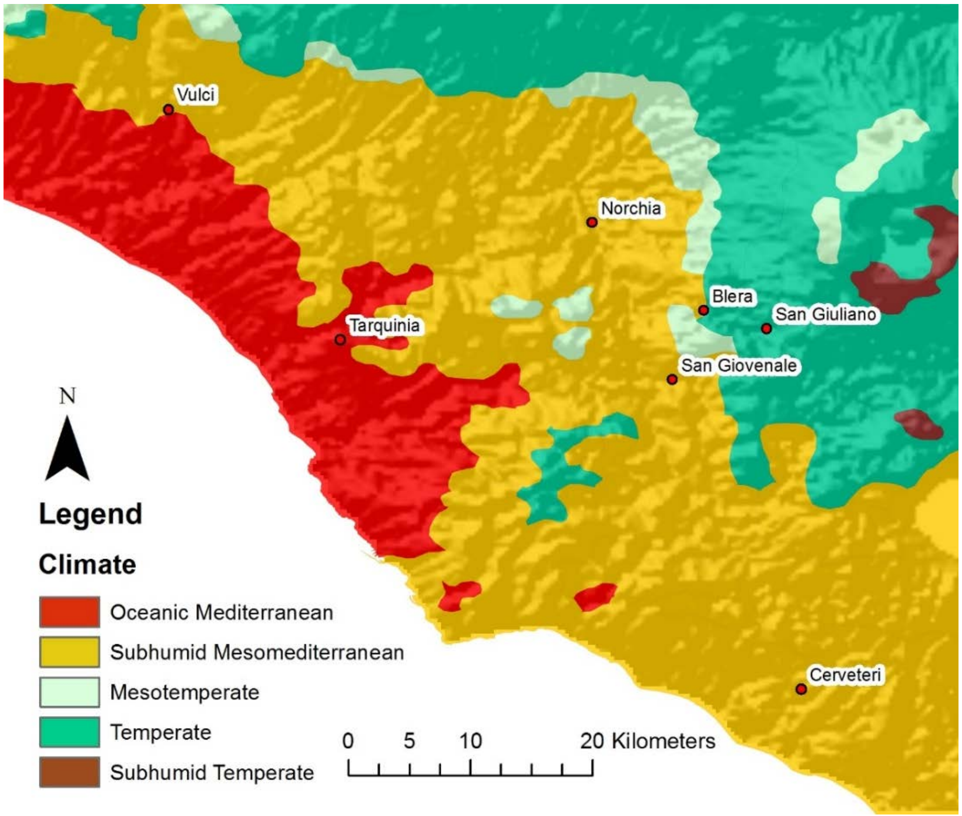


Figure 7. Map of the nominal climatic zones of the region. Data acquired from Geoportal Nazionale.

The overall climate of the region is relatively mild, with climate zones ranging from Oceanic Mediterranean environments to Subhumid Temperate further inland from the coast. Modern weather station data at nearby Ronciglione reports that throughout these zones, the mean annual temperature is 13.6°C and the mean annual precipitation is 1440 mm (Magri and Sadori 1999, 243). While the Mediterranean climate has undoubtedly changed throughout the longue durée, climate variation following the Late

Holocene has remained relatively stable in the area, with the climate for the period in question similar to the modern climate (Broodbank 2013, 256).

Data Acquisition

Primary data used in this study includes those displayed in the maps for the preceding section of this chapter. Necessary regional data for this study included elevation data and water sources, both of which were downloaded from the Open Data Lazio geodatabase. Geolithology, soil, and climate data were acquired via request from the Italian government's Geoportale Nazionale. Similarly, CORINNE land cover data was acquired at request, as this dataset offered the most comprehensive regional vegetation data, despite that past land use would have looked drastically different.

There are several limitations that should be acknowledged as potentially undermining the accuracy of the model as a reconstruction of optimal settlement choice on the ancient landscape. Firstly, the information available from online geodatabases were only in Italian, meaning legends and symbols with highly technical geological or ecological terms had to be manually translated into English without losing ideographic or technical meaning. Additionally, these geodatabases were highly limited in their selection of available data for GIS, and often, available datasets were too poor in resolution to be useful for anything the Southern Etruria region. Thus, original downloaded zip files were uploaded into the SGARP file geodatabase without being edited in case of future relevance to SGARP, while all datasets relevant to this study were organized categorically under "dbfiles" (Appendix 1).

From these datasets, secondary data was created in ArcMap. A hillshade was created from the regional elevation data, which underlies each of the photos in this study for better visualization of the data on the terrain. Slope was calculated from the elevation raster cells, and the near tool, which calculates the geodesic proximity between features, was used to generate a distance to water table. Furthermore, a multi-ring buffer around Open Data Lazio's river vectors was rasterized for appropriate weighted overlay analysis. Additional data, such as regional aspect and sun exposure were generated, but found little applicability in modeling site location, and thus were not included in the final draft of this report.

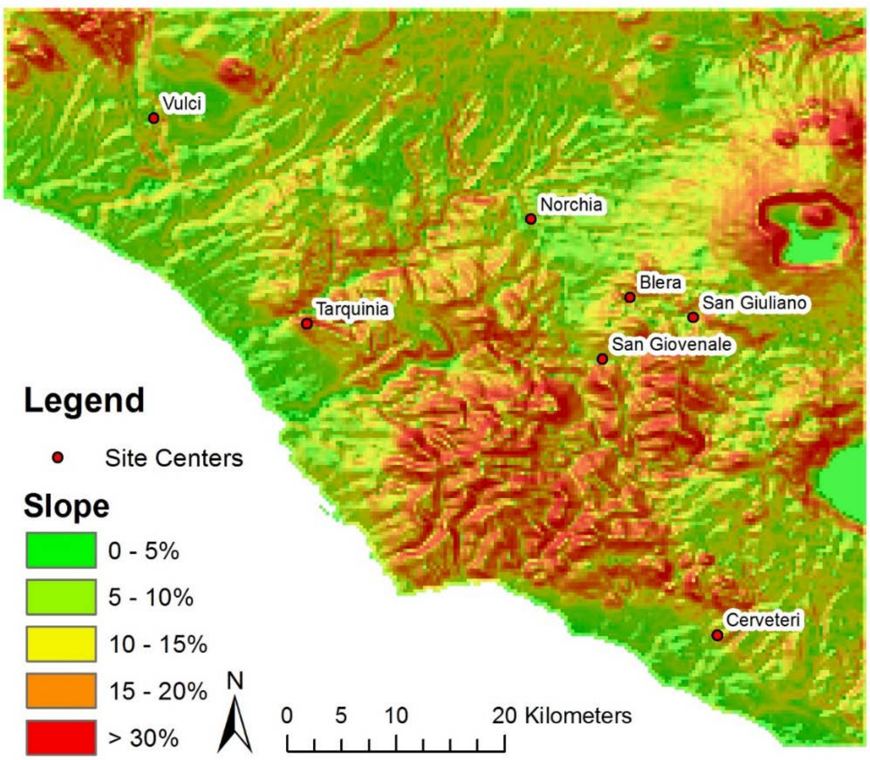


Figure 8. Map of landscape slopes developed in ArcMap.

Site Suitability Index

The SSI structure for the Southern Etruria region was developed in accordance with preceding scholarship on settlement suitability modeling (Issa and Saleous, 2018).

Two overarching categorical parameters for the SSI were "Geological" data, which included Geology and Soil base layers and derived slopes and distance to water layers, and "Climatological" data, which included Climate and Land Cover data (which was used as a baseline for regional vegetation patterns and agriculture viability). A weight of 65% was assigned to the Geological parameters as availability of volcanic tuff stone, soil nutrient and mineral content, defensibility, and water proximity seem to have a larger influence on determining subsistence strategies.

Parameter	**Weight**	**Layer Name**	**Variable**	**Classification**
Geological	65%	Geology	Volcanic	3
			Clay	2
			Other	1
		Slope	0%-5%	3
			5-30%	1
			>30%	3
		Distance to Water	<150	3
			150-300	2
			>300	1
		Soil	Andisol	3
			Entisols	2
			Other	1
Climatological	35%	Climate	Mesomediterranean	3
			Temperate	2
			Other	1
		Vegetation	Arable land	3
			Forest cover	2

Table 1. Site Suitability Index for Southern Etruria.

Thus, scores were assigned to optimal variables, with a score of 3 indicating highest optimality and a score of 1 indicating lowest. For the Geology layer, volcanic tuff stone environments were prioritized as most optimal, with clay environments scored as second best given that the need for clay resources for ceramic production in the region. For the slope layer, flat ground or elevation steeper than 30% was scored as most optimal as these criteria should reveal both plateau structures and their surrounding eroded valleys. Distance to water was scored based on determined optimality of reasonable daily energy expenditure as discussed in Conolly and Lake (Conolly and Lake 2006, 146). In terms of soils, andisols were prioritized as they are the most nutrient dense in the region, with entisols offering the second best alternative where andisols are unavailable (Conolly and Lake 2006, 167). For layers within the Climatological parameter, mesomediterranean environments were ranked 1 and 2 for optimal agriculture subsistence, while the vegetation from modern land use data broadly ranks areas that are now being used for agriculture as areas that would have been viable for agriculture in the past, and therefore as the most optimal environments for site location.

Site Suitability Modeling and Interpretation

Using this SSI, attributive data from primary and secondary layers was reclassified according to each variable's optimality score. These reclassified layers were combined using weighted overlay with respect to the constitutive parameter weights, creating a resulting raster in which each cell is defined by the mean optimality score from each layer. Cells with an average value of 1, indicating low suitability, are represented in red. Cells with an average value of 3, indicating high suitability based on optimality theory, are represent in green. The scores in between are represented on a continuum, showing areas of the landscape that are moderately suitable for settlement.

Overall, the site suitability model has more predictive power for the smaller sites than the larger sites on the landscape. Sites Norchia, Blera, San Giovenale, and San Giuliano are all located in cells with a value of 3 or near 3, indicating settlement location

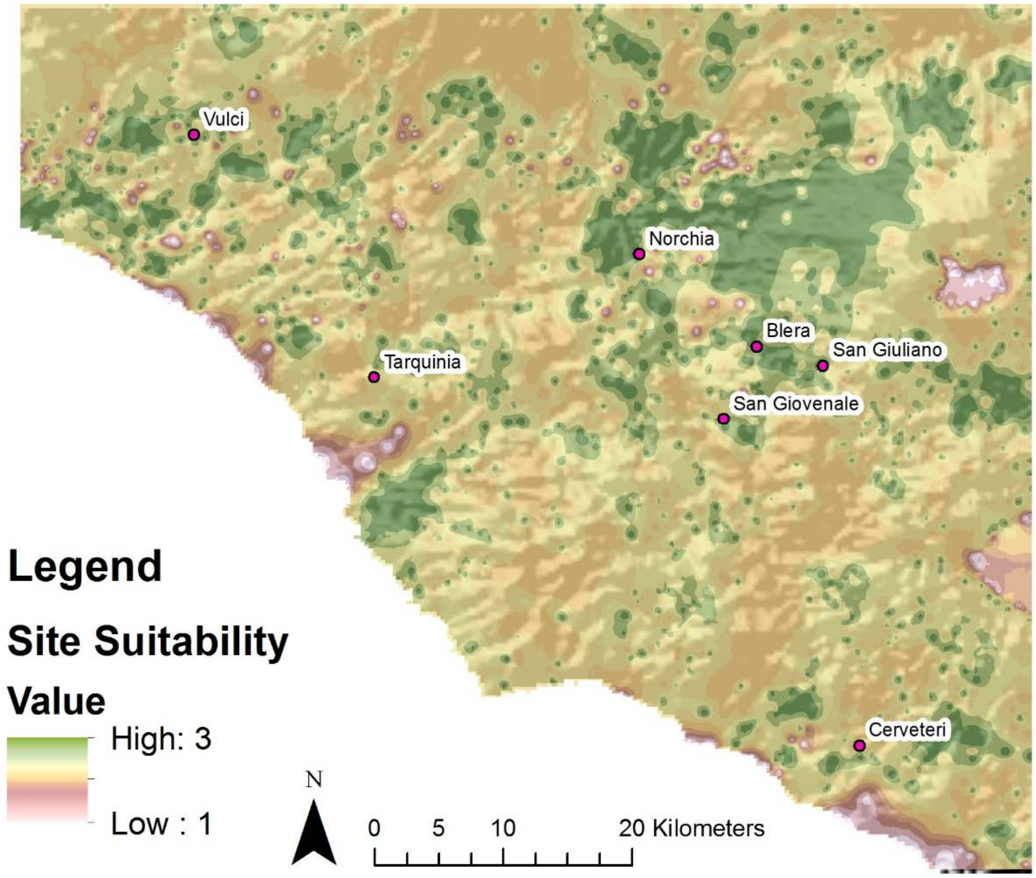


Figure 9. Site suitability assessment given Site Suitability Index scores for each raster cell.

decisions in near perfect alignment with the SSI determined optimal response to the landscape. The point representing Vulci looks as if it is located amongst green cells, however, it is actually located in association with a yellow cell, suggesting that the location is only moderately optimal. Similarly, Tarquinia and Cerveteri are located in association with yellow-orange cells, indicating even less suitability of the environment.

Analysis of this model suggests that, as the SSI values were based on optimal response to the environment for maintaining agricultural subsistence, larger scale sites do not adhere to this optimality model because they are less reliant on agriculture. This seems to align with contextual information about these larger scale sites. Stefan Steingräber estimates populations of Vulci, Tarquinia, and Cerveteri at 15,000, 20,000, and 25,000 people respectively (Steingräber 2001, 14). Subsequently, while this site suitability model represents these sites' centers as single points on the landscape, their territoriality was much more expansive than that of the smaller inland sites. Thus, urban center placement for these sites does not seem to be contingent upon agricultural subsistence, but instead suggests prioritizing environments best suited for some external economic variable. This aligns with Giardino's assessment of Tarquinia, Vulci, and Cerveteri's engagement in mining and metallurgy, most likely relying on maritime and inland trade and surrounding hinterlands for subsistence (Giardino 2014, 769).

There are definitely limitations to Human Behavioral Ecology site suitability modeling using GIS, especially when working with data in an unfamiliar language, when trying to apply modern data to the past landscape, and in assessing model successes and failures. Finding high resolution metal abundance data, which I was unable to obtain for this study, would confirm hypotheses about the larger sites' placement suitability. However, this model has predicted how the suitability of location possessed by smaller inland sites, such as San Giuliano, played out in the region of Southern Etruria. Inland sites engaged in agricultural subsistence, while coastal sites, which were not located in agricultural subsistence optimal environments, were most likely relying on trade networks for subsistence and bolstering their economy through mining and metallurgy.

CHAPTER FOUR

Intervisibility between the San Giuliano Plateau and Necropolis

One of the most remarkable aspects of the San Giuliano landscape is the extensive necropolis of Etruscan rock-cut tombs surrounding the plateau, which would have been the largest necropolis of any contemporaneous site in the immediate region. The tomb surveys conducted by SGARP from 2016 to 2018 located 541 tombs at San Giuliano, the majority of which are concentrated around the eastern end of the plateau in areas called: Chiusa Cima, San Simone, and Caiolo. While regional patterns from nearby Etruscan sites, such as San Giovenale and Blera, suggest that the populations burying their dead in the San Giuliano necropolis would have lived atop the plateau, every trace of the Etruscan habitation settlement has disappeared, given that most constructions would have been made from wood (Gargana 1931, 326-37). Augusto Gargana, who published the first comprehensive survey of the necropolis in 1931, goes so far as to assert that the very existence of Etruscan inhabitants at San Giuliano could be denied if it were not for the presence of this extensive necropolis (Gargana 1933, 326-327).

Thus, this chapter relies on Phenomenological interpretations of intervisibility between the San Giuliano necropolis and plateau to suggest the extent of the relationship between the “city of the living” and the “city of the dead.” Intervisibility between the plateau and the necropolis reveals underlying patterns about the social structure and experience of the inhabitants of San Giuliano during the Etruscan period, in that the tombs served to order social memory and collective understandings of space. This study specifically relies on viewshed analysis in ArcGIS, given that substantial changes have occurred to the San Giuliano landscape since the Etruscan period; namely, that the area is the most densely vegetated it has been since the Early Bronze Age, so assessing intervisibility on the modern landscape is unfeasible.

