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Landscapes of (dis)connection: Modelling connectivity in west Samos with least cost path analysis

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ABSTRACT

This study explores connectivity in west Samos, an island whose landscape was defined by steep topography and which was largely inaccessibly by sea in the winter months. The first part of this paper reviews bibliographic, cartographic, ethnographic and archaeological evidence for terrestrial connectivity, while the second applies least cost path analysis to investigate possible routes between five key sites in southwest Samos to five key sites in the northwest. The GIS-rendered routes are compared to the field data to further explore the finer details of pathfinding and environment. All data types indicate the importance of route-making along two major river courses, the Megalo Rema and the Fourniotiko. Early Modern travelogues, ethnographic interviews, and maps all highlight the importance of seasonal waterways for cutting through areas of steep slope gradient. Both in exploratory hikes taken by the author and in GIS modelling, the Megalo Rema is deemed to be the more effective waterway for connecting south to north, while the construction of the island's modern road network largely deviates from the calculated least cost routes. Anisotropic modelling is also employed to estimate travel times along the least cost paths. It is suggested that a return journey by foot or donkey is possible between the two sides of the island in one day, but that travel by loaded cart would have been impractical in most situations. These findings contribute to broader debates on island connectivity in the Aegean, emphasising the role of terrestrial pathways in supplementing maritime networks.

1. Introduction

The question of how individuals move through a landscape is integral to understanding lifeways. Duly, understanding ancient and more recent mobility requires examining how a landscape's connectivity shapes movement opportunities. Particularly interesting from this perspective are island environments. Degrees of isolation and connection, the interplay between maritime and land-based connectivity, and the concentration of movement in discrete environmental zones are all factors that variously affect the degrees of connectivity in a fixed island landscape.

This paper is about connectivity on Samos (Fig. 1, Fig. 2), the ninth largest of the Greek islands, and located in the east Aegean less than 2 km shy from the mainland of modern-day Turkey. Samos was renowned in antiquity and in the early modern period for a maritime connectivity that plugged the island into large overseas trade and exchange networks (Petersen 2006; Webb 2016; Henke 2019), and already from the sixth century BCE, with a reputation for being one of the first ship-building cities of the ancient Greek world, Samos was considered to have been a 'thalassocracy' (Herodotus 3.39–44, Thucydides 1.13.2–3). Although lesser understood, land-based connections were just as important for this island from its early days: both ethnographic and early modern accounts attest to effective communication between remote villages, and that vast resources of olive, vine, timber, and other crops were moved within Samos from across its rural territories (Dapper 1703: 192; Tournefort 1717: 307; Sonnini 1801: 306). Particularly important in this regard is the area of west Samos around the modern towns of Marathokampos and Karlovasi (Fig. 3), two basins well populated by a network of small villages in which recent archaeological work has indicated diachronic use of rich natural resources, possibly agricultural communities (Fig. 4, Christophilopoulou et al. 2025).[1] Given the apparent evidence for land-based connections, then, Samos' natural landscape warrants a detailed study of its connectivity. And this is despite the evident natural obstacles in west Samos: a chain of steep hills across the island originating from the Kerkis and Karvounis mountain peaks renders large parts of the landscape practically difficult to cross owing to sheer slopes —the very

[1] Moreover, studies of maritime connectivity have indicated that, owing to tempestuous weather conditions and rocky outcrops particularly on the north side of the island, for large parts of the year circumnavigating the island in a small ship is practically impossible (Loy 2024). This would imply that for many months of the year, the only option for navigating between Samos' villages or for moving resources was terrestrial.

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Fig. 1. Location of Samos island, with the main study area of this paper marked.

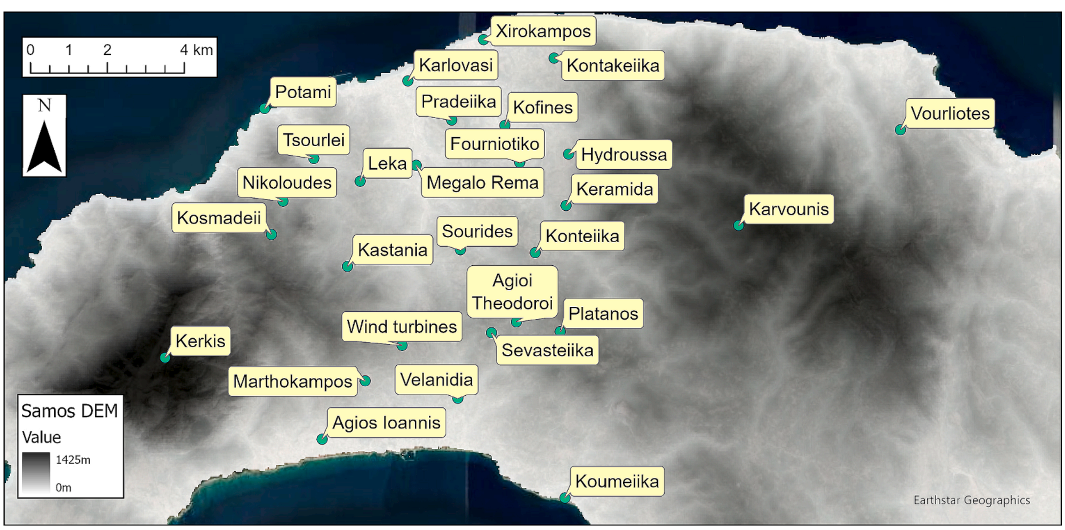

Fig. 2. Study area of west Samos, with places marked that are mentioned in the text.

name ‘Samos’ is thought to derive from an ancient word for ‘mountainous’ (Stamatiadou 1862: 32–40).

Even given the topography and situation of west Samos’ landscape, that there is only 10 km from one coast to the other seems to imply that moving terrestrially from one side of the island to the other was indeed possible: this paper investigates the logistics of that travel, however difficult it might have been. It will consider what were some possible main routes, and how much time and effort might have been needed to progress along them, either on foot or assisted by an animal with pack saddle. This issue is important to discuss: island studies largely prioritise movement *by sea* between or around islands, and generally less considered is the notion that islanders might want to circulate *within* the island by land; in fact, regular and relatively unhindered access between villages was crucial to the identities and operations of inland island communities (cf. Conkling 2007). And apart from simply circulating between the villages, it is possible that terrestrial travel was undertaken in west Samos for moving heavy goods like timber or cut stone (Raepsaet 2002: 277–9; Bresson 2016: 84–8),[2] particularly as an alternative to sea travel in the tempestuous winter months. Survey evidence has suggested the presence of ancient built settlement in this part of the island (Christophilopoulou et al. 2025), while the presence of marble quarries and the availability of other resources is scarce here (Matarangas et al.

[2] In the ancient world, travelling long distances across rugged landscapes for religious festivals is well-attested (Burkert 1985: 99–100; Kavoulaki 1999; Connelly 2011; Kubatzki 2018); however, even though there is a growing understanding of the cults and festivals celebrated at the Heraion on Samos, nothing secure is known about any possible cults in the west, and sacred travel cannot be sensibly investigated here.

Fig. 3. Left: view of the Marathokampos basin from the road below Platanos. Right: the Karlovasi basin from the road towards Vourliotes.

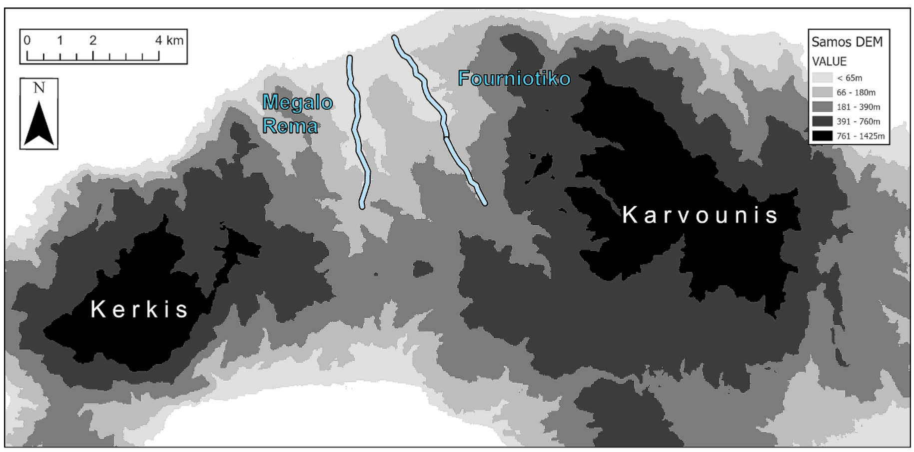

Fig. 4. Topographic map of west Samos, with named mountains marked, along with the Fourniotiko and Megalo Rema rivers.

2011). Duly, this paper focuses on the logistics of terrestrial connectivity, while also pushing this further to consider the possibility of moving heavy resources by land. The first section summarises the evidence for landscape connectivity from bibliographic and field sources; the second uses least cost path analysis to further explore connection. The results of the GIS modelling are calibrated against the field data to evaluate the apparent effectiveness of moving between these different parts of the landscape, both on foot and on mounted and wheeled transport.

2. Previous research

2.1. Bibliographic sources

Early Modern texts provide limited information relevant to landscape connectivity in west Samos. Of travellers who visited Samos, many stuck just to the east side of the island, near Chora and at the ancient remains of the Temple of Hera (Randolph 1687; de Thevenot 1727; Sonnini 1801; Ross 1843; Murray 1872); of those who visited the west, many mentioned just the villages themselves and not the space in-between (Dapper 1703). What one can discern, though, is that the area south and east of Hydroussa (formerly Fournoi) was deemed inaccessible due to steep slopes and dense forest, stretching approximately 30 km. (Georgirenes 1677: 22; Tournefort 1717: 322; Lacroix 1853: 221). The texts are also helpful in giving an estimate of some travel times: from the peaks of Kerkis (Katabacte) down towards Marathokampos at least six hours by foot is estimated (Tournefort 1717: 321; Guérin 1856: 282); journeys from Marathokampos to Platanos and Vourliotes are also documented (Tournefort 1717: 321–3) and it is noted that, in February, to go by mule did not quicken the pace much at all after a six–eight mile trek as the cold was too piercing and the animals too starved with hunger. Finally, landforms are discussed, and streams cutting ravines through hills are noted as aiding transit (Guérin 1856: 270); the river running down from Leka is noted for being particularly useful as a passage (Guérin 1856: 268), which must be the Megalo Rema.

Two maps provide a wealth of contemporary and historic information on landscape infrastructure.[3] The first is the 2020 'Terrain Editions' map (1:30,000) produced by Stephanos Psimenos for 'Samos Hike' (Fig. 5). Field surveys collected data for this map, documenting major and secondary roads on Samos and the island's rivers and water courses. This map is produced in companion to the *Samos Hiking Guide* (Psimenos 2016), which sets 32 recreational hiking routes across the island. No hiking routes cut through the middle of the basins under investigation, but on the west side routes 2, 3 and 4 connect the area of Potami to the towns of Karlovasi, Nikoloudes and Tsourlei, and route 5 is a circular between Leka, Kastania and Kosmadeii; while on the east side the number 16 route goes from Platanos down past Hydroussa and Kontakeiika to the coast, and route 17 is a circular around Platanos. Second,

[3] The scope of the current project was to investigate the maps used by the WASAP field team during the main project campaign. As a development of this work, additional maps could be taken into consideration: maps from the Hellenic Military Geographical Service drawn at 1:5000 could provide a view of the landscape at an even higher resolution.

