People, land, and sea

Changing topographies in Asia Minor and their impact on coastal communities during the Roman Empire

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PEOPLE, LAND, AND SEA: CHANGING TOPOGRAPHIES IN ASIA MINOR AND THEIR IMPACT ON COASTAL COMMUNITIES DURING THE ROMAN EMPIRE

Maria del Carmen Moreno Escobar, Stefan Feuser, Henrik Gerding

INTRODUCTION AND RESEARCH QUESTION

The last decade has witnessed the increased attention Classical Archaeology is placing upon the topics of movement and connectivity in the ancient world, especially relevant for research on ports. In this area, spatial and network perspectives are increasingly frequent, a trend of which this volume arises. As part of this trend, the present paper focuses on the development of coastal communities during the Roman Imperial period (end of 1st century BC to beginning of the 3rd century AD) in western Asia Minor, where the fundamental role of port cities between Archaic times and the Middle Ages motivated successive changes of harbor locations across time to ensure their access to the sea (e.g., Ephesus). Although Asia Minor constitutes an excellent case study for this research, thanks to the diversity of known cities and harbors in antiquity, it also poses substantial challenges related to its complex geographic and physiographic context. The combination of factors such as tectonic dynamics, eustatic sea-level changes, and erosion and sedimentation processes has deeply transformed long stretches of the Turkish coastline, resulting in the sinking of ancient infrastructure and ongoing processes of coastline progression and regression. Fortunately, a sound tradition of geoarchaeological studies has generated good coverage of these aspects, thus contributing towards the interrelated understanding of all these factors and their effect on the region.

The advances within archaeological and geoarchaeological research have resulted, nonetheless, in a certain divorce between these two research scopes, whose only partial communication might generate out-of-date interpretations about the historical development of these coastal communities. In contrast, the frequent relocations of harbors in cases such as Ephesus provide clear testimony to how topographic and environmental change affected the historical development of local communities in Asia Minor and their opportunities for connecting with others while also highlighting the fundamental role of integrating the archaeological and geoarchaeological data. With the aim of providing a more nuanced understanding of these communities' changing relationships with the sea, we seek to identify the connections these geomorphological transformations offered by placing our focus on, first, which harbors were open or closed to these communities and, second, what impact the availability of harbors had in the connectivity of the region. Such emphasis on harbors relies on their role as hubs of exchange between land and sea, a role whose exploration is key to a proper understanding of their land-based communications in a changing coastline and environment. This is carried out through a combination of spatial and network analysis, an approach that makes it possible to explicitly identify changes on (i) the distance and cost of access to the coast from these towns and harbors, (ii) the harbors open or closed to these local communities, and (iii) the differences (if any) between the connectivity networks of inland movement in each situation modeled. In doing so, we aim to explore and assess the potential effects of considering geography and its transformation in the construction of our interpretations about the past, endeavors that will hopefully result in a more holistic understanding of the interconnectedness of ancient settlements in western Asia Minor.

Methodologically, such aims imply the investigation into potential consequences of using different approximations than topographic conditions in the past when modeling movement and connectivity. Despite the uneven coverage of geoarchaeological studies across western Asia Minor, their inclusion into the present study has the potential for unlocking the impact of these topographic changes not only at local scales of analysis but in wider regional contexts. This is explicitly explored through the execution of "experiments" within a GIS-environment over two different models: Scenario A, based on modern topography, and Scenario B, which models the region's historical topography using data from geoarchaeological studies and analysis of remote sensing imagery. The importance of such explicit modeling and analysis cannot be overemphasized: while we may assume that the approach applied in Scenario B would constitute a better representation of the past and generate more "correct"/"real" results, both approaches need to be explicitly explored and compared through spatial and network analysis in order to highlight their differences and similarities. Only then, the need for fully combining and integrating geoarchaeological, topographic and archaeological considerations into the study of mobility and connectivity in antiquity can be properly addressed and qualified.

CONTEXT OF RESEARCH AND STUDY AREA

This paper takes as its study area the western coast of modern-day Turkey from the Hellespont and Troad in the north to the Carian Chersonese in the south. The regional topography is highly fractured, with a clear East-West orientation originating in local tectonics[1], making the establishment of terrestrial connections in a North-South direction difficult. The coastal topography, with its numerous peninsulas, islands and bays, however, offers abundant opportunities for shelter to maritime vessels, thus providing an alternative north-south axis of communication. Recent archaeological and geoarchaeological research has shown how this situation was further enhanced in ancient times, highlighting the proficiency of the Greek communities of Asia Minor in maritime navigation and colonization[2].

1. Marek 2010, pp. 27-33.
2. Mauro 2019; Feuser 2020; Leidwanger 2020.

In a geographical sense, the study area is characterized by folds and trenches extending to the west, which the sea penetrates to form nine large bays[3]. The maritime topography, thus, consists of a combination of offshore islands and deeply incised bays reaching between 30 and 100 km inland. The foothills of the Anatolian plateau stretch along the west coast to the sea. Several river valleys drain from the east into the Aegean Sea. These valleys provided access to the hinterland up to the Anatolian plateau, and their alluvial plains were suitable for agricultural use. Along the southwestern coast, the mountain ranges reach directly to the sea in many places resulting in rugged promontories such as the Bodrum Peninsula or the Datça Peninsula. The combination of geographic and topographic configurations together with recent research trajectories reinforces a perception of Asia Minor in ancient times as a fractured geography with several microecologies in the sense of Horden and Purcell[4].

