Research Article

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Landscapes of Movement Along the (Pre) Historical Libyan Sea: Keys for a Socio-Ecological History

https://doi.org/10.1515/opar-2022-0346
received April 30, 2023; accepted November 15, 2023

Abstract: This study examines the influence of Human Ecodynamics and Historical Ecology to understand the complexities of historical mobility. Based on Landscape Archaeology, this study considers some of these theoretical principles for studying and reconstructing the movements of past human populations. This discussion is grounded on the example of a research project focused on modelling movement and interaction patterns between the Aegean area (Crete) and northeastern African region (Marmarica) from the Late Bronze to Roman times. The project works with multivariate data representative of the routes and non-human *factors* that may interplay in biocultural processes. Three key aspects structure this article: (1) the emergence of Human Ecodynamics and Historical Ecology in archaeology, (2) their impact on the theoretical evolution of Landscape Archaeology, and (3) the methodological implementation of these principles through a case study. We specifically discuss the strengths of Human Ecodynamics and Historical Ecology to enhance the conceptualisation of mobility by considering the heterarchical interrelationships between human and non-human agents. Our methodological implementations showcase this by using computational approaches to model human pathways influenced by and in constant relationship with their environment. This research thus highlights the importance of transdisciplinary approaches to studying historical mobility from an archaeological and complex systems perspective.

Keywords: Human Ecodynamics, Historical Ecology, Landscape Archaeology, past movements, complex systems theory, Eastern Mediterranean

1 Introduction

Mobility has been a defining feature of human history, shaping societies and cultures across time and space. Understanding the drivers of these movements and the agents that shape them is essential to gaining insights into past human societies. This study explores an approach to understanding movement across landscapes from an archaeological perspective. Therefore, we seek to introduce a series of conceptual tools and methods to trace historical mobility. Influenced by Human Ecodynamics and Historical Ecology, our study highlights the socio-ecological context of past movements and, by extension, adopts a complex systems approach.

In the context of this study, the concept of migration enhances our approach to historical mobility by providing an alternative insight by which to interpret the past movements of people and their impact on

Special Issue on Archaeology of Migration: Moving Beyond Historical Paradigms, edited by Catharine Judson & Hagit Nol.

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societies. Understanding why people chose to move in the past provides insights into environmental dynamics, socioeconomic activities, political pressures, and cultural influences. We conceptualise migration (based on the Oxford English Dictionary, 2023) as the seasonal, temporal, or permanent movement of individuals, people, or communities, entangled with animals, plants, and so forth, from one place to another, in conjunction with material (objects) or immaterial (ideas) flows – implying exchange or the act by which objects and ideas are being passed. Such movements are normally triggered by external factors (e.g. conflict, climatic changes, trading, etc.) and leave footprints on landscapes (e.g. change in or extension of socio-ecological niches). Thus, our definition underscores the idea that movement occurs in the landscape and involves non-human agents. This is an operational definition that suitably conforms to our approach, which specifically focused on tracing and modelling the movement along the Libyan Sea (Crete and Marmarica) from the Late Bronze to Roman times (ca. 1400 BCE–300 CE) (Figure 1). In this, we adopt a complex systems perspective to unravel the interaction patterns of the communities that inhabited these regions that additionally accounts for the human–environment interactions associated with historical mobility.

Our purpose is to develop a diachronic account of possible regional and supraregional flows of movement generated by different communities' economic and social exchanges. This study explores these dynamics through a case study focused on Marmarica (northeastern Libya and northwestern Egypt). This region has often been marginalised within a narrative that predominantly relies on textual and iconographic sources from neighbouring groups (Cooper, 2022). Moreover, prior archaeological endeavours within Marmarica have tended to focus on specific locales – for instance, northern zones of Western Marmarica (Hulin, 2008; Hulin, Timby, Muftah, & Mutri, 2010; Hulin, Timby, & Mutri, 2009) and Eastern Marmarica (Rieger, 2017, 2019, 2023), among others. Notwithstanding these studies, there is no comprehensive study of the entire Marmarica region, nor research considering it in its own historical right. Such an absence is problematic, considering its relevant geographic position as a hub within the exchange circuits between Cyrenaica and the Nile Valley, as well as between the Eastern Mediterranean harbours and the hinterland oases. Therefore, shedding light on its historical mobility and interaction patterns contributes to a more comprehensive understanding of the interconnections that have shaped the northeastern African landscapes in the broader Mediterranean context.

The complexity of this research has led us to implement different approaches such as site mapping, GIS spatial analysis, and network research. The systematic exploration of historical cartography and aerial

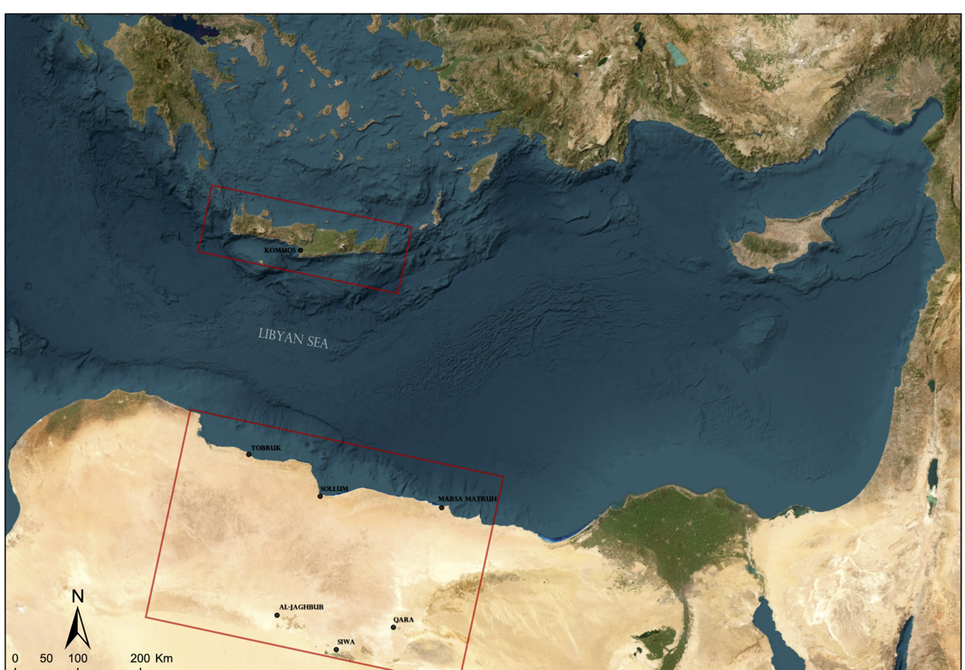


Figure 1: Map of the Eastern Mediterranean with general locations mentioned in the text (Basemap: © ESRI).

imagery enabled the mapping and recording of archaeological remains (Rayne et al., 2017; Wilson, 2021), serving as *proxies* to infer human mobility. Furthermore, we deployed accumulated cost surface analysis, specifically the focal mobility network (FMN) (Déderix, 2016; Llobera, Fábrega-Álvarez, & Parcero-Oubiña, 2011), to derive historical human pathways. Finally, archaeological network research (Brughmans, Mills, Munson, & Peeples, 2023; Brughmans & Peeples, 2023) enabled us to examine the intricate connections that have shaped human interactions across the Marmarican landscapes. Our research also considered various environmental factors and their interrelationships with humans. Principles derived from Human Ecodynamics and Historical Ecology (Fitzhugh, Butler, Bovy, & Etnier, 2018) helped to better conceptualise, model, and shed new light on the complexities of analysing these landscapes from an archaeological approach.

This article ultimately intends to connect the theoretical and methodological aspects of our research. Therefore, the first part of the article is a brief theoretical presentation of Human Ecodynamics and Historical Ecology and their impact on Landscape Archaeology. We subsequently present some insights into what these approaches bring forward for understanding the landscape from a complex systems perspective. The following sections expound on different aspects in which this theoretical basis directly influences our methodological approach to modelling past movements. The article concludes by discussing our approach to conceptualising past, but also present, mobility dynamics.

2 Theoretical Framework: The Role of Socio-Ecological *Factors*

2.1 Human Ecodynamics and Historical Ecology

Since J. McGlade coined the concept of Human Ecodynamics in 1995, it has steadily gained traction in archaeological research. It aims to study the historical and long-term interrelationships between humans and the environment through space and time, assessing the agency that both these entities have on each other (Harrison & Maher, 2014; McGlade, 1995). In other words, its aim is to analyse the socio-natural system(s). Similarly, the concept of Historical Ecology developed by Crumley and colleagues (1994a) has also been increasingly used in anthropological and archaeological research. Like Human Ecodynamics, Historical Ecology refers to the study of the coevolutional, dialectical, dynamics between human and non-human agents, where non-humans' agency enacts its influence upon both themselves and humans, and vice versa (Crumley, 1994b). These mutual and entangled interrelationships facilitate the development of sociohistorical structures that work at different spatial, temporal, and systemic scales (Fitzhugh et al., 2018; Marquardt, 2019).

Both approaches might arguably be complementary, considering their aims – the synthetic and historical study of the interactions between human and non-human agents. Moreover, both assemble a number of features that can be implemented in a complementary fashion, specifically to understand landscapes as the spatial manifestation of such interactions (Barruezo-Vaquero & Laguna-Palma, 2022; Fitzhugh et al., 2018; Ray, 2019; Sinclair, Moen, & Crumley, 2018). In sum, they share a common understanding of non-linear dynamics/heterarchical agency to trace human–environment interrelationships from a long-term perspective (Crumley, 1994a,b, 2019; Fitzhugh et al., 2018; Harrison & Maher, 2014; McGlade, 1995). If at all, it could be argued that Historical Ecology studies human ecodynamics. But in any case, these scholarly approaches converge (Kirch, 2005). For this reason, and for the sake of simplicity, henceforward we will normally use "HE" to encompass both Human Ecodynamics and Historical Ecology.

