The use of Thiessen polygons and viewshed analysis to create hypotheses about prehistoric territories and political systems: A test case from the Iron Age of the Spain's Alcoy valley

Introduction

The reconstruction and inference of prehistoric political and community territories from archaeological remains continues to intrigue and motivate archaeologists (Steadman 2000; Robb and van Hove 2003; Savage and Falconer 2003). Thiessen polygons have in the past been proposed for inference of prehistoric territorial boundaries (Renfrew 1973; Hodder and Orton 1976). The construction of viewsheds, combined with the analysis of viewshed content and Thiessen polygons, promises a finer analysis and can be used to generate hypothetical prehistoric territories which reflect both local topography and spatial distribution of sites.

This paper explores the combination of Thiessen polygons and viewshed analysis for the generation of hypothetical prehistoric territories for a group of Iron Age hill forts (*oppida*) in Spain's Alcoy valley. We also ask whether the combined Thiessen polygon and viewshed analysis suggest a ranking of hill forts in a stratified regional system, or whether their territories are consistent with a peer-polity system (Renfrew and Cherry 1986).

The Region

The sites examined in this study date to circa 1100-700 BC and were established during the Bronze Age. They consist of 51 settlements and 8 associated hillforts, known as *oppida*. Evidence suggests that the settlements preceded the *oppida* and were uniformly small with areas smaller than a half hectare (ha). The settlements were clustered together in prime agricultural areas mainly on the valley floor along the river where dry farming of wheat, barley, and legumes was practiced. Later Alcoy valley administrative centers, the *oppida*, were larger, usually 1 to 2 ha, and were generally located on promontories. The greater size of *oppida* resulted from the addition of elite residences (Gilman 1991). These *oppida* were non-agrarian fortified settlements holding a central position in the territory. They acted as administrative centers containing aristocratic residences where political, religious, and economic power coalesced (Ruiz and Molinos 1998). A system of paths has been identified along the valley floor which served for trade and information exchange (Grau Mira 2003).

Data and Software

The analyses presented here were performed using Idrisi32 v.2. Data was obtained from paper contour maps of the Alcoy valley, with a resolution of 1:200.000 (Fig. 1) from which we hand-digitized a contour map (Fig. 2) (Instituto Geografico y Cas-

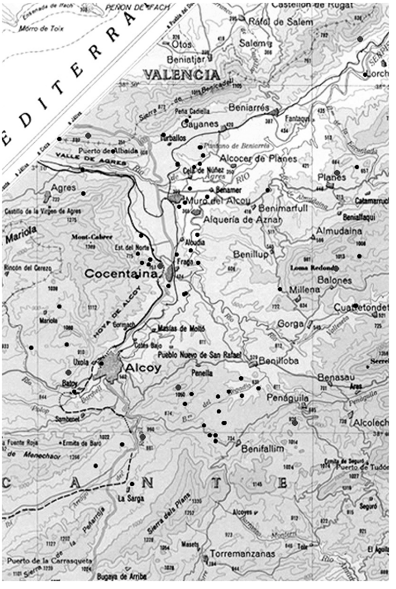

Fig. 1 – Original scanned map.

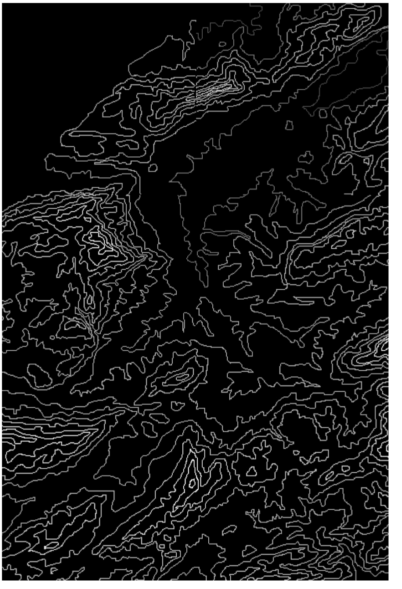

Fig. 2 – Digitized image.

tral 1965). From this digitized contour map we interpolated a digital elevation model (DEM). Data on the Alcoy valley archaeological sites were acquired from Grau Mira (2003).

Methods

Thiessen polygons were used to create an initial territorial boundary for each *oppidum*. Thiessen polygons involve the division of a region into a number of separate territories each of which focus on a separate site. Straight lines are drawn between neighboring sites and then a second series of lines are drawn at the mid-point along each of the first series of lines at right angles.

Viewsheds allow for a better understanding of landscape and site interaction by displaying what is visible from each *oppidum*. The use of viewshed analysis for territorial reconstruction is based on two assumptions: what is not visible to the *oppidum* is less easily controlled and defended and what is visible from the *oppidum* lies within its direct zone of influence. The viewsheds of each *oppidum* can be examined to determine the extent of their influence and to generate hypotheses about the extent of their control. Individual binary viewshed maps may be combined to create a total viewshed map, which aggregates all of the binary *oppidum* viewsheds. For the purposes of this paper the viewable distance value was set to infinity. The viewing height was set at 10 meters.

Viewshed content was quantified by determining the number of settlements and other *oppida* which lie within a given *oppidum*'s viewshed. This is a rough quantification, but in the absence of more precise data and for the purposes of a pilot study, it will suffice for the generation of hypotheses.