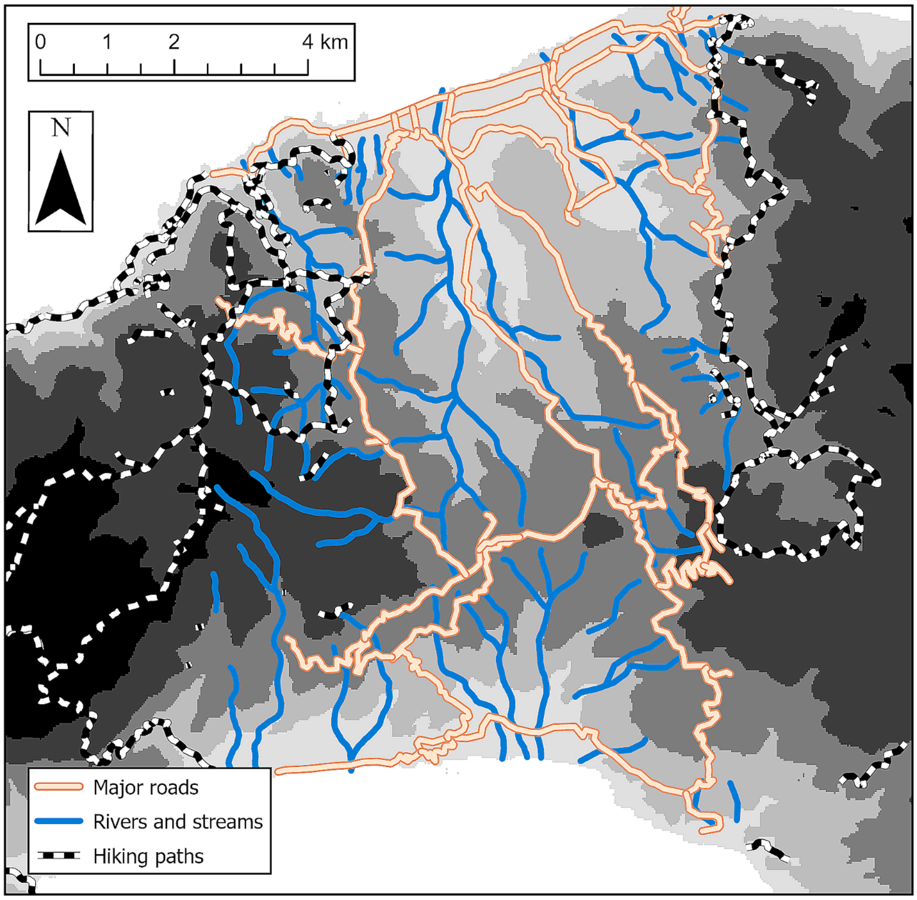

Fig. 5. Tracings of major roads, rivers and hiking paths from the 'Samos Hike' map.

useful is the 1943 'Aegean Islands: G.S.G.S. 4468′ map (1:50,000),[4] drawn up by the Field Survey Company of Royal Engineers in 1943 ('British Staff Map') (Fig. 6). Based on aerial photographs from 1942 and 1943, this map captures the routes connecting west Samos' rural villages before the tourism boom. The map documents metalled and non-metalled roads, along with mule tracks (kalderimia) and cart paths.[5]

2.2. *Field evidence*

Field information relevant to the theme of connectivity in west Samos was generated over the course of the West Area of Samos Archaeological Project (WASAP). This landscape archaeological project, conducted under the auspices of the British School at Athens between 2021 and 2024, undertook exploratory intensive pedestrian survey in the environs of Marathokampos and Karlovasi in west Samos, with a view to documenting chronological settlement patterns in an area rich natural resource and famed for its maritime connections.

2.2.1. *Points Of Interest*

During extensive survey across west Samos, WASAP used the 'Point Of Interest' (POI) as a mechanism to capture any landscape information that did not fit into the categories recorded during systematic transect exploration.[6] Forms for documenting POIs captured landscape features in a standardised way (*e.g.* estimate of vegetation coverage, slope percentage, erosion type, viewshed) as well as providing free-text space for qualitative description and interpretation of the landscape by field team members.

29 POIs (out of 340 POIs) documented over the lifetime of the survey are particularly relevant to the question of landscape connection between north and south Samos (Fig. 7, Fig. 8, Table 1), both located within the area of the current study and relating to waterways or features of landscape access: 16 of these POIs were documented during fieldwork transect walking, and 13 were documented during extensive exploratory hikes (see 2.2.2 below). Streams and seasonal waterways were recorded in both southwest Samos (P085,[7] P086, P096, P163, P167, P172) and northwest Samos (P197, P216, P252, P266, P286),

[4] This is a fairly low resolution map to be used for spatial analysis, but it is appropriate for two reasons. First, it is used to give the general location of roads and tracks, the general topographic and landscape situation of such routes can be ascertained even if they are not completely accurately plotted. Second, where these features are used in quantitative analysis below (section 3.2) they are compared against route lines that are buffered, with a minimum buffer distance of 100m.

[5] As indicated above, one could take this project further by including more maps, but to do so is outside the scope of the current study, which restricts itself only to the maps used by the WASAP field team during the main project campaigns. One could look, for instance, at Ottoman period maps compiled by Heinrich Kiepert in the nineteenth century.

[6] For a fuller discussion of POIs and their place within the overall data structure of WASAP, see Loy, Katevaini and Vasileiou 2024. Christophilopoulou et al. 2025 provides more detail on when and where the team decided to register POIs: as the result of exploratory visits to the landscape made on the basis of a study of previous literature and aerial imagery; second, with targeted visits to landscape features of particular geographical or topographical interest (*e.g.* springs, hilltops); and, third, to note any features such as walls, cut features or dense scatters of pottery encountered during transect exploration.

[7] Reference numbers for POIs are given by 'P' followed by a three digit number. A full data dump of WASAP data is available at https://doi.org/10.5281/zenodo.14929961.

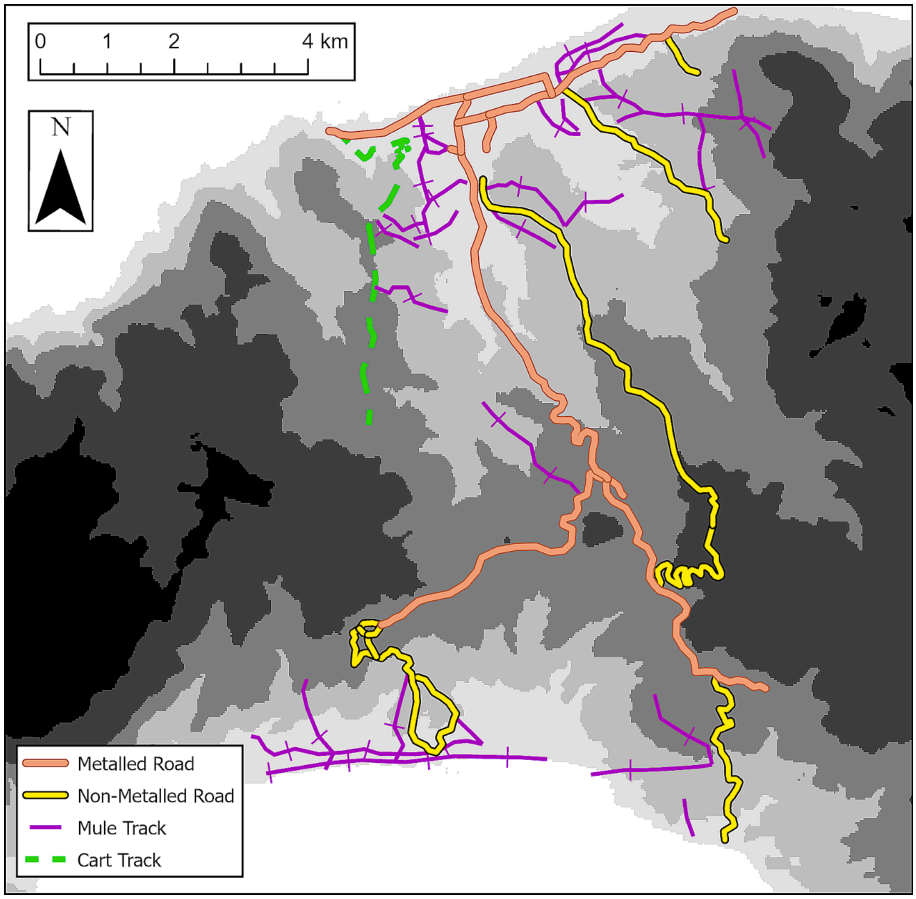

Fig. 6. Tracings of major and secondary roads from the 1943 British Staff Map.

Fig. 7. Landscape features documented during exploratory hikes. Left: possible remains of road structure. Right: river channels cut by the Fourniotiko.

many of which were dried up during the high summer months of the field team's work. Possible remains of roads in the southwest (P111, P112) and northwest (P243, P255, P271) were identified, parallel stone-lined courses sunken below the level of the modern-day road

2.2.2. Exploratory hikes

On days off from the main survey programme, WASAP members took hikes throughout the west Samos landscape (Fig. 9, Fig. 10, Table 2). In 2023, five exploratory hikes were taken between southwest and northwest Samos to explore pedestrian access on different routes, as well as to capture some data regarding the time taken to walk between various points of the island. All five hikes were recorded with Strava loaded on mobile devices, such that movement time was automatically logged and a GPX file of any route could be exported into GIS.

The first and second hikes both began on the ridge along which the wind turbines above Marathokampos are strung out. This high point in southwest Samos occupies a peak between the Marathokampos and Karlovasi basins (it is also one of the only places within west Samos from

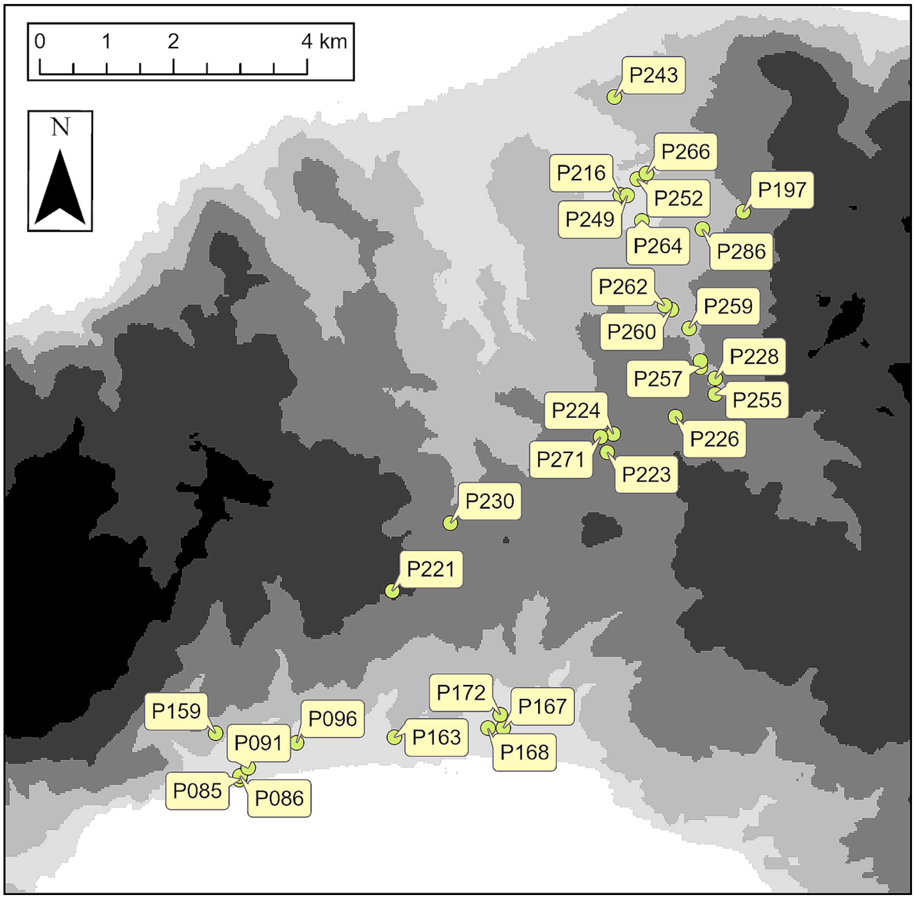

Fig. 8. Location of extensively marked Points of Interest mentioned in the text.

Table 1
List of extensively marked Points of Interest mentioned in the text.