2.2 Exploring the Core Tenets of HE: Entangled Relationships

One of the core concepts that sets HE is the recognition of entangled relationships between human and non-human agents. Such entanglements have significant implications for understanding landscapes as entangled places (Eriksson, Ekblom, Lane, Lennartsson, & Lindholm, 2018). The idea of entanglement also bears significance because it can merge other concepts brought by HE, including mutual agency, non-linearity, and heterarchy. By incorporating these concepts, HE's research can provide a more comprehensive and nuanced understanding of the relationships between humans and their environments. This understanding is essential in studying historical mobility, as it recognises the interconnectedness of both *factors* and how they shape one another over time. Ultimately, HE's approach to entangled relationships provides a rich framework for investigating complex and evolving interactions in changing socio-ecological contexts.

2.2.1 Mutual Agency

HE renders a dialectical interrelationship between the human and non-human agents of the Earth's biophysical system to explain how socio-natural systems operate (Marquardt, 2019). As stated by McGlade (1995), "structures are maintained only by constant energy/matter and entropy exchange, in which the action of positive feedbacks of environmental and cultural processes drive the system to new evolutionary states, which in turn provide the conditions for renewal of higher entropy production." In other words, HE emphasises the interconnectedness between the human and non-human agents of socio-natural systems and how they mutually shape and influence one another through constant exchange and feedback loops.

Hence, it follows that analysing socio-natural systems requires envisioning these systems as composites, wherein each component can potentially interact with every other component. This has both epistemological and ontological implications. Following Ingerson (1994, p. 45), we should understand the culture/nature dichotomy as "quantitative variations along a single spectrum rather than as an either/or dichotomy [which, as a consequence,] requires us to disassociate qualities and characteristics" traditionally labelled either as "social" or "natural." We find the concept of mutual agency quite suitable in this context. Mutual agency implies that humans and non-humans are deeply entangled through their agency. Indeed, as Bauer (2018; also, Bauer & Ellis, 2018) argued, it is through the recognition of this bidirectionality that we can correctly understand the ontological intertwinement between humans and non-humans. Moreover, such mutuality through bidirectional connections allows the system to change and, therefore, evolve. Thus, the synergy between humans and non-humans drives co-evolutional dynamics, which leads to arguing that history might be conceptualised as the coevolution of multiple species (Fitzhugh et al., 2018).

Understanding the synergy generated by the mutual agency of human and non-human agents is the task of HE (Maher & Harrison, 2014, pp. 2–3). To do so, HE incorporates an approach based on Complex Adaptive Sciences (CAS). The approach of CAS is not so much placed on the agents *per se*, but rather on the holistic picture derived from the agents' interactions, changes, and patterns at multiple scales (Sinclair et al., 2018). These interactions and their governing mechanisms are thus of utmost interest; two other concepts in HE can be quite useful to describe them: non-linearity and heterarchy.

2.2.2 Non-Linearity

HE applies a reasoning based on non-linear dynamics of causality (McGlade, 1995). Complex dynamical systems, such as socio-cultural or biocultural ones, have the capacity to generate unpredictable, emergent behaviour via non-linear, especially chaotic, feedback. A direct consequence is that the systemic dynamics of causality hinge on an (initially) indeterminate number of agents who vary in number and effect depending on the moment, place, and scale of analysis. As such, "ecosystem structure is viewed as a series of weakly coupled sets within a hierarchy of process rates involving biotic interaction […] and abiotic factors […]. The non-linear couplings in these processes are further complicated by human action" (McGlade, 1995, p. 121). To understand these complex dynamics, it is essential to decompose the global picture into smaller parts, following a hierarchical analytical approach – as McGlade uses it within the context of hierarchy theory –, and gear them into a concrete, broad narrative.

This approach to causal explanations is fundamental to interpreting human–environment entanglements. Non-linearity accounts for the interlaced dynamics of complex systems, offering a more nuanced and comprehensive understanding of the interactions that occur within socio-natural systems (Maher & Harrison, 2014,

p. 2; McGlade, 1995; Winterhalder, 1994). It can be said that non-linearity is one of the foundational governing principles driving the mutual agency of human and non-human agents.

2.2.3 Heterarchy

If non-linearity governs human–environment interrelationships, heterarchy is a type of organisation that defines the character of such interrelations for HE. Heterarchy defines a complex system that allows elements to be ranked or unranked (relative to other elements) in several ways depending on systemic requirements, creating a dynamic structure in which power and influence are distributed among various agents (Crumley, 1994b, p. 12). This is in contrast to hierarchies, where elements are ranked in a fixed order. In a heterarchy, the relative importance and behaviour of agents, whether human or non-human, are not constant but fluctuate depending on spatial and temporal contexts, leading to a flexible and adaptive structure of human–environment interrelationships.

As previously mentioned, non-linear bidirectional interrelationships involve multiple agents operating within a complex system across diverse spatial and temporal scales. The power that agents – be they human or not – can effect upon others is not static but variable; at times, they might be stimulators/dominant or respondents/dominated (Crumley, 2019, p. 293). Consequently, the relative behaviour and importance of agents are not static; their actions, interactions, and results fluctuate in response to changing circumstances, leading to a context-sensitive and adaptable system.

2.2.4 Multiscalar: Long-Term, Large (Distributed) Scale

Historical ecologists have been vocal about the importance of using multiscalar archaeological data to gain a comprehensive multitemporal and multi-scalar understanding of human–environment interrelationships (Hambrecht et al., 2020; McGovern, Hambrecht, & Hicks, 2019; Ray, 2019). According to this approach, the landscape is the fundamental unit of analysis from which to develop a framework that includes distributed (local, regional, interregional, and supra-regional), longitudinal, and multitemporal (*longue durée*) sites. The coinage of the conceptual phrase "Distributed Observing Network of the Past" (DONOP) by some practitioners encompasses this perspective: "through the analysis of archaeological datasets, we have the potential to access long-term records of human interactions with natural systems at a wide variety of temporal and spatial scales and thus both reconstruct past environmental conditions and reveal the human dimensions of these processes" (Hambrecht et al., 2020).

Incorporating different spatial scales, from local to interregional, enhances the study of historical human–non-human interrelationships (Hambrecht et al., 2020). However, it is important to note that inclusion does not mean decontextualisation. Instead, a comparative and inclusive perspective that pays attention to each context is necessary to deploy coherent analyses. Multiscalar thus means to integrate different cartographies within the same narrative. The ultimate goal of such an approach is to provide "historical and diachronic knowledge of human–environmental relationships" and their impacts, which can inform present concerns (Ray, 2019).

2.3 Complex Systems Theory

The exploration of complex systems – or at least its conceptualisations – enhances the understanding of Human Ecodynamics and Historical Ecology, as these arguably analyse complex systems (for a comprehensive study on complex systems applied to archaeological research, see Daems, 2021). Complex systems are those characterised by complexity. Although sketchy to define, complexity can be described as the convergence of a plurality of properties: non-linear behaviour, self-organisation, emergence, adaptation, non-equilibrium, interdependencies among components of a system, processing of information, etc. (Daems, 2021, p. 35). Any complex system thus possesses these properties, albeit the degree of complexity may vary within the system (and scale of analysis). It is important to note that complex systems adapt through time due to the constant exchange of feedback and processing by the components of said systems. For this reason, complex systems can be considered complex adaptive systems (Daems, 2021). Complex systems theory describes and seeks to understand how these systems behave and evolve through time.

The epistemic basis of complex systems theory clearly benefits HE, which, in essence, studies complex adaptive systems. Indeed, the core analytical tenets of HE previously described match with the properties exhibited by any complex system: mutual agency describes the profound interdependencies among human and non-human agents, as well as the processing of information happening between them. Moreover, mutual agency develops in a heterarchical and non-linear way, which leads to emergent phenomena and changes in the system's state. These processes occur at multiple levels within a biocultural system; hence, HE seeks to understand multi-scalar changes and their drivers. In this context, complex systems theory emerges as an appropriate analytical and conceptual tool for HE.

2.4 Epistemological Considerations: A Brief Comment on Research Methodologies

The study of complex systems, such as human–environment co-developments, has epistemological consequences and requires a framework capable of articulating human and non-human agents in a multi-scalar approach (Marquardt, 2019; Winterhalder, 1994). From a spatial point of view, this means not to privilege one scale over another but to account for the interlacement of different spatial scales, from the micro to the macro. The concept of DONOP reinforces this latter aspect.

Understanding heterarchy challenges traditional hierarchical frameworks. Strict hierarchical models are normally at odds with unravelling heterarchical processes because they assign fixed and rigid categories or values to explain how agents work within a given system. This is problematic for understanding complex, dynamic, and multidimensional chains of causation (Crumley, 1994b, p. 13). A heterarchical approach is essential to overcome these problems. In a framework based on HE, each agent's importance will vary according to the spatial-temporal context and degree of freedom-to-act in that context (Marquardt, 2019). Any framework seeking to articulate HE or that considers human–environment interrelationships should thus develop mutable interlinks between the chosen scales of analysis.