Sedimentation processes in the main river valleys, together with tectonic dynamics and eustatic sea-level rise, drastically changed the littoral topography from the Late Bronze Age until Byzantine times. This resulted in a complex pattern of relative sea-level evolution on a local level in the late Holocene[5]. The relevance of this factor cannot be over-emphasized. For example, it holds the key to explaining the development of Miletus, an important maritime power in Archaic times with multiple harbors which are now c. 9 km away from the coast due to the sedimentation of the Maeander (**Fig. 1**)[6]. An even higher sedimentation rate and a rapid progradation of the coastline in the Hellenistic and Roman Imperial periods was caused in Ephesus by alluvium from the Kaistros, resulting in a landlocked harbor city laying more than 1 km from the sea and connected to it by a canal[7].

Archaeological research along the coast is predominantly developed at local scales of analysis, carried out by local museums, cultural institutions, and international missions. A longstanding tradition of research exists on key sites such as Ephesus[8], Miletus[9], and Pergamon[10], resulting in an extended knowledge of the urbanism and material record of these settlements. The hinterland and areas around these major cities and other smaller settlements are less well known, although recent attention to the hinterland of sites such as Pergamon over the last two decades is casting new light on broader settlement systems[11]. In contrast, studies looking at western Asia

3. Marek 2010, p. 29.
4. Horden-Purcell 2000.
5. Seeliger *et alii* 2021.
6. Brückner *et alii* 2017.
7. Stock *et alii* 2013; Stock *et alii* 2014.
8. Ladstätter 2016.
9. Niewöhner 2020.
10. Pirson 2017.
11. Ludwig *et alii* 2023.

Fig. 1. Reconstruction of the physiographic context of Miletus in the 1st century AD over Google Earth satellite image (in blue, waterbodies; in dark orange, land) (Source: M.C. Moreno Escobar, after Müllenhoff; Müllenhoff 2005, p. 214, Fig. 56).

Minor on a regional level and analyzing the archaeological record beyond single cities emerged just recently. Some relevant examples are the diachronic regional study of the maritime connectivity of the Datça Peninsula (southwest Asia Minor) by Justin Leidwanger[12], the study by Rinse Willet on the chronology and extent of urbanism in Asia Minor between the 1st and 3rd century AD[13], and Eva-Maria Mohr's analysis of burial customs in western Asia Minor during the Iron Age (9th to 6th century BC)[14].

In a political sense, this region was composed of small-scale entities (e.g., independent poleis and small Hellenistic kingdoms) in almost constant struggle, conflict, and competition from the Archaic period onward[15]. Bigger political entities such as the Achaemenid Empire in the 6th century BC or the Seleucid Empire in the

12. Leidwanger 2020.
13. Willet 2020.
14. Mohr 2015.
15. On the history of Asia Minor from the Late Bronze Age to the 3rd c. AD, see Marek 2010.

3rd century BC only unified the area partially and temporarily. With the integration into the Roman Empire in the 2nd century BC and the establishment of the *pax Romana* under Augustus, the conflicts between the cities calmed and the communities' efforts and competition transitioned into the cultural and religious sphere, giving space for economic prosperity, population growth, and the intensification of maritime traffic.

DATA SOURCES AND ARCHAEOLOGICAL ANALYSIS

Developing regional approaches in Asia Minor is not an easy objective, hindered also by the high degree of dispersion of information about the archaeology and history of these ancient communities. Important resources that facilitate regional initiatives are the Turkish bulletins of archaeological interventions, published by the Ministry of Culture and Tourism, which provide the necessary overview of archaeological research undertaken in Turkey. Furthermore, there are some collective and individual initiatives that offer enough temporal resolution to initiate regional approaches to Asia Minor for long periods of time, as in this case of the Roman Imperial period, such as:

- Pleiades Stoa[16] and the OXREP Cities database[17], informing about the higher hierarchical levels of the occupation and organization of these landscapes and territories of Asia Minor;
- The OXREP Shipwrecks Database[18], complemented with other resources to add context about maritime activities in this area[19];
- The Barrington Atlas as digitized by the Ancient World Mapping Center[20], providing additional context on the region's administrative organization and road network. Despite the usefulness of this resource, its use is problematic in part because of its idealized representation of roads, due to its small geographical scale. On certain occasions, these roads cross areas formerly occupied by bodies of water, as geoarchaeological research has shown (e.g., northern road to Ephesus).

