GIS and Archaeological Survey Data: Four
Case Studies in Landscape Archaeology from
the Island of Kythera (Greece)

Andrew Bevan and James Conolly

Postprint of a 2004 paper in
Journal of Field Archaeology 29: 123-138
(doi: 10.2307/3181488)

Abstract

This paper uses GIS and quantitative analysis to explore a series of simple but important issues in relation to GIS-led survey. We draw on information collected during intensive archaeological field survey of the island of Kythera, Greece, and consider: (i) the relationship between terracing and enclosed field systems; (ii) the effect of vegetation on archaeological recovery; (iii) site definition and characterization in multi-period and artifact-rich landscapes, and; (iv) site location modelling, which considers some of the decisions behind the placing of particular Bronze Age settlements. We have chosen GIS and quantitative methods to extract patterns and structure in our multi-scalar dataset, which demonstrates the value of GIS in helping to understanding the archaeological record and past settlement dynamics. The case studies can be viewed as examples of how GIS may contribute to four stages in any empirically based landscape project insofar as they move from the spatial structure of the modern landscape, to the visibility and patterning of archaeological data, to the interpretation of settlement patterns.

Introduction

GIS is a well-established archaeological tool, but few analyses relating to field survey have gone beyond discussing data-structures, field collection routines, processing methods or visualization of static data patterns. Notable exceptions include Bintliff (2000) and Bell et al. (2002) which explore thematic issues in human-landscape relationships using GIS. We continue this trend and demonstrate the potential of GIS with four case-studies in Mediterranean landscape archaeology: (i) an investigation of spatial structure of the modern agricultural landscape; (ii) an assessment of the impact of ground visibility on the recovery of archaeological remains; (iii) a study of site definition and characterization; and (iv) an analysis of the human decision-making behind ancient site location. The focus is not on the use of GIS per se, nor the mechanics of the analysis, but on the spatial organization of the contemporary and ancient landscape. We suggest that the case studies can be viewed as examples of stages in any empirically based landscape project insofar as they move from an assessment of the modern landscape, to the visibility and patterning of archaeological data, to the interpretation of settlement patterns.

Our case studies come from the intensive field survey of the island of Kythera, Greece (FIG. 1). Lying 15 km off Cape Maleas on the southern tip of the Peloponnese, this island is a stepping-stone between the culturally and

geographically distinctive areas of the Greek mainland to the north, and the island of Crete to the SE. Some 280 sq km in area, it is a classic semi-arid Mediterranean landscape. Yet as with many Mediterranean environments (Horden and Purcell 2000), small-scale topographic and environmental variability is an important factor and has had an underlying effect on past and present settlement dynamics and land-use. While Kythera might be treated as a distinctive cultural entity in its own right, its integration within larger networks of cultural interaction is a defining factor in the island's long-term history (Broodbank 1999).

Our work on the Kythera Island Project (KIP), directed by Cyprian Broodbank, investigates many of these issues. It has several components, the foremost of which is an intensive archaeological field survey of an area comprising more than one third of the island (FIG. 1). Complementary research agendas target specific questions relating to geomorphology, biodiversity, ethnography, and historical geography. The need to coordinate these studies provides an ideal opportunity to deploy GIS as an integrative and analytical tool. GIS has been an inextricable part of the project from the onset, a vehicle for the collection and treatment of data, and the primary tool for exploring relationships between cultural and environmental dynamics.

Digital Data Integration and the Management and Analysis of Multiscalar Datasets

A wide range of digital topographic, physiographic, geological, and vegetation data are part of the KIP dataset and was digitized and processed prior to the start of the fieldwork to form the underlying digital environment within which subsequent research was organized (TABLE 1). Additional spatial data were collected as part of the intensive archaeological survey and the mapping of several geo-archaeological study areas. Table 1 lists the broad range of datasets and their spatial resolution and describes the main acquisition and processing methods. Details of the survey methodology and preliminary archaeological results are described by Broodbank (1999).

The spatial datasets describe the Kytheran landscape at a variety of scales, ranging from 1:2000 local geoarchaeological maps, to remotely sensed multi-spectral imagery with a 20 m resolution. Integrating this data is methodologically challenging, but heuristically valuable. Many proponents of GIS claim that the technology facilitates the seamless movement between different spatial scales, but this is rarely the case. Site location choices, the visibility of surface ceramics, and site identification and characterization are three areas where the effect of scale is rarely acknowledged. Our base maps are detailed enough that major variations in the physical landscape can read-

ily be identified and are sufficient for investigating widespread patterns, such as regional site distribution and its relationship with the physical landscape and environmental data. Such large scales are usually inappropriate for examining specific local conditions influencing the location, survival or modern visibility of archaeological remains. For this reason, we used geomorphological maps of selected sub-regions, and within these of the immediate environment around sites, to identify the local characteristics of the landscape that may have influenced site location and archaeological visibility.

Behind many of the recorded archaeological patterns are human decision-making processes, which themselves occur at different temporal and spatial scales. The challenge offered by a GIS approach is to move between the analytic scales available, and to identify for any given pattern and process the most relevant scale at which human choices were being made. The following examples address specific survey questions, but have in common a concern with exploring spatial scale in more detail.

Four Case Studies in Mediterranean Landscape

Archaeology

Extant Field Systems

This first study exploits the rich detail of the KIP dataset to look at an challenge central to Mediterranean subsistence strategies: the effect of slope on agricultural practices (Horden and Purcell 2000: 234-7, 585). The modern Kytheran landscape has countless agricultural field systems, which can be broken down into two main groups: enclosed fields and contour (hillslope) terracing. Most of the physically visible examples appear to date to the last three or four centuries, specifically the later Venetian and British occupations (Leontsinis 1987: 214). These systems appear on aerial photos and have been mapped by the Greek army. They have also been independently studied in the field by survey teams and geoarchaeologists. This provides us with an opportunity to compare these various sources of information and to consider a wide range of questions relating to anthropogenic landscapes.

