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Challenges in Palaeolithic Spatial Archaeology: Two Eurasian Case Studies

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Abstract

Palaeolithic applications of Geographic Information Systems (GIS) are increasingly common, however, theoretical discussion specifically addressing issues of Palaeolithic GIS is practically non-existent. In this paper, we argue that such a discussion is necessary because Palaeolithic applications of GIS are subject to unique conditions and challenges. We specifically highlight the issues of data quality, the vast spatio-temporal scale, and the difficulty of interpreting patterns of hominin behaviour in relation to the first two conditions. We illustrate and discuss these problems as they related to our own doctoral projects, studying Lower Palaeolithic dispersal and occupation first in Central Asia and then in the Aegean (NE Mediterranean). We discuss the methodological approaches we took in tackling the major topics of our study regions, and identify several commonalities in the difficulties we faced implementing them. In concluding, we define three 'challenges' of Palaeolithic GIS, and three 'temptations' arising out of those challenges.

Keywords: Palaeolithic, GIS, dispersal, landscape, affordances, accessibility

Introduction

Palaeolithic researchers today are using Geographic Information Systems (GIS) at many different levels of research, such as in site prediction, prospection, and survey (e.g Cuthbertson et al. 2021; Jennings et al. 2015; Sauer, Stott and Riede 2018, in combination with remote sensing see Breeze et al. 2015, 2016, 2017), intra-site spatial analysis (e.g. Coil et al. 2020; García-Moreno et al. 2021; Neruda 2017), and in reconstructing palaeolandscapes, resources, and dispersals (e.g. Field and Lahr 2005; Field, Petraglia and Lahr 2007; Holmes 2007; Li et al. 2019; Tsakanikou, Galanidou and Sakellariou 2020). However, there is very little explicit discussion on what that usage means for the discipline, in what ways that usage may be unique in comparison to later periods, and how that usage might be directed into the future. An example of what such a discussion would look like can be seen in an informative paper published by Anemone et al. (2011). The paper reviews a number of applications of GIS in palaeoanthropology, showing how palaeoanthropological questions can be addressed using geospatial analyses, but also how spatial analysis itself can provide innovations to the framework of palaeoanthropological research. Palaeolithic archaeology has not yet had a similar 'watershed' moment of self-reflection centred on Palaeolithic applications of GIS.

Common challenges that the present authors faced during our doctoral projects highlight some of these issues as they relate to applications of GIS in the Palaeolithic. We both tackled broadscale dispersal topics for our projects, and discovered in discussion that we had many similarities in the challenges we were encountering. We wondered if these were broader issues faced by other practitioners, and were surprised when we found little to no body of literature addressing them.

This was the starting point for us organising the

CAA2018 session 'Palaeo-GIS', because we wanted to bring together practitioners of Palaeolithic GIS to get an assessment of the 'state of the art', and to gauge interest in a theoretical discussion grounded in Palaeolithic applications. We also wanted to see if ideas for future development of the sub-discipline could be discussed, and if we could propose some of our own. The reception of the session was very positive, and underlined the need for such a discussion to take place.

Although Palaeolithic applications of GIS can be broadly divided into fieldwork-focused projects and desk-based analyses, many of the researchers doing Palaeolithic GIS are also Palaeolithic fieldworkers performing data collection, which is not always the case in other areas of archaeological GIS. This practical focus suggests that currently innovation in Palaeolithic GIS emerges primarily from technological innovation (such as the use of drones, remote sensing data, etc.) rather than innovations in Palaeolithic spatial theory. These factors heavily favour a view of prospection and predictive mapping as the primary aim of GIS in Palaeolithic research, while later periods have arguably achieved a wider range of theoretical and methodological concerns decades earlier (for a variety of examples see Lock 2000; Lock and Stančič 1995).

It is our contention that Palaeolithic applications of GIS deal with unique issues in comparison with GIS applications of other periods, and that these issues are chiefly caused by three main factors;

Firstly, unique uncertainties are introduced by the fragmentary nature of the record and the unevenness of the coverage. Coping with the incompleteness of the data available requires serious consideration of how certain spatial analyses might be applied, whether certain analyses are valid at all for such datasets, and requires careful consideration of the validity of reconstructing datasets.

Secondly, the vast spatio-temporal scales that Palaeolithic contexts require for their study is something that Palaeolithic research shares with no other period of archaeological study. The struggle of implementing concepts such as deep time and continental dispersal within spatial analysis is not something that later period archaeology deals with to the same extent. However, it is a struggle that Palaeolithic researchers share with geologists, and much value may lie in an approach combining concepts from both in spatial analysis.

Thirdly, both the spatio-temporal scale and the fragmentary nature of the dataset affect the resolution of questions and behavioural interpretations (adaptive and evolutionary) that are possible in Palaeolithic applications of GIS.

There is a substantial lack of theoretical consideration supporting Palaeolithic applications of GIS, and the present authors contend that the development of such a body of research is doubly necessary to address the unique issues of such applications, not least of all those three main factors outlined above.

Although intra-site spatial analysis is also a very common application for GIS in Palaeolithic periods, our focus here is on landscape-level applications. Using two case studies from the Lower Palaeolithic peopling of Eurasia, firstly in the area of Central Asia and secondly in the area of the Aegean, we will illustrate the problems we faced in the course of our projects, and our thoughts on possible future directions for Palaeolithic applications of GIS.

Lower Palaeolithic Central Asia and the Northern Dispersal Route

Central Asia represents a challenging region for discussions of Lower Palaeolithic dispersal in Asia. The region is bracketed by significantly older dates to the west and east. The oldest widely-accepted securely-dated sites currently known in Asia are Dmanisi (Georgia, 1.8 Mya, Ferring et al. 2011) and Shangchen (China 2.12 Mya, Zhu et al. 2018). However, the oldest dated site in Central Asia is no older than about 1 Mya (Ranov and Dodonov 2003). This is notable because Central Asia lies on roughly the same latitude as these older sites, and is a known migration route in later periods, the eponymous silk road. Substantial mountainous and desert zones are also likely to have constrained hominin movement through the region.

The primary causes of this pattern could be taphonomic, a result of investigation bias, or a result of Pleistocene environmental dynamics. This question was investigated by reconstructing elements of the early Pleistocene environment in Central Asia, and using versions of the concept of 'affordances' and accessibility analysis to interrogate that environmental dataset. Three challenges in particular presented themselves relating to the three main factors highlighted earlier;