The processing and re-evaluation of the information in these resources constituted the base dataset on which this research is built, as it is our belief that it is fundamental to (re)use this vast wealth of information, already made available to both researchers and the public, instead of (re)generating data. However, such an aim should not hide the complexities of reusing data, which is highly heterogeneous in origin, temporal and spatial resolution, and methods of research applied, to name a few factors. This heterogeneity could also lead to uneven coverages of archaeological knowledge across

16. Ancient World Mapping Center, Institute for the Study ofthe Ancient World 2006.
17. Hanson 2016.
18. Strauss 2013.
19. E.g., Parker 1992.
20. Ancient World Mapping Center 2016a; Ancient World Mapping Center 2016b.

the study area, more acute for some types of occupation like high-status settlements, farms, and undefined settlements than for higher-level settlement hierarchies (e.g., towns and sanctuaries). We addressed these shortcomings in two different phases: first, by processing the available data within a common framework and evaluating its integration into a unique relational geodatabase, a process that revealed certain divergences across the sources, particularly concerning site location; and second, by incorporating additional context and details regarding the occupation of the littoral areas using additional resources and publications (including the analysis of satellite imagery), which also solved the data conflicts detected earlier. This time-consuming process resulted in a large dataset of archaeological features represented as points across the landscape[21]. More interestingly, the integration of this data into a common framework allowed both its joint analysis under unified standards of archaeological characterization (both typological and chronological) and its qualification regarding the methodological approaches applied and the temporal resolution of the chronologies ascribed. This work, spanning several months in 2022 and 2023, resulted in an integrated dataset consisting of 711 sites, 943 structures, and

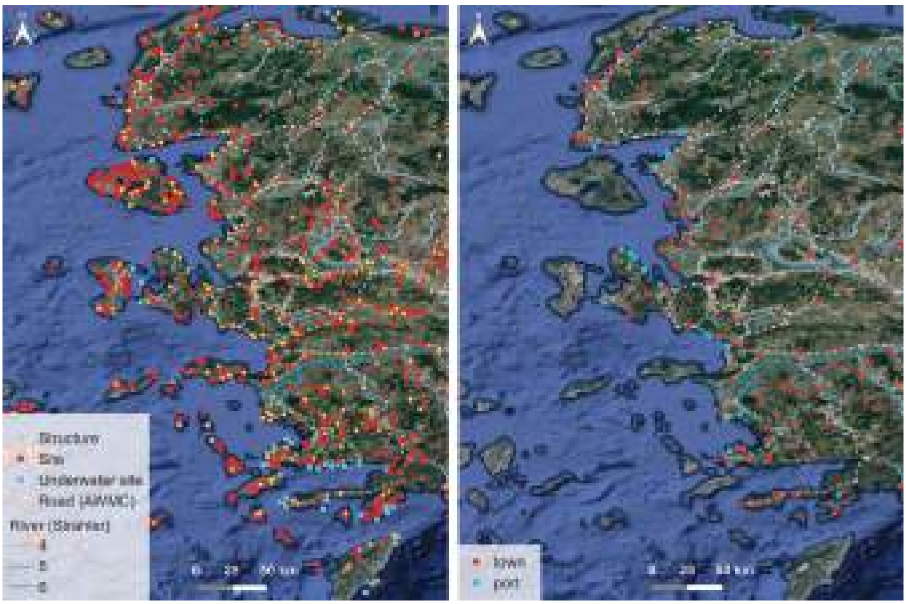

Fig. 2. Left: general distribution of sites considered (Source: M.C. Moreno Escobar, with data from the AWMC and the European Environment Agency; Ancient World Mapping Center 2016a; European Environment Agency 2020); right: distribution of towns and ports in the mainland of Asia Minor considered in this study (Source: M.C. Moreno Escobar).

21. Of importance to this study is the impact of reducing the town or harbor to a unique point in the landscape. This work considers "average" locations within the perceived spatial limits of towns and harbors, avoiding placement in particularly steep areas or very close to rivers and streams, and thus potentially generating artificially high costs or restricted ranges of movement.

77 shipwrecks (**Fig. 2, left**), in turn permitting the identification of 146 towns that were considered an appropriate representation of the higher hierarchical levels of occupation in Asia Minor in the Roman Imperial period.

Particularly important in this research is the identification and consideration of topographic variation within Asia Minor since antiquity, on the coast and inland. Change in littoral areas was primarily identified through geoarchaeological research, thanks to the multiple studies developed across the western coast of Turkey (see first section) and complemented by the analysis of remote sensing imagery and interpretation in connection with the general development of the physiography. In contrast, change inland is considered through the impact of the construction of water dams and reservoirs on the potential mobility and connectivity in this region, as modern infrastructure prevents movement across areas that were accessible in antiquity. This instance was defined through the analysis of recent cartography, especially the EU-HYDRO dataset[22], which was combined with satellite imagery that allowed us to characterize these inland water bodies as either natural lakes or artificial reservoirs.

All of this information (i.e., archaeological, geoarchaeological, physiographic) was then integrated within a Geographic Information System that made possible the visualization and integrated analysis based on the spatial relations established between the different features. Under such conditions, it was then possible to study both the physiographic transformations and their timing together with the occupation and organization of territories. This integration also resulted in the identification of a relevant sub-dataset centered in the distribution of both towns (understood as the main nodes of commercial redistribution across the region) and harbors serving as points of entry/exit of trade flows. These flows would then circulate amongst towns before their dispersion across the countryside, following the opposite direction (i.e., countryside to towns to harbors) in the case of exports of local produce.

