Archeologia e Calcolatori
14, 2003, 217-236

A DIGITAL MEDITERRANEAN COUNTRYSIDE: GIS APPROACHES TO THE SPATIAL STRUCTURE OF THE POST-MEDIEVAL LANDSCAPE ON KYTHERA (GREECE)

1. Introduction

This paper presents GIS-driven analysis of spatial patterns left mainly by post-Medieval agriculture and settlement on the island of Kythera, Greece. Its purpose is a) to highlight useful analytical techniques that can be applied to regional-scale digital datasets and b) to offer important insights into the aggregate spatial structure of anthropogenic Mediterranean landscapes. As such, it contributes to the wider, multi-disciplinary mission of the Kythera Island Project (KIP)[1]. Kythera covers ca. 278 sq km in area and lies ca. 15 km off the southern tip of the Peloponnese. It has a history of human exploitation spanning at least 7000 years, from the Neolithic to the present day. KIP is an on-going research initiative designed to study the island's long-term environmental and cultural history and consists of several components, including an intensive archaeological survey (Broodbank 1999), as well as geoarchaeological, ethnographic, botanical and historical studies. GIS (Geographic Information Systems/Science) has been used to integrate these different perspectives since the project's inception in 1998 (Bevan, Conolly in press a).

This paper explores four key elements of Kythera's recent cultural landscape: field enclosures, terraces, trackways and buildings. It draws on one principal dataset, supplemented by more detailed KIP geoarchaeological fieldwork. The principal information comes from a digitised version of 1:5,000 scale maps produced in the 1960s from aerial photographs by the Hellenic Military Geographical Service (HMGS). These maps record the cultural topography of the island in great detail and have been digitised (by KIP) as vector entities across the whole island (Tav. IVa). While some of the limitations of this digital resource are considered below, it offers an opportunity, hitherto unavailable at such a scale, to explore the spatial organisation of villages and rural structures, both with respect to each other and to such environmental variables as slope, aspect and geology.

[1] This paper draws on the collaborative efforts of the many people involved in the Kythera Island Project (KIP). Our particular thanks go to Cyprian Broodbank and Vangelio Kiriatzi (KIP co-directors), John Bennet and James Conolly for advice and guidance on this subject at many stages. The Venetian to modern period on Kythera is also the subject of a much broader research agenda, including both ceramic analysis (Joanita Vroom, Leiden) and archival studies (John Bennet, Oxford; Siriol Davies, Cincinnati; Debi Harlan, Oxford). Bevan's research was made possible by a Leverhulme Trust Research Grant.

The following discussion is broken up into four sections. The first section introduces the variety of field systems visible on Kythera and considers one major type, flat-field enclosures. The second section then turns its attention to the well-known, but poorly quantified question of contour terracing. The third section explores the distribution and directionality of trackways in the landscape with a particular emphasis on their relationship to slope. The fourth section addresses the spatial organisation of buildings on Kythera and highlights how the pattern of villages and more isolated rural shelters relates to the distribution of field systems.

2. Kytheran field systems

Agricultural fields and related pastoral systems have fragmented the modern Kytheran landscape into countless smaller units. The systems may in some cases have much older (perhaps Classical or Byzantine) pre-cursors, but in their now-visible incarnation, they mostly reflect the practices of the last three or four centuries, specifically the later Venetian (ca. 1600-1808) and British (1808-63) occupations, followed by the island's incorporation into the Greek nation-state (Leontsinis 1987, 214). A rough distinction can be made between "enclosed fields" (or "field enclosures") found on flatter ground and "hillslope terraces" (or "contour terraces") used to stabilise and cultivate the steeper slopes and more undulating terrain (Tav. IVb).

"Cross-channel terraces" comprise a third, hybrid category, where low check dams have been built across shallow channels of Quaternary alluvium and frequently enclosed into larger groups. The traditional farming cycle on Kythera was well-established at least by the British Protectorate if not earlier in the Venetian period (Leontsinis 1987, 228). It consisted of a farmed-fallow, two-year rotation with most fields being used to graze livestock in the "off-year". Enclosure walls served to mark off individual holdings, but more importantly controlled the movement of livestock, penning them into fallow fields and excluding them from cultivated ones. This seems to have been less true of the hillslope terraces as these structures are rarely enclosed on Kythera (unlike on Kea: Whitelaw 1991, 408-10).

This study identifies aggregate patterns in the management of these three components of the subsistence landscape, focusing on the first two[2]. In the future, such quantification will provide a useful basis for integrating a host of other KIP perspectives on this subject, including geoarchaeology, remote sensing, aerial photography, intensive archaeological survey, archival studies, and ethnographic research.

[2] Cross channel terraces have for now been included in the enclosures category. Future work will seek to address this strategy as a separate phenomenon.

Enclosed fields cover most areas of flatter ground on Kythera, including some where the soil cover is now (if it was not always) extremely poor. These structures are built with drystone walls up to 2m high and 1m thick, and serve an important secondary role as an efficient way of removing field stones from cultivated areas. Observations both by archaeological survey teams and geoarchaeologists suggest that the 1:5,000 maps offer a relatively good basic impression of the distribution and character of these systems (which are often now abandoned and covered in *phrygana* and 0.5-2m *maquis* scrubland).

Field enclosures exhibit great variation in shape (strips, squares, ovals and more irregular forms) and size (though usually less than 1 ha, and often ca. 0.25-0.5ha). However, because many are not completely closed entities (they are only partially bounded by walls or have been mapped this way) they remain difficult to analyse as discrete areal units. An important starting point therefore is to calculate wall density per hectare (wall length per 100m grid cell). We can then use this as a background measure to consider more complicated parameters relating to field sub-division and curvature. The most efficient method to explore the latter two issues is to exploit the inherent topology of the vector polyline data. The digital KIP field systems were acquired and processed in a standardised way: they were manually digitised using a free-sketching algorithm with a 0.5m increment and then "weeded" at a search corridor tolerance of 2m [3]. This degree of standardisation means that the pattern of nodes/vertices along a polyline is highly structured and can be compared meaningfully across the whole dataset. More precisely, if we ignore the end-points of polylines, any remaining nodes/vertices are present (grey dots in Tav. IVc) because they express curvature and the more nodes there are on a given line the curvier it is. Similarly the density of intersection nodes (black squares in Tav. IVc) on a line (where different polylines cross) is an excellent expression of the degree of field subdivision. Both of these measures can be standardised across the whole landscape by dividing them by the wall density per ha measure.

This allows us to map enclosure wall curviness and field sub-division as it varies across the landscape. These mapped spatial indices are not only useful visual aids, but can be used as statistical correlates (cell by cell) to compare with the vegetation patterns identifiable from satellite imagery, to the distribution of particular plant species or to spatial variation in land use or tenure practices suggested by detailed Kytheran historical archives (Leontsinis 1987; Maltezou 1991). For example, further analysis may eluci-

[3] Enclosures were digitised from a tablet (with calibration RMS of < 3m) into AutoCAD Map and weeded using the software's implementation of the Douglas-Poiker algorithm. All lines were broken where they crossed each other and dangles were removed at a search tolerance of 0.5m.