POI ID number	Description
P085	Double sited stream coming down towards the sea.
P086	Dried stream: it looks as if it has not had any water for some time. Area has cultivated terraces and old olive trees.
P096	Stream.
P111	Parallel line of stones, beneath the present ground level.
P112	Continuation of built structure from P111.
P163	Some form of drainage system. Unclear whether if it is modern or not.
P167	Small stream cutting through middle of transect.
P172	Large stream bed with some ceramics and cut stone.
P197	Seasonal stream with bridge.
P216	Wide seasonal river bed.
P243	Stones built into the centre of a sloping road.
P252	Seasonal stream bed.
P255	Another structure built into the road – possibly something to do with road construction, or with terracing.
P266	Seasonal stream / spring, surrounded by reeds.
P271	More evidence from road construction or from old terracing, with a built structure running perpendicular to the main road.
P286	Stream mouth, dry now, with modern bridge over and reeds. Very worn sherds.

which the sea on both the south and north of the islands can be seen). The first hike went west from the wind turbines through the villages of Kastania and Leka, down towards Potami on the coast. Although this team had been given the instruction to find the most efficient route northwards by whatever means, due to the density of forested areas south of Kastania, the first team could not fulfil this goal and instead followed marked hiking trails that cut away from the main roads; the second team were able to fulfil the original aim and made their way northeast towards Hydroussa. The third and fourth hikes both followed river courses, with the first following Fourniotiko from Konteiika, and the second following the Megalo Rema from near Sourides. The Fourniotiko hike began in small waterways that cut a deep and almost impassible valley in the landscape. The fifth and final hike was made along the main roads connecting the villages of Agio Theodoroi and Konteiika, and down along the main Konteiika-Karlovasi highway.

POIs were captured during the exploratory hikes, to record interpretive observations on the landscape and to relate any information documented back to the core survey dataset (Fig. 11, Table 3). On the first hike, the most prominent seasonal streams were noted in the areas between Sevasteiika and Hydroussa (P223, P224, P228). On the second hike, the view of the two coasts was formally recorded and photographed from the point of the wind turbines (P221), and the change of strategy was noted when it became apparent that it would not be possible to make it to Kastania without walking on the asphalt (P230).

Fig. 9. WASAP team members on exploratory hikes, summer 2023.

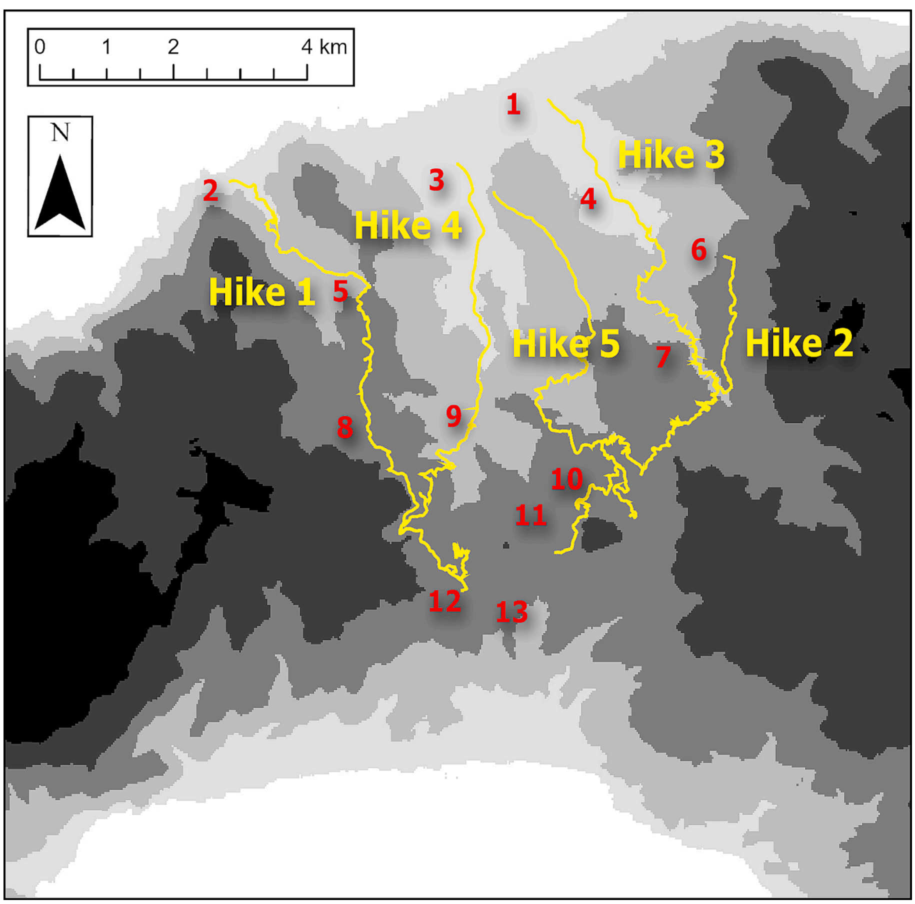

Fig. 10. Route plot of the five exploratory hikes, with GPX polylines imported into GIS from Strava. 1) Xirokampos, 2) Potami, 3) Karlovasi, 4) Kontakeiika, 5) Leka, 6) Hydroussa, 7) Konteiika, 8), Kastania 9) Sourides, 10) Agioi Theodoroi, 11) Sevasteiika, 12), Wind turbines, 13) Marathokampos.

Table 2
Details of the five exploratory hikes taken in Summer 2023.

Hike number	Route	Length (km)	Time (h: mm)
Hike 1	Sevasteiika – Hydroussa	11.66	2:37
Hike 2	Kastania – Leka – Potami	13.61	2:54
Hike 3	Fourniotiko river	10.55	2:50
Hike 4	Megalo Rema river	10.22	2:30
Hike 5	Agio Theodoroi – Konteiika – Karlovasi	8.79	2:08

And on the third hike, various features of the Fourniotiko were noted: there were huge boulders found in the river, suggesting its strength when full in the winter months (P257); it was noted that local fields were watered from the river by trailing irrigation pipes straight out of the valley (P258 and P259); most relevant to landscape connection, it was noted that the route was so slow to progress and the team had to keep crossing from one side of the river to the other for safety (P260), and the points were noted both at which it was no longer possible to progress down the river (P262) and where the last point of river water was found in the summer (P264). No POIs were recorded during hikes four and five, but a number of ethnographic interviews were taken during hike five around the village of Sourides (see below).

2.2.3. *Ethnographic information*

Any information given to the team by residents of Samos —either in a semi-structured interview or through informal conversations— was recorded systematically as a project citable datapoint: oral information was recorded in the 'ethnographic database' rather than in the POI dataset. A large number of these conversations took place as encounters with landowners, undertaken during the progress of transect exploration, but a week of off-season ethnographic data collection also took place in February 2023.

Thirty-five ethnographic datapoints were recorded over the lifetime of the project, of which nine are relevant to the theme of landscape connectivity (Table 4). One resident of the village of Koumeiika (E011[8]) spoke of the importance of the streams to the villages, and that bridges were necessary to cross them in their seasons of full flow; another resident of Koumeiika village (E031) noted the rerouting of streams near Marathokampos, both to bring a supply of water to the village but also to facilitate movement throughout the landscape. Similarly, a resident of Hydroussa (E016) talked about the Fourniotiko being extremely destructive to the landscape in winter months. According to a different interlocutor (E017), there was a large flood in 1901 that destroyed many buildings along the path of the river. One resident (E006 and E007) considered how these dangers of the river had made their way into local folklore, with many stories being told locally about mischievous stream and river fairies. Outside of rivers, villagers in southwest Samos (E002

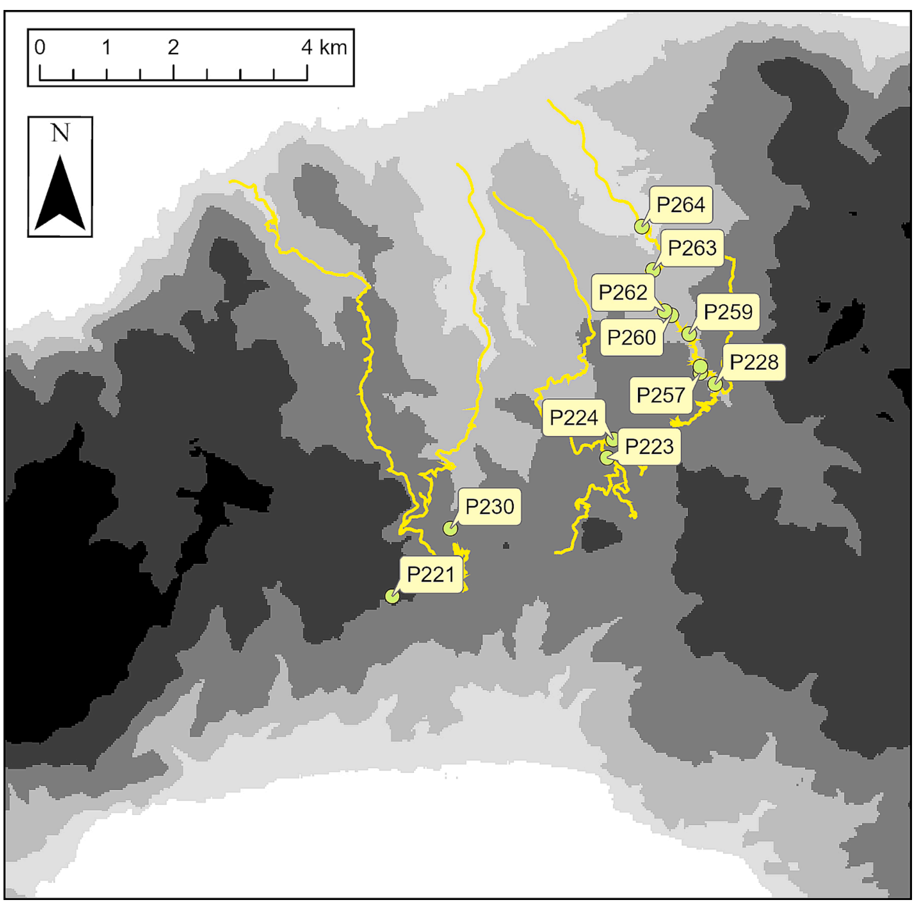

Fig. 11. Location of Points of Interest along the exploratory hike routes.

[8] Reference numbers for items in the ethnographic dataset are given by 'E' followed by a three digit number. A full data dump of WASAP data is currently in preparation.

Table 3
List of points of interest along the exploratory hike routes.

POI ID number	Description
P221	From the wind turbines above Marathokampos, there is a good view back to Ormos bay. One needs to cross the ridge to see the Karlovasi bay. There is only one point in this area where both bays can be seen (unlike at Kastrovouni or at Platanos, also recently visited).
P223	Seasonal stream.
P224	Seasonal stream.
P228	Stream (in September, it had water in it).
P230	Between the wind turbines and Kastania, it is impossible to hike along any paths that are not the main asphalt road. There are small winding field paths, but these are all dead ends. The topography and maquis combination is too extreme to move between any of these paths.
P257	The river is so wide at this point that it branches out into two separate streams. There are huge boulders inside the river valley, indicating a very heavy seasonal flow.
P258	Many pipes lead out of the river valley up the steep slopes into nearby fields, for irrigation. There is one larger pipe that runs all the way down the valley, following its course.
P259	Old (?) piping connected to the larger of the irrigation pipes.
P260	Throughout the river valley we had had to cross the stream every ten metres or so, and it was slow going. From this point, we were able to walk on the concrete covering the long village pipe, and this greatly improved our speed.
P262	This was the point where we had to leave the river valley and join the road.
P264	This is the last point in Fourniotiko where there was water present in September.

and E005) noted that the ways people navigated the landscape had changed greatly since the focus of the area had shifted from farming to tourism, particularly with the need for new roads. In northwest Samos (E035) it was noted that many of the older roads were much steeper.

