3. GIS methods for analysing mobility, transport and road systems

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GIS began to spread among engineers and land managers in the 1960s and was immediately adopted by geographers,[1] who realized that it could be a tool with great potential for regional planning and land management. It became widely used among geographers in the 1970s and both the theoretical approach of geographers and the use of this tool in geography strongly influenced archaeologists, when GIS began to widespread in archaeology in the late 1970s. Since its origins, the theoretical assumptions underlying GIS applications have been strongly influenced by the concept of the relationship between human communities and the environment, so different theoretical points of view have influenced GIS analysis in archaeology in these decades.

However, there is still a traditional indifference towards theoretical archaeology in classical Mediterranean archaeology, both Italian and European, with the exception of Great Britain and the Netherlands, where the Theoretical Archaeological Group, which has periodically held annual conferences (the 44th in 2023) and the TRAC (Theoretical Roman Archaeology Conference, the 32nd conference in 2024) have been very active in recent decades. The Nordic TAG operates in the Nordic countries (15 meetings since 1985). It describes its mission on its website as follows: "The aim was to promote a common debate and discussion of issues in theoretical archaeology in the Nordic countries, particularly among young researchers in archaeology" (Anna Severine Beck). The reference to young researchers in this statement is essential to address a need we know well: to make archaeologists understand that GIS is not a simple analytical tool, but, like any technology, it is not neutral, and must be used with awareness of the theoretical assumptions underlying its use.

In Italy, archaeological GIS began to be employed in ancient topography in the second half of the 1980s, through the collaboration between the Institute of Ancient Topography of the University of Rome La Sapienza (P. Sommella) and ENI (Ente Nazionale Idrocarburi), the national oil company of Italy. The series "Ancient Cities in Italy" published the results of urban archaeology programs in

* This paper will have a little didactic slant, because it is also aimed at the students of the double-degree Göttingen-Palermo.

1 R.F. Tomlinson, A geographic information system for regional planning, in: Land Evaluation, G.A. Stewart (ed.) (Melbourne 1968) 200–210. https://doi.org/10.1017/S0016 75680 00589 69.

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seven cities,[2] all with continuity of life, and this example was soon followed by other universities (we also in Palermo, with our book on Termini Imerese).[3]

In all these works, GIS is used essentially in two ways:

1) for the production of computerized cartography, which can be implemented over time and interfaced with historical cartography;

2) for data management, since the cartography is combined with an alphanumeric database, which can be queried starting from the cartography.

The main use of these capabilities was the production of historical cartography, in particular archaeological maps and phase maps in surface archaeology research[4]. It is clear that, in this approach, GIS is considered a technical tool that facilitates data management, especially if these are in considerable quantity, as in archaeological survey, where the intensive and systematic research methodology produced the discovery of dozens and dozens of archaeological sites and scatter areas. Phase maps have been considered a useful tool for historical analysis of settlement and population, despite the wide time span that each map covers, due to our limitations in dating archaeological finds, maps also conditioned by the current periodization of ancient history.

Only in the second half of the 1990s, at least in Italy, did the potential of GIS begin to be explored to understand landscape dynamics, using the three classic spatial analyses: site location analysis (i.e. the analysis of the preferential choices for locating a settlement), movement and transport modelling and visibility analysis. These analyses were strongly influenced by the site catchment analysis of Vita Finzi and Higgs,[5] while the relationship between settlement and land-

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2 https://www.lerma.it/catalogo/collana/29

3 O. Belvedere – A. Burgio – R. Macaluso – M.S. Rizzo, Termini Imerese. Ricerche di topografia e archeologia urbana (Palermo 1993).

4 M. Gillings – P. Hacıgüzeller – G. Lock, On maps and mapping, in: Re-Mapping Archaeology. Critical Perspectives, Alternative Mappings, M. Gillings – P. Hacıgüzeller – G. Lock (eds.) (London 2019) esp. 1–3; M. Gillings – P. Hacıgüzeller – G. Lock, Archaeology and Spatial Analysis, in: Archaeological Spatial Analysis: A Methodological Guide, M. Gillings – P. Hacıgüzeller – G. Lock (eds.) (London 2020) 11, on archaeological mapping and GIS. See also P. Hacıgüzeller, Archaeological (Digital) Maps as Performances: Towards Alternative Mappings, Norwegian Archaeological Review 2017, 1–2. DOI: 10.1080/00293652.2017.1393456.

5 Ph. Verhagen, Spatial Analysis in Archaeology: Moving into New Territories, in: Digital Geoarchaeology, Natural Science in Archaeology (C. Siart et al. eds.) (Cham 2018) 13. DOI 10.1007/978-3-319-25316-9_2.

scape was analysed by LCP, as well as the potential range of action of the members of a community.

In Italy, but not only in Italy, GIS-based spatial analysis was considered a neutral methodology, an analytical tool, without a clear perception that at the basis of a method there is always a theory, and that the use of an analytical tool such as GIS, is always conditioned by our assumptions. For example, perhaps few of us are aware that the historical cartography of African countries must be "decolonized", because "*these tools, in the ways in which they turn Indigenous knowledge into computer-processed data, repeat the work of the colonial state*".[6] I do not know how much this assertion is correct, but it is a good example of the need to be aware of the assumptions that condition our GIS analysis. Therefore, it is not surprising that a strong absence of theoretical awareness was found in a recent review of 571 publications[7] and a very recent review of 21,227 publications from 1982 to 2022.[8] It was understood that spatial analysis was conditioned by a positivist and therefore deterministic vision of the relationship between human communities and the environment, but it was thought that it could be corrected by the predominant view of archaeology as a historical science.

In 2015 I wrote: "*In my opinion the full potential of GIS as a system of data analysis, rather than data management, have not yet exploited. The cost-surface or visibility and inter-visibility analyses are quite repetitive, often (not always) lead to obvious or trivial results. We have to record some disappointment. This also explains why the social archaeology of landscapes aroused so little echo in Italy. The real perception of the landscape by human communities remains difficult to reconstruct, using archaeological data only. Often analysis has been limited to the usual recurrent landscapes: settlement, sacred, ethnic landscapes, landscape of security and landscape of memory*".[9] This is a problem, which not only concerns GIS applications, but still today other applications in archaeology, such as RSBD (Remote Sensed Big Data) analytics.[10]

6 M. Unangst, (De)Colonial historical geography and historical GIS, Journal of Historical Geography 79, 2023, abstract and 76–77.

7 F. Menéndez-Marsh – M. Al-Rawi – J. Fonte et al., Geographic Information Systems in Archaeology: A Systematic Review, Journal of Computer Applications in Archaeology 6,1, 2023, 40–50. https://doi.org/10.5334/jcaa.104

8 I.I. Ullah – Z. Clow – J. Meling, Paradigm or Practice? Situating GIS in Contemporary Archaeological Method and Theory, Journal of Archaeological Method and Theory 31, 2024, 1185–1231. https://doi.org/10.1007/s10816-023-09638-1

9 O, Belvedere, Archaeological Survey in Italy between Ancient Topography and Landscape Archaeology, in: Survey-Archäologie in Italien und Deutschland/La Ricognizione Archeologica in Italia e Germania, J. Bergemann – O. Belvedere (eds.) (Rahden 2017) 26.

10 K.E. Herndon – R. Griffin – W. Schroder et al., Google Earth Engine for archaeologists: An updated look at the progress and promise of remotely sensed big data, JASc: Reports 50, 2023, 104094.

In fact, we must be aware that "*We cannot expect a method or technique to operate in a theory-neutral environment; our choice of research questions, study regions, methods and data sets is governed by what we think we know about the past and by what we think we need to do to expand our knowledge*".[11]

We must, therefore, be aware of the need to include not only environmental, but socio-cultural elements in archaeological GIS, using specific techniques, such as SNA (Social Network Analysis)[12] and ABM[13] (Agent-Based Modelling) useful to study the impact of environmental and social factors on settlement and landscape systems;[14] be aware of the difference between "representational" and "non-representational" views, according to the distinction of Hacıgüzeller,[15] who distinguishes between two views of understanding the past. In the first view, the past is supposed to have an objective reality; in the second, the past is not seen as static, but dynamic, so we have to build a dynamic narrative of this changing past in our reconstructions.[16] These approaches are specific to CST (Complex System Theory) and aim to "capture" complexity and overcome the "false dichotomy" between processual and post-processual archaeology.[17]

We can now move on to the topic of our seminar: ancient road systems or more generally movement and transport systems.

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11 Ph. Verhagen, Spatial Analysis in Archaeology: Moving into New Territories, in: Digital Geoarchaeology, Natural Science in Archaeology, C. Siart et al. (eds.) (Cham 2018) 14. DOI 10.1007/978-3-319-25316-9_2.

12 M.A. Peeples, Finding a place for networks in archaeology, Journal of Archaeological Research 27, 2019, 451–499. https:// doi. org/ 10. 1007/ s10814- 019- 09127-8; T. Brughmans, – M.A. Peeples, Network Science in Archaeology (Cambridge 2023); The Oxford Handbook of Archaeological Network Research, T. Brughmans – B.J. Mills – J. Munson – M.A. Peeples (eds.) (Oxford 2023).

13 F. Bertoncello – M-J. Ouriachi – C. da Costa Pereira et al., Modelling complex systems in Archaeology: general issues and first insights from the ModelAnSet project, in: Proceedings of the Complex Systems Academy of Excellence (Nice 2018) 145–154. hal-02014645; I. Romanowska – C.D. Wren – S.A. Crabtree, Agent-Based Modeling for Archaeology: Simulating the Complexity of Societies (Santa Fe 2021).

14 D.S. Davis, Past, Present, and Future of Complex Systems Theory in Archaeology, Journal of Archaeological Research 32, 2024, 563. https://doi.org/10.1007/s10814-023-09193-z

15 P. Hacıgüzeller, GIS, critique, representation and beyond, Journal of Social Archaeology 12,2, 2012, 245–263.

16 Of course, this distinction also concerns cartography in general and consequently archaeological mapping, P. Hacıgüzeller, Archaeological (Digital) Maps as Performances: Towards Alternative Mappings, Norwegian Archaeological Review 2017, 1–2. 6–10. 17–18. DOI: 10.1080/00293652.2017.1393456

17 Davis, loc. cit. 579–581. D. Daems, Social Complexity and Complex Systems in Archaeology (London 2021), for CS in archaeology.

The adoption of GIS for the reconstruction of road systems led to an exponential diffusion of LCP analysis, often without a clear awareness that leaving to GIS the task of determining the cost-surface associated with the main morphological factors,[18] means ignoring other fundamental variables, such as the type of transport, which following Verhagen,[19] we could define in three ways: "on foot, unburdened and burdened, on mule-cart", to which we could add the state mail, the *cursus velox* of the Roman Imperial period. And again, the time factor (i.e. the required travel speed), seasonality and so on, useful to answer the question: "for which travellers is the road designed?". From an archaeological point of view these parameters are linked to the presence of settlements and infrastructures essential for transport, such as the *stationes* of the *cursus publicus* of the Imperial period.

