CHAPTER 1

Modern technologies, past realities: GIS-based approaches to the layered making of the Maltese landscape

Gianmarco Alberti, Reuben Grima and Nicholas C. Vella

Introduction

Geographic Information System (GIS) is a widely used tool for the analysis and interpretation of social science data. GIS provides facilities to acquire heterogeneous spatial data, to integrate them in a common analytical framework, and to meaningfully organise and interrelate spatial information (Conolly & Lake, 2006, p. 13; O'Sullivan & Unwin, 2010, pp. 22–28). The relevance of GIS to the analysis of social data rests on the obvious, yet crucial, fact that spatial data are *pervasive* (Fotheringham, Brunsdon, & Chalrton, 2002, p. 16). As a matter of fact, human beings do not act in a void, but live in and are surrounded by a physical world. Any human behaviour, be it performed either in the past or in the present, inescapably features inherent spatial components. GIS provides the proper analytical infrastructures to make sense of those spatial components by exploring, visualizing, testing, and modelling relations among spatial variables. Spatial data analysis is therefore capable to bring latent or new patterns to the fore, to get insights into spatial processes, to infer broader trends and to generalise to larger realities from smaller manageable samples in a reproducible and explicit fashion, and to ultimately turn information into useful knowledge (Baddeley, Rubak, & Turner, 2016; Conolly & Lake, 2006; O'Sullivan & Perry, 2013; O'Sullivan & Unwin, 2010; Rogerson, 2001). As such, GIS and spatial data analysis prove crucial to research fields as diverse as environment and earth science (Formosa, 2015; Tian, 2017), ecology (Wiegand & Moloney, 2014), agriculture (Plant, 2012), public health (Baluci, Vincenti, Conchin, Formosa, & Grech, 2013; Kurland & Gorr, 2014), socio-economic (Wang, 2014) and forensic disciplines (Elmes, Roedl, & Conley, 2014), crime studies (Chainey & Ratcliffe, 2005; Formosa, 2007), archaeology/anthropology (Conolly & Lake, 2006; Nakoinz & Knitter, 2016; Wheatley & Gillings, 2002).

In archaeology/anthropology, even though quantitative methods have witnessed ups and downs during the development of the discipline after the rise of the processualist approaches (Gamble, 2008, pp. 28–30; Watson, 2009), formal and explicit methodologies for data quantification and analysis are today widely used (Baxter, 1994; Blankholm, 1991; Buck, Cavanagh, & Litton, 1996; Carlson, 2017; Drennan, 2010; Nakoinz & Knitter, 2016; Orton, 1980; Shennan, 1997; VanPool & Leonard, 2010), and the analysis of spatial data is no exception. GIS is used to address different research questions in a wide variety of contexts such as the study of prehistoric travel corridors (Bell, Wilson, & Wickham, 2002; Kantner, 2004; Teeter, 2012; Whitley & Hicks, 2003), human movement and land accessibility (Byrd, Garrard, & Brandy, 2016; Contreras, 2011; Murrieta-Flores, 2012; Richards-Rissetto & Landau, 2014; J. W. H. Verhagen, Posluschny, & Danielisova, 2011), human spatial behaviours and decisions (Gorenflo & Gale, 1990), monuments visibility and inter-visibility (Friedman, Look, & Perdikaris, 2010; Williams & Nash, 2006), maritime pathways (Alberti, 2017; Indruszewski & Barton, 2006; Newhard, Levine, & Phebus, 2014), Roman aqueducts (Orengo & Miró, 2011) and roads (P. Verhagen & Jeneson, 2012), and for the prediction of the location of archaeological sites (Rogers, Collet, & Lugon, 2014; Westcott & Brandon, 2000).

The present work is framed in the context of the use of GIS and, broadly speaking, geo-spatial approaches as means to get insights into the development of the human-made landscape in Malta in relatively recent historical periods. The study rests on the research pursued by the authors within the five-year ERC-funded FRAGSUS project, which has sought to examine fragility and sustainability in small island contexts, with a focus of human-environment interactions in prehistoric Malta. As detailed elsewhere (Alberti, Grima, & Vella, 2018), one of the main objectives of our research was to focus on evidence related to the Maltese landscape in better-documented historical periods to shed light on the ways in which the landscape has been exploited and, in a broader perspective, on the determinants (either environmental or cultural, or both) of human-landscape interaction in Malta. The goal was both to enrich the interpretation of evidence dating to earlier periods and to suggest new archaeological/anthropological questions. It is worth noting that, albeit with few ground-breaking exceptions mainly framed in the context of archaeological research (Grima, 2005; Grima & Mallia, 2011), GIS and quantitative methods have not been used so far in Malta to study the development and the layered making of the landscape in more recent historical times.

While the present work describes some of the main achievements of the authors' research, it will do that from a specific standpoint. It seeks to show how GIS-based quantitative approaches can be proficiently used, in conjunction with qualitative data (for instance, cadastral maps and ethnographic accounts) (Formosa, Scicluna, Azzopardi, Formosa Pace, & Calafato, 2011, pp. 13–21), not as an end in themselves but to address specific research questions in an explicit, formal, and reproducible fashion. As a matter of fact, the use of quantitative methods allowd scientists to ask themselves if there is indeed a case to answer (Orton, 1980, p. 195). As Stephen Shennan (1997, pp. 2–3) puts it, archaeologists (and social scientists in general):

[…] must have sufficient quantitative awareness to recognise when problems arise which can be helpfully tackled in a quantitative fashion. […] in as much as all interpretation […] is concerned with identifying patterning, it can benefit from a quantitative approach. The point that […] we are identifying patterning rather than creating it is an important one […] without such an assumption […] evidence would not tell us anything […].