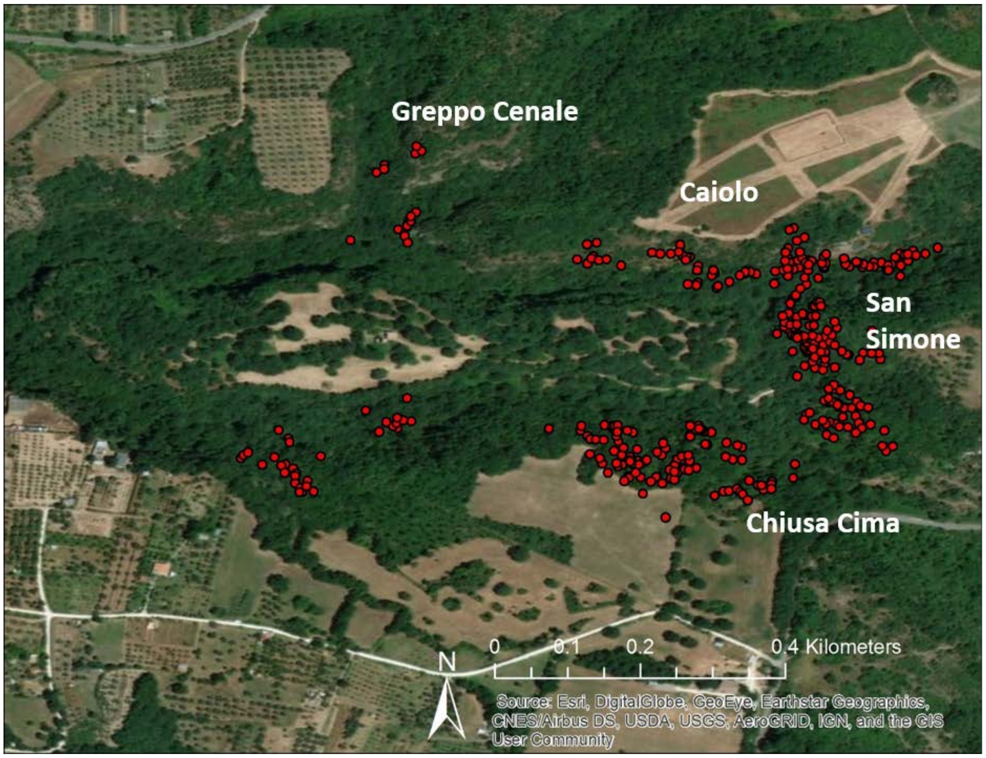


Figure 10. Tomb distribution around the San Giuliano plateau.

Etruscans and Constructions of Memory

What is known about Etruscan domestic patterns has largely been inferred from carved architectural elements in tombs, which presumably mimic the internal forms of Etruscan homes. For example, the well-known Tomb of the Reliefs at Cerveteri features a carved roof beam, columns, couches, and the decorative schema of a funerary banquet held in an aristocratic home. This tomb is particularly apt for discussing the relationship between the Etruscan realm of the living and the realm of the dead, as the ornateness of the tomb not only offers a detailed image of an aristocratic domestic space, but also demonstrates a held belief in the continuity of social status and social affiliations in the afterlife. The funerary banquet in itself is an occasion of memorialization, as well as a time of selective forgetting, according to Van Dyke on memory in mortuary rituals. In mourning, memory of the identity of the deceased is created; and ultimately, visibility ties the living to the deceased by tying memory to the landscape (Van Dyke 2016, 433).

Figure 11. Tomb of the Reliefs at Cerveteri. Photo by author, June 2018.

The San Giuliano landscape is filled with less elaborate examples of the same concept; carved roof beams and couch structures demonstrate what an Etruscan domestic space may have looked like, and they also reveal the held beliefs about the afterlife of those who buried the deceased and inform archaeologists about how they constructed memory.

In conjunction with understanding Etruscan domestic life through internal tomb architecture, the spatial organization and clustering of these tombs have significant

Figure 12. Interior of tomb at Chiusa Cima, San Giuliano. Photo by author, June 2018.

implications on Etruscan habitation patterns and social organization. Intervisibility between the necropolis and the plateau would place inhabitants of San Giuliano in constant visual contact with the deceased, functioning to incorporate memory and mythic identities of the deceased into their daily lives. Thus, one hypothesis for determining a more precise location to look for the Etruscan habitation zone at San Giuliano would be to find areas of high intervisibility on the plateau with the tombs in the necropolis.

Data Collection

Tomb Survey

Tomb survey was conducted from 2016 to 2018 via pedestrian survey methods, in which students field-walked using a latitude-longitude grid system that incorporated the entirety of the San Giuliano necropolis. Students walked in 10-meter pedestrian transects across the grids, supplementing with opportunistic survey of likely tomb locations in each sector, especially along escarpments facing the plateau. Discovered tombs were photo-documented and recorded as waypoints in Garmin GPS units.

Drone Survey

Drone survey was conducted over the 2017 and 2018 field seasons with a DJI Phantom 4 Professional drone. Flights were conducted approximately 100 meters above ground level, giving a resolution of 3cm/pixel with a 66% side overlap and a 75% frontal overlap. To ensure coverage of the entire site, Drone Deploy was used to plan flight paths and automate aerial photography. In the first field season, 1484 aerial photos were recorded and imported into Agisoft Photoscan Professional, from which a dense point cloud was interpolated. A digital elevation model (DEM) of San Giuliano was created from the point cloud and was further used to generate orthomosaic images of the site.

The DEM derived from available data in 2017 was sufficient to conduct viewshed analysis for 114 of the 541 tomb sites, so further drone survey in 2018 aimed to collect elevation data for areas to the north and east of the existing DEM extent. In 2018, 635 images were taken with the DJI Phantom 4 Professional drone and were combined with the 1484 images taken during the 2017 field season. With the new photographs, we were able to extend our imagery and elevation model to account for 429 tombs in the necropolis.

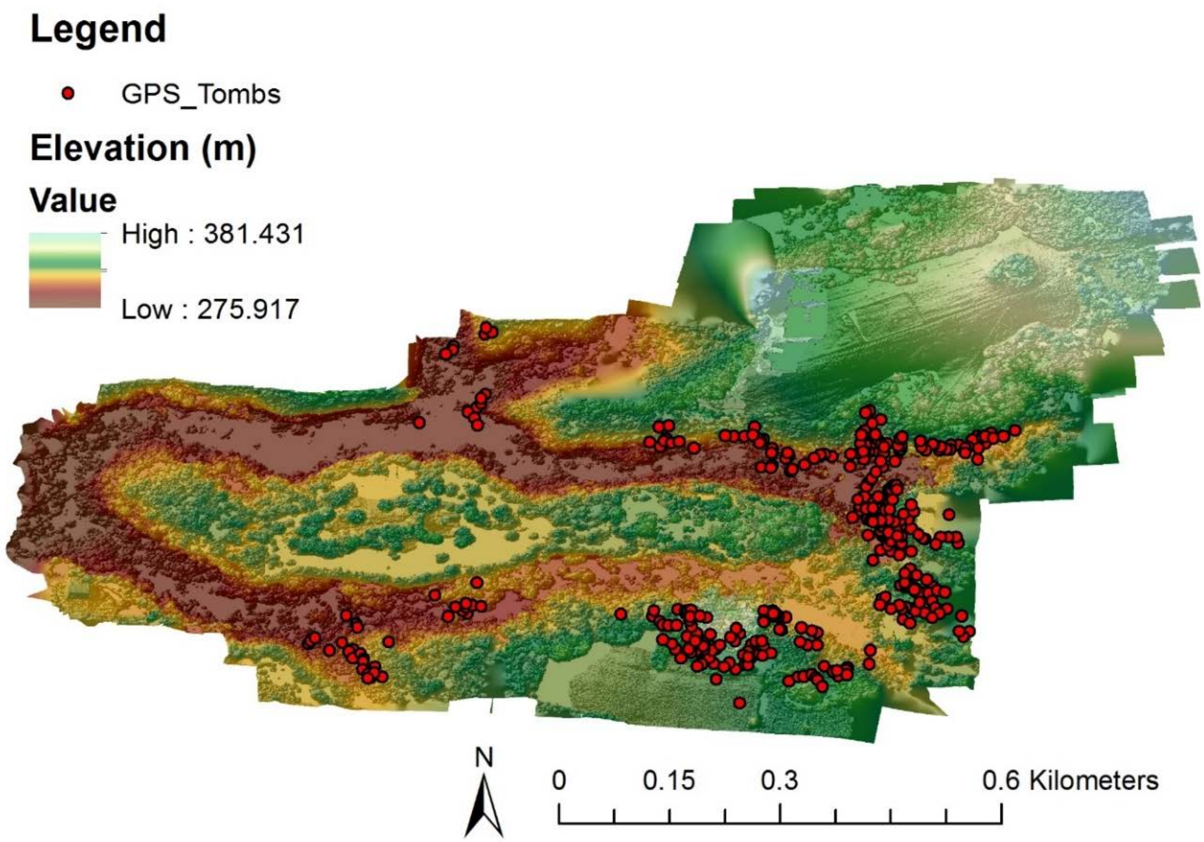


Figure 13. Digital Elevation Model created with drone survey data.

Viewshed Analysis

Total Viewshed

Using ArcMap 10.5.1, a total viewshed model was generated using the drone derived DEM and the georeferenced 429 tombs to determine which areas of the plateau were visible from the tombs and vice versa. In a total viewshed map, binary values are assigned to raster cells, with 0 indicating that a cell is not visible and 1 indicating that the cell is visible from the observer points. On this model, all cells with a value of 1 are displayed in green over the DEM, while cells with a value of zero are transparent. The purpose of this model is to display the cells on the DEM that are within the line of sight of any of the 429 tombs surrounding the San Giuliano plateau, serving to verify the claim that there is at least some level of intervisibility between the necropolis and the plateau.

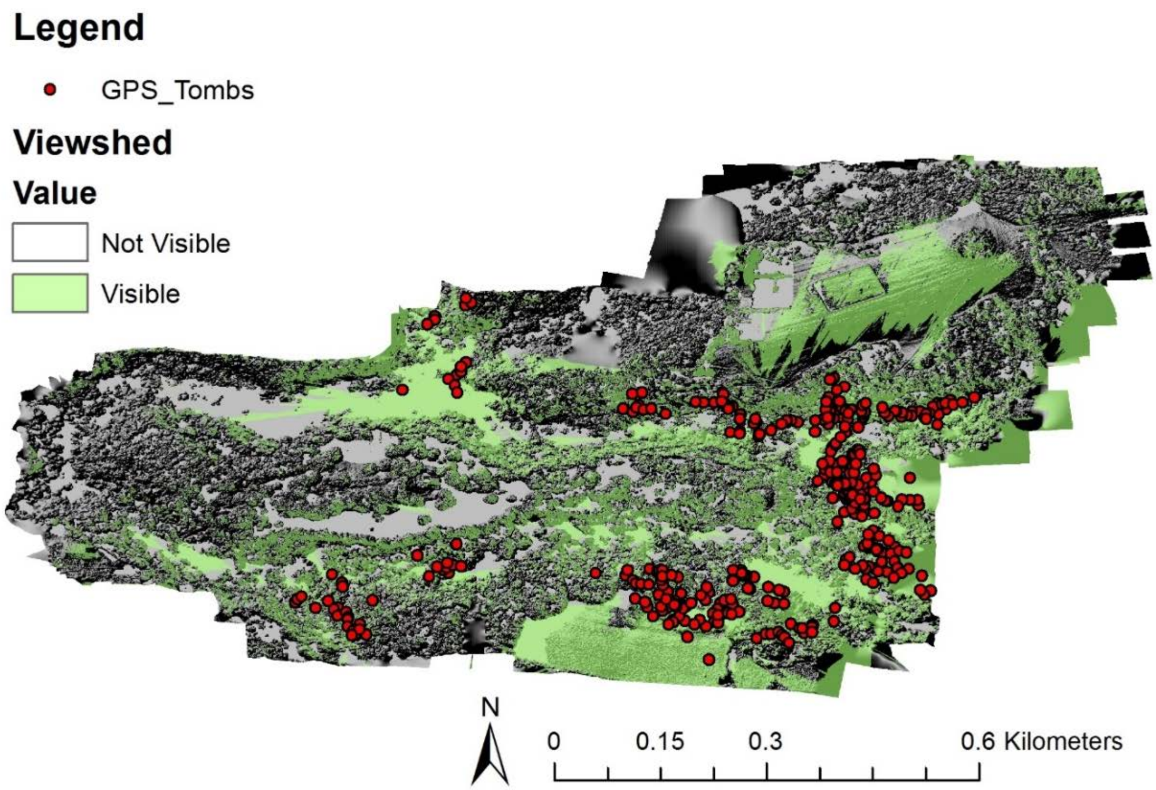


Figure 14. Total viewshed between the San Giuliano necropolis and plateau.

Cumulative Viewshed

Next, a cumulative viewshed map of San Giuliano was generated, in which cells were assigned values ranging from 0 to *n* to show areas of higher and lower intervisibility. In this case, while *n* was technically 429 because there were a total of 429 tombs analyzed, the highest cell value on the cumulative viewshed model was 176. This means that at the area of highest intervisibility on the plateau, 176 tombs are visible. Thus, to determine whether this intervisibility was statistically significant, a

Kolmogorov-Smirnov statistical test was applied to the viewshed distribution values (as in Conolly and Lake 2006, 137). Analysis revealed that the D value at its maximum, 0.557986 was greater than the critical value calculated at 0.110156 for an alpha of 0.05, indicating that the null hypothesis – that the tombs were distributed throughout the San Giuliano necropolis irrespective of intervisibility – could be rejected with 95% confidence (Appendix B).

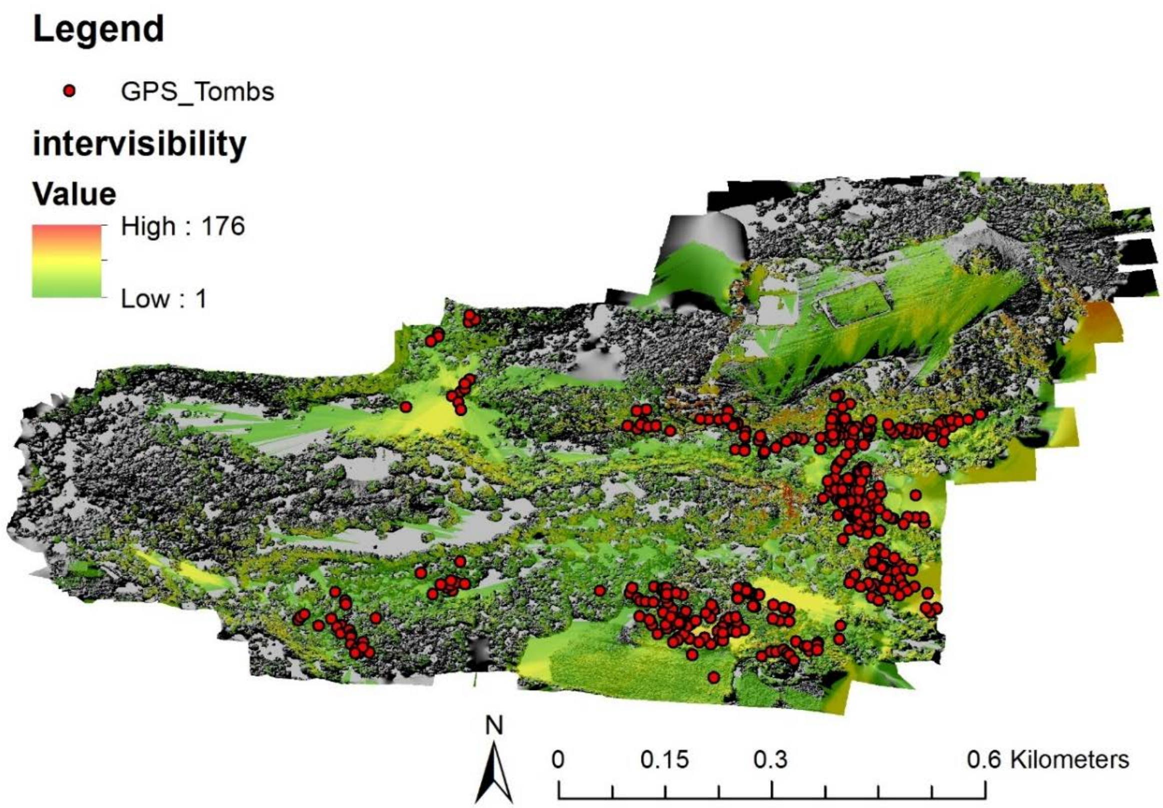


Figure 15. Cumulative viewshed between the San Giuliano necropolis and plateau.