Field walls are dry-stone constructions, normally less than 2 m high and 1 m wide and used to enclose irregular units of land (hereafter ‘field enclosures’ or ‘enclosed fields’). Terraces take a variety of forms and fulfil a variety of functions (Rackham and Moody 1992; Frederick and Krahtopoulou 2000),

but those of interest here were built with dry-stone risers. Both enclosed fields and terraces are now used for many purposes (e.g. cereals, vines, orchard crops, garden vegetables and animal pens). In contrast to this recent diversity of function, local Kytheran historical records (Leontsinis 1987) and comparative evidence from neighboring regions (Allen 1997: 263) suggests that for the last few centuries, most of these were used primarily for cereal agriculture (even in marginal areas where the soil cover is now quite thin). The traditional farming cycle on Kythera involved a biennial cultivated-fallow rotation (with manuring by grazing flocks as part of the ‘off’-year practice) and so, enclosed fields also controlled the movement of livestock, penning them into fallow fields and keeping them out of cultivated ones. Concern with the proper construction and maintenance of these boundaries is found in both Venetian and British period sources (Leontsinis 1987: 82-3, 220-8).

Land enclosure patterns and terracing tend to follow quite regional patterns in Greece, reflecting the impact of different local histories and environments. The Kytheran system may be broadly similar to practices in the Mani (Allen 1997: 264), but certainly differs from the pattern found on Kea (Whitelaw 1991: 408-10). Studies of the Cretan terrace and field systems also reveal a wide variety of different regional configurations, origins, and functions (Rackham and Moody 1996: 140-53). The strong impression that the Kytheran field systems are the specific products of the socio-economic

history of the island and not a pan-Aegean phenomenon should urge caution in extrapolating results of any local Kytheran analysis to the wider Aegean or Mediterranean sphere. However, the relatively strong spatial separation of terraces and enclosed fields on Kythera does provide an opportunity to explore the relationship between these constructions and the gradient of the terrain on which they are found. This analysis should have relevance to the relationship between agricultural strategies and slope observed in other regions.

Terraces tend to be found mainly on steeper slopes and field enclosures on flatter ground. Overlap occurs most frequently on patches of Quaternary alluvium within small drainage systems, where enclosed cross-channel terraces are often found. The use of terracing in steeper areas reflects the negative impact of slope, in the absence of such human intervention, on soil stability and moisture retention. Analysis of prehistoric and historic period agriculture has usually assumed that cultivation could only occur without terracing on land of less than 10-15 degrees of slope (based on empirical observation in the field: Wagstaff and Gamble 1982: 101; Whitelaw 1991: 405; Wagstaff 1992: 155). Using a GIS and taking advantage of fine resolution topographic data,¹ we can test this assumption. The slope values of the terrain underlying all field enclosures within the KIP survey area were extracted and grouped into ranges of one degree. Within each slope range, we calculated the proportion

of terrain that is covered by such enclosed systems (FIG. 2). For example, of terrain in the survey area with a slope of 0-1 degree, about half seems to be covered in field enclosures. This association can be further modelled with log-linear regression analysis (using a method similar to Warren 1990), and suggests a well-defined relationship between slope and the prevalence of field enclosures.

Intensive field investigation by survey teams and geoarchaeologists has shown that the enclosure systems mapped by the Greek Army in the 1960s and used for this analysis are broadly accurate. In contrast, field observations have also made it quite clear that the terraces shown on the same maps are a very meagre and patchy sample of the actual terrace systems on the island. However, careful geoarchaeological investigation for two sub-regions of the survey area (FIG. 3) allows us to use a smaller analytical scale to get a much more accurate impression of the relationship between terracing and slope. Zones of terraced hillslope identified in the field can also be classed by slope angle as was done for the fieldwalls.²

The chosen sample regions are known to have quite different agricultural histories with more intense activity in the Medieval and post-Medieval periods around Mitata than around Palaiopolis. Mitata shows greater evidence for terraces on all types of slope than Palaiopolis, but the proportion of total land surface with terraces is quite similar in both locales (30% around Mitata

and 25% around Palaiopolis). This can be compared to much hillier terrain on NW Keos where ca. 84% of the surveyed area showed signs of having been terraced at some stage (Whitelaw 1991: 405). Viewed as separate plots, or in combination (FIG. 4), the evidence suggests that terraces increase in prevalence up to ca. 12-13 degrees of slope and then reach a plateau.

This contrasts with the pattern described for enclosed fields, which decrease steadily in relative frequency as slope angle increases. While there is no unequivocal break between flat field agriculture and terracing, the Kytheran evidence broadly supports the traditional assumptions that field management strategies are likely to change within the 10-15 degrees range. A plot of the cumulative frequencies of these data confirm that an appropriate threshold would be at ca. 12-13 degrees (FIG. 5).

The Effect of Surface Visibility on Artifact Recovery and Site Discovery

Mediterranean survey projects have long acknowledged the effects of surface visibility on the recovery of archaeological remains, and certain types of agricultural activities have been shown to have a profound effect on visibility (e.g. Ammerman 1995; Cherry 1983; Cherry et al. 1988; Verhoeven 1991). For these reasons it is standard practice to record both current land-use and the

degree to which vegetation obscures the ground surface within each survey unit. Our own experience demonstrates the effect of vegetation on recovery rates; a re-survey of a previously densely-vegetated area following a bush fire produced a dramatic increase in artifact recovery. Our second case study examines the relationship between surface visibility and artifact recovery, to see whether or not the former can be usefully used to predict the latter.

Vegetation cover has traditionally been recorded by assigning a ‘visibility class’ value to the survey unit under question, and we follow this practice. This has at times been used to ‘weight’ the absolute number of artifacts recovered from a survey unit (e.g. Bintliff et al. 1999: 153-154; Gillings and Sbonias 1999: 36), for example by the inverse of the proportion of visible ground. In this way 10 artifacts from a unit where only 50% of the ground is visible might be given a weighted artifact count of 20 sherds. As sensible and logical as this seems, such an assumption has with few exceptions never been properly tested (c.f. Schon 2000: 109) and we remain unconvinced that measures of ground visibility can be used in this manner. While it may influence the recovery rate of archaeological data, it does not do so in any usefully predictable manner.

Our test of the relationship between visibility categories and the quantity of artifacts recovered from any unit shows no simple relationship at any scale. Although mean tract densities do increase with ground visibility, there

is no linear correlation between individual tract artifact densities and tract visibility ($r^2 = 0.06$). In order to determine if this lack of correlation is a product of the large size of survey tracts, the same test was performed using 5095 highly standardized 5 sq m units (collected in a timed 5-minute period) for site recovery. The same lack of correlation ($r^2 = 0.04$) emerged, suggesting that it does not matter if collection units are large or small, visibility does not have a predictable role in determining the amount of artifacts that will be recovered at the level of the survey unit.