3. GIS analytical evidence

A framework is needed to go from these scattered datapoints in the landscape into a more homogeneous understanding of movement within the landscape. Of recent years, the number of techniques deployed within GIS environments has been manifold, exploring landscape connectivity through the lens of, among others, focal mobility networks (Llobera et al. 2011; Déderix 2017; Parcero-Oubina et al. 2023), circuit-based modelling (Kelly et al. 2023), agent-based modelling (Wernke et al. 2017), and reconstruction of communication routes (Wheatley et al. 2010; Wilkinson 2014; Palmisano 2017). One of the most frequently used tools, though, remains the Least Cost Path (Murrieta-Flores 2012, Verhagen & Jeneson 2012, Herzog & Yépez 2013, Seifried & Gardner 2019): a tool for determining a path between two points based on the least accumulated cost of travel (Verhagen et al. 2019; Herzog 2020). The most commonly assigned cost value is slope (cf. Márquez-Pérez, Vallejo-Villalta & Álvarez-Francoso 2017), engaging with the principle of minimal effort (Zipf 1949), that in an 'ideal' scenario with no other factors taken into account, people will move in the most efficient path possible. Due to the 'push-button functionality' of generating cost paths, it has been noted that models can map poorly onto

Table 4
Details of ethnographic interviews that contained information relevant to the subject of landscape connectivity.

Ethnographic interview ID	Participant notes	Relevant summary notes on connectivity
E002	Resident of Marathokampos village, c.70 years old	Kampos and Marathokampos were well watered areas. In the mid-20th century, there were sesame, cotton, and wheat fields, but those diminished and eventually completely disappeared when people started small scale gardening (tomatoes, etc.). There is very little shepherding now as people started working on merchant ships after WW 2, which provided steady income. The landscape looked very different before the mid-20th century.
E005	Owner of a bar/coffee shop in Kampos town, c.50 years old	Tourism started in the 80s, but before that the area was agricultural. The area was poor and swampy: 5 m below the surface is rock and water table.
E006	Secretary of the university in Karlovasi, interviewed in Leka.	Streams around Karlovasi are usually vibrant. Streams come down from the mountain. This year (2023) due to lack of rain the streams are barren. Water features, mostly streams and rivers are associated with fairies (ksoutkies). These creatures were playful and mischievous and children were warned about them.
E007	Second interview with secretary of the university in Karlovasi.	Story of fairies are associated with the streams called Kerkitio and Fourniotiko. The fairies also took people's voices. The interlocutor and her family went to Seitani to collect olives from their plot and the work kept them until nightfall. At night they felt that some creatures were shaking them and the food fell from their cloths and vanished. It was like they were trying to make them scream or speak in order to steal their voices.
E011	The previous mayor of Koumeiika village, c.60 years old.	The importance of streams in everyday life. The interlocutor remembered from when he was a child there were washing constructions along the stream that passes through the village. He mentioned bridges around the village and that they were necessary because of the strong flow of the streams. He also mentioned that there are myths connected with the streams and especially that fairies and ptiptilia (gnomes) were drowning children.
E016	Mayor of the village of Hydroussa.	The Fourniotiko river used to be extremely strong and destructive especially in the winter months when people could not go to Karlovasi (from Hydroussa) due to its strong flow. But during the summer months when they had to go to Karlovasi they passed through it. There are a lot of water mills now abandoned in the area.
E017	Representative of the farmers' union in Kontakeiika, interviewed in Hydroussa.	A large flood of 1901 destroyed a lot of the local area (possibly the church of Kelia). all along the Fourniotiko river.
E031	Former art conservator, from the village of Koumeiika.	Both streams in this area were once powerful, but have now been diverted higher up to provide water for Marathokampos.
E035	Farmer from the area of the Kofines site.	The area used to be much steeper. A bulldozer was used in 2015 to create a gentler slope in the currently ploughed fields.

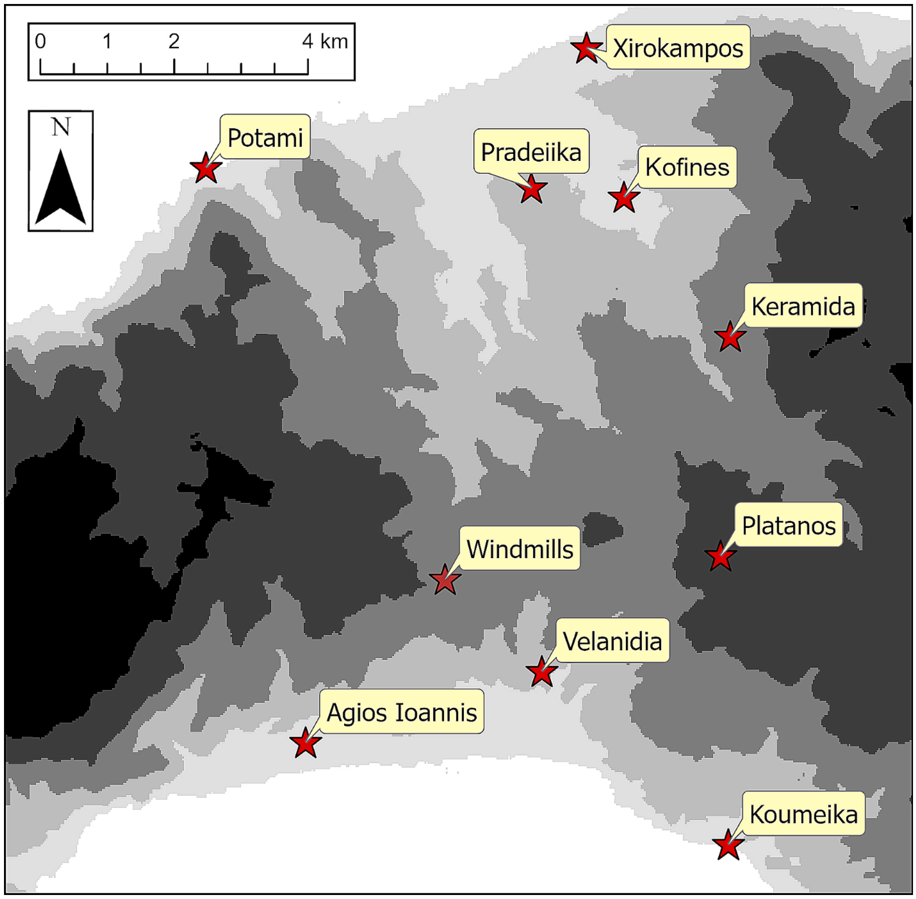

Fig. 12. Location of the ten sites in west Samos, tested here for their connection through least cost paths.

Table 5
Reclassification of cell values from the slope raster to the reclassified slope raster.

Input cell value from slope raster	Output bin for reclassified raster
1–5	1
6–11	2
12–17	3
18–22	4
23–27	5
28–32	6
33–38	7
39–44	8
45–51	9
52–66	10

known or documented routes (Fovet and Zakšek 2014; Supernant 2017; Parcero-Oubiña et al. 2019), and that predictively generated routes are weak interpretive tools without the calibration of relevant real-world data (Bevan 2013; Herzog 2014). By bringing in landscape, excavated, ethnographic or literary data alongside GIS-rendered cost paths, though, much success has been made in interpreting the connective potential of ancient landscapes both for the Greek world (Delacruz 2021; Malaperdas and Sarris 2023; Davidson 2024), and more broadly (Jakel et al. 2022; Younsi and Ciampi 2023).

The remainder of this paper will model connection between known sites of activity in the landscape of west Samos, and consider how the data discussed above sit alongside these models. Movement is modelled from the southwest to the northwest of the island, testing degrees of connection between five sites in the south to five sites in the north (Fig. 12): from south to north, these are Koumeiika, Agios Ioannis, Velanidia, the unnamed ridge on which the modern wind turbines sit ('Wind Turbines'), Platanos, Keramida, Kofines, Pradeiika, Potami and Xirokampos. These sites have been chosen based on findings from the WASAP survey, and from further bibliographic or ethnographic research. In the southwest, Agios Ioannis and Velanidia are tested as the points of the highest surface ceramic density as documented in the WASAP survey of the area. Coastal Koumeiika is noted as a possible locus of ancient activity in early modern literature (Guérin 1856: 270–1), and ethnographic research suggests that there might be ancient material in the area (E001 and E010). The wind turbines represent the point at which the exploratory hikes began, being the point at which both sides of the island can be seen. The village of Platanos, as well as being another point at which both coastlines can be seen, is one of the earliest villages of the area that existed before the modern road network (Dapper 1703: 192; Guérin 1856: 267–8), an area that has also been suggested as a site of possible ancient activity (Shipley 1987: 259). In north Samos, Keramida is a site marked on the Staff maps and no longer extant, but is linked in local folklore with ancient pottery production (E030, E0032). Pradeiika and Kofines are tested as points of the highest surface ceramic density as documented in the WASAP survey in 2024, and Xirokampos in 2023. The latter, along with Potami, tipped as the site of an ancient marble quarry (Shipley 1987: 253; Kokorou-Alevra et al. 2014: 26, Fig. 3), is a far coastal point, an equivalent test to Koumeiika on the south side of the island.

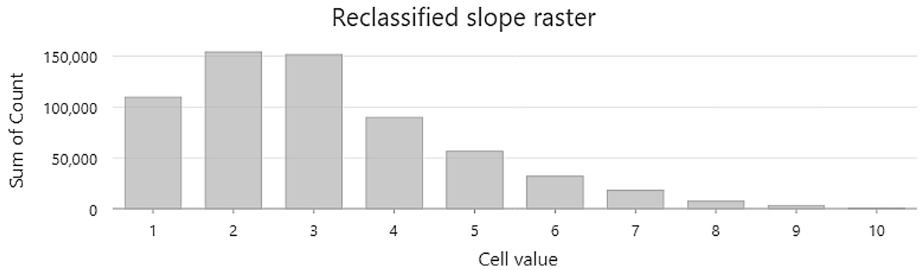

Fig. 13. Sum of cells with given values in the reclassified slope raster.

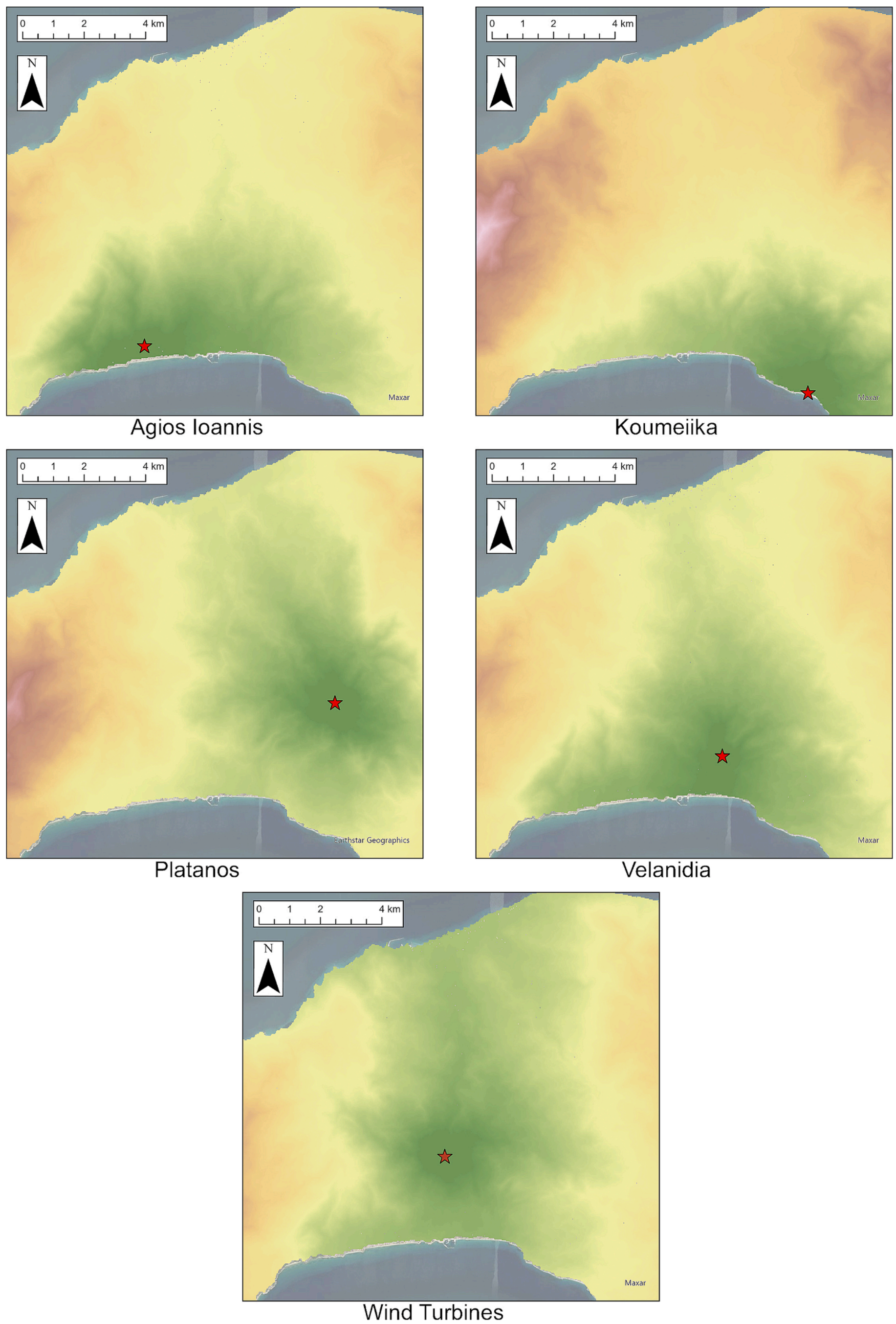

Fig. 14. Composite of accumulated cost rasters generated for the five sites in southwest Samos.

