



# Byzantine fortifications and their natural settings in crete: A geo-spatial analysis

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## ABSTRACT

Byzantine fortifications are increasingly understood from contemporary research not as isolated or static military structures but as elements integrated into their environmental, social, and historical settings. This study examines three Middle Byzantine fortifications in the Kissamos region of northwestern Crete: Polyrrenia, Malathyros, and Rokka. The sites, which vary in type and scale, date to the late 10th to early 13th centuries AD. Their placement is assessed through a combination of archaeological methods, including Geographic Information Systems (GIS) and remote sensing, and additionally complemented with historical sources. The analysis considers the fortifications' relative placement to nearby arable land, grazing areas, coastal access, and possible land routes. GIS results show that Polyrrenia commanded wide views over the coastal plain and maintained inter-visibility with Malathyros and Rokka, allowing for communication and coordinated defense. Malathyros, offered more limited coastal views, yet provided oversight toward the Spatha promontory and strengthened inland connectivity. Rokka oversaw fertile catchments and had quick access to the coast, functioning as a smaller but multifunctional stronghold. Least-cost path modeling indicates that the three fortified sites were within two to three hours walking distance, supporting mobility and resource access. Land use and land cover mapping confirms that the fortifications were embedded in productive agricultural and pastoral zones. These results suggest that the fortifications formed an interconnected system of defense, resource management, and communication rather than serving only as separate defensive outposts. They reflect a deliberate dual strategic objective, in which security and economic sustainability were intertwined, with fortifications safeguarding both population and production. This perspective enhances our broader understanding of how Byzantine frontier strategies integrated military needs with local resources and may offer a comparative framework for analyzing fortified landscapes, both in other areas of the island and across Greece or the wider Byzantine Empire.

## 1. Introduction

Traditional archaeological approaches to Byzantine fortifications have largely emphasized architectural features and military functionality. Within this framework, such structures were often conceptualized as static and isolated, positioned in remote or inaccessible locations for defensive purposes. However, this perspective overlooks their broader roles within the social, economic, political, and environmental landscapes of the Byzantine world.

In recent years, a shift toward interdisciplinary methodologies has redefined fortifications as dynamic and integrated components of the Byzantine landscape, functioning not only as isolated military strongholds, but also as interconnected hubs of administration, trade, and social interaction (Bakirtzis 2010; Hill et al. 2017, 2018; Hill and

Ødegård 2018; Kontogiannis 2022; Roussos 2017, 2020, pp. 431–440, 2024; pp. 213–226; Veloudaki 2019; see also Blackler 2022 on medieval tower communication networks in Greece; Colburn 2013 on connectivity in ancient empires). This evolving perspective has been facilitated by advances in environmental archaeology, digital spatial technologies, and landscape studies.

This study examines Middle Byzantine fortifications on Crete, focusing specifically on the Kissamos region in the northwest. Crete's strategic position in the Aegean and the Eastern Mediterranean made it a key island in Byzantine political and economic networks. The analysis centers on three Middle Byzantine fortifications, Polyrrenia, Malathyros, and Rokka dating from the late 10th to early 13th centuries AD, each differing in scale and typology. By combining archaeological and historical methods with advanced geospatial methods, including

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**Fig. 1.** Topographic map of the Kissamos region in northwestern Crete, showing elevation across the study area, the Gulf of Kissamos, and the Gramvousa and Rodopou (Spatha) peninsulas. The locations of the three fortified sites are marked: Polyrrhenia (fortified town), Rokka (military stronghold), and Malathyros (fortified settlement). Inset shows the study area on the island of Crete.

Geographic Information Systems (GIS) and satellite remote sensing, this study aims to reconstruct the ancient landscape and analyze the human-environment interactions. Key spatial analyses include viewshed (visibility) and least-cost path (mobility) modeling, which explain site placement by revealing visual control, intervisibility, and mobility corridors. Remote sensing is also employed to generate land use and land cover maps, offering insights into historical resource use, environmental change, and settlement patterns. By examining present-day vegetation, soil conditions, and terrain, it becomes possible to understand the environmental context in which these fortifications operated. The approach considers a range of environmental variables (topography, arable land, grazing zones, coastal access) and examines spatial relationships between fortified sites and their surrounding landscape, including visibility over maritime approaches and overland connectivity as inferred from cost-surface modelling. The analysis frames these fortifications not as isolated entities, but as interconnected nodes embedded in military, administrative, and socio-economic networks.

Our research aims are structured based on the following questions:

- What were the primary functions of these fortifications, and what roles did they play within the economic, socio-political and military landscape of the Middle Byzantine period (961–1204 CE)?
- How did these fortifications interact with and influence their surrounding environment?

- What spatial relationships existed between the fortified sites?
- In what ways can these fortifications further enhance our understanding of the historical, political, and economic dynamics of the Byzantine period?

## 2. Historical background

Crete's strategic location in the Aegean and the Eastern Mediterranean has shaped its historical trajectory, from antiquity through the medieval period. Under the Roman rule from 67 BC, Crete and Cyrenaica were united into a single province (*Creta et Cyrenaica*). By the late 3rd or the early 4th century CE, this administrative unit was divided, with Crete assigned first to the diocese of Moesia and later to the diocese of Macedonia (Chevrollier 2016, pp. 23).

The foundation of Constantinople in 324 CE marked a pivotal moment in the history of the Aegean islands. In the following centuries, the Aegean Archipelago played an increasingly vital role as a conduit for commerce and finance within the Eastern Roman Empire (Abadie-Reynal, 1989). These islands, situated along key maritime routes, served as supply stations linking the imperial capital to its provinces. Crete benefitted from these favorable conditions and appeared to have enjoyed considerable prosperity until at least the 7th century CE. However, in the late 7th and 8th centuries AD, the Aegean world underwent significant changes driven by economic hardship, political and social upheaval, and the expanding presence of Arab naval forces. Following the loss of the wealthy Eastern provinces in the second half of the 7th century CE, Crete, along with neighboring southern Aegean islands such as the Cyclades and Dodecanese, became a border region of Byzantium (Roussos 2020, 2024). As the challenges of provisioning Constantinople intensified and Arab naval threats increased, the Aegean maritime region assumed a vital role in safeguarding and protecting the Byzantine Empire's economic and military interests, especially regarding the defense and supply of the capital (Koder 2002; Poulou and Leontsini 2022).

Between 824 and 828 CE, Crete fell to Andalusí Muslim exiles from Cordoba, who established the Emirate of Crete (Hammond 2017, pp.122–123; Randazzo 2019). The island remained under Islamic control until 961 CE. During this period, Crete served as a strategic base for Arab activity in the southern Aegean. Far from being a loosely organized raiding outpost, the emirate appears to have pursued a centralized plan of expansion, combining piracy with state-building efforts (Vionis 2017, pp. 174–175).

After several attempts to recapture the island (Makrypoulias 2000), Nikephoros Phokas, a prominent Byzantine general (and future emperor) succeeded in reconquering Crete for the Byzantine Empire. The re-establishment of Byzantine control marked the beginning of a new era of military reorganization, administrative restructuring, and fortification building, particularly in response to external threats. Crete once again became a border region of Byzantium. The Middle Byzantine period (961–1204 CE) witnessed a renewed emphasis on inland settlement, religious patronage, and the reinforcement of fortifications, often strategically placed to protect vital resources, control land routes, and anchor imperial authority in the countryside. It has been suggested that most of the population and wealthy landowners were possibly concentrated in the countryside (Coutsinas et al. 2021, pp. 431–433; Coutsinas et al. 2022, pp. 397–398; Hammond 2017, pp. 125–129; Hayden 2004).

Following the Fourth Crusade in 1204 CE and the fragmentation of the Byzantine Empire, Crete came under Venetian control, marking the beginning of a long period of Latin rule (Gigourtakis 2015).

## 3. Kissamos region – A Mediterranean landscape

The Cretan natural landscape has always played a significant part in the lives of the islanders. Kissamos is a geomorphologically diverse region situated in the northwestern extent of Crete (Fig. 1), and includes two prominent peninsulas, Gramvousa and Rodopou (Spatha). These

peninsulas consist of uplifted limestone and feature steep coastal escarpments with extensive karstic cliffs. The coastline is highly indented, with embayed shorelines, sandy beaches, and rocky promontories. Inland, the region transitions from coastal lowlands to rolling hills and then into the foothills of the Lefka Ori (White Mountains). The terrain rises gradually from sea level to elevations of 800–1,000 m and beyond, consistent with the elevation gradients recorded across western Crete (Tzanakakis et al. 2022). Terraced slopes in the olive-growing zones reflect human modification integrated into the natural slope morphology. Narrow intermontane valleys, often aligned with fault lines, are frequently filled by colluvial and alluvial deposits, supporting both agriculture and natural passageways (Kirsten and Heinrich 2022). The landscape also features deep gorges carved into carbonate strata, which display classical karstic features such as steep walls, subterranean conduits, and seasonal water flow (Manoutsoglou et al. 2022).

#### 4. Study area and sites

As mentioned earlier, the varied natural environment of Kissamos offered extensive areas for agriculture, including farming and animal husbandry, as well as suitable space for the construction and development of communication routes. It is unsurprising that three Middle Byzantine fortifications of differing types and scales, Polyrrhenia, Malathyros, and Rokka, have been identified in the region (Fig. 1).

##### 4.1. Chronology and archaeological evidence

Polyrrhenia and Malathyros are securely dated to the Middle Byzantine period (post-961 CE reconquest) based on masonry diagnostics, specifically the cyclopean belt technique paralleled at Evciler fortress in Armenian Cilicia, built under Nikephoros Phokas c. 964 CE (Gigourtakis 2011). Both can be considered centrally planned, state-funded constructions. Rokka presents more chronological ambiguity; however, based on archaeological evidence (cisterns, walls and surface ceramics), Gigourtakis (2004; 2011) catalogues it among the Kissamos network positions with Middle Byzantine characteristics.

Ancient Polyrrhenia occupies a strategic conical hill in western Crete, approximately 17 km south of the port of Kissamos, commanding the plain and the passes toward the interior and southern Crete. The east side is naturally defensive, dropping steeply into the Kamarianos gorge; the modern village spreads along the south flank on the line of the Hellenistic wall (Markoulaki and Christodoulakos 2018). With a long occupation sequence that flourished from the 4th century BCE, the central height, already fortified in the Hellenistic period was later encircled by a monumental circuit with large square and cylindrical towers (Markoulaki and Christodoulakos 2018). Water management is a defining feature of Polyrrhenia's defensive landscape: the rock-cut aqueduct outlet at the fortification and the large semicircular Tower A in front of it were stabilized and presented together with works on Tower B; the aqueduct remains operative and embedded in daily life (Markoulaki and Christodoulakos 2018; Voudouris et al. 2013). Small rescue excavations and systematic fieldwork by the former 25th Ephorate of Prehistoric and Classical Antiquities since the 1990s (survey of the circuit; recording of inscriptions and finds; museological preparation for the Kissamos Museum) have refined the topography and documentation of the fortification and civic infrastructure (Markoulaki and Christodoulakos 2018). In the Middle Byzantine (961–1204 CE) phase, the fortification's masonry reuses Hellenistic elements, and at least three large cisterns have been documented within the enceinte. These installations imply long-term provisioning capacity and an ability to shelter the population during crises (Voudouris et al. 2013). Polyrrhenia's fortified acropolis thus functioned as an inland stronghold closely tied to Kissamos and its maritime elements.

Malathyros lies inland in the Kissamos hinterland (~576 m asl), facing the Selino Mountains to the south. The fortress uses the rocky cliff as part of its walls, taking advantage of the terrain's natural defensibility

(Gigourtakis 2011). Within the corpus of Cretan Middle Byzantine forts, Malathyros appears to be part of a centrally planned, technically sophisticated 10th-century building program rather than a vernacular provincial tradition (Gigourtakis 2011). Two constructional traits are diagnostic. First is an outerwork (proteichisma), a hallmark of major Middle Byzantine forts on Crete, documented at Malathyros and Polyrrhenia among others (Gigourtakis 2004, 2011). Second is a distinctive belt of very large blocks running horizontally through a semi-cylindrical tower. This technique was noted clearly at Temenos and to a lesser degree at Malathyros, likely improved seismic resistance and bearing capacity (Gigourtakis 2004, 2011). The site does not appear to have been reused in the later Venetian period, which helped preserve its characteristic Middle Byzantine features (Gigourtakis 2011; Markoulaki and Christodoulakos 2018). Malathyros's vantage points provide selective maritime oversight toward the Spatha promontory and strong inland connectivity, reinforcing, but not duplicating the regional role of Polyrrhenia.