Probabilistic Viewshed

However, as viewsheds are purposed to generate experiential data for a past environment, which may be drastically different from the modern environment in terms of vegetation, erosion, geological events, or observer heights, a method developed by Fisher in 1994 for probabilistic modeling provides a means of interpolating visibility models with higher statistical certainty (Fisher 1994, 1321). In these probabilistic models, uncertainty of surface elevation values is increased by introducing Root Mean Square Error (RMSE) to the model. Consequently, the visibility results in the probabilistic models show the sum of probabilities that a tomb feature is visible to a cell rather than the number of tomb features visible from a cell (Fisher 1991, 1323).

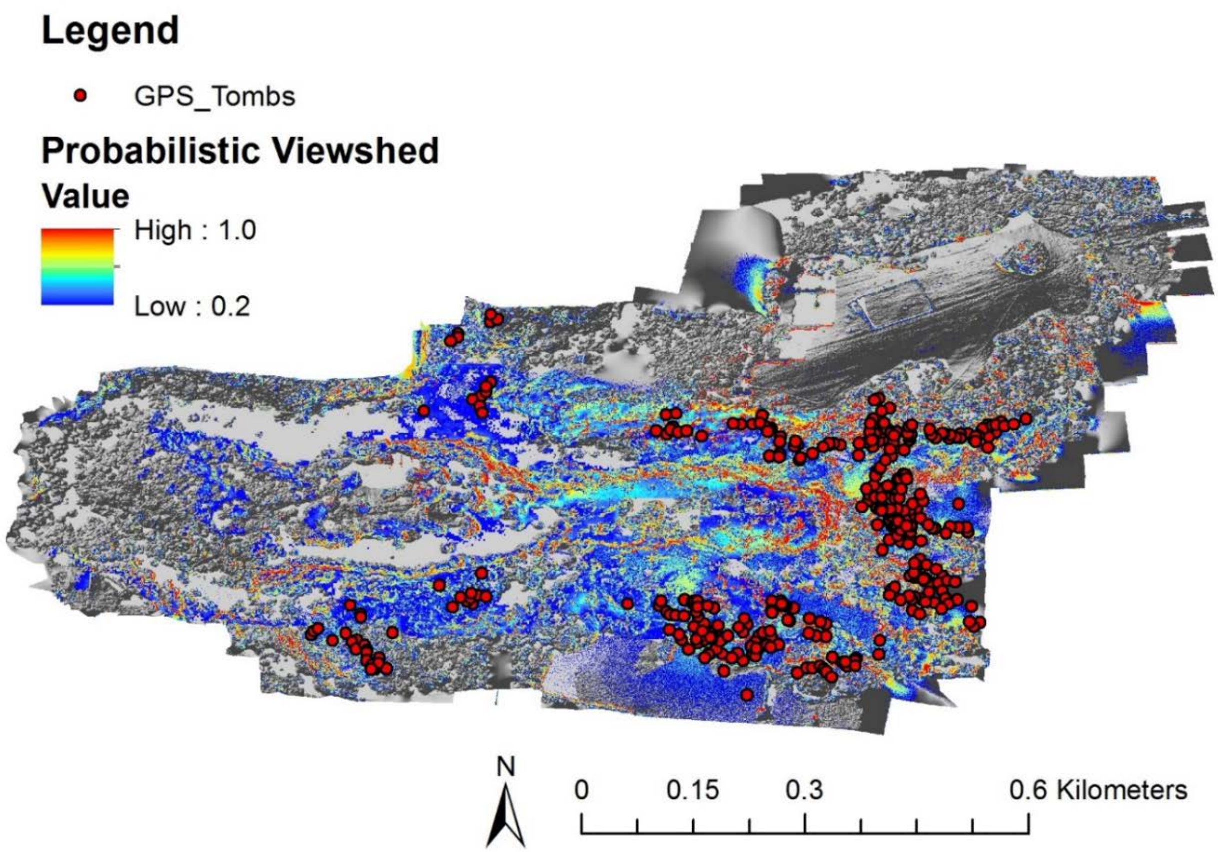


Figure 16. Probabilistic Viewshed between the San Giuliano necropolis and plateau.

The values in this model, with a RMSE variable of 2 meters, range from >0 to 1, where any valuable greater than 0 indicates that the cell is unlikely to be outside of the line of sight of at least one feature. A cell value of 1 indicates certainty of 95% that the cell is within at least one tomb's line of sight. Cells that are shown with a color closer to red have a probabilistic value closer to 1 and are thus more certainly in line of sight with at least one tomb. Cells with colors closer to blue are still likely to be within the line of sight of at least one tomb but are not certain within 95%. Cells with no color don't have a probabilistic viewshed value and are unlikely to be in the line of sight of any tomb. From the probabilistic viewshed model, it seems like the areas of the plateau most certainly visible from the necropolis is the eastern wall, which is significant considering that Gargana suggests the presence of a sacred structure or temple at the eastern edge of the plateau that we no longer have evidence of.

Clustered Viewshed

A potential criticism of this approach is the reductive nature of the model, in that it views the necropolis as a single monumental structure instead of a complex, diachronic landscape (Wheatley and Gillings 2000, 8). Although the earliest tombs, such as the tumuli at Chiusa Cima, San Simone, and Caiolo, undoubtedly persisted as significant and visible landscape markers, further analysis of intervisibility between identifiable clusters of tombs according to location and chronology can contribute to contextualized narratives of experience of space at San Giuliano.

Gargana writes that the San Giuliano necropolis essentially formed around four nuclei: Chiusa Cima, San Simone, Caiolo, and Greppo Cenale, with Cima and Caiolo being the most important areas and the only true "cities of the dead" in terms of organization (Gargana 1931, 334-115). It is worth noting that Gargana's tomb chronology is very general and based entirely on the chronology from Bieda, as the

Zone	Tumuli	Dado Tombs
Chiusa Cima	Late 8th - Late 7th BCE	Late 7th -Early 6th BCE
San Simone	Early 7th BCE	Late 7th - Early 6th BCE
Caiolo	Late - Early 6th BCE	Late 6th – Middle 4th BCE
Southern Cluster		Middle 4th BCE
Greppo Cenale		3rd century BCE

Table 2. Tomb chronology adapted from Gargana (1931).

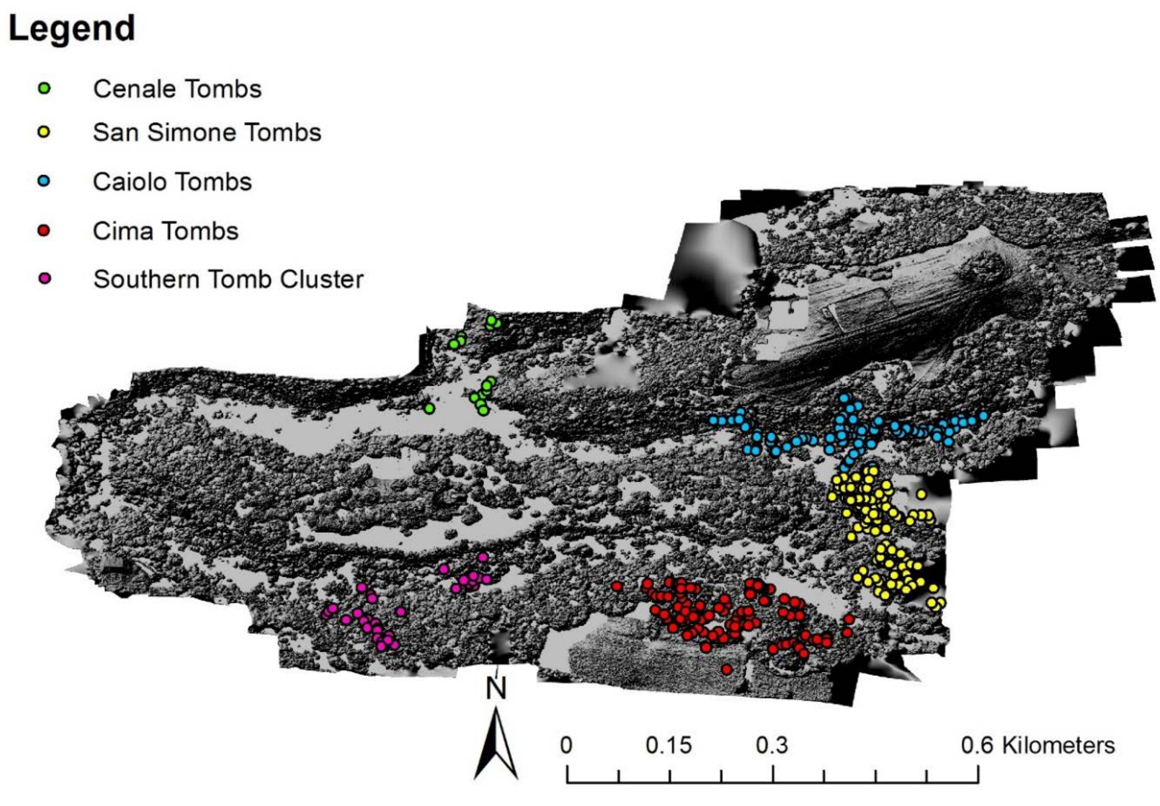


Figure 17. Tomb clustering in the San Giuliano plateau in accordance with Gargana's typology of tombs.

extensive looting of the San Giuliano necropolis has made exact dating difficult, and so some of SGARP's excavations of tombs in the Cima and Caiolo areas have produced slightly different time frames than Gargana suggests. However, as Gargana has provided the widest encompassing chronology, upon which most studies of the San Giuliano necropolis are based on, his chronology was also used for this study. Of additional note is that his clustering of tombs ignores a significant portion, which are located to the south of the San Giuliano plateau, indicated in purple. He dates tombs to the west of Chiusa Cima as middle fourth century, but he doesn't describe them otherwise. For these models, I have called this group of tombs the southern cluster.

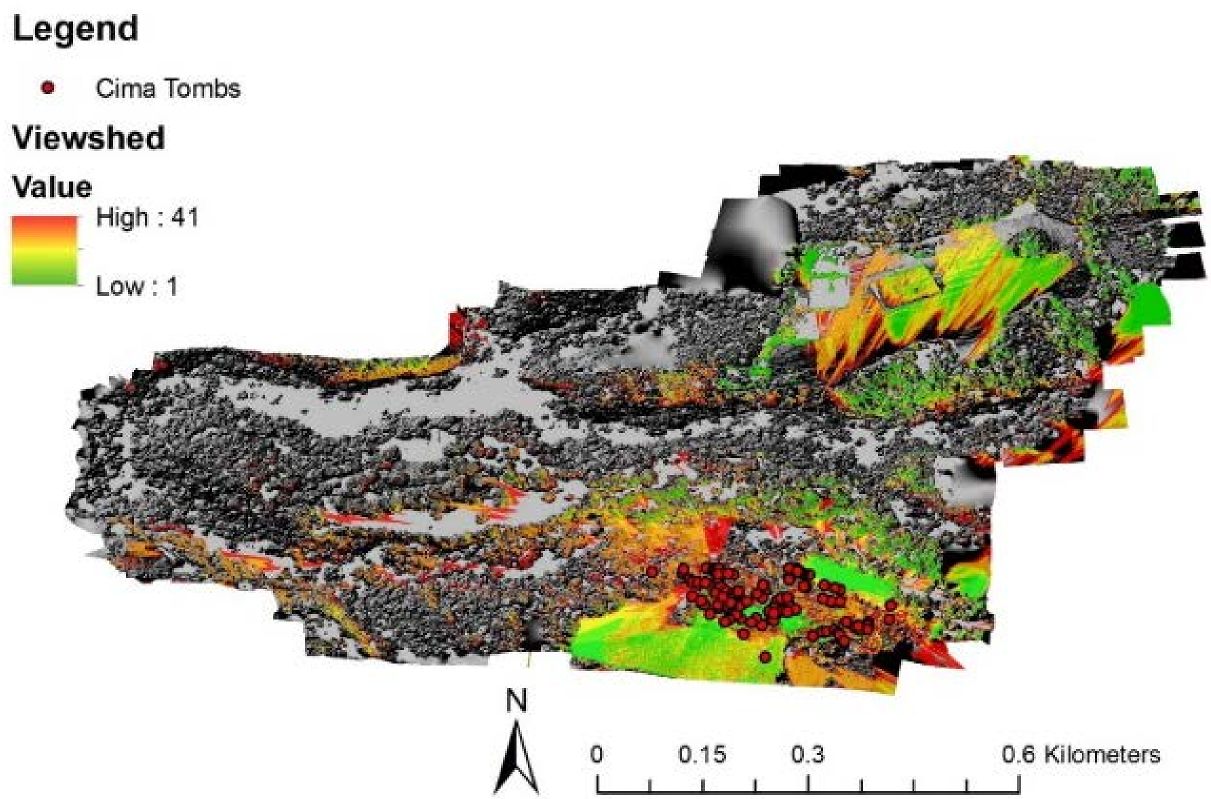


Figure 18. Viewshed from tombs in the Chiusa Cima cluster.

At Chiusa Cima, Gargana dates the tumuli structure from the Late 8th to the Early 7th century, and the rock-cut *dado* tombs to the late 7th to early 6th century. Intervisibility analysis between these tombs and the plateau suggests that the highest levels of intervisibility is along the southern edge of the border. However, this cumulative viewshed shows the highest value at 41 visible tombs, which means that from the area on the plateau with the highest intervisibility with Chiusa Cima, only 38.3% of tombs are visible.

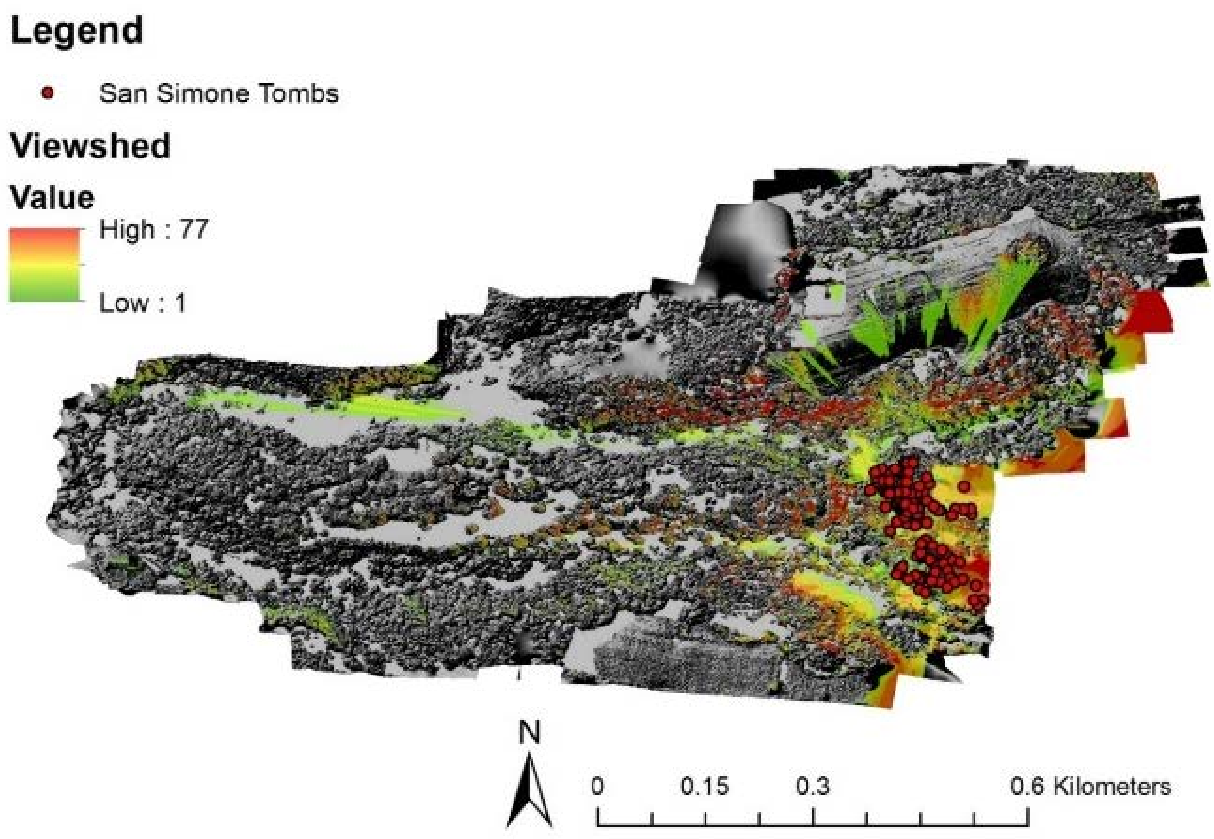


Figure 19. Viewshed from tombs in the San Simone cluster.