More interestingly, the integration of time, topographic transformation, and archaeological entities in the mainland (thus, excluding islands) permitted the definition and characterization of possible harbors and land-water interfaces that were open to these communities in the Roman Imperial period but closed afterwards due to factors such as tectonic sinking, alluvial sedimentation, and coastal regression discussed earlier. This dataset consisted of a total of 95 towns and 128 elements of harbor infrastructure on the mainland, from which it was possible to identify 93 ports, attending to factors such as the immediate proximity of towns to the sea, thus assuming the existence of associated harbor areas (12 instances), as well as the identification of potential harbor infrastructure in satellite imagery (16 instances) or by previous archaeological and/or geoarchaeological research (65 instances) (**Fig. 2, right**).

22. European Environment Agency 2020.

METHODOLOGICAL APPROACH

The previous context and aims were made explicit in the present study of western Asia Minor during the Roman Imperial period, where we tested the (hypothesized) strong influence of geography in the relations established between local communities and their surroundings as well as how they used these settings to connect with others. In doing so, we also aimed to showcase possible approaches to modeling the impact of geographic change, building upon the integration of geoarchaeological, archaeological, and topographic data to enable the "quantification" of geography's impact on potential mobility and connectivity at a regional scale. For this purpose, this study develops a comparative approach of two different scenarios: Scenario A, where no topographic changes are considered; and Scenario B, where transformations in both coastal and inland areas are considered.

These two scenarios consider a range of physiographic factors, such as the region's relief, its hydrology, and the presence of inland and coastal water bodies in different ways (**Tab. 1**). However, it is important to note that these models leave aside other elements potentially affecting mobility due to either insufficient data (e.g., existence of bridges) or an inadequate spatial resolution (e.g., road network as represented in the Barrington Atlas). More importantly, the main objective of this modeling and analysis is explicitly to explore the impact of topographic change, and as such the consideration of the main factors included in Table 1 is assumed to fit this purpose. In practical terms, these factors were included in two different versions of a Digital Elevation Model (DEM), specifically the EU-DEM[23] whose 25-m resolution was considered a suitable option. Besides the lack of a digital model representing the topography of the entire region in antiquity, this DEM successfully balances the need for a proper representation of the topography and the computational requirements for the visualization and analysis that this study implements, whilst also effectively smoothing the presence of many modern elements (e.g., highways) that could alter the results of these experiments[24]. The resulting DEMs for Scenario A and Scenario B thus constituted the appropriate background over which to lay the remaining physiographic and archaeological data, allowing not only its combined visualization but (most importantly) its integrated analysis.

23. European Environment Agency 2017.

24. The use of a DEM representing the modern topography implies the initial assumption that no substantial topographic change has occurred since antiquity, a claim that should be rejected for some of the areas under study after both geoarchaeological research and the analysis of satellite imagery. For this purpose, partial modifications of this DEM were carried out to account for the changes in both coastal and inland areas (as defined in Table 1), namely by effectively preventing any land-based movement across areas formerly occupied by bodies of water.

FACTOR	DESCRIPTION	SOURCE	SCENARIO A	SCENARIO B	CONCEPTUAL IMPLEMENTATION IN SPATIAL ANALYSIS
Relief (i.e. slope)	Level of ruggedness of the landscape	Computed in ESRI ArcGIS from EU-DEM[25]	Included	Included	The higher the slope, the more difficult the movement
Hydrology	River and stream network,	EU-Hydro[26]	Included	Included, modified in Scenario B to account for historical course of rivers (when known)	The higher the hierarchy according to Strahler[27], the more difficult to cross it.
Natural waterbodies	Lakes and other natural bodies of water found inland	EU-Hydro[28] and satellite imagery	Included	Included	Considered an obstacle to terrestrial movement (i.e. very high cost)
Artificial waterbodies	Built water reservoirs and dams	EU-Hydro[29] and satellite imagery	Included, as obstacle to movement	Included, as possible to traverse	In Scenario A, obstacle to movement (i.e. very high cost); in Scenario B, possible to traverse (i.e. low cost)
Reclaimed coastal waterbodies	Areas formerly occupied by the sea, and subject to processes of coastal regression and sedimentation	Geoarchaeological studies and interpretation of satellite imagery	Not included	Included, as obstacle to terrestrial movement (i.e. by providing new limits to the study area)	In Scenario B, obstacle to movement (i.e. very high cost)
Sunk coastal land	Former land areas, currently underwater due to tectonic sinking	Geoarchaeological studies and interpretation of satellite imagery	Not included	Included	

Tab. 1. Factors considered when modeling Scenario A and Scenario B and forms of implementation in spatial analysis (Source: the authors).

25. European Environment Agency 2017.
26. European Environment Agency 2020.
27. This method starts by defining the order of all streams without any tributaries to be 1. Then, subsequent stretches of river and stream courses are re-assessed according to two possible situations: first, when two streams of the same order meet, the order of the resulting stretch increases; and second, the intersection of streams of different order will not change the order of the resulting stretch. For more information, see Strahler 1952.
28. European Environment Agency 2020.
29. European Environment Agency 2020.