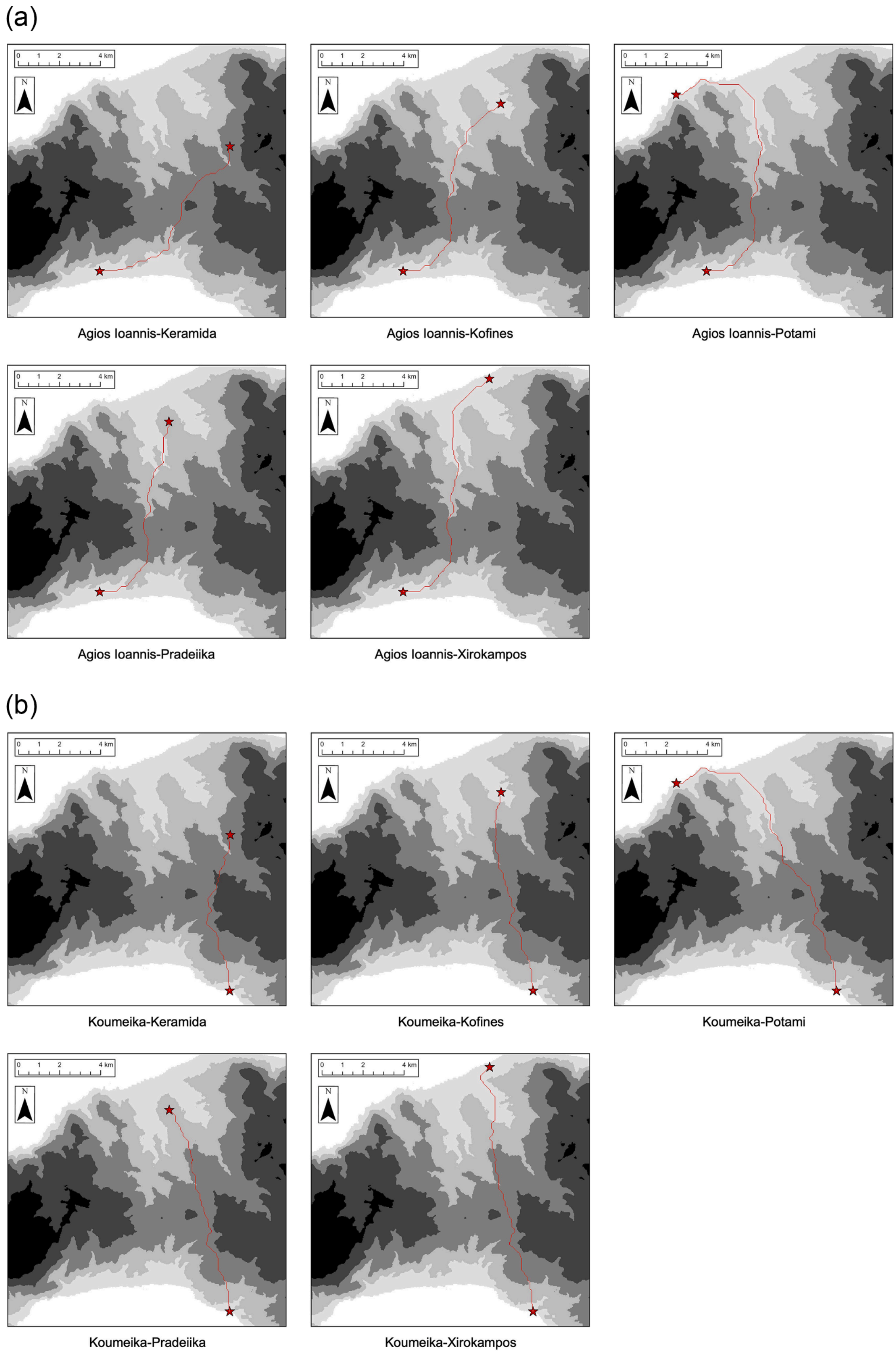

Fig. 15. Composite of least cost paths generated for going between the five sites in southwest Samos to the five sites in the northwest. Paths beginning at a) Agios Ioannis, b) Koumeiika, c) Platanos, d) Velanidia and e) wind turbines.

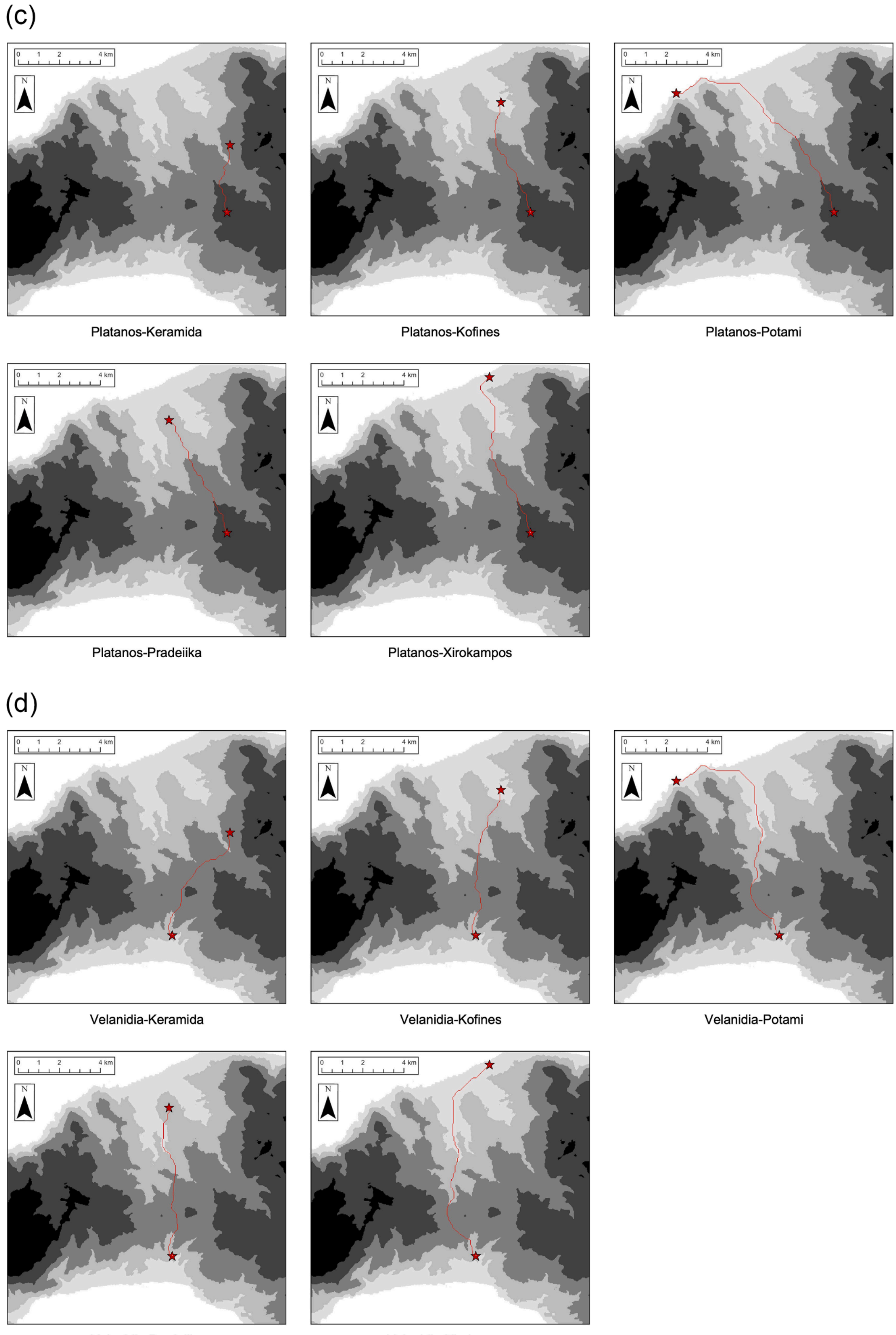

Fig. 15. (*continued*).

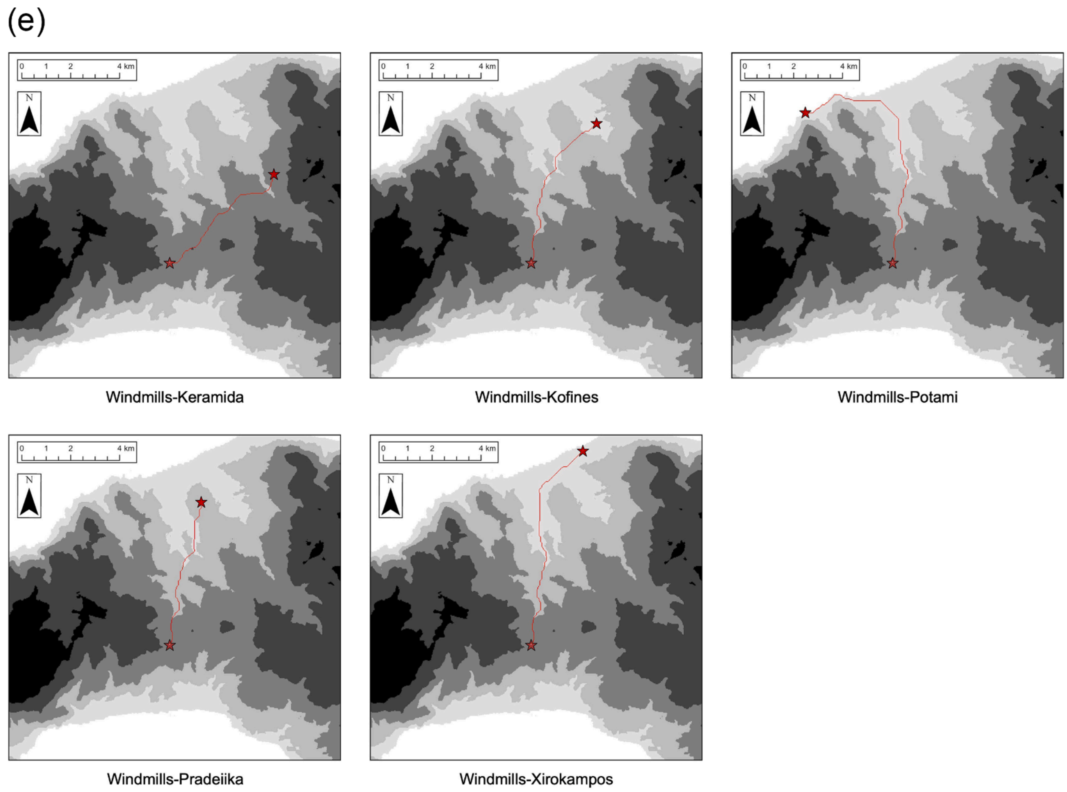

Fig. 15. (*continued*).

3.1. Accumulated cost rasters and cost paths

A Digital Elevation Model (DEM) was downloaded from the ASTGTM3 dataset.[9] Tiles N37E026 and N37E027 cover Samos to a resolution of 1 arc second, and ArcGIS Pro's 'Slope' geoprocessing tool was used under default settings on the DEM to create a slope raster measured in degrees. Slope was given by raster cells with values between 1 and 66: this raster was reclassified, with its values sorted into 10 bins (Table 5, Fig. 13). Slope value is conceptualised as the cost to movement in the present experiment.