Rokka (Roka) is listed among the principal Middle-Byzantine forts of Chania Prefecture, situated a short distance from the Bay of Kissamos. The small fortress sits on a steep hill, with evidence of continuous occupation since prehistoric times. It features fortification walls, which follow the bedrock contours, water cistern, and basic infrastructural installations (Gigourtakis 2011). Although less extensively described in published overviews, the site's placement balances inland defensibility with quick access to coastal corridors and fertile valleys, reflecting typical Middle Byzantine strategy.

#### 5. Methods

This study adopts an integrated methodology, combining spatial analyses in a GIS environment and remote sensing to systematically examine the spatial logic underpinning the placement, organization, and functional roles of Middle Byzantine fortified sites within the Kissamos landscape.

##### 5.1. Geographic Information Systems (GIS) and spatial analysis

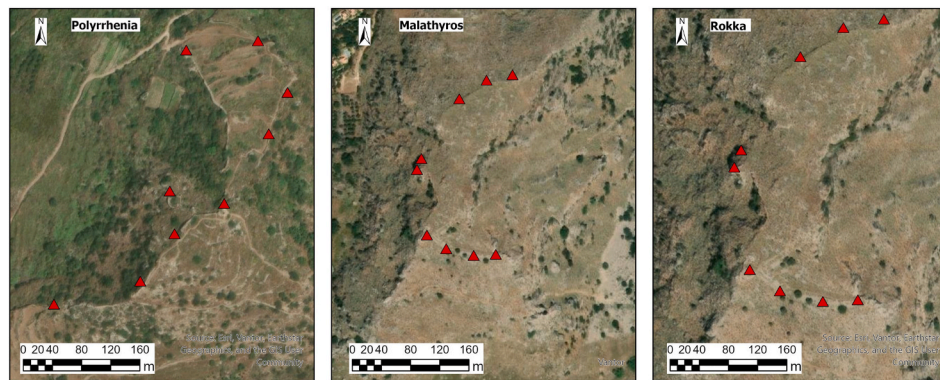
The spatial analyses presented in this study were conducted using ArcGIS Pro (version 3.6.2, Esri Inc.). Both visibility and movement modelling were implemented through standard geoprocessing tools, supplemented by a structured workflow to ensure analytical consistency.

A SPOT-derived Digital Elevation Model (DEM) with a spatial resolution of 20 m is employed as the primary topographic dataset. This high-resolution surface model provided a robust geomorphological framework for quantitative spatial analysis, enabling the derivation of both viewshed surfaces and least-cost path networks. Together, these analytical outputs facilitate a rigorous assessment of visibility interrelationships and movement potential across the landscape, thereby supporting the reconstruction and interpretation of spatial connectivity among the Middle Byzantine fortification systems in the Kissamos region.

Visibility constitutes a fundamental analytical dimension for understanding the spatial logic underpinning the placement of fortified sites and their capacity to monitor, control, and engage with surrounding territories. This is particularly significant in strategically sensitive regions that experienced recurrent cycles of conflict and military pressure. In this framework, viewshed analysis provides a computational means of modelling visual exposure, estimating the spatial extent of terrain visible from a given observation point. It has become an established methodological tool within archaeological landscape studies (for more on GIS-based visibility analysis see Topouzi et al. 2000; Gilling and Wheatley 2020; for Crete specifically, see Déderix 2019).

In the present study, viewshed modelling was generated to assess the degree of visual control exercised by each fortification, with the aim of clarifying their roles within wider socio-political, economic, and





**Fig. 2.** Viewshed observation points (red triangles) selected along the fortification wall circuits of Polyrrhenia, Malathyros, and Rokka, shown on high-resolution satellite imagery (Esri, Vantor, Earthstar Geographics, and the GIS User Community). Points correspond to visible circular, semi-circular, or rectangular towers identified in satellite imagery.

military networks. The analyses incorporated multiple directional sightlines extending from fortified circuits toward the hinterland, the coastal zone, and the broader maritime environment of the Gulf of Kissamos, as well as between fortified sites themselves in order to assess intervisibility relationships.

Observer parameters were defined on the basis of human perception and architectural elevation. A standard eye-level height of 1.7 m was employed to represent an average standing observer, supplemented by an additional elevation component to account for the vertical extension of walls and towers. On this basis, an effective observer height of approximately 16 m was adopted, reflecting the combined height of a tower structure and an elevated observation position.

To ensure spatial representativeness, multiple observation points were selected along the entire wall circuits, corresponding to visible circular, semi-circular, or rectangular towers identified in high-resolution satellite imagery (Fig. 2). Viewshed analyses were computed using variable radii ranged from 20 km to 30 km. The upper threshold was applied to elevated observation points, where increased topographic prominence significantly extends theoretical line-of-sight distances beyond lower-lying positions. This dual-range approach enables a differentiation between proximal visual control zones, associated with immediate territorial surveillance, and extended regional visibility fields that articulate broader landscape and seascape awareness.

Finally, cumulative viewsheds were generated to identify mutually visible areas across the three fortified sites. This approach facilitates a systematic assessment of overlapping surveillance domains within the study region and provided a spatially explicit framework for interpretation the integration of these fortifications into a coordinated visual network across land and sea.

Recent GIS-based spatial analyses have demonstrated significant potential for modeling and interpreting ancient patterns of movement (Bevan 2013; Verhagen et al., 2019). Mobility patterns provide insight into accessibility, communication, and potential inter-relationships between inland fortified sites. Movement across the landscape was modelled using Path Distance tool within the Spatial Analyst toolbox in ArcGIS Pro. This method was selected because it calculates a cost-distance surface from each fortified site to all surrounding cells, incorporating both horizontal and vertical cost factors, and thus producing an anisotropic raster surface. This approach accounts for the directional variability of movement, particularly slope-dependent travel costs, which are critical in the rugged terrain of the Kissamos region.

The cost surface was derived from slope values calculated from the 20 m SPOT DEM, with walking speeds estimated using Tobler's anisotropic hiking function (see Herzog 2020; Drillat 2022 for comparative discussion of cost functions). This function estimates walking speed according to slope and accounts for slope direction by assigning different movement costs to uphill and downhill travel, thereby producing more

realistic travel-time estimates than isotropic models. Path distance analysis radiated outward from each source site across the anisotropic cost surface, while least-cost paths (LCPs) between site pairs were computed as 1-to-1 paths. Because anisotropic surfaces are direction-dependent, the optimal path from A → B may differ from the path from B → A (Herzog 2014).

From these cost-distance surfaces, travel-time catchments (one-, two- and three-hour thresholds) were generated for each fortified site. These represent the spatial extent reachable outward from each site under the assumption of continuous movement across the terrain.

In addition to examining inter-site connectivity, pairwise Least-Cost Paths were calculated between the fortified sites using Cost Path tool. These were derived individually for each origin–destination pair (i.e. 1-to-1 calculations), rather than through a multi-source averaged model. Each path was derived independently from its corresponding cost-distance and backlink rasters. As a result, the routes vary according to terrain configuration and slope. No averaging or aggregation of LCPs was performed.

It is worth noting that the LCP analysis revealed a potential network of natural mobility corridors connecting the fortified sites across the region, allowing for a more nuanced understanding of their spatial interconnections and the dynamics of movement within the surrounding landscape. By “main natural corridors”, we mean topographically constrained routes of movement identified through LCP analysis. That is, the paths of lowest accumulated travel cost between sites as determined by terrain slope and elevation. Since ancient communication routes typically followed physiographic constraints, the reconstruction of probable road alignments sheds light on the likely circulation patterns of people, goods, and resources.

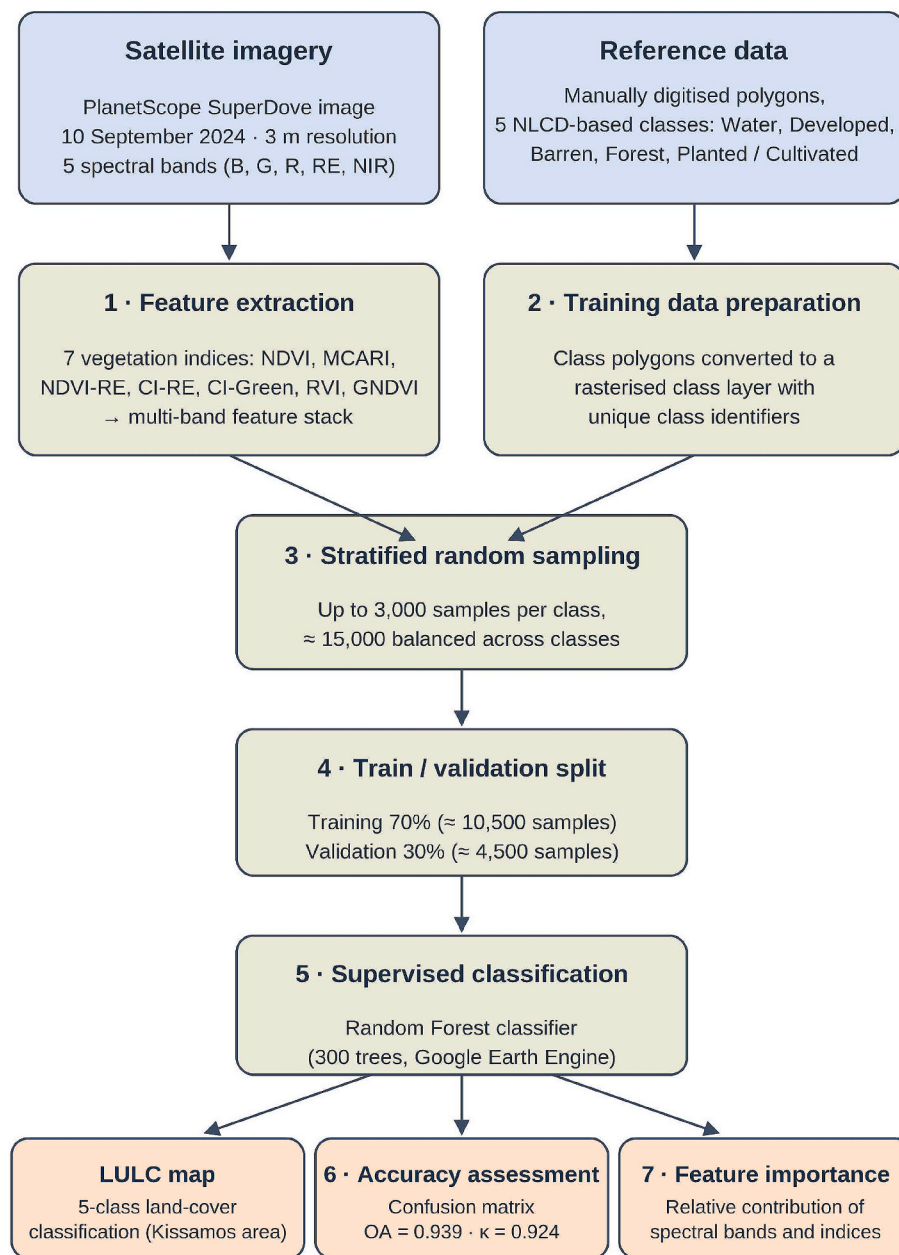
Three considerations apply to the results of this study. First, all travel-time estimates are unidirectional, representing outbound travel from each fortification. Return journeys, particularly uphill returns to elevated sites like Malathyros (576 m), which may differ due to asymmetries in slope and terrain conditions, would require additional time and fall outside the scope of the present study. The model therefore provides a conservative estimate of the zone of regular interaction. For the purposes of identifying hinterland extent and comparing sites, however, the relative differences between catchments remain valid even if absolute travel times are underestimated for return trips (Bevan 2013). Second, the one-, two- and three-hour thresholds are based on unburdened pedestrian movement, representing an optimistic baseline for provisioning activities. Third, the transport of goods or movement involving pack animals would likely have reduced travel speeds and altered route dynamics. Ethnographic evidence from modern donkey-transport studies in Mediterranean and Near Eastern contexts indicates laden pack animals travel at approximately 3–3.5 km/h on moderate terrain, compared to ~ 5 km/h for unburdened walkers (Shai



**Table 1**

Summary of viewshed coverage and land-use composition within walking-distance catchments for each fortified site and the combined network.

| Site                   | Visible terrain within 1-hour catchment (%) | Visible terrain within 2-hour catchment (%) | Planted/cultivated land within 1-hour catchment (%) |
|------------------------|---------------------------------------------|---------------------------------------------|-----------------------------------------------------|
| Polyrrhenia            | 50                                          | 26                                          | 66                                                  |
| Malathyros             | 39                                          | 16                                          | 47                                                  |
| Rokka                  | 23                                          | 25                                          | 72                                                  |
| All sites (cumulative) | 60                                          | 30                                          | 62                                                  |