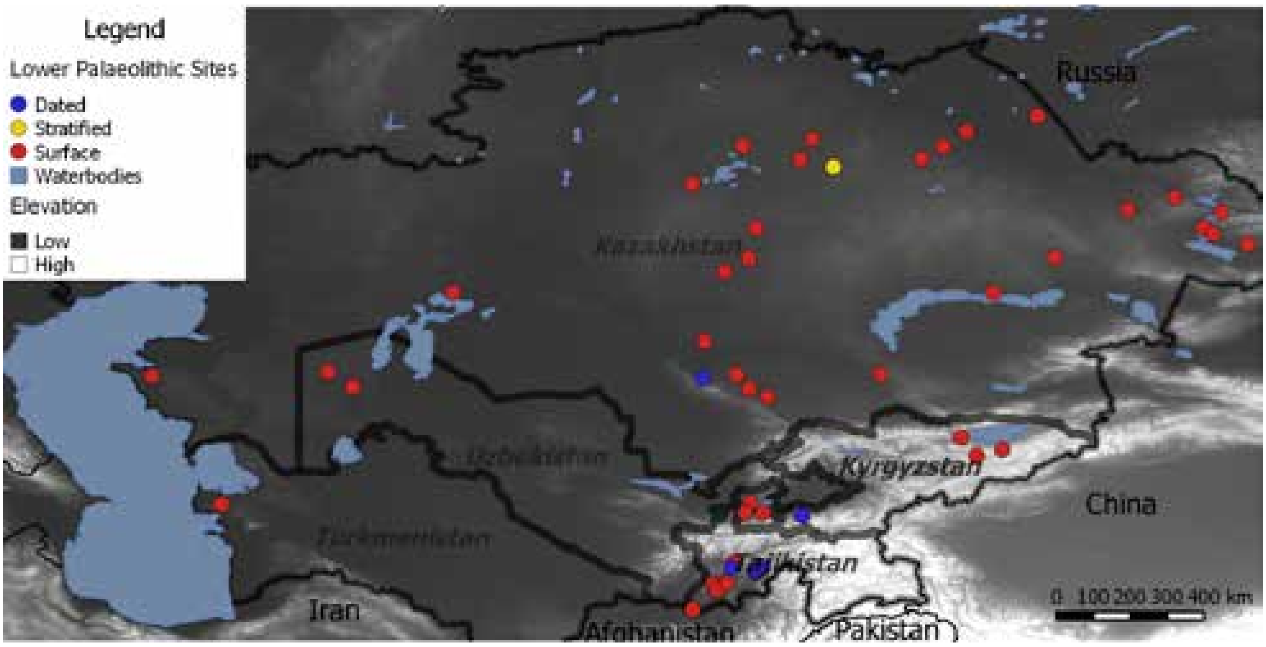

Figure 1. The study region of Central Asia includes the modern boundaries of Kazakhstan, Kyrgyzstan, Tajikistan, and Turkmenistan. The heavily clustered nature of the few Lower Palaeolithic dated sites in the study region provided a substantial challenge for analysis. This map includes data provided by M. Glantz, T. Beeton, S. Temirbekov, & B. Viola. Global Administrative Areas (GADM), developed by Robert Hijmans and colleagues. Made with Natural Earth. Free vector and raster map data @ naturalearthdata.com. Shuttle Radar Topography Mission (SRTM) Version 4, Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org. Map produced using QGIS 2.18.9.

1. How to deal with variability in preservation and data coverage, particularly because the region has not been extensively investigated previously and existing sites are heavily clustered (see Figure 1).

2. How to deal with a spatio-temporal scale that includes a time-range of almost 900 ky and a continental spatial extent.

3. How to model and interpret patterns of hominin behaviour from such datasets and at such scales.

Data Problems and Best Practice

In the course of this Central Asian Palaeolithic GIS project, two major issues related to data quality were noted early on;
Firstly, there was little certainty about the necessary quality of data and the minimum best practice for data-use. Although several Palaeolithic GIS applications exist in the literature as case studies, very few address data or quality requirements (but see Kamermans and Rensink 1999 for a rare example, and also see Brouwer Burg 2013; Spikins and Engen 2010 for two Mesolithic examples with relevance to Palaeolithic applications).

Secondly, there is a lack of discussion about methodological solutions to uncertainty in the record, and best practice surrounding this issue. A lack of understanding about what constitutes best practice means that students have little support in planning their own GIS projects tackling Palaeolithic research questions. Furthermore, the sub-discipline as a whole lacks clarity for assessing such projects.

A lack of Lower Palaeolithic sites in Central Asia presented a substantial challenge, as only five dated sites are reported, and the dating quality varies between them (see Figure 1). It remains challenging to address this uncertainty in analysis without making unnecessary assumptions, such as introducing arbitrary weighting, or in a way that is not purely a visual representation. Furthermore, all of these dated sites are located in the south-east of a very large study region. This clustering required careful consideration of the analytical methods used and what kinds of assumptions these methods made. A common solution has been simply to ignore dating uncertainty or temporal gaps of thousands of years, and treat sites as de facto contemporaneous, especially in more derived analyses that may be reliant on site location such as least-cost analyses.

The difficulty of acquiring data with coverage over Palaeolithic time periods raises a further challenge surrounding the use of related relevant datasets. The use of a relevant proxy dataset can be a way of overcoming a dearth of data for a chosen spatio-temporal bracket, but exactly how good a proxy dataset should be, and what justifies its use, is still largely undefined as an issue of best practice. This became a crucial question in the use of climate data in the present project for building an affordance surface of Central Asia.

Although numerous sections and cores across the study region contribute a wealth of environmental information for the Lower-Middle Pleistocene, data with a spatial extent (such as that produced by climate simulation models) are rare to non-existent. Although palynological data from a large number of sites was available with reasonable temporal coverage, these are heavily concentrated in the loessic regions of the south and east, in much the same way as the archaeological sites are. Vertebrate remains that may also have helped reconstruct environment were also extremely limited for the timeframe in the study region, surviving poorly in the loess. We regarded these data as too meagre for even an ambitious and experimental modelling procedure. The WorldClim Last Interglacial climate models were the closest, freely available match for my own project (Otto-Bliesner et al. 2006), but only covered the very end of the time range considered. Therefore, it could not account for the numerous oscillations between glacial and interglacial conditions throughout the Lower-Middle Pleistocene, which are sure to have had a profound effect on the amenability of the environment for hominin occupation.

The solution arrived at was to average the monthly WorldClim data together to provide a yearly average for different climate variables, and to then normalise these surfaces to remove the absolute values of the Last Interglacial. Individual absolute estimates from environmental data within the time range were used to 'anchor' these patterns discursively, and provide an idea of the variability within glacial cycles. Literature-based arguments were used to support the idea that the relative patterning of these climate variables was likely to have been broadly preserved, even as the absolute values had certainly changed. More detailed consideration of environmental change could only be approached discursively in the literature review and in the interpretations of the results.

It is unclear in the current Palaeolithic GIS literature what constitutes 'best practice' for data challenges such as these. An explicitly theoretical discussion is not yet established for issues of data quality and best practice in Palaeolithic applications of GIS, and this represents a great omission, particularly felt by young researchers who are attempting to develop in this sub-discipline. It remains an issue that much palaeoclimate data is not available to Palaeolithic researchers in a way that is spatially meaningful to their analyses, and that the tools and best practice to address this are still poorly explored.

Spatio-Temporal Scale

We suggest that the wider spatio-temporal scale of Palaeolithic GIS is the source for much of the unique difficulties faced by researchers in this sub-discipline. Questions about best practice and theoretical approach are hard to transpose wholesale from later periods for just this reason.

There is good reason to expect that unique spatio-temporal factors affect Palaeolithic GIS. Palaeolithic archaeology has always been closer in theoretical and methodological basis to geology rather than to later period archaeology. The record is itself more akin to a geological one in its fragmentary nature and its material contexts. Inevitably, some forms of spatial analysis in later periods should be expected to relate differently to the Palaeolithic record, or may even be of little or no relevance to human behaviour at Palaeolithic scales at all.