Research background

Our research has adopted what could be termed a retrospective view. In our opinion, insights into the subsequent evolution of the Maltese landscape may prove crucial for a better understanding of the human-landscape interaction in earlier periods for a number of reasons: first, because they form part of the same landscape palimpsest that can only be understood in diachronic terms; second, to allow more informed predictions of where evidence of earlier landscapes may be preserved; third, because different cultural responses in better documented periods may suggest new questions that may be posed to the more meagre evidence from earlier periods, and enrich their interpretations.

At the outset of our research, two broad overarching research questions were elicited. The first was to formally assess the existence (if any) of either environmental or cultural (or both) determinants of agricultural productivity in Malta before heavy mechanization. While the existence of those determinants can be postulated from a theoretical point of view, as studies in other geographical contexts show (e.g., Akıncı, Özalp, & Turgut, 2013; Prishchepov, Müller, Dubinin, Baumann, & Radeloff, 2013), no such attempt had been previously done for Malta. The second, intertwined, research question regarded shedding light on the way(s) in which other forms of economic exploitation, such as herding and animal husbandry, related to the agricultural landscape, to other forms of human economic investment in the Maltese landscape, and to actual evidence on the ground.

It is worth noting that different types of data constituted the building blocks of our research. On the one hand, qualitative data were available to us. These comprised information about land agricultural quality and location of farmhouses embedded in mid-1800s cadastral maps, collectively called *cabrei* (Ginori Lisci, 1978), access to which was kindly made possible by Dr Charles Farrugia (CEO and National Archivist, National Archives of Malta). Also, ethnographic data regarding movements of flocks across the Maltese landscape were collected by one of us (NCV) from interviews of local shepherds.

Other information, qualitative in nature even though stored in GIS format, have been manually acquired from a body of different cartographic sources (Alberti et al., 2018): for instance, the location and extent of geological layers; the layout of the 1800s road network; the extent of the 1800s urbanized areas; the location and extent of the so-called "public spaces" (wasteland); the extent of different soil types across the entire Maltese landscape; the location of springs; the extent and location of parcels featuring different agricultural quality (manually extracted to GIS from the above-mentioned *cabrei* maps).

On the other hand, quantitative data were also available for this study. These comprised Light Detection and Ranging (LiDAR) data and orthophotos acquired in the context of the European project ERDF156 *Developing National Environmental Monitoring Infrastructure and Capacity*, which were made available by the former Malta Environment and Planning Authority (MEPA), with the kind assistance of Prof Saviour Formosa and Prof Timmy Gambin, both from the University of Malta. LiDAR data proved crucial for many aspects of our research because they provided the basis to build a fine-grained Digital Terrain Model (hereafter DTM) for Malta. This, in turn, allowed to calculate different landscape geomorphological characteristics used in our GIS-based analyses, such as slope, aspect, topographic wetness index, terrain planar and profile curvature. Other quantitative information was derived from the qualitative data to which reference has been made above, such as the distance from the 1800s road network, from the coast-line, from the major geological fault-lines, and from the 1800s urbanized areas.

From the preceding description, it should be apparent how our research entailed from the outset the stimulating challenge of handling, integrating, analysing and making sense of a large variety of data. A particularly challenging aspect was the devising of a strategy to transfer the important information on land agricultural quality stored in the *cabreo* maps from the realm of qualitative data to that of quantitative information. This required a tailor-made methodology to be developed since, while the cabrei have been object of study in other parts of the Mediterranean in their quality of historical documents providing insights into land division and territorial administration (Caucci von Saucken et al., 1997; Ginori Lisci, 1978; Spiteri & Borg, 2015), no attempt had been previously done (to the best of our knowledge) to coherently integrate them in a GIS-based modelling strategy.

Study Aims

Our research sought to address a number of intertwined research questions, listed below:

1. Given the information stored in the *cabreo* maps, is it possible to identify environmental and cultural variables that can be considered determinants of agricultural quality in Malta?
2. What is the impact (if any) of the identified variables on the agricultural quality?
3. What overall patterns emerge when the predicted agricultural quality is extrapolated to the entire Maltese landscape?
4. Given that literature (e.g., Bevan & Conolly, 2013), ethnography, and common sense indicate that grazing journeys tend to avoid cultivated fields, is it possible to use the modelled agricultural quality as an heuristic tool to locate likely pastoral foraging routes across the Maltese landscape?
5. From a postdictive standpoint (Patacchini & Nicatore, 2016), how do the estimated foraging routes relate to other herd-related evidence present in the same landscape (i.e. features connected to movement of flocks between grazing areas, location of lost villages possibly linked to animal husbandry, or herd-related place-names)?
6. From the same standpoint, are the GIS-based postulated foraging routes consistent with the information provided by ethnographic accounts?