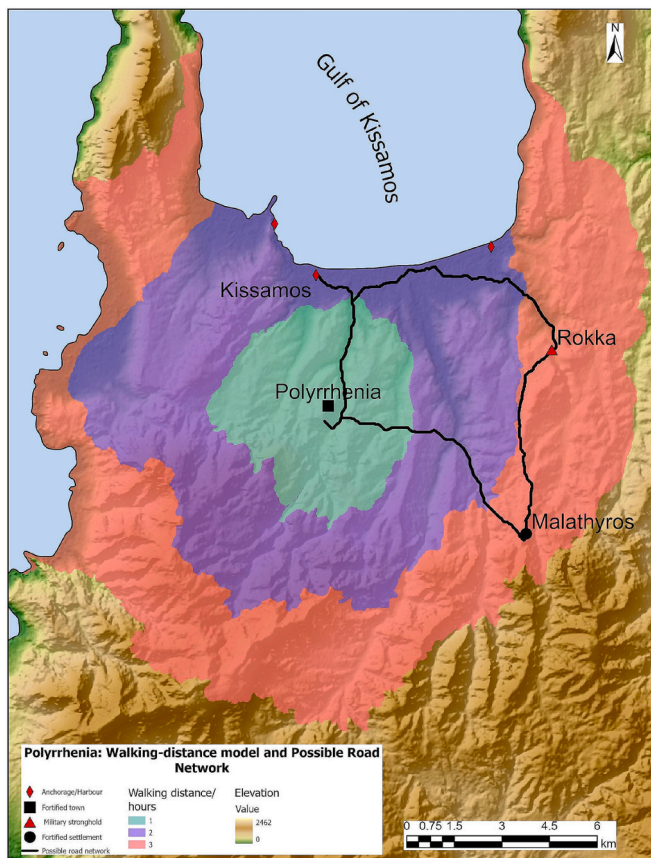


**Fig. 3.** Workflow of the supervised land use / land cover (LULC) classification implemented in Google Earth Engine. Spectral bands and vegetation indices derived from PlanetScope imagery (3 m resolution), together with manually digitized reference polygons for five NLCD-based classes, feed a stratified random sampling scheme (~15,000 balanced samples), followed by a 70/30 train-validation split, Random Forest classification (300 trees), accuracy assessment (overall accuracy = 0.939; Kappa = 0.924), and feature importance analysis. The abridged Google Earth Engine code is provided as Supplementary Material.

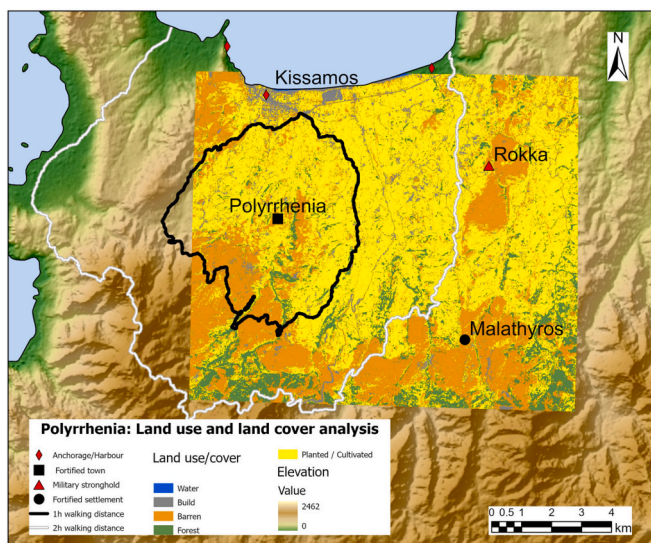
et al. 2016). This would extend the effective 2-hour walking catchment to approximately 2.5–3 h for loaded pack-animal transport. This does not fundamentally alter the network structure but refines the interpretation of provisioning range.

The GIS maps presented in this study are multi-thematic in nature. In order to avoid redundancy and to provide a comprehensive

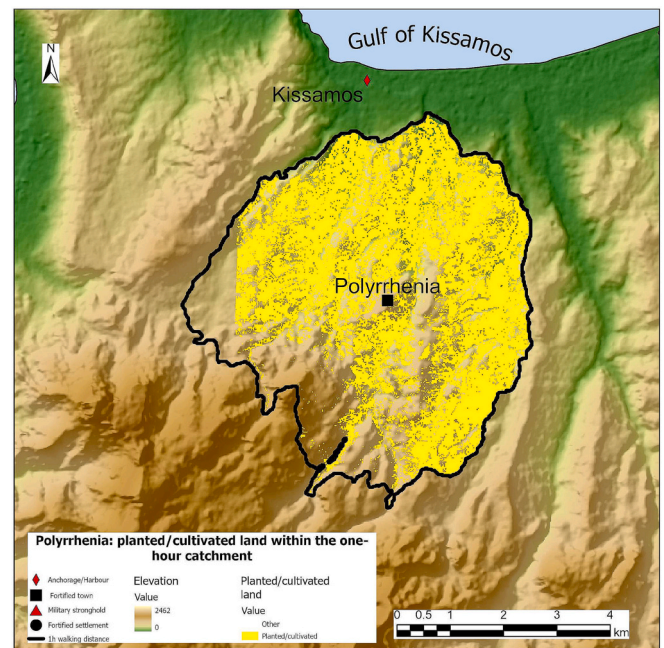
representation of each site, they integrate and visualize a combination of outputs derived from the analytical procedures described above, including both viewshed and least-cost path analyses.



**Fig. 4.** Walking-distance model centred on Polyrrhenia, showing 1-hour (green), 2-hour (purple), and 3-hour (red) travel-time catchments derived from path distance analysis. The black line represents the reconstructed probable road network connecting the fortified sites and the harbour of Kissamos. Within less than two hours, Polyrrhenia maintained access to Kissamos; within three hours, to both Malathyros and Rokka.



**Fig. 5.** Land use and land cover (LULC) classification centred on Polyrrhenia, derived from Planet satellite imagery (3 m resolution). Classes shown: Planted/Cultivated (yellow), Barren (orange), Forest (green), Water (blue), and Built (grey). The black outline marks the 1-hour and the white outline the 2-hour walking-distance boundary. Planted/cultivated land dominates the one- and two-hour walking zones, with barren and forested areas concentrated at higher elevations.



**Fig. 6.** Planted/cultivated land (yellow) within the one-hour walking catchment of Polyrrhenia. Approximately 66 % of the catchment area is classified as planted or cultivated, highlighting the productive character of the immediate hinterland.

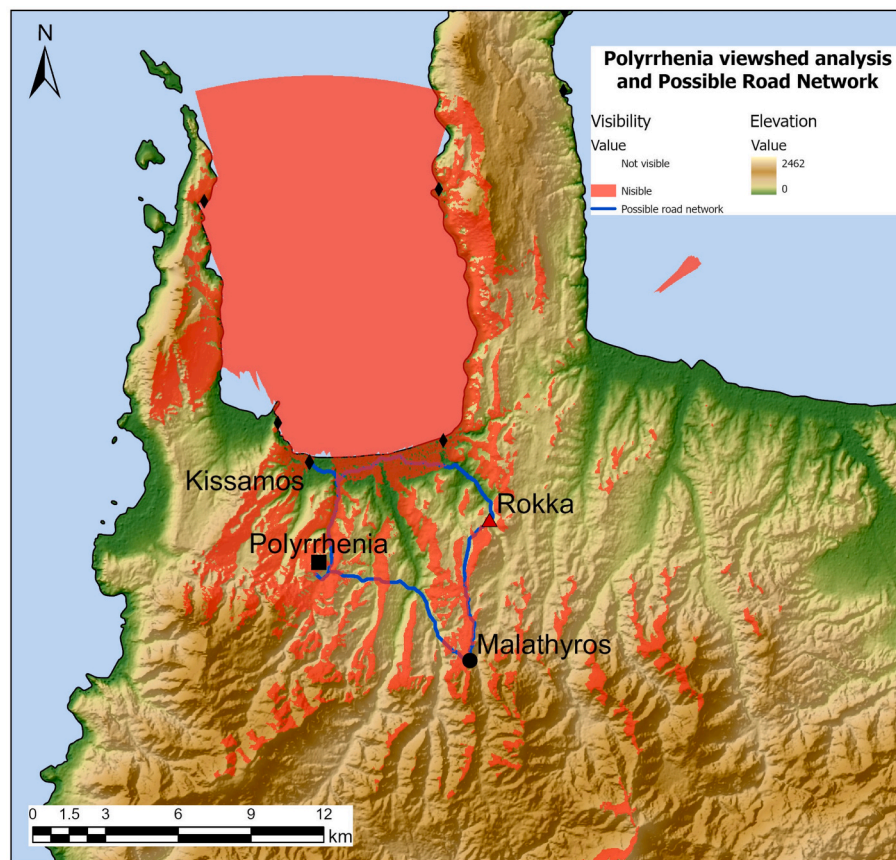
## 5.2. Remote sensing

The integration of land use and land cover (LULC) analysis into archaeological studies has grown substantially in recent decades, as it provides a powerful spatial and temporal framework for understanding how past human societies modified, managed, and interacted with their environments (Alders et al. 2024; Banerjee 2013; Moise et al. 2021). By combining satellite remote sensing, GIS, and archaeological data, LULC approaches allow to researcher to understand past landscapes and investigate long-term human–environment dynamics.

The LULC classification is employed as a first-order approximation of the landscape's productive potential, acknowledging that specific land parcels and crop types have certainly changed over the intervening millennium, while the broader spatial distribution of cultivable versus non-cultivable terrain has been substantially constrained by the region's karst geomorphology and relief. This approach is consistent with comparable archaeological landscape studies in the Mediterranean (Mercuri et al. 2019; Roberts et al. 2019; Grove and Rackham 2001). Several converging lines of evidence support reasonable continuity in the Kissamos region: (1) The karst geomorphology constrains viable agricultural zones to the same valley floors and coastal plains across centuries, as Mediterranean karst landscapes exhibit low geomorphological dynamism in terms of soil distribution (cf. Kosmas et al. 1997; Grove and Rackham 2001). (2) Archaeological and historical evidence documents continuous pastoral and agricultural use, the very name 'Polyrrhenia' (Mycenaean for 'many sheep') reflects a pastoral tradition predating the Byzantine period by millennia (Markoulaki and Christodoulakos 2018). (3) Palynological studies from NW Crete (Bottema and Sarpaki 2003, Lake Kournas 9000-year record) show that while specific species composition shifted, the fundamental pattern of olive/cereal cultivation on lowlands and maquis on uplands has persisted since at least the Bronze Age. (4) Gigourtakis (2011, 2015) documents agricultural terracing patterns consistent with long-term landscape stability in western Crete.

In this study, a supervised land use / land cover spatial based classification was conducted using a Planet Image acquired on 10 September 2024, with a spatial resolution of approximately 3 m. Five thematic





**Fig. 7.** Viewshed analysis of Polyrrhenia within a 30 km radius. Red/pink shading indicates terrain visible from the fortification's towers. The blue line represents the reconstructed probable road network. Polyrrhenia commands extensive visual control over the Gulf of Kissamos, the coastal plain, and inland approach routes, with direct lines of sight to both Malathyros and Rokka.

classes were defined, following the National Land Cover Database legend: Water, Developed, Barren, Forest, and Planted / Cultivated. The NLCD scheme was adopted because its legend categories (Developed, Barren, Forest, Shrubland, Cultivated, Wetlands) align well with the landscape types in the Kissamos study area and provide a simpler, universally applicable typology for archaeological landscape characterization. CORINE Land Cover has a minimum mapping unit of 25 ha and a spatial resolution of 100 m. At this resolution, the 1-hour walking catchments from each fortification (~15–25 km<sup>2</sup>) would contain only a handful of CORINE polygons, rendering any proportional analysis of land cover types meaningless. Our custom classification using Planet imagery provides ~1,100 × finer spatial detail, enabling meaningful differentiation of cultivated valley floors, pastoral slopes, and scrubland within catchment zones that would appear as single homogeneous polygons in CORINE. Furthermore, CORINE's class hierarchy includes categories specific to European policy contexts (e.g., “industrial or commercial units”) that are not analytically relevant to a Mediterranean archaeological landscape.

Reference data for the classification were derived from manually drawn polygons representing the five-target land-cover classes. These polygons were created through visual interpretation. Each polygon was assigned as a unique class identifier and converted into a raster class layer to facilitate sampling.

The classification workflow was implemented in Google Earth Engine, a powerful cloud-based platform that enables large-scale analysis and visualization of geospatial data. The Random Forest algorithm was chosen because it is among the most widely applied and reliable methods for land cover classification with remote sensing data (Prodromou et al. 2024).