Many sources of error may affect the accuracy of viewsheds. Such errors include inaccuracies within the DEM as a result of digitizing errors and low spatial resolution. Both types of error can strongly affect the lines-of-sight. Moreover, precise coordinates of the *oppida* and settlements as well as the exact height of the *oppida* were not available and therefore they had to be estimated. More accurate numbers could change the results considerably. Additionally, the original paper contour map from which we digitized our DEM was missing a corner thus producing an almost flat plane in the northwest region of our map. This paper contour map was also slightly smaller than our region of study. This forced us to exclude one of the *oppida* (n. 4) in addition to a cluster of settlements and four outlying settlements in the Alcoy valley system. Finally, it is important to note that the precision of scanners and the detail of the original images vary. Such factors directly impact the quality of the resultant raster or vector data layer.

Results

Simple Thiessen polygons resulted in a fairly even territorial distribution among the *oppida*, suggesting a lack of ranking and thus the existence of a peer-polity system in the region's Iron Age. *Oppidum*/settlement intervisibility, however, suggests a ranked system (Table 1). *Oppidum* 8 has both the largest viewshed area and a view on 85% of settlements and all but one of the other *oppida*. *Oppidum* 6 has the second largest viewshed area but has a view on fewer settlement clusters. Other *oppida* have lesser viewshed areas and even fewer *oppida* and settlements in view.

Oppidum Number	1	2	3	4	5	6	7	8	9	10
Number of Settlements Viewed	7	1	2		3	18	2	11	3	2
Number of Other Oppidum Viewed	1	1	2		3	5	3	5	3	3

Table 1 – Number of settlements and *oppida* viewed by each *oppidum*.

The combined viewshed (Fig. 3) shows that a majority of settlements lie within view of three to five *oppida*. It also shows that the valley floor was the most visually well covered. The total viewshed shows that all but one of the settlements are within the viewshed of at least one *oppidum*.

Because of an edge effect problem, Thiessen polygons used alone suggest that the outermost *oppida* are the most influential since their polygons extend outward to the corners of the map. Individual viewsheds point to *oppidum* 8, with the largest area viewed (Table 2), as a primary administrative center. However, because of its central position and close proximity to other hill forts, *oppidum* 8 has a relatively small Thiessen polygon. This suggests that Thiessen polygon area alone is not sufficient to infer territory or political importance.

Oppidum 6 commands views on the largest number of individual settlements. *Oppida* 6 and 8 each have 5 other *oppida* within their viewshed. Based on number of settlements and other *oppida* viewed, *oppida* 6 and 8 therefore seem to be im-

	Oppidum 1	Oppidum 2	Oppidum 3	Oppidum 5	Oppidum 6	Oppidum 7	Oppidum 8	Oppidum 9	Oppidum 10
Thiessen Polygon Areas Within Viewshed (km^2)	59.45	21.80	44.67	42.98	56.71	48.31	30.62	32.61	44.44
Viewshed Areas (km^2)	64.41	111.16	114.93	65.28	175.40	134.26	249.34	61.01	24.09

Table 2 – Areas of viewsheds and polygons.

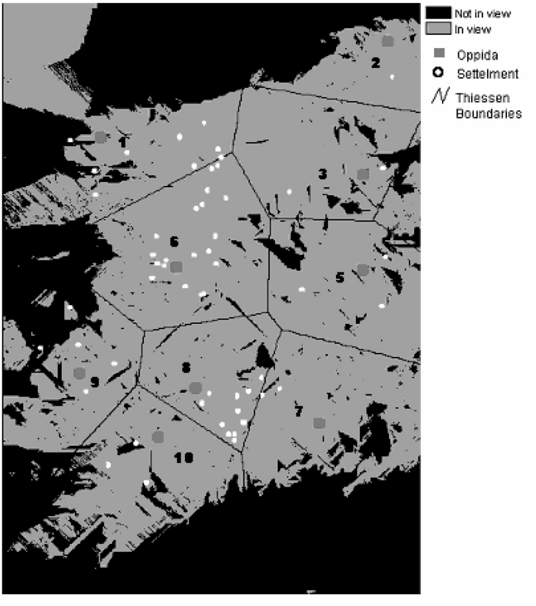

Fig. 3 – Total viewshed with Thiessen polygons.

portant centers in a local hierarchy of hill forts. Although the sample is extremely small, Fig. 4 shows a fall-off curve for number of settlements viewed per *oppidum* that is not inconsistent with a stratified system.

Discussion

Neither Thiessen polygons nor individual viewsheds alone seem to be appropriate for the inference of prehistoric territories for hill fort systems. Thiessen polygons are highly sensitive to edge effects and ignore local topography and other environmental factors. Individual viewsheds do not take viewshed overlap into account for multi-site, clustered systems. The use of a total or cumulative viewshed alone does not allow the separation of territories.

Thiessen polygons overlain on a total viewshed mitigate edge effects and delineate potential territories. The analysis of the content of individual viewsheds (in settlement and other types of sites) allows a quantification of the potential importance and influence of proposed political centers.

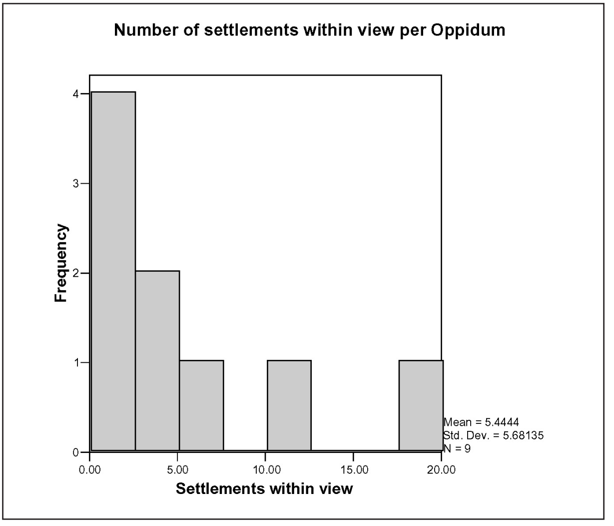

Fig. 4 – Fall-off curve per number of settlements viewed per *oppidum*.