For example, reconstructing river hydrology from contemporary topography is a standard form of spatial analysis for later periods of archaeology. Sometimes specific reasons exist why such analyses are not valid in later period case studies, but these reasons are further compounded by the spatio-temporal scale of the Palaeolithic. Despite this, the ubiquity of hydrological analysis in later periods has meant that this form of analysis has often been suggested to

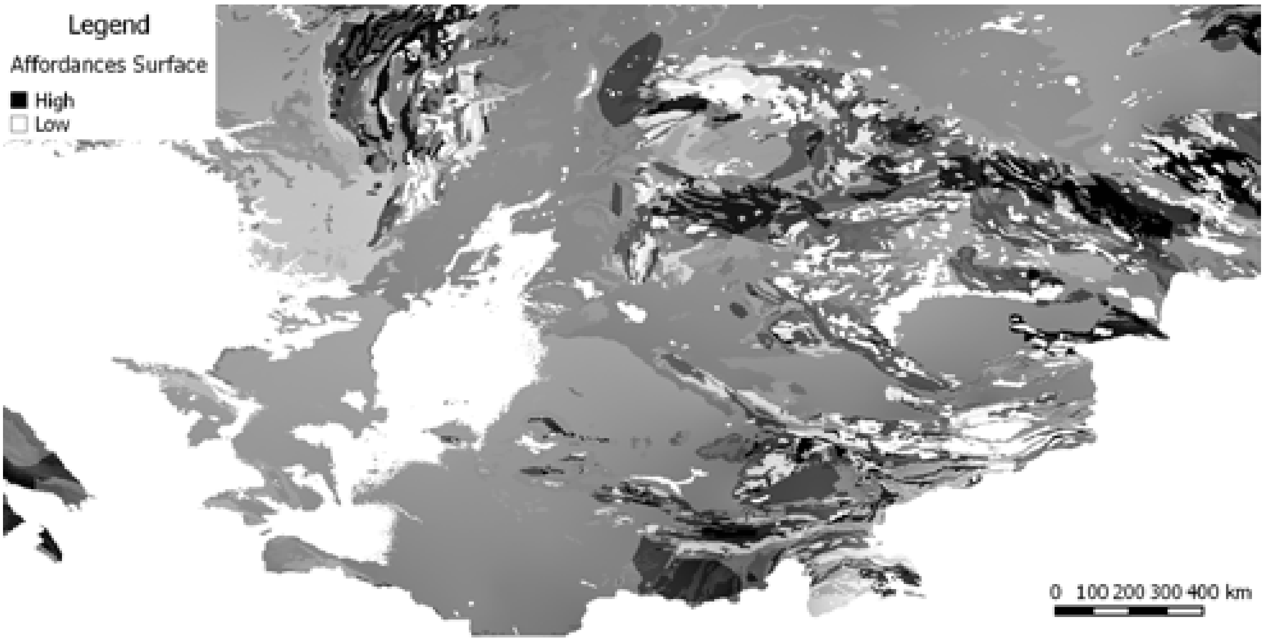

Figure 2. The affordances analysis combined a number of environmental attributes, including precipitation, groundwater potential, and raw material availability, to produce a 'hominin-centred' view of the landscape of Central Asia. Using datasets derived from WorldClim 1.4 temperature and precipitation derived from LIG palaeoclimate models, published by Otto-Bliesner et al. (2006) http://www.gadm.org/about and datasets derived from Generalized Geology of the Former Soviet Union (geo1ec). Published 1998 by the U.S. Geological Survey, Central Energy Resources Team and Dr. Thomas Ahlbrandt. https://certmapper.cr.usgs.gov/data/we/ofr97470e/spatial/shape/geo1ec.zip https://energy.cr.usgs.gov/oilgas/wep/. Map produced using QGIS 2.18.9.

one of the authors (P. Cuthbertson) for application to early Pleistocene Central Asia. This form of analysis was not attempted or credited for two main reasons;

Firstly, the majority of the dated sites in the study region come from loess sequences. These sequences have a non-trivial relationship with hydrology, as they often form where major rivers cut into loess deposits. Therefore, there is a clear non-behavioural reason for such sites to be located along major rivers, and therefore 'proximity to water' as represented by a modelled river network is worse than meaningless.

Secondly, even within historical times, the major rivers of Central Asia have been known anecdotally to change course after earthquakes (Hopkirk 1993: 160). This is compounded by the aeolian erosional and depositional processes active in the region, where dust storms have transported vast quantities of sediment from one side of Central Asia to the other. At a very broad spatio-temporal scale such as this, most of the depth of loess accumulation falls within the error range of the most common elevation datasets that can be used at this scale. In spite of this, the fact that the river systems have been known to change within this region within historical times highlights the folly of attempting such an analysis, and in assuming that such features derived from modern digital elevation models would prove meaningful for Pleistocene behaviour.

The challenges of the spatio-temporal scale are at the root of the difficulties of modelling human behaviour in these contexts. Exactly what forms of analysis are valid for examining human behaviour at this scale, and how to interpret the results of those analyses, constitutes an additional challenge in and of itself.

Interpreting Behaviour: The Role of Environment versus Mobility and Access

Related to the challenges engendered by the spatio-temporal scale of Palaeolithic GIS, is the issue of how researchers interpret hominin behaviour at these scales. A specific example of such a problem that needs consideration is the issue of the role of the environment in determining hominin behaviour.

Where research in later periods might be criticised for overt environmental determinism (ED) (Gaffney

& van Leusen 1995), this debate has to be uniquely considered for the Palaeolithic. It must be assumed that many of past peoples' decisions would have been conditioned by the environment. For hominin ancestors this may have been even more so the case, due to their limited behavioural and technological adaptive buffers against environmental change compared to later periods. Considering their actions to be heavily determined by the environment may in fact provide the most parsimonious model for hominin ancestors. Therefore, any role that hominin agency should have within our models is not entirely clear.

The concept of affordances in the present project focused on Central Asia was based on Gibson's (1986: 127) definition, and was primarily driven by environmental data, such as geology, hydrology, precipitation, and temperature (see Figure 2). The analysis therefore had to make certain assumptions about how hominins identify and use resources in the landscape, and how this might manifest behaviourally. In order to avoid an overly environmentally deterministic methodology, any environmental data included within this analysis was specifically justified with reference to known parameters of hominin behaviour within the literature. Although this does not provide an absolutely concrete solution, it is at least an explicitly self-reflective framework for the use of environmental data to model hominin behaviour. Other possible assumptions of hominin behaviour exist, and could provide alternative parameters for models.

Movement and mobility generally, and the specific methodologies used with some success in later periods such as least-cost pathways and site catchment analyses (see Herzog 2020 for a recent summary), also become ambiguous at Palaeolithic spatio-temporal scales. For instance, it is unclear how a least-cost pathway analysis relates to a multi-generational timescale, or at what spatio-temporal scales increasing topographic cost can seriously be considered an obstacle either to access into or knowledge of an area. This is especially important, because sites that are considered broadly contemporary in the Palaeolithic may have dates with extremely large error-ranges versus those of later periods, and connectivity between them cannot be considered meaningful a priori. At worst, least-cost analyses are uncritically assuming that location is far more behaviourally meaningful than taphonomic factors of differential survival may suggest. In a similar way, although site catchment analyses are informative, they tell us foremost about the arbitrariness of a constrained site-centred focus. They reveal little about broader patterns of hominin-landscape interaction away from 'sites', which we must assume would characterise a continuous behavioural space like the Palaeoscape (à la Foley 1981).