A stratified random sampling approach was applied using the

rasterized class layer to extract training samples. Specifically, up to 3000 samples were generated per class within the study area, resulting in a total dataset of approximately 15,000 samples. This strategy ensured that all classes were adequately represented during model training. The resulting dataset was balanced across classes, with an equal target number of samples per class. In cases where fewer valid pixels were available within a class, all available samples were retained. In this study, all classes reached the target sample size, resulting in a fully balanced dataset.

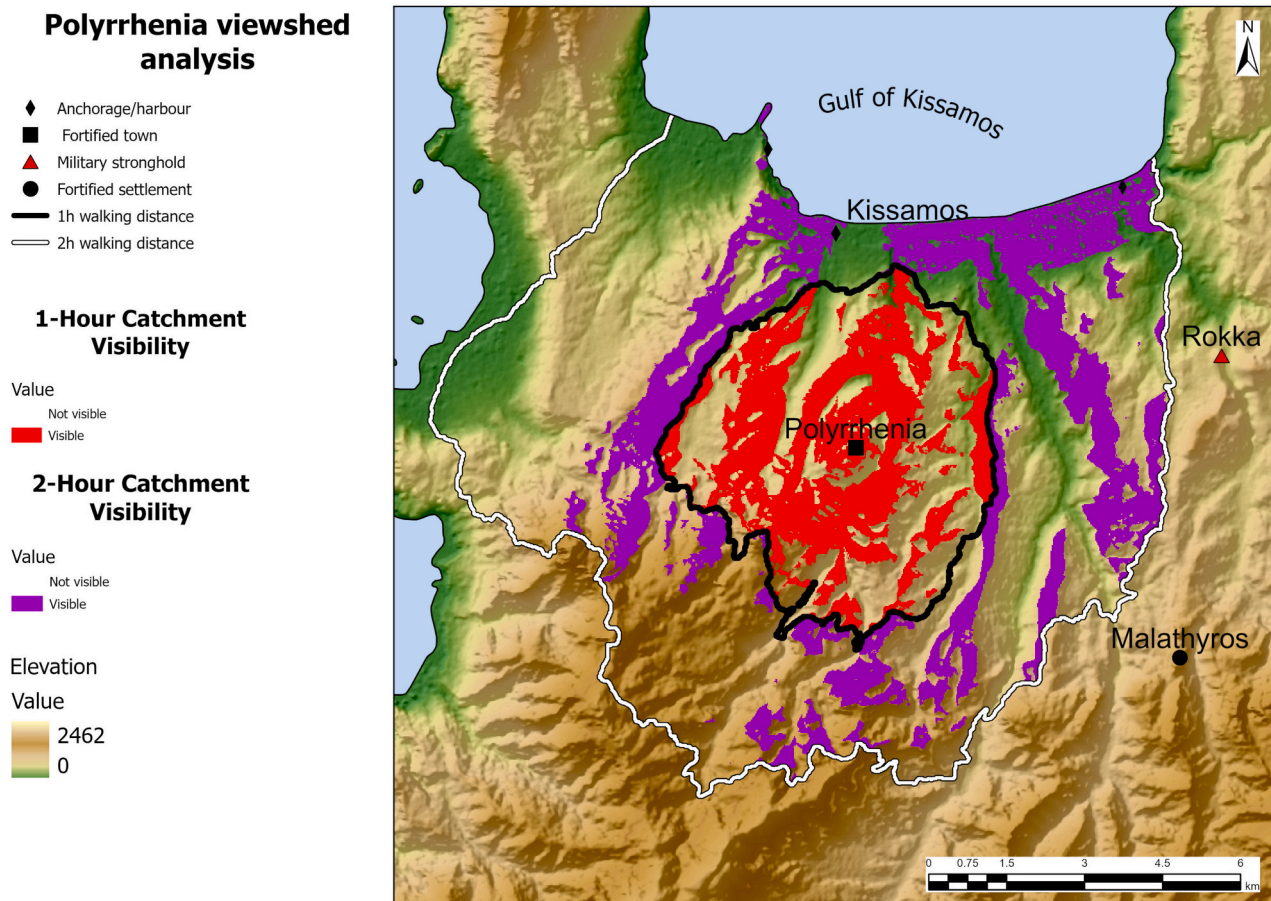
The samples were spatially distributed within the delineated class polygons across the study area through stratified random sampling. The use of multiple polygons and random point selection allowed the sampling process to capture the spatial variability and heterogeneity of each class, reducing potential spatial bias in the training data.

Five spectral bands (blue, green, red, red edge, NIR) have been used for the classification in combination with vegetation indices: NDVI, MCARI, NDVI Red Edge, Chlorophyll Index, Chlorophyll Index Green, RVI, and GNDVI. Spectral indices were incorporated as each contributes complementary information that enhances the analysis.

The dataset was randomly divided into training (70 %) and validation (30 %) subsets using a uniform random sampling approach. This resulted in approximately 10,500 samples for training and 4,500 samples for validation, which were used for classifier development and independent accuracy assessment.

The accuracy assessment reported an overall validation accuracy of 0.9391 and a Kappa statistic of 0.9239, confirming the robustness of the classification. Due to the fact that the available Planet satellite imagery did not fully cover all walking-distance catchments, planted/cultivated land percentages presented in Table 1 and Figs. 5, 12, and 17 were calculated only within the areas covered by the LULC classification. To





**Fig. 8.** Combined viewshed and walking-distance analysis centred on Polyrrenia. Red shading indicates visible terrain within the 1-hour catchment (black outline); purple shading indicates visible terrain within the 2-hour catchment (white outline). Approximately 50 % of the 1-hour catchment and 26 % of the 2-hour catchment are directly visible from the fortification (see also Table 1).

minimize the influence of incomplete spatial coverage, the analysis was restricted to the 1-hour walking distance catchments, where unclassified areas were limited. As such, portions of the catchments outside the classified imagery extent were excluded from the analysis. This methodological approach does not affect the overall interpretation of the results.

A critical consideration in this study concerns the use of modern LULC data as part of the spatial analysis. It is important to emphasize that present-day LULC is not employed here as a direct proxy for Middle Byzantine landscapes, nor is it intended to reconstruct past land use patterns in a literal sense. Rather, the classification is used as a heuristic and modelling framework, providing an indicative representation of environmental affordances, such as the relative distribution of cultivable versus marginal land, within which the fortified sites operated. This approach builds on the premise that, despite well-documented changes in land use practices over the last millennium, certain fundamental geomorphological characteristics of the landscape remain broadly stable over long-time scales. Features such as valley systems with colluvial and alluvial deposits, slope gradients, and karstic formations continue to structure the spatial distribution of agricultural potential, even if specific cultivation practices, terracing systems, or vegetation regimes have undergone significant transformation.

Within this framework, the LULC data are interpreted in conjunction with archaeological and historical evidence, which points to a predominantly rural population and the importance of agricultural production in the Middle Byzantine period (961–1204 CE). The spatial association observed between fortifications and areas identified as agriculturally productive is therefore understood as consistent with

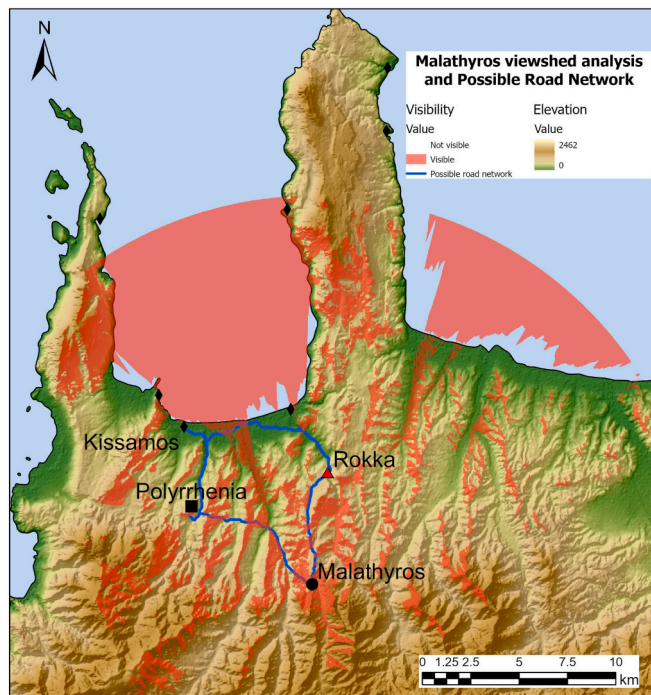
these broader historical patterns, rather than as independent proof of medieval land use. Consequently, the interpretations presented here should be read as probabilistic and relational, used to explore how fortified sites may have related to potentially productive landscapes.

The complete classification workflow is summarized in Fig. 3. Abridged excerpts of the key Google Earth Engine operations are provided as [Supplementary Material](#), and the full script is available from the corresponding author upon reasonable request.

## 6. Geo-spatial analysis results

As detailed in Section 5.2, the LULC classification is interpreted in the following sections as a first-order approximation of the landscape's productive potential, identifying areas capable of supporting cultivation and pastoral activity rather than reconstructing Middle Byzantine land cover. Within this framework, the inclusion of LULC data provides an analytical dimension that not captured by topography variables alone. While slope and elevation are essential for modelling movement and accessibility, they cannot distinguish between different forms of land use or their potential economic value. LULC classification addresses this limitation by differentiating between cultivable land, pasture, forest, and barren terrain, enabling a more precise assessment of landscape usability.

This distinction is central to interpreting the economic role of fortified sites. When combined with GIS analyses, LULC data allow site catchments to be related to zones of agricultural productivity, thereby providing insights into resource accessibility and subsistence strategies. Fortifications can therefore be understood not only as defensive



**Fig. 9.** Viewshed analysis of Malathyros within a 20 km radius. Red/pink shading indicates terrain visible from the site's towers. The blue line represents the reconstructed probable road network. Despite its inland position, Malathyros commands partial views over the Gulf of Kissamos and offers visibility east of the Spatha promontory. Direct intervisibility with Polyrrhenia is maintained, but not with Rokka.

structures but also as components of broader systems of resource management and economic organization.

More broadly, the landscape was a decisive factor shaping settlement patterns, agricultural exploitation, and the movement of goods, while also influencing how authorities monitored populations and activities. From the Roman period onward, environmental conditions played a decisive role in determining the placement, design, and character of fortifications (Oltean and Fonte 2021). The GIS-based spatial analyses performed here highlight this underlying logic in the setting of the Middle Byzantine fortresses in the Kissamos region, the results of which are discussed below.

### 6.1. Polyrrhenia

A closer examination of the spatial data highlights the central and strategic location of Polyrrhenia within the Kissamos hinterland. This positioning is confirmed by analyses of two complementary dimensions of spatial organization: mobility and visibility.

Through LCP analysis we identified the main natural corridors that could have linked Polyrrhenia with Kissamos, the region's primary harbor, as well as with other key fortified sites such as Malathyros and Rokka (Fig. 4). Such a mobility network would have facilitated the movement of people, goods, and resources between the fortified sites and the harbour of Kissamos. This embeddedness of fortified sites within regional systems of communication and exchange is well attested in the Byzantine Greek countryside (Vionis 2017; Veikou 2012), where fortifications operated as nodes articulating local production, mobility, and provisioning rather than as isolated military installations.

The LCP model was also used to estimate areas accessible on foot from Polyrrhenia within successive one-hour intervals, up to a maximum of three hours. The results of this analysis are illustrated in a thematic map (Fig. 4), where turquoise, purple, and red correspond to durations of one, two, and three hours, respectively. The visualization

provides a clear understanding of Polyrrhenia's catchment area and the patterns of daily mobility, accessibility, and interaction with its surrounding environment. Within a one-hour walking distance, Polyrrhenia was directly connected to the slopes descending toward the coast. Within less than two hours, it maintained access to the harbor of Kissamos, and within less than three hours, to both Malathyros and Rokka. When combined with LULC data, the model reveals that cultivated and planted lands (yellow) dominated the one-hour (red outline) and two-hour (white outline) walking zones (Fig. 5). More specifically, within one-hour catchment, 66 % of the land can be classified as planted/cultivated land, highlighting the exceptionally productive character of the immediate hinterland (Fig. 6 and Table 1). This suggests that Polyrrhenia's immediate hinterland likely possessed strong agricultural potential, capable of meeting subsistence needs and potentially generating a surplus. In contrast, barren and forested areas (orange and green) appeared mainly at the periphery of the two-hour zone, particularly to the south and southeast (Fig. 5). These areas provided secondary resources such as timber and grazing, while their steeper topography excluded them from intensive cultivation, yet kept them within practical reach of the settlement.