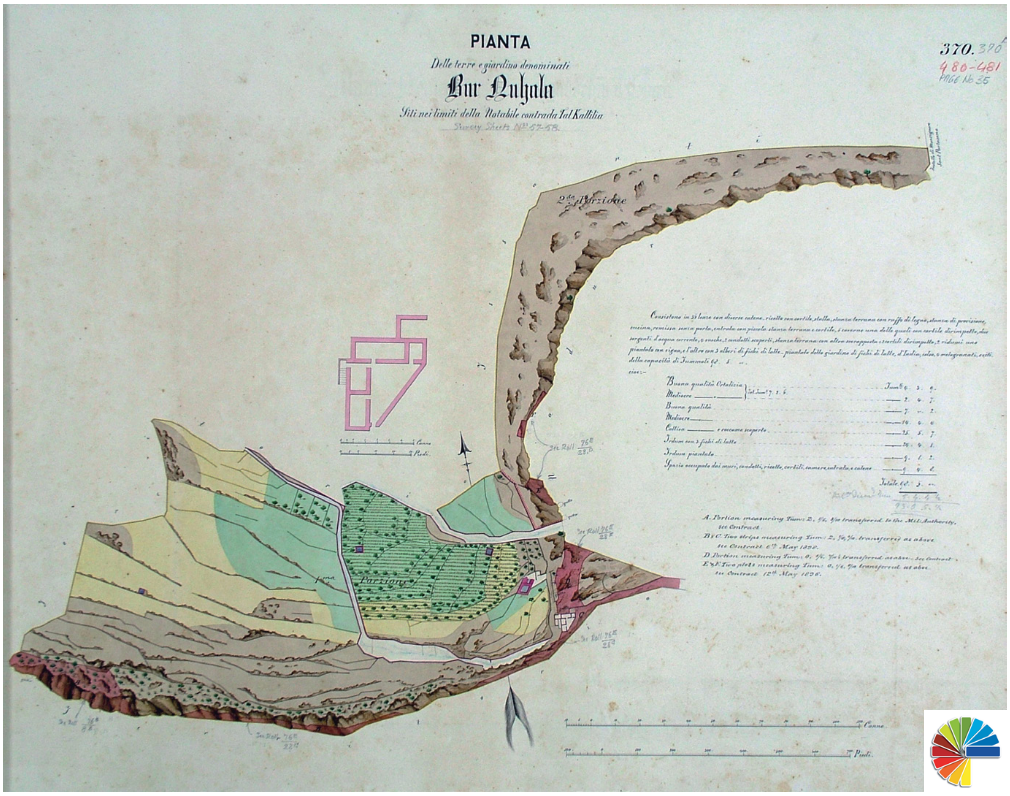
Materials and Methodology

Agricultural quality modelling

Questions (a) and (b) have been addressed using Logistic Regression (hereafter LR) (Hosmer, Lemeshow, & Sturdivant, 2000; Pampel, 2000) as a means to gauge the contribution of a set of topographic and cultural variables (hereafter predictors) on the chances for optimal agricultural quality. LR makes it possible to estimate the probability that a particular outcome of a binary dependent nominal variable will occur based on information from one or more predictors. For each predictor, LR allows estimating coefficients that, once exponentiated, can be meaningful interpreted as odds ratio (Pampel, 2000). An odds ratio of 1 leaves the odds for the positive outcome of the dependent variable (optimal agricultural quality, in our case) unchanged, while a coefficient greater or smaller than 1 increases or decreases the odds respectively.

In the *cabrei* (Figure 1), *agrimensori* (land surveyors) gave land parcels different colours according to a qualitative assessment of the agricultural yield (further details in Alberti et al., 2018). The full qualitative scale used in the cabreo was: *buona* (good), *mediocre* (mediocre), *cattiva* (bad), *inferiore* (lower), *infima* (lowest).

Figure 1. Example of cabreo map: the different colours are assigned to different sectors within the parcel to represent different agricultural qualities (e.g. brown=lowest quality, yellow=mediocre, green=good). Also note the hand-written notes systematically recording the number and type of structures present, presence and type of water facilities, presence of animal pens, and other information.



Courtesy of the National Archives in Malta; first published in Alberti et al., 2018

Out of several hundreds cabreo maps, a smaller more manageable sample has been georeferenced in GIS, and information about the location, extent, and agricultural quality of the parcels (or part thereof) was recorded with the use of 318 polygons. It was decided to collapse the *cabreo* classes into two broad ones, i.e. optimal (corresponding to the *good* class) vs. non-optimal quality (comprising the *mediocre*, *bad*, *low*, and *lowest* classes). Within the polygons, a total of 3,897 sampling points were drawn, and information about the dependent variable (agricultural quality, either as optimal or non-optimal) and about the value of a set of predictors at each sampling point, was extracted.

Different predictors have been used in the model: slope, elevation, aspect, planform and profile curvature, topographic wetness index, distance to geological fault-lines, to the coastline, to the 1895 road network (main, secondary, and minor roads), distance to footpaths, distance to 1895 urban areas, soil type, x (easting) and y (northing) coordinates. While modelling agricultural suitability is not a simple endeavour since a complex interplay of variables may indeed affect the inherent properties of the land (Akıncı et al., 2013; Prishchepov et al., 2013), the predictors used in this study were deemed useful based on the literature review and data availability. To avoid models with unnecessary complexities and to give preference to simpler models (Beh & Lombardo, 2014; Eve & Crema, 2014), we used a backward stepwise procedure (Austin & Tu, 2004; Rizopoulos, 2009), which is fully described elsewhere along with other more technical aspects of the modelling strategy (Alberti et al., 2018).