A related question of whether visibility influences the recovery of larger and denser scatters of artifacts (e.g. ‘sites’) was also examined. Table 2 shows the number of sites in each of the visibility categories, and the expected number of sites for the proportion of land in each visibility class. Although there is a suggestion that we are perhaps missing two sites in the 0-20% visibility range, and site identification is slightly better than expected in better visibility classes, these patterns are not statistically significant (χ^2 , $\alpha = 0.69$) and we can therefore state with some confidence that lack of ground visibility has had no easily defined effect on site discovery.

While our observations suggest that dense vegetation does affect recovery rates, we conclude that the relationship between surface visibility and recovery rates is not predictable. The problem arises when a relationship between artifact frequency (i.e. the actual number of surface artifacts in any given

area) and recovery rate is assumed (i.e. the chance of seeing them, which is a product of several factors, of which surface visibility is but one). There is no a priori relationship between the two, but using one (visibility) to estimate the other (frequency) imposes a false relationship and introduces errors. We suggest therefore that adjusting counts according to a measure of visibility, at least without first exploring the relationship between these two variables, is at best inaccurate, and at worst, can lead to erroneous distribution patterns.

Site Definition and Characterization

Aegean landscapes are strewn with cultural remains, in places quite densely, which present a formidable challenge to the site-based approach on which settlement system reconstruction usually depends. Mediterranean landscape survey benefits from a long history of well-developed and well-tested methods for site discovery and a lively debate concerning both human-landscape relationships, and the extent to which these can be reconstructed using archaeological survey data (Pettegrew 2001; Whitelaw 2000; Gillings and Sbonias 1999; Bintliff et al. 1999). One methodological issue concerns the differentiation between ‘on-site’ and ‘off-site’ artifact scatters and their respective formation processes (Bintliff 2000; Bintliff and Snodgrass 1988; Cherry 1983). Recent reviews of surface archaeology in North America and Europe have

called for an abandonment of the site concept when dealing with survey data because of the inherent difficulties in distinguishing ‘sites’ from ‘off-site’ areas on the basis of artifact distribution patterns (e.g. Ebert 2001; Kuna 2000a; Kvamme 1998). Aegean archaeological survey data are particularly well suited to investigate these issues given the prevalence of survey projects that have documented by intensive survey methods, not only sites, but also inter-site artifact distributions. Our third case study examines the relationship between site and off-site artifact density patterns on Kythera and suggests how the former can be distinguished from the latter in meaningful ways.

We have retained the term ‘site’ as a convenient and shorthand term to refer to clusters of artifacts that, on the basis of their composition and contextual association, are assumed to represent the visible material remains of either short or long-term, and often multi-phased, places of human settlement, although the choice, duration and scale of settlement is obviously of major interest. At the same time, the identification of sites is clearly dependent on a number of factors that range from the types of activities that were performed, their duration and intensity, the taphonomic processes that have transformed the original settlement and activity-place into the contemporary archaeological record, and the surface visibility of the archaeological remains (e.g. Pettegrew 2001; Cherry 1983; Allen 1991; Hayes 1991; Schofield 1991).

The site concept may be more problematic when studying the archaeological remains of highly mobile groups (Foley 1981), but notwithstanding that some constituents of Neolithic and later communities are mobile and the duration of occupation of ‘permanent’ occupations certainly varies, we have not found any archaeological evidence of pre-Neolithic (i.e. hunter-gatherer) activity on Kythera. Our retention of ‘site’ as both a conceptual and methodological tool does not lead to the exclusion of ‘off-site’ archaeology (or study of past land-use), as this is of a major interest to us and is the focus of further work. Defining specific locations as ‘sites’ can be used together with site size and chronology to develop and test models of settlement systems and long-term settlement dynamics in a manner similar to our work on Bronze Age settlement choices (Bevan 2002).

GIS brings many advantages to the study of artifact distributions that can help answer these questions. Methods of visualizing distribution patterns (Lock et al. 1999), analytical methods to identify clustering and site definition (Gillings and Sbonias 1999), and interpolation methods to help understand off- and on-site distributions (Robinson and Zubrow 1999) have all received attention in the past. Kythera presents its own specific problems and contexts in this regard, but we believe that our case study of site versus off-site characterization is of relevance to other Mediterranean landscape projects. We attempt to generalize about the nature and character of ‘sites’ using both

large and small-scale analysis of artifact distribution patterns (c.f. Gillings 2000).

Our survey strategy divided the landscape into irregular sub-hectare units ('tracts'), typically using field-walls, vegetation zones, or physiographic features to define natural boundaries. Surveyors spaced at 15 m intervals walked across the tract and counted the number of ceramic sherds, lithics and other cultural remains. We surveyed nearly ca. 8700 tracts with a median area of 3825 sq m, which has given us a picture of artifact distribution over a very extensive area. Large scale strategies such as this are suitable for the identification of clusters of artifacts, typically ceramic, of which some but not all are designated as sites. For instance, figure 6 shows the distribution of multi-period artifacts in an area roughly 2 sq km, collected in ca. 200 individual tracts (individual tract boundaries are not shown for clarity, and an unsurveyed area is represented by the polygon in the lower right corner). Each dot represents a single ceramic sherd, randomly placed within the tract in which it was recorded. This 'window' contains several sites, most multi-period and some overlapping, but is centered on a predominantly Neopalatial (ca. mid-2nd millennium BC) artifact cluster defined as 'site 28'. Artifact clustering occurs here and elsewhere in this area (i.e. the distribution is neither random nor regular), but at the same time this figure clearly shows the difficulty, if not futility of attempting to define cluster boundaries for multi-period land-

scapes solely on the basis of artifact distribution patterns.

We conclude, as have others (e.g. Ebert 2001), that defining site boundaries at the tract-based level is difficult in landscapes of this kind. Small scale (i.e. site-based) patterns can be investigated, however, with more intensive artifact collection strategies, giving better indication of the size and shape of a specific localized artifact distribution. Figure 8 shows a higher resolution artifact distribution pattern for the cluster defined as ‘site 28’ than figure 6 above. These different methods point to a relationship between artifact density and observation scale, but as they each involve different types of collection strategy, they make direct comparison difficult. As we are interested in the nature of the relationship between site scatters and off-site scatters, the more extensive, but less intensive, dataset must be used because of the consistency of the collection strategy across the wider landscape.