This study so far has been concerned with the integrated visualization of the compiled data, but to properly characterize the impact of topographic change a more efficient approach is required to compute the actual divergence between the two scenarios. Therefore, as a second step, a quantitative approach based on the application of spatial analysis was developed to focus specifically on modeling potential movement as a means to make explicit the connections between towns and harbors in Asia Minor under the two proposed scenarios. For this purpose, we modeled the transport of heavy loads between the harbors and towns identified, following the assumption that traded goods arrived at harbors and circulated towards the towns (and vice versa) as main nodes of commercial redistribution following the most efficient paths that connected the harbors and towns in their vicinity. This analysis was performed using the module "cost connectivity" of ESRI ArcGIS Desktop (version 10.5), allowing the definition and calculation of the optimal network of least-cost paths that connect all the locations considered[31]. This particular study uses a friction map specifically created for estimating the cost as the force required to move a load of 1300 kg in an oxcart using the algorithm by G. Raepsaet[32]. This friction map included the factors mentioned earlier for Scenario A and Scenario B in different ways (**Tab. 1**) to make possible a more realistic approach to potential mobility between the towns and harbors in Asia Minor. Despite a more arduous implementation and use than other resources (e.g., ORBIS)[33], this also allowed for greater flexibility in deciding the sites and locations for consideration.

This spatial analysis was then applied individually for both Scenario A and Scenario B and resulted in the generation of two different networks comprising the most efficient paths crossing the modeled landscapes of Asia Minor that connected the neighboring towns and harbors. These modeled networks can be seen as an (ideal) approximation of the Roman road network in Asia Minor only under two conditions:

- First, assuming that all nodes were equally important as points of departure and destination, and consequently that each node primarily connects to its closest neighbors.
- Second, assuming that slope is the main factor affecting the travel cost, hence the disregard for the possible influence of pre-existing infrastructure that developed under different conditions (e.g., in an earlier phase, involving a different set of nodes).

30. Esri 2023.

31. Also called a cost-of-passage map, this is usually a raster map that computes the cost of travelling across cells. Such costs can be represented in wide range of magnitudes, such as energy expenditure and time, amongst others: see Connolly-Lake 2006, pp. 291-292.

32. $T = kP + Pi$, where k is a coefficient for the type of surface where movement develops, P is the total weight of the loaded vehicle, estimated at 1300 kg, and i is the slope (as percentage), in Raepsaet 2002, pp. 23-27.

33. Scheidel-Meeks 2012.

Regarding the first condition, we could also assume that some nodes (or edges) were more important than others. This would require another algorithm for generating the network: that is, one that favors edges between inland towns and harbors, or one that uses some form of preferential attachment. For the second condition, one alternative would be to simulate the formation process of the road network over an extend period, an undertaking involving several additional challenges. For this investigation, however, the predictive strength of the model is less important, since we are mainly interested in the potential significance of considering the physiographic transformations of the coastal landscape, that is, the difference between our two scenarios. The impact of this particular factor is likely to show, regardless of which of these assumptions we make. In any case, the visual inspection and comparison of the resulting networks through spatial analysis provided insights and interpretations towards the evaluation of the effects of considering topographic changes when interpreting the connectivity of Asia Minor.

ANALYSIS AND DISCUSSION OF RESULTS

The comparison between the topographic models generated for the mainland of Asia Minor under Scenario A and Scenario B and the compiled dataset of towns and harbors began to reveal the impact of topographic change (**Fig. 3**): whilst for Scenario A, 95 towns and 83 harbors were located within the limits of the study area, for Scenario B there were 94 towns and 92 harbors. This disparity was expected

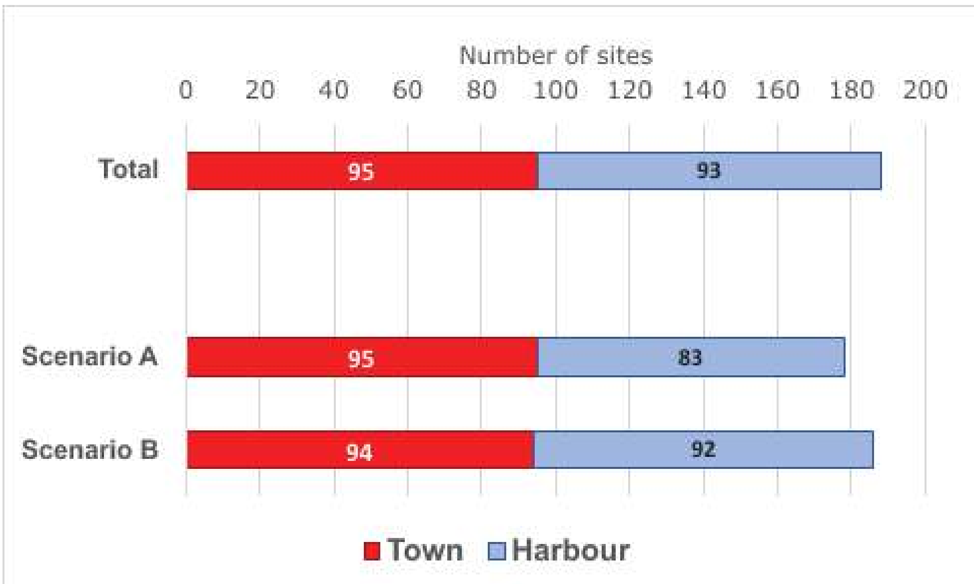

Fig. 3. Number of towns and harbors considered in this study (up), and the distinction between Scenario A and Scenario B (down) (Source: M.C. Moreno Escobar).