Heterarchy is also applicable to the use of diverse disciplines, theories, and methods. Diversity can be an opportunity to deploy holistic research, instead of being seen as an insurmountable divergence (Crumley, 2019). Disciplinary barriers work against the analysis of complex phenomena. To resolve this issue, some researchers (Crumley, 1994a,b; Meyer & Crumley, 2011) have proposed to use as many theories and methods as possible to solve a specific problem, depending on the context and available sources of information. This heterarchical vision conceives disciplines, theories, and methods not as closed boxes but rather as intertwined sets of tools – a toolbox (Crumley, 2017). Thinking of disciplines, theories, and methods as a toolbox can open up the possibility of working within transdisciplinary frameworks (e.g. Acosta-Naranjo & Domínguez, 2014; Lethbridge & Hartman, 2016; note, however, that 'transdisciplinary' has also been used to refer to the inclusion of different social sectors to our research: Milek, 2018). Complex systems theory can also reinforce this perspective by signaling the need for a consilient approach capable of merging data, methods, and theories across disciplines (Daems, 2021, p. 10).

2.5 How These Theories Influence Our Understandings of Landscapes

The incorporation of many of the ideas brought by HE has enriched discussions about how to attain our original aim, i.e. understanding movement through the landscape. Movement, i.e. human interactions, does not occur in a vacuum or a blank setting but occurs in the landscape. Hence, this research is fundamentally based on Landscape Archaeology. Admittedly influenced by Crumley (2017), we argue that HE's framework is better deployed through the study of landscapes. The project thus considers the definition of “landscape” fundamental to operationalise our research. Our way to represent and analyse interactions across landscapes is through an ontological approach influenced by HE. This section aims to connect HE’s principles seen above with conceptualisations purely based on Landscape Archaeology.

From a general and broad perspective, we conceive the landscape as a space that encompasses, as if it were a single unit, the physical environment and other non-human agents and human remains (settlements, sacred and productive places, mobility structures, etc.) (Ashmore & Knapp, 1999; David & Thomas, 2016, pp. 38–40; Martín Civantos, 2008, pp. 26–35; Moreland, 2010). All of these factors are arguably interconnected, entangled, as in a network. For this reason, we conceive the landscape as a network compounded of multiple and distinct elements present in the same reality (see Kowalczyk, 2020 for a similar proposal).

Accordingly, concepts used in Landscape Archaeology, such as environment or nature, should be understood from a broad and integrative perspective, although excluding humans for analytical reasons. In this guise, “nature” or “environment” encompasses the non-human biotic and abiotic *factors* (atmosphere, relief, water flows, soil pedogenesis, vegetation, etc.) (Malpica Cuello, 2009). In sum, what landscape archaeologists have normally denominated as environment or nature can also be called non-human agents, or *factors*, according to the influences of HE and posthuman thinking (Crellin & Harris, 2021).

Landscapes are anthropic artefacts, too (Martín Civantos, 2009). As Trigger (1967, p. 158) points out, every social relationship and process has an impact and reflection on the landscape. Moreover, humans socialise their landscapes, both communally and individually, through different experiential dynamics (Ashmore & Knapp, 1999; Egeler, 2019; Ingold, 1993; Johnson, 2012; Martín Civantos, 2008). Thus, human agency, with its social and symbolic dimensions, is also part of the landscape. Therefore, landscapes are both social and cultural (Giacomorra, 2006, p. 34). Ancillary to this premise is the temporality of landscapes, which, in a sense, resonates with Crumley’s concept of longitudinal research (McGovern et al., 2019). If landscapes are reflections of human action throughout history, then the social actions in a place over time add different modifications and additions to the landscape – they are historical palimpsests (Martín Civantos, 2011; Tello, 1999). From this perspective, landscapes are (partly) the epidermal manifestation of economic, cultural, and political changes; i.e. they are historical, cultural, and socio-economic (Criado-Boado, 2017; Martín Civantos, 2008, 2011) and should be analysed a la *longue durée*.

It can be argued, in sum, that landscapes are the product of historical and dialectical interrelationships between humans and non-humans. They are historical socio-ecosystems (Martín Civantos, 2018), and hence, the “spatial manifestation” of humans and non-humans through time (Ray, 2019). Applied to our study, this requires understanding key cultural aspects of movement while recognising the embeddedness of non-humans in such a process.

3 Materials and Methods

3.1 Case Study: The Marmarica Region (NE-Libya/NW-Egypt)

Considering the scope of this article, we have selected the region of Marmarica, present-day northeastern Libya and northwestern Egypt (Figure 1). The purpose is to illustrate the potential of our theoretical and methodological approaches for a better understanding of past movements and historical interactions. In this way, we can illustrate how these procedures can be applied in a specific context and demonstrate their results in practice.

3.1.1 Sources and Data Acquisition

Our study required sources and data, including legacy data, of different natures to cross-check and obtain further archaeo-historical and environmental information about this northeastern African region. Therefore, integrating published field data surveys, archaeological reports, maps, historical aerial photographs, and satellite imagery has proven valuable. These resources have been particularly useful in identifying scattered archaeological remains and traditional paths, which are typically considered *proxies* for inferring the human mobility of communities across landscapes. Moreover, environmental and geographical indicators can be reconstructed from these resources, thus allowing for a more holistic approach in line with our theoretical framework.

The identification of these archaeological remains in the specific case of Marmarica draws upon a variety of sources, most notably the aerial photographs taken by Squadron 113 of the Royal Air Force (RAF). The RAF flew over large stretches of the Eastern Marmarica coast using Hawker Hind Lighter Bomber biplanes from September 23 to November 1, 1938, to map through photographs this strategic region in the pre-war context of the Second World War (Ray & Nikolaus, 2022). These photographs provide a unique snapshot of the landscape and environment. Another crucial source of information is the cartography used, primarily based on a series of maps produced by the US Army Map Service that covers the entire study area and dates from the Second World War to the Cold War (Figure 2). Specifically, the P502 series (1954) of the US Army Map Service, 1:250,000 stands out. This latter series derived from the information provided by the Middle East Command maps produced in 1941–1942, which were based on the information collected in 1916 by the "Survey of Egypt" for the territories covering northeastern Africa (Vetter, Rieger, & Nicolay, 2014, p. 44).

The information gleaned from these sources is of great relevance for two main reasons. First, it provides insights into both human and non-human agents, encompassing topographic and hydrographic features, as well as the exact locations of ancient settlements, burial sites, productive areas, traditional routes, and so on. Second, the collected information predates the large-scale agricultural, urban, and industrial developments that took place in this region from the second half of the twentieth century. As such, these data provide a valuable record of landscapes that no longer exist or that have undergone significant changes over time.

Two comprehensive datasets were developed to collect and process the archaeo-historical and environmental information within a GIS framework (ArcGIS 10.5). This was done in order to systematically record the archaeological sites and traditional paths that were identified. The first dataset integrates the information

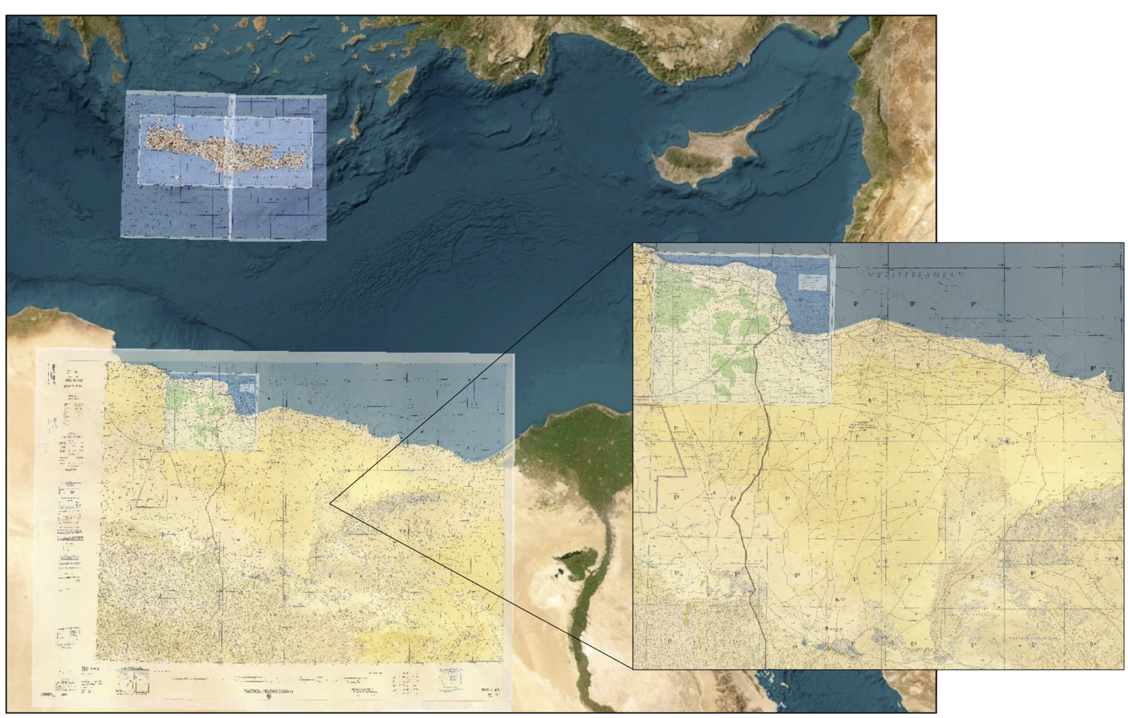


Figure 2: Georeferenced historical topographic maps of Crete (Greece) and Marmarica (northeastern Libya/northwestern Egypt) (Basemap: © ESRI).