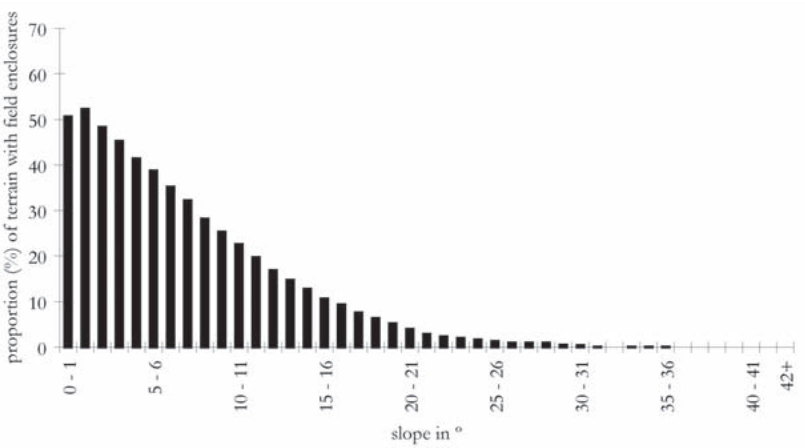

Fig. 1 – Histogram of the proportion of terrain with enclosed fields in relation to slope (coverage limited to KIP survey area).

date circumstantial evidence that the more subdivided, rectilinear systems are older (late Byzantine-Venetian) than the less sub-divided more curved field units. Most of the latter cover areas of more marginal land known to have been enclosed only quite recently in the 19th and 20th centuries.

Another useful way of understanding the role of field enclosures is to plot their prevalence in relation to slope (for a preliminary version, see Bevan, Conolly in press a). For this analysis and those that follow below, a 10m grid cell Digital Elevation Model (DEM) was used, based on 4m (and judgmental 2m) contours and spot heights[4]. A slope map was derived from this and the values grouped into 1° classes. The amount of land falling into each class (e.g. 2-3°) was calculated and then the percentage of this covered by field enclosures. A near-exponential fall off in the prevalence of field enclosures is apparent as slopes become steeper (Fig. 1). The relationship between this pattern and a very different one exhibited by terraces is discussed further below.

3. Terraces

Hillslope terraces concentrate on the steeper slopes on the island, especially those close to villages and other permanent establishments (e.g. churches, monasteries and isolated farms). Terraces are often used for fruit crops (olives, grapes, figs etc.), but were also planted with cereals. They have

[4] A large number of different interpolation methods were explored, but ArcInfo's TOPOGRID algorithm (Hutchinson 1989; Hutchinson, Dowling 1991) was found to produce the best results. At this scale, there are no signs of the inter-contour benching sometimes associated with such contour-based interpolations.

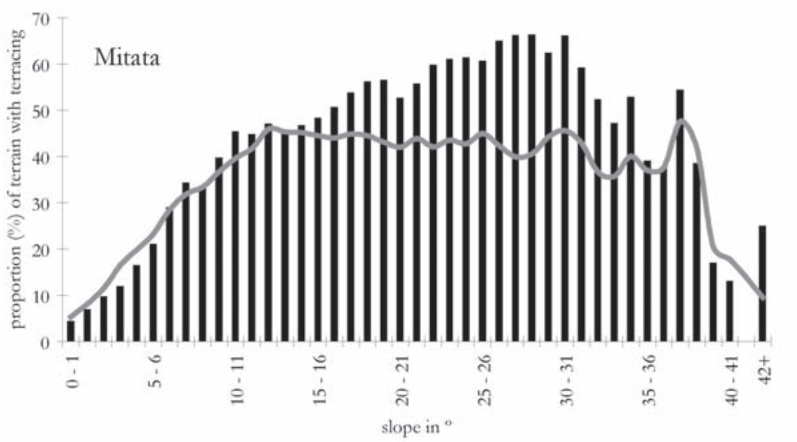

Fig. 2 – Histogram of the proportion of terrain with hillslope terraces in relation to slope in the Mitata area (for comparison, the average across the three geoarchaeological areas of Mitata, Palaioplis and Livadi is shown as a grey line).

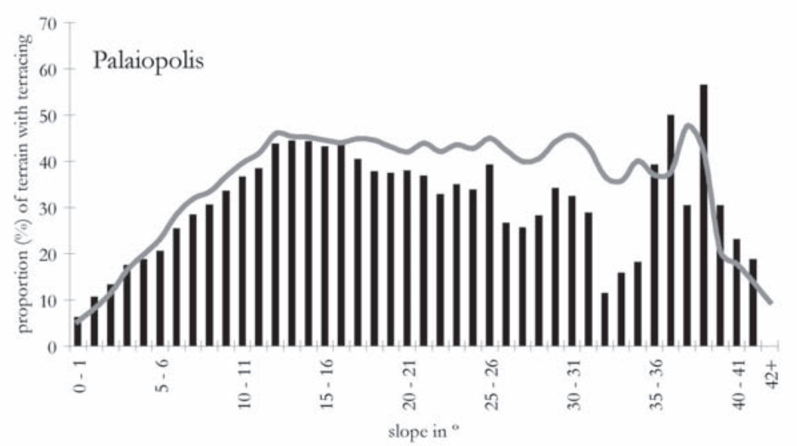

Fig. 3 – As previous Fig., but for the Palaiopolis area.

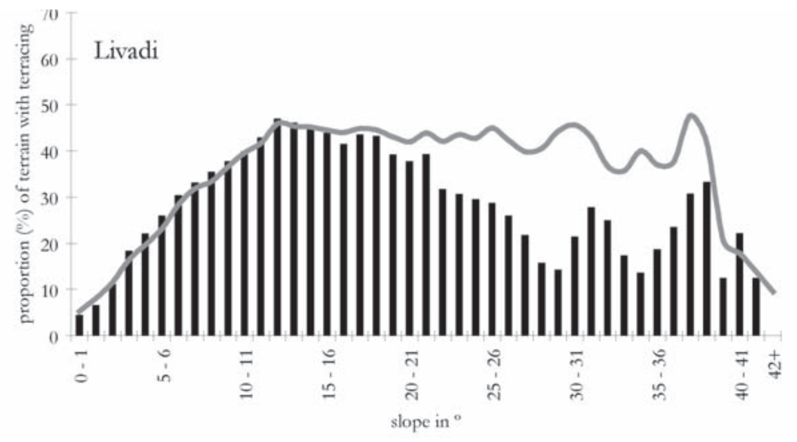

Fig. 4 – As previous Fig., but for the Livadi area.

been constructed in a variety of ways (FREDERICK, KRAHTOPOULOU 2000), but until very recently, when bull-dozer terracing has become common, most possess carefully built, dry-stone risers. The 1:5,000 maps give a good overall indication of main terraced areas on the island (Tav. IVb, especially the large number found on Metamorphic phyllite/schist formations in the north), but nonetheless heavily under-represent the actual amount of terraced landscape, especially in patches of thick vegetation or very steep slopes where photogrammetric identifications would have been difficult.