Conclusions

The use of Thiessen polygons combined with viewshed analysis allows the generation of hypotheses about prehistoric political and social territories. Quantification of viewshed content allows the generation of hypotheses about the relative importance of individual sites in a regional system, and the identification of correlates of various modes of social organization. In this case, it can be hypothesized that Iron Age hillforts in the Alcoy valley of Spain functioned within a stratified system rather than a peer-polity. These hypotheses can serve as the basis for the design of excavations directed at collecting data appropriate for testing them.

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Ager Romanus antiquus: Defining the most ancient territory of Rome with a GIS-based approach

Introduction

In a Congress on "The ancient town and its territory" held in Santa Maria Capua Vetere in 1998 Silvio Panciera complained about the scarce knowledge of the territory of primitive Rome. He suggested different methods to define *Ager Romanus antiquus*'s boundaries such as analysing place-names, considering *tribus* and municipal inscriptions, literary sources or theoretical methods as Thiessen polygons (Panciera 1999: 11).

The literary approach has already been explored; in this paper I intend to develop different theoretical approaches based on GIS applications:

1. constructing Thiessen polygons around Rome and others sites of *Latium Vetus* in proto-historic time in order to define their notional territories;
2. employing Cost Surface Analysis and visible area analysis to explore whether the *Ager Romanus antiquus* was an area suitable for a proto-urban centre in term of land exploitation and territorial control.

Traditional Literary Approach

a) The sanctuaries at the fifth-sixth miles around Rome as limits of the Ager Romanus antiquus

Since the 19th century different scholars have suggested the identification of the limits of the *Ager Romanus antiquus* as a line marked by a series of sanctuaries at about five to six Roman miles from Rome (Fig. 1)[1].

This opinion is based on Strabo V, 3, 2, who mentions the *Ambarvalia*, a ceremony held in *Festoi*, a place that lies about five to six miles from Rome, and in other boundary places at the same distance. On the basis of this textual account, scholars have tried to identify the same boundary in sanctuaries situated at the same distance from Rome generally on the main roads: *Lucus Deae Diae*, between the fifth and the sixth mile from Rome on the via Campana[2]. *Terminalia*, at the fifth-

[1] Mommsen 1854-1856: 35; De Sanctis 1907: 377-378; Beloch 1926: 169, who consider the *Ager Romanus antiquus* linked to the site of Rome from its origin; Ashby 1927: 29; Momigliano 1963: 100-101; Lugli 1951, 1966; Alföldy 1962, 1965: 296-304; Quilici Gigli 1978; Scheid 1987, 1990: 98-102; Colonna 1991.

[2] Lugli 1966: 647 and recently Coarelli 2003 have connected *Ambarvalia* and *Festoi* named by Strabo with *fratres Arvales* and *Lucus Dea Dia* but Alföldy 1965: 297-298, Scheid 1987: 586, 1990: 101-102 and Colonna 1991 reject this interpretation because, following Strabo and Lucano, *Ambarvalia* were celebrated by senatorial *pontifices*.

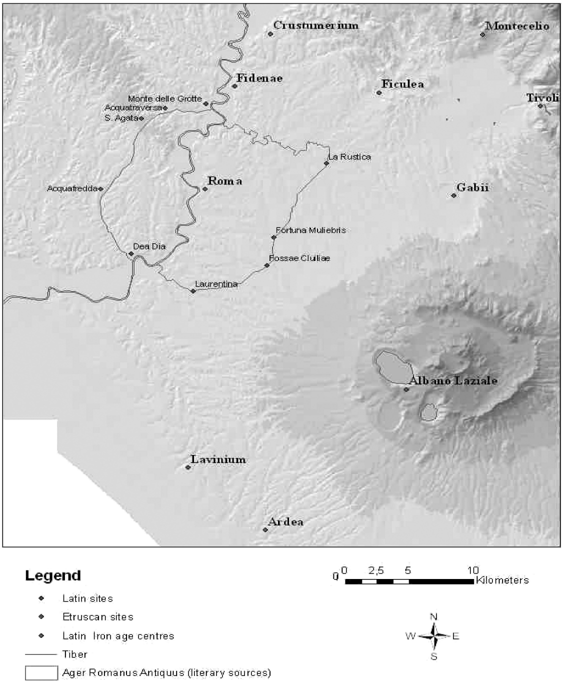

Fig. 1 – The *Ager Romanus antiquus* according to literary sources.

sixth mile of the via *Laurentina Vetus* identified by Giuseppe Lugli (1966) and Giovanni Colonna (1991) with the site of Laurentina Acqua Acetosa[3]. *Fortuna Muliebris*, between the fourth and the fifth mile of the via Latina[4]. *Robigalia*: at the fifth mile of the via Clodia (Lugli 1966: 643).

As Scheid (1987: 592) has remarked all deities of these sanctuaries are linked to war and to agriculture, as they are boundary sanctuaries aimed to protect the city and its fields.

b) Topographical reconstruction of the fifth-sixth mile limit

To define the *Ager Romanus antiquus* I have followed the indications given by G. Colonna (1991) (Fig. 1): on the south the sanctuary of *Dea Dia* (Monte delle Piche) and the sanctuary of *Terminus* (Acqua Acetosa Laurentina); on the east the *Fossae Cluiliae* (Horatii and Curiatii's tumuli on the via Appia). On the right bank of

[3] Bedini 1994 with references; according to Colonna 1991 this is *Festoi* mentioned by Strabo 5.3.2, contra Coarelli 2003, note 5.