The present project preferred a form of cost 'accessibility' analysis that used cost distance to investigate hominin dispersal into and through Central Asia from its most likely earliest entry point along the southern border. Accessibility analysis often refers to a form of network analysis (Conolly and Lake 2006: 241), usually applied in an urban setting. However, the current implementation used cost distance rasters drawing on the approach of Llobera, Fábrega-Álvarez and Parcero-Oubiña (2011), and originating from points on the southern border in an 'origin points to everywhere' style of analysis (see Figure 3). The analysis used the 'Cost Distance' tool in the ESRI ArcGIS 'Spatial Analyst' toolkit.

The results of the affordances mapping were used as the cost surface, meaning that the analysis rated movement through areas rich in predicted resources as less costly than movement through areas low in predicted resources. This drew on the approach of Whitley et al. (2010), where potential caloric yield of areas around sites on the Georgia Coastal Plain was used as a form of cost surface to examine issues of territory, dominance, and exchange. The goal of using affordances as a form of cost in the present project was to provide a model of mobility in Central Asia grounded primarily in subsistence activities and human action. An alternative would have been to incorporate topographic cost, however, although we must be fairly certain that substantial mountain chains in and around Central Asia would have provided obstacles to movement, exactly how and to what extent is not clear. Topography was specifically excluded from this analysis for this reason, as it is unclear how it relates to broad patterns of disperal and resource use in the landscape at these timescales.

Site location was also excluded, so the cost surfaces were calculated from 1000 points placed along the southern border of the study region (this represented the upper feasible limit for computa-

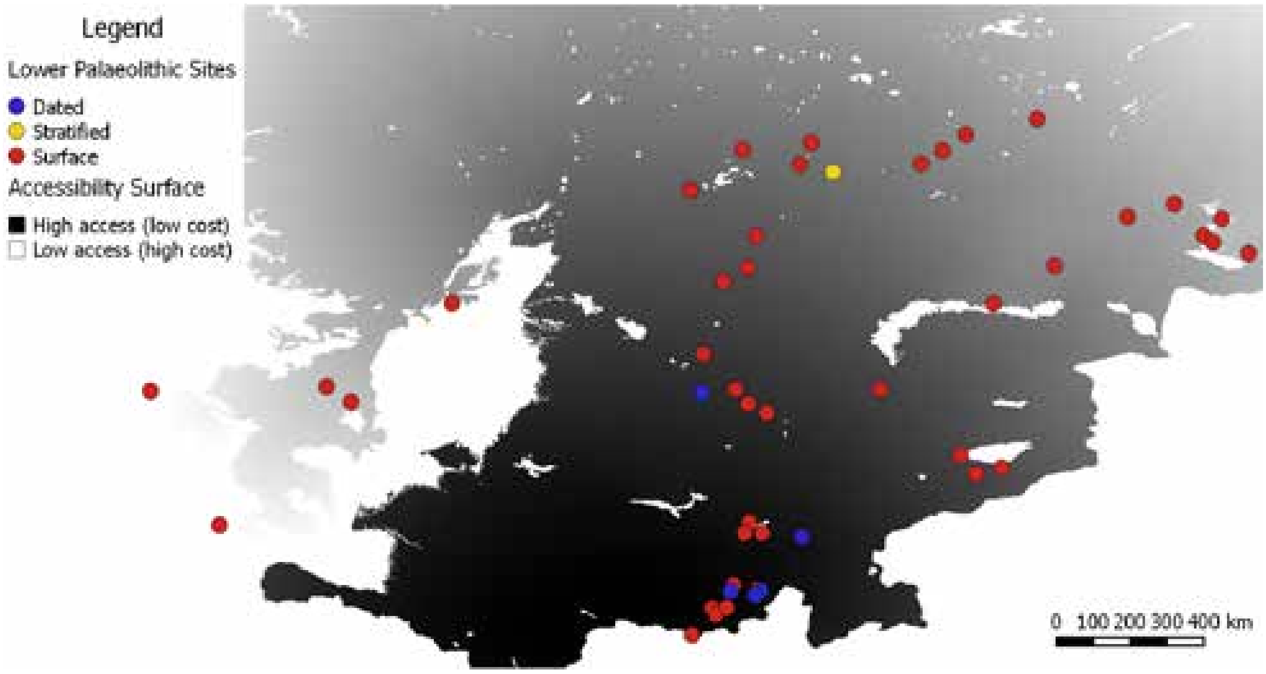

Figure 3. Accessibility was calculated as cost distance from the southern boundary which provides the most probable entry point into Central Asia during the Lower-Middle Pleistocene. It is assumed that the distribution of resources would play a large role in continental dispersal patterns, and that these results can be used to contextualise the positions of the existing sites. This map includes data provided by M. Glantz, T. Beeton, S. Temirbekov, & B. Viola. Map produced using QGIS 2.18.9.

tion). The 1000 resultant surfaces were combined together to provide a single surface that effectively represented the accessibility, costed through richness of environmental affordances, of every cell in the study region from the southern border points. In this way, it was possible to compare the accessibility of the different sites, without having to assume meaningful connectivity or contemporaneity between them.

In this Central Asian case study, we have highlighted problems the project faced due to issues of data coverage, and a lack of existing discipline-specific guidance for best practice in data requirements, the reconstruction of datasets, and the appropriate use of proxies. Issues of spatio-temporal scale in particular added a layer of difficulty to choosing appropriate datasets and analyses to address the research questions effectively. As Palaeolithic archaeologists, ultimately we are most concerned with understanding how those issues might map to the interpretation of hominin behaviour and the role of the environment at these scales. The solutions arrived at in regards to Central Asia were by no means perfect or definitive, but they were explicitly chosen, with alternatives considered and rejected.

The Aegean dry land hypothesis

Our second case study considers the Palaeolithic of the Aegean, which provided related but unique questions and solutions of its own. The Aegean is located at a crossroads between Africa, Europe and Asia, at the southernmost end of the Balkan Peninsula. The wider eastern and northeastern Mediterranean has been highlighted as a vital area during the Early and Middle Pleistocene, hosting refugia (Dennell, Martinón-Torres and Bermúdez de Castro 2011) and offering multiple and multidirectional dispersal routes (Kahlke et al. 2011; Spassov 2016). Despite the promising location, the Lower Palaeolithic evidence from the Aegean is sparse and the record is characterised by extensive spatio-temporal discontinuities and few securely dated sites. This low density of Lower Palaeolithic evidence is possibly the result of interpretation bias, reinforced by landscape dynamics (Tourloukis 2010). The Aegean is tectonically active, and this has an important impact on the availability and visibility of the Early and Middle Pleistocene material, favouring preservation and accessibility within specific geological contexts and under specific geomorphic circumstances.