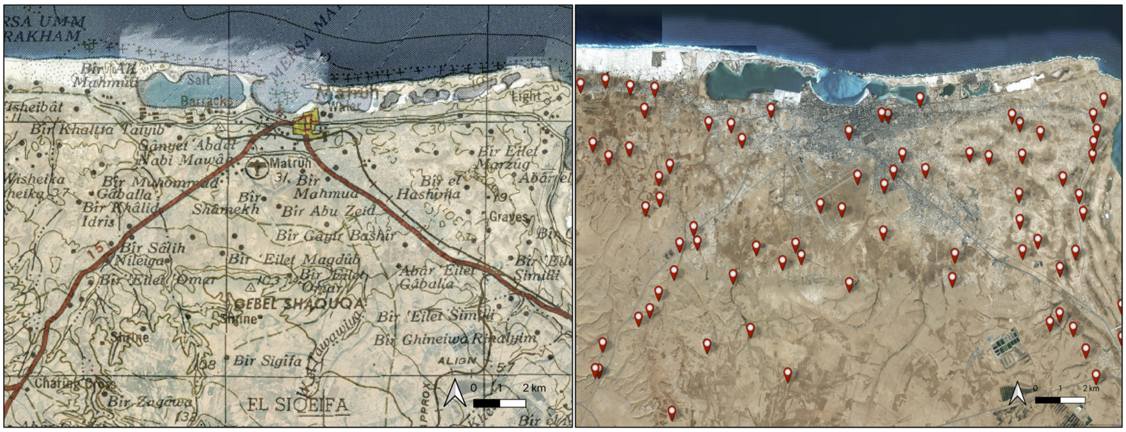


Figure 3: (Left) Topographic map from 1954, US Army Map Service (P502, Sheet NH 35-3 Matruh). (Right) Spatial distribution of digitised sites covering the Marsa Matruh area (Basemap: © ESRI).

associated with each archaeological site, considering the variables listed in Table 1. The second dataset contains information related to historical routes, considering the variables listed in Table 2.

The subsequent step involved mapping the terrain surface using remote aerial survey techniques. GIS was used to georeference a variety of historical sources, including topographic maps, historical aerial imagery (as detailed above), field survey data, and published archaeological reports. Control points located on the surface were systematically used to select easily identifiable topographic features, which allowed precise linkages in terms of geospatial position. The study area was then divided into $10 \times 10\ km^2$, within which a thorough remote aerial survey was conducted by crosschecking our sources and imagery. Thus, GIS was instrumental in allowing us to obtain precise information on the locations of archaeological sites and historical paths (Figures 3 and 4).

This process also included the identification of topographic and hydrographic elements, for instance, integrating various digital elevation models (DEMs) and generating the hydrographic network (rivers, wadis,

Table 1: Sites database's record structure

Variable	Type	Example
ID	String	PE_00004
Zone	Numeric	2
Modern_Name	String	Zawiyet Umm el - Rakham
Old_Name	String	Unknown
Coord_x	Numeric	27.025833
Coord_y	Numeric	31.4
Accuracy	String	High
Validation	Numeric	4
Type	String	Settlement
Subtype	String	Fort
Eco_Zone	String	Coastal zone and northern tableland
Risk_Level	String	High
Cod_Risk	String	5, 6, 7
Remains	Dichotomous	Yes
Chronology	String	Late Bronze
Keywords	String	New Kingdom, Ramesside period, Cannanite amphora, Stirrup-jar, Temple
Description	String	Located on the Marmarica coast of Egypt, 20 km to the west of Marsa Matruh. During the Ramesside period, it was the location of a major fort which probably marked the western extent of Egyptian influence
Biblio_ref	String	(Snape, 2003, pp. 19–20; Nielsen, 2017); http://vici.org/vici/21476

Table 2: Routes database's record structure

Variable	Type	Example
ID	String	PE_NET0004
Zone	Numeric	2
Name	String	Masrab Istabi
Start_point	String	Marsa Matruh
End_point	String	Siwa
Length	Numeric	308
Type	String	Main route
Cod_type	Numeric	3
Knowledge	String	Demonstrable
Cod_know	Numeric	3
Aegean_chr	String	Iron Age
Egypt_chr	String	Third Intermediate period
Description	String	Digitization based on satellite imagery, cartographic, and survey data
Biblio_ref	String	US Defense Mapping Agency Aerospace Center. 1991. TPC H-4B, Egypt. [Tiff]. 1:500,000. (Vetter et al., 2014, p. 477; Grosskopf & Rieger, 2019, p. 54; Rieger, 2017, p. 54)

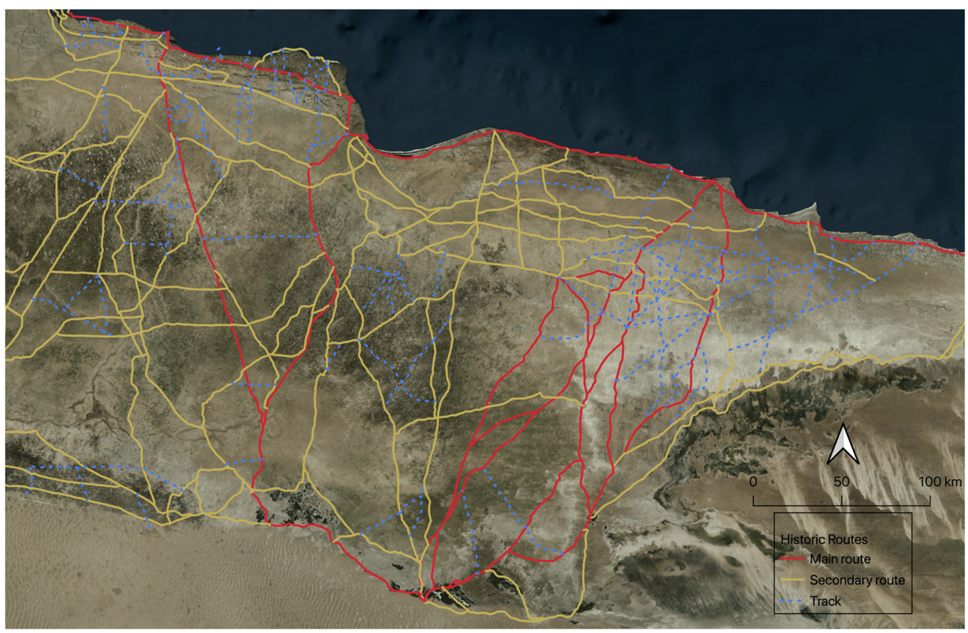


Figure 4: Digitisation of historical routes and traditional paths in Marmarica. This process involved various historical sources and aerial imagery (Basemap © Microsoft).

potentially floodable areas, etc.) from them. This highlights the importance of GIS in facilitating a comprehensive evaluation and systematisation of data related to not only archaeological sites and historic routes but also geographic and ecological *factors* (Figure 5). It additionally enables the analysis of multivariate data, thereby contributing to the reconstruction of how these communities (humans) moved across the landscape, while considering other (non-human) agents that influenced and were involved in these dynamics.

3.1.2 (Re)constructing Past Movements

Besides GIS, the specific application of spatial analysis and network research are also fundamental in achieving our aims. Accumulated cost surface analyses have proven to be highly useful, and among them,

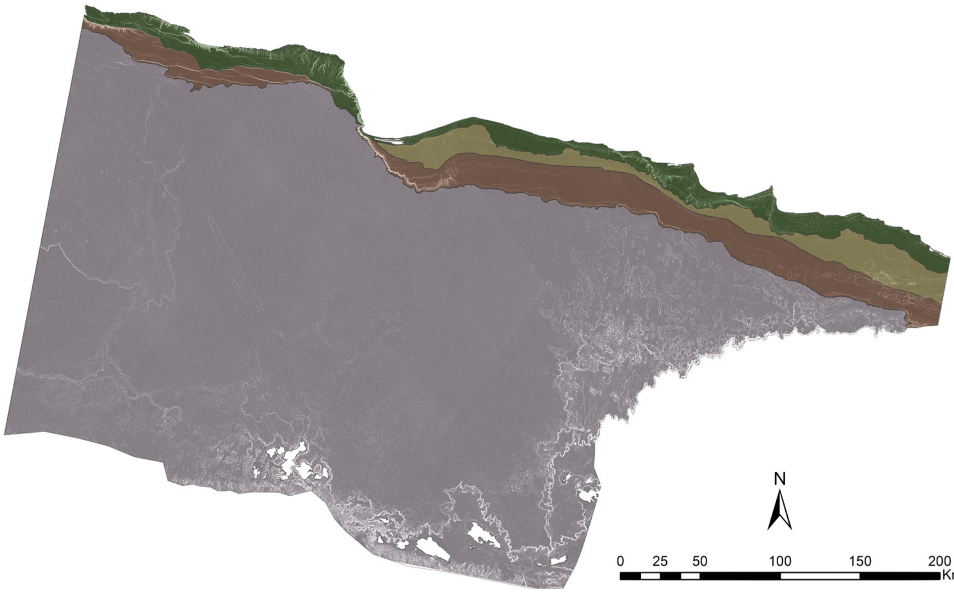


Figure 5: The project delineated the diverse ecological contexts of the Marmarica region, encompassing a range of landscapes defined by the coastal zone, Northern tableland, the Pre-Marmarican Plain, Marmarica Plateau, and desert margins (based on fieldwork conducted on the Eastern Marmarica Plateau in northwestern Egypt (Rieger, 2023)). These contrasting ecosystems contribute to the unique biodiversity and environmental significance of the region as a whole.

the use of FMN has yielded highly satisfactory results in several case studies for different contexts (Aceituno & Uriarte, 2019; Déderix, 2016; Fábrega-Álvarez, 2006, 2016; Llobera et al., 2011; Moreno-Navarro, 2022; Pažout, 2017; Stančo & Pažout, 2020; among others). Other methods for reconstructing and studying past movements, such as least cost path, have the limitation of starting from known sites as origins and destination points from which to establish routes (Fábrega-Álvarez & Parcero-Oubiña, 2007; Güimil-Fariña & Parcero-Oubiña, 2015; Maniére, Crépy, & Redon, 2020; Verhagen & Jeneson, 2012; Verhagen, Nuninger, & Groenhuijzen, 2019; among others). Therefore, given that the nature of archaeological data makes our sample always biased and unequal, we tend to overrepresent specific zones within the study area. By contrast, FMN can overcome the limitation of not having high reliability regarding all the archaeological sites in a given region or even not knowing them due to various issues such as lack of reliable dating. As discussed below, this method is based on the application of hydrological and cost–distance analysis tools, resulting in pathways or routes with potential flow accumulation, i.e. movement potential. Additionally, this method allows us to obtain accumulation values that are key to applying network approaches to our data and research aims.