due to the change of topographic conditions, resulting in the changing roles played by certain harbors, as some were active in antiquity but not in modern times due to sedimentation and infill processes (e.g., Lion harbor in Miletus, Imperial harbor in Ephesus). Regarding towns, the difference between both scenarios is specifically associated to the case of Leukai, currently connected to the mainland but located on an archipelago in antiquity.

Then, the cost connectivity analysis was applied using the resulting datasets for Scenario A and Scenario B, analyses that considered proximity between the nodes as a factor to compute the links between them and not any potential hierarchy between them. This generated two different networks for Scenario A (**Fig. 4, left**) and Scenario B (**Fig. 4, center**), with a total length of 9403 km and 9294 km, respectively, and a total cost of movement across these networks of 14,246 million Newtons and 14,059 million Newtons, respectively. Despite the difference between both, their relative comparison through the calculation of the cost of movement per km shows the Scenario B network (1512700 N/km) to be only slightly more efficient than the Scenario A network (1514988 N/km), a difference of only 0.15%. Focusing on their geographical distribution, a high degree of overlap is evident between them: 83.60% of the Scenario A network falls within 100 m of the Scenario B network, and 84.95% of the Scenario B network falls within the same distance of the Scenario A network, increasing to 88.57% and 90.10% respectively at 500 m.

Despite this high level of overlap, it is the difference between the networks that more clearly reflects the impact of the variability of conditions for movement. Some areas were expected to show differences between Scenarios A and B, such as around Miletus and Ephesus, where geoarchaeological research has shown that deep changes occurred in these areas over the last 3000 years. Similarly, the change of context of Leukai, which in antiquity was not joined to the mainland as it is now

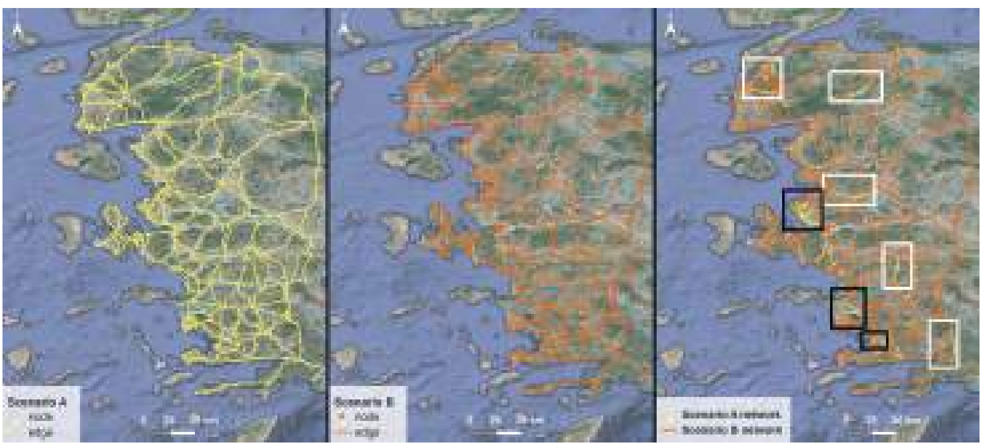

Fig. 4. Resulting networks for Scenario A (left) and Scenario B (center) and comparison between them (right) (Source: M.C. Moreno Escobar).

(**Fig. 4, right, in black**), could also be taken as a decisive factor that could potentially affect connectivity within its surrounding region. More strikingly, this modeling also exposes the changes in the patterns of mobility introduced by the construction of modern water infrastructure, which effectively canceled more efficient pathways between ancient towns (**Fig. 4 right, in white**). We limit our analysis here to the differences between networks in three specific regions of Asia Minor —the Troad, and the areas around Pergamon and Ephesus-Miletus (**Fig. 5**)—as they provide a more complex combination of factors for exploring the potential effects of geography and its transformation in our interpretations of the past.

Fig. 5. Comparison between the networks in Scenario A and Scenario B in the Troad (left), around Pergamon (center), and around Ephesus-Miletus (right) (Source: M.C. Moreno Escobar).

Focusing first on the Troad, the networks generated for Scenario A and Scenario B present some differences, observable not as much in their total lengths (1062 km and 1075 km, respectively) as in their geographical distribution (**Fig. 5, left**), which shows an extensive overlap between the networks that progressively increases at longer distances. While 81.72% of the Scenario A network falls within 100 m of the Scenario B network and 79.81% of the Scenario B network falls within 100 m of the Scenario A network, the overlap at 500 m increases to 85.73% and 83.38% respectively. Interestingly, the levels of overlap calculated for the specific case of the Troad are generally lower than those calculated for the entire area, a fact interpreted as evidence of the higher impact of the transformation of geography in this region.