Addressing question (c) entailed using the coefficients estimated by the LR to predict the probability for optimal agricultural quality for those parts of the Maltese landscape for which no cabreo information was available. This, in turn, rested on using Map Algebra in GIS (Conolly & Lake, 2006) to implement the LR equation, which consists of values of the predictors plus the model's coefficient. In other words, once LR has been run, and the model's parameters (i.e., intercept and coefficients) have been found, it is possible to calculate the probability for optimal agricultural quality by plugging those parameters and any known value of the predictors into the logistic regression equation.

Pastoral foraging routes modelling

To address question (d), we have implemented in GIS the calculation of least-cost paths (hereafter LCPs), which is a widely applied approach in the study of how human behaviour relates and engages with movement across the landscape (Conolly & Lake, 2006; Herzog, 2014; Van Leusen, 2002; Wheatley & Gillings, 2002). We have conceptualized the cost of moving in terms of walking time since literature and ethnographic accounts (Arnon, Svoray, & Ungar, 2011; Endre Nyerges, 1980; E. Schlecht, Dickhoefer, Gumpertsberger, & Buerkert, 2009; Eva Schlecht, Hiernaux, Kadaouré, Hülsebusch, & Mahler, 2006) frame foraging excursions in terms of time spent to move from the starting location to the target grazing areas. Since livestock trails follow least-effort routes trying to minimise the impedance provided by the terrain's slope (Arnon et al., 2011; Ganskopp, Cruz, & Johnson, 2000; Stavi, Ungar, Lavee, & Sarah, 2008), we decided to implement the widely used Tobler's hiking function (Tobler, 1993), modified to fit animal walking speed. The latter is predicted as dependant on slope according to the following formula:

$$v = 6 * exp[-3.5 * abs(s + 0.05)]$$

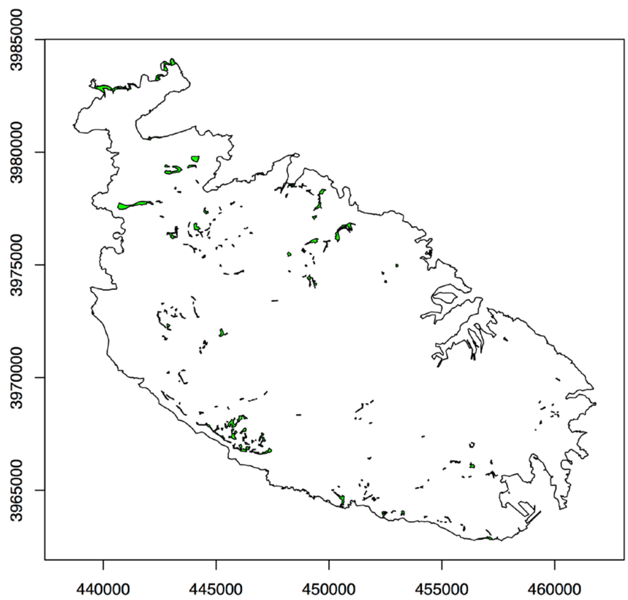
where *v* is the walking speed in km/h, *s* is the slope measured as rise over run. The maximum predicted walking speed of about 6 km/h is reached on a gentle (-2.86 degrees) downhill slope (Conolly & Lake, 2006, p. 218). In an attempt to find a balance between different animal walking speed values reported in literature (Arnon et al., 2011; Endre Nyerges, 1980; E. Schlecht et al., 2009; Eva Schlecht et al., 2006), Tobler's hiking function has been scaled down by a factor of 0.25 to represent the walking pace of a flock during excursions in which grazing takes place while walking, which in most situations can be considered a typical form of grazing (Arnon et al., 2011).

We calculated LCPs using ArcGIS 10.1's Path Distance tool (ESRI, 2017) following the procedure used by Tripcevich (2007). The calculation of LCPs employed garrigue areas, which we know were used for grazing (Lang, 1961; Rolé, 2007), as both the source and the destination of movement, in order to estimate the path network between them. Within the polygons representing the garrigue areas, a total of 139 random points were generated and used as destination points in the calculation of LCPs. In addition, two raster layers were fed into the Path Distance tool: a LiDAR-derived 10m DTM, and a slope raster used as the cost-surface. On the informed assumption that during their grazing journeys shepherds tend to avoid cultivated fields (Bevan & Conolly, 2013), the slope raster was preliminarily modified (e.g., Rogers et al., 2014, p. 264; White, 2015, p. 410) to factor agricultural quality into the LCP analysis. A higher slope value has been assigned to those parts of the landscape featuring a probability for optimal agricultural quality larger than 0.60, according to the cabreo agricultural model devised in response to the abovementioned research questions (a) and (b). This rendered those areas more costly to traverse.

Relation between estimated foraging routes and herd-related evidence

Research question (e) was addressed by coupling qualitative data with the use of quantitative approaches. The location and extent of landscape evidence linked to animal husbandry and herding belong to the former type of data. One of such pieces of evidence relates to those areas described as "public spaces" (waste land) by the colonial administration, which we imported into GIS from early 1900s survey sheets. A total of 217 polygons were employed (Figure 2).

Figure 2. Extent and location of areas described as "public spaces" (waste land) by the colonial administration; manually acquired into GIS from early 1900s survey sheets. In this and in the other figures, coordinates conform the UTM 33N ED1950 (projected) coordinate system.