San Simone had a higher proportion of tombs intervisible with the plateau. Gargana dates the tumuli structure, called the Tesoro tumulo, to the early 7th century and the rock cut *dado* tombs to the late 7th to early 6th century. The eastern edge of the plateau has highest intervisibility, from which 60.6% of San Simone tombs are visible.

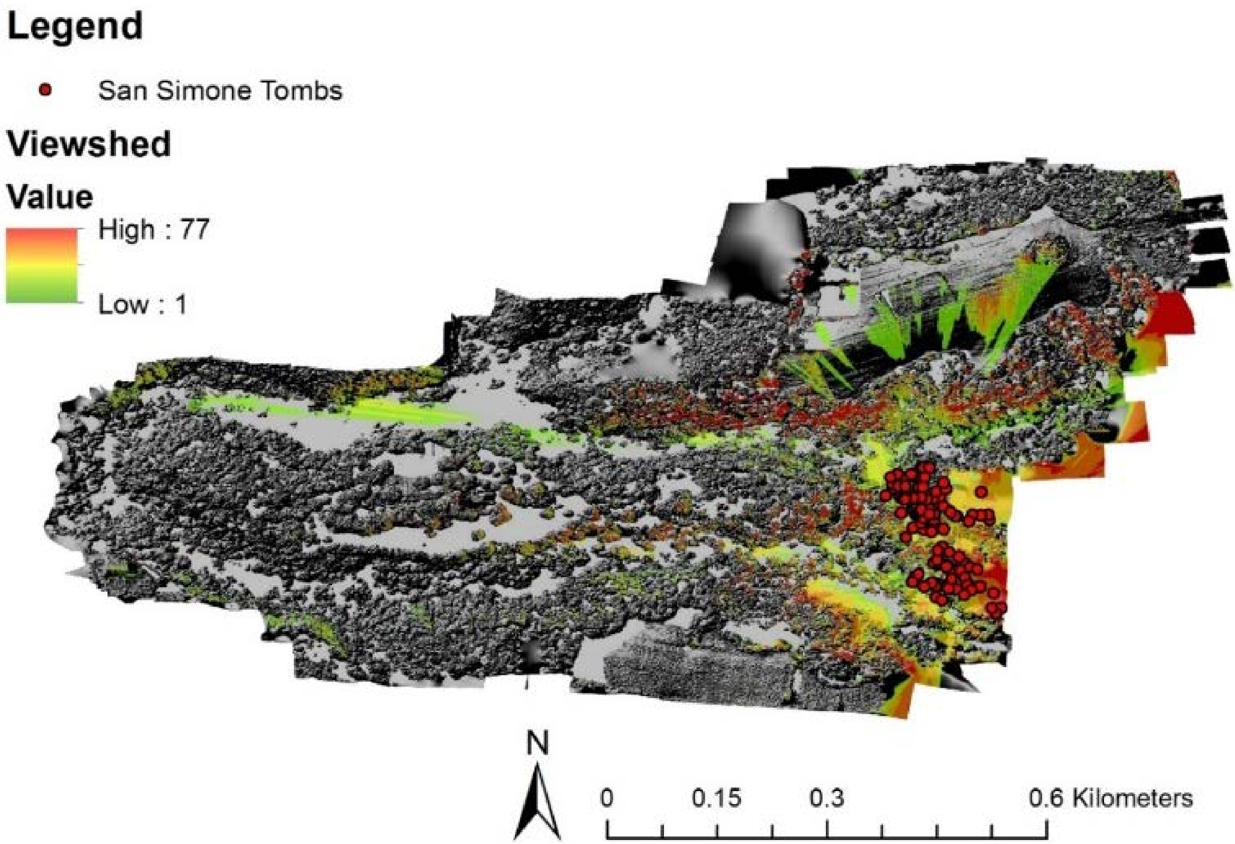


Figure 20. Viewshed from tombs in the Caiolo cluster

The Caiolo cluster had the highest proportion of cells on the plateau intervisible with tombs, with a high of 65.3% of tombs visible from the northeastern edge. Gargana dates the tumuli at Caiolo to the late to early 6th century and the rock cut *dado* tombs to the late 6th to middle 4th century, suggesting that intervisibility may have become a more important factor in Etruscan tomb construction moving into the Archaic period.

Most interesting from this intervisibility analysis were the results of the cluster of tombs along the south side of the plateau and the cluster of tombs at Greppo Cenale. The tombs to the south of the plateau seem to have no overlapping visibility with the areas that were most commonly intervisible on the plateau with the Chiusa Cima, San Simone, and Caiolo clusters. Instead, any intervisibility between the tombs and the plateau seems to be focused on the southern edge of the plateau.

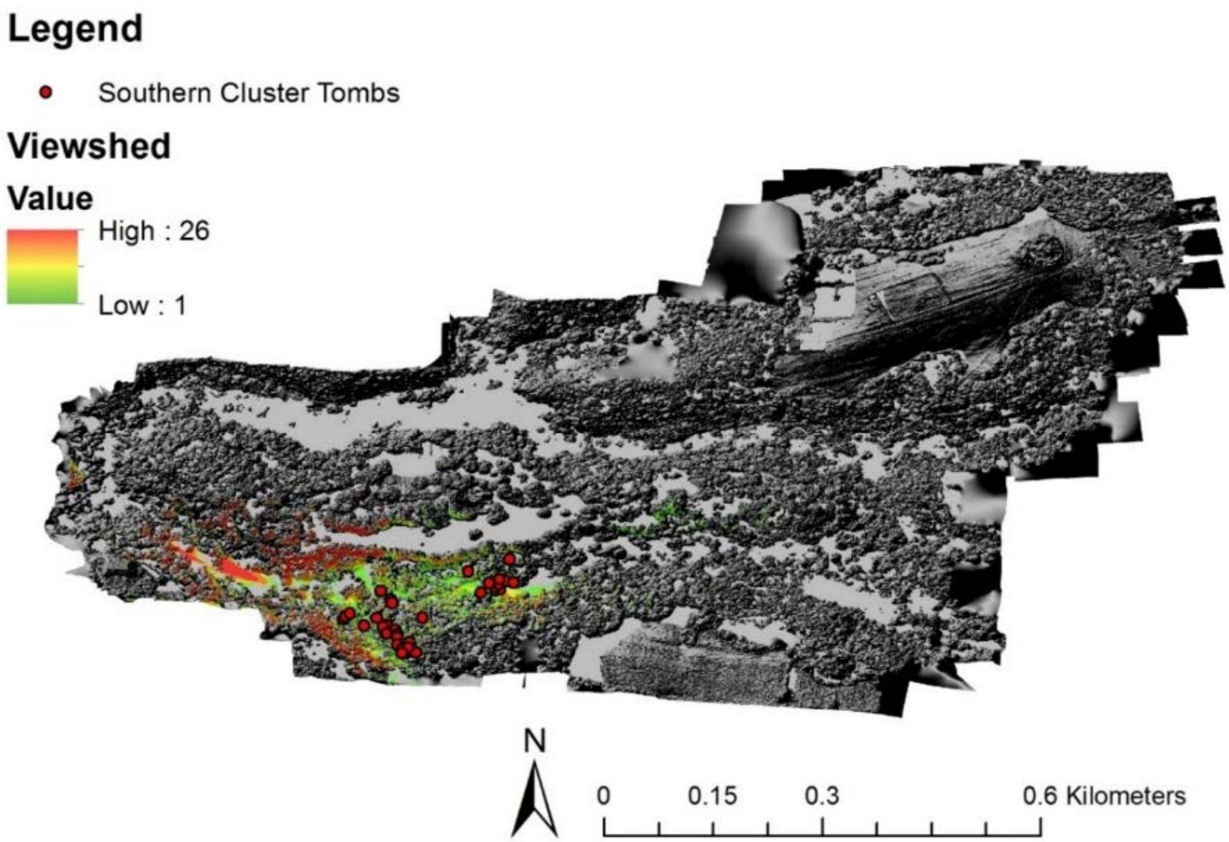


Figure 21. Viewshed from tombs located south of the plateau.

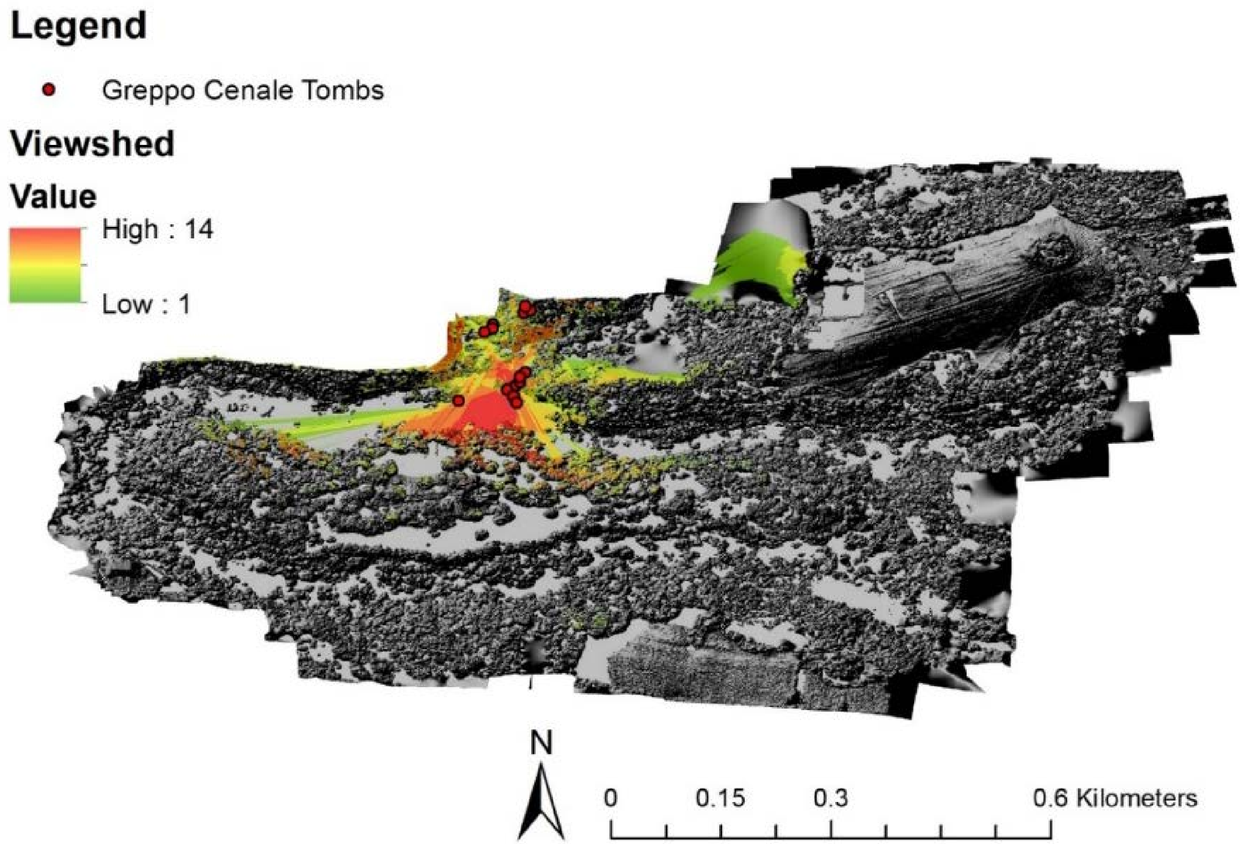


Figure 22. Viewshed from tombs in the Greppo Cenale cluster.

Similarly, at Greppo Cenale, which Gargana dates latest as being constructed during the third century, there seems to be no intervisibility with the areas of the plateau from which Chiusa Cima, San Simone, and Caiolo were intervisible. What this seems to suggest is that either intervisibility came to play less of a role in the construction of tombs into the Classical period, or that use of space on the plateau may have changed, with a shift in civic-ceremonial importance away from the eastern edge of the plateau.

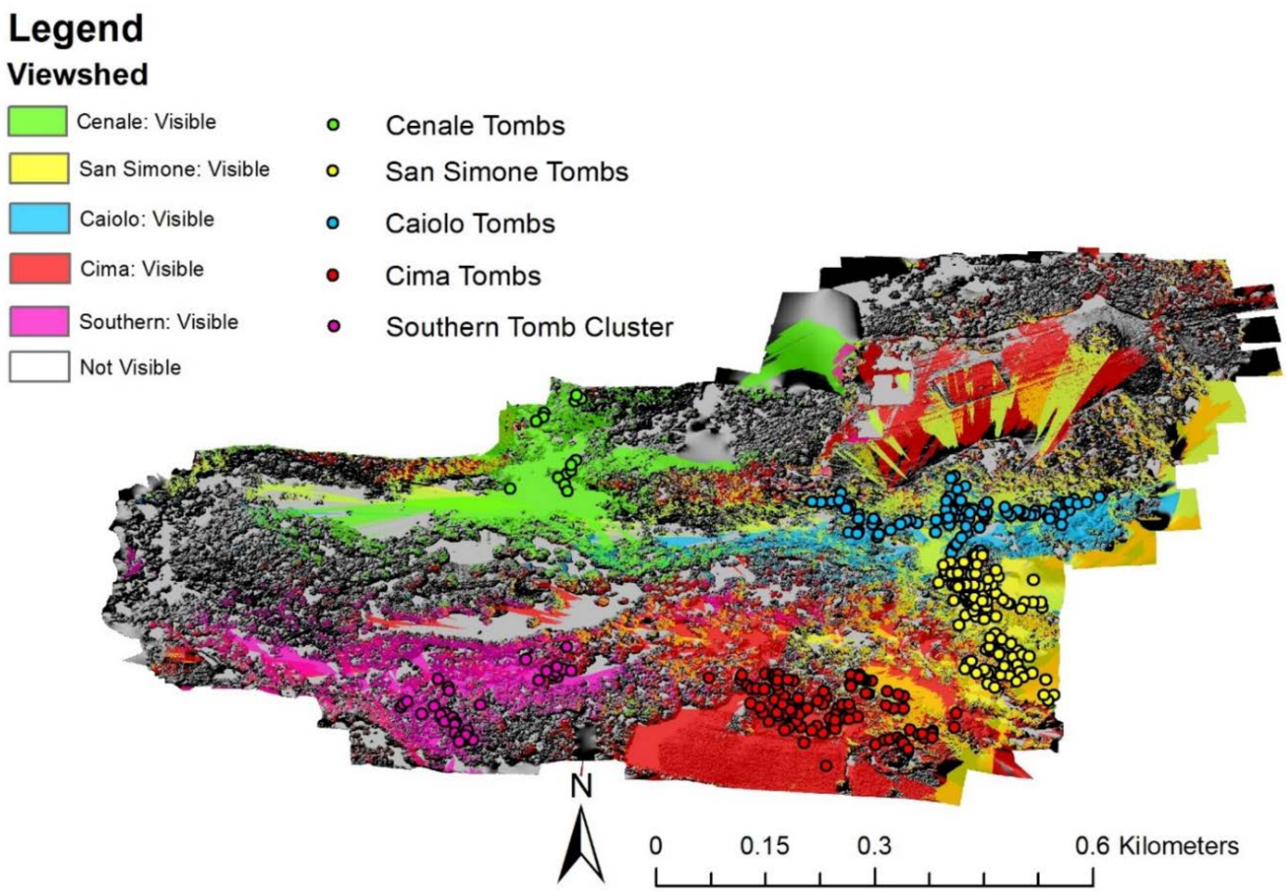


Figure 23. Combined viewsheds from each tomb cluster to determine areas of overlapping intervisibility.

This final map shows each of the viewsheds overlayed, further indicating the similarities between the lines of sight for tombs at Chiusa Cima, San Simone, and Caiolo, and how disparate the viewsheds are for the tombs south of the plateau and at Greppo Cenale. These clustered viewshed analyses seem to suggest that earlier tombs on the San Giuliano landscape are prioritizing intervisibility in their construction, and this coincides with the historical record well.