The presence of hominins in the Aegean prior to 200 Kya was not previously securely documented, leaving this territory out of the discussion about the early colonisation of Europe. However, recent archaeological finds dated to around 400-500 Kya (Galanidou et al. 2013, 2016; Panagopoulou et al. 2015, 2018), and the re-examination of palaeoanthropological material attributed to the Middle or even the earlier Pleistocene (Harvati 2016), offer evidence for the reconsideration of the biogeographical role of the region. Furthermore, recent work on the submerged landscapes of the Aegean (Lykousis 2009; Sakellariou and Galanidou 2016, 2017) has revealed the existence of extensive exposed landmasses during the Middle and possibly Early Pleistocene. The current working hypothesis is that the Aegean was not a barrier during the Lower Palaeolithic, but instead an open terrestrial landscape, from at least MIS 10-12 (~480 Kya) until at least MIS 8 (~250 Kya).

Methodological Challenges

The main research question emerging is 'Could the exposed landscapes of the Aegean provide routes connecting Western Asia and Europe – an eastern passage to Western Europe (?) – and/or offer attractive lands for occupation during the Lower Palaeolithic?'

Several limitations pose serious methodological challenges;

1. In this project, the Aegean is treated as a terrestrial landscape. However, the environments and the topography of the now submerged landscapes are largely unknown.

2. The dynamic character of the tectonically active Aegean landscape, means that, the palaeotopography and the palaeogeography of the region suffered massive transformations throughout the Pleistocene and the Holocene.

3. Available datasets from the Aegean are problematic due to their scarce and discontinuous nature and due to temporal limitations, with available information covering efficiently only the last glacial cycle (last 130 Kya).

Assessing the Nature of the Palaeolandscape

The production of accurate and detailed reconstructions for the Aegean's deep past becomes extremely difficult due to the geotectonic history of the region and the ongoing geomorphic processes (framing the first two limitations outlined above).

The 'complex topography' concept offers a rigorous approach to overcome satisfactorily limitations relating to the nature of the past landscape because (a) it uses modern topography as a proxy (bypassing unavailability/lack of early data), and (b) it is applicable in (and suitable for) tectonically active areas (dealing with active processes). Bailey and King (2011; Bailey, Reynolds and King 2011; King and Bailey 2006) proposed the 'complex topography' hypothesis to suggest that tectonically active zones in East Africa favoured hominin occupation by providing diverse environments and natural pathways for movement.

In dynamic landscapes such as the Aegean, the topographic complexity can be measured by recording an index of landscape roughness using current elevation and bathymetry. Modern topographic complexity reflects to a certain extent the topographic complexity of the past landscape in areas with ongoing tectonic activity through the rejuvenation of the features produced by the geotectonic disturbance; landscape roughness – the measurement of irregularities on the surface morphology – is used as a proxy for identifying areas favourable to hominins.

Producing an index of landscape roughness for the Aegean highlights several specific areas as possible targets for further study (see Figure 4). High values of topographic roughness in the modern dynamic landscape would indicate areas with high topographic complexity in the past and over the same areas, and thus higher possibilities of recovering Lower Palaeolithic remains – if and where they were preserved. However, given that this work is based on modern elevation and bathymetry in a dynamic setting, where subsidence, uplifting, sedimentation, erosion, and sea-level fluctuations are taking place, what criteria should be followed to identify targets with the highest research potential? This concern led the preliminary identification of areas with high values of topographic complexity to be focused on parts of the Aegean where; (a) the main landscape features persist in time despite the action of

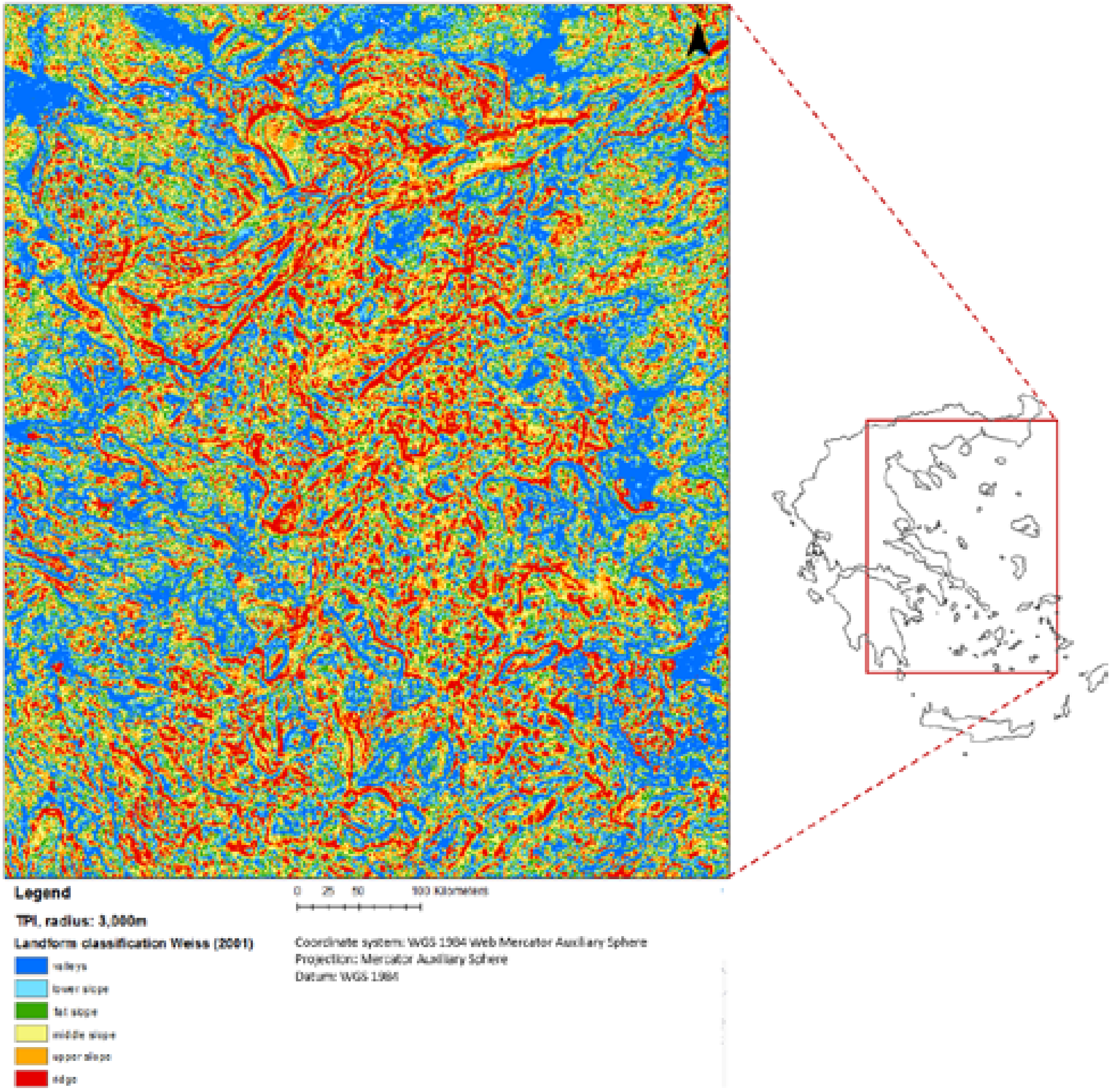

Figure 4. Roughness mapping on the Aegean, using the Topographic Position Index (3km radius). The landform classification follows the Weiss (2001) system. Terrain data: ASTER Global Digital Elevation Map, version 2 (ASTERGDEM V2) (30m resolution), available at NASA Land Processes Distributed Active Archive Center (LP DAAC). Bathymetric data: Eastern Mediterranean Bathymetric Map (2016) (250m resolution) by courtesy of the Hellenic Centre for Marine Research. The map is produced using ArcMap 10.4.

the geomorphic processes and where; (b) abundant and variable natural resources suggesting favourable environments for hominins have been documented through proxy data. Two areas meet these criteria: at the northern Aegean, along the continental self and the basinal structures of the North Aegean Trough, and at the south-central Aegean, over the Cycladic Plateau and along the Aegean Volcanic Arc (Tsakanikou and McNabb 2020).