These spaces, often overgrown and ideal for roadside grazing, may open up along the roads or tracks flanked by rubble walls, actually consisting in an enlargement of the area taken up by the road itself. While these spaces warrant further study, our working hypothesis was that public spaces acted as important nodes along the routes used for the movement of herds across the landscape. If that hypothesis held true, we expected public spaces to be spatially related to the estimated LCPs. To empirically assess this, we coupled descriptive statistics with a randomized distance-based approach (O'Sullivan & Unwin, 2010; M. S. Rosenberg & Anderson, 2011) implemented by one of us (GA) in an R package, which also contains other spatial analysis facilities and is freely available (Alberti, 2018). The distance of each public space's centroid to the nearest LCP was first computed. The 217 obtained distances were then averaged and the average was set against a distribution of average minimum distances calculated across 499 sets of random points drawn within a study window. The latter was the extent of Malta excluding the urbanized areas and those zones that the LCPs intentionally avoid (modelled probability of optimal agricultural quality larger than 0.60). The distribution of randomized average minimum distances is used to construct an expected distribution of public spaces-to-LCPs distances under the null hypothesis that public spaces are randomly located with respect to the latter. A p-value can be empirically worked out by calculating the proportion of cases in which randomized average minimum distances prove equal or smaller than the observed average minimum distance (Baddeley et al., 2016, pp. 384–387). The analysis of other evidence, such as the location of disappeared villages bearing the Maltese prefix *raħal* and the location of herd related place-names, is provided elsewhere (Alberti, Grima, & Vella, n.d.).

Estimated grazing journeys vis-à-vis ethnographic accounts

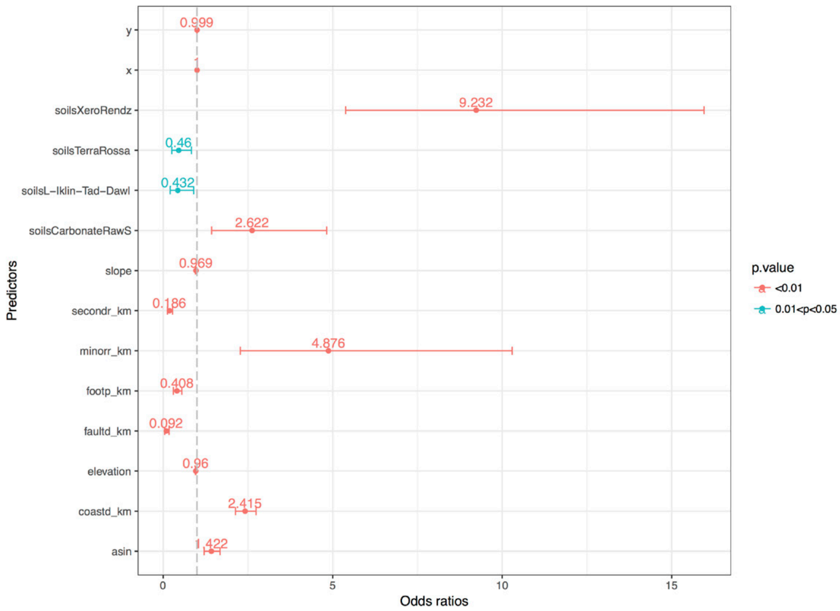
Research question (f) has been addressed by calculating the time it takes to move flocks from the farmhouses that were the object of the abovementioned ethnographic accounts toward those areas indicated by the informants as actual grazing land. These GIS-based estimates and the actual time details provided by the informants have been compared in order to gauge any existing match between them. A more extensive analysis, including the estimation of GIS-based foraging excursions starting from a number of farmhouses recorded in the mentioned sample of *cabreo* maps, is provided elsewhere (Alberti et al., n.d.).

Results

LR made it possible to locate a subset of predictors having an influence, either positive or negative, on the suitability for agriculture at the time when the cabreo was created. The selected predictors' odds ratio is reported in Figure 3.

Our findings indicate that terrain elevation and slope have a negative effect (odds ratio smaller than 1) on optimal agricultural quality. Literature indicates that elevation is associated with lower temperatures (Akıncı et al., 2013) and moisture content (Famiglietti, Rudnicki, & Rodell, 1998, p. 261). Furthermore, elevation may affect water retention since terrains at greater elevation may have more soil water draining down and are subject to receive less water from upslope (Qiu, Fu, Wang, & Chen, 2001, p. 737). Research elsewhere also indicates that steeper slopes tend to be drier than flat areas due to lower infiltration rates and higher surface runoff, and are also likely to have shallower soils (Qiu et al., 2001, p. 737; Tromp-van Meerveld & McDonnell, 2006, p. 300). Other things being equal, steep slopes also feature a higher amount of solar energy (Chang, 2009; N. J. Rosenberg, Blad, & Verma, 1983), since the quantity of solar radiation per unit area of the land surface decreases as the slope decreases. Steeper slopes are also more difficult to cultivate relative to more gentle sloping terrains (Akıncı et al., 2013, p. 75; Stewart, 2013, p. 27).

Figure 3. Logistic Regression results: predictors' odds ratios (point estimate plus 95% confidence interval) representing the influence on the chances for optimal agricultural quality. A value smaller or larger than 1 decreases or increases the chances by a factor equal to the odds ratio respectively. Colour code: light blue=p value between 0.01 and 0.05; red=p value smaller than 0.01.