Moreover, on the resulting maps they are portrayed as lines (the break of slope where the stone riser is located) rather than as actual cultivatable areas. However, KIP geoarchaeologists (Frederick and Krahtopoulou) mapped terraced areas for three sub-regions of the island (Tav. IVb) and the distribution of terraces vs. slope can be calculated for each of these (Figs. 2-4). All three plots show a gradual increase in the prevalence of terraces up to ca. 12°. Indeed, this is also the point when the respective cumulative frequency distributions for terraces and field enclosures diverge the most (BEVAN, CONOLLY in press a, fig. 5), suggesting that, while the changes are relatively gradual, this is an appropriate rule-of-thumb threshold for distinguishing between two different field management strategies, "flat-field" and terraced hillslope agriculture.

The variation in the plots from ca. 12-40° could reflect the different land use histories of the three study regions or their specific geomorphological environments. In favour of the latter explanation is the similarity of the Palaiopolis and Livadi plots, which may reflect the fact that, despite quite different levels of agricultural investment in the past, both regions possess broad alluvial basins that were ideal for flat-field agriculture. The exploitation of this fertile flat land may have had comparable knock-on effects in both landscapes on the spatial distribution of neighbouring terraced areas.

Overall, ca. 28% of the land in the geoarchaeological zones is terraced and ca. 44% of that which is over 12° in slope. Individually such structures undoubtedly are the product of particular human decisions or historical events, but seen in aggregate, they are clearly influenced by environmental factors such as slope, aspect and geology that are particularly amenable to GIS-led correlation.

For example, we can show that south-facing slopes are preferred locales for terraced agriculture, probably because they are exposed to greater amounts of sunlight, particularly in winter months. Initial results for the geoarchaeological zones revealed no clear pattern, but when analysis is limited to slopes over 12°, a highly significant preference ($p<0.001$) for south-facing slopes becomes apparent. Moreover, the least preferred slopes to terrace were north-west facing ones that receive poor solar irradiation and are exposed to the prevailing winds on the island. Fig. 5 explores the relationship further: aspect values have been grouped into 10° classes and polar aspect

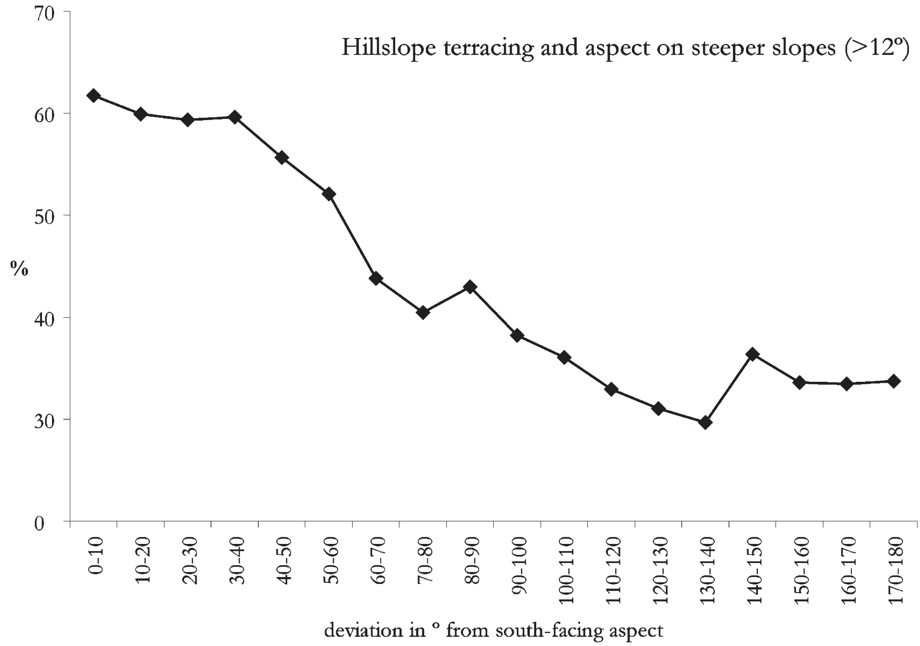

Fig. 5 – Plot of the proportion of steeper terrain (over 12° in slope) with hillslope terraces in relation to aspect (expressed as deviation from south-facing).

Geology Type	Observed % of land terraced	% expected from aspect distribution	% expected from slope distribution	% expected from village distance distribution
Eocene flysch (55 ha)	83	43.8	44.6	49.4
Neogene regressive conglomerates (170 ha)	72	46.2	38.8	44.5
Neogene marl limestones (95 ha)	44	47.0	43.7	42.2
Tripolitza & Olonos Pindos limestones (215 ha)	29	42.3	43.9	44.3

Fig. 6 – Table of the observed percentage of terracing per major bedrock type in the three geoarchaeological areas and expected percentages based on the distribution of slope, aspect and village distance variables.

measures have been "linearised" by expressing them in terms of their deviation from south-facing (i.e. from 180°). There is a clear fall-off pattern: the more a slope deviates from a south-facing aspect, the less attractive it appears to be as a place to terrace.

It also appears that certain bedrock units were thought more worth terracing than others. Fig. 6 considers four major geological formations found within the KIP geoarchaeological study areas (other bedrock types of limited extent have not been considered here). The very different proportions of terraced terrain for each bedrock type suggest that specific formations, the Eocene flysch and Neogene regressive conglomerate landscapes in particular, were preferred. We can test these observed percentages not only against the usual expected values we might calculate based on bedrock type area, but also those we might expect given the different distributions of aspect and slope per geology type. A third possible contributing factor (considered in greater detail below) is the distance to the nearest village. In all cases, the observed values remain significant (X^2, $a<0.001$): in other words, above and beyond the influence of slope, aspect and village-terrace distance, certain bedrock units were being preferentially targeted. This may reflect the fact that flysch and conglomerate landscapes were particularly prone to geomorphological instability and were therefore far more intensively managed by terrace-works, but it also suggests that they possess soils and/or drainage properties deemed superior for certain types of crop. Ethnographic work with older Kytheran residents will hopefully reveal some of the human assessments and strategies behind these patterns.

Further analysis is necessary however, because the contributions of geology, slope, aspect and town distance are inter-dependent variables: for example, different geologies exhibit different gradient profiles. Slope tends to be distributed lognormally for most landscapes, but beyond this general pattern, the erosional and hydrological character of the underlying bedrock geology produces quite different proportions of flatter or steeper slopes. Fig. 7 shows separate slope distributions for three major formations across the island[5]. The Metamorphic system in the north of the island is heavily dissected into networks of gullies and this is reflected in the rather less skewed shape of its distribution. In contrast, the harder limestones distribution reveals more flattish areas of extensive plateau, but also some extremely steep gorges (the majority of slopes over 35° are found in limestone). The Neogene marls are even more heavily skewed towards flatter ground.

So geology and slope are inter-related phenomena. Multiple logistic regression offers a well-established method to assess covariance and assign priority of influence among such variables (Warren 1990; Maschner, Stein 1995;

[5] The IGME 1:50,000 geological map of Kythera is not sufficiently accurate to support close analysis, particularly of the smaller geological units (such as the flysch and regressive conglomerate deposits), but nonetheless sustains gross comparison between these three major formations. All subsequent analysis of geology in this paper confines itself to the three KIP geo-archaeological zones for which all bedrock units have been carefully re-mapped at 1:5,000.