Conclusions

Gargana argues that San Giuliano's location was chosen because of its abundance of volcanic tuff stone, which made it an apt environment for construction with tuff stone blocks and made it a strong southern fortress against Rome in the Tarquinian region, as the water-carved plateau would be easily defensible (Gargana 1931, 299). However, the natural visibility of the landscape cannot be written off as coincidence. Archaeologist Criado-Boado devised the term "will to visibility" to describe the tendency of cultural groups to settle at sites with naturally visible topography, as topographical elements that remain visible throughout space and time serve as a shared symbol of the perpetuity of the group (Criado-Boada 1995, 199). Furthermore, Bernardini and Peeples write about "sight communities," defining them as groups that share "visual anchors," or common spatially referenced points that function to define space and act as a fundamental source of shared culture (Bernadini and Peeples 2015, 215). These sight communities have similar cognitive maps of their landscapes, which in turn, implies a shared understanding of aspects of cosmogony, religious beliefs, or the afterlife (Bernardini and Peeples 2015, 216). Having tombs as this visual anchor, in the case of San Giuliano, suggests that Etruscan inhabitants used memory as a tool for constructing a shared mythic past and shared understanding of the afterlife, in a way that unified the sight community and legitimized social structures.

Etruscan occupation at San Giuliano represented a major social, cultural, and demographic change from prior Villanovan occupation. It should be expected that this Etruscan urbanization ushered in increased social complexity, notably in the construction of spaces of civic-ceremonial importance to the overall community. Stanish and Haley write that according to game theory, public cooperation is often indicated in the archaeological record by physical accessibility and the visual accessibility of monumental structures (Stanish and Haley 2004, 63). In the earlier phases of tomb construction from the Orientalizing to the Archaic Period, the tendency to prefer intervisibility between the plateau and the Cima, Caiolo, and San Simone region may speak to a more egalitarian period of flourishment, consistent with the historical record. The Etruscans in the Tarquiian region experience a period of political, economic, and social prosperity, culminating in the Battle of the Sardinian Sea in 540 BCE, when the Etruscans gain commercial control over the Tyrrhenian Sea over the Greeks.

Furthermore, it is fitting that intervisibility would be greatly reduced in the Classical Period. Following the "Etruscan Crisis" in 474 BCE, when Etruscans were defeated in the naval battle of Cuma, ending their monopoly on the Tyrrhenian Sea, the reduced economic contribution from international trade led to period of difficulty throughout the Tarquiniian region, where nearby sites like San Giovenale, entirely disappear (Sasso 2005, 11). There is also some evidence that aristocratic families began intensely hoarding wealth, leading to increased social stratification (Sasso 2005, 11). Discontinued preference for intervisibility could suggest less public cooperation, or visibility with new parts of the plateau could represent an attempt to construct new collective memory and subvert the traditional social order at San Giuliano.

Ultimately, this viewshed analysis shows at the very least that there is convincing evidence of intervisibility between the plateau at San Giuliano and the necropolis, despite that densely overgrown vegetation makes this difficult to determine on the modern landscape. Having tombs as a visual anchor for Etruscan inhabitants indicates a social cohesion unified by constructed memory and shared understanding of the afterlife. While there are certainly limits to what viewshed and intervisibility can reveal about individual experience of a landscape, the contextualization of the clustered tomb data with the historical record allows for a discussion of changes in social order at San Giuliano alongside statistically rigorous models of sensory experience (Llobera 2007, 67).

CHAPTER FIVE

Cluster and Network Analysis of Caves at San Giuliano

The settlement transformations that occur at San Giuliano following the regional Etruscan collapse are unclear. Roman occupation of Etruria occurs around 300 BCE, leading to the disappearance of Etruscan culture and political structures as the population is gradually Romanized (Sasso 2005, 14). Gargana discusses written evidence of San Giuliano's fate, claiming that the site is mentioned by Livy as one of the Roman conquests in Tarquinian territory around 388 BCE, but this is contested (Gargana 1931, 323). Otherwise, there is no written record for the site or the immediate area until the Late Middle Ages.

The archaeological record for occupation at San Giuliano after the Etruscan period provides a clearer image of the social and political transformations that may have occurred. While the only potential evidence of Roman occupation is a Roman imperial column, reused as *spoila* in the construction of the plateau's Romanesque church, the presence of fortification structures and of artificial cave structures dispersed around the plateau evidence a phase of increased occupation and development beginning in the Early Middle Ages and ending with abandonment around AD 1300.

Guerrini most comprehensively addresses this phase of medieval occupation through her survey of the medieval landscape and cave structures at San Giuliano. This chapter builds upon her initial survey, using additional data from further pedestrian survey in the 2018 SGARP field season, to analyze the Medieval caves using GIS and spatial syntax theory. The caves, which were carved into available tuff and presumably served the function of animal housing, human habitation structures, and ritual spaces, can be analyzed using GIS to understand the networks and relations between the cave structures. Representation of the relations through spatial syntax aids in analysis of the underlying social logic of space that ordered the medieval landscape at San Giuliano.

Background

Spatial Syntax Theory

Hillier and Hanson's system of spatial syntax is written out in their 1984 book, *The Social Logic of Space*. Definitions of the main components of the system are discussed in Chapter 2, where they write "The reader is warned that this chapter is the most tortuous and perhaps the least rewarding in the book" (Hillier and Hanson 1984, 50). Given the complexity of their logical and mathematical ordering of the system, it is suggested that the reader refer to Hillier and Hanson (1984) for answers to questions about the syntactical logic of space that are beyond the scope of this chapter.

In broad overview, the system of spatial syntax is designed to classify space irreducibly by representing only objects and their relations (Hillier and Hanson 1984, 52). Objects on a landscape, such as architectural features, are represented as simple nodes, with interconnecting lines showing their relations. Another important aspect of this syntactical system is that the representational style has ideographic connotations for ease of interpretation, this so that "the difficulty of always having to use cumbersome verbal constructs for sets of ideas which are used repeatedly" is avoided (Hillier and Hanson 1984, 52). Thus, in this elementary means of visualizing and classifying a landscape, spatial patterns can be recognized that may have been previously unnoticed on a complex, multi-component landscape.

Thus, this system seems apt for use with GIS considering that a network dataset in ArcMap is constructed of lines and points, with each point's topographical information represented as data attributes. Additionally, as the system tries to represent objects with visual ideographic connotations, the ease of editing symbology in ArcGIS allows for the representation of objects with specific shapes or colors that communicate relevant ideographic meaning, such as function, architectural style, accessibility, or chronology.

It is these principles and aims that this study seeks to incorporate into the analysis of the San Giuliano plateau, rather than Hillier and Hanson's entire methodological approach of space syntax. For example, aspects of network decision making outside of least cost paths and walking accessibility are not considered or addressed in this study. This seems appropriate, however, given multi-theoretical and novel applications of GIS is at the heart of this thesis. Thus, Hillier and Hanson's spatial syntax theory acts as a rhetorical framework for the interpretation of GIS network analysis of the San Giuliano cave systems. Even if there is no intended meaning behind the placement of these caves, spatial syntax theory provides the means for constructing an effective morphology of space that rejects the idea that these caves are the result of a random enumeration of placement possibilities that have no social or cultural logical relevance. Instead, the elementary representation of these spaces and their attributes demonstrates that qualities like accessibility and distribution represent an underlying social logic of space.

Guerrini's Typology

Guerrini's article, "Il territorio di Barbarano," is a comprehensive catalog of thirty-one caves present at San Giuliano, organized into a typology of four distinct cave types. These types are defined by variables of plan, architectural attributes, and vicinity on the plateau. The earliest type, which Guerrini calls Type I, are located around the perimeter of the plateau. This type has a square or trapezoidal opening and a carved trough inside the cave indicating use for animal husbandry (Guerrini 2003, 133). Type II caves, which Guerrini suggests were built after Type I in the 11th century, are characterized by an irregular or polygonal opening and their proximity to the site's dry moat complex, functioning as habitation structures (Guerrini 2003, 134).

	Layout	**Location**	**Architecture**	**Function**	**Chronology**
Type I	Trapezoidal	Northwest slopes of plateau	"Dromos" and manger	Stable	Pre-11th c.
Type II	Mixed-form	Moat on plateau	Doorway	Habitation	11th -12th c.
Type III	Rectangular	Along road on west plateau	Depressed arched niches, ventilation hole, manger	Habitation then stable	Post Type II
Type IV	Square	South slopes of plateau	Wall with collapsed façade	Unclear – reworked multiple times	Also unclear

Table 3. Guerrini's cave typology. Function and chronology are not mentioned specifically by Guerrini as defining features of the types, but are relevant information included in her article.

Type III caves, found along an east-west axis on the plateau, were constructed in the 12th century, and feature regular, rectangular openings, a ceiling ventilation hole, and sometimes a trough (Guerrini 2003, 136). Finally, Type IV caves located on the southern slopes of the plateau along a path that seems to have been in axis with the roads Cassia and Clodia (Guerrini 2003, 138). The most notable common architectural feature is that they are nearly square and that their facades have all eroded. Their initial function is unclear, but Guerrini suggests that these types of caves had multiple periods of reworking.

While Guerrini's cave typology is effective, it does not incorporate every tomb present on the landscape, with those that do not fit into a type description unclassified. Consequently, these caves were resurveyed and digitized so that statistically determined cave types using k-means cluster analysis could be used for further analysis of every cave.

Data Collection

Pedestrian survey was conducted using the same grid system used to survey the San Giuliano necropolis. Survey in 10 meter transects was coupled with opportunistic survey according to Guerrini's drawn map of cave locations. However, there was some difficulty in finding all of the caves mentioned in Guerrini's article. A conversation with her this summer at the site suggested that a dramatic increase in vegetation overgrowth and erosion events have left some of the cave locations inaccessible or possibly destroyed since she surveyed 20 years ago. However, further survey should be conducting in following field seasons to attempt to locate these tombs and to add to the cave dataset for the site.

In total, there were 20 caves found and recorded at San Giuliano. Locations of the caves were recorded in a Garmin 64st GPS and relevant features, including troughs, niches, pillars, and jambs, were recorded via photography and in a field journal. These cave GPS locations and their attributive data were digitized and combined with the drone derived DEM for cluster and least cost network analysis.

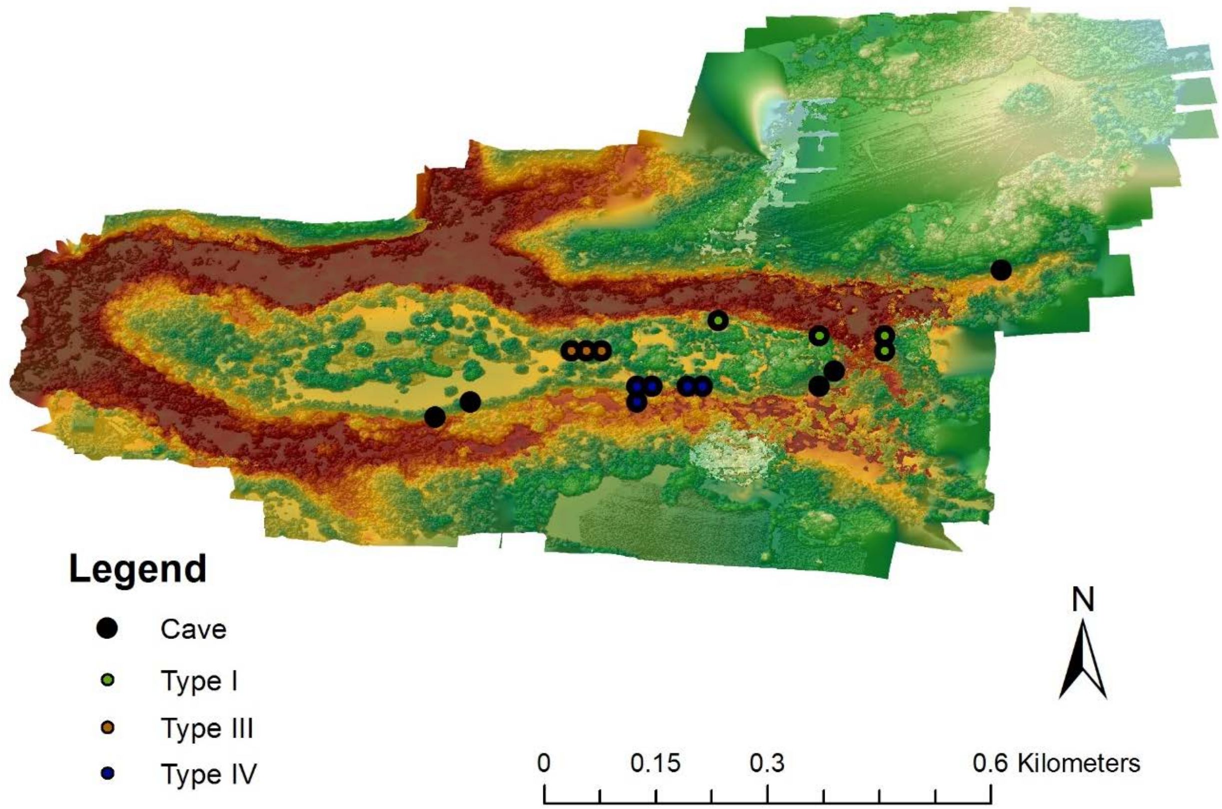


Figure 24. Distribution of caves throughout the plateau, with Guerrini's typology symbolized.

Analysis

Accessibility

Classification of the overall accessibility of the San Giuliano plateau was conducted using the cost measures of walking speed and slope (Conolly and Lake 2006, 219). First, slope values were calculated from the drone derived digital elevation of the San Giuliano plateau within ArcMap. Next, the Remap Values tool in ArcMap allowed for reclassification of the slope raster by cell value according to the equation for the effect of slope on the speed of walking: $v = 6e^{-3.5|s+0.05|}$, with s being the cell's slope value (Gorenflo and Gale 1990, 241). This yielded a raster with cells ranging in value from around 1 to 5, which were rounded and represented as distinct classes of accessibility, with areas in red being the most difficult for walking.

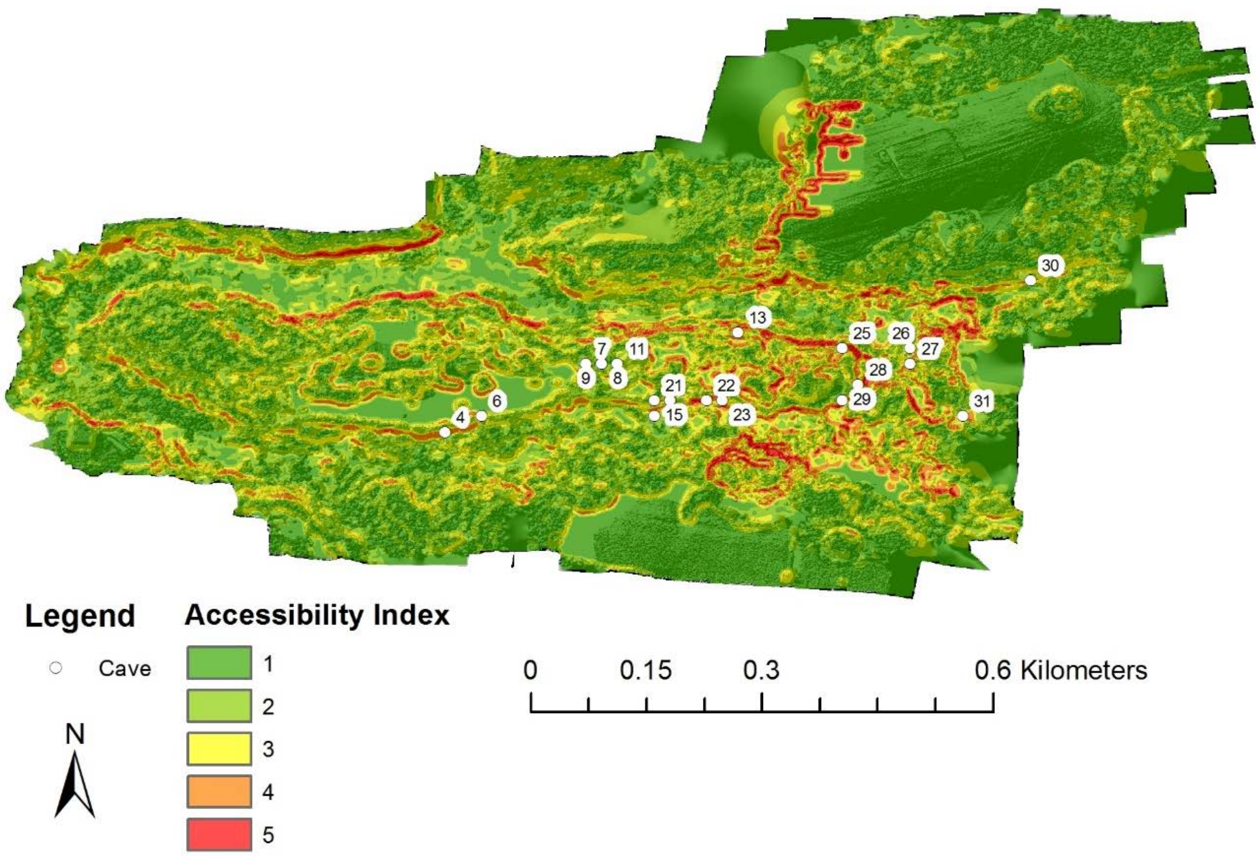


Figure 25. Accessibility Index according to slope and walking equation.