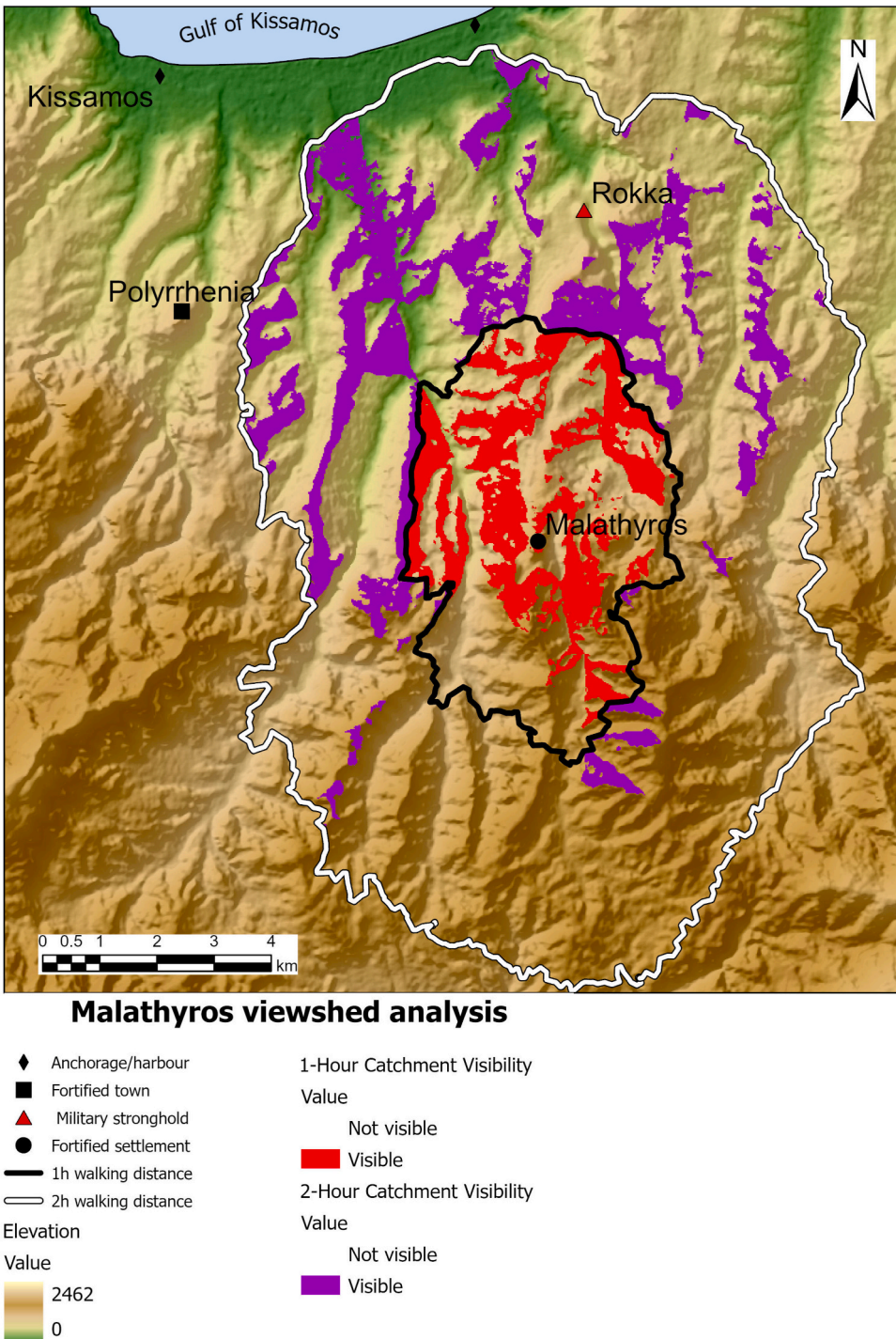
Complementing the mobility study, viewshed analysis provided critical insights into Polyrrhenia's ability to control visually its surroundings. The results of the viewshed analysis are presented in a thematic map (Fig. 7), where the red shading represents areas visible from Polyrrhenia's towers within a 30 km radius. Polyrrhenia commanded extensive visual control over the main natural approach routes from the coastal areas of the Gulf of Kissamos. Its fortifications oversaw much of the coastal plain as well as the possible road system connecting it with other fortified centers, including Malathyros and Rokka. Crucially, these fortified sites were visible from Polyrrhenia, enabling signaling and coordinated defenses across the hinterland.

This visual dominance can be quantified: within the one-hour walking catchment, approximately 50 % of the terrain is directly visible from the fortification, indicating a high degree of local surveillance capacity (Fig. 8 and Table 1). Visibility, however, was not uniform. The fragmented terrain dominated by deep north-south valleys meant Polyrrhenia's visual coverage was most complete within roughly a one-hour radius, where observers could scan in all directions. Beyond this zone, visibility declines substantially, reflecting the constraints of the topography. Within the two-hour walking catchment, only about 26 % of the terrain remains visible, demonstrating a marked reduction in effective visual control with increasing distance (Fig. 8 and Table 1). This contrast between high short-range visibility and more limited medium-range coverage highlights the site's strong control over its immediate hinterland but a more selective surveillance of peripheral zones.

Finally, despite its inland location, Polyrrhenia maintained clear lines of sight toward the Kissamos Gulf to the north. This was a decisive advantage in a territory frequently exposed to seaborne threats. From its elevated position, the garrison could monitor nearly the entire maritime zone, track shipping movements, and detect the approach of hostile fleets long before they reached the coast. While the recognition of fine details becomes difficult for the naked human eye beyond a certain distance, the detection of fleets at sea remained well within the realm of possibility even at considerable distance. As Ogburn (2006) observes, larger objects maintain detectability far beyond the distance at which fine detail is lost. Moreover, the fortification enjoyed commanding views over much of the shoreline, including both the main harbor of Kissamos and secondary landing sites along the gulf. When considered together with the quantified visibility values, this suggests that Polyrrhenia's strategic strength lay in combining local surveillance with targeted long-distance observation towards key coastal and maritime areas.

Taken together, the results of the LCP and viewshed analyses underline the dual strategic role of Polyrrhenia within the Kissamos region. Its inland location combined accessibility to fertile agricultural lands, secure overland links to neighboring fortifications and the harbor, and





**Fig. 10.** Combined viewedshed and walking-distance analysis centred on Malathyros. Red shading indicates visible terrain within the 1-hour catchment (black outline); purple shading indicates visible terrain within the 2-hour catchment (white outline). Approximately 39 % of the 1-hour catchment and 16 % of the 2-hour catchment are directly visible (see also Table 1).

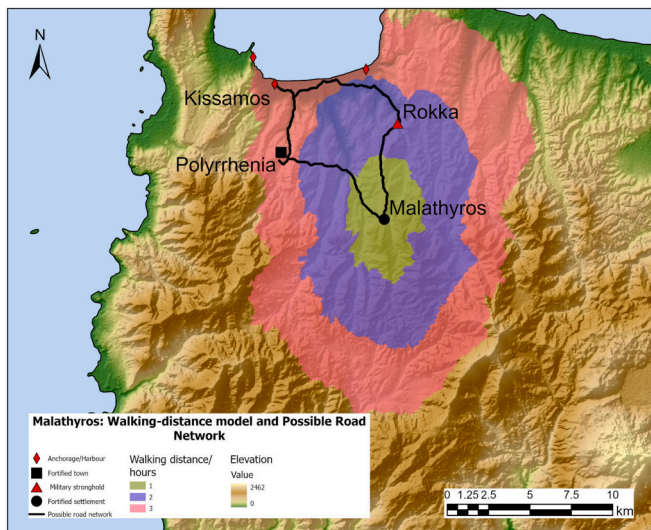
wide-ranging visibility over both terrestrial routes and the maritime approaches of the gulf. This integration of mobility and surveillance highlights Polyrrhenia as both a defensive stronghold and a central hub of control and resource management in western Crete. Far from being an isolated hilltop settlement, it emerges as a nodal point in a wider geopolitical landscape, balancing agricultural productivity, inter-site connectivity, and long-distance maritime oversight.

## 6.2. Malathyros

Turning to the smaller fortified site of Malathyros, located further inland within the Kissamos region, patterns of visibility and mobility display notable similarities to those observed at Polyrrhenia, while also revealing distinctive features of its strategic role. The results of the viewedshed analyses are illustrated in a thematic map (Fig. 9), where areas visible from the site's towers within a 20 km radius are shaded in red.

As in the case of Polyrrhenia, Malathyros, despite its inland location, commanded significant views over the maritime approaches within the





**Fig. 11.** Walking-distance model centred on Malathyros, showing 1-hour (green), 2-hour (purple), and 3-hour (red) travel-time catchments. The black line represents the reconstructed probable road network. Within approximately two hours, Malathyros could reach Rokka; within three hours, Polyrrhenia and the harbour of Kissamos.

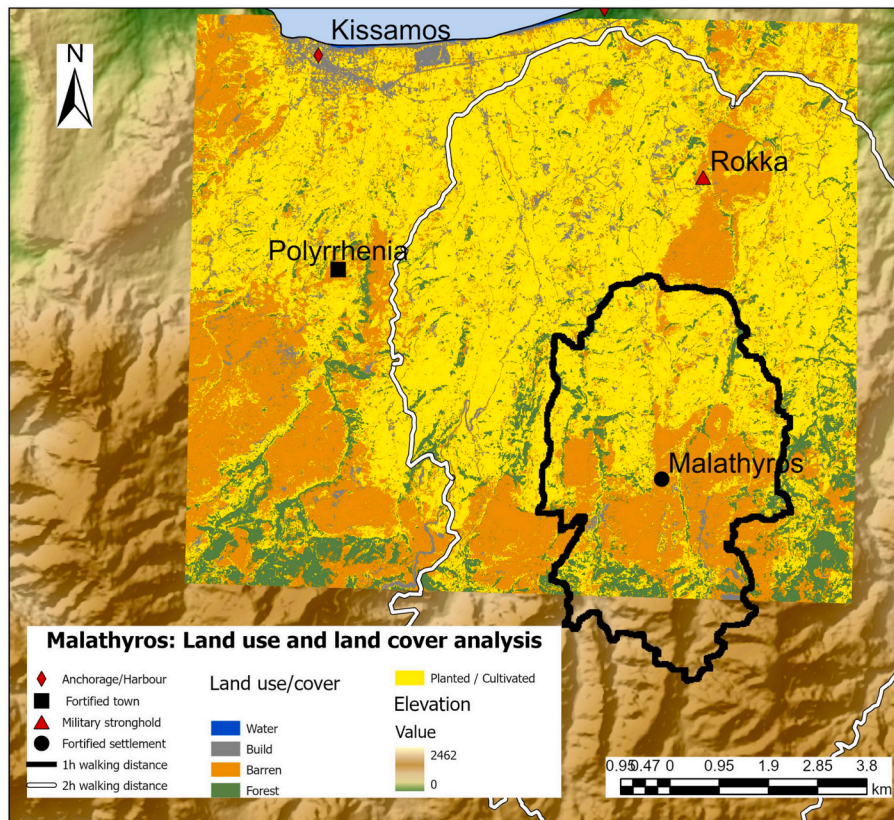
gulf of Kissamos. However, Malathyros's towers offered only limited views of the gulf's immediate coastal zone. They did provide partial visibility east of the Spatha promontory, which allowed monitoring of maritime traffic in that sector and early detection of potential threats from the eastern seaways. This suggests that Malathyros added a

complementary coastal lookout function, extending the fortified network's overall surveillance capacity.

On land, Malathyros maintained visual control over fragmented portions of the potential natural approach routes linking it with Polyrrhenia and Rokka (Fig. 9). Visibility was most effective within a one-hour walking radius, where continuous oversight of the immediate hinterland was possible. Quantitatively, approximately 39 % of the terrain within the one-hour catchment is visible from the site, indicating a moderate level of local surveillance compared to Polyrrhenia (Fig. 10 and Table 1). Beyond this threshold, particularly within a walking distance of up to approximately two hours, visual coverage became fragmented and discontinuous, reflecting the constraints imposed by rugged topography. Within the two-hour catchment, visibility drops to around 16 %, demonstrating a substantial reduction in medium-range visual control and highlighting the site's more limited capacity to oversee distant areas (Fig. 10 and Table 1). Views toward the southern interior of Crete were severely limited or completely obstructed, emphasizing the site's primarily northern and coastal orientation.