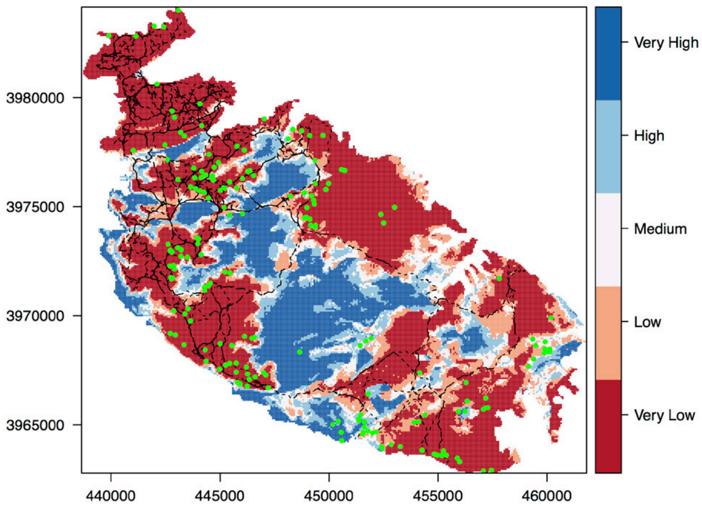
In our model, easterness (i.e. sine of the aspect, abbreviated as *asin* in Figure 3) and distance to the coastline have a positive effect on the optimal agricultural quality, while the distance to the nearest geological fault has a negative influence. Literature shows that slope orientation affects solar radiation and evapotranspiration, soil moisture, and soil nutrients (Begum, Bajracharya, Sharma, & Sitaula, 2010; Famiglietti et al., 1998; Qiu et al., 2001, p. 736; Reid, 1973). Furthermore, slopes with different orientation are differentially subject to prevailing winds. The positive influence of eastern aspects on the optimal agricultural quality can be explained by the fact that east-facing slopes are relatively cooler than southern and western exposure, so retaining more soil moisture and featuring a lower rate of evapo-transpiration (Anderson, 1997, p. 111). It is also worth noting that west-facing and southwest-facing slopes receive a greater amount of solar radiance, resulting in drier conditions and in a different microclimate at ground level (Sulebak, Tallaksen, & Erichsen, 2000, p. 91). The positive impact of the distance to the coastline can be explained by the fact that being further away from the coast implies being less prone to sea-spray and salt-laden air. On the other hand, since the distance from the nearest geological fault is a proxy for fresh water availability (Alberti et al., 2018), the model indicates that being far from a fault line translates into a decrease in the chances of having access to fresh water, which is a crucial factor in the development of agriculture in arid climates (Vella, 2001).

Our model also allowed us to gauge the influence of different soil types on the agricultural quality. Brown Rendzinas soils have a positive effect, and the same holds true for Carbonate Raw and Xerorendzinas soils, while Terra Rossa soils are associated with a negative effect. Our findings confirm many of the empirical observations made in the 1960s by Lang, who noted that Xerorendzinas, Brown Rendzinas, and Carbonate Raw soils used to give satisfactory crops, while Terra Rossa soils were left uncultivated since they were rather dry, compact, and difficult to cultivate (Lang, 1961, p. 94).

As for land accessibility, the distance to the nearest secondary road and to the nearest footpath was found to have a negative effect on the optimal agricultural quality. This makes sense since the secondary road network can be thought of as allowing a gradual shift from urbanized areas to more peripheral zones, going deeper into the landscape relative to the main road system (which, remarkably, turned out not to have a significant contribution to the model), and providing access to the countryside. The same holds true for the distance to the nearest footpath, which has a negative effect. On the other hand, the distance to the nearest minor road is associated with a positive influence on agricultural quality. While its interpretation is less straightforward (Alberti et al., 2018, p. 21), the result of the model would indicate that, since minor roads occur in areas of garrigue and karstland which are generally less favourable for agriculture, optimal land quality would be found further away from minor roads, downslope or in valley bottoms.

Besides gauging the effect of the isolated predictors on the agricultural suitability, our analysis allowed the extrapolation of the predicted agricultural quality to the entire Maltese landscape. The estimated regression coefficients have been plugged into the ArcGIS raster calculator to perform a map algebra operation that produces the image in Figure 4. It represents the fitted model and features a colour scale reflecting the probability for optimal agricultural quality. It is apparent (as will be discussed later on) that there is a considerable variability of agricultural potential even over small distances, with large zones highly suitable for agriculture, and other ones (e.g., the karstic plateaux) featuring the lowest suitability value.

Figure 4. Fitted agricultural quality model for the entire Maltese landscape: the colour scale indicates the probability for optimal agricultural quality according to the cabreo model and is broken down into five classes (very low corresponds to a probability of optimal agricultural quality between 0.0 and 0.2; low: 0.2-0.4; medium: 0.4-0.6; high: 0.6-0.8; very high: 0.8-1.0). The estimated least-cost paths (black lines), representing potential pastoral foraging routes, and the location of public spaces (green dots; see also Figure 2) are also shown.