K-means cluster analysis

To reevaluate the cave typology of tombs outlined by Guerrini, significant architectural and environmental features that relate to the functionality of a space were recorded as attributes for each of the cave points within their attribute tables. The features chosen to be recorded as attributes were the plan of the cave, which could be trapezoidal, rectangular, or square, the presence or absence of an animal trough, the presence of niches in doorway jambs indicating potential mechanisms for entrance closure, and the presence of a purposefully carved hole in the ceiling of the cave for the ventilation of smoke. Additionally, the cave's relative accessibility according to the calculated accessibility index was added as integer attribute data.

Cluster Group	**Accessibility**	**Plan**	**Manger**	**Jamb**	**Ceiling**
Cluster 1	3-4	Trapezoidal	Yes	Yes	No
Cluster 2	1	Rectangular	Yes or No	No	Yes
Cluster 3	2-4	Rectangular or Square	Yes	No	No
Cluster 4	2-4	Rectangular or Square	No	Yes	No
Cluster 5	5	Rectangular	No	No	No

Table 4. New San Giuliano cave typology based on results from K-means clustering analysis.

K-means cluster analysis was then used to re-evaluate the categorical divisions of Guerrini's typology, as well as suggest the need for additional categorical cave types. K-means analysis in ArcMap uses feature attributes and spatial constraints to group features into clusters. This analysis revealed five categories of cave clusters, with most of Guerrini's cave types coinciding with the new clustered groups, with the exception of

Cluster 5 being a new category of caves predominantly defined by their lack of accessibility on the landscape (Appendix 3).

Two cave clusters most discernibly warranted analysis through spatial syntax theory, as their dichotomous nature and function on the landscape should reveal varying patterns for the social ordering of space at the San Giuliano plateau. The first of these is cave Cluster 2, in which caves are primarily defined by their accessibility on the plateau. In direct contrast is cave Cluster 5, whose lack of typical cave architectural features and relative inaccessibility suggests that the caves served ritual purposes as opposed to the functional purposes of the other cave types. Further analysis will look more specifically at Cluster 2 and Cave number 31 from Cluster 5.

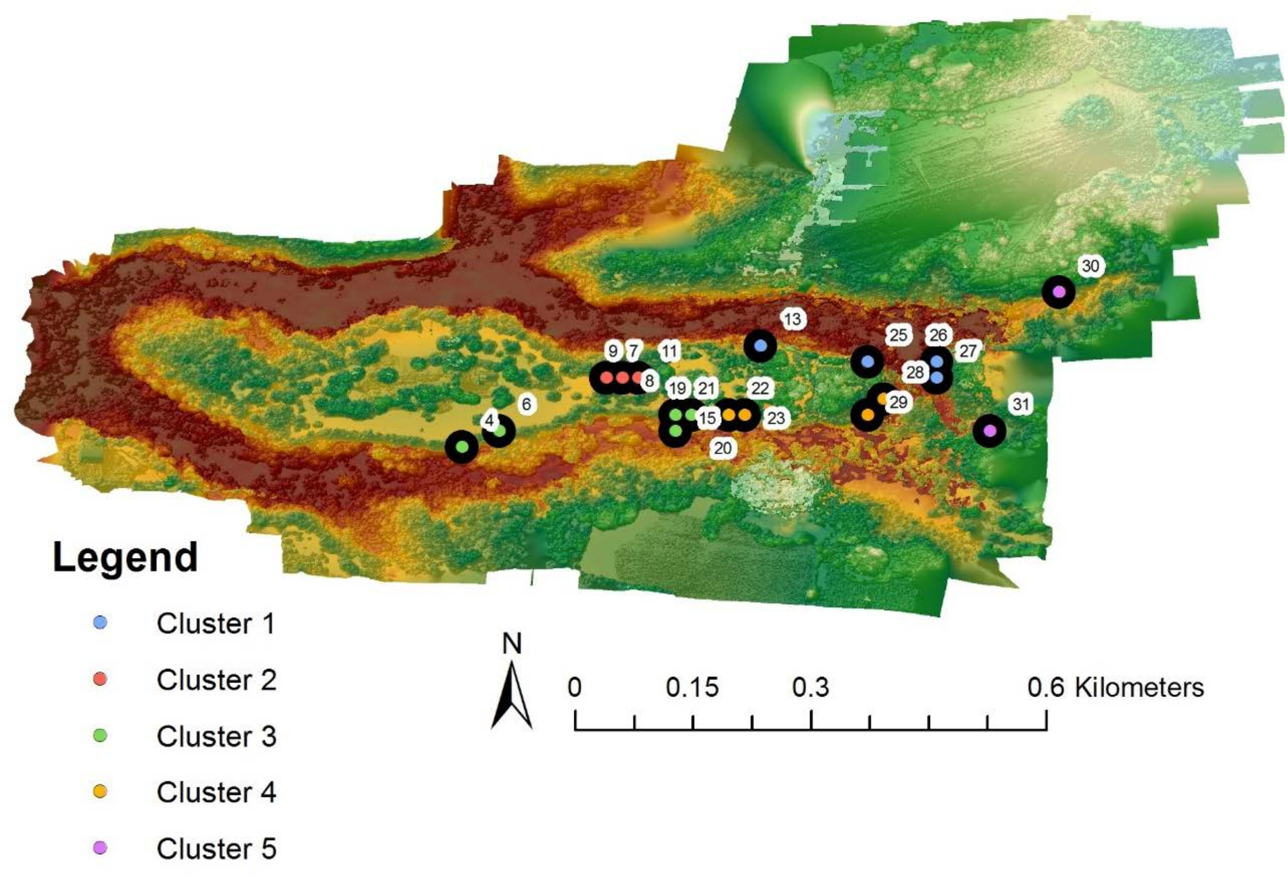


Figure 26. Map of cave clusters derived from k-means analysis.

Cluster Two Syntax

Guerrini hypothesizes in her article that each of these caves were built along an established walking path (Guerrini 2003, 143). For this reason, relationships between these tomb clusters were classified in ArcGIS using network analysis. Networks were constructed in ArcMap according to least cost paths for walking between caves in a cluster. Much in the same way that watershed is calculated, these least cost paths were calculated with respect to the accessibility index, and thus the Flow tool was chosen for this process. Overall, the network between nodes in Cluster 2 exhibited the lowest cost value of all the cave cluster networks.

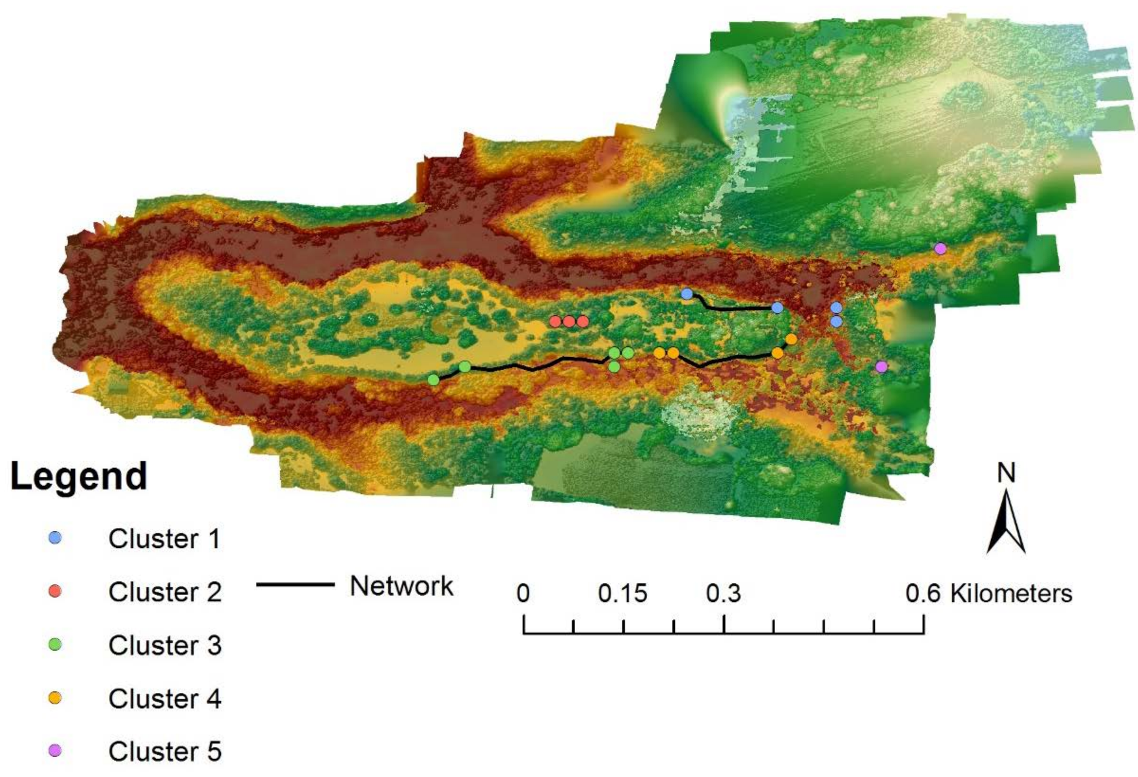


Figure 27. Networks according to least cost accessibility index, with caves as nodes.

In terms of spatial syntax, Cluster 2 exhibits syntactical behavior of symmetry and non-distributedness. According to Hillier and Hanson, spaces are considered symmetrical when routes between nodes are direct and equivalent (Hillier and Hanson 1984, 93). The implication for symmetry in nodal patterning is a prioritization of social integration rather than social segregation (Hillier and Hanson 2003, 97). This is further supported by the cave cluster's centrality and ease of accessibility on the San Giuliano plateau. However, the cluster's non-distributedness, which is spatial organization of nodes along a single, nonintersecting route, suggests a superordinate control of the spaces' functionality (Hillier and Hanson 2003, 97). The combination of these patterns seems to support the interpretation that these caves served as spaces for human habitation according to the nondistributedness quality, but also reflects an underlying social structure that is relatively egalitarian evidenced by the space's accessibility and symmetry.

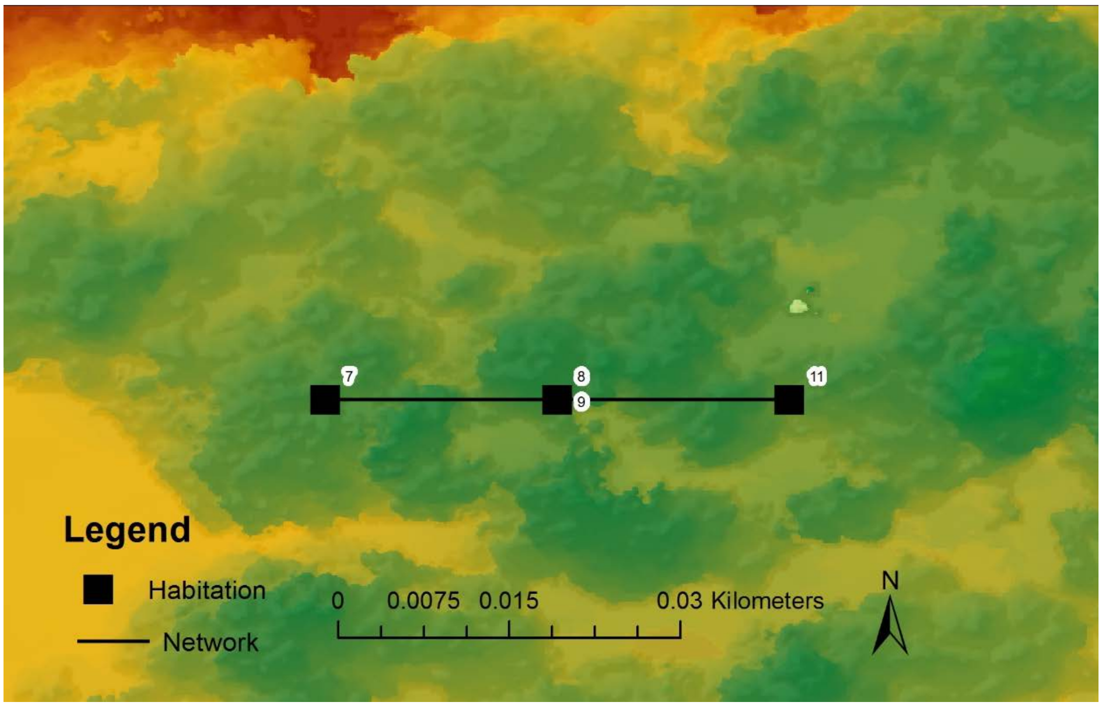


Figure 28. Cluster 2 first occupation.

More interestingly, the presence of a trough in caves 9 and 11 suggest multiple phases of use. Guerrini suggests that the phase of human occupation, evidenced explicitly by the presence of ceiling ventilation features, preceded the phase in which the space was used to house animals. Spatial syntax allows for the representation of these phases of occupation through differentiation of nodal symbology. Analysis of the cluster with regards to both phases of occupation suggest a transition in social structure occurring when the spaces are transformed into a stable. If habitation was abandoned here in favor of less accessible or less symmetrical spaces, this may represent an increase in social segregation and underlying social stratification in later medieval periods.

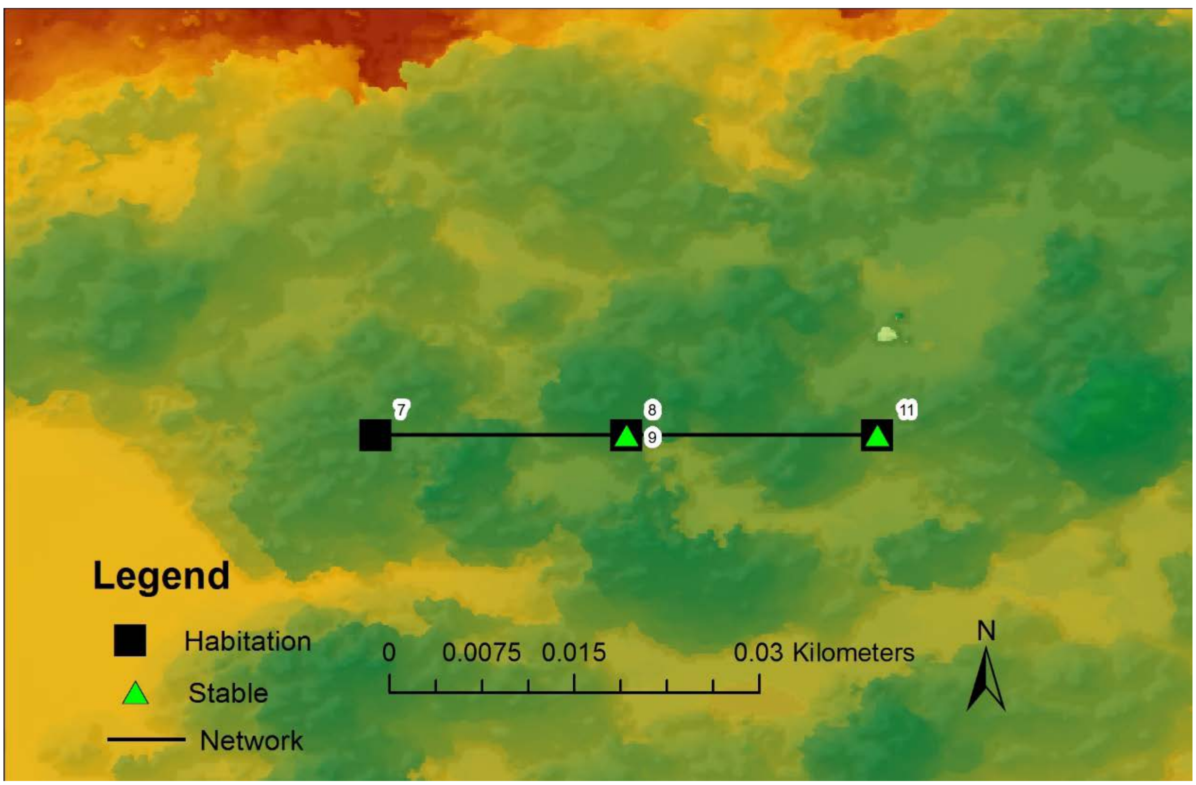


Figure 29. Cluster 2 second occupation.