[4] This is the place where *Coriolanus*, exiled among the Volscans and rebelling against Rome, met twice his mother *Veturia* and his wife *Volumnia*, sent by Romans to convince him to save the city (Lugli 1966: 644).

the Tiber, he suggests the localisation of some Etruscan sites of which the most relevant seem to be Colle S. Agata and Acquafredda[5].

Colonna also states that the *Ager Romanus antiquus* boundaries should have been indicated by Fosso dell'Acqua Acetosa on the south, Fosso della Magliana on the west and with the Aniene river on the north-east at least till Ponte Mammolo. In order to identify the path between sanctuaries I have used the "shortest path" function of Spatial Analyst in ESRI ArcGIS 9 using the same cost surface which has been employed for Cost Surface Analysis. The area defined by this limit has an extension of 18.822,0128 ha.

c) Dating of the fifth-sixth mile limit according to different scholars

The dating of the *Ager Romanus antiquus* is strictly linked with the opinion of historians regarding the area of Roman territory under the kings and more generally the reliability of the annalistic tradition on early Rome.

In general it can be observed that "sceptical" historians such as Andreas Alföldy (1965: 305), followed by John Scheid (1990), date the *Ager Romanus antiquus* to the fifth century B.C., the middle and the beginning of the century respectively. They follow the opinion of Niehbur who strongly considered the conquest by the kings as invented and to be regarded with great suspicion (Alföldy 1965: 123).

"Moderate" historians and archaeologists instead are more inclined to date the *Ager Romanus antiquus* at the beginning of the monarchy or even earlier because they admit the expansion of Rome under the kings. Arnaldo Momigliano (1963: 101) and Stefania Quilici Gigli (1978: 572) propose the age of Numa, while Giuseppe Lugli (1966: 644) and Carmine Ampolo (1988: 321) relate the *Ager Romanus antiquus* to Romulus. Also Thomsen (1980: 135) dates the *Ager* a long time before the fall of the monarchy: «on the whole, it undoubtedly represents the original territory of the city-state of Rome, as was already realised by Beloch».

Giovanni Colonna (1991: 212) and Andrea Carandini (1997) go further: they are both inclined to connect the *Ager Romanus antiquus* with the very beginning of Rome, that is the first unified settlement of Rome on the so-called seven hills (the synecismus between *Montes* and *Colles* according to Carandini) in Latial Period IIB-IIIA. With different theoretical approaches it will be made an attempt to contribute to this debated question.

Theoretical GIS-based Approaches

a) Thiessen polygons

The first theoretical approach undertaken to address the question of the *Ager Romanus antiquus* is the construction of Thiessen polygons. This method was firstly used by the U.S. Weather Bureau in generalizing the rainfall of a given water

[5] Colonna 1991: 210 note 2 with references. To these sites it could be added Acquatraversa (on the north-east of Colle S. Agata, near the Acquatraversa small river) and Monte delle Grotte (near the confluence between Crescenza and Acquatraversa): for location and references see De Santis 1997: 102, fig. 1.

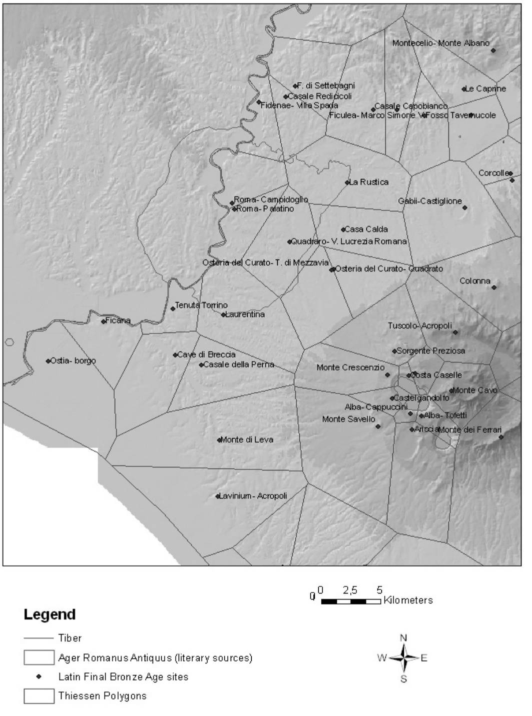

Fig. 2 – Final Bronze Age notional territories according to Thiessen polygons.

catchment from a network of meteorological recording station (Haggett 1965: 247). From geography it was borrowed by archaeologists in the early seventies and used in different cultural contexts[6]; with particular reference to central Italy it has been used by Renfrew (1975: 17, fig. 5); di Gennaro (1986) applied it to Etruria, Bietti Sestieri (1992) and Pini Seripa (1986) to *Latium Vetus*.

The method employed to build Thiessen polygons is very simple: different centres are joined by a line; from the midpoint of these lines a boundary line is drawn at right angles to give a series of polygons (Haggett 1965). The problem of Thiessen polygons method is that it is based on two assumptions:

1) the area defined by a polygon is constituted by all the points which are closer to the enclosed centre than any other centre;
2) a metropolis dominates all the area that lies geometrically nearest to it.

That means that the model does not take into account the concept of hierarchy or political dominance expressed by territoriality (Grant 1986).

To avoid this problem it was considered only the larger centres of Early Iron Age *Latium Vetus* assuming the existence of a hierarchy proportional to settlement

[6] Some bibliography in Hodder and Orton 1976: 187 and Grant 1986: 19.