Attending to the specific differences between both networks, we can observe how considering topographic change generates alternative connections between Achilleion and Alexandria (more inland in Scenario B) and Ilium and Gergis, and partially divergent courses between Arisbe and Kenchreai (longer but more efficient in Scenario B), Dardanium and Kenchreai, and Gergis and Kenchreai (longer and more efficient in Scenario B in both cases). More interestingly, the direct connections between Abydus and Kenchreai, as well as Arisbe and Gergis established in Scenario B do not exist in Scenario A as both are cut by the construction of a modern water reservoir. Nor does the connection exist between Gengis and Astyra, as established in Scenario B but made indirectly in Scenario A through Chryse. However, despite the relative proximity between Dardanium and Arisbe, no link is established between them in Scenario B, as their connection is made indirectly through Abydus. Despite these local differences, the level of connection amongst towns and harbors remains generally quite similar between scenarios, with exceptions in the cases of towns such as Kenchreai and Gergis, whose connections with other nodes (known as the degree of the node in network analysis)[34] decrease in number from Scenario B to Scenario A (Gergis: degree 9 to 8, Kenchreai: degree 5 to 4) when topographic change is considered.

Moving our focus to the region around Pergamon, the visual inspection of the resulting networks offers quite striking differences (**Fig. 5, center**), motivated in part by the change of situation of Leukai from an inland town (Scenario A) to an island not connected to the network on the mainland (Scenario B). This change has a decisive impact on the total length of the Scenario B network (1484 km), as many connections are removed when compared with the network of Scenario A (1863 km). The quantification of the overlap between them supports this interpretation, as 78.83% of the Scenario A network falls within 100 m of the Scenario B network and 83.62% of the Scenario B network falls within 100 m of the Scenario A network, increasing the overlap to 85.32% and 90.70%, respectively, at 500 m. In this sense, the differences in the percentages of overlap between both networks (regardless of the distance considered) is set around 5%, higher than any of the situations discussed so far (i.e., 1-2% for the entire region, c. 2% for the Troad), thus highlighting the substantial change introduced by considering the topographic position of Leukai.

This change had other effects at more local scales of analysis, such as the level of connectivity of the ancient town at Buruncuk, slightly higher in Scenario B than Scenario A (degree 8 and 7, respectively). Another difference between both networks is presented in the connection between the towns of Aegae and Hermokapeleia. While the path calculated for Scenario A is substantially shorter than that of Scenario B (53 km and 63 km, respectively, a 16% difference), Scenario B presents a more efficient course than Scenario A (88537560 N and 88736272 N, respectively), made more evident when the cost per km is calculated (1397925 N/km and 1678894 N/km, respectively). Interestingly, this divergence arises from the construction of a water reservoir in the vicinity of Aegae, highlighting the impact of topographic change in estimating potential mobility and connectivity. This situation is again clearly shown in the connections between Aegae and Buruncuk, where the course in Scenario A avoids a modern water reservoir, reducing its length (28 km) at the

34. Brughmans-Peeples 2023, pp. 107-109.

expense of increasing its cumulative cost (43848728 N), whereas the path in Scenario B crosses the valley where this reservoir is built, generating a slightly longer course (1% longer) but a more cost-efficient one (42186284 N, i.e. 3.94% less compared to Scenario A). Finally, it is interesting to note that the connections of Pergamon with its surroundings do not change significantly, which could be linked to its persistence as one of the main urban centers in the region.

Finally, the region around both Ephesus and Miletus presents interesting situations and differences between scenarios (**Fig. 5, right**). Again, these are identified in the different lengths of networks, with Scenario A producing a substantially longer network (1312 km) than Scenario B (1084 km), computed as a 21% difference. Looking at the level of overlap, we can observe percentages that are the lowest of all the regions explored: 74.10% of the Scenario A network falls within 100 m of the Scenario B network and (conversely) 75.89% of the Scenario B network falls within 100 m of the Scenario A network, increasing the overlap to 79.47% and 81.24%, respectively, at 500 m. Although many of these differences have their roots in the transformations that occurred in the river valleys where Ephesus and Miletus are located, it is worth exploring them individually to cast light on other factors.

Focusing on the region around Ephesus, we can observe how the infill of the marine estuary where this town developed permits the establishment of direct connections between Ephesus and several potential harbors nearby (e.g., Colofon) in Scenario A, whereas the reconstructed topography of Scenario B draws alternative courses surrounding this basin, both substantially longer (27%) and less efficient (41.57% increased cost). Changes also occur in the connection between Metropolis and Colophon, where Scenario A makes use of a currently infilled river valley, whereas Scenario B generates an alternative course (shorter but less efficient) crossing an inner valley to the east instead. Similar transformations also occur between Colofon and some potential harbors to its west, with shorter and more efficient courses developing closer to the coast in Scenario A than in Scenario B.