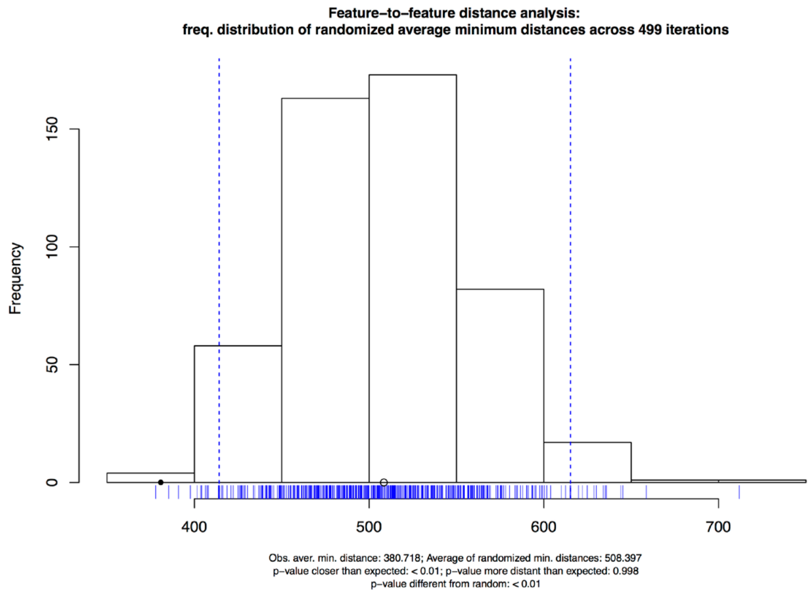


The *cabreo* model has been used as a constraint for the calculation of LCPs representing pastoral foraging routes between garrigue areas used as pastures. The abovementioned Figure 4 shows the potential routes along which a foraging journey may take place. The calculated paths (139 in total) minimise the traversed slope, as expected: the minimum and maximum average slope is 1.28 and 15.77 degrees respectively, the median average value is 5.19, with 90 per cent of the cases having an average slope equal to or smaller than 9.76, and just the top 10 per cent of the cases featuring an average slope between 9.76 and 15.78. As already noted, the LCPs tend to avoid areas with a high probability for optimal agricultural quality, valley bottoms in particular. The median average probability of the terrain they traverse is 0.05, with a minimum and maximum equal to 0 and 0.51 respectively. In 90% of the cases it is equal to or smaller than 0.23.

From a postdictive standpoint, we gauged the plausibility of the estimated LCPs by assessing their spatial relation with above-mentioned public spaces. We found that public spaces tend to lie close to the estimated LCPs. Their median planar distance to the nearest LCP turned out to be 89 m. Cumulatively, 73% (159) lie within a distance of 300 m, and only

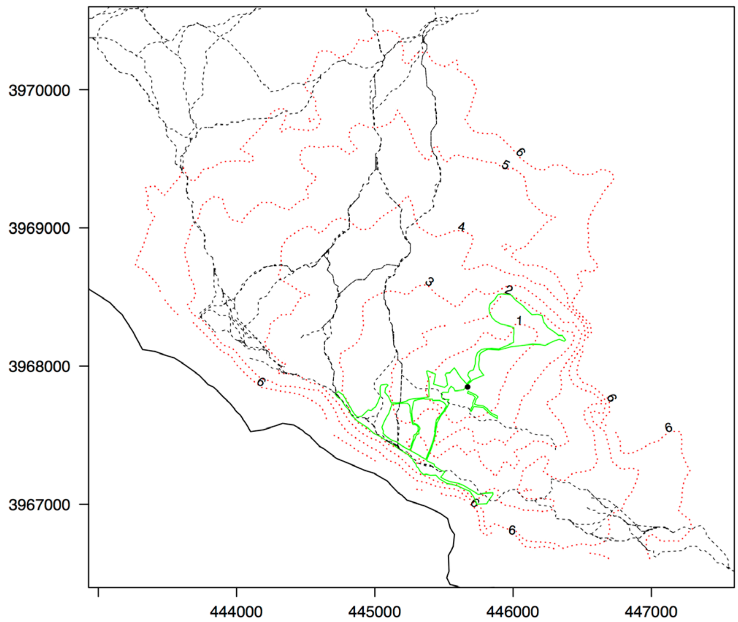
12% (27) feature a distance equal to or larger than 1 km to the nearest LCP. Remarkably, these more distant public spaces (see Figure 4) are mainly located at the fringe of the densest urbanized area of the island, which would indicate that they could possibly have been related to garrigue areas cancelled out by modern urbanization. Our analysis also showed that the observed average minimum distance between public spaces and LCPs is 380 m, which is smaller than the average of the randomized minimum distances, which is equal to 516 m. The tendency for public spaces to lie close to the estimated LCPs proved statistically significant, with a p-value equal to 0.004 (Figure 5).

Figure 5. Test for spatial association between public spaces and estimated pastoral foraging routes (see also Figure 4): the histogram shows the frequency distribution of randomized average minimum distances, calculated across 499 iterations. The observed average minimum distance between public spaces and foraging routes is 380 m (solid black dot), while the average of the randomized minimum distances is 508 (hollow dot). The blue lines at the base of the chart represent the 499 random average minimum distances. The observed average minimum distance falls in the left tail of the distribution, with an associated p-value of 0.004. Test performed in R using the 'GmAMisc' package (Alberti, 2018).



Our GIS-based estimates also proved consistent with ethnographic data to which reference has been made earlier and which is object of a larger analysis provided elsewhere (Alberti et al., n.d.). These data relate to practices dating between the 1950s and 1970s when the informants used to tend flocks with their father or other relatives. A shepherd living in the Għar il-Kbir area reported that the main grazing area for his flock consisted of the garrigue zones lying immediately southwest and northwest of his farmhouse, along the escarpment of the Dingli Cliffs and at Il-Bosk respectively. His foraging excursions used to be done between 6:00 and 8:30 a.m. in summer (June-October), and between 9:00 and 14:00 in winter (November-May). The duration of the reported excursions are consistent with the accumulated (animal) walking time surface calculated moving from the farmhouse outwards (Figure 6).