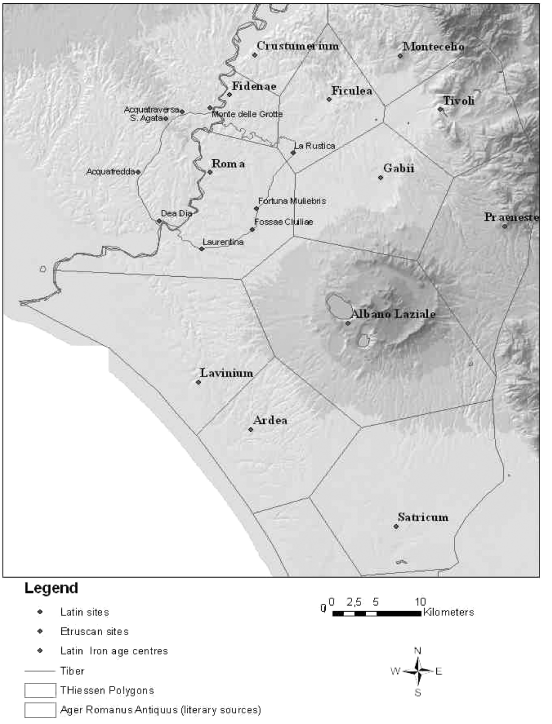

Fig. 3 – The *Ager Romanus antiquus* according to literary sources compared with Thiessen polygons (Early Iron Age).

size, which seems to be plausible in this context [7]. For Final Bronze Age all settlements were considered equal, even though I suspect that a closer analysis could reveal a more articulated situation.

As it is evident from the comparison between Figs. 1, 2 and 3, dispersed settlements of Final Bronze Age dominate small territories (Fig. 2) which cannot be compared with the large area identified for the *Ager Romanus antiquus* according to literary sources (Fig. 1).

The areas identified by the two different approaches are more comparable when we consider nucleated Early Iron Age settlements: this situation is likely to be actual from Latial Period IIA-IIB, when, according to Pacciarelli (2001), proto-urban centres are also formed in *Latium Vetus* (Fig. 3).

In particular it can be observed that, on the north of Rome, the Thiessen limit coincides with the Aniene, while, on the south-west side, the dominance of Rome

[7] I considered the Alban Hill as a whole area because in this area there was not a real and complete proto-urban development like in the rest of *Latium Vetus* and there was none big proto-urban centre but many small settlements.

according to Thiessen polygons seems to extend towards the sea, because there is a lack of a large centre near the mouth of the Tiber [8].

b) Cost Surface Analysis and visibility

As defined by Van Leusen (2002) Cost Surface Analysis is a «generic name for a series of GIS techniques based on the ability to assign a cost to each cell in a raster map, and to accumulate these costs by travelling over the map».

The origin of Cost Surface Analysis can be considered traditional Site Catchment Analysis, introduced to archaeology by Vita Finzi and Higgs (1970). The scope of the analysis is to investigate the economic potential, in term of natural resources, of a certain territory, the catchment area, associated with a particular settlement. The first step, and this is our main interest, is to define a territory. With reference to ethnographic data Vita Finzi and Higgs (1970) suggested different territorial size for different type of communities, calculated on the basis of the principles of "least effort and land rent": after a certain distance it is time-consuming and unproductive the work invested in food procurement compared to time lost in return travel. Thus Vita Finzi and Higgs suggested that hunter-gatherer settlements might be associated with territories up to a 10-kilometre radius, pastoral herder sites with some 7,5-kilometre radius of territory and farming communities with 5-kilometre territorial radius. The Cambridge Palaeoeconomy Group converted these territorial sizes in human walking times and respectively: 2 hours for hunter-gatherer, 1,5 hour for herders and 1 hour for farmers (Bintliff 1999: 506-509).

The problem of Site Catchment Analysis, as well as Thiessen polygons discussed above, is that they consider landscape as a flat, two-dimensional space and that resistance to movement across this space is isotropic (uniform in all direction). As Van Leusen (2002) pointed out «Cost Surface Analysis provides a way out of this by allowing the simple 'flat' geographical space to be supplanted by a set of complex cost surfaces incorporating many relevant properties of the terrain. It also allows for the distance- and gravity based rule for defining the catchment or territory boundaries to be replaced by a time or energy expenditure based rule for accumulating costs». He also provided a good review of different factors and criteria used by different authors to calculate cost surface but the most common has been and continue to be slope.

In this paper I have used an isotropic cost surface, derived from slope and based on empirical walking data effort, which was first used by Rajala (2002). The correlation between slope and cost of moving is based on an unpublished study of Machovina (1996) and is shown in the Table 1.

Slope	Constant	Seconds/25 m
0-3	1	19
4-11	1,5	28
12-15	1,75	33
16-25	2	38
26-30	3	56

Table 1

[8] Settlements are attested in the area of Ostia for Recent and Final Bronze Age but not later and Ficana, which is attested also in Iron Age and is a small settlement which was probably subordinated to Rome.

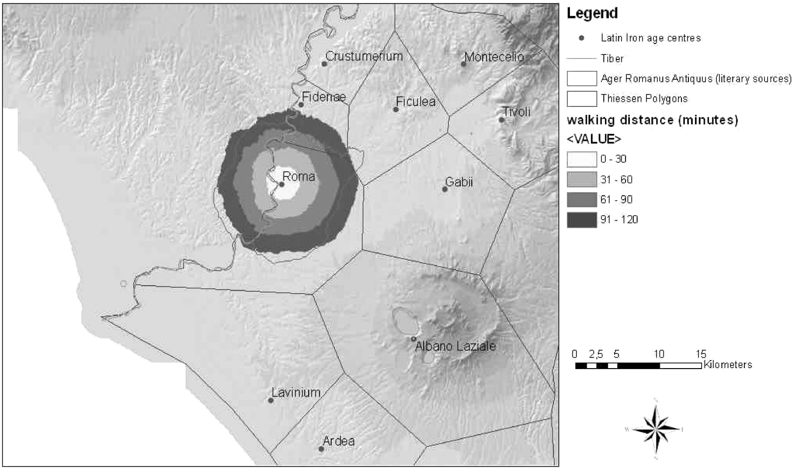

Fig. 4 – The *Ager Romanus antiquus* according to Cost Surface Analysis.