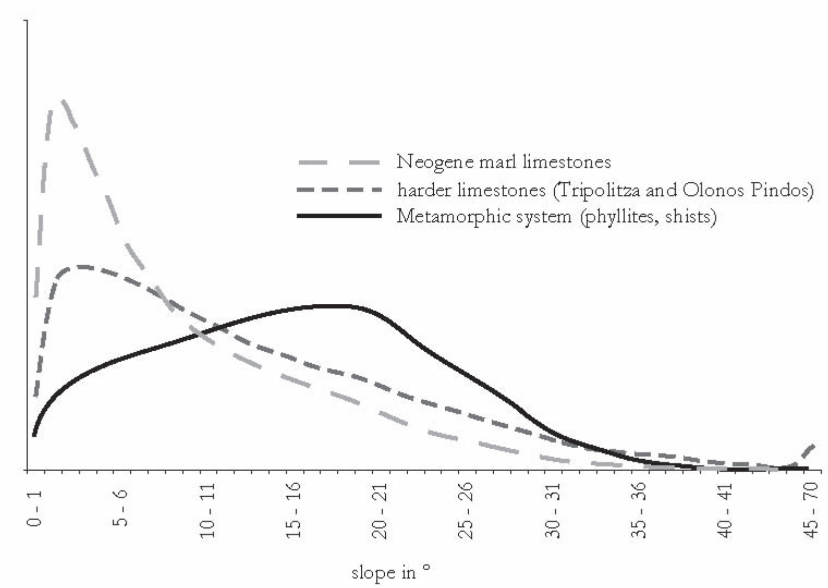

Fig. 7 – Approximate island-wide frequency distribution of slope values in relation to three major geological units on Kythera.

Warren, Asch 2000). Nonetheless, there are under-appreciated problems involved in deploying such techniques in a geographic context, especially where significant patterns of spatial autocorrelation exist (Fotheringham *et al*. 2002, 162-166). For the latter reason, quoting partial correlation statistics (or various equivalents available for logistic regression) is probably misleading, but the technique is still sufficiently robust to suggest that geology is the most important of these variables influencing whether land above ca. 12° is terraced or not, southerly aspect makes a more limited contribution, and village distance and slope add very little independently[6]. This result is worth considering more fully. As Figs. 2-4 suggested, slope does have an important impact on whether land *below* ca. 12° degrees is terraced (the probability increases steadily with increasing gradient), but a relatively minor influence thereafter. The limited independent contribution of village distance in the regression reflects the fact that many villages are located near to the most popular geology types, but suggests that specific soils (assuming that, apart from Quaternary alluvium channels, these are usually a function of bedrock) were the primary concern,

[6] Logistic regression was carried out in SPSS using standard dummy variables for the nominal scale geology co-variate. Ideally, these types of land use priorities should be modelled with a geographically-weighted version of logistic regression especially since the dependent variable, presence or absence of terracing, shows strong spatial autocorrelation (Fotheringham *et al*. 2002, 162-166, discuss geographical weightings for standard multiple regression and a software implementation called GWR is available).

and that both settlement location and terracing regimes were influenced by them, perhaps from a relatively early stage.

Indeed, an important issue that cannot be addressed in detail here, but which KIP with its emphasis on the long-term history of the island is well-placed to answer in the future, is the degree to which early landesque capital investment[7] in certain areas continues to define subsequent land use strategies. In particular, we might ask the degree to which possible Classical terracing projects and definite Byzantine ones may have retained a lasting influence on the organisation of the Kytheran landscape. At least three areas of dense terracing on the island are suggestive of original investment at a much earlier date, even though often they have continued to be used until recent times: specifically those a) immediately west of the Classical polis on Palaiokastro, b) around the Minoan-Late Roman settlements in the Palaiopolis valley, and c) inland from the abandoned Byzantine town of Palaiochora[8].

4. Trackways

GIS is frequently used in archaeology and elsewhere to tackle the phenomenon of movement through the landscape. However, with few important exceptions – usually either analytically-constrained case studies (Bell, Lock 2000) or theoretical discussions (Llobera 2000) – the methodologies involved remain highly problematic both in terms of the algorithms they use (e.g. Douglas 1994) and the degree to which these are deployed in a coherently-theorised way. The best approaches to such questions are probably to be found in multi-agent simulations (e.g. Lake 2000) where the emergent and dynamic properties of human way-finding and information-sharing can be modelled more realistically.

Another approach which may complement such efforts is the dedicated analysis of existing routes. Mediterranean landscapes are criss-crossed by numerous roads and trackway systems and these are occasionally referred to in existing GIS landscape studies (e.g. Bommelijé, Doorn 1996; Bell *et al.* 2002). As with field systems, land-based routes are heavily influenced by terrain gradient. The 1:5,000 maps only offer a limited impression of the actual number of paths in the Kytheran landscape (this is probably the least well-recorded of the four classes of evidence described here), but still repre-

[7] This term is usually used to describe farming innovations, such as terraces or drainage systems, that create long-term, re-useable capital in the landscape (Blaikie, Brookfield 1987, 9-10). Even after abandonment, visible evidence of their existence may remain and they can often be brought back into service many years later.

[8] This town and its environs are the subject of on-going fieldwork by the Australian Paliochora-Kythera Archaeological Survey (APKAS, http://acl.arts.usyd.edu.au/research/kythera/index.html), including a study of local terracing. Johnston and Wilson (2003) also discuss the potential and problems of the 1:5,000 map dataset in relation to APKAS research.

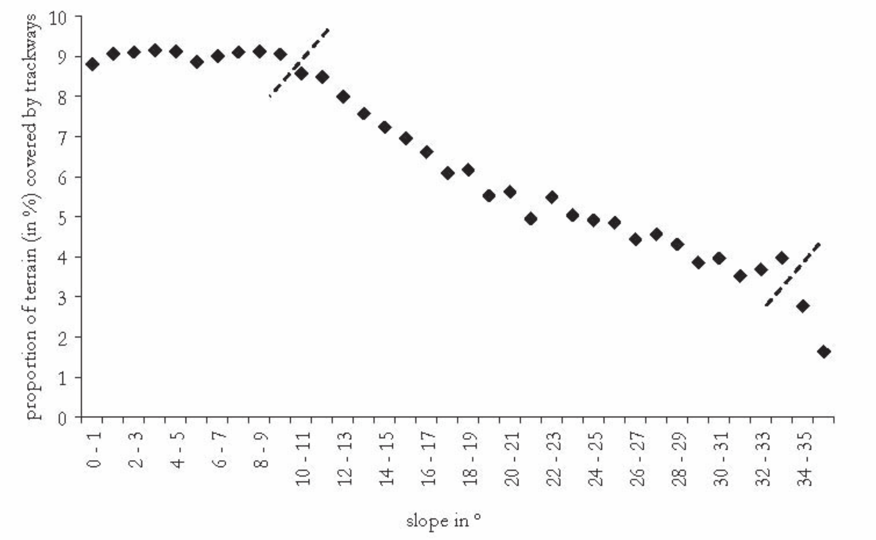

Fig. 8 – Plot of the proportion of terrain with trackways in relation to slope.

sent a huge dataset (totalling ca. 1720 km in length across the island)[9]. If we run the same analysis conducted above for field enclosures and terraces, it appears that the proportion of terrain covered by tracks remains relatively stable up until ca. 10-12° and then begins to decline steadily (Fig. 8).