I therefore show two images that I often use, because they seem very effective to me, taken from the work of Marco Sfacteria on the *Catina-Agrigentum* road.[20] The first (Fig. 1) shows the LCP computed by the system, without other inputs, the second (Fig. 2) takes into account the settlement and *statio* of Philosophiana, documented by the *Itinerarium Antonini Augusti*, also in its *version mansionibus nunc institutis*, dating back to the first half of the 4th century AD. *Philosophiana*, a secondary settlement of considerable importance, could not be ignored by the official road network, which is why it was chosen to locate the *statio* there.

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18 M. Gillings – P. Hacıgüzeller – G. Lock, Archaeology and Spatial Analysis, in: Archaeological Spatial Analysis: A Methodological Guide, M. Gillings – P. Hacıgüzeller – G. Lock (eds.) (London 2020) 13, for "black block" logics of algorithms.

19 Ph. Verhagen, Spatial Analysis in Archaeology: Moving into New Territories, in: Digital Geoarchaeology, Natural Science in Archaeology, C. Siart et al. (eds.) (Cham 2018) 17. DOI 10.1007/978-3-319-25316-9_2.

20 M. Sfacteria, Un approccio integrato al problema della ricostruzione della viabilità romana in Sicilia. La via Catania-Agrigento (Oxford 2018) 16–17 figs. 12–13.

Fig. 1. Catania-Agrigento road. LCP weighted on sources and gradients (M. Sfacteria

Fig. 2. Catania-Agrigento road with Sofiana as attractor (M. Sfacteria).

It is clear, indeed, that movement must be studied in chronological periods and above all we must not forget that every computational analysis starts from very precise assumptions, even theoretical ones, as mentioned before.

Movement and transport in prehistoric times take other factors into account, so we need to be well aware of the reasons why we perform an LCP computing. In the case of herd movements in prehistoric times, identifying the "natural corridors" from the plain to the mountain through LCP, can be a good approach, as in the case that will be illustrated by Cinzia Forgia. But the results, as we shall see, have to be validated against the archaeological data collected on the ground.

The role of natural corridors for prehistoric mobility is also demonstrated by an exemplary study[21] where intervisibility is employed to show the relationship

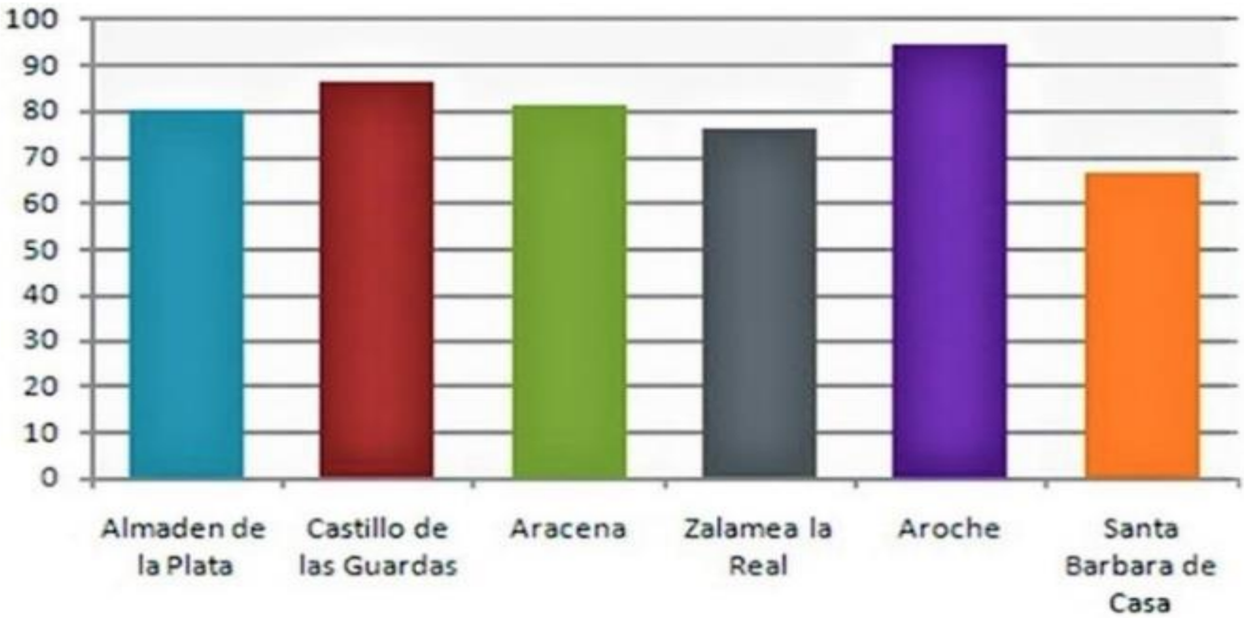


Fig. 3. Sierra Morena. Percentages per group of monuments that present a dominant direction towards natural corridors (Murrieta-Flores 2015, fig. 14)

between natural corridors and the megalithic monuments that marked the territory and served as guides in transhumance routes in the Sierra Morena (Figs. 3-4).

21 P. Murrieta-Flores, Developing computational approaches for the study of movement: assessing the role of visibility and landscape markers in terrestrial navigation during Iberian Late Prehistory, in: Computational Approaches to the Study of Movement in Archaeology, S. Polla – Ph. Verhagen (eds.) (Berlin–Boston 2014) 99–131.

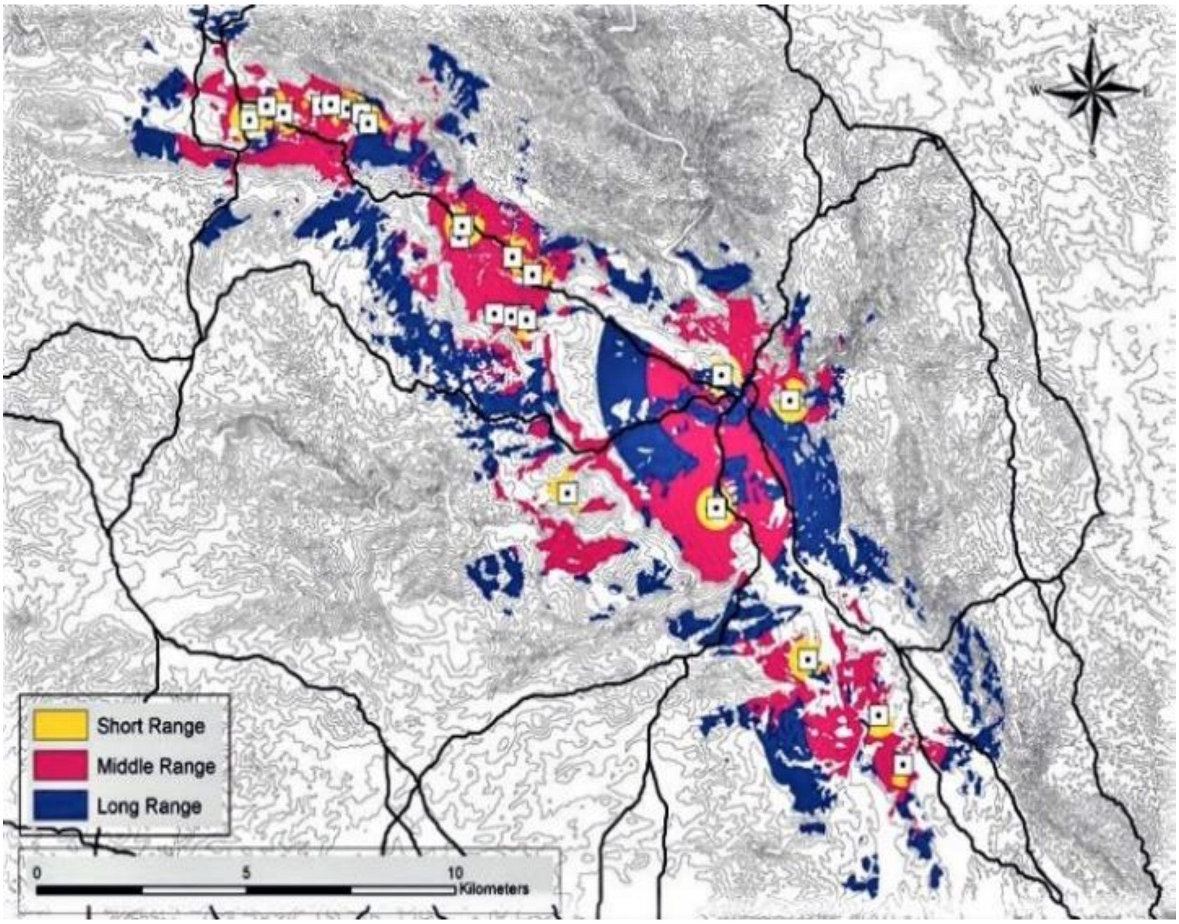


Fig. 4. Sierra Morena. Coincidence between the dominant view direction of La Portilla and Pasada des Abad in Aroche with natural corridors (Murrieta-Flores 2015, fig. 17)

"This can help us to understand the visual structure of the megaliths from corridors, allowing us to detect whether there was an intentionality behind the location of these monuments that could be related to ***both visibility and movement.****"*[22]

This association between visibility and movement, in relation to the dominant view direction, allows Murrieta-Flores to hypothesize a multifunctional role of the megaliths in the construction of a sacred landscape and a landscape of memory, demonstrating the complexity of the role that these landscape markers assumed for those who moved along these natural corridors.