One useful method is to examine the internal variability of the survey tracts. This is accomplished by calculating a coefficient of variation for each tract, on the basis of the mean and standard deviation of numbers of artifacts recorded for each of the several transects that make up a survey tract. Comparison of the aggregate coefficients of variation between those tracts that contain sites and those without sites shows that the former have a slight but significantly lower (at $p < 0.05$) coefficient of variation (tracts with sites = 1.1, tracts without sites = 1.4). In other words, tracts with site scat-

ters are slightly more homogenous in terms of artifact variability, whereas off-site tracts are more heterogeneous. Good examples of the types of phenomena contributing to slightly greater off-site variability are the occasional ‘pot-smashes’ or tile dumps found in tracts with an otherwise low density of artifacts. These result in a high coefficient of variation for that tract, compared to a site which has a more even spread of material over a greater area of the tract, resulting in a lower coefficient of variation.

This analysis can be usefully extended by creating a ‘variability surface’ from an interpolation of the tracts’ coefficient of variation on a 50 m grid. This surface can be examined for patterning in relation to the distribution of sites (FIG. 9). This image suggests that sites do not sit on areas of high internal variability, nor on areas where variability is low to non-existent. This is confirmed by a lack of linear correlation between the variability surface and distance from site center. Put simply, the possibility of the landscape containing dense but highly localized ‘blips’ when viewed against a background of a generally low and even distribution of artifacts increases as one moves away from sites. By examining the difference between site and off-site artifact distribution patterns and the composition of these patterns we are in a better position to understand what it is that makes a site distinctive from the background ‘noise’ around it.

In conclusion, although it is actually quite difficult to define sites bound-

aries on the basis of ceramic fall-off patterns, the composition (rather than simple density) of the artifact landscape is quantitatively different as one moves away from the center of a site distribution. This suggests that we may define ‘sites’ by their extensive, relatively dense, and relatively homogenous sherd scatters, when compared to a less dense and more heterogeneous artifact pattern. Further work remains to be done, particularly once we have better chronological control, and are better able to ascertain differences between the nature of site scatters of different time periods and can question the sorts of cultural behavior responsible for the scatters themselves, as Pettegrew (2001: 195-203) has done for Classical artifact scatters. For the present, however, we regard our analysis as explaining and justifying our retention of the site concept in Mediterranean landscape archaeology.

Terrain and Site Location

The advantages of using GIS to formalize the correlation of site location with cultural and environmental variables has been recognized for over a decade. Efforts at modelling have been inspired by the demands of Cultural Resource Management (mainly in North America) and incorporated into the (usually post-fieldwork) research designs of landscape survey projects (Warren 1990; Dalla Bona 1994; Petrie et al. 1995; Kuna 2000b; Wescott and Brandon 2000).

Our final case study seeks neither to produce a full predictive model nor to espouse a deterministic approach to understanding how humans decide where to live, but considers how a range of insights about site location might be gained by explicit study of these phenomena at different scales. The principal focus is on the use of multi-scalar techniques to characterize terrain, and as a useful counterpoint to this we also refer to the impact of local hydrology on site location. In both parts of this case study, large numbers of Middle-Late Bronze Age sites found by the KIP survey are used as the test case.³

Various measures of the overall ruggedness of terrain (also known as its texture or relief) have been proposed in archaeology (Warren and Asch 2000: 14), ecology (Forman 1995: 304-6), and geomorphology (Wood 1996: section 2.2.1) as a useful means of broadly characterizing landscapes. For example, one frequently used index is the range of elevation values within a specific neighbourhood around a given point in the landscape. Such a measure expresses relief as a single value, which could just as well be calculated over larger or smaller neighborhoods, and does not provide any idea of the shape of the landscape.

Alternative measures of terrain ruggedness can be more sensitive (e.g. fractal dimensions, Mandelbrot 1967; Burrough 1981; Mark and Aronson 1984; Clarke 1986, or positive wavelet analysis, Gallant and Hutchinson 1996). The approach offered here looks at terrain curvature as it varies over

different spatial neighborhoods. This is calculated by fitting a quadratic surface to a given cell neighborhood⁴ and measuring the curvature of a two-dimensional slice through this surface: in this case ‘cross-sectional’ curvature measured directly across channels and ridges (Wood 1996: section 4.2.2).⁵ The simplest calculation uses the elevation values of the chosen cell and its immediate neighbors (a 3 x 3 matrix), but the same operation can be performed on any (odd) number of adjacent cells. Landforms that stand out at one scale may not do so at others (FIG. 10); shallow channels for example may appear as an extreme negative curvature co-efficient at small-scales (e.g. 3 x 3 cells or 0.1 ha), but appear relatively flat (close to zero) when seen at larger scales (e.g. 51 x 51 cells, or more than 26 ha). The simplest expression of this dispersion of curvature values across different scales is the range⁶ and this was calculated for the Kythera survey area at all neighborhoods from 3 x 3 cells to 99 x 99 cells (ca. 100 ha). There is a significant pattern ($p < 0.001$) suggesting that Bronze Age (Neopalatial) sites are located in areas of low-medium multi-scale dispersion of curvature which can be satisfactorily modelled by linear regression (FIG. 11).

This measure is useful for excluding certain types of terrain, namely steeper slopes and the flatter sections of ridge and channel that lie between, that did not have rural sites. While sensitive to variation over different neighbourhood scales, it is better at defining broad types of terrain. It is also

worth examining other possible contextual scales at which environmentally-based site location parameters might operate. Elevation data and stream courses can be used in a GIS to model hydrology (e.g. Mark 1984; Jenson and Domingue 1988; Garbrecht and Martz 1999). For example, stream networks can be extracted automatically from a digital elevation model (DEM) and used for a variety of purposes. Figure 12 shows the watersheds that can be delineated for stream segments with less than 6.25 ha of surrounding land flowing into them in the upland plateau region of Mitata. Watersheds define those areas that drain to the same outlet point in the drainage network. They can be explored at a number of different scales and represent natural basins, often bounded by ridges and sharing the same erosion patterns and similar soil moisture. At the scale shown in figure 12 (minimum basin size of 6.25 ha), it is significant ($p < 0.001$) that all of the known Neopalatial sites within the Mitata region are within 50 m of a watershed boundary and regression analysis indicates a strong linear relationship ($r^2 = 0.91$).