Moreover, even the casual observer of track-systems will have noted the fact that as slopes become steeper, trackways tend to follow more oblique routes, often winding rather than heading directly up hillsides. This has to do with the near-exponentially increasing effort required to climb steeper slopes (Bell, Lock 2000, fig. 3; Llobera 2000, fig. 2). Again, the mapped Kytheran trackways give us an opportunity to explore this issue quantitatively using a real-world dataset.

First, the track polylines were exploded into their constituent line segments. Second, the bearing in degrees (modulo 180)[10] of each track section was calculated. Third, slope direction (i.e. aspect, modulo 180) was recorded for each track section with reference to the DEM. By comparing track bear-

[9] For the purposes of this analysis all roads and tracks shown on the 1:5,000 maps have been included without regard to their probable date.

[10] Any given track section has two possible (opposite) bearings, but to aid calculation the more easterly one (falling between 0° and 180°) is used here. The same is true for aspect: although slopes only face in one direction, they run up- and downhill in two (opposite) directions and the more easterly of these two directions is again used here. This method makes it straightforward to calculate the minimum difference between slope direction and track direction: for example, if a track runs NW-SE (315°-135°) along a south facing slope (uphill=0°, downhill=180°), the difference between track bearing and aspect is ca. 45°.

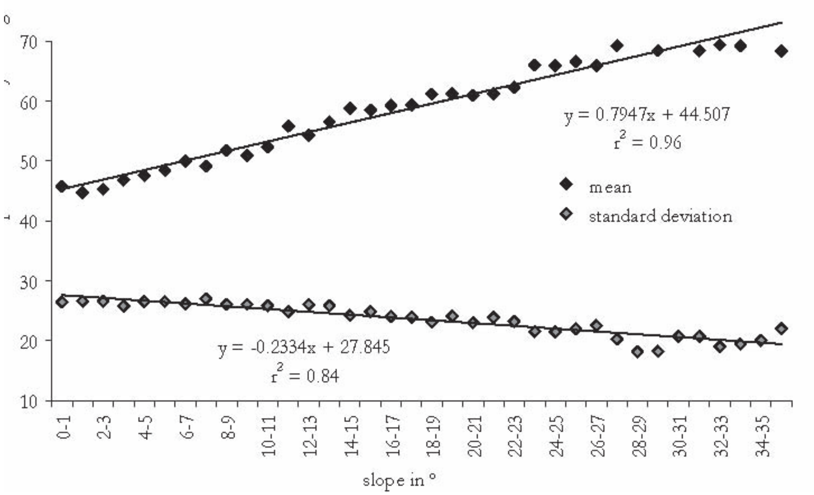

Fig. 9 – Plot of first and second order moments (mean and standard deviation) of the difference between slope and trackway direction by slope category.

ing and slope direction, we can measure the extent to which a track section runs up- and downhill, along the line of steepest gradient (where the difference between track bearing and slope direction is small) or across it (where the difference is large).

These difference measures can then be plotted in relation to slope. There is little clear relationship ($r^2<0.1$, logged) when the differences of *individual* track sections are correlated with the slopes they are found on, but a strong linear relationship is visible when *average* differences are plotted per degree of slope (Fig. 9). As slopes become steeper, the average difference between the direction of steepest slope (i.e. the aspect) and trackway bearing also increases as more routes that cross slopes more obliquely are used. Further summary statistics of the distributions of bearing-aspect differences per degree of slope also reveal important patterns (Figs. 9-10). and by combining the insights of these different moments, we can get a clear picture of the process involved. On lower slopes, tracks are free to run in any direction and the reasons for the bearing of any given section of track are numerous: hence, the mean bearing-aspect difference falls almost exactly in the middle of the 0-90° range (ca. 45°), but relative to steeper slope categories, the standard deviation is low and the distribution is symmetrical about the mean (skewness = 0) but quite flat (kurtosis < 0). As slope increases, the trackways run at more oblique angles (the mean increases) and there is a linear trend towards *less* overall variability in bearings relative to this gradient (lower standard deviation). Distributions on steeper slopes have longer lower tails of "uphill" bearings and more compact upper tails of oblique bearings (a

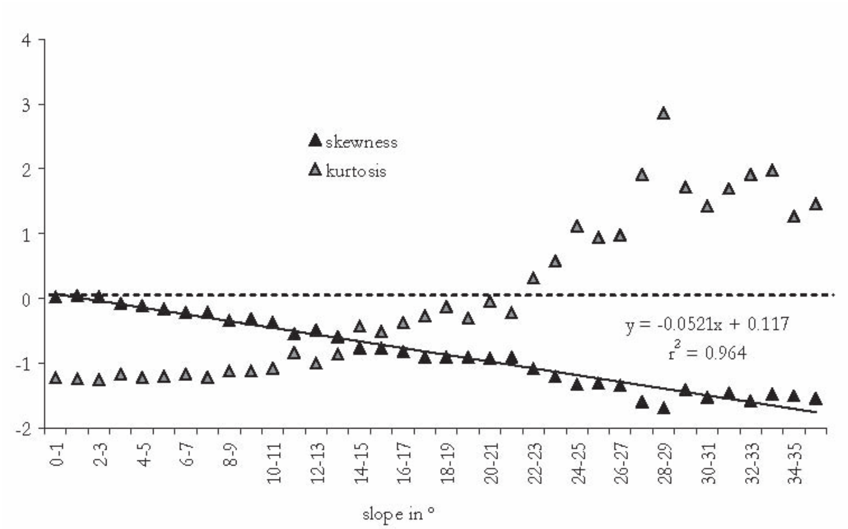

Fig. 10 – Plot of third and fourth order moments (skewness and kurtosis) of the difference between slope and trackway direction by slope category.

linear trend towards greater negative skewness). Furthermore, the distributions remain relatively flat until ca. 10°, but then the central tendency becomes increasingly dominant (kurtosis increases). On very steep slopes, as might be expected, we can describe a pattern in which a very circumscribed set of routes are followed, longer stretches of oblique paths (usually running at ca. 67.5° from uphill) punctuated by shorter sections of more direct uphill climb.

In other words, despite the incomplete nature of the dataset, this analysis confirms our intuitive understanding of how gradient structures land-based routes, but more importantly it clarifies the nature of this relationship. The influences for the most part appear to be gradual ones, but we can nonetheless suggest a threshold at ca. 10° after which the overall prevalence of trackways begins to decrease and the central tendency towards more oblique routes becomes more pronounced.

5. Buildings

The location of buildings can be modelled in similar ways to those considered for terracing above. Final analysis requires accurate remapping of the bedrock units across a larger portion of the island, but it seems clear that the older villages are preferentially located close to those types of agricultural land deemed most suitable for specific Kytheran crops and agricultural strategies (intensively exploiting patches of Quaternary alluvium, and the soils formed on Eocene flysch and Neogene regressive conglomerate units).