San Simone Cave Syntax

In contrast, analysis of the San Simone cave, which is cave number 31 in Cluster 5, through spatial syntax theory offers insight into the religious structures underlying San Giuliano inhabitant's spatial cognition of the landscape. The San Simone cave was first an Etruscan tomb, which was reutilized in the Middle Ages as evidenced by the tomb's extensive innovation and expansion, as well as the presence of a fresco of the presentation of Christ to St. Simon. This fresco, combined with the relative inaccessibility of this cave structure, as well as the fact that it is not in a recognizable network with any other structure on the plateau resonates with an interpretation that this cave served as a sacred space.

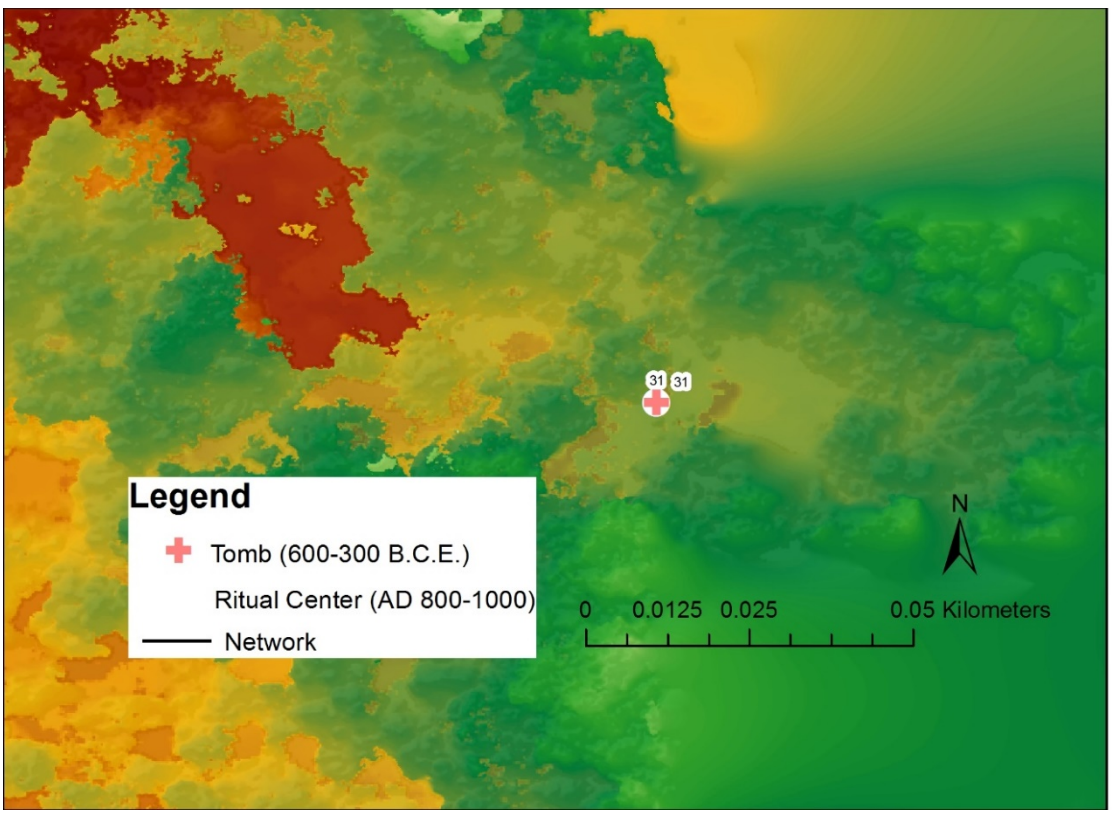


Figure 30. San Simone occupations.

Mircea Eliade suggests of the reuse of sacred spaces that, "religious architecture simply took over and developed the cosmological symbolism already present in the structure of primitive habitations" (Eliade 1959, 58). Thus, it is possible that the San Simone cave had an imbued sacredness preceding the medieval inhabitants at San Giuliano, extending back to the Etruscan period of occupation. However, analysis of the attributive data such as the orientation and internal architecture of the cave suggests additional factors for this tomb's reuse as well as holds significant implications for understanding the Christian cosmogony of San Giuliano's medieval inhabitants.

Figure 31. The fresco Christ's Presentation to St. Simon in the San Simone cave.

The layout of the cave seems to be in reference to Christian sacred architecture, as the back-interior wall seems to represent a central apse, complete with a carved arch above it. Eliade writes that an important element of a threshold in a sacred space is that it opens the space in an "upward direction and ensures communication with the world of the gods" (Eliade 1959, 26). Furthermore, the entrance to this cave opens in the west, with the back wall where the fresco of San Simone is located to the east, paralleling the typical orientation of a Christian church. This signifies the sacredness of the space, as Eliade writes that the interior of a church serves to symbolize the universe, and in turn, reflect the religious individual's understood cosmogony. Eliade claims, "The altar is paradise, which lay in the East… The West, on the contrary, is the realm of darkness, of grief, of death, the realm of the eternal mansion of the dead, who await the resurrection of the flesh and the Last Judgment. The middle of the building is the earth" (Eliade 1959, 61). Thus, if the tomb was selected due to its East-West orientation, it follows that the poignancy of the binary opposition of Paradise and Damnation present in church architecture is even stronger given that the middle ground of this worship space, representing earth, was a literal tomb. The rhetorical implications of the earth as a tomb supports the Christian cosmological understanding of death as impermanent, as Christ's divine manifestation as flesh mediates between life and death.

Ultimately, spatial syntax analysis of Cluster 2 and Cluster 5 type caves demonstrate a basic relationship between the social organization and spatial logic of medieval inhabitants at San Giuliano. While the scope of this chapter is limited to these two case studies, the newly generated k-means cave clusters should be further studied using spatial syntax theory to create a comprehensive portrait of how rock structures were used diachronically at San Giuliano.

CHAPTER SIX

Conclusions

In assessing the longitudinal occupation of the San Giuliano landscape, a single theoretical approach fails to offer comprehensive conclusions that speak to each rung of Hawkes' ladder of inference. The multi-component theoretical framework adopted by this study builds upon foundational regional information regarding subsistence and technology from positivist deductive modeling to make inferences about visual experience and social ordering at San Giuliano. The results demonstrate the complex diachronic changes that are otherwise invisible in the site's known historical record, and demonstrate the strength of GIS for visualizing these changes.

Positivist predictive models showing deviation from optimal behavior on a landscape offer a means of understanding San Giuliano in a regional context. Human Behavioral Ecology suggests that sites where populations grow and thrive are places where inhabitants have adopted optimal strategies for adapting to the environment. Thus, the urban centers of the Etruscan period in Southern Etruria should be the result of earlier settlement decisions, which optimized location according to the available resources of the Southern Etruria landscape. Results from the site suitability modeling in Chapter Three corroborate this assessment, as well as suggest the constitutive roles that various settlement centers may have played.

The weighted overlay model, which prioritized site location decisions on optimal responses to the Vico volcanic geological system, best applied to smaller sites in Southern Etruria, such as Norchia, Blera, San Giovenale, and San Giuliano. These sites received high suitability scores, while the larger sites Tarquinia, Vulci, and Cerveteri exhibited varying scores. This suggests that sites with higher populations and territories in the landscape were not centrally located in areas where optimal agriculture subsistence could occur, but instead engaged in other economic means of subsistence. Most probably, these sites coastal location allowed for broader trading networks than inland sites. San Giuliano would likely have been in trade with these larger communities, but its location fits with the model hypothesis that environmental factors affecting the optimality of agricultural subsistence had the most weight in past peoples' decision to occupy the San Giuliano plateau.

However, limitations of this approach are that large-scale regional GIS data is difficult to acquire and often too low of resolution for accurate modeling. Furthermore, this approach can only comment on the bottom rungs of Hawkes' ladder – technology and subsistence. Thus, continued Phenomenological analysis of the San Giuliano landscape specifically can inform social and religious interpretations that are lacking in the site's historical record.

Viewshed analysis in ArcGIS actualizes the aims of embodiment without abandoning the rigor of positivistic modeling. Total and cumulative viewshed allow for assertions about intervisibility and visual anchors, while probabilistic viewshed overrides the substantive problems of modeling ancient landscapes with statistical certainty. These models revealed that at the San Giuliano plateau, there is statistically significant certainty between the necropolis and the eastern edge of the plateau, where Gargana has previously suggested the location for now destroyed Etruscan structures.

Furthermore, GIS analysis prevents reductive phenomenological conclusions that treat experience of the modern landscape as experience of the ancient landscape, reducing centuries of experience on a landscape to a single chronological monolith. Evaluating objects on the landscape based on their attributes in conjunction with their viewshed allows for a prediction of how visual experience of the landscape may have changed over time, which may resonate with how underlying social structures changed over time. Multiple viewshed analysis at San Giuliano revealed significant changes in intervisibility after the fifth century, which may evidence ripples in San Giuliano social organization, in correlation with regional shifts in Southern Etruria economics and trade networks.

Phenomenological approaches are less valuable for interpreting the San Giuliano landscape following the Etruscan collapse, as there is less evidence for monumental architecture. Spatial syntax offers an alternative theory for interpreting caves, which held functional and religious significance, on the San Giuliano landscape that appear during the medieval period. The classification of elementary objects and their relations in ArcGIS reveals underlying spatial patterns

Combined with interpretation of the site's accessibility, networks demonstrating principles of symmetry and distributedness between clustered architectural objects suggest an underlying spatial logic that resonates with a culture's social order. At San Giuliano, changes in chronological attributive data for cave structures in the most accessible cluster, Cluster 2, suggest changes in social order and land use presumably around the time that La Rocca is fortified. Additionally, spatial syntax analysis of the attributive data of a cave in Cluster 5 suggests that its low accessibility, architectural modifications, and east-west orientation reflect the medieval Christian cosmogony.

Ultimately, each of these models offers critical insight into chronologically segmented layers of the palimpsest of the San Giuliano landscape. With a modified multi-component theoretical approach that reflects the data that is available, interpretation of these layers of occupation can allow for inferences than span the rungs of Hawkes' ladder of inference. GIS modeling effectively deconstructs subsequent phases of reuse of the landscape, salvaging vital information about technology, subsistence, social organization, and cognition lost in the historical and material record.

Further Research

Suggestions for further research include further analysis of the roads present in the San Giuliano necropolis. Especially in the southern cluster and Greppo Cenale cluster, where intervisibility with the plateau may not be the primary determinant for tomb location, recording potential roads as networks could allow for further interpretation of social organization and memory during the Etruscan period. Following the hypothesis that accessibility of tombs is an important mechanism of collective memory, constructing tombs along roads, pathways, or areas of high accessibility would bolster this conclusion.

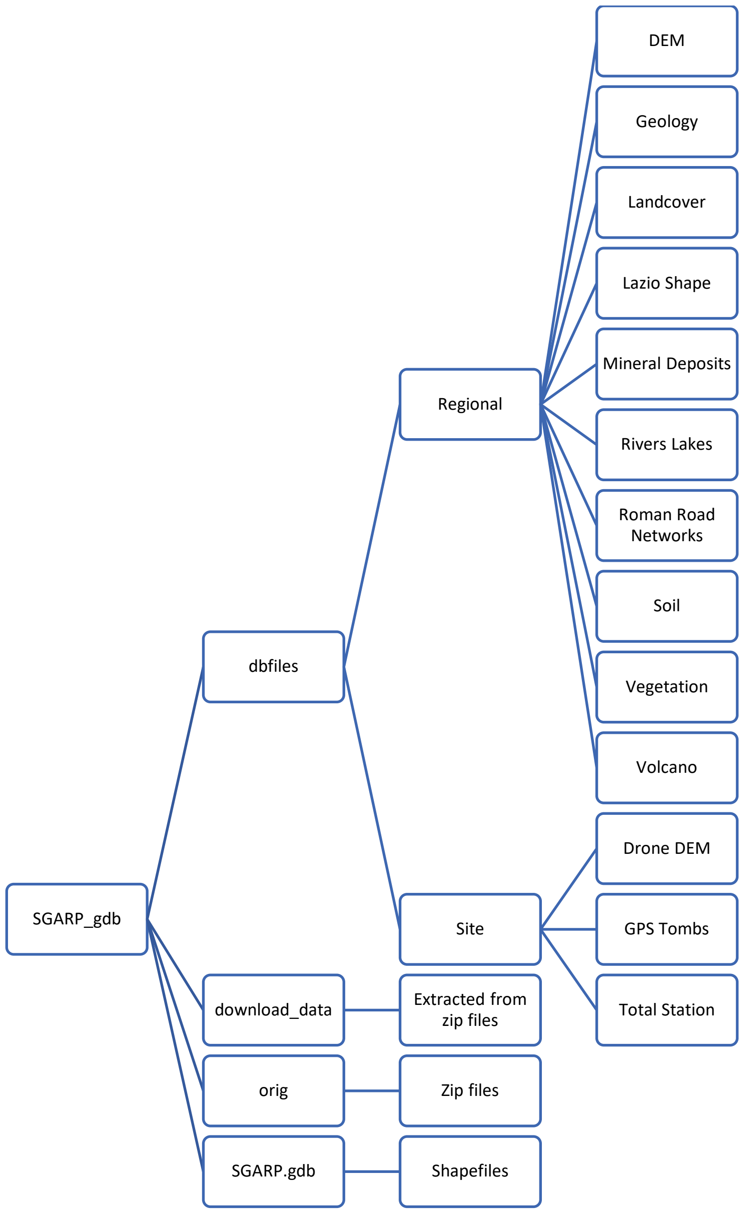
Additionally, the continued survey of caves along the plateau, specifically trying to locate caves that Guerrini identified that were not found during the 2018 field season, would be a valuable endeavor. These caves could be added to the present cave dataset for continued analysis, revealing even more information about changes in land use during the medieval period.

Lastly, SGARP should seek to access a LIDAR attachment for the drone, as LIDAR survey of the landscape would allow for the creation of a bare earth surface model, which would circumvent the need for probabilistic models that introduce error to address problems of vegetation coverage and changes in the landscape. Hopefully, the creation of an organized geodatabase will allow for further survey data to be combined and reevaluated through the proposed multi-theoretical framework in future SGARP seasons.