22 Murrieta-Flores, ibidem 105–106, my emphasis.

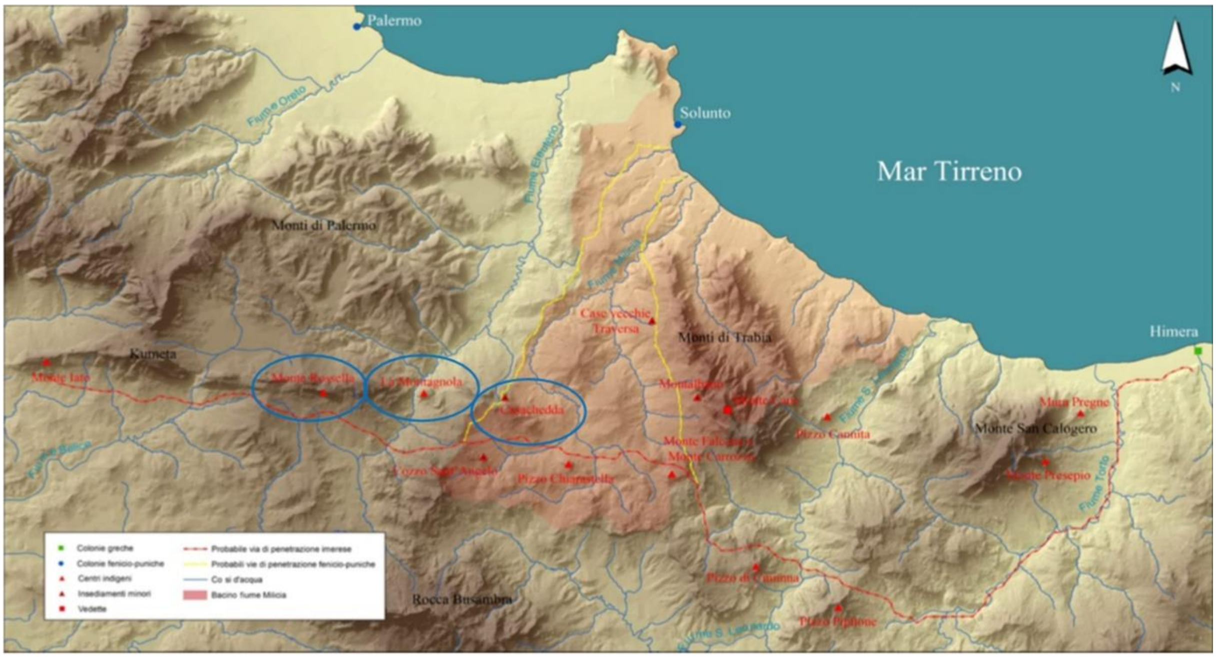


Fig. 5. Route from Himera to Ietai: LCP weighted on gradients (Computer processing G. Bordonaro).

Otherwise, LCP analysis may prove useful to identify potential routes not documented by historical or archaeological sources, as we attempted to do in our reconstruction of the connections between the Greek colony of Himera and the native centre of Ietai (Monte Iato).[23] This potential route is validated by the fact that the LCP, although roughly computed on gradients alone, touches all the main known intermediate settlements between Himera and Ietai (Fig. 5).

23 O. Belvedere – A. Burgio, Landscape Dynamics and Cultural Contacts in the Territory of Himera in the Archaic Period, in: Comparing Greek Colonies. Mobility and Settlement Consolidation from Southern Italy to the Black Sea (8th – 6th Century BC), C. Colombi – V. Parisi – O. Dally (eds.) (Berlin–Boston 2022) 315–318 fig. 7.

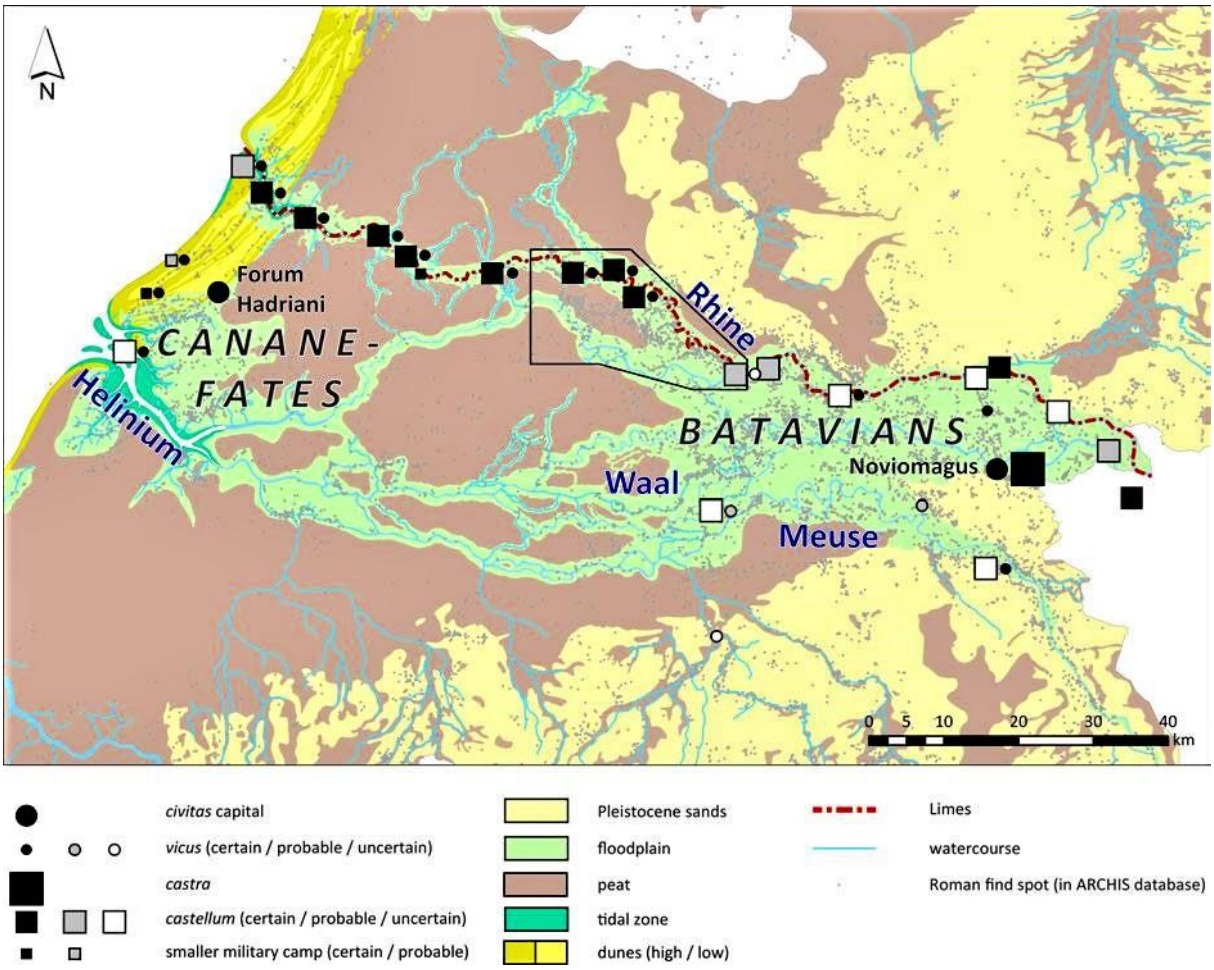


Fig. 6. Palaeogeographic map of the Dutch river area around AD 100 (Groenhuijzen – Verhagen 2015, fig. 1).

Scholars tried to overcome the limitations of LCPs, taking into account some factors dependent on human agency, using SNA (Social Network Analysis). In this sense, I find very interesting a work by M-R. Groenhuijzen and P. Verhagen,[24] since they take into consideration various factors (paleo-geographical, morphological, archaeological) and insert them into the computer analysis, in their study of mobility in the lower Rhine region (Fig. 6). Through SNA, they define a series of networks that refer to settlements of different typologies (nodes). These networks measure the intensity of connections (network density) for different types of transport; an analysis that can also be conducted in a chronological sense, comparing them with known roads and archaeological data (Fig. 7). One of the most interesting results, I think, is that unburdened and mule cart transport show the highest network density and were the most attrac-

[24] M-R. Groenhuijzen – Ph. Verhagen, Exploring the dynamics of transport in the Dutch limes, eTopoi. Journal of Ancient Studies, Special Volume 4, 2015, 25–47. For the project as a whole, see Finding the Limits of the Limes, Ph. Verhagen – J. Joyce – M-R. Groenhuijzen (eds.) (Cham 2019) esp. ch. 11, for our purposes. https://doi.org/10.1007/978-3-030-04576-0.

tive for long-distance transport and more remote areas.[25] More obviously, higher status sites are better interconnected than smaller settlements.

From the overall picture, it can be deduced that transport relating to the supply

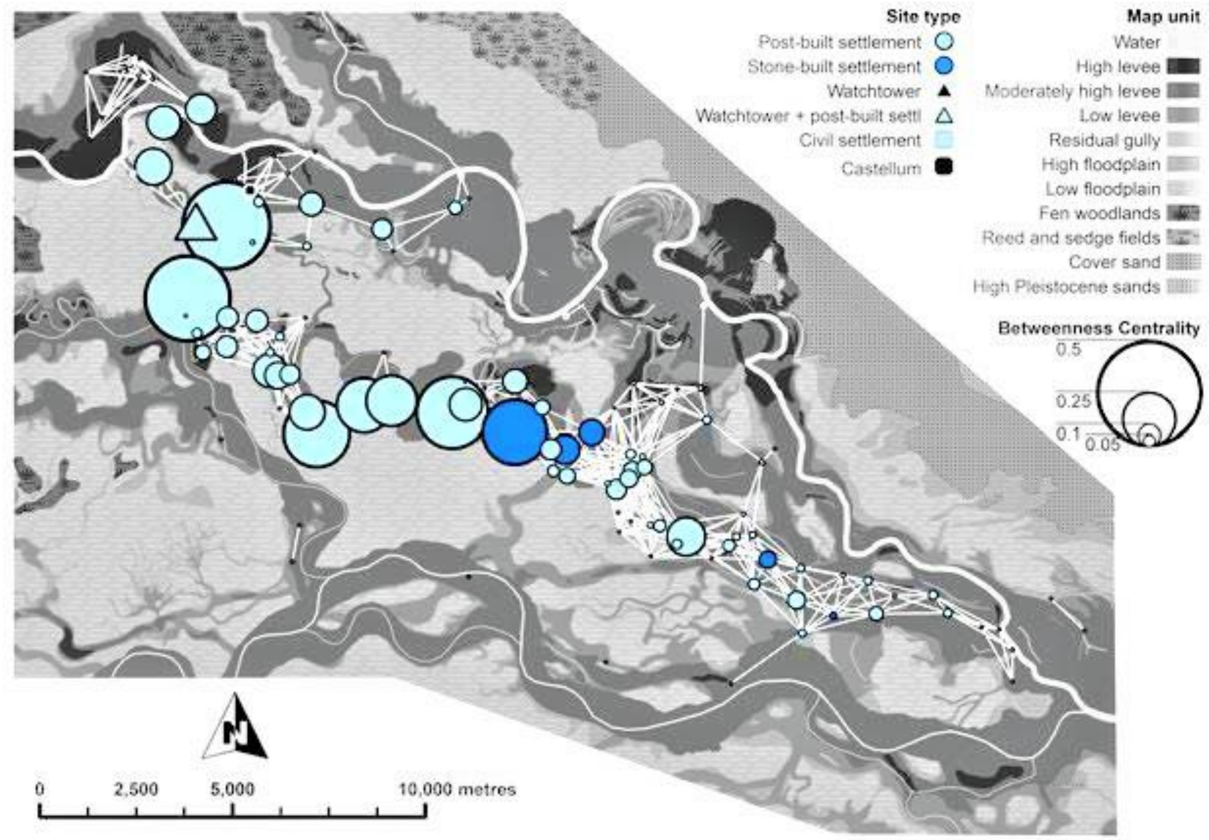


Fig. 7. Betweenness centrality measurements of all sites in the Early Roman mule cart network (Groenhuijzen – Verhagen 2015, fig. 11).

of the *castella* on the *limes* followed different routes from those of the local transports which headed towards the civilian settlements, further back than the military line, which leads us to reflect on the role of river transport (Fig. 8).[26] Indeed, river transport played an essential role in supplying the garrisons on the *limes*, as well as a fundamental economic role in the exchange of goods between the Mediterranean world (but also with Great Britain and the North Sea) and the Rhine provinces, as Rebecca Klug's paper shows.