Testing Hypotheses on Hominin Mobility and Survival over the Extended Terrestrial Aegean

The landscape roughness mapping sets the background to investigate further the nature of the Aegean terrain and its affordances (inspired by Gibson's (1986: 127) original definition). The research questions address two issues: (a) the traversability of the Aegean dry land and (b) the attractiveness of its habitats.

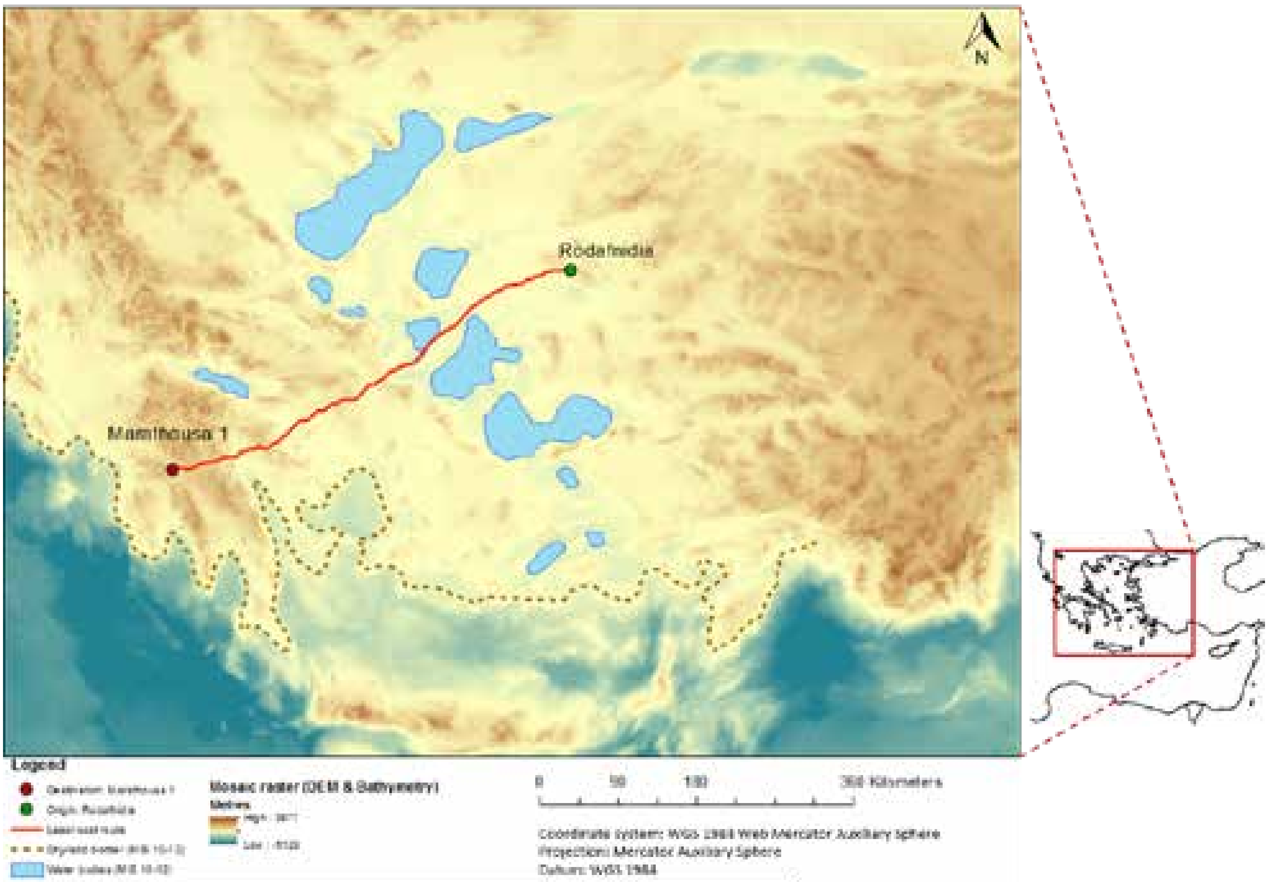

Figure 5. Least-cost route between Rodafnidia and Marathousa 1 sites. The location of the water bodies and the southernmost border of the Aegean exposed landscape during MIS 10-12 follow Lykousis (2009) palaeogeographical reconstruction. The background mosaic raster combines modern elevation and bathymetry. Terrain data: ASTER Global Digital Elevation Map, version 2 (ASTERGDEM V2) (30m resolution), available at NASA Land Processes Distributed Active Archive Center (LP DAAC). Bathymetric data: Eastern Mediterranean Bathymetric Map (2016) (250m resolution) by courtesy of the Hellenic Centre for Marine Research. The map is produced using ArcMap 10.4.

A least-cost route analysis approach was followed to test the potential of the Aegean as a traversable terrain. Although the least-cost route analysis has a gradually increasing application in archaeology as a useful tool to explore movement patterns, exploitation ranges and dispersal (e.g. Herzog 2014), among other human behavioural processes, relevant examples for the Lower Palaeolithic deal mostly with the Later Pleistocene (e.g. Anderson and Gillam 2000; Field, Petraglia and Lahr 2007). This lack of earlier cases is not irrelevant with the limited available evidence (and usually poor in accuracy and resolution) on the Early and Middle Pleistocene palaeogeography and palaeoenvironments, which is crucial for such modelling.

Topographic parameters based on current bathymetric and elevation data (slope, landscape roughness) and elements of the palaeogeography that could have acted as barriers to movement (location of waterbodies over the exposed Aegean landscapes and the location of the palaeocoastline) have been considered for the creation of the cost surface. It is assumed, for modelling purposes, that hominin groups would have taken easier routes, requiring the least effort (cost) to cross the landscape – at least the easiest routes within challenging complex landscapes, such as the Aegean. Effort here is relevant to, and determined by, the topographic configuration. The cost surface in this example represents time of travel, i.e. the time it takes to cross each grid cell to walk from point A to point B, using Tobler's hiking function (Tobler 1993). The speed is affected by topography; smoother terrain permits fastest walking, while complex terrain reduces walking speed.

Archaeological sites from mainland Greece and Western Anatolia have been used as origins and destinations. The selection of the sites is based on general chronological (isochronous sites supported by secure dates) and cultural associations. Due to the fragmented nature of available records and the extensive spatio-temporal discontinuities, it has not been always easy (or even possible) to draw strict and detailed cultural links. For example, for the MIS 10-12, a least-cost route has been calculated between Rodafnidia (origin) and Marathousa 1 (destination) (see Figure 5). Both sites have been dated to the Middle Pleistocene (400-500 Kya) using absolute methods (Galanidou et al. 2016; Panagopoulou et al. 2018) however, the Marathousa 1 industry is attributed to the Mode 1 tradition, while in the assemblage from Rodafnidia an Acheulean technocomplex has been identified with possible African affinities. Nevertheless, hominin groups, even with different traditions, were present at roughly the same time in different areas of the Aegean.