There are a variety of reasons why this might be the case: (a) the areas closer to watershed boundaries are likely to include the low to moderate relief terrain we identified in figure 11 as being preferred; (b) watersheds represent the structure of surface water flow, and site location within them may reflect the land use priorities necessary for certain agricultural strategies; or (c) watershed boundaries are sometimes physically prominent features such as

ridges, that might serve as landmarks or features against which to build.⁷

Multi-scalar approaches in a technical sense (e.g. exploring terrain roughness across different spatial neighborhoods) are important, but our analysis of terrain roughness and watersheds also show that this will not always be enough. Human decisions are made at a variety of contextual scales from the regional (e.g. this general landscape is or is not suitable to live in), to the local (e.g. this patch of land is large enough to sustain a family, or this ridge is a good place to build a house). If our modeling is sensitive to the context of such behavior, it will not be deterministic and will also necessarily leave room for an array of contingent human motivations.

Conclusions

This paper examines GIS data connected with the Kythera Island Project, and raises a number of issues that have significance for all intensive archaeological survey projects. The case studies move from modern landscape structure to the visibility and definition of archaeological sites, to the interpretation of site distribution patterns.

The first case study use the different scales of data collection and field investigation (map-based, photographic, geoarchaeological) to test a traditional assumption about flat-field vs. terraced agriculture in relation to slope. It was

possible to quantify the transition from one agricultural strategy to another over terrain of varying steepness and show that this occurs gradually, but that for practical analytical purposes a meaningful threshold value can be distinguished of 12 to 13 degrees.

The second case study investigated the relationship between survey unit visibility and artifact recovery. We show that there was no simple correlation between the two at any scale. We concluded that visibility is perhaps a useful variable to assess, but cannot be used to modify (weight) density calculations in any simplistic way.

The third case study considered site and off-site artifact patterns and established that, at a large scale on a continuous surface of archaeological material, fall-off patterns can be reliably and meaningfully defined for sites. This has utility for understanding site-formation processes, and when integrated into the fieldwork stage of the research, it can enable a more reflexive approach to site-definition.

In the last case study, we used a specific multi-scale technique for looking at terrain ruggedness and discussed how it could be deployed to shed light on the locations of a particular group of Bronze Age sites on Kythera. When combined with watershed scales, this study emphasized that human decisions about site locations themselves reflect multi-scalar concerns.

In conclusion, we have identified some of the pattern underlying the con-

temporary and ancient Kytheran landscape and some of the factors influencing and governing site identification and definition in an artifact-rich environment. In each case study we have chosen quantitative methods to extract patterns and structure to demonstrate the value of GIS approaches, and while further work is necessary using more detailed chronological and geomorphological data, we trust that our initial analyses demonstrate the way we can combine multi-scalar datasets successfully in ways that lead to a better understanding of the archaeological record and of the dynamics of settlement on Kythera.

Acknowledgments

This research draws on a dataset which is the product of collaborative efforts by the many people involved in the Kythera Island Project. We would particularly like to thank Cyprian Broodbank (KIP Director) for assistance and encouragement at every stage. Our thanks also to Charles Frederick and Nancy Krahtopoulou, as well as to Curtis Runnels and two anonymous reviewers for their helpful comments and suggestions. Any remaining errors are our own. Bevan's contribution was made possible by the tenure of a Leverhulme Trust Research Fellowship.

Authors' Biography and Contact Details

Andrew Bevan (a.bevan@ucl.ac.uk) is a Leverhulme Research Fellow at the Institute of Archaeology, University College London. His current research interests include GIS and landscape archaeology, value theory and trade in the Eastern Mediterranean Bronze Age.

James Conolly (j.conolly@ucl.ac.uk) is a Lecturer at the Institute of Archaeology, University College London. His research interests include GIS and landscape archaeology, lithic technology, and the Neolithic of the Eastern Mediterranean.

Both authors can be contacted at: The Insitute of Archaeology, University
College London, 31-34 Gordon Sq., London WC1H 0PY, England.

References Cited

Allen, M.J.

1991. "Analysing the landscape: a geographical approach to archaeological problems," in Schofield, A.J., ed., *Interpreting Artifact Scatters: Contributions to Ploughzone Archaeology*. Oxford: Oxbow Books, 39-57.

Allen, P.S.

1997. "Finding Meaning in Modifications of the Environment: The Fields and Orchards of the Mani," in Kardulias, P.N. and M.T. Shutes, eds., *Aegean Strategies: Studies of Culture and Environment on the European Fringe*. Lanham: Rowman and Littlefield, 259-269.

Ammerman, A.J.

1995. "The dynamics of modern land use and the Acconia Survey," *Journal of Mediterranean Archaeology* 8(1):77-92.

Bell, Tyler, Andrew Wilson, and Andrew Wickham

2002. "Tracking the Samnites: Landscape and Communications Routes in the Sangro Valley, Italy," *American Journal of Archaeology* 106(2): 169-186.

Bevan, A.

2002. "The Rural Landscape of Neopalatial Kythera: A GIS Perspective," *Journal of Mediterranean Archaeology* 15(2): 217-256.

Bintliff, J.

2000. "Beyond dots on the map: future directions for surface artifact survey in Greece," in Bintliff, J., Kuna, M., and Venclová, N., eds., *The Future of Surface artifact Survey in Europe*. Sheffield: Sheffield Academic Press, 3-20.

Bintliff, J., Howard, P., and Snodgrass, A.

1999. "The hidden landscape of prehistoric Greece," *Journal of Mediterranean Archaeology* 12(2): 139-168.

Bintliff, J. and Snodgrass, A.

1988. "Off-site pottery distributions: a regional and inter-regional perspective," *Current Anthropology* 29: 506-513.

Broodbank, C.

1999. "Kythera Survey: Preliminary Report on the 1998 Season," *Annual of the British School at Athens* 94: 191-214.

Burrough, P.A.

1981. "Fractal dimensions of landscapes and other environmental data," *Nature* 294: 241-242.

Cherry, J.F.

1983. "Frogs round the pond: perspectives on current archaeological survey projects in the Mediterranean region," in D.R. Keller and D.W. Rupp, eds., *Archaeological Survey in the Mediterranean Area*. Oxford: British Archaeological Reports, International Series 155, 375-416.

Cherry, J.F., Davis, J.L., Demitrack, A., Mantzourani, E., Strasser, T., and Talalay, L.E.

1988. "Archaeological survey in an artifact-rich landscape: A Middle Neolithic Example from Nemea, Greece," *American Journal of Archaeology* 92: 159-176.

Clarke, K.C.

1986. "Computation of the fractal dimension of topographic surfaces using the triangular prism surface area method," *Computers and Geosciences* 12: 713-722.