Figure 6. Isochrones (red dashed lines) around the farmhouse (black dot) located in the Għar il-Kbir area (west-central Malta): isochrones enclose the space that can be covered on foot during the time intervals (hours) indicated by the numbers. The walking time is estimated on the basis of the slope-dependant Tobler's hiking function, adapted for animal walking speed while grazing. The green lines represent the extent of the area used by the farmhouse owner as grazing ground for his flock. Black dashed lines represent part of the garrigue-to-garrigue least-cost path network corresponding to estimated pastoral foraging routes (see also Figure 4).



The grazing area immediately surrounding the farmhouse lies well within the 1-hour walking time buffer. The larger garrigue zones southwest of the farmhouse, lying between the Maddalena Chapel and Ta' Żuta, is reachable within four hours, while the foraging area lying to the northeast at Il-Bosk can be reached within a maximum walk of two hours. In these settings, it is possible to complete the two legs of the journey (outbound and inbound) well within the limits of the time windows reported by the informant, especially during the most time-constrained summer excursions.

Discussion

Our research into the development of the Maltese landscape proved both challenging from a methodological standpoint and intriguing in its findings. The research provided the unique opportunity to set qualitative and quantitative data in a common analytical framework and to work out methods to make the most out of both. For the first time in the literature (to the best of our knowledge) our research has made use of mid-1800s cadastral data not as simple cartographic base-maps, but as building blocks for agricultural suitability modelling. It has been possible to isolate a number of environmental and cultural predictors that are likely to have affected agricultural suitability before heavy mechanization. The different contribution of the different predictors has been gauged for Malta for the first time.

The cabreo model we have devised has also allowed us to generalise from our sample of maps to the entire landscape, enabling to arrive at a broader inference regarding the whole landscape. This has brought to the fore one of the striking characteristics of Malta, which is the wide variability in land quality even over small distances. As apparent from the mentioned Figure 4, the modelled landscape in Malta turns out to be a complex patchwork featuring different agricultural potentials and resulting in dramatically different micro-environments. The fragmented and variable nature of the Maltese landscape is evidently an enduring characteristic, which would have been no less variable in more remote periods. Mixed subsistence strategies, such as those combining animal grazing and food collecting on more inhospitable areas with crop cultivation in more sheltered and favourable zones, appear to be better suited to such an environment.

Our coupling of a predictive approach (cabreo model) with a postdictive analysis (GIS-based pastoral foraging routes estimation and comparison with other evidence on the ground and with ethnographic data) has allowed to add more dimensions to the analysis of the use of the Maltese landscape, and to further characterise that part of the landscape that has been flagged by our model as not optimal for agriculture. The LCPs estimation allowed us to locate potential pastoral foraging routes connecting "less productive" areas.

This apparently unproductive landscape was indeed an important part of the agrarian economy. In fact, the uncultivated areas provided grazing grounds for sheep and goats as well as quarried stone for construction, brushwood for fuel, apart from herbs, greens, wild game, and flowering plants for bee pasture (Blouet, 1963; Forbes, 1996; Lang, 1961; Rolé, 2007; Wettinger, 1982).

The use of quantitative approaches enabled the assessment of the plausibility of the estimated pastoral foraging routes vis-à-vis other independent herd-related evidence, such as the location of public spaces. While our findings cannot be used to claim a causal relationship between the estimated LCPs and public spaces, the tendency of the latter to lie close to the former is taken here to indicate a functional connection between the two. The importance of public spaces for economic activities as important as agriculture, such as animal husbandry, is witnessed by the investment in demarcating such apparently unproductive areas with rubble walls that permitted access to them for humans and herds through walled paths or tracks, while segregating them from sown land. They represent the embodiment of those strategies aimed at optimising the exploitation of land that was less optimal for agriculture.

Our research has also sought to couple, again for the first time, GIS-based analyses and ethnographic accounts. From a postdictive perspective, it turned out that the timing of estimated foraging excursions is broadly consistent with the information provided by our informants. All in all, our findings on the modelled agricultural quality, our GIS-based estimation of pastoral foraging routes, their relation with public spaces, and the comparison between modelled data and ethnographic accounts regarding foraging excursions, provide us with a portrait of intensive exploitation of the landscape. This was achieved through a mixture of strategies, each adapted to the highly variable affordances presented by those different micro-environments to which reference has been made earlier. The relationship between these different strategies, most notably between crop cultivation and pastoralism, was very carefully managed and regulated.

Conclusions

This chapter has sought to describe the main achievements of our research into several aspects of the Maltese landscape in recent historical periods, while highlighting the ways in which different analytical approaches may be combined and applied to better understand social and cultural phenomena. From this standpoint, our research is considered to break new ground for a number of reasons. First, the joint analysis and reconstruction of the ways in which the landscape has been exploited for different economic tasks represents a novelty in the literature regarding Malta and the Mediterranean area more generally.

Secondly, the historical development of the Maltese landscape has been approached from a GIS perspective for the first time. Thirdly, qualitative data such as cadastral maps and ethnographic accounts have been set within a modelling framework that makes explicit use of cutting-edge geo-spatial methods. Overall, the research has sought to approach the development of the Maltese landscape from a novel perspective, in which different types of data, once set in a robust, coherent, and explicit methodological framework, have converged to shed a new light on the layered development of the landscape in Malta.

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