The produced least-cost routes (ArcGIS (ESRI)> spatial analyst extension > distance toolset> cost distance>cost route), travel across the central and northern Aegean, offering a general idea of cost-effective possibilities to cross this area, based on the modern landscape structure and assuming a continuous exposed terrain during the Early and Middle Pleistocene. This is not a straight-forward answer to the question about the traversability potential of the Aegean palaeolandscape and should be treated with caution; firstly because slope is only one factor, out of many, that affect biogeographical processes such as movement, and dispersal, and secondly because modern topography is used in this example as a proxy to provide rough approximations on the natural configuration of the landscape in the past – a palaeo-DEM for the spatial extent of the Aegean case study is not yet available. This modelling is used here merely as a heuristic device, bearing in mind the above-noted limitations and what we have already elaborated earlier about assumed connectivity and contemporaneity in Palaeolithic least-cost routes between sites. It provides a model of what travel on a traversable Aegean terrain during the Lower Palaeolithic between these locations could look like, but should not be taken as suggestive of specific pathways or specific movement patterns during this time. The least-cost route analysis is only a first step towards developing arguments supporting this hypothesis. More parameters could be implemented in this modelling to further investigate hominin mobility and movement patterns, such as energetic costs and palaeoclimate evidence (from the last interglacial).

If we accept the hypothesis that the central and northern Aegean was a traversable terrain during the Lower Palaeolithic, could it also provide viable – in terms of resources – terrestrial pathways for movement and further enable hominin occupation? One of the current authors (P. Tsakanikou) has attempted to assess this possibility, using the concept of suitability, derived from land-use analysis (for an overview see Malczewski 2004), through the development of predictive models for identifying the most appropriate spatial pattern of suitability according to specific parameters.

In the model developed here, suitability refers to conditions that would have favoured hominin presence, survival, and activity, based on the distribution of landscape features corresponding to water resources and volcanic material, natural elements that encompass affordances (sensu Chemero 2003) The selection of the affordance variables is not random but founded upon; (a) observations on topographic complexity, where landscape features related to affordances are located in areas with high topographic complexity and (b) a preferential association with hominins reflecting exploitation and survival opportunities as documented in the existing literature (e.g. Bailey, Reynolds and King 2011; Barboni et al. 2019; Chauhan et al. 2017).

Three zones (0-10km, 10-30km and >30km) were created around specific landscape features such as volcanic centres, palaeolakes, palaeorivers, springs etc., corresponding to the affordance variables. These features are perceived as ‘anchors’ (sensu Golledge 2003) over the landscape and are used as reference points in the spatial analysis. Last Glacial Maximum evidence has been used as a proxy for the earlier parts of the Pleistocene.

The 10km radius, the first zone around the reference points, has been selected as indicative of an exploitation territory during the Lower Palaeolithic, following the ‘site region’ definition given by Bailey & King (2011: 1533). Within the suitability model, a classification system has been developed, ranging from 0 to 3, with 0 indicating the least suitable areas and 3 the most suitable areas. The cells included in the first zone are attributed the value 3 corresponding to areas expected to be the most favourable. As the distance from the reference point increases, the

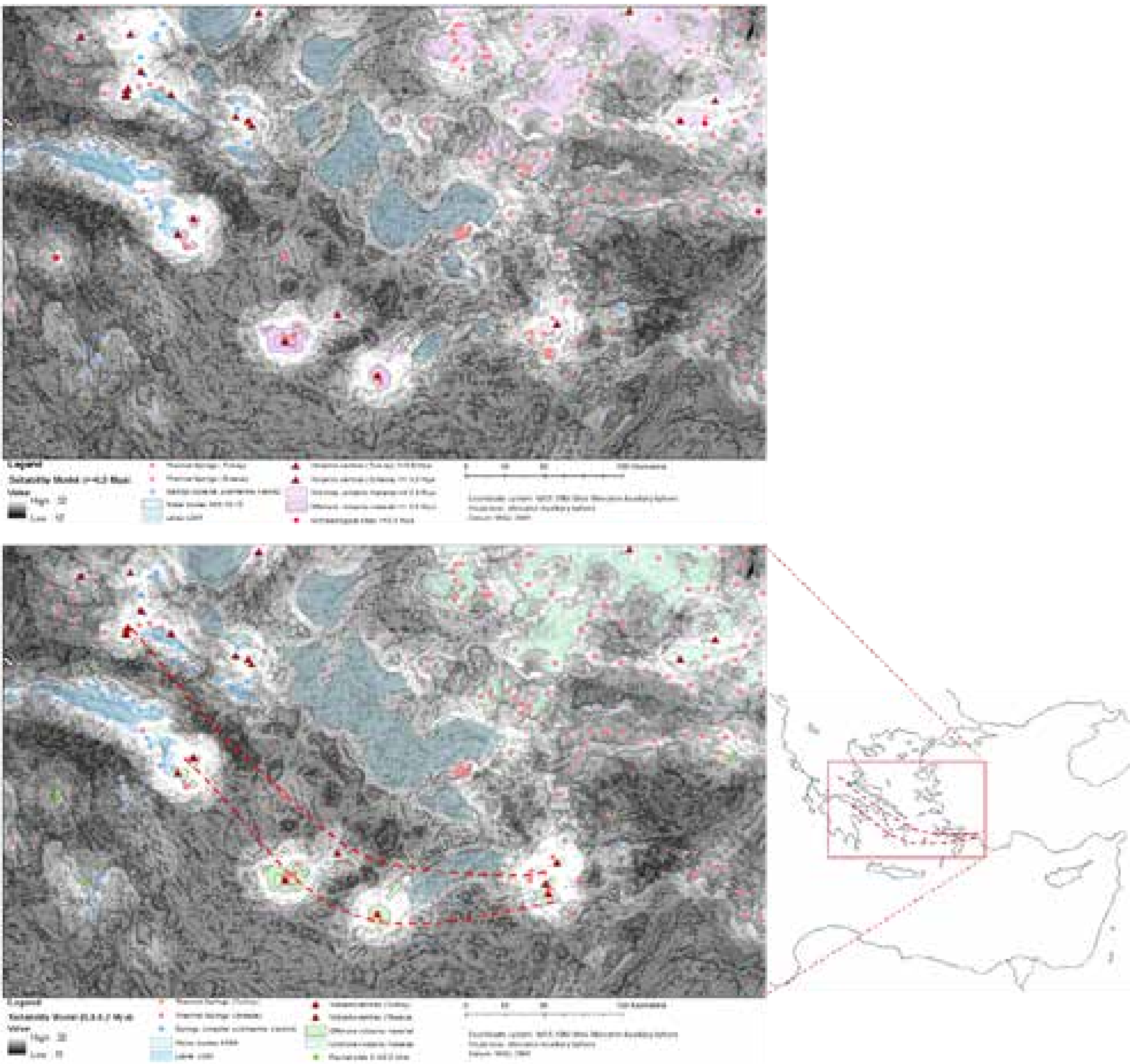

Figure 6. Suitability of the south-central Aegean for the intervals ≥0.9 Mya (top) and 0.4-0.2 Mya (bottom). The colour range from white to black indicates the suitability range from more to less suitable areas. The landscape features corresponding to water resources and volcanic material are visible on the maps, as well as the archaeological, palaeoanthropological and palaeontological sites dated to the specific time intervals. The red dotted line on the main map indicates a corridor with high research potential, at the southern part of the Cycladic Plateau and along the Aegean Volcanic Arc, connecting SW Anatolia and mainland Greece (the 'Volcanic Route Hypothesis'). The maps are produced using ArcMap 10.6.

suitability decreases. Consequently, the second zone is attributed the value 2, and the third zone the value 1. The actual reference points have been attributed the value 0 (representing in the case of the palaeolakes for example the area covered by water).