Ebert, James I.

2001. *Distributional Archaeology*. Salt Lake City: University of Utah Press.

Foley, R.

1981. "A Model of Regional Archaeological Structure," *Proceedings of*

the Prehistoric Society 47: 1-17.

Forman, R.T.T.

1995. "Land Mosaics. The Ecology of Landscapes and Regions". Cambridge: Cambridge University Press.

Frederick, C. D. and A. Krahtopoulou

2000. "Deconstructing Agricultural Terraces: Examining the Influence of Construction Method on Stratigraphy, Dating and Archaeological Visibility," in Halstead, P. and C. Frederick, eds., *Landscape and Land Use in Postglacial Greece*. Sheffield: Sheffield Academic Press, 79-94.

Gallant, J.C. and M.F. Hutchinson

1996. "Towards an understanding of landscape scale and structure. Proceedings of the Third International Conference on Integrating GIS and Environmental Modelling," accessed at 14.23, 14.9.01 at: http://www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sf_papers/gallant_john/paper.html.

Garbrecht, J., and L.W. Martz

1999. "Digital elevation model issues in water resources modelling. Proceedings of the 19th ESRI International User Conference, Environmental Systems Research Institute, San Diego," Internet Edition:

<http://grl.ars.usda.gov/topaz/esri/paperH.htm>

Gillings, M.

2000. "The utility of the GIS approach in the collection, management, storage and analysis of surface survey data," in Bintliff, J., Kuna, M., and Venclová, N., eds., *The Future of Surface artifact Survey in Europe*. Sheffield: Sheffield Academic Press, 105-120.

Gillings, M. and Sbonias, K.

1999. "Regional survey and GIS: the Boeotia Project," in Gillings, M., Mattingly, D. and van Dalen, J., eds., *Geographical Information Systems and Landscape Archaeology*. Oxford: Oxbow Books, 35-54.

Hayes, P.P.

1991. "Models for the distribution of pottery around former agricultural settlements," in Schofield, A.J., ed., *Interpreting artifact Scatters: Contributions to Ploughzone Archaeology*. Oxford: Oxbow Books, 81-92.

Horden, P., and N. Purcell

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: 211-232.

Hutchinson, M.F. and T.I. Dowling

1991. "A continental hydrological assessment of a new grid-based digital elevation model of Australia," *Hydrological Processes* 5: 45-58.

Jenson, S.K. and J.O. Domingue

1988. "Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis," *Photogrammetric Engineering and Remote Sensing* 54(11): 1593-1600.

Kuna, M.

2000a. "Session 3 discussion: comments on archaeological prediction," in Lock, G., ed., *Beyond the Map: Archaeology and Spatial Technologies*. Amsterdam: IOS Press, 180-186.

Kuna, M.

2000b. "Surface artifact studies in the Czech Republic," in Bintliff, J., Kuna, M., and Venclová, N., eds., *The Future of Surface Artifact Survey in Europe*. Sheffield: Sheffield Academic Press, 29-44.

Kvamme, K.

1990. "GIS algorithms and their effects on regional archaeological analysis," in Allen, K.M.S., S.W. Green and E.B.W. Zubrow, eds., *Interpreting Space: GIS and archaeology*. London: Taylor and Francis, 112-

125.

Leontsinis, G.N.

1987. *The Island of Kythera. A Social History (1700-1863)*. Athens: S. Saripolos.

Lock, G., Bell, T., and Lloyd, J.

1999. "Towards a methodology for modelling surface survey data: the Sangro Valley Project," in Gillings, M., Mattingly, D. and van Dalen, J., eds., *Geographical Information Systems and Landscape Archaeology*. Oxford: Oxbow Books, 55-64.

Mandelbrot, B.

1967. "How Long is the Coast of Britain? Statistical Self-Similarity and Fractional Dimension," *Science* 156: 636-638.

Mark, D.M.

1984. "Automatic detection of drainage networks from digital elevation models," *Cartographica* 21: 168-178.

Mark, D.M., and P.B. Aronson

1984. "Scale dependent fractal dimensions of topographic surfaces: an empirical investigation with applications in geomorphology and computer mapping," *Mathematical Geology* 16(7): 671-683.

Olivera, F., S. Reed and D. Maidment

1998. "HEC-PrePro v. 2.0: An ArcView Pre-Processor for HEC's Hydrologic Modelling System. ESRI User's Conference," accessed at 10.30am, 18.8.01 at: <http://www.ce.utexas.edu/prof/olivera/esri98/p400.htm>

Pettegrew, David K. 2001.

2001. "Chasing the Classical Farmstead: Assessing the Formation and Signature of Rural Settlement in Greek Landscape Archaeology," *Journal of Mediterranean Archaeology* 14(2): 189-209.

Petrie, L., I. Johnston, B. Cullen and K. Kvamme

1995. GIS in archaeology: an annotated bibliography. Sydney: University of Sydney.

Rackham, O. and J.A. Moody

1992. "Terraces," in Wells, B., ed., *Agriculture in Ancient Greece*. Stockholm: Paul Astroms, 123-130.

Rackham, O. and J.A. Moody

1996. *The Making of the Cretan Landscape*. Manchester: Manchester University Press.

Robinson, J.M and Zubrow, E.

1999. "Between spaces: interpolation in archaeology," in Gillings, M., Mattingly, D. and van Dalen, J., eds., *Geographical Information Systems and Landscape Archaeology*. Oxford: Oxbow Books, 65-83.

Schofield, A.J.

1991. "Interpreting artifact scatters: an introduction," in Schofield, A.J., ed., *Interpreting artifact Scatters: Contributions to Ploughzone Archaeology*. Oxford: Oxbow Books, 3-8.

Schon, R.

2000. "On a site and out of site: where have our data gone?," *Journal of Mediterranean Archaeology* 13(1): 107-111.

Shennan, S.

1997. *Quantifying Archaeology*. 2nd Edition. Edinburgh: Edinburgh University Press.

Tarboton, D.G.

1997. "A New Method for the Determination of Flow Directions and Upslope Areas in Grid Digital Elevation Models," *Water Resources Research* 33(2): 309-19.

Verhoeven, A.A.A.

1991. "Visibility factors affecting artifact recovery in the Agro Pontino

survey,” in Voorrips, A., S.H. Loving, and H. Kamermans, eds., *The Agro Pontino Survey Project*. Amsterdam: Universiteit Van Amsterdam, 87-96.