Spatial analysis first requires identifying the *factors* influencing mobility and the temporal changes in landscapes. Our case encompasses a vast region located in northeastern Africa, predominantly characterised by flat terrain and arid and semi-arid conditions. Consequently, the *factors* affecting mobility for our study were (i) the physical and topographic characteristics of the terrain surface, such as elevation, slope, and the presence of valleys, plains, and plateaus; and (ii) the hydrographic network, which includes elements such as rivers, water catchment areas, and the presence of wadis (i.e. dry streams or channels with seasonal flood potential typical of arid and semi-arid regions).

Table 3: Variables that affect mobility in the Marmarica region and the mechanisms to quantify each of them

Variables	Description
Slope	Percentage of slope based on orography
Water catchment sources (Cisterns + Wadis with higher potential flooding)	Gradual increase in resistance the further away from water sources, until a maximum value similar to a 10% slope is reached at 5 km from the water points
Wadis	Gradual resistance to crossing

After clearly defining the *factors* affecting mobility for our case, the next step was to establish precise mechanisms to quantify each one. The goal was to create a friction or cost surface map that represents the difficulty of moving across landscapes. In the case of Marmarica, due to its semi-arid and arid conditions, the presence of water catchment areas, wadis, and slopes are particularly relevant to consider (Table 3). Thus, each *factor* was quantified depending on the spatial context, for, as the principle of heterarchy states, not every agent is equally relevant (in this case, for human mobility); the significance varies according to the spatiality.

A comprehensive friction or cost surface map should not only represent the physical characteristics of the terrain but also embed a mobility function to simulate movement across different landscapes. This is critical for the model to reflect the complexities of historical mobility accurately. To this end, Naismith's rule (1982) was applied as a foundational component of the mobility function. This function provides duration estimation by positing that a travel cost (i.e. time and effort) is expected to double for every 12% increase in slope. This rule was instrumental in the calculation of our final friction map, providing a nuanced view of how topography impacts mobility (Figure 6). Our choice is not arbitrary; it is grounded on the recognition that human movement is a key factor influencing mobility along transport routes. Indeed, it is highly likely that the use of packs or draught animals through these routes was accompanied by people on foot (Verhagen et al., 2019), which emphasises the importance of considering human mobility as a key in our analysis. The implications of this are twofold: not only does it acknowledge the role of humans as active agents shaping the landscape through mobility but it also asserts the critical nature of human mobility patterns in our spatial analysis.

The successful implementation of FMN requires a series of sequential operations following the acquisition of the friction map or surface cost for the region. Initially, it is necessary to generate a mesh or grid of points, which can be achieved by creating a set of random points or an orthogonal layer of uniformly spaced points covering the entire study area (Figure 7). The generated mesh was then associated with a friction map, which was obtained by assigning cost values to each *factor* (Table 3). The following procedure entails executing a sequence of operations using GIS. The first step involved calculating the distance from each point in the mesh to each pixel with respect to the friction layer generated in the previous step. This is followed by the calculation of the flow direction using hydrological tools based on the cost distance layer calculated in the previous step. Finally, the flow accumulation at each point is computed based on the flow direction. All of these

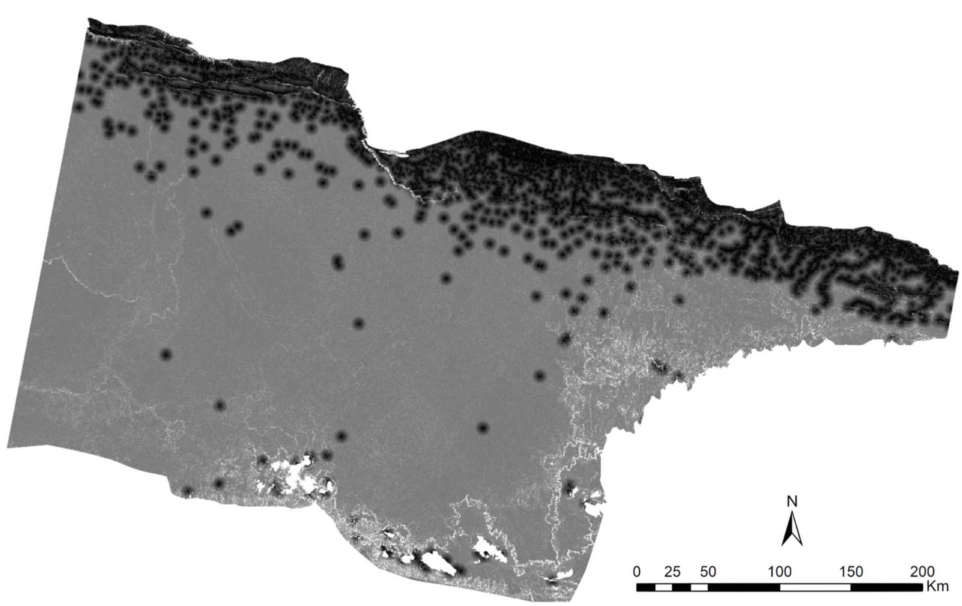


Figure 6: Friction map generated by assigning a gradual cost to the hydrographic network depending on the ecological context and calculating the slope from a DEM. Values are represented using a colour categorisation scheme, with lighter shades indicating greater resistance to movement and darker shades indicating lower resistance. Dark-coloured circles indicate water catchment areas.

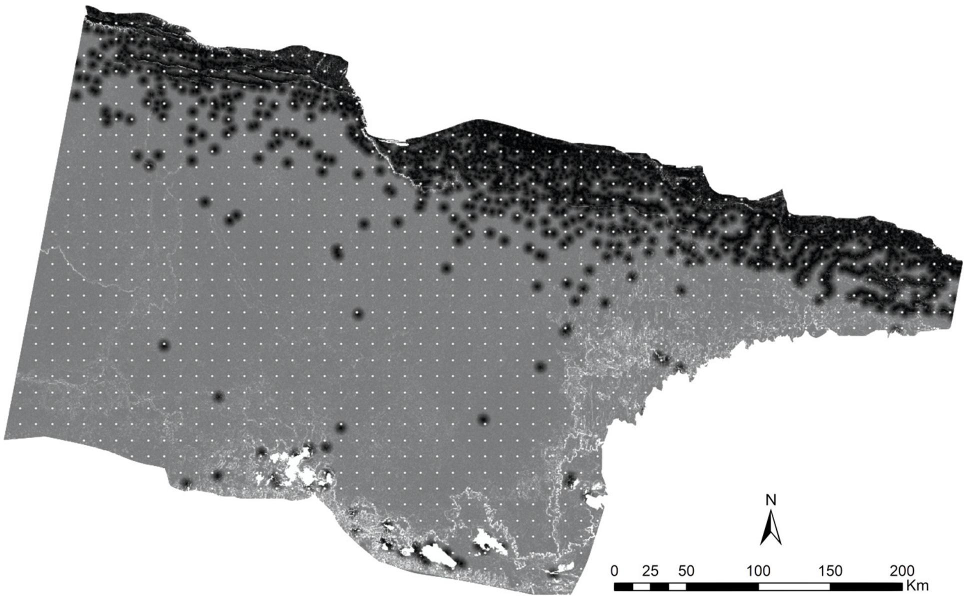


Figure 7: Orthogonal point layer covering the entire study area, with points spaced 10 km apart.