The case of Miletus (**Fig. 5, right**) presents striking similarities with Ephesus, where Scenario A allows its direct connection with Heraclea which is not possible in Scenario B because of the expanse of water between this town and Priene, creating an alternative course (both longer and less efficient) along the southern edge of the Latmos lake. The same situation develops in the case of the connections between Priene and Heraclea. Additional, but more limited, differences between Scenario A and Scenario B are also shown in the connections between Priene and Magnesia, Priene and Amyzon, Ephesus and Metropolis, and Metropolis and Larisa, with minor changes in the length of the courses between both scenarios and generally similar or more efficient courses in Scenario B. Changes are also identified on the fringes of the area under study, as the modeled connections between Metropolis and Lebedus (in the north) and between Iasus and its neighbors (in the south): in the first case, Scenario B generates a course connecting Metropolis and Lebedus that crosses a river valley occupied by a water reservoir in Scenario A, whose avoidance in this case gives way to an alternative course that is both longer and less efficient. In contrast, the connections established between Iasus and Euromus, Mylasa and Bargylia under Scenario B are all longer and less efficient than in Scenario A due to the sedimentation of the river basin to the east, a natural process that made it possible to cross this area formerly occupied by water.

Some final thoughts must be also expressed about the spatial relationships between the modeled networks and the roads represented in the Barrington Atlas. Their comparison through means of spatial analysis shows a generally low degree of correlation, quantified at 500 m as 14.54% for Scenario A and 15.20% for Scenario B, overlap that increases to 26.95% and 27.96%, respectively, at a longer distance of 1000 m. Such differences might be partially attributed to the difference in geographical scales applied in either dataset, since the roads digitized from Barrington Atlas are represented at a 1:1.000.000 scale and the networks generated in the previous experiments are built upon a topographic model of the area at a much more detailed resolution (i.e., 25 m). However, we find a more relevant factor in the rationale behind the representation and creation of all three networks: whilst the networks developed from Scenarios A and B assume that establishing the most efficient courses between towns and harbors in their immediate surroundings is crucial for the connectivity network in the region, the roads in the Barrington Atlas (synthetizing many previous hypotheses and research) are based on fragmented data that likely favors major (regional) routes, which do not represent a complete communication network[35]. Furthermore, their somewhat idealized courses are also affected by the small scale of their representation, courses that could be further informed by both the recent geoarchaeological research and the interpretation and analysis of remote sensing imagery in this area.

CONCLUSIONS

This paper has focused on exploring how our perceptions of the mobility and connectivity between ancient communities are shaped by our knowledge and explicit consideration of the transformation of littoral and terrestrial landscapes across time. Taking as a case study the region of western Asia Minor in the Roman Imperial period, a land filled with a dense urban network and a coast dotted by numerous harbors that allowed their inhabitants to establish connections from local to supra-regional, we have focused first on the notable changes to these topographies since antiquity, as detected mainly by geoarchaeological research and (to a lesser extent) satellite imagery. Then, we proceeded to integrate this information into our current knowledge of the occupation of this region, making it possible to start identifying divergences within our potential perceptions of the characteristics and the development of mobility and connectivity. In this sense, by explicitly incorporating this data into topographic models and running experiments using spatial analysis,

35. E.g., Magie 1950; Marchese 1986.

it was possible to generate two different connectivity networks built upon different assumptions, one based on modern topography (Scenario A) and another based on a "reconstructed" historical topography that considers the transformation of landscapes (Scenario B). Further exploration of these two scenarios by means of spatial analysis made it possible to explicitly compare their resulting networks, thus allowing us to explore and assess the impact of topographic change on our perceptions of the past.

This paper has been focused on the characteristics of terrestrial mobility and the potential opened by harbor sites for improving the connectivity of towns in Asia Minor. This was based on what we consider as the fundamental role that ports and harbors played at a regional level, namely as entry/exit points for the production and commercial activities of the communities inhabiting Asia Minor in the Roman Imperial period. Resulting from this work, the impact of topographic change (both in coastal and inland areas) has been not only demonstrated, but also explicitly compared and quantified. More interestingly, it has allowed the identification of harbors active in antiquity and later made obsolete by physiographic processes, thus highlighting important elements of transformation in the territorial organization of this region. This approach has also allowed the modeling of potential routes of transport and communication that incorporate these transformations. In doing so, this work has revealed how the topographic changes developing in western Asia Minor since antiquity have affected general terrestrial connectivity, explored in more depth for the Troad and the areas around Pergamon, Ephesus, and Miletus, generating networks between towns and harbors that are generally less efficient for the transport of heavy goods. Further work will incorporate other aspects into our modeling of potential mobility and connectivity in western Asia Minor, particularly those related to maritime connectivity (both successful and unsuccessful, as represented by shipwreck data), the role played by rivers as bidirectional transport axes (thus extending the maritime/fluvial scope further inland) and by bays and estuaries (e.g., in the context of Miletus), across which multidirectional movement and transport was possible between the different harbors and coastal settlements. In doing so, we aim to continue exploring the complexities of movement and connectivity and the role ancient local communities played in making these connections possible.

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