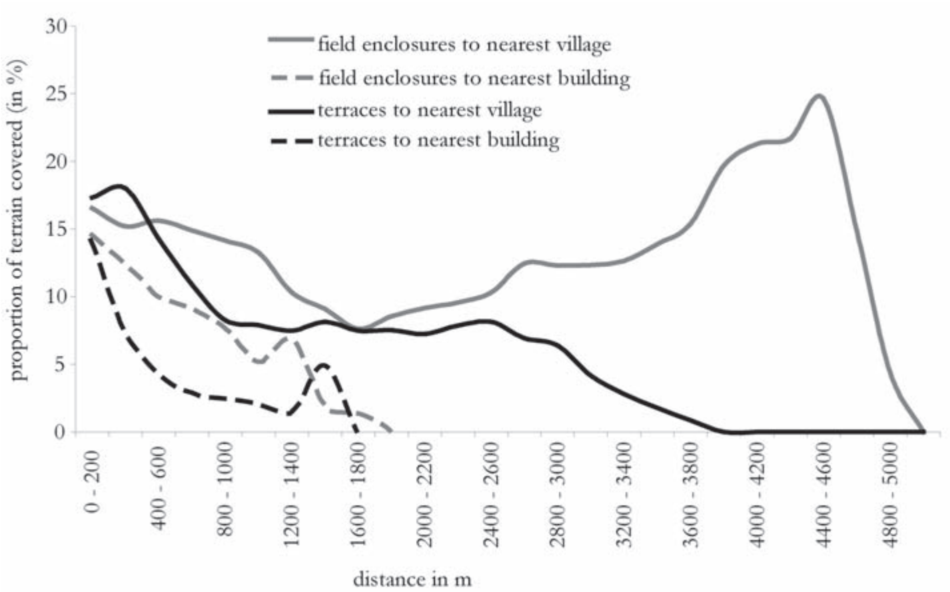

Fig. 11 – Plots of the prevalence of field systems in relation to distance to nearest village and nearest building.

Some (e.g. Mitata) may also have developed at the interface between different geology types, particularly limestones, where seep-lines provide freshwater springs (Pagounis, Gertsos 1984; Stedman 1996, 180).

As we have seen the location of villages also relates to the distribution of field systems. Fig. 11 plots the prevalence of field enclosures and mapped terraces at different distances away from a) village centres and b) all mapped buildings. This analysis gives only a rough impression as the 1:5,000 map coverage of terraces is incomplete, the function and age of buildings is not defined and linear distance measures are used. However, it is clear that most agricultural activity occurs within ca. 1-1.5 km of a built shelter of some kind. In the better agricultural areas there are many more villages and these distances more than halve. These results accord well with both cross-cultural evidence for how far farmers were prepared to travel from dwelling or depot to field, particularly in cases where land holdings are highly fragmented (Chisholm 1968, 45-49)[11]. In particular, the terrace to village distribution is

[11] Wagstaff and Augustson (1982, 109-10) summarise Greek data on this subject: the average maximum distance that informants from the Greek islands were prepared to travel to their fields was 2.2 km (ca. 25 minutes walk). The specific results for Melos however appear unusually high, but as Whitelaw suggests (1991, 453), probably fall into line with the overall pattern when *spitakia*/seasonal farms are taken into account.

comparable to figures calculated by WHITELAW for NW Kea (1991, figs. 21-25). Moreover, in contrast to terracing, it is notable that, on Kythera, as we move away from villages, field enclosures actually become *more* prevalent. We might conclude that enclosure strategies were driven for the most part by the desire to enclose flat land, no matter where it was located (though relative emphasis on arable or pastoral use may vary). If we compare the distribution of field enclosures vs. distance to village with that vs. distance to any sort of building, it is clear that much of the flat land 2-5 km from the nearest village was managed via isolated farms, semi-permanent dwellings and temporary shelters, that both fieldwalking and the HMGS maps suggest exist to the order of 12-15 per sq km.

Another obvious feature of the modern Greek landscape is settlement nucleation. This pattern of clustered dwellings has coevolved with particular land use regimes (e.g. extensive arable farming and fragmented land holdings) and particular social behaviours associated with communal village life. The spatial organisation of such events or locations can be explored by point pattern analysis (HODDER, ORTON 1976, 30-97; BAILEY, GATRELL 1995, 75-139)[12]. For example, we can calculate an R statistic (CLARK, EVANS 1954) of 0.12-0.33 for the spatial aggregation of individual buildings on the island, suggesting a highly clustered pattern[13].

We can also consider patterning at the larger scale of the village. The analysis will be approximate because defining what building clusters constitute "villages" is subjective and total estimates for the island can vary from 60-80 distinct village communities, even in the 20th century, depending how we define them (here and elsewhere we have used a maximal estimate). Not least, this reflects the fact that the "becoming" a village is a dynamic process, driven by both demography and local politics. In any case, an R-statistic of 0.74-0.84 suggests a slightly clustered village pattern, reflecting the fact that many settlements concentrate in inland areas next to the more suitable agricultural land. If we focus exclusively on this preferred inland zone, the pattern is more regular (R=1.26-1.31 within a minimum convex polygon of the inland villages) suggesting that in a relatively homogenous environment (e.g. with similar local access to suitable soils) villages tend to share out the available space more evenly and to establish clearer individual catchments.

[12] The 1:5,000 maps represent the distribution of buildings in the 1960s villages quite accurately and are a significant if less comprehensive a record of the rural buildings (to judge by KIP field checks). For this analysis, the centre-points of individual buildings were used (abutting structures were treated as separate points).

[13] The range reflects the different values derived from using either median or mean observed nearest neighbour values. The edge effect problems often associated with this statistic are irrelevant here because we are dealing with a complete, island-wide sample.

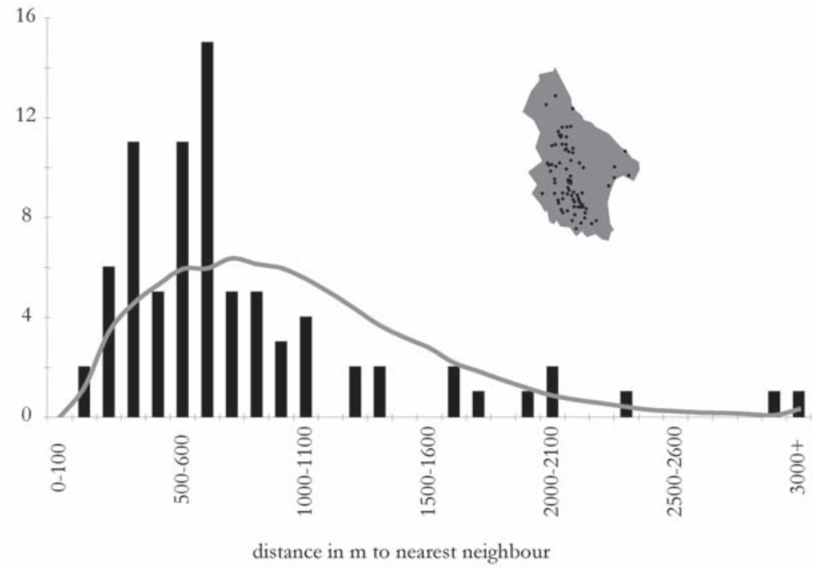

Fig. 12 – Histogram of nearest neighbour distances for Kytheran villages. The grey line represents an expected distribution derived from 1000 random iterations.