25 Groenhuijzen – Verhagen, ibidem 38.
26 Groenhuijzen – Verhagen, ibidem 40.

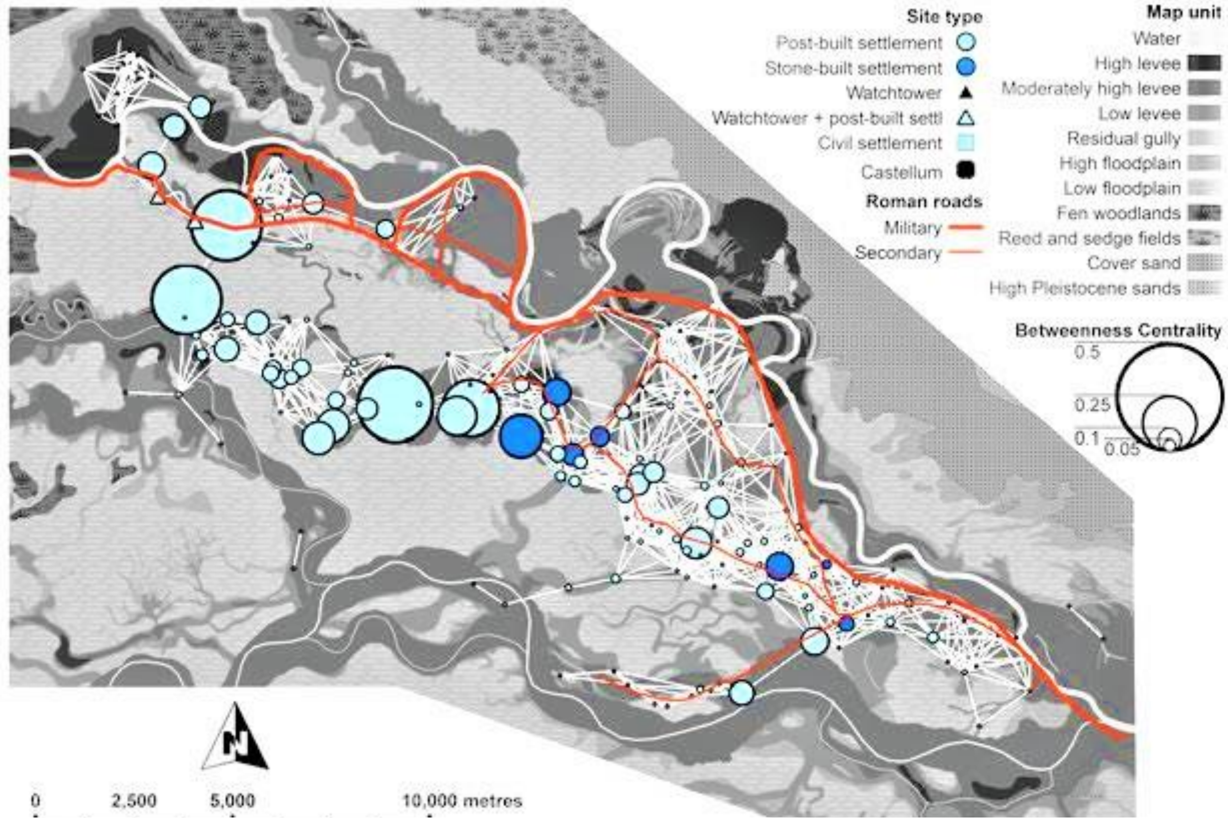


Fig. 8. Roman road reconstruction based on archaeological evidence, overlain on the Middle Roman mule cart network (Groenhuijzen – Verhagen 2015, fig. 17).

But other factors, such as the safety of a route, should not be underestimated. Visibility and inter-visibility analyses can be useful when it is believed necessary to monitor a road route of military importance. I show the results of a research along the Scottish *limes*, from which it appears that the roads that connected the rear forts to the outposts were controlled by signal towers.[27] Therefore, the route was conditioned by a system of towers, some controlling larger areas, others limited areas (towers A and B) with viewpoints located directly on the line of the Roman roads (Figs. 9-10).

27 K.M. Murphy – B. Gittings – J. Crow, Visibility analysis of the Roman communication network in southern Scotland, JASc: Reports 17, 2018, 111–124. https://doi.org/10.016/jasreport.2017.10.047

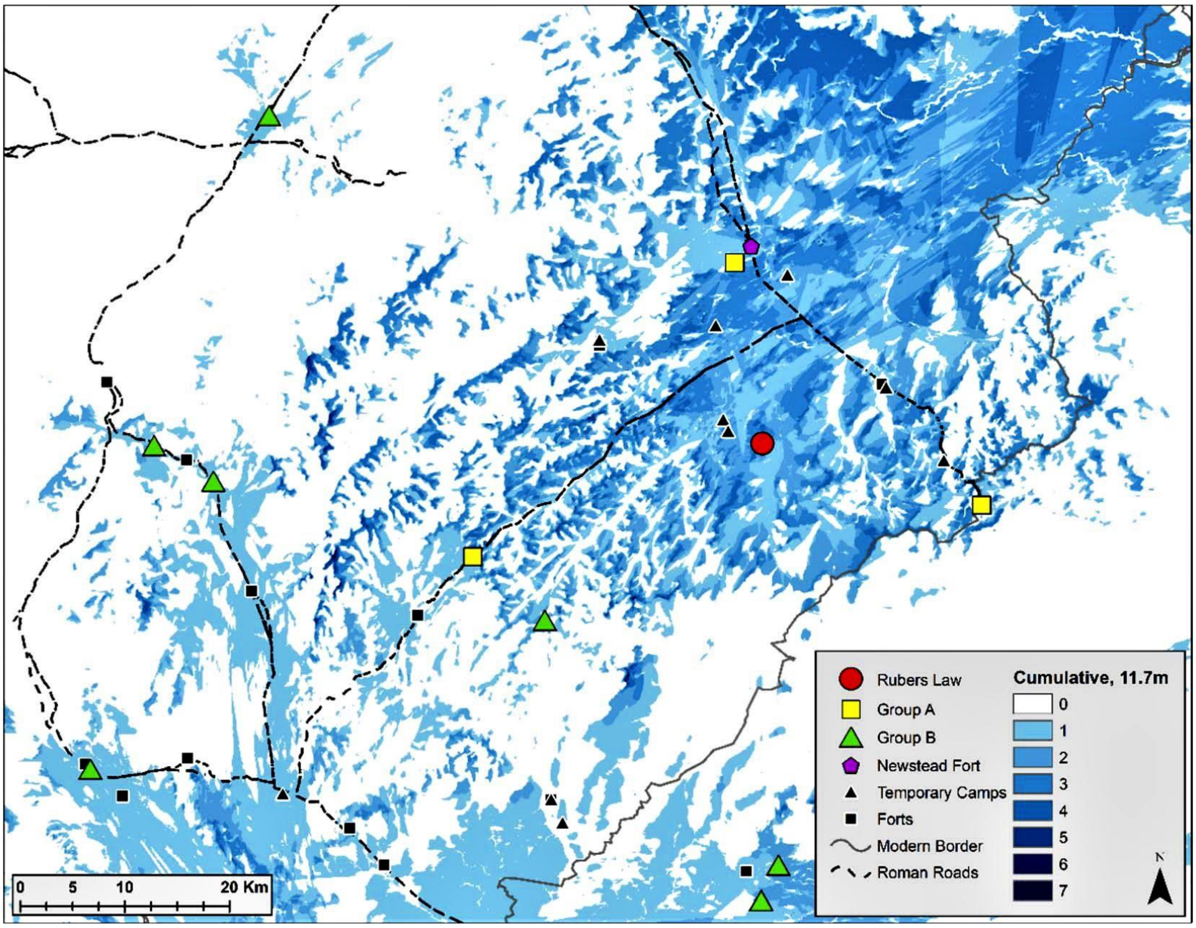
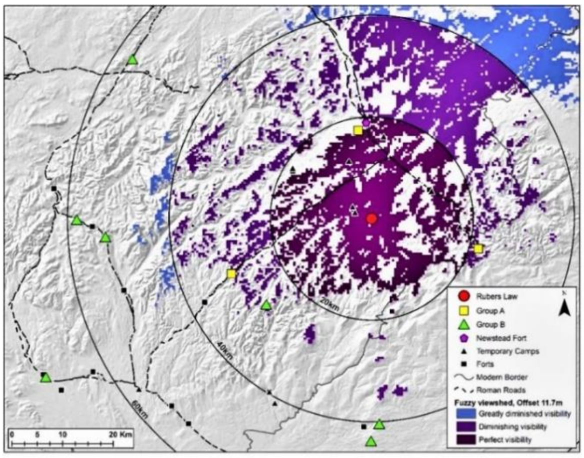


Fig. 9. Southern Scotland. Cumulative viewshed for the Rubers Law study area with an offset of 11.7 m (Murphy – Gittings – Crow 2018, fig. 10). In black the Roman road network.



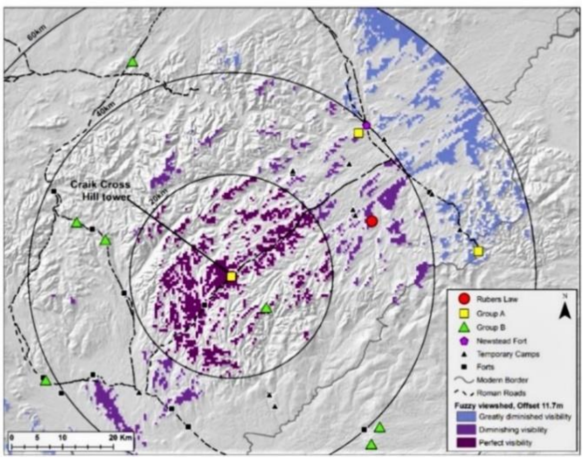


Fig. 10a. Fuzzy viewshed analysis from Rubers Law with an offset of 11.7 m (Murphy – Gittings – Crow 2018, fig. 11). - 10b. Fuzzy viewshed analysis from Craic Cross Hill with an offset of 11.7 m (Murphy – Gittings – Crow 2018, fig. 14).