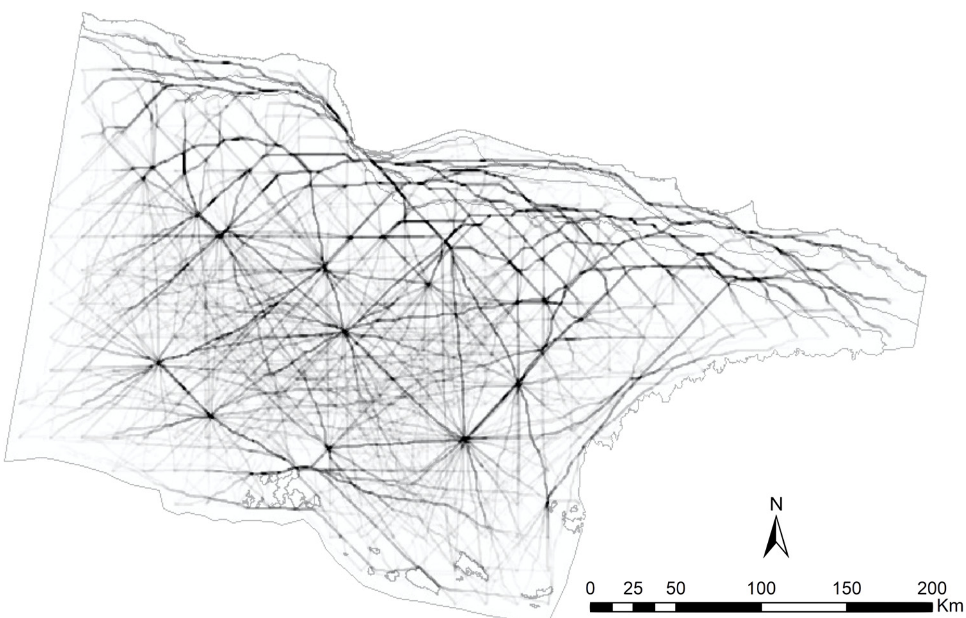


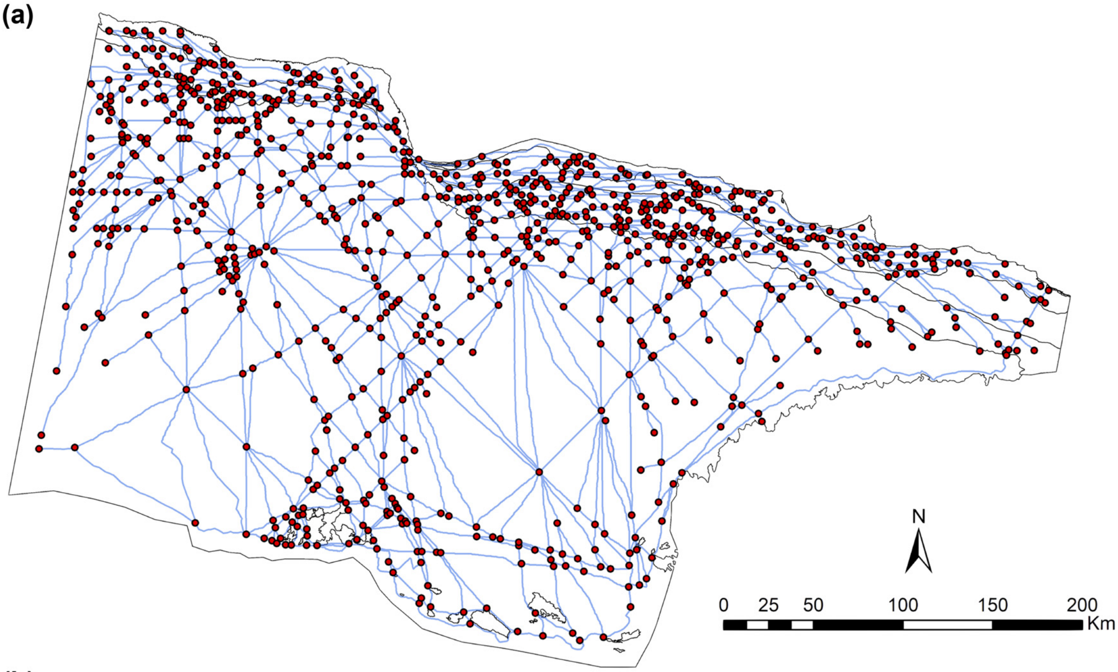
Figure 8: Preliminary results of the application of the FMN. Potential routes are depicted in graduated shades of black based on the accumulation of values obtained.

operations can be automated, leading to the generation of a raster layer for each point, in which the pixel value represents the accumulated flow towards that point. To generate the final network using FMN, the mean value of all layers was calculated, resulting in an integrated layer with the values of the accumulated flow, indicating potential circulation (Figure 8).

3.1.3 Exploring Network Dynamics

The aforementioned procedures provide an opportunity to identify pathways or routes with circulation potential. However, our research focused not only on the archaeological study of routes but also on representing and analysing interaction patterns and connectivity within and between the target regions. To achieve this, we employed network approaches to represent our archaeological data as network data, so that it can be analysed and explored. The reconstruction of possible pathways enhances our understanding of the topological structure of the routes within the region under study, while also obtaining accumulation values that allow measuring the strength of connections between different places based on their potential circulation. This

(a)



(b)

Nodes

FID	ID	Lat	Long
0	1	30.0133716475794	23.0463872773481
1	2	30.081782712399	23.0575622854979
2	3	30.4068977206629	23.1325187921164
3	4	30.9938158099196	23.200347349518
4	5	31.3083422475425	23.1924860205454
5	6	31.3966589831111	23.1889207720026
6	7	31.1260598866348	23.2007379450676
7	8	31.2168107810776	23.1971083783313
8	9	30.026583121649	23.2530749132861
9	10	31.1832523087994	23.2144934683281
10	11	31.2503808855772	23.2317366622134
11	12	31.3536013455963	23.2417071854268
12	13	31.4210771343042	23.2465831444065
13	14	30.6320079504257	23.2849452119061
14	15	31.5804113541049	23.2856889182501
15	16	31.4905215634349	23.2911441983436
16	17	31.8535601376021	23.277618194709
17	18	31.3115734421911	23.3029084673539
18	19	31.1300745549058	23.3392119884722
19	20	31.0532718405928	23.3487560613467
20	21	30.7024227719496	23.3648701714835
21	22	31.7164053480083	23.3315173825847
22	23	31.7928831893629	23.3328810728556
23	24	30.682785101557	23.384958421707
24	25	31.1311678255586	23.3778388987094
25	26	31.3133122207642	23.3737121792176
26	27	30.4563056011432	23.4133876504509
27	28	31.7515815580811	23.3700044260393
28	29	31.8775927998285	23.3793263866524
29	30	32.0339883832107	23.3731776320327
30	31	31.6725962615766	23.3882622383701
31	32	32.1247715203539	23.370539699987

Network_Marma

FID	ID	Endpoint_1	Endpoint_2	Count	Sum	Mean	Std	Range	Length
0	1	63.000000000000000	34.000000000000000	5152	246656000.0000000	47875.8984375	184573.0000000	1766300.0000000	20.8873997
1	2	70.000000000000000	76.000000000000000	1043	218383008.0000000	209380.0000000	692358.0000000	4660810.0000000	4.1454201
2	3	90.000000000000000	121.000000000000000	4151	490318016.0000000	118121.0000000	509327.0000000	5668720.0000000	16.8859005
3	4	112.000000000000000	171.000000000000000	7507	1318390016.0000000	175622.0000000	812935.0000000	9191820.0000000	30.4881992
4	5	32.000000000000000	61.000000000000000	2760	392652992.0000000	142266.0000000	518391.0000000	3196190.0000000	14.2539997
5	6	54.000000000000000	61.000000000000000	402	392652992.0000000	142266.0000000	518391.0000000	3196190.0000000	4.2722702
6	7	61.000000000000000	76.000000000000000	1824	382580000.0000000	209748.0000000	808366.0000000	5486190.0000000	9.9228802
7	8	61.000000000000000	79.000000000000000	2791	70544400.0000000	25275.6992188	79683.7031250	645239.0000000	14.4267998
8	9	76.000000000000000	121.000000000000000	4992	907782016.0000000	181847.0000000	789769.0000000	5038220.0000000	22.9090004
9	10	229.000000000000000	237.000000000000000	1298	95364704.0000000	73470.5000000	218216.0000000	1315670.0000000	5.2620902
10	11	556.000000000000000	565.000000000000000	1506	46982400.0000000	31196.8007813	137308.0000000	1595920.0000000	6.0715699
11	12	565.000000000000000	569.000000000000000	783	13315600.0000000	17005.9003906	65758.5000000	433275.0000000	3.1937599
12	13	614.000000000000000	630.000000000000000	1787	310780992.0000000	173912.0000000	584414.0000000	4053210.0000000	7.2536702
13	14	433.000000000000000	424.000000000000000	1425	2989040128.0000000	2097570.0000000	8714060.0000000	55307400.0000000	5.7980099
14	15	448.000000000000000	458.000000000000000	1851	177391008.0000000	95835.1015625	436614.0000000	5316990.0000000	7.6305199
15	16	343.000000000000000	364.000000000000000	2449	66285300.0000000	27066.3007813	90865.1015625	1009070.0000000	9.9408903
16	17	393.000000000000000	413.000000000000000	1925	50227300.0000000	26092.0996094	84641.2031250	657742.0000000	7.7933102
17	18	667.000000000000000	677.000000000000000	2780	15021600.0000000	5403.4399414	12521.7001953	287109.0000000	11.2658005
18	19	639.000000000000000	677.000000000000000	6631	873326976.0000000	131704.0000000	2582840.0000000	79608304.0000000	27.3243008
19	20	615.000000000000000	639.000000000000000	3818	243239008.0000000	63708.3984375	742434.0000000	25344200.0000000	15.6168003
20	21	571.000000000000000	615.000000000000000	7406	69413296.0000000	9372.5800781	20023.0996094	211239.0000000	31.1872997
21	22	540.000000000000000	571.000000000000000	3628	75040200.0000000	20683.5996094	63414.5000000	568790.0000000	14.8557997
22	23	403.000000000000000	442.000000000000000	6421	1218790016.0000000	189814.0000000	1347010.0000000	51756200.0000000	26.7889996
23	24	442.000000000000000	490.000000000000000	8749	201055008.0000000	22980.4003906	76560.7968750	1758660.0000000	35.6407013
24	25	490.000000000000000	540.000000000000000	7722	1502809984.0000000	194614.0000000	1297390.0000000	32245500.0000000	34.3056984
25	26	485.000000000000000	490.000000000000000	1725	814731008.0000000	472308.0000000	1633720.0000000	24117400.0000000	9.2979498
26	27	122.000000000000000	206.000000000000000	22857	276679008.0000000	12104.7998047	46818.8007813	1266340.0000000	92.4297028
27	28	206.000000000000000	133.000000000000000	7360	172992000.0000000	23504.4003906	97911.7968750	904980.0000000	32.3834000
28	29	133.000000000000000	9.000000000000000	19786	284012000.0000000	14354.2001953	67740.0000000	985626.0000000	80.2723999
29	30	9.000000000000000	1.000000000000000	4868	30021000.0000000	6167.0000000	13526.0996094	116747.0000000	20.1110001
30	31	549.000000000000000	638.000000000000000	24058	553841984.0000000	23021.0996094	118902.0000000	3777800.0000000	97.4465027
31	32	704.000000000000000	684.000000000000000	2963	3703470080.0000000	1249910.0000000	9940830.0000000	172810000.0000000	12.3456001

Figure 9: (a) Topological network (in blue) of the Marmarica region obtained by processing results from the FMN approach and generating nodes at each intersection. The endpoint of each route segment is represented as a node (in red). (b) Table showing the different metrics calculated using statistical tools and integrated into network attributes.

is particularly significant in our study, which relies on spatial networks (Brughmans & Peeples, 2020), as connectivity is determined not by the number of connections between specific places but by the intensity of those connections.