We can also explore nearest neighbour distances in more detail with a histogram (Fig. 12, for the whole island). The grey line represents the average nearest neighbour totals for each distance category calculated from 1000×80 random point sets, offering a distribution of expected values. As with the R-statistic, the observed pattern suggests deviation (significant at $p<0.001$, Kolmogorov-Smirnov one-sample test) from what we might expect in a random distribution. More precisely, two observed distance ranges are noticeably more frequent that we might expect: 300-400m and 500-700m. These neighbouring villages include ones for which a budding off process is known to have occurred historically, where specific families have founded new communities close to but separate from their original homes), and probably also reflect general regularities in village spacing associated with such issues as landholding, refuse disposal and local political organisation.

As with the individual buildings, this analysis of villages remains scale-specific as it is restricted to *nearest* neighbour distances, but we can also deploy alternative techniques to consider variation across different spatial scales. Fig. 13 shows a modified version of a Ripley's K-function analysis (Ripley 1977; Bevan, Conolly in press b). The black line is produced by the average density of inland Kytheran villages, measured in 50m buffered intervals out from each village. The grey lines represent a confidence envelope at the $p=0.01$ level and edge effects due to the shape of the inland sample area have been accounted

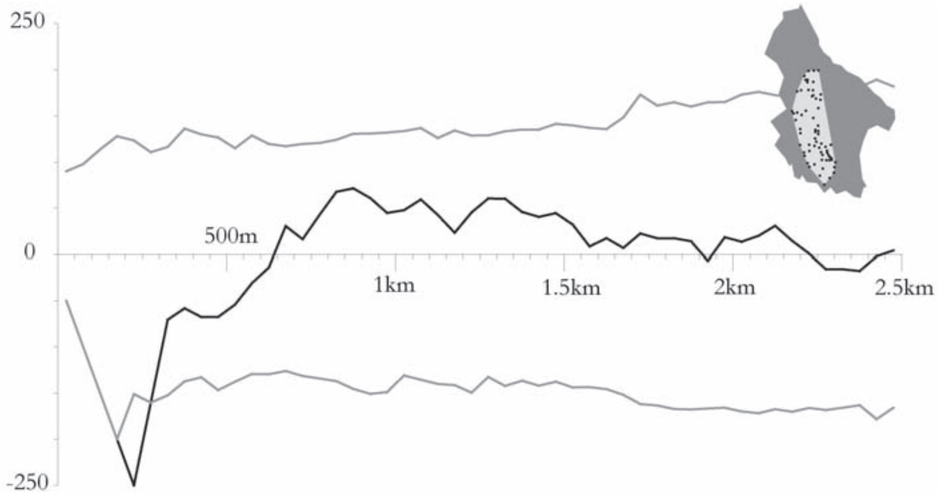

Fig. 13 – Ripley's K as a modified function (L). The black line shows the observed density values for Kytheran villages and the grey lines represent a *p=0.01* probability envelope. The x-axis bars are at 50m intervals.

for using a correction method proposed by GOREAUD and PÉLISSIER (1999)[14]. The plot confirms for the inland area, the island-wide pattern shown in Fig. 12, with a greater than expected regularity at smaller scales (statistically significant up to ca. 300m radius)[15], but also reassures us that at larger scales, the pattern is not noticeably different from a random one.

6. CONCLUSION

Fig. 14 offers one final aggregate impression from the Kythera data of how a Mediterranean cultural landscape might be structured, in this case by slope (HORDEN, PURCELL 2000, *Tyrannie de la pente*, 234-237). It plots standardised distributions of various structure types in relation to 1° slope categories. On Kythera, we can usefully talk of two broad cultural landscapes though

[14] Analysis was carried out in ADE-4 (http://pbil.univ-lyon1.fr/ADE-4/ADE-4.html) which automatically computes local confidence interval values for the null hypothesis of spatial randomness based on Monte Carlo tests and also implements Goreaud and Pélissier's edge correction methods.

[15] K-function analysis was restricted to the inland area because the technique assumes that the processes behind a point pattern are operating in spatially homogenous ways – this is unlikely to be true for the varied geological environments across the whole island, but is more probable for the inland zone. In addition, at any specific scale, the modified K-function shown in Fig. 16 will be less discerning than a plot such as Fig. 15 because the former relies on a single summary statistic, mean density. It is therefore a very useful multi-scale tool, but one best used to indicate scale thresholds where more detailed analysis can be carried out.

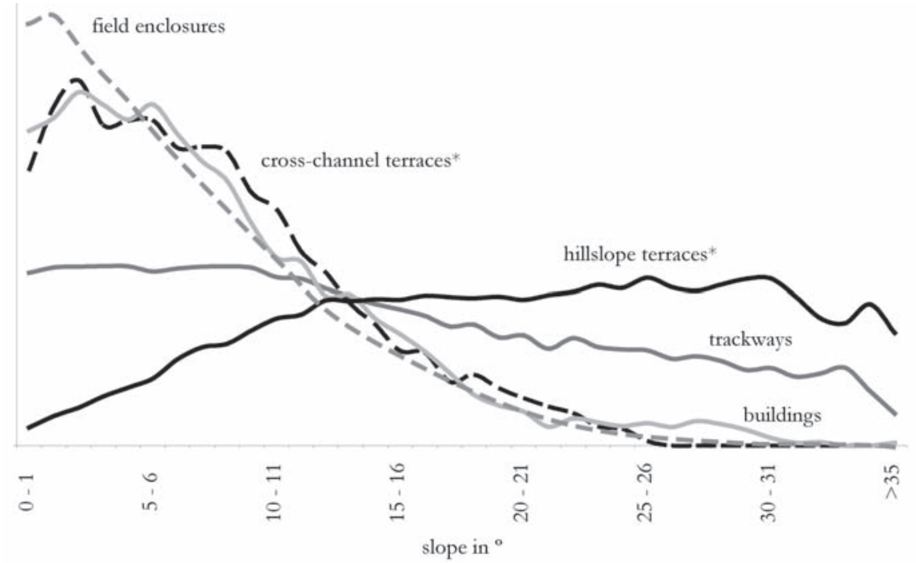

Fig. 14 – Standardised plots of the prevalence of different built structures in relation to slope.

not exclusive in their segregation of components: one of villages, multitudinous trackways, flat field and cross-channel terraced agriculture, and another of fewer shelters, some (winding) tracks and terraced hillsides. The broad transition between these two ecologies occurs at ca. 10-12° and the extent to which they exist as distinct geographical zones or are densely interspersed with each other will relate to the texture of local terrain.