Of course, it is essential to accurately establish the height of the observer, in our case the height of the tower plus that of the person, as well as the limits of human vision. This analysis was conducted for two offsets of 8,7 and 11,7 m.[28] Fuzzy viewshed analysis proved to be the best of the four visibility analyses tested to take into account the human factor,[29] because it measures the decrease in visibility over distance (Fig. 10).[30]

Let us now focus on another aspect of GIS: the infinite number of analyses that are possible by varying the parameters entered into the system. From this point of view, I was interested in a work dedicated to the reconstruction of the Imperial period road system in the north-west of the Iberian Peninsula, due to its methodological approach. Güimil-Fariña and Parcero-Oubiña tried to propose an alternative use of GIS tools.[31]

The methodological approach consists in identifying the locations that constituted the main nodes of the potential roads, rather than predicting or reconstructing them, aiming to understand why the roads are "*where they actually are*"[32]. Speaking from a historical point of view, to understand whether the Roman road system was imposed on the landscape or was based on already existing roads. The work studies the connections between three capital towns: *Asturica*, *Lucus Augusti* and *Bracara*.

28 Murphy – Gittings –Crow, ibidem 113.
29 Regular, cumulative, fuzzy and probable visibility analyses.
30 Murphy – Gittings – Crow, ibidem 113. 123.
31 A. Güimil-Fariña- C. Parcero-Oubiña, "Dotting the joins": a non-reconstructive use of Least Cost Paths to approach ancient roads. The case of the Roman roads in the NW Iberian Peninsula, JASc 54, 2015, 31–44.
32 Güimil-Fariña – Parcero-Oubiña, ibidem 32.

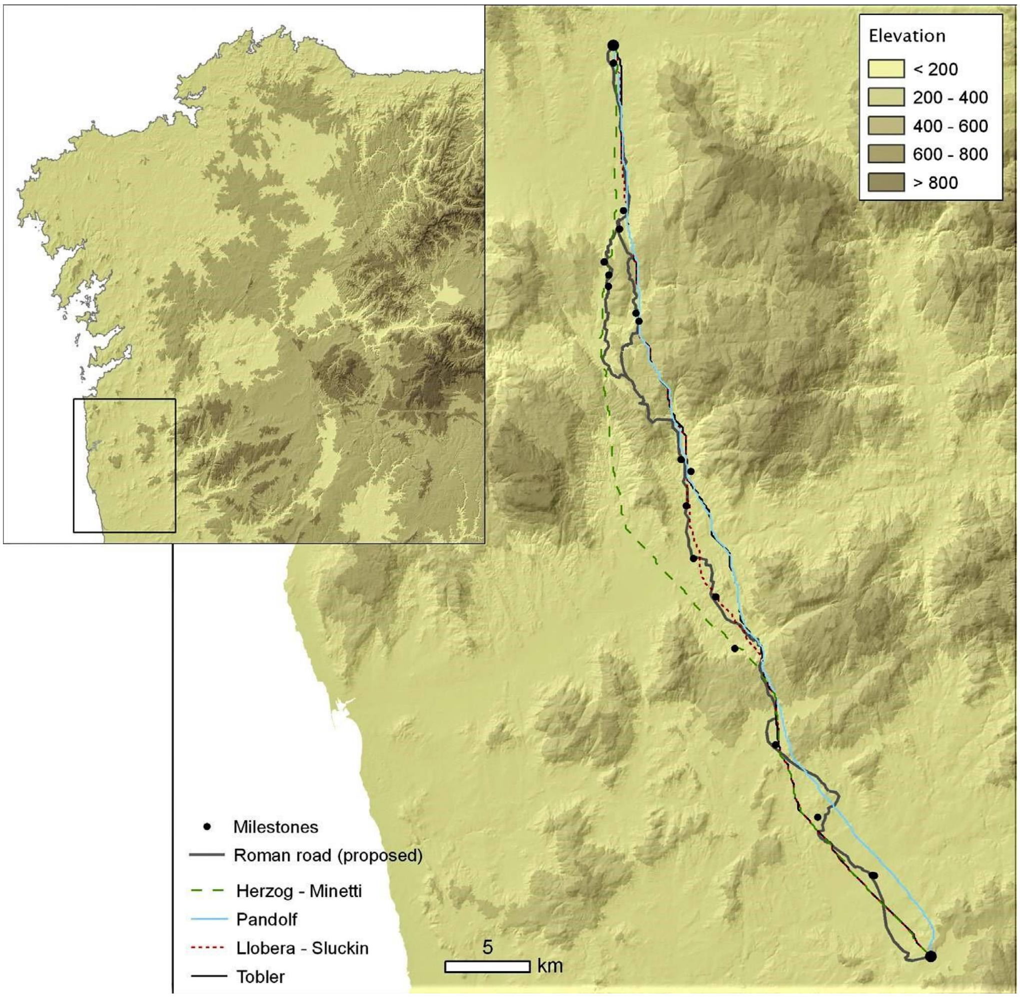


Fig. 11. NW Iberian Peninsula. Comparison of LCP produced by the used cost functions in a test area (Güimil-Fariña – Parcero-Oubiña 2015, fig.3).

What I find interesting in this paper is:

a) the comparison of four LCPs (based on Llobera-Slucking, Pandolf, Herzog-Minetti and Tobler cost-functions), which give results that are sometimes divergent, sometimes not very different from each other (Fig. 11);[33]

b) that the logic of the LCPs connecting the main centres of the region allows to understand only a small part of the road network, so that most of the roads followed a logic other than the optimal pedestrian connection between places;[34]

33 Güimil-Fariña – Parcero-Oubiña, ibidem 34 fig. 3.
34 Güimil-Fariña – Parcero-Oubiña, ibidem 36–37.

c) that by including secondary settlements in the analysis, the results suggest that when defining the route of the road XIX (*Bracara-Lucus Augusti*), the town of *Iria* was among the primary nodes chosen;[35]

d) this is not the case of the road XVII (*Bracara-Asturica*), even inserting the secondary settlement of *Aquae Flaviae*: the results suggest that when defining the route of this road there is low coincidence with LCPs. LCP is not useful to understand the logic of this road (Fig. 12).[36]

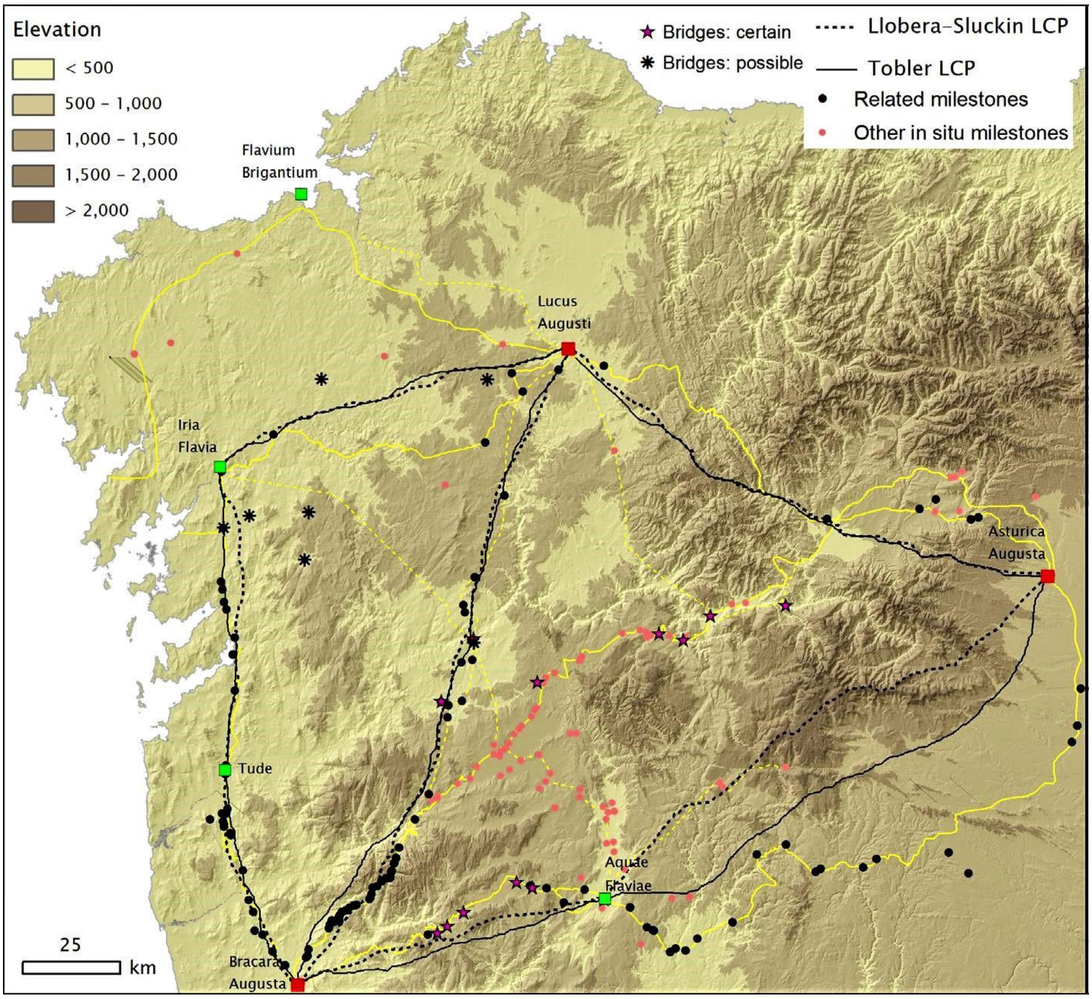


Fig. 12. NW Iberian Peninsula. LCP between the regional capitals and the secondary settlements. In light yellow, the proposed reconstructions of the main roads (Güimil-Fariña – Parcero-Oubiña 2015, fig.9).

35 Güimil-Fariña – Parcero-Oubiña, ibidem 38. See what we said above about Philosophiana: secondary settlements could not be ignored.
36 Güimil-Fariña – Parcero-Oubiña, ibidem 38 fig. 9.

This way of proceeding may seem unusual, but should be considered that "*It is important to remark that the proposed approach is not aimed at providing a significant new knowledge (reconstructing) on the routes under analysis, in our case the Roman roads of the NW Iberian Peninsula. In a different direction, it provides new clues on what decisions could have been taken when constructing that network*".[37]

The authors are aware that the results of their analysis must be compared with the archaeological data and correctly admit that it would be necessary to know more about settlement in the region under consideration, to fully understand the logic of the roads. We could add that pedestrian mobility was not the main purpose of Roman roads and note that the route of road XVII, identified through the position of milestones, crosses less rugged areas, following a way more favourable to transport by mule drawn-carts (Fig. 12).