Network science can inform us from additional angles of different patterns and explore the structure of our region's relationships between places. However, prior to applying network science methods to our data, a sequence of preparatory steps must be carried out. First, it is necessary to review and correct topological errors that may have arisen during the network generated using FMN. These errors include fragmented segments and discontinuous intersections (Figure 8). This process is essential for obtaining a network that generates the least possible distortions when analysed. Second, our research necessitated the development of junction nodes that indicate the points at which each route segment or section ends (Figure 9a). This is because our goal was to study the network structure independently, treating each segment or section as an entity to be analysed.

The subsequent step involved integrating the corresponding values for each network segment. These values include the area, number of cells, sum, mean, standard deviation, range, and length for each segment (Figure 9b). The statistical analysis tools provided by GIS have allowed their calculation, which in turn allows us to integrate them as attributes associated with our network. In this way, we can correlate both, nodes and metrics, for each segment. The outcome is a layer representing our network for the study region and, most importantly, a network containing all the necessary information to carry out network analysis.

At this stage, we can delve into the exploration of our data using different techniques, simulations, and analyses through network visualisation software (Visone v. 2.24.1) to explore our networks from different configurations and structures (for various methods, see Brughmans et al., 2023; Brughmans & Peeples, 2023). For example, we can explore the role of nodes based on their positions and relationships with others within the network structure (Figure 10).

In our approach, the application of centrality measures has provided key insights into the structure and function of a network (Freeman, 1979). Centrality measures, such as "betweenness centrality," were used to evaluate the influence of a node within the network structure (Figure 11a). This metric allows us to assess the relevance of a node in terms of its position based on the number of times this specific node acts as

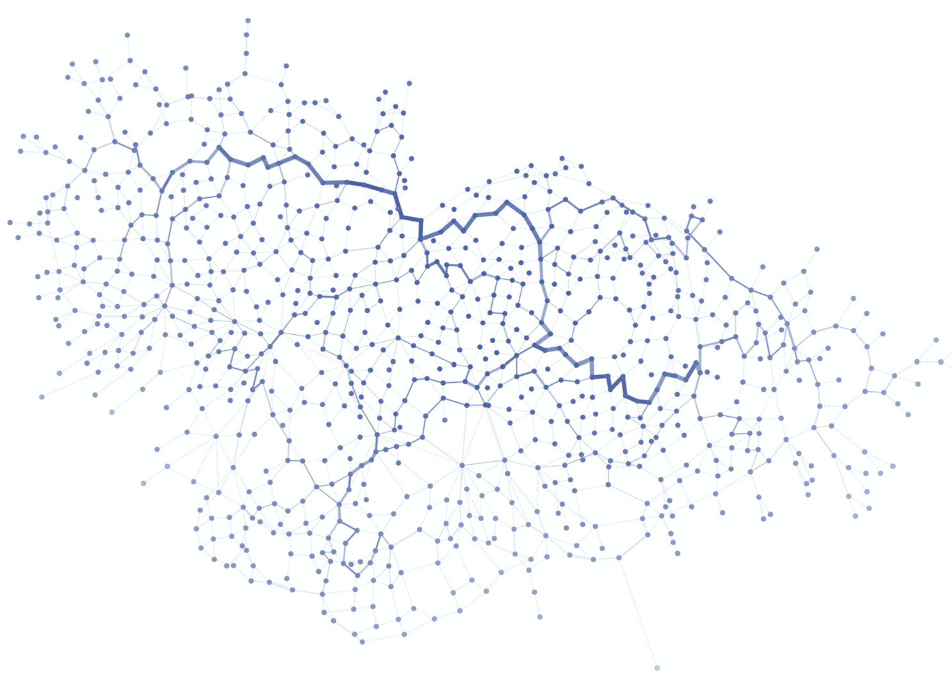


Figure 10: Network representation of the Marmarica region. Nodes (in blue) have been freed from their geographic position, allowing a visualisation based on the strength of their connections and the number of links within the network.

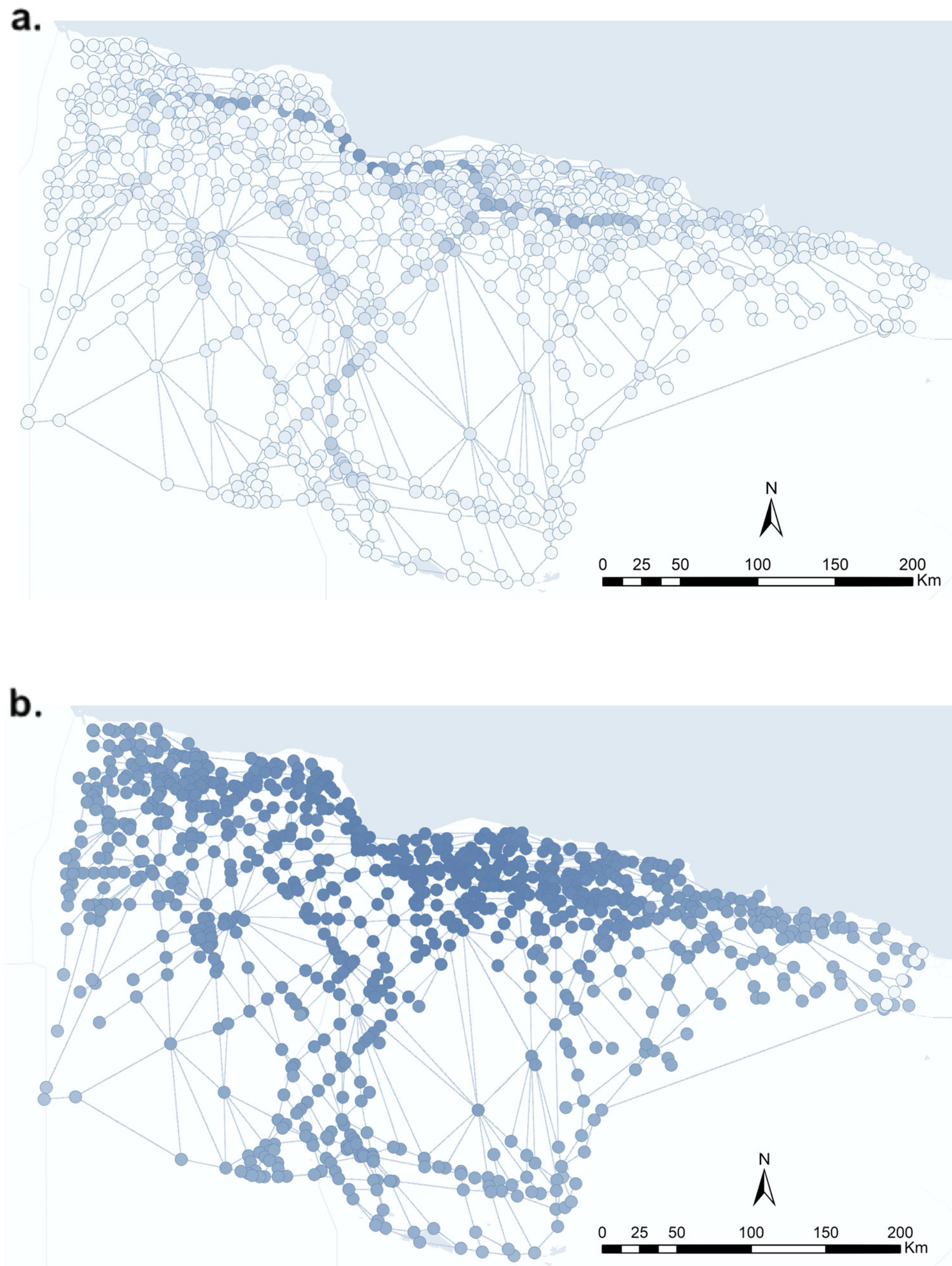


Figure 11: Representation of the mobility network in the Marmarica region with nodes in their geographic position. (a) Nodes are gradually represented according to the betweenness centrality. Higher values are clearly observed along the coast and the central connection towards the inland oasis. (b) Nodes are gradually represented according to the closeness centrality. Higher values are again clearly observed along the coastal area.

an intermediary between the nodes. Nodes with high betweenness centrality are considered key points because they are essential for the flow and connection between different areas of the network. Another important centrality measure is "closeness centrality," which is used to quantify the proximity between nodes (Figure 11b). Nodes with high closeness centrality indicate how close they are to each other and are important for fast and effective communication across the network (Brughmans et al., 2023). Analysing various network metrics was therefore crucial, as they enhanced our understanding of the network dynamics.