3.1.1. Results

Five accumulated cost rasters were generated from the reclassified slope raster for the five sites of interest in the southwest study area (Fig. 14): ArcGIS Pro's Cost Distance tool was employed under its default settings, taking as input the reclassified slope raster and the point location of sites in southwest Samos, *i.e.* Koumeiika, Agios Ioannis, Velanidia, Wind Turbines and Platanos. Back link rasters were also generated for each of the five sites of interest: again, these used default settings on ArcGIS Pro's Cost Back Link tool, using the reclassified slope raster and the site points. In combination, the accumulated cost raster and back link raster for each site were used as inputs to ArcGIS Pro's Cost Distance tool under default settings: the tool was run five times per site in the south, each time using as input a different point location for a site in the north, i.e. Keramida, Kofines, Pradeiika, Potami and Xirokampos. This generated 25 cost distance rasters in total (cf. Surface-Evans 2012: 132–9) (Fig. 15). These 25 rasters were summed using ArcGIS Pro's raster calculator, producing an aggregate cell value for areas where two or more cost path rasters overlapped. The raster was converted to a polyline. The aggregate cell values were retained in transforming from raster to polyline, so that a kernel density raster could be produced, using the polyline as input with ArcGIS Pro's Kernel Density tool, under default settings. This final raster summarises the location of all computer-generated route paths between all sites of interest between southwest and northwest Samos, taking into account topography and slope only (Fig. 16).

3.1.2. Discussion

A quick visual qualitative inspection of these images reveals some initial information about the accessibility of each site. Agios Ioannis and Velanidia indicate only easy access to the Marathokampos basin, with the ridge around the wind turbines marking a transition point at which cost greatly increases. From Koumeiika there is the highest level of resistance up through the Marathokampos and Karlovasi basin of all sites investigated. As one might expect based on the omnidirectional viewshed from this site, the wind turbines offer almost even access to areas in both basins. And from Platanos, too, there is a low cost accumulated in going to either the Marathokampos or Karlvasi basin.

From Agios Ioannis, most cost paths follow around the foothills of Kerkis towards the wind turbines, but occasionally (as when going from Agios Ioannis to Keramida) the most efficient route passes by Velanidia. Similarly from Velanidia, a number of routes go up first to the wind turbines before progressing along the streams above Megalo Rema. From Koumeiika, all routes away from the site follow the same path north and only branch off into separate routes when the path was level with Platanos. From the wind turbines, apart from one path that veers east towards Keramida, the most cost efficient route is to go straight north along the Megalo Rema stream, branching out around the village of Leka towards the other sites northwards. By contrast, from Platanos unique routes fan out from the site: in general, for the sites in the southwest there are more options going north towards the east, while there are fewer good paths going north from the west side. The ubiquity of these different routes can be seen by the multiplicity of different cost path polylines fanning towards Keramida, Kofines and Pradeiika; while there are only single viable paths towards Potami (around the foothills by the

[9] The ASTER DEM was chosen to match the data source used elsewhere in the West Area of Samos Archaeological Project.

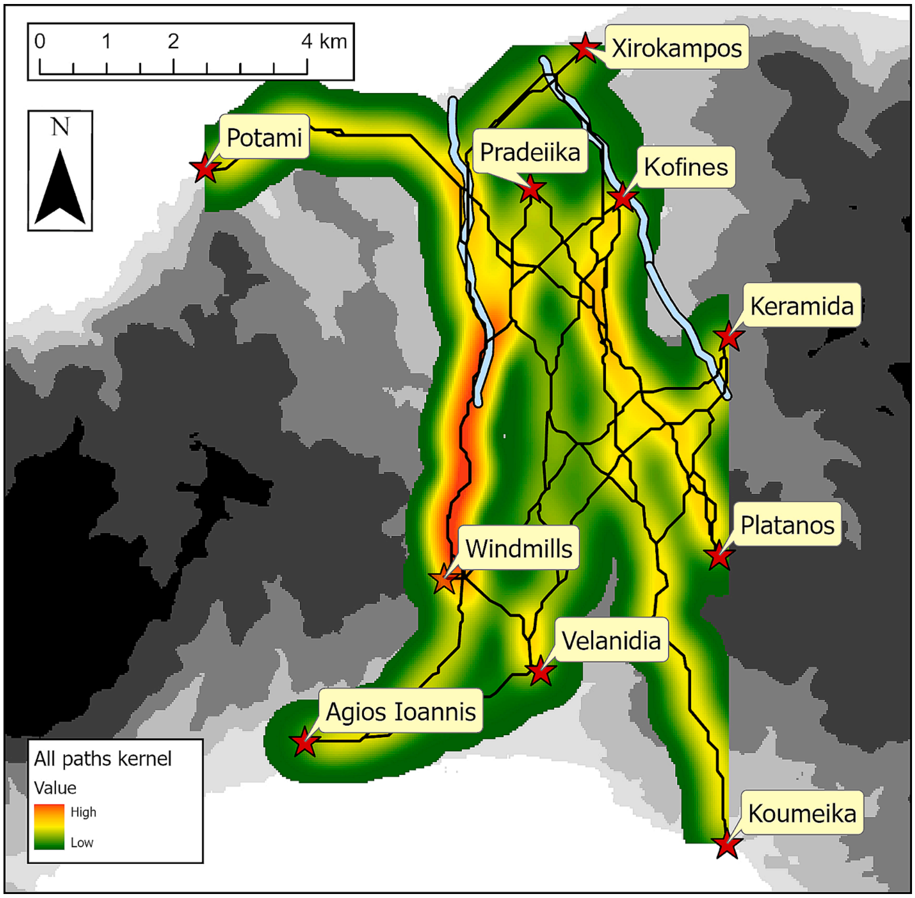

Fig. 16. Combination of all cost paths, projected onto a kernel density raster to indicate the most frequently taken routes through the landscape, according to the GIS-generated routes.

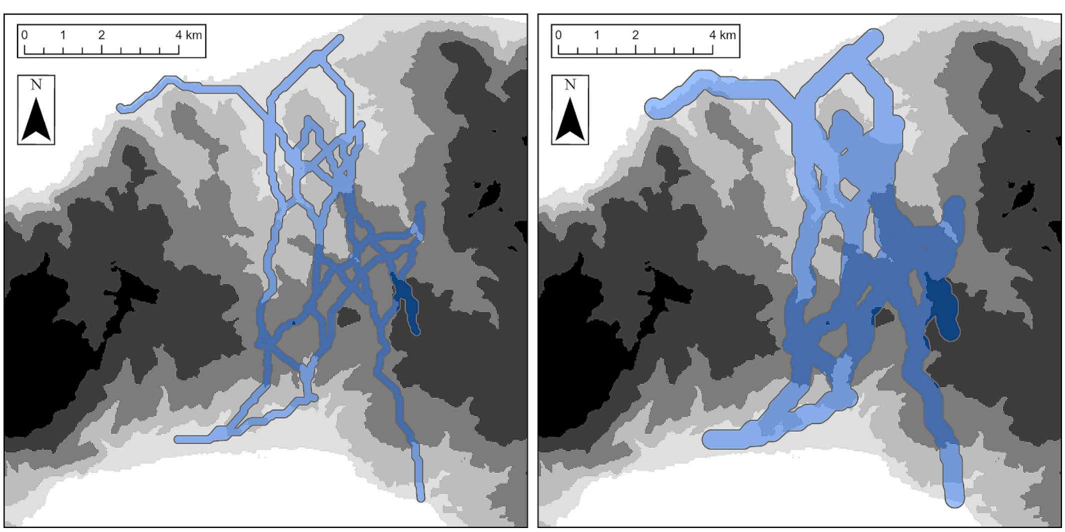

Fig. 17. Buffered catchment area around the cost path composites. Left: 100 m buffer. Right: 250 m buffer.

coast) and Xirokampos (turning straight towards the coast when reaching the north-side end of either Megalo Rema or Fourniotiko).

The kernel density raster indicates that the majority of routes between southwest and northwest Samos follow the low-lying contours of the basins, and that they narrow towards the north. There are two main 'highways' that routes tend to follow, namely that on the east roughly following the Fourniotiko, and that on the west following Megalo Rema in its lower sections. By their higher accumulation, the kernel plot indicates that the routes on the west side are more cost efficient than those on the east. Generally, the most efficient routes follow a north–south orientation and there is less crossing between these two 'highways'.

3.2. Comparison of cost paths and field data

The next step is to compare how the cost paths sit alongside other

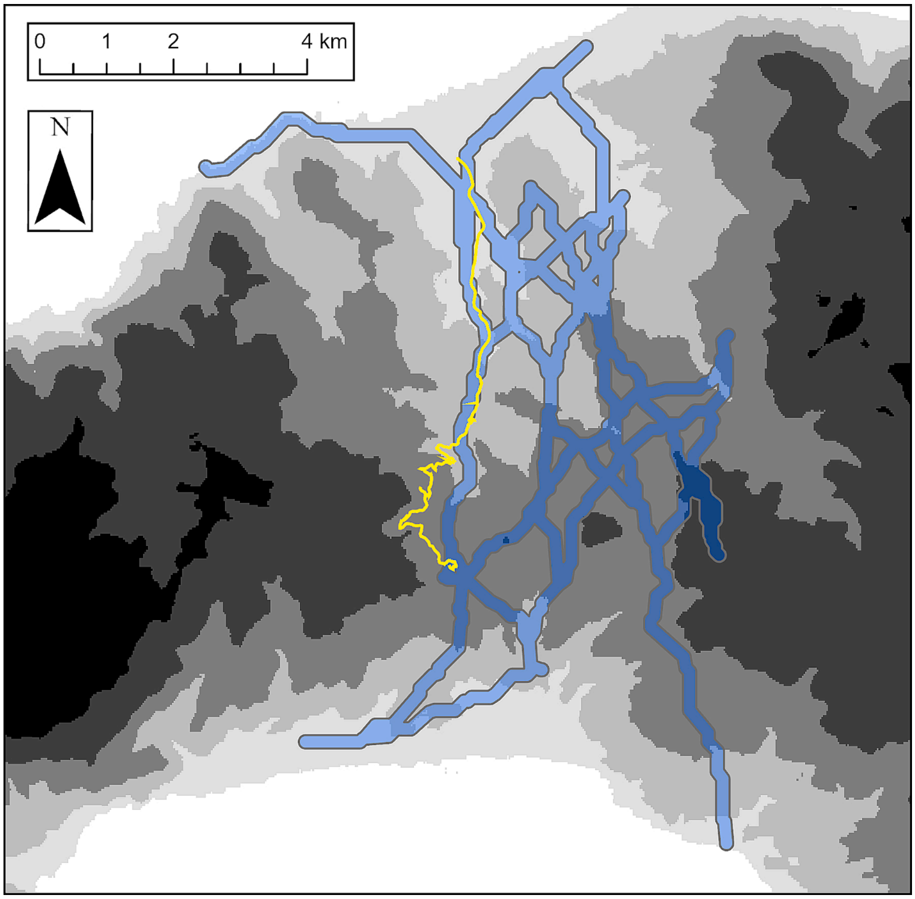

Fig. 18. Illustrative figure indicating the overlap between Hike 4 and the 100 m buffer line.