The project members, well aware of the critical points of their approach, continued to work on the topic, introducing other types of transport, such as wheeled movement (thus obtaining a good coincidence between the computerized route of road XVII and the *in situ* milestones), trying also to use other analysis tools, which produced good results in identifying route variants and the network of potential secondary roads.[38] But it is necessary to choose among the various possibilities, and reading in full the archaeological and historical context of a road network is a non-negligible task for archaeologists.

In fact, for many years in ancient topography, we have tried to move from the identification of basic roads to the definition of routes and paths, aiming to identify variants with chronological or temporal significance, up to seasonal variations, and to move from the official road system of the *cursus* to secondary road systems. The role of archaeological data collected by a systematic survey is essential in this research.

I provide four examples from the Himera and Mazara Projects, prior to the widespread use of GIS and LPCs for the study of ancient roads. The Himera survey allowed us to identify two routes of the *Catina-Thermae* road in the Serra di Puccia area. The first pathway passes downstream from the settlement on the Serra, dating back to the Archaic period; the second (dating back to the Roman period, when the settlement no longer existed) follows a shorter route, along the

[37] Güimil-Fariña – Parcero-Oubiña, ibidem 40. For this "postdictive" point of view, C. Parcero-Oubiña – A. Güimil-Fariña – J. Fonte – J.M. Costa-García, Footprints and Cartwheels on a Pixel Road: On the Applicability of GIS for the Modelling of Ancient (Roman) Route, in Finding the limits of the Limes, Ph. Verhagen – J. Joyce – M-R. Groenhuijzen (eds.) (Cham 2019) 295–296.

[38] Parcero-Oubiña – Güimil-Fariña – Fonte – Costa-García, ibidem 297–307.

course of the Passo Mattina valley.[39] An alternative route has also been recognized in the Susafa area, along which settlements from the Roman Imperial age are located (Fig. 13a).[40]

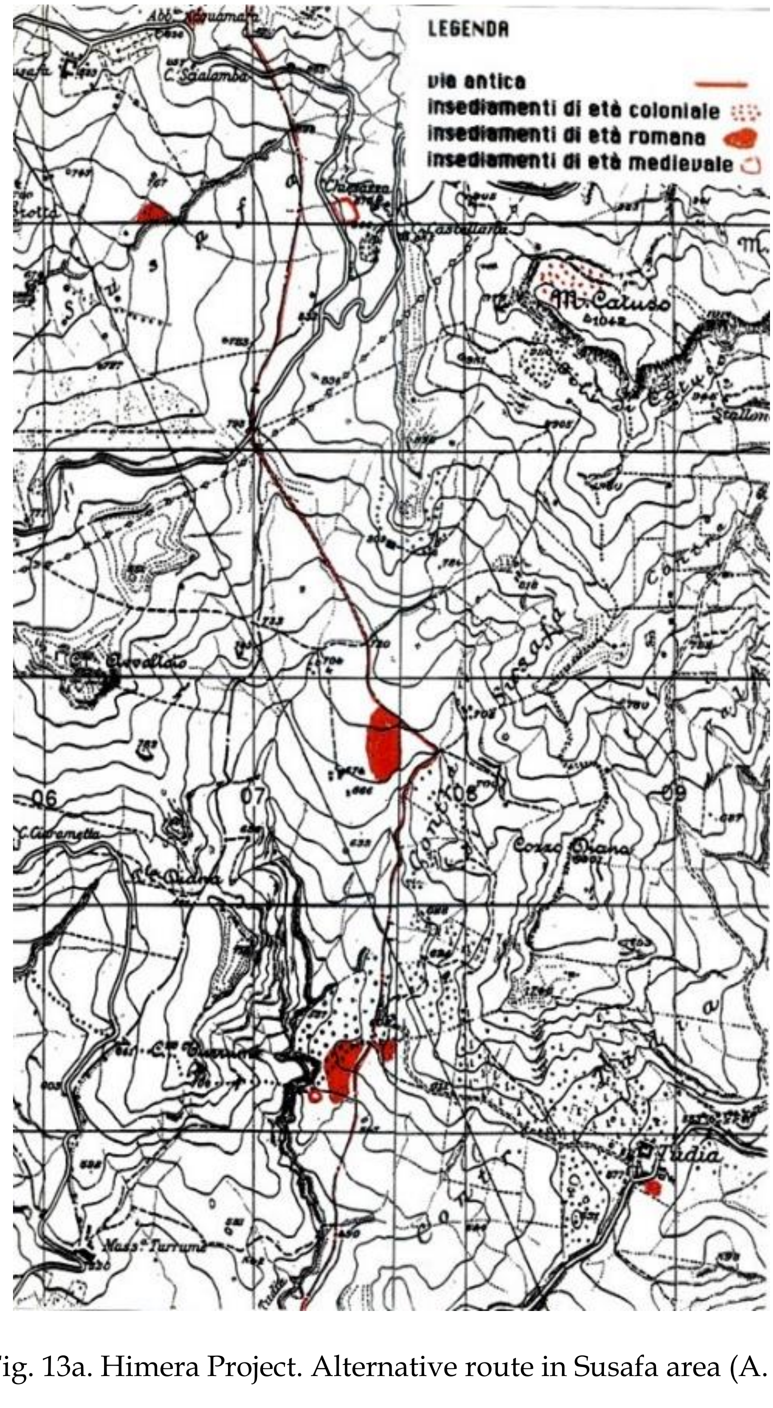
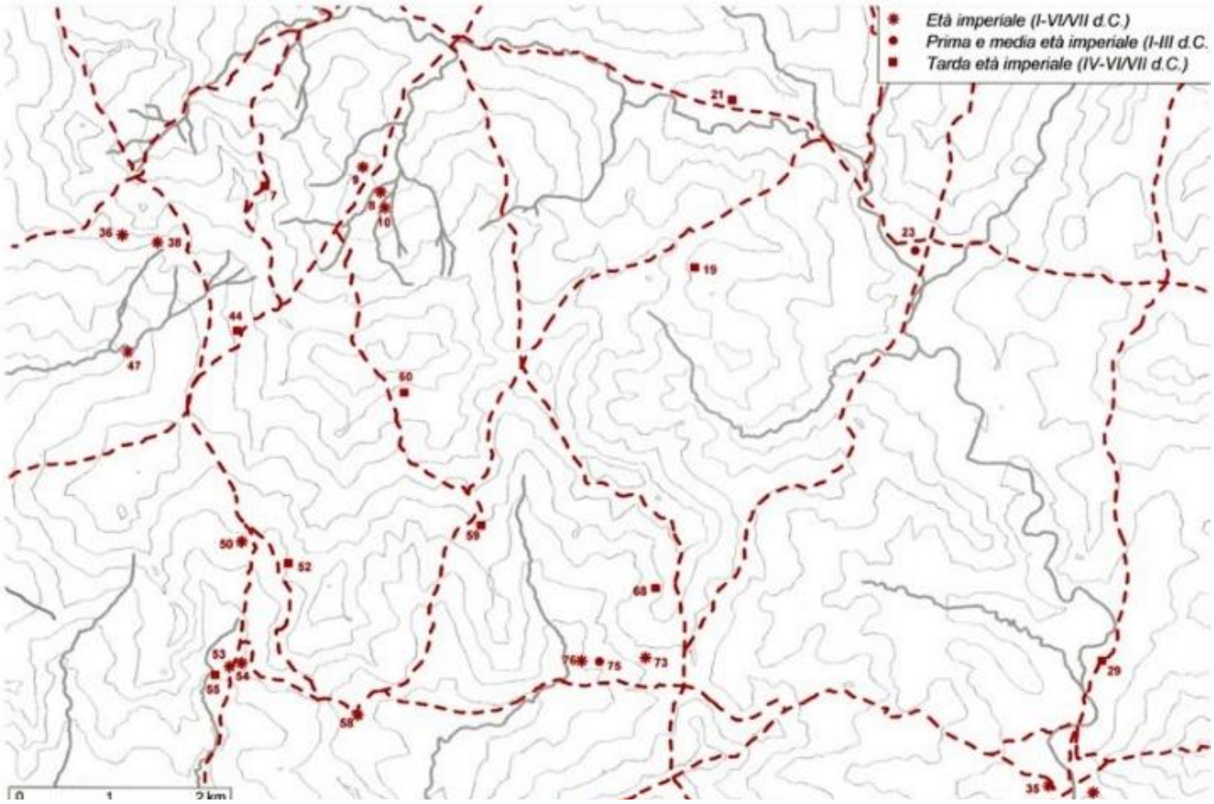


Fig. 13a. Himera Project. Alternative route in Susafa area (A. Burgio)

39 A. Burgio, Osservazioni sul tracciato della via *Catina-Thermae* da Enna a Termini Imerese, RTopAnt X, 2000 190–194 fig. 5.

40 Burgio, ibidem 194–198 fig. 9.

Our survey also allowed us to identify the networks of main and secondary roads and their stability from prehistory to the Middle Ages, for example in the upper valley of the Southern Imera river (Fig. 13b).[41]



13b) Road network in Southern Imera River valley in the Roman Imperial period (A. Burgio).

In the Mazara area, Mosca suggests to reconstruct a para-coastal road along the hillside edge, where archaeological sites of all periods are located, upstream from the coastal road which was impassable in winter, due to the marshes.[42] The level of reconstruction, therefore, does not only depend on the resolution of a DEM or on the optimal cost-surface quantification, but also depends on the quality of the archaeological data collected on the ground.

41 A. Burgio, Resuttano, Forma Italiae 42 (Roma 2002) 173–178 figs. 19–24.

42 A. Mosca, Natural Environmental Factors and Human Settlement in Western Sicily. The Example of Lilybaeum, in: Archaeology and Economy in the Ancient World, Proceedings of the 19th International Congress of Classical Archaeology, vol. 3 Panel 2.1: The Ancient City and Nature's Economy in Magna Graecia and Sicily, J. Bergemann – M. Rempe (eds.) (Heidelberg 2022) 84–85 fig. 5; Ead., Il territorio ad oriente di Lilybaeum dall'età imperiale alla tarda antichità, in: La Sicilia Romana: Città e Territorio tra monumentalizzazione ed economia, crisi e sviluppo, O. Belvedere – J. Bergemann (eds.) (Palermo 2017) 102.

Let us now move on to another field of GIS analysis, which has recently attracted my attention, maritime transport. It is a field of research where significant progress has been made, developing specific software that allows to calculate travel times, identify preferential or potential routes and simulate virtual trips, taking into account also weather conditions and climate systems.[43]

Three works by Gal, Saaroni and Cvikel, published between 2021 and 2023,[44] have particularly caught my attention, because, in addition to technical aspects of navigation, such as sailing against the wind, they take into account the Mediterranean routes as a whole and coastal navigation, which is a system of communication and trade of great importance, often underestimated.