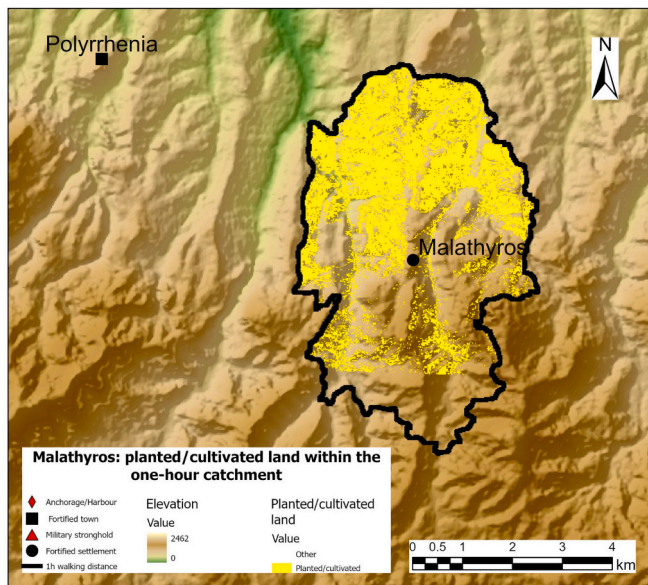
Importantly, Malathyros maintained direct intervisibility with Polyrrhenia, facilitating signaling and coordination between the two sites (Figs. 7 and 9). By contrast, there was no direct line of sight to Rokka, which may suggest a more hierarchical or segmented structure of inter-site communication. When considered together with the quantified visibility values, this pattern reinforces the interpretation of Malathyros as a secondary node within the network.

The LCP analysis further clarifies Malathyros's connectivity. Within roughly two hours' walk, Malathyros could reach Rokka; within three hours, a traveler could continue to Polyrrhenia (Fig. 11). When combined with LULC data, the analysis shows that cultivated and planted lands (yellow) dominated both the one-hour and two-hour walking catchments, particularly in lower-elevation areas and valley floors



**Fig. 12.** Land use and land cover (LULC) classification centred on Malathyros. Classes shown: Planted/Cultivated (yellow), Barren (orange), Forest (green), Water (blue), and Built (grey). The black outline marks the 1-hour and the white outline the 2-hour walking-distance boundary. Cultivated land dominates the lower-elevation areas and valley floors, with barren and forested zones along the steeper southern periphery.





**Fig. 13.** Planted/cultivated land (yellow) within the one-hour walking catchment of Malathyros. Approximately 47 % of the catchment area is classified as planted or cultivated, indicating a substantial agricultural potential in the immediate hinterland.

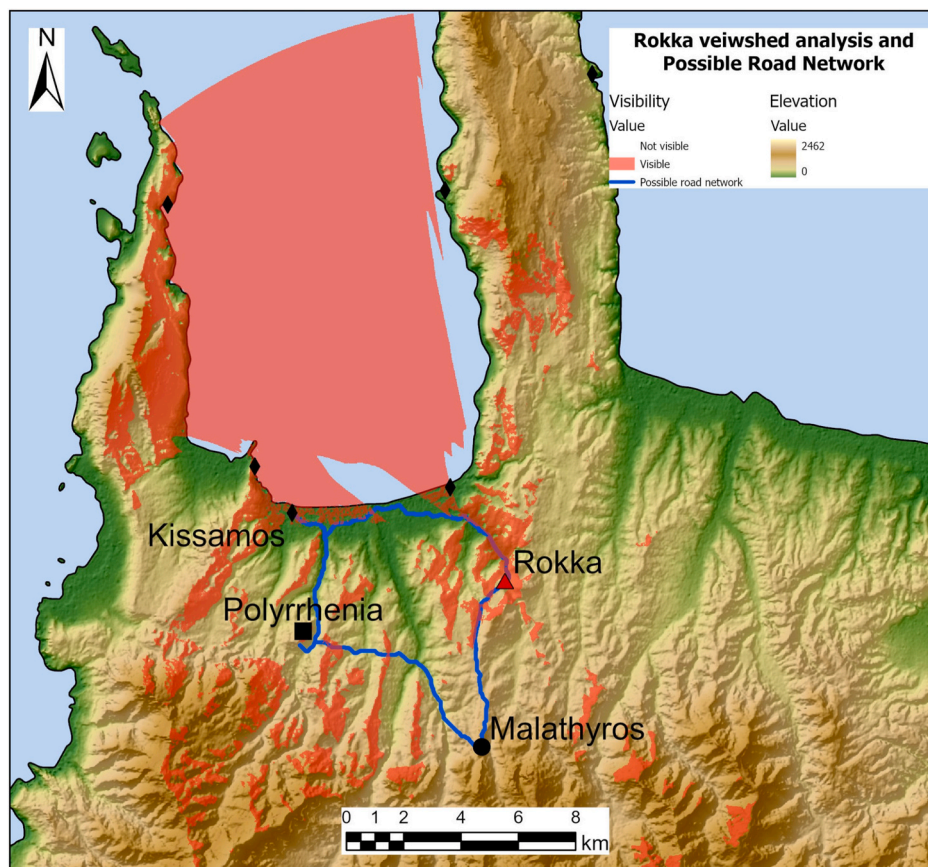
(Fig. 12). These fertile zones would have ensured a stable agricultural base, supporting sustained food production and a degree of resilience, providing food security for the settlement and any garrison. Barren land

(orange) appears more frequently in the southern parts of the catchments, especially near the two-hour boundary, where steeper gradients reduced the feasibility of intensive cultivation (Fig. 12). These marginal areas were likely exploited for pastoral activities or resource extraction. Forested zones (green) are concentrated along the rugged southern and southeastern peripheries, offering timber, fuelwood, and other secondary resources while lying outside the core agricultural zone (Fig. 12). Within the one-hour catchment, approximately 47 % of the land is classified as planted/cultivated, indicating a substantial, though not overwhelming, agricultural potential in the immediate hinterland (Fig. 13 and Table 1).

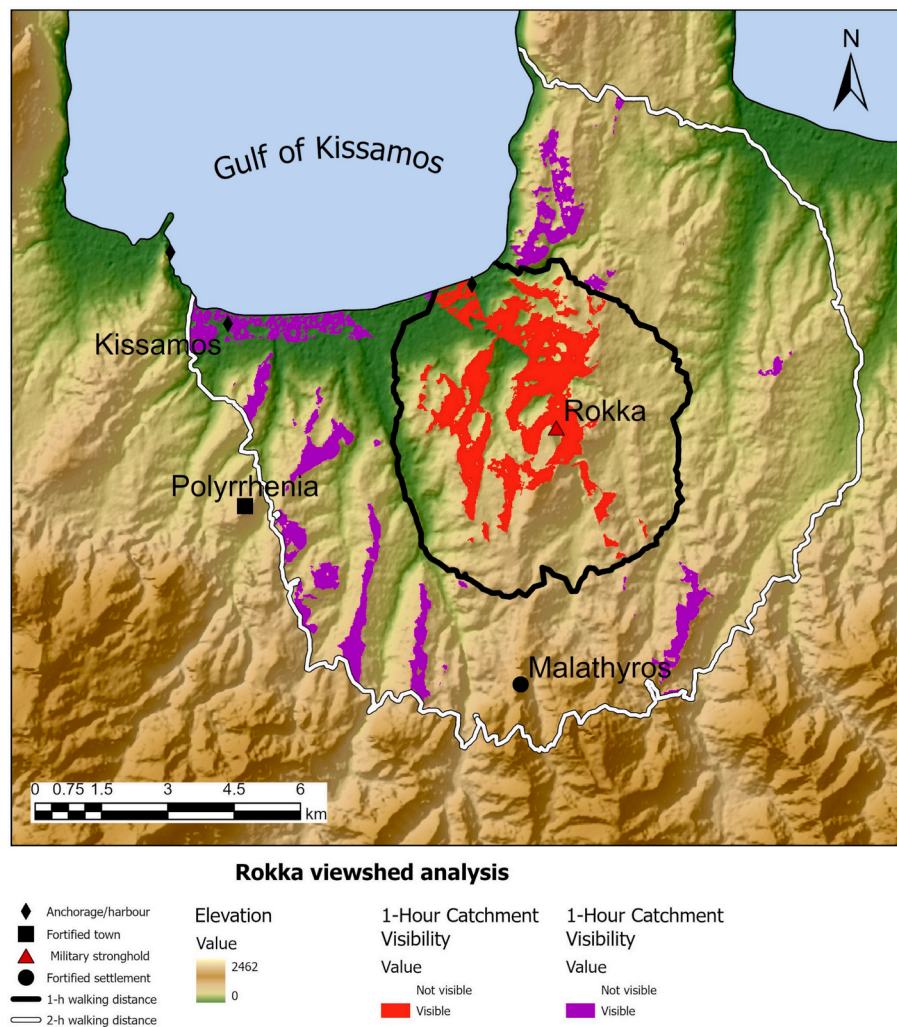
The geo-spatial analyses underscore Malathyros' role as a secondary but strategically significant fortified site within the Kissamos hinterland. While smaller in scale than Polyrrhenia, its vantage points allowed complementary maritime surveillance toward the Spatha promontory, while also overseeing inland communication corridors. Its agricultural hinterland ensured a steady subsistence base, while its intervisibility with Polyrrhenia, but not Rokka, suggests a more selective integration into the regional defense and communication system. In this way, Malathyros emerges not as an isolated stronghold, but as an intermediate node that reinforced the broader fortified landscape of Kissamos through a balance of agricultural productivity, inland connectivity, and targeted visual control.

### 6.3. Rokka

Finally, turning to the small fortress of Rokka, situated inland on the elevated terrain east of Polyrrhenia, the results of the LCP and viewshed analyses are illustrated in thematic maps (Figs. 14–17). This visualization highlights Rokka's surrounding landscape, its coastal and inland



**Fig. 14.** Viewshed analysis of Rokka within a 30 km radius. Red/pink shading indicates terrain visible from the site's towers. The blue line represents the reconstructed probable road network. Rokka commands broad views northward over the Gulf of Kissamos and maintains direct intervisibility with Polyrrhenia, but not with Malathyros.



**Fig. 15.** Combined viewshed and walking-distance analysis centred on Rokka. Red shading indicates visible terrain within the 1-hour catchment (black outline); purple shading indicates visible terrain within the 2-hour catchment (white outline). Approximately 23 % of the 1-hour catchment and 25 % of the 2-hour catchment are directly visible (see also Table 1).

connections, and its travel-time catchments.

Following a similar pattern to Polyrrhenia and Malathyros, Rokka commanded broad views northwards over the Gulf of Kissamos, though with more limited direct control over the coastal zone (Fig. 14). Despite this restriction, its vantage point enabled effective monitoring of maritime approaches and facilitated the early detection of fleets entering the gulf. On land, the site maintained limited visual control over fragmented portions of the natural approach routes linking it with Malathyros to the south and the harbor of Kissamos to the northwest (Fig. 14).

Within the one-hour walking radius (black outline), Rokka's towers provided fragmented visibility of its immediate hinterland, reflecting the broken topography of the surrounding landscape. This is reflected quantitatively in the relatively low visibility values of approximately 23 % within the one-hour catchment, indicating a more restricted capacity for local surveillance compared to both Polyrrhenia and Malathyros (Fig. 15 and Table 1). In the two-hour walking zone (white outline), visibility became increasingly irregular and constrained, particularly toward the rugged southern interior where deeply incised valleys restricted lines of sight and limited long-distance surveillance (Fig. 13). Quantitatively, approximately 25 % of the terrain within the two-hour catchment is visible from the site (Fig. 15 and Table 1).