4 Results and Discussion

Our results have significantly expanded the available archaeo-historical information on these regions. By using digital research methods and techniques, we were able to reach and cover areas that would otherwise have been inaccessible. This allowed us to exhaustively compile, evaluate, and systematise heritage data published on known archaeological sites as well as locate and record previously unknown sites, such as ancient settlements, burial sites, or historic resource catchment areas. As a result, this has allowed the recording of more than 3,000 archaeological sites, which in turn has shed light on settlement patterns and human occupation within these areas. Moreover, by associating each site with its ecological context, we gained a better understanding of the interrelationships between human and non-human agents across landscapes and the biocultural heritage that they represent. However, the chronological resolution of the data should be considered; it must be noted that certain areas lacked the necessary fieldwork to establish fine-grained chronologies for many of our sites. This may limit the accuracy of our accounts for shorter time periods and requires further investigation.

Our study also obtained significant results regarding mobility and interaction patterns within these regions through spatial analysis and network science. In the case presented in this article, our results demonstrate that coastal areas exhibit greater connectivity than inland zones. Similarly, these areas present a high concentration of multi-period sites that tend to align with regions where mobility is more prominently articulated. This fact is evident in areas surrounding present-day Tobruk in Libya, Sollum and Marsa Matruh in Egypt, and, to a lesser degree, around the oases of Siwa (Egypt), and al-Jaghbub, (Libya). Additionally, we identified connections that followed the north–south and east–west axes between the same coastal areas and the hinterland oasis. These connections are evident from the existence of short-, medium-, and long-distance communication structures (as illustrated in Figures 8, 9, and 11). These results are crucial to the reconstruction of mobility and patterns of interaction, which might have contributed to the development of settlement and subsistence strategies for the communities that moved across these landscapes. The spatial distribution of these concentrated potential routes, compared to the distribution of archaeological sites, suggests a propensity for settling in proximity to key socioeconomic focal points, such as maritime ports, agricultural lands, or the borders of political territories. Consequently, these regions primarily functioned as attractors within a complex network system, facilitating connections with the surrounding territories over the long term.

It is important to note that the mobility model presented does not respond to analyses conditioned by the presence of archaeological remains and rather yielded from independent modelling: sites' location and distribution were obtained by site mapping through remote aerial survey, whereas our movement model was obtained by applying FMN analyses. Consequently, the results from our modelling have the potential to reflect how movement occurs not just because of human settlements but also due to—in conjunction with—non-human agents. The same reasoning applies to the location of settlements and of the spatial structure as a whole. Thus, the convergence of areas that articulate mobility and of archaeological sites respond to complex patterns of human–non-human entanglements and not just to "simpler" reasons (e.g. this pathway is here because there is a settlement nearby). Our study exemplifies this by applying approaches from complex systems (integrating HE, GIS spatial analysis, and network science) to study past movements and interaction patterns.

Complex systems are characterised by interdependence and feedback between their components, which often exhibit emergent behaviours that cannot be explained by examining individual components in isolation. Connecting with our theoretical framework, this emergence is caused by non-linear dynamics. Think, for instance, how our analyses and models embed ecological zones, terrain relief, settlements, or water catchment areas (some of which are constituted by both humans and non-humans). None of these factors, in isolation or combined in pairs, can explain the spatial structure exhibited by Marmarica. It is rather the summatory combination (non-linearity) of all of them, measured independently and differently (heterarchically), what causes the emergence of new behaviours (in this case, human movement). In our case, the non-linearity of the agents involved in (the emergent behaviour of) mobility has been represented through a network approach.

The movement of people through a series of landscapes can thus be better understood by adopting a complex systems approach. Historical mobility can be understood as complex systems where people's movements are influenced by a wide range of *factors*, including social, economic, and environmental. Such an approach points towards understanding migrations as the intertwinement (mutual agency) of human and non-human agents, even in contexts where humans are a priori those who decide (socio-economic reasons). Equally, such an approach enhances our understanding of how these movements influenced their social, spatial, and economic organisations, while considering different geographic and environmental conditions.

Revisiting the Marmarica case study provides a valuable illustration of the underlying theoretical principles and concepts. Our study focused on a vast region with different ecological areas, diverse human communities, and multiple interacting agents. This broad focus is arguably an example reflecting the principles of DONOP. These principles advocate for merging multiple scales, from the local to the supra-regional, to generate a long-term perspective of human–environment interactions. Although this article explicitly focuses on a meso-to-macro level, future work will also allow the integration of local scales. This allows us to reflect on the complex and multidimensional dynamics involved in historical mobility, in our case, chiefly propelled by socioeconomic reasons. We contend that such an integration of multiple chronological and spatial scales to understand movement accounts for different historical cartographies. The interconnectedness of such cartographies, moreover, favours a multi-scale perspective without privileging local over global, or vice versa, and rather supports an analysis of complex dynamics.

Although not stated before, it is also important to note that researchers in HE are committed to generating social outcomes (Costanza et al., 2007; Crumley, 2019; McGovern, 2014; Nelson et al., 2015). This commitment stems from considering that understanding ecosystems from a historical, non-lineal, and entangled perspective might generate insights applicable to the present (Crumley, 2019; Hambrecht et al., 2020; Ray, 2019). The core idea is that a comparative analysis of long-term records of the interactions of human–natural systems might help in the overall effort to understand and ameliorate anthropogenic-driven climate change (Hambrecht et al., 2020). As a preliminary example, our study highlights past ways of movement that are mostly unthinkable in today's globalist present. The obtained mobility patterns reflect the possibility of moving across harsh landscapes without necessarily producing unsustainable changes in the ecosystem. Human movement can thus be performed without a degrading approach towards non-human agents, but rather through more flexible attitudes – societal development should go together with its ecosystem.

5 Concluding Remarks

This article has discussed some of the core tenets of HE and their potential applicability to the study of landscapes from a complex systems perspective. This topic was explored through a case study, whose main aim was to map past movements across the landscapes of significant regions in the Eastern Mediterranean context. Thus, although this study does not directly focus on understanding human ecodynamics, it is influenced by such an approach. We have also shown some possible areas of applicability by factoring non-humans in the archaeological analysis of plausible landscapes of (mainly) human movement. This does not mean to bluntly equalise humans and non-humans for understanding movement but to recognise the fluid force of agents across a multiplicity of contexts.

Drawing on different authors from the remits of HE and Landscape Archaeology, we have argued that landscapes are complex systems due to their diachronical, synchronical, agency, and phenomenological qualities (Criado-Boado, 2017; Fairclough, 2012; Opitz, Nuninger, & Fruchart, 2012; Van Dyke, 2014). Therefore, HE potentially enhances our conceptualisation of the landscape by envisioning them as historical biocultural constructions that involve the participation of human and non-human agents, which are historical socio-ecosystems (Crumley, 2017; Martín Civantos, 2018; McGlade, 1995). Moreover, this study has expounded how non-linearity and heterarchy enable a non-historicistic understanding of the landscape. Landscapes are not the products of concrete or fixed moments. On the contrary, they are dynamic, in continual, non-lineal, flux; in other words, they are the product of a flowing genealogy (*sensu* Criado-Boado, 1988) of human–environment entanglements. Mobility, we have claimed, is to be understood as a dynamic involving humans and non-humans. Although movement comprises many aspects of the human past (e.g. phenomenological practices, practical movement, trade and exchange, flow of information and ideas, etc., in sum, human interactions), human–environment entanglements occur here and there, in every process. Therefore, we argue that Mediterranean archaeological research should account for such interrelationships.

Hamilakis expounded in an interview with Pintucci (Hamilakis & Pintucci, 2021) that understanding migrations needs not to focus just on the people-on-the-move but also on the apparatus itself. This study suggests that the same applies to the underlying human–non-human (eco)dynamics. Movement in general, and migrations in particular, always involve human–non-human entanglements and changes within the system that might affect food security, population distribution, etc. Migrations are not just economical, political, or cultural, but biocultural. Movement and related phenomena such as migrations involve multiple species and diverse spatio-temporal contexts. The entanglement of all this, as well as its impacts, should be accounted for in our narratives. The patterns of interactions shown in this article reflect this and open the possibility of considering the influence movement might have on human and non-human populations or the impacts brought about (e.g. traditional approaches to movement and their impacts on food security, etc.). Thus, there are compelling socio-ecological arguments for considering in our present the impact of movement and migrations from a historical fashion.

Acknowledgments: We are thankful to Maurizio Toscano, from the Spanish Foundation for Science and Technology (FECYT); Pau de Soto, from the Autonomous University of Barcelona; Borja Legarra Herrero, from the Institute of Archaeology at UCL; Tom Brughmans, from UrbNet at Aarhus University; Fernando Moreno-Navarro from the University of Carlos III, and Carlos Rodríguez-Rellán, from the University of Granada, for their invaluable contributions to this project. We are also grateful to the editorial team and two anonymous reviewers for their useful comments and for enhancing the overall manuscript.

Funding information: The PERAIA Project: Landscapes, Networks, and Society along the ancient Libyan Sea has been funded by the Spanish Ministry of Universities (FPU17/06503) and the Vice-Rectorate for Research and Knowledge Transfer of the University of Granada (Ref: PPJIB2020.18).

Author contributions: This article has been written collaboratively by both authors.

Conflict of interest: The authors state no conflict of interest.

Data availability statement: All the data and associated information are available at https://peraia.ugr.es/gazetteer/ and https://zenodo.org/record/7678852.

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