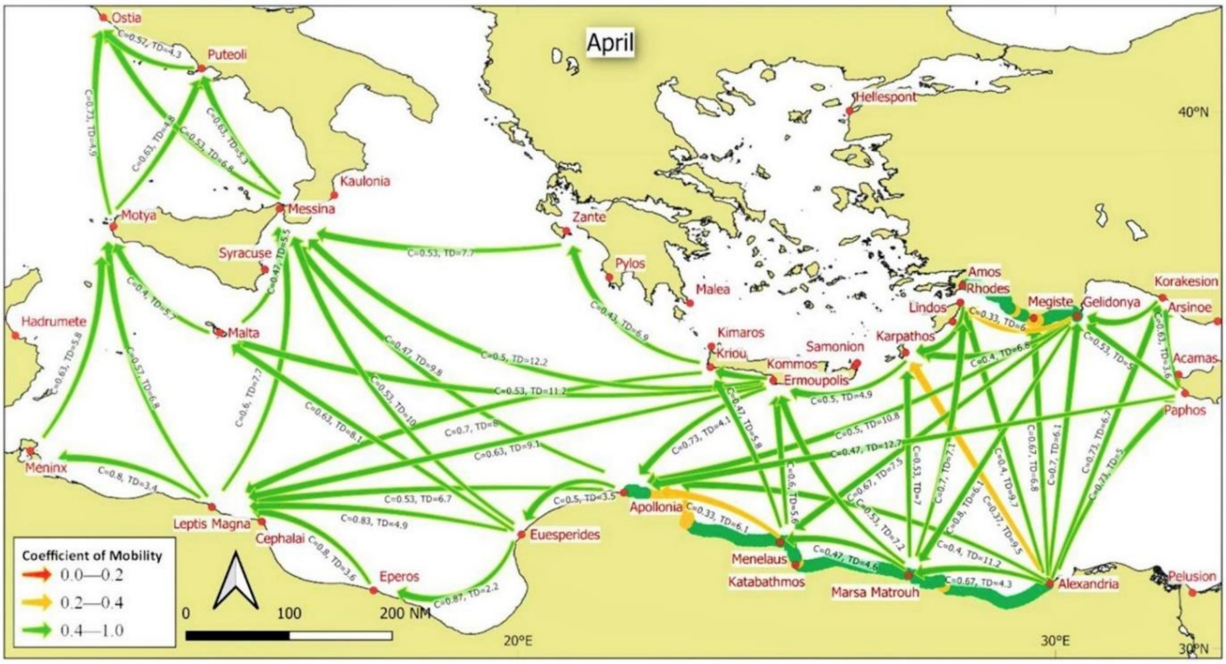


Fig. 14. Maritime route Alessandria-Ostia in April (D. Gal).

Quantitative methods and computer analysis allow the authors to map potential maritime mobility in different months of the year (Fig. 14) and therefore to indicate the most favourable routes on the basis of different parameters, such as

43 P. Warnking, Simulating Roman Maritime Trade: Modelling Sailing Times and Shipping Routes, in: Simulating Roman Economies. Theories, Methods and Computational Models, T. Brugmans – A. Wilson (eds.) (Oxford 2022) 39–68.

44 D. Gal – H. Saaroni – D. Cvikel, A new method for examining maritime mobility of direct crossings with contrary prevailing winds in the Mediterranean during antiquity, JASc 129, 2021, 1–15, 105369; D. Gal – H. Saaroni – D. Cvikel, Mappings of Potential Sailing Mobility in the Mediterranean During Antiquity, Journal of Archaeological Method and Theory 30, 2023, 397–448. https://doi.org/10.1007/s10816-022-09567-5; D. Gal – H. Saaroni – D. Cvikel, Measuring potential coastal sailing mobility with the loose-footed square sail, JASc 136, 2021, 1–15, 105500.

seasonality, climate, winds, ship and navigation technology, speed, travel and waiting times (Fig. 15), and even the expectations of sailors and passengers for a journey of reasonable duration and comfort.[45]

Month	Route options	Segments	Sailing (Days)	Waiting (Days)	Total duration (Days)
January	Via Crete	Marsa Matrouh, Kommos, Messina, Ostia	17	20	37
April	Via Cyrenaica	Apollonia, Leptis Magna, Motya, Ostia	19	20	39
	Via Crete	Marsa Matrouh, Kommos, Messina, Ostia	17	13	30
June	Via Rhodes	Marsa Matrouh, Rhodes, Karpathos, Kommos, Leptis Magna, Motya, Ostia	28	30	58

Fig. 15. Monthly routing options and voyage durations for grain ships sailing from Alexandria to Ostia (Gal – Saaroni – Cvikel 2023, tables 3-5).

Experimental archaeology also played a very important role in this research, retracing the routes with trial trips made with replicas of ancient ships, such as the replica of the 5th century BC ship from the Ma'agan Michael wreck (Israel), or the replica of the archaic ship from the Jules Verne 9 wreck, near Marseille, renamed Gyptis, voyages very useful to test the validity of the theoretical assumptions (Fig. 16).

The main problem is therefore to consider "*the difference between physical and practical mobility, the latter driven by human factors*".[46] Human factors are also mentioned by P. Arnaud.[47] But we shall see that the human factors considered by Gal et al. are very different from those taken into consideration by Arnaud.

45 As Cicero said: "The only thing worse than waiting for a ship was being a passenger on one", Cicero, *ad Atticum* V 12.1.

46 I quote from the abstract of D. Gal – H. Saaroni – D. Cvikel, A new method for examining maritime mobility of direct crossings with contrary prevailing winds in the Mediterranean during antiquity, JASc 129, 2021, 2.

47 P. Arnaud, Ancient sailing-routes and trade patterns: the impact of human factors, in: Maritime Archaeology and ancient trade in the Mediterranean, D. Robinson – A. Wilson (eds.) (Oxford 2011) 59–78.

Fig. 16a. The Ma'agan Michael II replica ship (Gal – Saaroni – Cvikel 2021, fig. 2).- 16b) The Jules Verne 9 (Gyptis) replica ship (Trapero Fernández – Aragón 2022, fig. 3).

Gal et al. tried to calculate the impact of human factors, classifying voyages into two groups, the reasonable and the unreasonable ones, but always from a technical point of view, from the point of view of the "hypothetical sailor".[48] Arnaud, on the other hand, gives great importance to political and economic factors and takes into consideration the role of the State with its treaties and trade rules, customs duties, fiscal procedures, the burden of loans and rents. And what about the purpose of the journey? It has been observed that in the Middle Ages routes and times were different for pilgrims and merchants.[49]

It would be interesting in my opinion to compare these models with pilot books and *peripli*, which in some way indicate the actual reality of travel and to some extent also imply political, economic, commercial or security factors that models cannot contemplate. In fact, if we compare Gal's and Arnaud's maps, we see that the potential routes could be much more numerous than those actually followed (figs. 17-18).

48 Gal – Saaroni – Cvikel, ibidem 11–12, 105369.

49 G. Petti-Balbi, Distanze e programmi di viaggi sul mare, in: Tempi e percorsi nell'Europa del Bassomedioevo (Spoleto 1996) 271–295, quoted by Arnaud, loc. cit. 59.

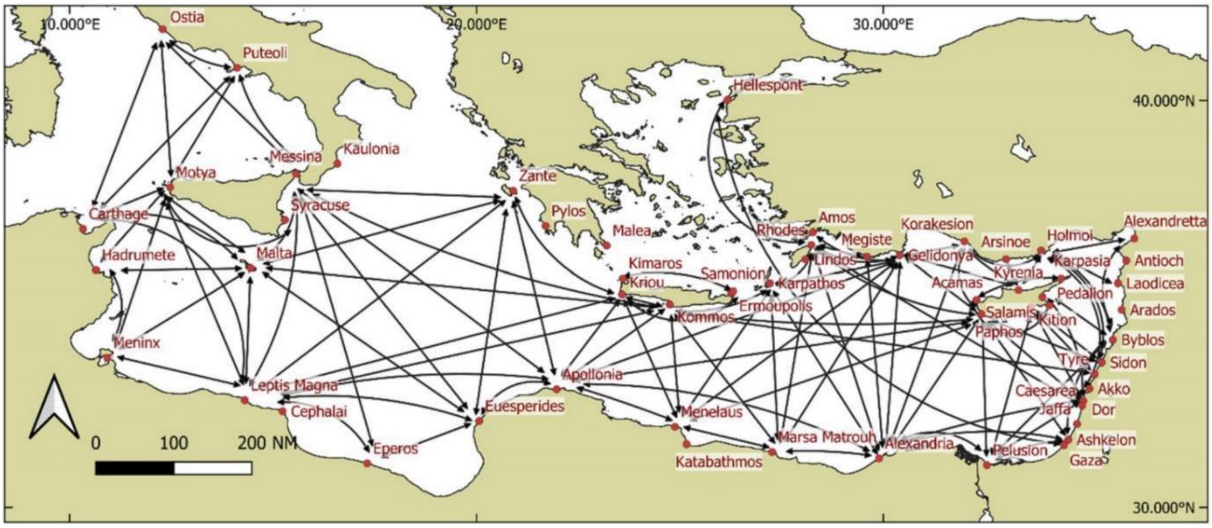


Fig. 17. Direct bi-directional passages (D. Gal).

Fig. 18. Roman shipping routes in the Mediterranean (P. Arnaud).

Let us go back to the basic problem of GIS analyses, their deterministic nature. Classifying trips into reasonable and unreasonable, Gal et al. consider climatic and meteorological factors, the duration of the journey, waiting days and so on. Certainly, if we put ourselves in the sailor's point of view, meteorological conditions are of the utmost importance for navigation, but in this way, we limit ourselves to seeing the problem only from a deterministic perspective, a "representational view", to use Hacıgüzeller's words, a static model to which dynamic elements must be inserted (also in a chronological sense). If we move on to a historical interpretation of maritime mobility, it appears clear that routes are not only conditioned by meteorological and climatic factors. The limits of climatic and technological determinism had been highlighted[50] even before the diffusion of GIS applications.[51]

It should also be noted, however, that in the field of maritime navigation, computational analysis has given impulse to research on coastal routes,[52] highlighting their value in long-distance transport (some routes could include both offshore and coastal sections)[53] despite the difficulties of coastal navigation emphasized by the authors,[54] thus allowing us to distinguish cabotage from sailing along coasts or in sight of coast[55] and reconsider the role of secondary ports. For example, underwater research in the port of Vendicari (south-eastern Sicily, south of Syracuse) shows, thanks to many ballast heaps and a large quantity of amphorae and other finds, that this harbour was frequented by long-distance ships from the Hellenistic Age to late antiquity. Cabotage from the main ports was not the only way to redistribute goods of overseas origin.[56] Of course, this does not mean that all ships touched secondary ports; it depended on the cargoes, for example the wrecks Marzameni I and II, which were carrying marble, sank not very far from Vendicari on their way to the port of destination, which is generally believed to be a great city (Syracuse or Carthage).[57]

A recent work that studied coastal navigation in the Western Mediterranean in the Archaic Age[58] used a GIS navigation model integrated by a social network analysis for maritime transport. The model takes into account parameters such as wave height, wind force and direction, combined with coastal visibility, while SNA allows to identify the intensity of relationships between nodes (=

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50 J. Huggett, Computers and Archaeological Culture Change, in: On Theory and Practice of Archaeological Computing, G. Lock – K. Brown (eds.) (Oxford 2000) esp. 8–11.