This pattern, lower short-range visibility combined with improved medium- and large-range coverage, indicates a different visual strategy, in which Rokka was less focused on intensive local control and more

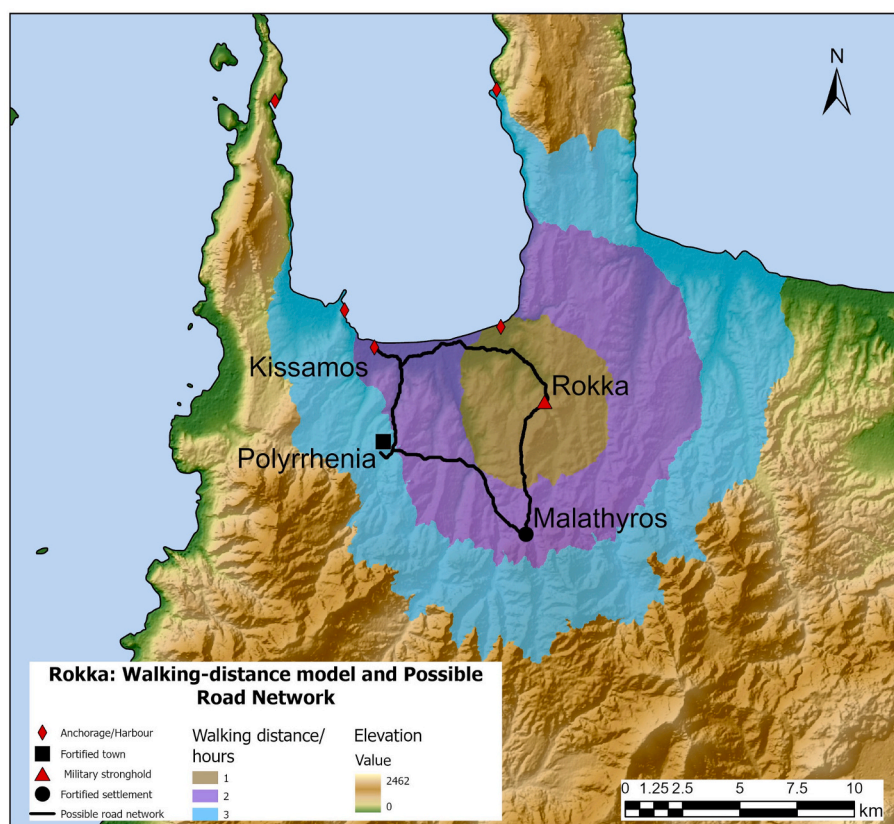
oriented toward monitoring selected coastal and inland corridors as well as sea routes.

As with the other fortified sites, intervisibility played a critical role in Rokka's strategic significance. The site maintained a clear line of sight with Polyrrhenia, ensuring its integration into a signaling and defensive communication network (Fig. 14). By contrast, there was no direct visibility with Malathyros, suggesting that communication between the two strongholds would have relied on Polyrrhenia or intermediate nodes. Taken together with the quantified visibility metrics, this supports the interpretation of Rokka as a specialized node within the network, optimized for corridor surveillance and communication rather than broad territorial oversight.

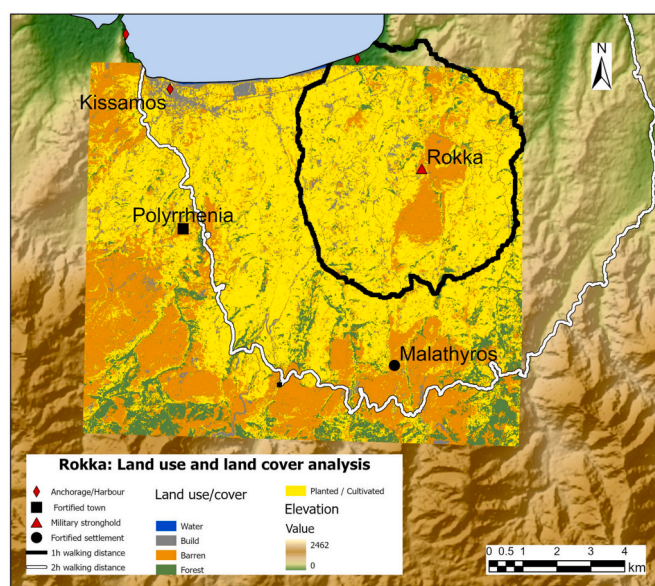
The LCP analysis underlines Rokka's strong integration into the regional mobility system (Fig. 16). Within one hour, the site was directly connected to the shoreline as well as to the surrounding valleys and slopes, ensuring swift access both to the sea and to the agricultural production zones. Within approximately two hours, Rokka was linked not only with Malathyros but also with the coastal corridors leading to Kissamos, the region's primary harbor. These connections underscore the site's role in facilitating and monitoring both inland and coastal movement. Within less than 3 h, Rokka was connected to Polyrrhenia.

When combined with LULC data, the catchments highlight the agricultural and economic foundations of the site (Fig. 17). Planted and cultivated lands (yellow) dominate both the one-hour and two-hour



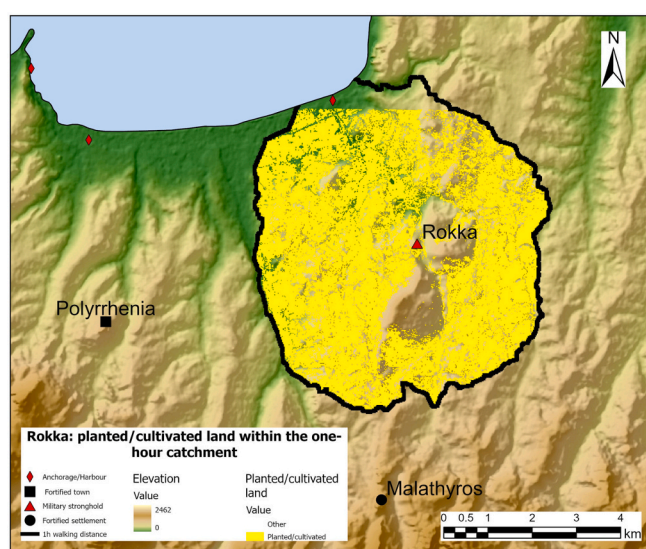


**Fig. 16.** Walking-distance model centred on Rokka, showing 1-hour (brown), 2-hour (purple), and 3-hour (blue) travel-time catchments. The black line represents the reconstructed probable road network. Within one hour, Rokka was connected to the shoreline; within two hours, to Malathyros and the coastal corridors leading to Kissamos; within three hours, to Polyrrenia.



**Fig. 17.** Land use and land cover (LULC) classification centred on Rokka. Classes shown: Planted/Cultivated (yellow), Barren (orange), Forest (green), Water (blue), and Built (grey). The black outline marks the 1-hour and the white outline the 2-hour walking-distance boundary. Planted/cultivated land strongly dominates both catchment zones, reflecting the highly productive agricultural character of Rokka's hinterland.

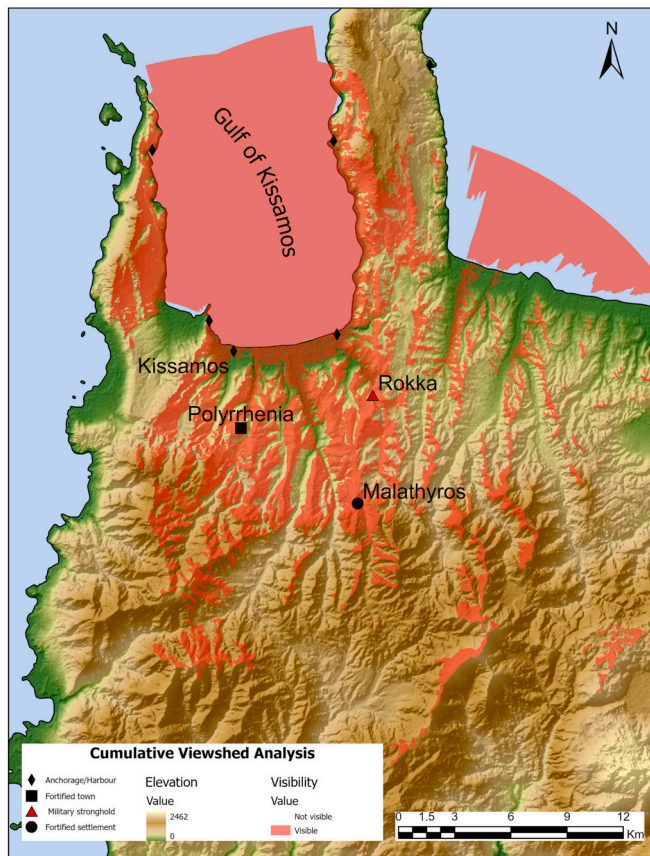
walking zones. Within the one-hour catchment, approximately 72 % of the land is classified as planted/cultivated, underscoring the highly



**Fig. 18.** Planted/cultivated land (yellow) within the one-hour walking catchment of Rokka. Approximately 72 % of the catchment area is classified as planted or cultivated, underscoring the highly productive agricultural character of the hinterland.

intensive agriculture character of the hinterland (Fig. 18 and Table 1). This fertile hinterland ensured reliable agricultural production at a notably high level of productivity, sufficient to sustain the local population and garrison, and likely to have generated an agricultural surplus. Barren land (orange) is concentrated along the margins of the two-hour





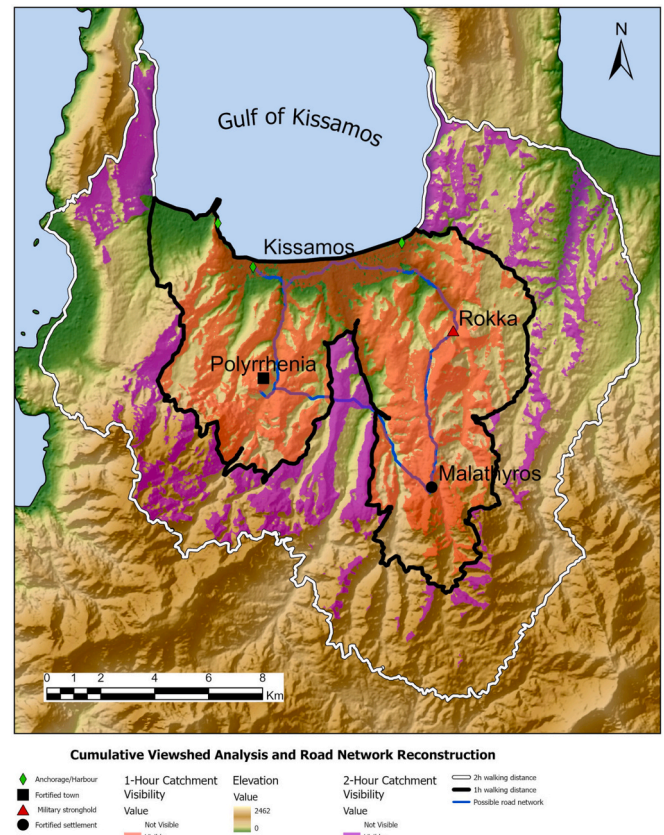
**Fig. 19.** Cumulative viewshed analysis combining visibility from all three fortified sites (Polyrrhenia, Malathyros, and Rokka). Red/pink shading indicates terrain visible from at least one site. The combined viewsheds cover the majority of the Gulf of Kissamos, the coastal plain, and the principal inland corridors, demonstrating coordinated surveillance with significant redundancy over key movement routes.

zone, particularly in the south, where steep slopes limited intensive cultivation. These areas were likely exploited for pastoral activities or resource extraction (Fig. 17). Forested areas (green) appear along the rugged peripheries to the south and southeast, providing timber, firewood, and secondary resources (Fig. 17).

The analysis reveals that Rokka combined strategic inland defensibility with strong agricultural and communication advantages. Its towers oversaw significant portions of the gulf, while its intervisibility with Polyrrhenia integrated it into the fortified signaling system of western Crete. Rokka's one- and two-hour catchments were dominated by cultivated land and offered quick access to the sea, underscoring the fortress's agricultural and communication advantages. Taken together, Rokka emerges as a multifunctional fortress that safeguarded fertile agricultural zones, provided oversight of maritime movements, and reinforced inland connectivity. Although smaller in scale than Polyrrhenia or Malathyros, its strategic placement allowed Rokka to complement both, contributing to the broader defensive, economic, and communication network of Kissamos. This integrated network secured the northwestern Cretan hinterland and linked inland strongholds with coastal harbors, ensuring resilience and adaptability in both peace and conflict.

#### 6.4. Cumulative network coverage

A cumulative perspective on the combined viewshed analysis demonstrates that the three fortifications discussed above exercised visual control over both the hinterland and the maritime approaches of the



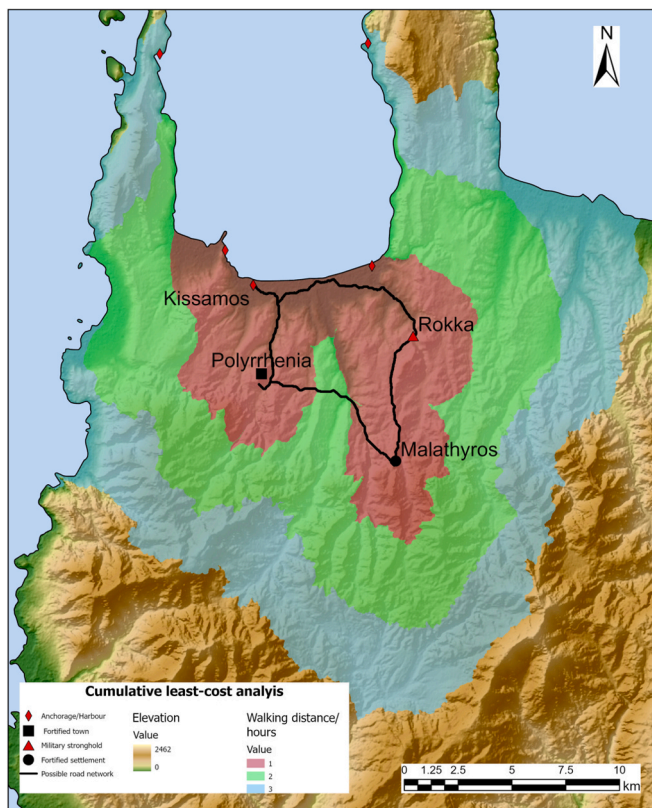
**Fig. 20.** Cumulative viewshed analysis and road network reconstruction for all three fortified sites. Visible areas within the one-hour (orange) and two-hour (purple) catchments are shown, along with the reconstructed probable road network (blue lines) and walking-distance boundaries.