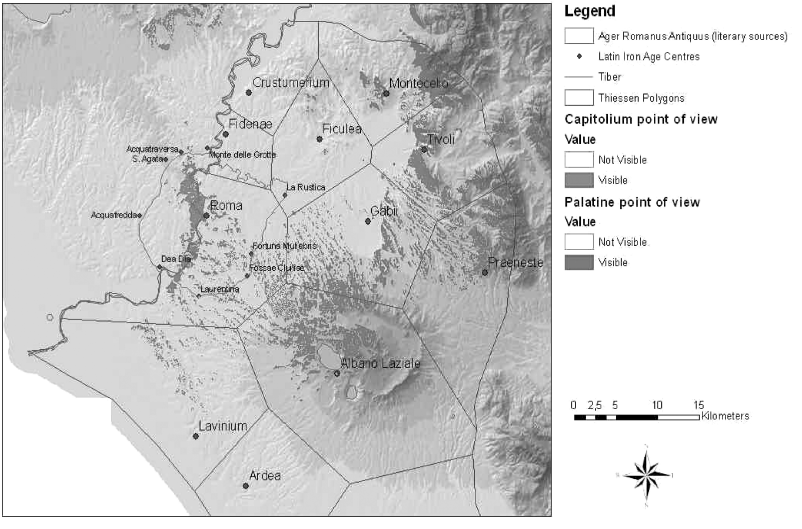

Fig. 5 – Visible areas from the Palatine and the *Capitolium*.

Slopes more than 30 degree have been considered impossible to pass over. Slope was derived from a DEM with a resolution of 20 metres obtained from the Italian Ministero dell'Ambiente.

As shown in Fig. 4 the *Ager Romanus antiquus* reconstructed according to literary sources lies between a walking distance of 1,5-2 hours. As we have seen before, according to the Site Catchment Analysis the territory of an agricultural prehistoric community should be no more than 1 hour-walking. In this case we have to consider that early Iron Age Rome was already a significant proto-urban centre with its dependent settlements distributed in a two or even three levels hierarchy (Early State module: Fulminante 2003) and it has surpassed the stage of a simple prehistoric farming settlement.

To explore the potential of the site of Rome in term of territorial control it was applied a Viewshed Analysis. The most higher point of the Palatine and of the *Capitolium* have been used as points of observation; a Z factor of 1,5 m was adopted to simulate the point of view of an observer; buildings of 10 and 20 metres have also been simulated (Fig. 5).

The results were quite different than expected: visibility was directed towards the mountains rather than in the valleys. It can be observed that from the *Capitolium* the focus seems to be on the river, where there was the landing place and the ford, which was the first core of the settlement (Grandazzi 1997: 75-91). From the Palatine's point of view the river is still visible but there is a wider visibility towards the south-east of Rome. Although it could be just coincidentally, from the place where Romulus took the *auspicia*, the Palatine, the visibility area comprises the location of three of the sanctuaries of the *Ager Romanus antiquus*.

Conclusions

The types of analysis presented in this paper have previously been widely applied by different scholars (for example Stančič *et al.* 1995) in diverse geographical contexts, particularly in central Italy, but they had not yet been applied to Rome.

The focal point of this paper was the application of combined spatial and statistical analysis to provide a contribution to the long debated question of the definition of the primitive territory of Rome. GIS can be criticised as an environmentally deterministic technique but it is our belief that it is the appropriate tool to produce an interpretation of the address question.

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The impact of terrain severity on variation in viewshed generation. Comparing Idrisi, ArcMap and GRASS

Introduction

Intervisibility and Viewshed Analysis, both based on line of sight calculations using Digital Elevation Models (DEM) and Geographic Information System (GIS) packages have recently become important tools in archaeological analysis (Lake *et al.* 1998; Swanson 2003). Different GIS packages use different methods to address the same problems. Different methods mean different results, even for the same analysis and data set. Yet, software selection is often based on convenience and other pragmatic concerns.

Building on previous work, that of Cheng and Shih in particular (1998), we will empirically demonstrate how software choice affects generated viewsheds. Calculation of viewsheds on a variety of terrain types with three standard GIS packages suggests that the discrepancy is greatest where the slope is changing, such as at ridgelines and the edges of depressions in the landscape. A simple measure of elevation range was tested and found to be insufficient to account for all variation but that certain GIS packages seem to be more sensitive than others to terrain severity when it comes to calculating viewsheds. Surprising and interesting problems of data compatibility were encountered in what should have been a straightforward experiment. They highlight some of the difficulties of these emerging techniques.

Methods

DEMs for six regions of Canada were selected for this study (Table 1). The DEMs cover 1201x1201 pixels meaning that over 1.4 million points are potentially visible. The data is available from the Canadian government and can be found at www.geobase.ca.