Each of the reclassified variables are represented by a raster surface, building up the suitability model. In the final raster suitability is indicated through a range of values from the most suitable (white) to the least suitable (black) (see Figure 6). Therefore, it defines possibilities rather than probabilities, which as a concept is more consistent with the fragmented nature of available data from the Aegean region and the use of proxy data. The aim here is to define particular areas, where favourable conditions are indicated by the presence or absence of the selected variables. In that sense, increasing the weight of one variable over the others cannot increase nor decrease the suitability value for a given area. This is why the weighted overlay or the weighted sum have not been selected for the suitability model.

The incorporation of archaeological, palaeoanthropological and palaeontological sites from the study area, securely dated to the Lower Palaeolithic, added a temporal element to the model, with the division into three time intervals ≥0.9 Mya, 0.9-0.4 Mya and 0.4-0.2 Mya, enabling for the first time observations in the changes of suitability over time and space (see Figure 6). Using the complex topography concept, suitability via an affordance approach, and least-cost pathways, the current project aimed to develop and execute new methodological approaches towards a better understanding of the nature of the palaeolandscape as a whole (including geographic sections that now may lie underwater but used to be part of the extended terrestrial Aegean during the Lower Palaeolithic) in order to place hominins within their affording environment. This in turn will allow the development of new models and hypotheses on behavioural aspects such as movement and settlement. This work, albeit preliminary, demonstrates that despite serious methodological challenges and limitations in the Lower Palaeolithic record of the dynamic Aegean, interdisciplinary approaches (archaeology and earth sciences) within a GIS framework offer new valuable insights into the deep past.

The Temptations of Palaeolithic GIS

Palaeolithic archaeology represents a unique research context, based in a unique history for the development of the discipline, but also shaped by the limitations and methodological challenges presented by the available evidence. Its research questions refer to wider processes, such as hominin mobility, landscape use, and exploitation of resources, emerging as patterns over larger spatio-temporal scales. At its most innovative, the use of GIS within the Palaeolithic goes beyond simple use as a tool for prospection or visualisation of data collected through other means. Palaeolithic applications actually have the potential to produce novel datasets, and enable novel arguments, discussions, and interpretations about the hominin record and hominin behaviour that are perhaps not possible without spatial analysis. But the complexities inherent in working with these data are compounded by the fact that the difficulties themselves can push researchers away from studying the more challenging questions or archaeological periods.

Emerging from this tension of complexities is a potential spectrum of effects, which we define here as the three ‘temptations’ of Palaeolithic GIS;

1. The temptation to follow the data coverage. For instance, if no climate data exist for an earlier period, the temptation is to study a later period with better data coverage.

2. The temptation of allowing the structure of datasets to condition the research questions. For instance, whether the environment is considered as a series of discrete patches of individual biomes, or a continuous landscape of resources is fundamentally a data issue, but it feeds directly into how we imagine hominins to move around a landscape.

3. The temptation to do spatial analyses that are easy to do or are a standard part of the GIS toolkit, although the logic of the record may not support their use. For instance, the use of hydrological analyses because they are commonly applied in later periods, without a specific understanding of what they would relate to in the period and study region in question.

All of these ‘temptations’ are relevant in later periods as well, but are arguably especially pronounced for Palaeolithic applications. These difficulties all potentially draw research away from research questions that are interesting and valuable from a Palaeolithic perspective, towards questions that perhaps seem easier to answer. Our inquiries, therefore, would be bent to the logic of the analysis, and not to the logic of the record. The net effect has to be a dampening effect on new discoveries as researchers focus on the known archaeological material, and a dampening effect on the development of new methodologies as researchers focus on what is already known to be possible. Ultimately, these effects would represent a move away from more exploratory or innovative methods of analysis in Palaeolithic research.

In both of our case study projects, the present authors have focused on addressing questions about the large scale landscapes and time periods of the Palaeolithic. We aimed to understand and conceptualise wider processes such as hominin mobility and landscape use, and also to develop methodological tools to actualise that understanding in our analyses. In our approaches, and those of others, a variety of different concepts and methodological approaches have been applied to tackle some of these issues; such as affordances (e.g. Webster 1999), accessibility (e.g. Llobera, Fábrega-Álvarez and Parcero-Oubiña 2011), topographic complexity (e.g. Bailey, Reynolds and King 2011; King and Bailey 2006), subsistence-based cost analyses (Whitley et al. 2010), and the averaging and resampling of data. These methodological tools have to make the most of a record with substantial challenges in terms of variable data coverage and variable spatio-temporal scales.

Conclusion

The use of GIS applications in Palaeolithic research is relatively new as a research field, and as such, it necessitates innovation and experimentation as a part of the process of full integration and realisation. To encourage that process, Palaeolithic GIS needs an explicitly theoretical discussion to complement its existing practical focus, and to support the growth of junior researchers and innovative methodologies. We have endeavoured to make these arguments concrete with reference to examples from our own doctoral projects in Central Asia and the Aegean. In the process, we have defined three challenges and three temptations of Palaeolithic applications of GIS, which are meant as theoretical discussion points;

Three challenges of Palaeolithic applications of GIS;

1. poor data coverage
2. vast spatio-temporal scale
3. the difficulty of inferring behavioural patterns under the conditions of problems 1. and 2.

Three temptations of Palaeolithic applications of GIS;

1. to follow the data coverage, rather than to try to generate data for difficult places and periods
2. to adapt questions to the logic of data structure, rather than rework data to suit questions
3. to do analyses that are familiar but irrelevant, rather than pioneer new methodological solutions

These points are meant to underline the necessity of an explicitly theoretical discussion for the development of Palaeolithic GIS. In the absence of guidelines representing acceptable approaches or best practice, the current best practice must be considered to be ‘tailor-made’, as researchers struggle with their unique research questions, issues of data availability, and the limitations of the standard GIS toolkit. Only by beginning to define these terms in discussion can we begin to develop our sub-discipline as a self-reflective and theoretically explicit field. The result of this process must be to better understand our goals and directions for development of the field, which will be crucial in developing and properly realising its interactions and borrowings from allied fields such as geology and geomorphology.

The CAA2018 Palaeo-GIS session was a good forum to start discussing these issues, and it became clear that many researchers shared our concerns in these areas. We should not expect definitive answers, but rather an opening of dialogue that permits us to make suggestions, discuss possibilities, and develop scenarios that can offer some new insights in the ways we record, study, and interpret early human behaviour over larger spatio-temporal scales.

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