Gulf of Kissamos (Fig. 19). The cumulative visibility model indicates that approximately 60 % of the terrain located within a one-hour walking radius of each site was visible, while a further 30 % of the terrain within the two-hour catchment also fell within their visual control (Figs. 19, 20, and Table 1). Considering the rugged, highly dissected, and topographically constrained landscape of the region, this represents a high degree of spatial coverage relative to what might be expected from more moderate terrain. The distribution of visibility was not spatially uniform: it was concentrated primarily along the coastal margins, major valley corridors, and probable terrestrial communication routes, rather than dispersed evenly across the landscape. This pattern indicates that the principal objective underlying the placement of these fortified sites was not the exhaustive observation of all the available terrain, but rather the targeted monitoring of the movement corridors, communication axes, and economically significant zones.

The combined viewshed analysis further indicates that the fortified sites, together, supervised almost the entire Gulf of Kissamos. Cumulatively, close to 100 % of the maritime zone extending from the northern entrance of the Gulf, together with the eastern, western, and southern coastlines, falls within the sites' collective visual range. This is consistent with the topographical positioning of each site, whether by original design or subsequent adaptation, to maximize broad and relatively unobstructed lines of sight toward the sea and the surrounding coastlines of the gulf. Along this coastline, some natural anchorages were available where hostile fleets could seek temporary shelter, reorganize, and prepare for potential attacks (Fig. 19). This strategic configuration would have strategically enhanced the capacity of early warning, marine surveillance, and coordinated response across the region.

The cumulative integration of the individual viewshed also generates a significant degree of visual redundancy. Extensive sectors, particularly





**Fig. 21.** Cumulative least-cost walking accessibility from all three fortified sites, showing overlapping 1-hour (pink/red), 2-hour (green), and 3-hour (turquoise) travel-time catchments. The black line represents the reconstructed probable road network. Most of the study area lies within a one- to two-hour walking distance from at least one fortified site, indicating effective coverage of the regional landscape.

the coastal strip as well as principal inland and maritime routes, were visible from multiple fortifications simultaneously. This overlapping surveillance could enhance both reliability and resilience of the monitoring system by reducing the likelihood of blind spots and ensuring continuity of observation. At the same time, the high degree of inter-visibility between sites would have facilitated rapid signaling, communication, and coordinated defensive responses across the region. Under such conditions, the concealment of movement by hostile forces along both sea and land would have become considerably more difficult.

These results are consistent with the cumulative LCP accessibility analysis (Fig. 21), which demonstrates that majority of the study area was situated within one- or two-hour walking distance from the fortified sites examined here. The correspondence between accessibility and visibility indicates that surveillance was intensive in zones of immediate practical reach, namely those areas where rapid mobilization, defensive intervention, and refuge-seeking would have been most critical for local populations. The convergence of movement accessibility and visual oversight therefore points to a highly integrated system of territorial supervision.

Beyond issues of security and defense, the relationship between visibility and land use provides further insights into the broader socio-economic logic underpinning the placement of these sites. Within the one-hour catchment from all sites combined, 62 % of the terrain is classified as planted or cultivated land, suggesting a deliberate prioritization of agriculturally productive zones. This pattern implies that surveillance was directed not only towards external threats, but also toward the protection of vital economic resources and productive capacity.

Furthermore, the cumulative road visibility analysis significantly

supports this approach (Fig. 22). More than 80 % of the reconstructed probable road system lies within the combined viewsheds of the three sites, indicating that the vast majority of terrestrial movement routes were subject to direct observation. Such extensive coverage implies a sophisticated degree of territorial control over circulation, communication, and resource management.

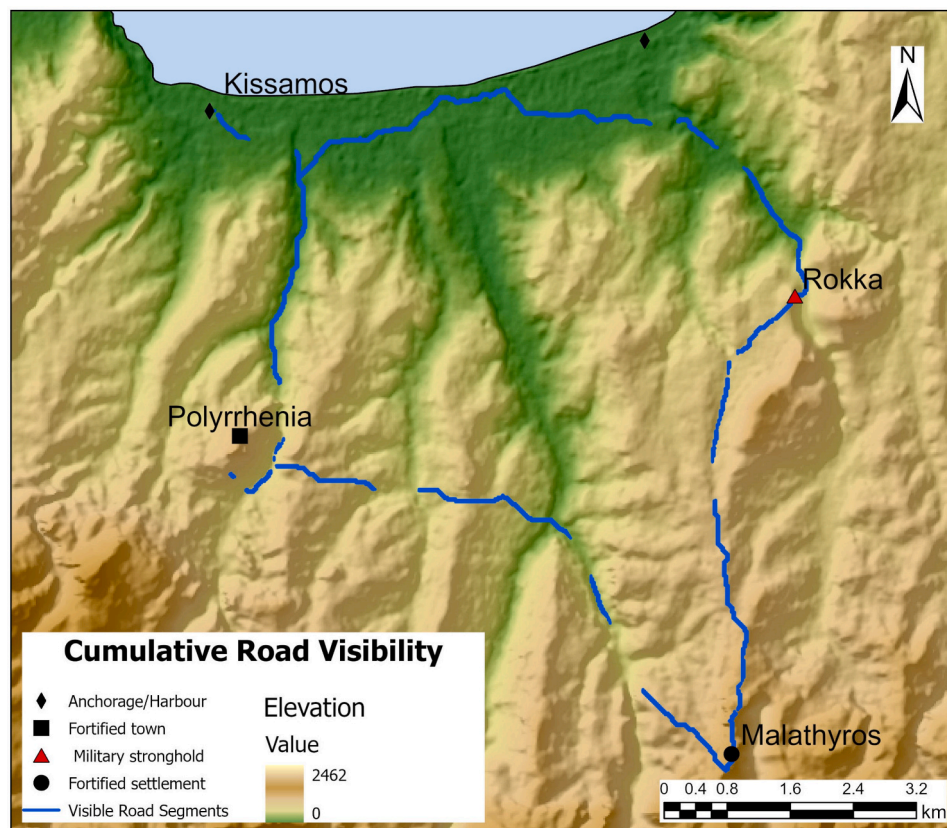
## 7. Discussion

The results of this study, situated within the broader methodological and interpretative trend of landscape archaeology, including GIS and remote sensing, allow the fortified sites of western Crete, Polyrrhenia, Malathyros, and Rokka, to be interpreted not as a series of isolated military installations but as a multifunctional defensive and administrative network. Although their primary role was defensive, their spatial organization and operational logic presented above indicate a close association with economic, administrative, and socio-political functions, reflecting a wide range of activities such as the monitoring of movement, the protection of agricultural production, the managing of resources, and the coordination of regional collective responses.

The analysis presented above suggests that the three sites occupied distinct functional positions within the network. Polyrrhenia combined high independent surveillance with a productive hinterland, consistent with its role as the network's administrative and logistic hub. This is further supported by the fact that it sees both Malathyros and Rokka, but the latter two do not see each other. As such, Polyrrhenia was the sole relay point for lateral visual communication. This structural centrality underpins its coordinating role. Malathyros occupies an intermediate position on surveillance and productive hinterland (39 %, 47 %) consistent with a secondary, bridging role. Rokka shows the weakest independent surveillance (23 % and 25 % within 1- and 2-hour catchment respectively) paired with the richest hinterland (72 % cultivated), suggesting a site specialized in production and corridor control that relied on the wider network's coverage rather than its own. This networked structure also underpinned near-total maritime surveillance of the Gulf of Kissamos. Polyrrhenia's coastal-plain visibility, Malathyros's oversight east of Spatha, and Rokka's northward view together closed what would otherwise have been gaps in coverage. Given Crete's documented history of seaborne threats, this shared maritime function was arguably as central to the network's strategic logic as its control of inland corridors, with detection at any point along the gulf plausibly relayed inland through the same intervisibility links, again centered on Polyrrhenia. This maritime dimension situates the Kissamos network within a wider trend in current scholarship on Byzantine frontier defense, which increasingly treats coastal and inland fortification systems as unified administrative entities (Koder 2002; Roussos 2020; Poulou and Leontsini 2022).

The sites' elevated, rugged placement maximized defensibility while preserving visual command over adjacent lowlands. At the same time, the accessibility analysis shows these sites remained integrated into daily mobility patterns. In periods of peace, the same corridors that structured visual and administrative control facilitated the routine movement of people, animals, and goods, supporting trade, seasonal agricultural labor, and the circulation of resources between settlements, fields, and harbors. In periods of war, most surrounding rural populations could reach a defensible location within a relatively short time, allowing opportunities for refuge and organized response to sudden incursions, including seaborne raids such as those attributed to Arab fleets. This is consistent with a deliberate dual strategic objective in which military security and economic sustainability were interconnected, with the fortification network safeguarding both population and productive landscape.

This spatial and functional pattern was not unique to western Crete but formed part of a broader defensive and administrative strategy evident across the byzantine Aegean from the 7th – 8th to the 10th – 12th centuries. In eastern Crete, for example, Oxa and Liopetro



**Fig. 22.** Cumulative road visibility analysis, showing segments of the reconstructed road network (blue) that fall within the combined viewsheds of Polyrrhenia, Malathyros, and Rokka. More than 80 % of the probable road system is visually monitored from at least one fortified site.

commanded the Mirabello Gulf and Sitia coastline, creating overlapping maritime and coastal surveillance zones (Roussos 2024). In the Cyclades, the fortified town of Apalirou on Naxos oversaw upland landscapes while monitoring seaways and adjacent islands, forming a maritime communication network with the fortified sites of Viokastro, near Paros and Palaioikastro, on Ios. Their combined views covered almost the entire maritime zone in order to control effectively every part of the key sea routes that passed through the central Cyclades (Roussos 2020). Such parallels strongly suggest that the Kissamos system should be understood within the wider Byzantine frontier policy, in which inland fortifications operated not merely as military outposts, but as multifunctional socio-economic centers designed to secure agricultural production, protect rural populations, regulate mobility, and maintain strategic control over both terrestrial and maritime space.

## 8. Conclusions

This study demonstrates that the Middle byzantine fortifications of Polyrrhenia, Malathyros, and Rokka in western Crete were structured through the systematic integration of military defense, territorial management, and economic control. These sites did not function as isolated installations but as functionally interrelated components of a structured territorial network, in which visibility, accessibility, and resource exploitation were deliberately aligned. Such spatial configuration produced a resilient and adaptive system capable of simultaneously managing security, mobility, and agricultural production, consistent with the broader political and economic organization of the Cretan countryside.

More broadly, the results of this study contribute to a deeper understanding of the interplay between environment, socio-economic organization, and strategic planning in Byzantine Crete. This suggests that fortified sites played a role in sustaining broader political regional

stability and imperial authority. At the same time, despite limitations, the study demonstrates the significant interpretative potential of geo-spatial and remote sensing methodologies for the investigation of byzantine frontier systems and defensive landscapes. By integrating spatial analysis and remote sensing data with archaeological and historical interpretation, this research also provides a transferable methodological framework for the study of byzantine fortification networks across the Mediterranean world.

Declaration of generative AI in scientific writing

During the preparation of this work, the authors used **ChatGPT (OpenAI, GPT-5 model)** to assist with **proofreading, language refinement, and improving grammar and clarity of expression**. After using this tool, the authors thoroughly reviewed, edited, and verified all content to ensure accuracy, scholarly integrity, and that the final text fully represents the authors' own analysis and interpretation. The authors take full responsibility for the content of the published article.

## CRediT authorship contribution statement

**Konstantinos Roussos:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Mahmoud Mardini:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Investigation. **Maria Cristina Salvi:** Writing – original draft, Methodology, Formal analysis, Conceptualization.

## Declaration of Competing Interest

The authors declare that they have no known competing financial



interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jasrep.2026.105947>.

## Data availability

Data will be made available on request.

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