Two DEMs of the Canadian Rockies (Mt. Sir Alexander and Croyden, BC), represent extreme elevation differences (High 1 and High 2). The total elevation range for these maps is greater than 2000 meters. Two DEMs of prairie regions (Maple

Location	CDED Code	Title	Range
Mt. Sir Alexander, BC	093H16	High 1	2365 meters
Croyden, BC	083E04	High 2	2249 meters
Mount McCook, BC	094F13	Med 1	1340 meters
Saglek Fiord, Nfld	014L06	Med 2	1042 meters
Maple Creek, Sask	072F14	Low 1	441 meters
Nevill, Sask	072G13	Low 2	168 meters

Table 1 – Summary of locations and elevation ranges for the chosen DEMs.

Creek and Nevill, Saskatchewan) represent areas of low elevation change (Low 1 and Low 2). These have elevation ranges of less than 500 meters. Saglek Bay in Labrador and Mount McCook in British Columbia will represent areas of intermediate elevation range. Orthographic perspectives of each terrain are available in Appendix A.

The viewshed for each DEM was found using the Viewshed module of Idrisi32 v2 by Clark Labs, the Spatial Analyst extension of ArcMap v8.3 by ESRI and the r.los module of GRASS v5.3 written by Kewan Khawaja. While all three of these algorithms use a DEM in the creation of a viewshed, each one has different requirements for selecting the viewpoint. Idrisi requires a binary raster map with the viewpoint cell coded as one and all others coded as zero. ArcMap uses a vector point file to specify the viewpoint. GRASS requires the manual input of the viewpoint coordinates.

In order to ensure that each program used the same data to create viewsheds, each DEM was imported into the program in its original form and each viewpoint was created with the most precise coordinates allowed. The point was initially chosen within Idrisi and then the geographic coordinates were recorded to six decimals places before being recreated within GRASS and ArcMap. A standard viewpoint height of three meters was used and the maximum visible distance was infinite.

Unfortunately, the r.los module of GRASS is not compatible with the latitude/longitude coordinate system of the CDED data being used. A conversion would have changed the data so that it would no longer be valid for testing viewshed modules. To work around this problem the existing DEMs had to be exported to a tiff file using Idrisi and then imported into GRASS without the "tiff world file" that records the coordinate system. Unfortunately this process also greatly changes the elevation data itself requiring new viewsheds to be calculated in Idrisi using the altered DEM values. Since ArcMap will not import this type of tiff file, the original data had to be used and then compared to the Idrisi viewsheds of the unaltered DEM. Simply put, GRASS can be compared to Idrisi, and ArcMap can be compared to Idrisi, but GRASS cannot be compared directly to ArcMap.

In order to formulate comparisons, viewsheds from GRASS and ArcMap were exported to tiff images and then imported into Idrisi so that the ImageDiff module could be used. Exporting to a tiff image did not alter the data by rounding or converting to a lower data type since binary viewsheds are composed of ones and zeros. The ImageDiff module subtracts one viewshed from the other pixel by pixel. The subtraction generated a "difference image" of the same dimensions as the viewsheds but with all agreements coded as zero and all differences as either a negative or a positive one. Images were calculated as "GRASS subtract Idrisi" or "ArcMap subtract Idrisi". The pixel was coded as -1 when Idrisi marked it visible and the other package didn't. The pixel was coded as 1 when Idrisi marked it as non-visible while the other package marked it visible. All agreements were marked as zero. Cheng and Shih (1998) took the total count of the negative and positive cells when analysing the difference between the viewsheds. However, we found that the negative and positive counts reveal important patterns and will be treated separately.

Results

Appendix A gives the viewsheds and difference images discussed in the following paragraphs. A visual review of the two pairs of viewsheds (Idrisi - GRASS and Idrisi - ArcMap) shows that the GRASS and Idrisi viewsheds are in close agreement. There were no obvious regions included in one viewshed and not the other. Some of the ArcMap - Idrisi comparisons showed considerable differences. The Idrisi viewsheds were generally larger, and in High 1 and High 2 whole regions were marked visible by Idrisi that were not visible by ArcMap.

The difference images created with the ImageDiff module of Idrisi emphasized these differences by showing exactly where the two maps disagreed and understating all points of agreement. For the GRASS - Idrisi comparisons, small portions of Low 1 and High 1 were shown to disagree. Additionally a sparse outline of the visible regions showed disagreement on all difference images. This indicates that the viewsheds disagree most where the slope is at a threshold, such as at ridgelines and other edges. This observation agrees with Cheng and Shih (1998) who remarked that «variation occurs frequently in the area where the gradient of the terrain changes». Then again, it can be noted that these are the only points where one could *expect* differences in viewsheds.

The ArcMap - Idrisi difference images showed large regions of disagreement in High 1 and High 2 and smaller regions of disagreement in Med 1. ArcMap - Idrisi comparisons also showed greater disagreement in viewshed outline than GRASS - Idrisi comparisons (Table 2). Differences in positive and negative cell counts varied considerably for the GRASS - Idrisi images and were not dependent on the elevation range of the DEM (Fig. 1). The number of negative and positive cells also varied widely indicating that neither program is notably liberal or conservative, relative to the other, in its calculation of a positive line-of-sight.