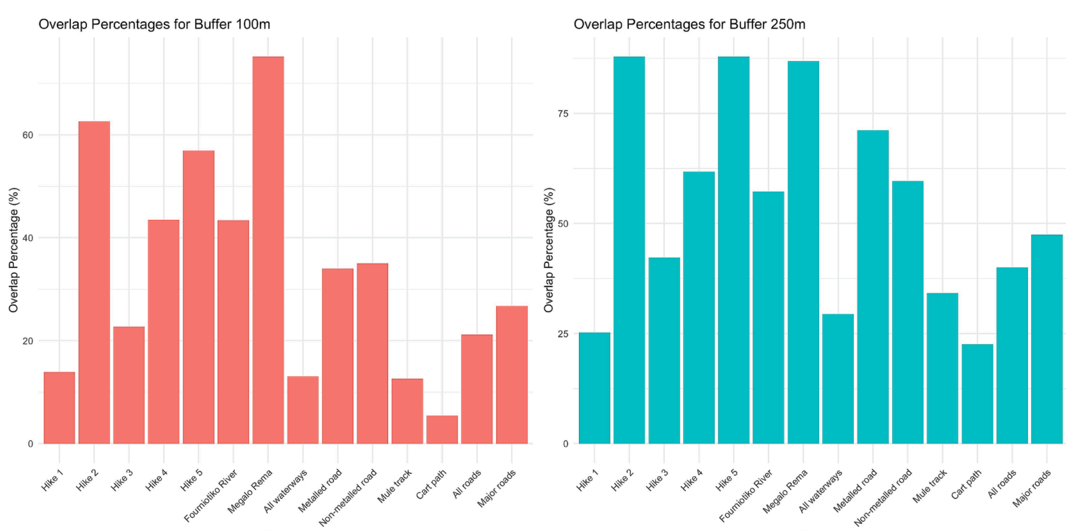

Fig. 19. Bar chart indicating the percentage overlap with each of the buffer zones of the various mapped and experimental polyline features.

known routes and features in west Samos, allowing for further insight into the specific terrain features that make certain routes more or less passable.

3.2.1. *Results*

Two buffer lines at 100 m and 250 m were drawn around the cost path aggregate (Fig. 17). Using ArcGIS Pro's Tabulate Intersection tool, a percentage overlap was calculated for each of the line buffers with: the five exploratory hiking routes, features from the 1943 British staff map, the location of rivers, and the modern-day road network (Fig. 18, Fig. 19, Table 6).

The quantitative results are presented here only as a heuristic to facilitate discussion on the relationship between computer-generated and human-navigated paths. The precise values for overlap percentage are fairly meaningless, as the cost paths and the hike routes are datasets generated at completely different resolutions. That is, the cost paths are

Table 6
Percentage overlap between buffer polygons and the various landscape features, as calculated by the Tabulate Intersection tool in ArcGIS.

	% overlap between buffer polygon and various polylines	
	100 m buffer	250 m buffer
Hike 1: Kastania – Lekka – Potami	13.89	25.21
Hike 2: Sevasteiika to Hydroussa	62.59	87.86
Hike 3: Fourniotiko	22.74	42.27
Hike 4: Megalo Rema	43.48	61.77
Hike 5: Agio Theodoroi – Konteiika – Karlovasi	56.94	87.86
Fourniotiko	43.36	57.25
Megalo Rema	75.17	86.92
All waterways, including streams	13.07	29.46
Metalled road	34.00	71.13
Non-metalled road	35.01	59.62
Mule track	12.60	34.16
Cart path	5.45	22.57
All roads	21.21	39.98
Major roads	26.73	47.49

generated from a DEM accurate only to the cell size of 0.027 km, while the GPS units attached to the hikers were accurate to 0.001 km. The computation, therefore, obscures some of the finer details of pathfinding and human ingenuity: but comparison between the two datasets still reveals qualitative patterns about the relationship between environment and navigability.

3.2.2. Discussion

The fit of the exploratory hike lines to the cost paths varied greatly (range for 100 m buffer overlap: 48.70 %; range for 250 m buffer overlap: 62.65 %). Hike 1 had a low fit (13.89 % and 25.21 %), following for the most part the 'number 5′ and 'number 3′ 'Samos hike' routes, paths that are meant to provide physical challenges for hiking tourism. Hike 4 along the Megalo Rema had better fit (43.48 % and 61.77 %) to the cost paths than Hike 3 along the Fourniotiko (22.74 % and 42.27 %), where the former followed a more clear path carved out by the river, and the latter hike had followed small winding streams in difficult terrain. For the other two routes tested the fit to cost paths was the greatest of all exploratory hikes (Hike 2: 6259 % and 87.86 %; Hike 5: 56.94 % and 87.86 %). The instruction had been given to the team on these routes not necessarily to follow built paths, but to find the most efficient route through. In both of these cases, it appears that around 60 % of the time walkers were able to determine the most cost efficient route, also indicating that such routes do not always fit built roads or river courses.

It is with no surprise that the Fourniotiko course has a reasonably low fit to the cost paths (43.46 % and 57.25 %), as its mapped course includes many small, unwalkable streams. By contrast, the fit of the Megalo Rema is extremely high (75.17 % and 86.92 %), perhaps indicating that this river has done more than its neighbour to carve out natural paths in the landscape. The fit for all mapped river courses is extremely low (12.07 % and 29.46 %), as these courses include many young streams that have barely carved the natural landscape and are unwalkable, many in steep gorges and ridges.

Turning to the results of the features traced from the 1943 British Staff map, the metalled and non-metalled roads have a fairly low fit to the 100 m cost path buffer (34.00 % and 35.01 %). These roads tend to cut across multiple cost paths: the only real fit is with the road between Platanos and Karlovasi, largely following the Platanos-Pradeiika cost path. This would suggest that the construction of the early road network on Samos did not necessarily follow existing routes. The high correlation between the early roads and the 250 m buffer (71.13 % and 59.62 %) appears to be a false positive: due to the wide area of the buffer and the criss-crossing of the road network across these zones, there is a high degree of overlap. There is a very low level of fit for the mule tracks (12.60 % and 34.16 %) and cart paths (5.45 % and 22.57 %). This is perhaps unsurprising, as many of these paths were constructed to make specific areas of the landscape more accessible. They were built to enhance connectivity between smaller settlements and are therefore located away from main roads (*e.g.* in the foothills of Kerkis, the area around Potami and Leka, and the area between Hydroussa and Xirokampos).

Table 7
Estimate of time taken to travel between various points in southwest and northwest Samos via different modes of transport, following the least cost paths.

Route		Estimate of time (hours) taken to travel between start- and end-point, taking the given mode of transport		
Start-point	End-point	Walking	Donkey travel	Cart travel
Agios Ioannis	Keramida	2.21	2.40	5.66
Agios Ioannis	Kofines	2.25	2.47	5.70
Agios Ioannis	Potami	2.86	3.21	7.18
Agios Ioannis	Pradeika	2.22	2.44	5.65
Agios Ioannis	Xirokampos	2.57	2.87	6.47
Koumeiika	Keramida	2.04	2.18	5.30
Koumeiika	Kofines	2.48	2.68	6.38
Koumeiika	Potami	3.20	3.53	8.09
Koumeiika	Pradeika	2.49	2.68	6.39
Koumeiika	Xirokampos	2.87	3.14	7.33
Platanos	Keramida	0.87	0.93	2.24
Platanos	Kofines	1.32	1.45	3.35
Platanos	Potami	2.16	2.43	5.42
Platanos	Pradeika	1.33	1.46	3.37
Platanos	Xirokampos	1.71	1.92	4.31
Velanidia	Keramida	1.49	1.59	3.86
Velanidia	Kofines	1.75	1.90	4.48
Velanidia	Potami	2.41	2.72	6.01
Velanidia	Pradeika	1.80	1.92	4.50
Velanidia	Xirokampos	2.12	2.39	5.32
Wind turbines	Keramida	1.36	1.47	3.50
Wind turbines	Kofines	1.40	1.54	3.55
Wind turbines	Potami	2.02	2.28	5.03
Wind turbines	Pradeika	1.38	1.51	3.50
Wind turbines	Xirokampos	1.73	1.95	4.33

The modern road network as a whole has a low fit to the cost paths (21.2 % and 39.98 %). Areas of the modern road network were previously served by mule tracks and cart paths, and they make more connected areas previously more difficult to reach.

3.3. Anisotropic modelling

Paths mean little by themselves: how long did it take to traverse these routes? If we consider simply moving people without the need to move resources too, walking and mounted (donkey) travel are the simplest modes of transportation to test; but, given that it has already been noted that for a number of months of the year it would have been practically impossible to circumnavigate ships around west Samos, we might also want to explore the possibility of transporting goods on carts from one side of the island to the other, too. In the pre-industrial period, 'heavy freight' (*sensu* Snodgrass 1983, cf. Bresson 2016: 84–8) transport overland was necessary by wheeled carts drawn by yokes of oxen (Raepsaet 2002: 277–9; cf. Field et al. 2019), with a technology already widely used in Greece since at least the Bronze Age (*e.g.* Cavanagh and Mee 1999, Bevan 2013). Ethnographic and experimental investigation have suggested that traction animals on either a flat or sloped road could transport c. 200–1000 kg at a time,[10] working up to eight hours per day (Brysbaert 2015, see also Raepsaet 2002: 33–4). The speed for a yoke to

[10] Such traction animals could be oxen—but oxen would be slow and fairly uneven on their feet on very steep surfaces. Mules, although expensive to breed, could draw a cart or carry a balanced load of around 100kg. Alternatively, a small train of (four) donkeys could pull a cart as effectively as two mules. Donkeys have the advantage of being able to go down narrow paths, and are cheaper to feed. I thank the anonymous reviewer for pointing out these details to me.

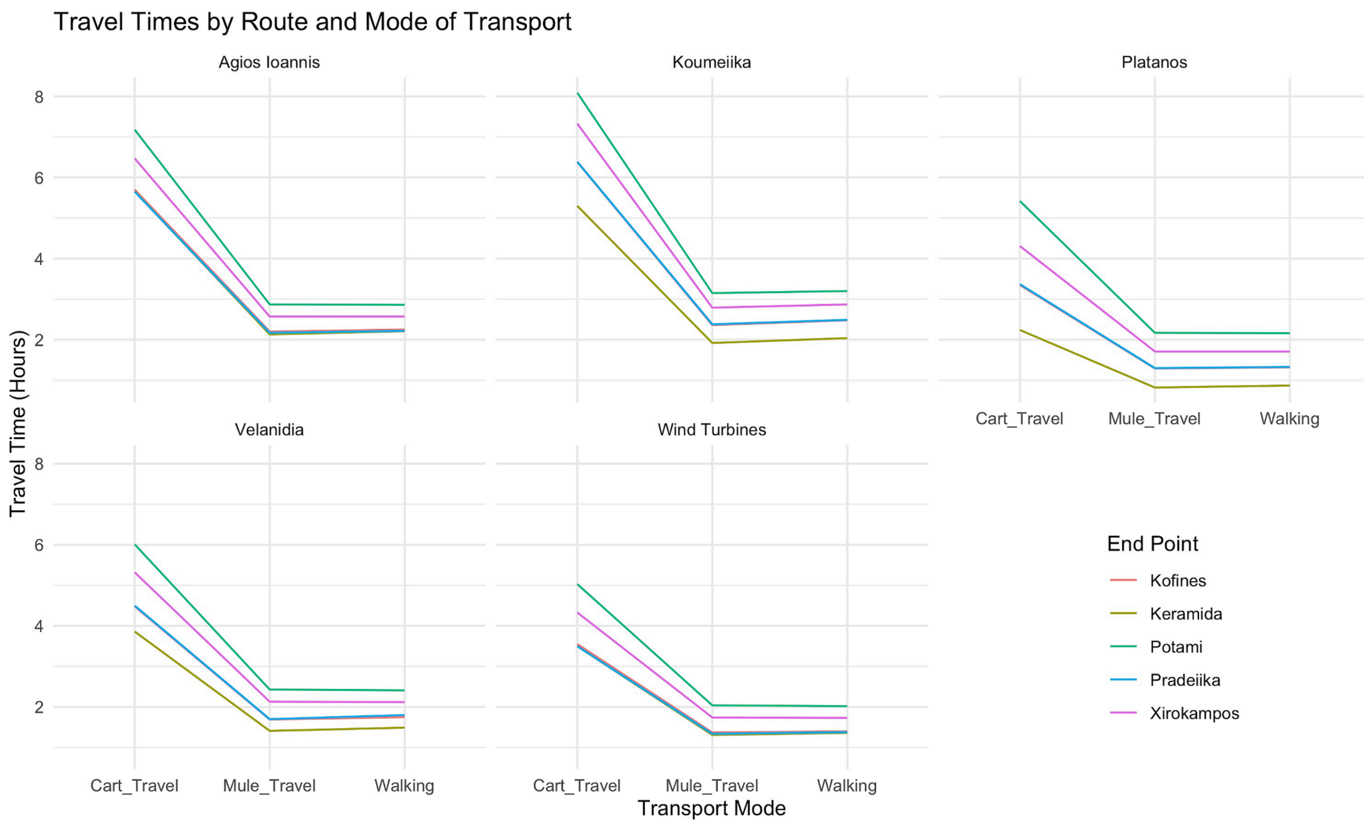

Fig. 20. Multiline diagram indicating the time taken by various travel means to reach each of the five sites in the northwest from the sites in the southwest.