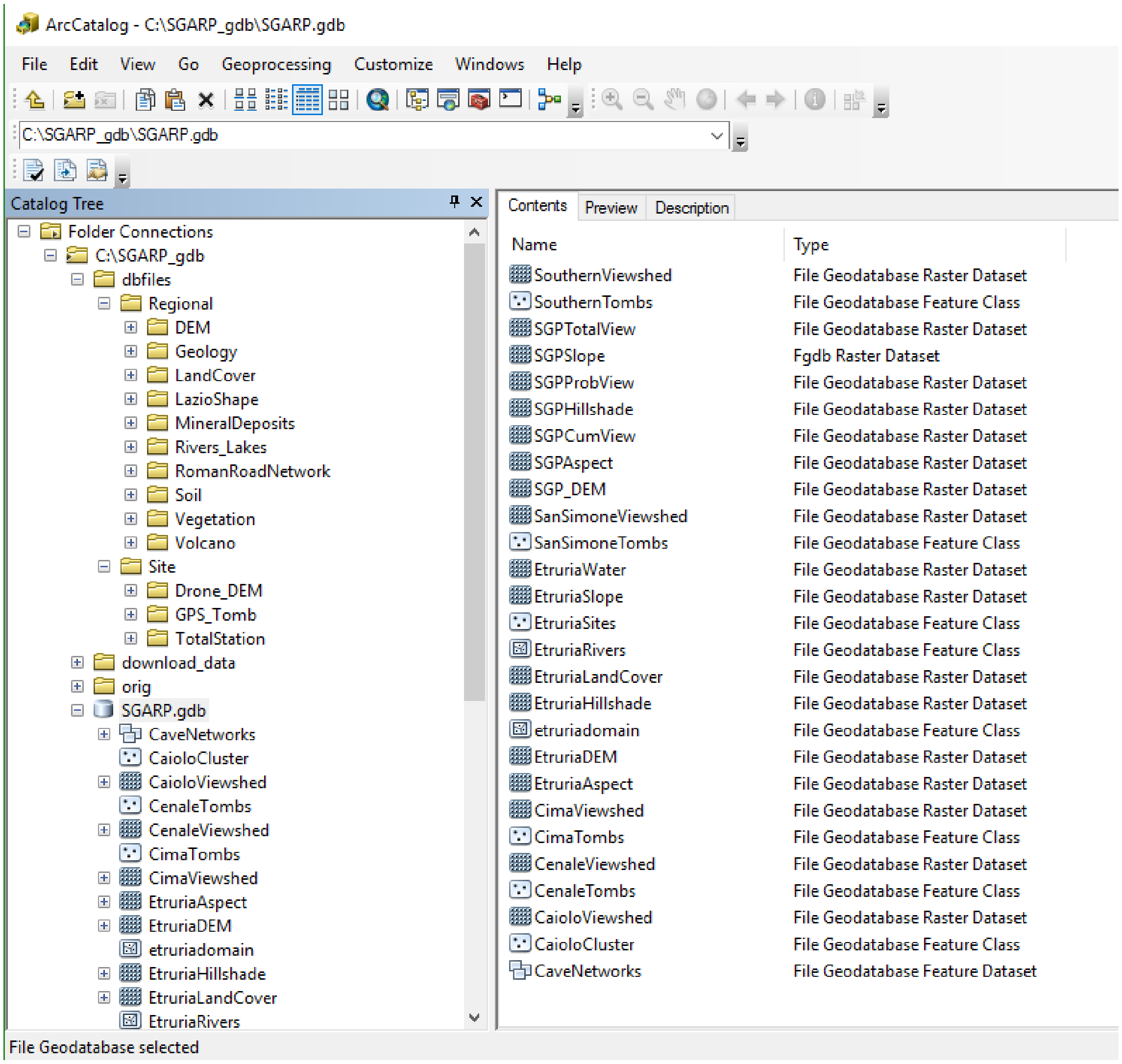
APPENDICES

APPENDIX A

SGARP Geodatabase Structure



This is a file structure map for C:\SGARP_gdb. Folder "dbfiles" contains relevant Regional and Site specific data which is unedited. Folders "orig" and "download_data" are processing folders for downloading and extracting geospatial data, which are important because they preserve relevant metadata. Folder “SGARP.gdb” is a geodatabase structure which should be accessed through ArcCatalog, the contents of which are processed shapefiles from the original “dbfiles” data. A screenshot of the “SGARP.gdb contents is below.



APPENDIX B

Kolomogorov-Smirnov Spatial Distribution Test

ObjectID	**X**	**FREQ**	**CUMUL**	**SN(X)**	**Z-SCORE**	**F(X)**	**DIFF**
1	0	5043258	5043258	0.545066	11.93915	1	0.454934
2	1	805110	5848368	0.632081	1.783396	0.962739	0.330658
3	2	582246	6430614	0.695009	1.249353	0.894232	0.199223
4	3	434123	6864737	0.741928	0.89441	0.814449	0.072521
5	4	333280	7198017	0.777948	0.652763	0.743045	0.034903
6	5	295661	7493678	0.809903	0.562618	0.713152	0.09675
7	6	269169	7762847	0.838994	0.499136	0.691158	0.147836
8	7	216304	7979151	0.862372	0.372457	0.645224	0.217148
9	8	179819	8158970	0.881806	0.285029	0.612189	0.269617
10	9	146792	8305762	0.897671	0.205887	0.581561	0.316111
11	10	112915	8418677	0.909875	0.124709	0.549623	0.360252
12	11	111456	8530133	0.921921	0.121213	0.548239	0.373682
13	12	85117	8615250	0.93112	0.058097	0.523164	0.407956
14	13	65538	8680788	0.938204	0.011181	0.50446	0.433743
15	14	55365	8736153	0.944187	-0.0132	0.494735	0.449452
16	15	51442	8787595	0.949747	-0.0226	0.490986	0.458761
17	16	47257	8834852	0.954854	-0.03263	0.486987	0.467868
18	17	40797	8875649	0.959264	-0.04811	0.480816	0.478448
19	18	36853	8912502	0.963247	-0.05756	0.477051	0.486196
20	19	31138	8943640	0.966612	-0.07125	0.471599	0.495013
21	20	25612	8969252	0.96938	-0.08449	0.466332	0.503048
22	21	23371	8992623	0.971906	-0.08986	0.464198	0.507708
23	22	19803	9012426	0.974046	-0.09841	0.460802	0.513244
24	23	17347	9029773	0.975921	-0.1043	0.458466	0.517455
25	24	15759	9045532	0.977624	-0.1081	0.456957	0.520667
26	25	14661	9060193	0.979209	-0.11073	0.455913	0.523295
27	26	13938	9074131	0.980715	-0.11247	0.455227	0.525489
28	27	13272	9087403	0.98215	-0.11406	0.454594	0.527556
29	28	12483	9099886	0.983499	-0.11595	0.453845	0.529654
30	29	12645	9112531	0.984865	-0.11557	0.453999	0.530867
31	30	12676	9125207	0.986235	-0.11549	0.454028	0.532208
32	31	11527	9136734	0.987481	-0.11824	0.452937	0.534544
33	32	9416	9146150	0.988499	-0.1233	0.450934	0.537565
34	33	8585	9154735	0.989427	-0.12529	0.450145	0.539281

ObjectID	X	FREQ	CUMUL	SN(X)	Z-SCORE	F(X)	DIFF
35	34	7131	9161866	0.990198	-0.12878	0.448767	0.541431
36	35	6448	9168314	0.990894	-0.13041	0.448119	0.542775
37	36	6316	9174630	0.991577	-0.13073	0.447994	0.543583
38	37	5852	9180482	0.99221	-0.13184	0.447554	0.544655
39	38	5821	9186303	0.992839	-0.13192	0.447525	0.545314
40	39	6023	9192326	0.99349	-0.13143	0.447716	0.545773
41	40	6306	9198632	0.994171	-0.13076	0.447984	0.546187
42	41	5054	9203686	0.994717	-0.13376	0.446798	0.547919
43	42	4588	9208274	0.995213	-0.13487	0.446357	0.548857
44	43	4265	9212539	0.995674	-0.13565	0.446051	0.549624
45	44	3776	9216315	0.996082	-0.13682	0.445587	0.550495
46	45	2749	9219064	0.996379	-0.13928	0.444615	0.551764
47	46	3374	9222438	0.996744	-0.13778	0.445207	0.551537
48	47	3217	9225655	0.997092	-0.13816	0.445058	0.552034
49	48	2893	9228548	0.997404	-0.13893	0.444751	0.552653
50	49	2707	9231255	0.997697	-0.13938	0.444575	0.553122
51	50	1849	9233104	0.997897	-0.14144	0.443763	0.554134
52	51	1390	9234494	0.998047	-0.14254	0.443329	0.554718
53	52	1227	9235721	0.99818	-0.14293	0.443174	0.555005
54	53	1131	9236852	0.998302	-0.14316	0.443084	0.555218
55	54	1127	9237979	0.998424	-0.14317	0.44308	0.555344
56	55	1150	9239129	0.998548	-0.14311	0.443101	0.555446
57	56	1044	9240173	0.998661	-0.14336	0.443001	0.55566
58	57	1004	9241177	0.998769	-0.14346	0.442963	0.555806
59	58	952	9242129	0.998872	-0.14358	0.442914	0.555958
60	59	852	9242981	0.998964	-0.14382	0.44282	0.556145
61	60	682	9243663	0.999038	-0.14423	0.442659	0.556379
62	61	671	9244334	0.999111	-0.14426	0.442648	0.556462
63	62	612	9244946	0.999177	-0.1444	0.442592	0.556584
64	63	602	9245548	0.999242	-0.14442	0.442583	0.556659
65	64	547	9246095	0.999301	-0.14456	0.442531	0.55677
66	65	458	9246553	0.99935	-0.14477	0.442447	0.556904
67	66	411	9246964	0.999395	-0.14488	0.442402	0.556992
68	67	407	9247371	0.999439	-0.14489	0.442399	0.55704
69	68	383	9247754	0.99948	-0.14495	0.442376	0.557104
70	69	357	9248111	0.999519	-0.14501	0.442351	0.557167
71	70	286	9248397	0.99955	-0.14518	0.442284	0.557266
72	71	322	9248719	0.999584	-0.14509	0.442318	0.557266
73	72	308	9249027	0.999618	-0.14513	0.442305	0.557313
74	73	267	9249294	0.999647	-0.14523	0.442266	0.55738

ObjectID	X	FREQ	CUMUL	SN(X)	Z-SCORE	F(X)	DIFF
75	74	252	9249546	0.999674	-0.14526	0.442252	0.557422
76	75	250	9249796	0.999701	-0.14527	0.44225	0.557451
77	76	228	9250024	0.999725	-0.14532	0.442229	0.557496
78	77	196	9250220	0.999747	-0.1454	0.442199	0.557548
79	78	219	9250439	0.99977	-0.14534	0.442221	0.55755
80	79	191	9250630	0.999791	-0.14541	0.442194	0.557597
81	80	177	9250807	0.99981	-0.14544	0.442181	0.557629
82	81	158	9250965	0.999827	-0.14549	0.442163	0.557664
83	82	144	9251109	0.999843	-0.14552	0.44215	0.557693
84	83	146	9251255	0.999859	-0.14552	0.442152	0.557707
85	84	129	9251384	0.999872	-0.14556	0.442136	0.557737
86	85	135	9251519	0.999887	-0.14554	0.442141	0.557746
87	86	99	9251618	0.999898	-0.14563	0.442107	0.557791
88	87	98	9251716	0.999908	-0.14563	0.442106	0.557802
89	88	86	9251802	0.999918	-0.14566	0.442095	0.557823
90	89	67	9251869	0.999925	-0.14571	0.442077	0.557848
91	90	52	9251921	0.999931	-0.14574	0.442063	0.557868
92	91	71	9251992	0.999938	-0.1457	0.442081	0.557857
93	92	55	9252047	0.999944	-0.14573	0.442066	0.557879
94	93	36	9252083	0.999948	-0.14578	0.442048	0.5579
95	94	27	9252110	0.999951	-0.1458	0.442039	0.557912
96	95	34	9252144	0.999955	-0.14578	0.442046	0.557909
97	96	27	9252171	0.999958	-0.1458	0.442039	0.557918
98	97	25	9252196	0.99996	-0.14581	0.442037	0.557923
99	98	21	9252217	0.999962	-0.14582	0.442033	0.557929
100	99	23	9252240	0.999965	-0.14581	0.442035	0.55793
101	100	19	9252259	0.999967	-0.14582	0.442032	0.557936
102	101	17	9252276	0.999969	-0.14583	0.44203	0.557939
103	102	19	9252295	0.999971	-0.14582	0.442032	0.557939
104	103	14	9252309	0.999972	-0.14583	0.442027	0.557946
105	104	20	9252329	0.999975	-0.14582	0.442032	0.557942
106	105	22	9252351	0.999977	-0.14581	0.442034	0.557943
107	106	19	9252370	0.999979	-0.14582	0.442032	0.557948
108	107	9	9252379	0.99998	-0.14584	0.442022	0.557958
109	108	11	9252390	0.999981	-0.14584	0.442024	0.557957
110	109	7	9252397	0.999982	-0.14585	0.44202	0.557962
111	110	8	9252405	0.999983	-0.14585	0.442021	0.557962
112	111	17	9252422	0.999985	-0.14583	0.44203	0.557955
113	112	7	9252429	0.999985	-0.14585	0.44202	0.557965
114	113	6	9252435	0.999986	-0.14585	0.442019	0.557967

ObjectID	X	FREQ	CUMUL	SN(X)	Z-SCORE	F(X)	DIFF
115	114	6	9252441	0.999987	-0.14585	0.442019	0.557967
116	115	11	9252452	0.999988	-0.14584	0.442024	0.557964
117	116	6	9252458	0.999989	-0.14585	0.442019	0.557969
118	117	3	9252461	0.999989	-0.14586	0.442016	0.557972
119	118	7	9252468	0.99999	-0.14585	0.44202	0.557969
120	119	10	9252478	0.999991	-0.14584	0.442023	0.557968
121	120	4	9252482	0.999991	-0.14586	0.442017	0.557974
122	121	7	9252489	0.999992	-0.14585	0.44202	0.557972
123	122	3	9252492	0.999992	-0.14586	0.442016	0.557976
124	123	4	9252496	0.999993	-0.14586	0.442017	0.557975
125	124	4	9252500	0.999993	-0.14586	0.442017	0.557976
126	125	2	9252502	0.999993	-0.14586	0.442015	0.557978
127	126	4	9252506	0.999994	-0.14586	0.442017	0.557976
128	127	4	9252510	0.999994	-0.14586	0.442017	0.557977
129	128	2	9252512	0.999994	-0.14586	0.442015	0.557979
130	129	4	9252516	0.999995	-0.14586	0.442017	0.557977
131	130	1	9252517	0.999995	-0.14586	0.442014	0.55798
132	131	3	9252520	0.999995	-0.14586	0.442016	0.557979
133	132	4	9252524	0.999996	-0.14586	0.442017	0.557978
134	133	2	9252526	0.999996	-0.14586	0.442015	0.55798
135	134	5	9252531	0.999996	-0.14585	0.442018	0.557978
136	135	5	9252536	0.999997	-0.14585	0.442018	0.557979
137	136	3	9252539	0.999997	-0.14586	0.442016	0.557981
138	137	5	9252544	0.999998	-0.14585	0.442018	0.55798
139	138	1	9252545	0.999998	-0.14586	0.442014	0.557983
140	139	1	9252546	0.999998	-0.14586	0.442014	0.557984
141	140	2	9252548	0.999998	-0.14586	0.442015	0.557983
142	142	3	9252551	0.999999	-0.14586	0.442016	0.557982
143	143	2	9252553	0.999999	-0.14586	0.442015	0.557983
144	144	1	9252554	0.999999	-0.14586	0.442014	0.557984
145	146	2	9252556	0.999999	-0.14586	0.442015	0.557984
146	147	2	9252558	0.999999	-0.14586	0.442015	0.557984
147	148	1	9252559	0.999999	-0.14586	0.442014	0.557985
148	151	1	9252560	1	-0.14586	0.442014	0.557985
149	153	1	9252561	1	-0.14586	0.442014	0.557985
150	154	1	9252562	1	-0.14586	0.442014	0.557985
151	160	1	9252563	1	-0.14586	0.442014	0.557985
152	176	1	9252564	1	-0.14586	0.442014	0.557986

MEAN	60872.13158	DN=max	0.557986
STDEV	417315.0775	Dn,a	0.110156

APPENDIX C

Cave Survey Location and Correlation with Guerrini Typology

Name	**Latitude**	**Longitude**	**Elevation**	**Guerrini #**	**Type**	**Cluster**
G9-C001	42.259437	12.074927	331.475372	4	N/A	3
G10-C001	42.259573	12.075351	336.914612	6	N/A	3
F13-C001	42.259942	12.079609	324.062073	29	I	1
F13-C002	42.259985	12.079785	324.229065	28	I	1
F13-C003	42.26044	12.079741	334.997375	25	I	1
F13-C004	42.260367	12.080415	333.176392	26	I	1
F13-C005	42.26029	12.080471	341.813904	27	N/A	1
F12-C001	42.259913	12.078194	320.171356	23	I	4
F12-C002	42.259918	12.078098	328.759796	22	N/A	4
F12-C003	42.260624	12.07838	329.573792	13	IV	1
F11-C001	42.259799	12.077646	322.481903	20	IV	4
F11-C002	42.259797	12.077619	323.571228	19	IV	3
F11-C003	42.259723	12.077402	325.058838	15	IV	3
F11-C004	42.25992	12.077431	323.094757	21	IV	3
F11-C005	42.260194	12.076991	343.979736	11	III	2
F11-C006	42.260261	12.0769	348.437256	9	III	2
F11-C007	42.260263	12.07683	351.088104	8	III	2
F11-C008	42.260264	12.07673	351.839508	7	III	2
E14 Complex	42.261267	12.081844	334.013123	30	N/A	5
G14 San Simone	42.259628	12.080972	325.048357	31	N/A	5

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