51 Arnaud, loc. cit. 60–61. J. Leidwanger, Modeling distance with time in ancient Mediterranean seafaring: a GIS application for the interpretation of maritime connectivity, JASc 40, 2013, 3302–3304, for the first attempts to use GIS in maritime mobility.

52 D. Gal – H. Saaroni – D. Cvikel, Mappings of Potential Sailing, 402–404.

53 Gal – Saaroni – Cvikel, ibidem 404. 437.

54 Gal – Saaroni – Cvikel, ibidem 441.

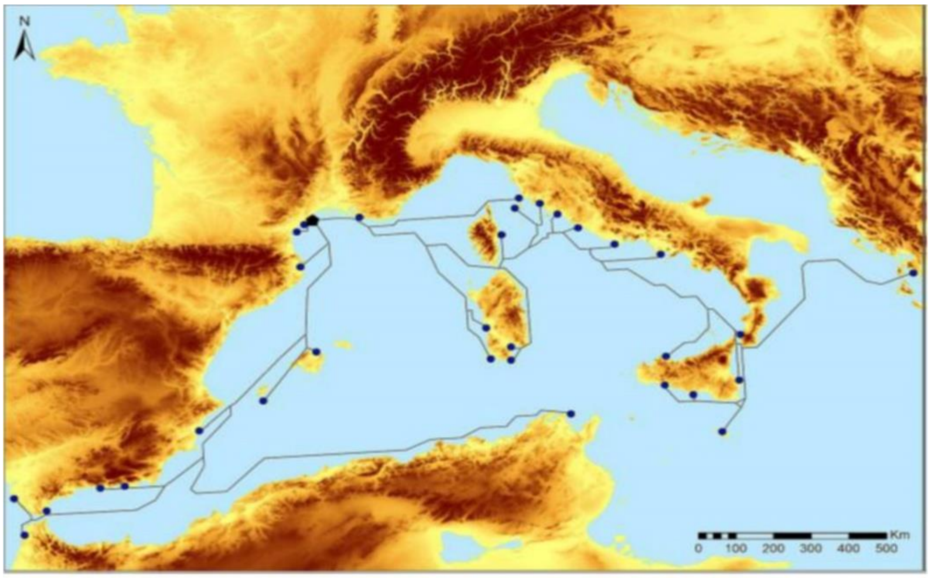
55 Gal – Saaroni – Cvikel, ibidem 437.

56 F. Sgroi – E.S. Greene – J. Leidwanger et al., Riserva naturale orientata di Vendicari. Ricerca archeologica subacquea e rappresentazione dei dati, in: L'isola dei tesori. Ricerca archeologica e nuove acquisizioni, M.C. Parello (ed.) (Bologna 2024) 240.

57 Sgroi – Greene – Leidwanger et al., loc. cit. 239; J. Leidwanger – N. Bartos – S.T. Wilker – E.S. Greene, Underwater archaeological investigations at Vendicari, Southeast Sicily: a preliminary report on the 2018-2022 work, Archaeologia Maritima Mediterranea 19, 2022, 113–120.

58 P. Trapero Fernández, E. Aragón, Modelling cabotage. Coastal navigation in the western Mediterranean Sea during the Early Iron Age, JASc: Reports 41, 2022, 1–12, 103270.

ports selected on the basis of archaeological data and the position of the wrecks, also considering the composition of their cargoes), according to the cost of contacts (= difficulty of navigation on a given route) established through GIS analysis.



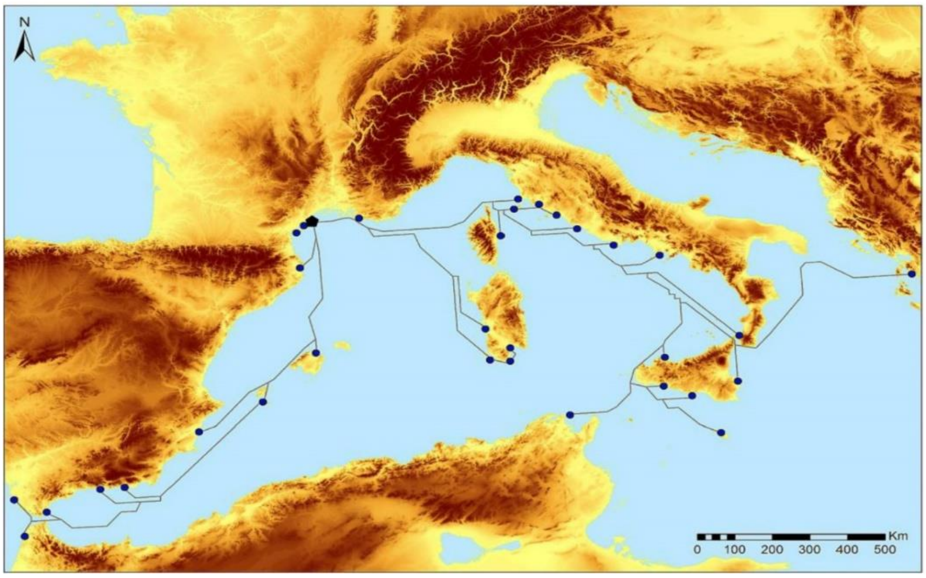


Fig. 19. Western Mediterranean Sea.- 19a. Comparative LCP for January. (Trapero Fernández – Aragón 2022, fig. 5).- 19b. Comparative LCP for July.

The model was tested with the ship Gyptis, a replica of the Jules Verne 9 wreck, which sank near Marseille. Computing distance and cost parameters, the most favourable routes were identified, also considering the seasons (Fig. 19),[59] while "*the visualisation of clusters based on similar levels of coastal navigation can be used to reflect areas of preferential maritime contact, and consequently micro-regions*".[60] SNA shows that there were small groups of nodes with close connections and that these groups were in contact with each other with less frequent but still important links (Fig. 20).[61]

Fig. 20. Geographical visualization of clusters and links based on cost of navigation (Trapero Fernández – Aragón 2022, fig. 12).

Of course, none of us will be surprised to hear that Ischia (Pithekoussai) played a fundamental role in the trade of the southern Tyrrhenian Sea in relation to Sicily, or that Pyrgi could mediate the connections between Marseille, Corsica and Sardinia. However, the comparison with the archaeological data allows the authors to confirm the presence of Etruscans and Western Greeks even before their definitive settlement with the colonies of Marseille and Emporion, or the role of Sicily and Sardinia in contacts with Carthage and Malta.[62]

It could not be otherwise, given that the model takes into account the cargo of the wrecks, therefore the parameter "archaeology" has a significant weight. I would also like to underline that by dividing the cargoes into classes of finds, for example *amphorae*, it would be possible to reconstruct the preferential distribution routes of their contents.

59 Trapero Fernández – Aragón, ibidem 4–7 figs. 5–6.
60 Trapero Fernández – Aragón, ibidem 8.
61 Trapero Fernández – Aragón, ibidem 10–11 fig. 12.
62 Trapero Fernández – Aragón, ibidem 11.

Finally, the contribution that GIS can give in the field of navigation technology should not be overlooked: night navigation, mobility with headwinds, sailing with or crossing prevailing winds, coastal navigation techniques, use of square sails, sailing in bad weather.[63]

What has just been said leads us to question the role of GIS in archaeology. I think this role can be summarized in five considerations:

1) By modifying the parameters, GIS allows us to calculate numerous if not infinite solutions to study the connections between two places, that is, it allows to analyse possibilities that were previously inestimable without GIS tools.

However, these possibilities must be placed in a historical and landscape context, so we have to choose between them. It is not always easy without adequate archaeological data. Think about the reconstruction of soundscapes in the past. It is not easy to apply to the past analysis models designed, for example, to calculate the most favourable sound environment in a contemporary city. It has been rightly said that it is not a question of reconstructing expressions of the past, but of exploring possibilities.

2) In any case, the results of computational analysis must be compared with the archaeological data, or better yet, the archaeological data must be an integral part of the analysis parameters.

3) I think that starting from a real archaeological problem and using GIS to solve it (in combination with SNA and ABM if useful), as in some examples we have given, is the most profitable way for us archaeologists, especially if we ask ourselves well-defined questions that are strongly connected to the geographical areas under consideration.

4) We must not neglect the contribution of computational analysis, even if we are aware of its limitations, and let ourselves be influenced by the fact that some results may seem obvious or trivial. We should rather think about exploring in a comprehensive and innovative way the potential of GIS in archaeological research.

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63 C.M. Mauro – F. Durastante, Nocturnal Seafaring: the Reduction of Visibility at Night and its Impact on Ancient Mediterranean Seafaring. A Study Based on 8–4th Centuries BC Evidence, Journal of Maritime Archaeology 18, 2023, 733–751. https://doi.org/10.1007/s11457-023-09385-0; D. Gal et al., A new Method; D. Gal et al., Measuring potential coastal sailing; S. Medas, Archeologia della navigazione, Il Mediterraneo antico. Approfondimenti (Roma 2024) 119–128.

5) Education in a proper use of computers is necessary in university archaeology courses. Indeed, the decrease in GIS programs in university courses has been noted with concern by many scholars, and not only with regard to GIS, but also for other applications such as augmented reality and three-dimensional modelling, not to mention artificial intelligence (whose applications in archaeology still need to be studied in depth)[64] which poses new challenges, because AI is not an immaterial or neutral technology.[65] But for some scholars, myself included, it could represent a new field of opportunities for our discipline, too[66]. It is therefore necessary to provide specific laboratories for students of our disciplines in archaeology courses.

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64 G. Gattiglia, Managing Artificial Intelligence in Archeology. An overview, Journal of Cultural Heritage 71, 2025, 225–233. https//doi.org/10.1016/j.cuhler.2024.11.020.

65 K. Crawford, Atlas of AI: Power, Politics, and the Planetary Costs of Artificial Intelligence (New Haven, CT 2021); see also https://libguides.reading.ac.uk/generative-AI-and-university-study/intro.

66 Gattiglia, loc. cit. 233.