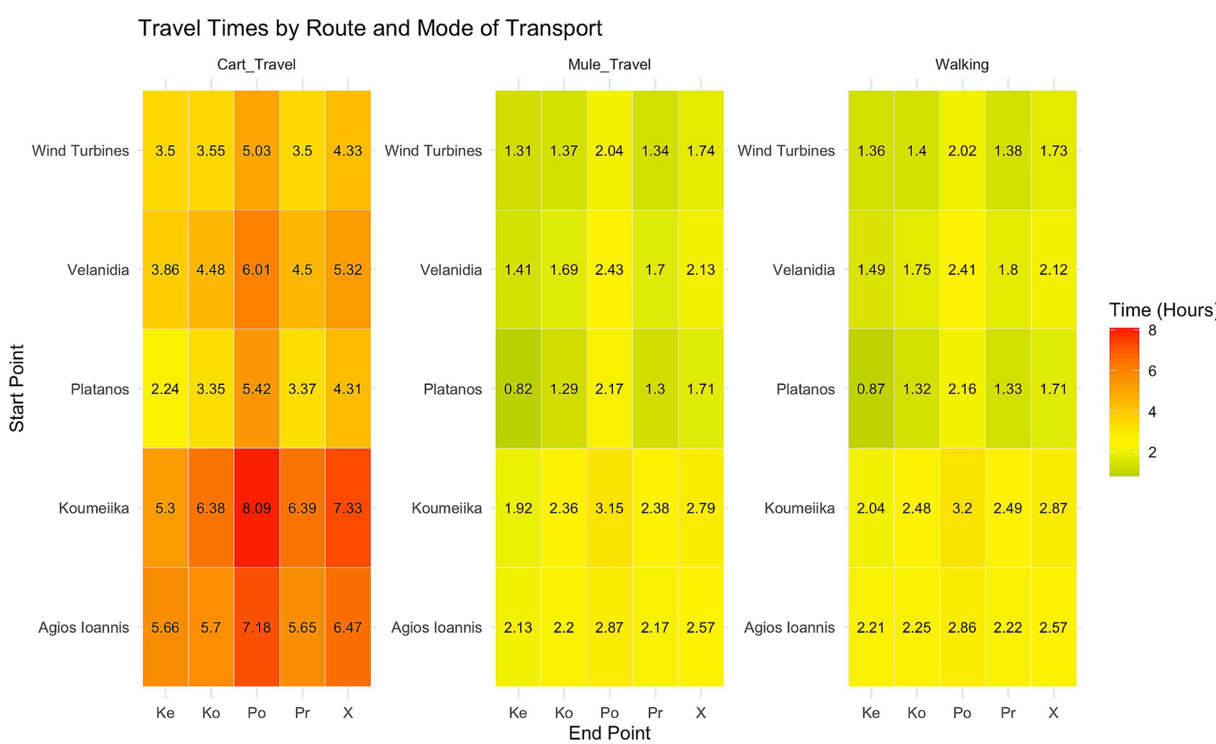

Fig. 21. Heatmap diagram indicating the time taken by various travel means to reach each of the five sites in the northwest from the sites in the southwest.

move heavy freight on a 0–5 % slope was taken as 2.5 km/hour (Delaine 1997: 108). Moving up or down slopes would take longer, with a speed of only around 0.75 km/hour possible on slopes greater than 10 % (cf. Grewe 2013: 125–7; Brysbaert 2022: 205).

Walking speed is investigated via Tobler's hiking function (Tobler 1993, cf. Wheatley and Gillings 2002, Herzog 2010), where an average pedestrian pace on flat surfaces is 6 km/h but reduced according to slope gradient:

Walking Speed (km/h) = $6 \times e^{-3.5 \times |slope|}$

For donkeys, average pace on a flat surface averages around 5 km/h, but there is less reduction in speed on slope gradient than compared to pedestrian movement. This requires some modifications to Tobler's hiking function:

Donkey Speed (km/h) = $5 \times e^{-2.7 \times |slope|}$

And for a cart loaded with heavy freight, one can expect both that the average speed is much slower (between 2 km/h and 3 km/h) and that the vehicle would be affected to an even greater extent by slope than pedestrians or donkeys. This requires further modifications to Tobler's hiking function:

Cart Speed (km/h) = $2.5 \times e^{-4.0 \times |slope|}$

3.3.1. Results

Three rasters (i.e. one each for walking speed, donkey speed and cart speed) were generated to indicate the speed estimated to progress from one cell to another based on the combination of slope and the relevant modification of Tobler's function. The raster calculator was used to compute the three formulas given above: for |slope|, the values from the slope raster generated from the DEM in section 3.1 was used, multiplied by 3.14159/180, to convert the units from arc seconds to the metric system. The resulting three new rasters can be considered 'speed rasters', where the values of the cells represent the speed in km/h for progressing from one cell to the next, given the constraints of slope. The raster calculator was used to divide each of the three 'speed rasters' by the cell size (in UTM Zone 35 N projection this was 0.027 km), to create three 'time rasters', i.e. rasters where the value represents the time taken in hours to progress from one cell to the next. Finally, statistics were calculated using ArcGIS Pro's Zonal Statistics tool under default settings for the combination of any given cost path between two chosen sites (the input raster, of which there were 25) and the newly created time raster (the input value raster, of which there were three), to give an estimate in hours for the time taken to move along that cost path. Seventy-five calculations were made, testing all 25 cost paths by each of the three modes of transport (Table 7, Fig. 20, Fig. 21).

3.3.2. Discussion

The difference between cost path time estimates for walking and donkey travel is small, with the range of difference in values being 0.35 h (21 min), and the average difference being 0.06 h (3.6 min). In all instances, donkey travel is calculated to have been marginally quicker than waking. There is a great difference predicted between walking/taking a donkey and going by cart, with the latter taking three or four times as long. In going to Pradeiika and Kofines from any start-point and by whatever means of transport, the difference in travel times is minimal (highest difference is 0.05 h, 3 min). Potami is calculated to take the longest time to reach, closely followed by Xirokampos: both sites require one to travel the furthest distance north, but to Potami there is additional slope gradient that must be traversed. Keramida is also as easy to reach from Agios Ioannis and from the wind turbines as Kofines and Pradeiika, but relatively difficult from elsewhere. In general, it can be clearly observed that topography is much more of a factor in the cost paths investigated than distance (range for walking and donkey transport is 2.66 h; range for cart travel is 5.85 h) —much to be expected this very steep and hilly landscape.

Turning to the quantitative patterns. It takes the most time to reach any destination site from Agios Ioannis and Koumeiika: paths from these areas require one to ascend the hill (towards the wind turbines) before heading down into the plain; Velanidia is already halfway up the hill and the extra distance towards the crest is negligible compared to these two other sites (for walking, only a difference of 0.13–0.41 h between scores for reaching destinations starting from Velanidia and from the wind turbines). To travel from Platanos with cart is relatively quick: to Keramida (a simple short journey mostly downhill) the time taken (2.24 h) is quicker than walking from Agios Ioannis (2.86 h) or Koumeiika (3.20 h) to Potami. For walking (and donkey travel) it appears reasonably comfortable to get from one side of the island to another and back in a day, if necessary: total walking times range between 0.87 h and 3.20 h one way, or 1.74 h and 6.40 h for a return journey. These are only calculated estimates made under ideal circumstances, *e.g.* one may have to divert or move more slowly depending on the season, on the flooding of river courses. For cart travel (particularly with factoring in loading and unloading time of the cart, which could be an extra hour each at the start and end of a journey) these calculated times are pushing into the maximum time that ethnographers estimate traction animals can pull carts per day, *i.e.* eight hours. These calculations would seem to suggest that it is a full day's job to pull a cart from the south side of the island to the north, and a return journey on the same day would not be possible.

4. General discussion

The importance of rivers in connecting the south and north of west Samos is clear: both the GIS analytical data and the exploratory hikes corroborate the information regarding rivers offered in ethnographic interviews. The Megalo Rema has proven more effective for connection than the Fourniotiko. Although numerous small waterways and streams flow into the Fourniotiko, exploratory hikes and modelling suggest these routes are impractical. The valleys are too steep and narrow for easy travel. Hiking through these areas proved challenging enough, and it does not seem reasonable to believe that donkeys or carts could have gone along these courses. It might also be suggested that these river-bound routes could only be seasonally used, based on the stories told locally about the dangerous of the fast-flowing currents. It has also been observed that some of the older roads followed the shape of the valleys carved by the water courses but were located at some distance away from the rivers. So much is necessary to avoid less stable ground (cf. Raepsaet 2002: 192–8; Younsi and Ciampi 2023, *contra* Fiz and Orengo 2008), particularly important in west Samos whose landscape is also subject to snow and meltwaters in the winter months.

It should also be noted that possibilities for landscape connection have changed drastically since the 1940s, with the development of the modern road network. There were historically fewer villages in west Samos, and only located in the most accessible areas, too; ethnographic interviews noted the difficulty in traversing the steep gradient of the 'old' road network. However, the increase in tourism of the island and changes in landscape usage have been linked to the development of the road network and, by extension, enhancements in terrestrial connectivity. Key to the development of this new network was the notion that the only safe route through the landscape is one that zigzags down steep slopes to slow the descent (cf. Llobera and Sluckin 2007). That said, even without the modern road network, experimental and analytical data have suggested that it is possible to pass from one side of the island to the other and back within a day, either on foot or by donkey.

Regarding the possibility of moving heavy loads by cart from one side of the island to another, the anisotropic analysis has suggested that this is possible within a (rather long) day. Long distance and time should not surprise us, as these are relatively short distances compared to known overland transit routes of heavy freight from the ancient world (Burford 1969: 168–75; Chiotis, Fotiadis and Tsombos 2007; Prignitz 2014; Brysbaert 2015), and, besides, possible sections of ancient road have been archaeologically attested in west Samos. This sort of movement, though, relies on good connective roads, and such roads needing to be kept dry to increase friction/traction for carts (cf. Kantner 2012) would require (annual) maintenance and would most likely need to be used in the height of the summer months (cf. Lichtenberger and Raja 2021: 16–7). That is to say, if one needed to move large volumes of goods from one part of west Samos to another, cart travel is certainly *possible* in an emergency, but not entirely *practicable* to justify an efficient or regular use of this resource (cf. de Vals and Moretti 2022).

5. Conclusions

Results suggest that, even though Samos' terrain poses challenges, it was the use of river courses in favourable seasons that made north–south connections on this island possible. This was the simplest means of connection, while the development of the sophisticated road network in recent years has allowed for an increased access to different parts of the island that were previously too steeply located. Out of season, the capillary of smaller roads was important for accessing cultivated land, and for moving agricultural goods relatively short distances, between households on a day-to-day basis. When it comes to moving large quantities of heavy goods from one side of the island to the other, circumnavigation remains the best option. That said, cart transport was certainly possible in ancient and early modern times during the winter months; but with so other many logistical factors requiring consideration, it was more likely the better to wait until the weather was more suitable to go by boat, and to prioritise maritime over terrestrial connectivity. Overall, for even a hilly and mountainous environment such as on Samos—where one might assume that sea travel provided the most direct means of getting from one part of the island to another—this paper has suggested that there were sophisticated seasonal means of circulating via land, and that terrestrial connectivity was not only possible and also of paramount importance in what appears an avowedly coastal and maritime zone.

CRediT authorship contribution statement

Michael Loy: Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

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Data availability

Survey project data is available at https://doi.org/10.5281/zenodo.14929961. Modelling data will be made available on request.

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