Exploring the spatial structure of field systems, tracks and buildings in a formal way will offer insight into the aggregate anthropogenic patterns and environmental relationships found in many Mediterranean landscapes. However, this study is a necessarily preliminary rather than an adequate explanation of these phenomena as it stops short of ascribing a full set of human motivations to explain these patterns. Such a holistic perspective is the intended subject of more multi-disciplinary contributions by KIP and the analysis presented here provides a quantitative platform for further study of vegetation and land use patterns, geomorphology, surface pottery distributions and historical geography.

Andrew H. Bevan
Institute of Archaeology
University College London

Charles Frederick, Athanasia Krahtopoulou

REFERENCES

BAILEY T.C., GATRELL A.C. 1995, *Interactive Spatial Data Analysis*, London, Longman.

BELL T.W., LOCK G. 2000, *Topographic and cultural influences on walking the ridgeway in later prehistoric times*, in G. LOCK (ed.), *Beyond the Map: Archaeology and Spatial Technologies*, Amsterdam, IOS Press, 85-100.

BELL T., WILSON A., WICKHAM A. 2002, *Tracking the Samnites: Landscape and communications routes in the Sangro Valley, Italy*, «American Journal of Archaeology», 106, 2, 169-186.

BEVAN A., CONOLLY J. (in press a), *GIS and archaeological survey data: Four case studies in landscape archaeology from the island of Kythera (Greece)*, «Journal of Field Archaeology».

BEVAN A., CONOLLY J. (in press b), *Multi-scalar approaches to settlement distributions*, in G. LOCK, B. MOLYNEAUX (eds.), *Confronting Scale in Archaeology: Issues of Theory and Practice*, New York, Kluwer Press.

BLAIKIE P., BROOKFIELD H. 1987, *Land Degradation and Society*, London, Methuen.

BOMMELIJÉ Y., DOORN P. 1996, *The long and winding road: Land routes in Aetolia (Greece) since Byzantine times*, in H. KAMERMANS, K. FENNEMA (eds.), *Interfacing the Past. Computer Applications and Quantitative Methods in Archaeology* (*CAA 95*), Leiden, Institute of Prehistory, 343-351.

BROODBANK C. 1999, *Kythera Survey: Preliminary report on the 1998 season*, «Annual of the British School at Athens», 94, 191-214.

CHISHOLM M. 1968, *Rural Settlement and Land Use*, London, Hutchinson.

CLARKE P.J., EVANS F.C. 1954, *Distance to nearest neighbour as a measure of spatial relationships in a population*, «Ecology», 35, 445-453.

DOUGLAS D.H. 1994, *Least cost path in GIS using an accumulated cost surface and slope lines*, «Cartographica», 31, 3, 37-51 (Internet edition: http://www.hig.se/~dds/research/leastcos/cumcost4.htm).

FOTHERINGHAM S.A., BRUNSDON C., CHARLTON M. 2002, *Quantitative Geography: Perspectives on Spatial Data Analysis*, London, Sage Publications.

FREDERICK C.D., KRAHTOPOULOU A. 2000, *Deconstructing agricultural terraces: Examining the influence of construction method on stratigraphy, dating and archaeological visibility*, in P. HALSTEAD, C. FREDERICK (eds.), *Landscape and Land Use in Postglacial Greece*, Sheffield, Sheffield Academic Press, 79-94.

GOREAUD F., PÉLISSIER R. 1999, *On explicit formulas of edge correction for Ripley's K-function*, «Journal of Vegetation Science», 10, 433-38.

HODDER I., ORTON C. 1976, *Spatial Analysis in Archaeology*, Cambridge, Cambridge University Press.

HORDEN P., PURCELL N. 2000, *The Corrupting Sea*, London, Blackwell.

HUTCHINSON M.F. 1989, *A new method for gridding elevation and stream line data with automatic removal of pits*, «Journal of Hydrology», 106, 211-32.

HUTCHINSON M.F., DOWLING T.I. 1991, *A continental hydrological assessment of a new grid-based digital elevation model of Australia*, «Hydrological Processes», 5, 45-58.

JOHNSTON I., WILSON A. 2003, *Making the most of maps: Field survey on the island of Kythera*, «Journal of GIS in Archaeology», 1, 81-89 (Internet edition: http://www.esri.com/library/journals/archaeology/volume_1/field_survey.pdf).

LAKE M. 2000, *MAGICAL computer simulation of Mesolithic foraging*, in T.A. KOHLER, G.J. GUMERMAN (eds.), *Dynamics in Human and Primate Societies: Agent-based Modelling of Social and Spatial Processes*, New York, Oxford University Press, 107-143.

LEONTSINIS G.N. 1987, *The Island of Kythera. A Social History*, Athens, Saripolos.

Llobera M. 2000, *Understanding movement: A pilot model towards the sociology of movement*, in G. Lock (ed.), *Beyond the Map: Archaeology and Spatial Technologies*, Amsterdam, IOS Press, 65-84.

Malthesou C. 1991, *Venitiki Parousia Sta Kithira*, Athens, Ballidis, 249-252.

Maschner H.D.G., Stein J.W. 1995, *Multivariate approaches to site location on the northwest coast of North America*, «Antiquity», 69, 61-73.

Pagounis M., Gertsos T. 1984, *Hydrological Investigation of the Island of Kithira,* IGME Publication 42, Athens, Institute of Geology and Mineral Exploration.

Ripley B.D. 1977, *Modelling spatial patterns*, «Journal of the Royal Statistical Society», 2, Oxford, Oxbow, 172-212.

Wagstaff M., Augustson S. 1982, *Traditional land use*, in C. Renfrew, M. Wagstaff (eds.), *An Island Polity. The Archaeology of Exploitation in Melos*, Cambridge, Cambridge University Press, 106-133.

Warren R.E. 1990, *Predictive modelling in archaeology: a primer*, in K.M.S. Allen, S.W. Green, E.B.W. Zubrow (eds.), *Interpreting Space: GIS and Archaeology*, London, Taylor and Francis, 90-111.

Warren R.E., Asch D.L. 2000, *A predictive model of archaeological site location in the eastern Prairie Peninsula*, in K.L. Wescott, R.J. Brandon, *Practical Applications of GIS for Archaeologists: A Predictive Modelling Kit*, London, Taylor and Francis, 3-32.

Whitelaw T. 1991, *The ethnography of recent rural settlement and land use in North West Keos*, in J.F. Cherry, J.L. Davis, E. Mantzourani (eds.), *Landscape Archaeology as Long-Term History: Northern Keos in the Cycladic Islands*, Monumenta Archaeologica 16, Los Angeles, UCLA Institute of Archaeology, 403-454.

ABSTRACT

Mediterranean landscapes have been fragmented, connected and reformed by countless trackways, buildings and field systems. On the Greek island of Kythera, an extensive and detailed map record of such structures has been recorded as part of broader multidisciplinary investigation of the island's long-term history by the Kythera Island Project (KIP). This rich dataset can be complemented further by KIP's intensive archaeological and geoarchaeological surveys, offering both practical checks on existing data and insights at greater resolution. This paper draws on this combination of material and deploys spatial analysis techniques to explore and quantify a range of issues relating to anthropogenic landscapes.