Wagstaff, M. and C. Gamble

1982. “Island Resources and their Limitations,” in Renfrew, C. and M. Wagstaff, eds., *An Island Polity: The Archaeology of Exploitation in Melos*. Cambridge: Cambridge University Press, 95-105.

Wagstaff, M.

1992. “Agricultural Terraces: The Vasilikos Valley, Cyprus,” in Bell, M. and J. Boardman, eds., *Past and Present Soil Erosion*. Oxford: Oxbow, 155-61.

Warren, P. and V. Hankey

1989. *Aegean Bronze Chronology*. Bristol: Bristol Classical Press.

Warren, R.E.

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

Warren, R.E. and D.L. Asch

2000. “A Predictive Model of Archaeological Site Location in the East-

ern Prairie Peninsula,” in Wescott, K.L. and R.J. Brandon, eds., *Practical Applications of GIS for Archaeologists: A Predictive Modelling Kit*. London: Taylor and Francis, 3-32.

Wescott, K.L. and R.J. Brandon, eds.,

2000. *Practical Applications of GIS for Archaeologists: A Predictive Modelling Kit*. London: Taylor and Francis.

Whitelaw, T.

2000. “Settlement instability and landscape degradation in the southern Aegean in the third millennium BC,” in Halstead, P. and Frederick, C., eds., *Landscape and Landuse in Postglacial Greece*. Sheffield Studies in Aegean Archaeology 3. Sheffield: Sheffield Academic Press, 135-161.

Whitelaw, T.

1991. “The Ethnography of Recent Rural Settlement and Land Use in North-West Keos,” in Cherry, J.F., J.L. Davis and E. Mantzourani, eds., *Landscape Archaeology as Long-Term History*. Northern Keos in the Cycladic Islands. Los Angeles: Institute of Archaeology, 403-454.

Wood, J.D.

1996. “The Geomorphological Characterisation of Digital Elevation Models,” unpublished PhD dissertation, University of Leicester.

Notes

¹The digital elevation model (DEM) of the survey area used in all of the following analyses has a 10 m resolution and was produced using ArcInfo's TOPOGRID algorithm (Hutchinson 1989; Hutchinson and Dowling 1991) from 2 m contours and spot heights (see TABLE 1). A large number of different interpolation algorithms were explored in the creation of the DEM, but given the nature of the base data, TOPOGRID was found to produce the best results. At this scale there are no signs of the inter-contour artificial terracing sometimes associated with contour-based interpolations.

²The local bedrock geology in these two sub-regions is predominantly Neogene marl, but there are also terraced areas on Cretaceous limestone, Neogene regressive conglomerate, and Eocene flysch. Our thanks to Charles Frederick and Nancy Krahtopoulou for permission to make use of this geoarchaeological information and for discussions on this topic.

³These can be dated more precisely to the Cretan Neopalatial Period or ca. 1700-1450 BC (Warren and Hankey 1989). Both terrain texture and hydrology are part of a much fuller analysis of the Kytheran Neopalatial sites to be published elsewhere (Bevan 2002)

⁴Significance levels in this section are those suggested by a Kolmogorov-

Smirnov one-sample test. ‘Sites’ (i.e. grid cells in locations for which sites have been detected) were compared to a background population represented by the cells making up the intensively tract-walked area. In this respect, the method partly follows that employed by Warren and Asch (Warren 1990; Warren and Asch 2000).

⁵More precisely it is calculated for the plane formed by the slope normal and perpendicular aspect. Channels have negative (concave) cell values and ridges, positive (convex) curvature values. The following analysis was conducted in Landserf: our thanks to Jo Wood for discussing aspects of his program and the possible relevance of multi-scale analysis.

⁶Range measures are often prone to the effects of anomalous extreme values. Alternative measures such as the inter-quartile range or, if the multi-scale curvature values of any given cell were shown to be unimodal and symmetric, a co-efficient of variation might be more robust or informative, but the range is the most straightforward to calculate and easy to understand. The problems of extreme values are likely to be less pronounced in this case because the original values themselves are a product of the averaging process involved in fitting the quadratic surface.

⁷The relationship between hydrology and these Neopalatial sites is ex-

plored in greater detail in Bevan (2002). The watersheds for figure 12 were produced using CRWR-PrePro (Olivera et al. 1998). This uses a traditional D8 flow distribution algorithm, but hydrological analysis was reassuringly consistent with that carried out using an alternative D_{∞} method (Tarboton 1997). The TOPOGRID algorithm used to interpolate the Kythera DEM is specifically designed to produce hydrologically correct interpolations (Hutchinson 1989; Hutchinson and Dowling 1991).

Tables

Table 1: KIP Datasets

Data type	Extent	Format	Entity	Scale/ Resolution
20 m contours	Island	Vector	Arc	1:5000
Spot heights	Island	Vector	Point	1:5000
2-4 m contours	Survey area	Vector	Arc	1:5000
Cultural topography	Island	Vector	Various	1:5000
Bedrock geology	Island	Vector	Area	1:50000
Aerial photographs	Island	Raster	Grid	1:15000
Satellite imagery	Island	Raster	Grid	20m resolution
Digital photos	Local	Raster	n/a	n/a
Elevation	Local	Vector	Point	n/a
Site location	Survey area	Vector	Point	ca. 1:15000
Site scatter	Local/Survey area	Vector	Area	ca. 1:15000
Ceramic distribution (i)	Local	Vector	Area	25-400 sq m collection units
Ceramic distribution (ii)	Survey area	Vector	Area	< 10000 sq m
Geoarchaeology (i)	Sub-survey area	Vector	All	1:5000
Geoarchaeology (ii)	Local	Vector	All	1:2000

Data type	Acquisition and processing methods	Notes
20m contours	Manual digitizing, automatic cleaning	Photogrammetrically extracted from 1960s aerial survey
Spot heights	As above	As above
2-4m contours	As above	As above
Cultural topography	As above	Roads, trackways, buildings, field-systems, terraces, toponyms
Bedrock geology	As above	
Aerial photographs	Scanned and rectified (rms <5m)	Taken in 1960s
Satellite imagery	Contrast stretch, histogram equalization	SPOT 4-band multi-spectral
Digital photos	Digital image processing	Site record photographs, used for QTVR development.
Elevation	Total station survey	
Site location	Intensive pedestrian field-survey	Estimated center of artifact distribution
Site scatter	As above	Estimated on the basis of grid-collections and local geomorphology
Ceramic distribution (i)	Intensive gridded collection	Resolution dependent on local conditions
Ceramic distribution (ii)	Intensive pedestrian field survey	Resolution dependent on local conditions
Geoarchaeology (i)	Geoarchaeological survey	Includes three study areas: Mitata, Palaiopolis, Livadi
Geoarchaeology (ii)	As above	Mapped environment around sites

Table 2: Observed and predicted site discovery by ground visibility

<i>visibility category</i>	<i>0-20</i>	<i>20-40</i>	<i>40-60</i>	<i>60-80</i>	<i>80-100</i>
Observed sites	35	44	34	25	32
Proportion of survey area in visibility category (%)	22	26	22	12	18
Expected sites	37	44	37	20	31

List of Figures

Figure 1. Kythera and the KIP Survey Area.

Figure 2. Histogram of the proportion of terrain with field enclosures by slope category (grouped in one degree ranges). Note the decline in the prevalence of field enclosures is gradual rather than abrupt. It can be modelled satisfactorily as an exponential curve.

Figure 3. Mitata and Palaiopolis terrace systems. Contours are in 4 meter intervals.

Figure 4. Histogram of the proportion of terrain with terraces, in both the Palaiopolis and Mitata areas, by slope category (grouped in one degree ranges). Note the prevalence of terraces increases steadily up to ca.12-13 degrees and then levels off.

Figure 5. Cumulative frequency curves for the Mitata and Palaiopolis field enclosures and hillslope terraces in relation to slope. Note that the greatest difference between the curves falls at ca.12-13 degrees.

Figure 6. Ceramic distribution around site 28. Each dot represents a single sherd that for illustrative purposes has been randomly placed within each tract (individual tract boundaries not shown). Other defined sites are designated by a label adjacent to the cluster. The regional data

collection strategy that this map is based on is instrumental in understanding site versus off-site artifact distribution patterns.

Figure 7. Examples of ceramic density fall-off as distance from scatter center increases, and increase as other adjacent clusters emerge. Note the pronounced effect of improved ground surface visibility on recovery rates (i.e. 3 to 4 times better), between first survey and re-survey after bush-fire.

Figure 8. Dot-density map of sherd distribution for site 28 as observed during intensive gridded collection. Each dot represents a single sherd, that for illustration has been randomly placed in each 5 sq m collection unit (not shown). Intensive site-based strategies provide an excellent means for interpreting localized distribution patterns and site size, but do not help us understand the relationship between on-site and off-site distribution patterns.

Figure 9. Example of interpolated artifact variability surface in the Kastri survey area. Cell shading is based on coefficient of variation (white=0, darkest=3.4). Sites sit neither on the highest or lowest values (the r^2 between distance from site center and mean coefficient of variation is 0.04).

Figure 10. The effect of scale on terrain curvature. The top row and lower left maps show a sub-section of the survey area near Mitata for which cross-sectional curvature values have been calculated at different cell neighborhood sizes (concave and convex landforms are present but not distinguished in this grayscale image). The lower right map shows the a measure of variation in curvature over different neighborhood scales calculated by taking the range of curvature values present for any given cell across all neighborhood sizes from 3 x 3 to 99 x 99 cells.

Figure 11. Correlation of Bronze Age site location and terrain curvature (linear regression: $y = -0.17x + 0.26$, $r^2 = 0.96$). Note that as curvature increases and terrain becomes rougher, the prevalence of site scatters steadily decreases.

Figure 12. Bronze age sites in the Mitata area and watersheds (minimum basin size = 6.25 ha). Note that all sites are located either on or close to watershed boundaries.

Figures

Figure 1: Kythera and the KIP Survey Area.

Figure 2: Histogram of the proportion of terrain with field enclosures by slope category (grouped in one degree ranges). Note the decline in the prevalence of field enclosures is gradual rather than abrupt. It can be modelled satisfactorily as an exponential curve.

Figure 3: Mitata and Palaiopolis terrace systems. Contours are in 4 meter intervals.

Figure 4: Histogram of the proportion of terrain with terraces, in both the Palaio polis and Mitata areas, by slope category (grouped in one degree ranges). Note the prevalence of terraces increases steadily up to ca.12-13 degrees and then levels off.

Figure 5: Cumulative frequency curves for the Mitata and Palaioapolis field enclosures and hillslope terraces in relation to slope. Note that the greatest difference between the curves falls at ca.12-13 degrees.

Figure 6: Ceramic distribution around site 28. Each dot represents a single sherd that for illustrative purposes has been randomly placed within each tract (individual tract boundaries not shown). Other defined sites are designated by a label adjacent to the cluster. The regional data collection strategy that this map is based on is instrumental in understanding site versus off-site artifact distribution patterns.

Figure 7: Examples of ceramic density fall-off as distance from scatter center increases, and increase as other adjacent clusters emerge. Note the pronounced effect of improved ground surface visibility on recovery rates (i.e. 3 to 4 times better), between first survey and re-survey after bush-fire.

Figure 8: Dot-density map of sherd distribution for site 28 as observed during intensive gridded collection. Each dot represents a single sherd, that for illustration has been randomly placed in each 5 sq m collection unit (not shown). Intensive site-based strategies provide an excellent means for interpreting localized distribution patterns and site size, but do not help us understand the relationship between on-site and off-site distribution patterns.

Figure 9: Example of interpolated artifact variability surface in the Kastri survey area. Cell shading is based on coefficient of variation (white=0, darkest=3.4). Sites sit neither on the highest or lowest values (the r^2 between distance from site center and mean coefficient of variation is 0.04).

Figure 10: The effect of scale on terrain curvature. The top row and lower left maps show a sub-section of the survey area near Mitata for which cross-sectional curvature values have been calculated at different cell neighborhood sizes (concave and convex landforms are present but not distinguished in this grayscale image). The lower right map shows the a measure of variation in curvature over different neighborhood scales calculated by taking the range of curvature values present for any given cell across all neighborhood sizes from 3 x 3 to 99 x 99 cells.

Figure 11: Correlation of Bronze Age site location and terrain curvature (linear regression: $y = -0.17x + 0.26$, $r^2 = 0.96$). Note that as curvature increases and terrain becomes rougher, the prevalence of site scatters steadily decreases.

Figure 12: Bronze age sites in the Mitata area and watersheds (minimum basin size = 6.25 ha). Note that all sites are located either on or close to watershed boundaries.