The negative cell counts of the ArcMap - Idrisi image were higher than the positive cell counts for all elevation ranges showing that, relative to ArcMap, Idrisi uses a consistently more liberal algorithm to calculate lines of sight (Table 3). However, the difference was only partially dependent on elevation range. The negative difference

The number of positive and negative cell differences in GRASS - Idrisi						
	Low 2	Low 1	Med 2	Med 1	High 2	High 1
Negative	2694	2930	8021	3009	5812	4165
Positive	2425	11010	4392	4870	3278	10320

Table 2

The number of positive and negative cell differences in ArcMap - Idrisi						
	Low 2	Low 1	Med 2	Med 1	High 2	High 1
Negative	7807	8402	6526	11922	25037	65080
Positive	2171	2303	3962	7156	2658	5339

Table 3

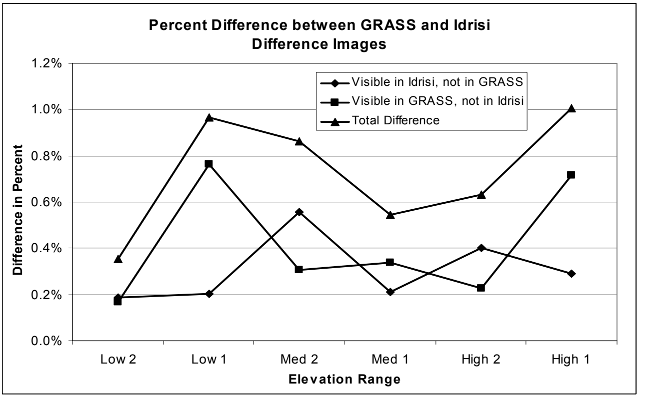

Fig. 1 – Differences vary widley and are not dependant on the elevation range of the DEM.

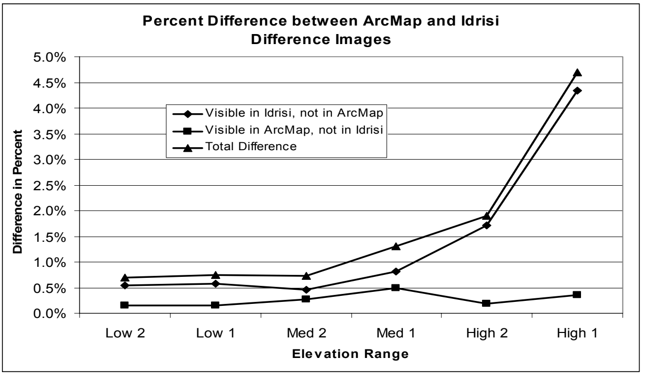

Fig. 2 – Negative difference increases as the elevation increases while the positive difference does not. The total difference, as used by Cheng and Shih (1998), does not detect this pattern.

(i.e. visible in Idrisi and not in ArcMap) is strongly correlated to the elevation range of the DEM but the positive difference (i.e. visible in ArcMap but not Idrisi) is not (Fig. 2). The plots below show a strong increase in the negative difference count as the elevation range increases, with the exception of Med 2. However, the relationship is not a constant one indicating that there is another unknown factor that is affecting this relationship. The positive differences were clearly not dependent upon elevation range, further suggesting the existence of an unknown factor affecting the relationship between viewshed difference and elevation range (Fig. 2).

Discussion

As noted by other researchers (Fisher 1993; Fisher *et al.* 1997: 582; Cheng and Shih 1998), viewsheds differ based on the GIS package used. The sensitivity of the

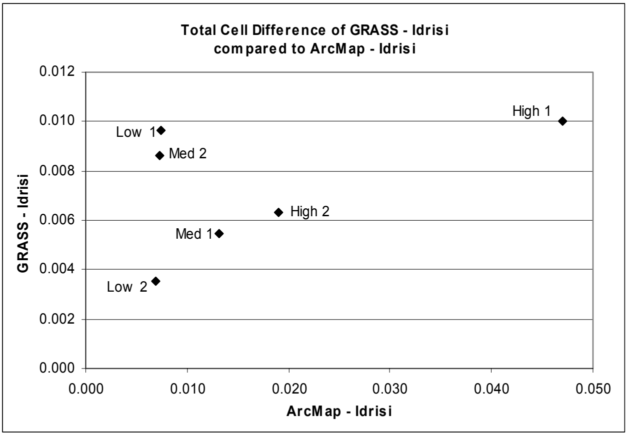

Fig. 3 – Relationship of the total GRASS - Idrisi difference to the total ArcMap - Idrisi difference. The ArcMap - Idrisi difference is much more sensitive to terrain elevation range than the GRASS - Idrisi difference.

ArcMap-Idrisi difference to elevation range may indicate that either 1) viewsheds generated with Idrisi become larger or 2) ArcMap's become smaller when terrain severity increases. Since the GRASS - Idrisi case does not show this correlation, ArcMap's algorithm is most likely responsible. This could be tested if ArcMap viewsheds were compared directly to GRASS viewsheds.

As Cheng and Shih (1998) noted, differences in viewsheds occur most frequently at thresholds in the terrain's slope. If ArcMap viewsheds become smaller as terrain severity increases while other viewsheds do not, perhaps ArcMap's algorithm is simply more sensitive to the effects of terrain severity. The unknown factor noted above as affecting the relationship could simply be that elevation range is not an adequate measure of terrain severity in itself. A different measure, potentially including range of slope and aspect in combination with elevation range could give a better measure of terrain severity that would lead to clearer results.

The conversion of data for the GRASS-Idrisi viewshed comparison involves rounding of all elevation values. This reduces the DEM's small-scale variation in elevation and may partly explain why the ArcMap - Idrisi comparison seems more sensitive to severity. A data source compatible with all three viewshed algorithms could be used to resolve this question.

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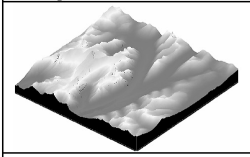
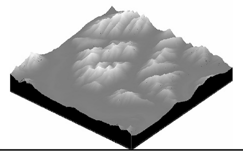
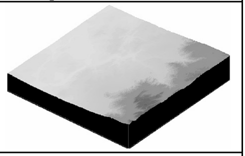
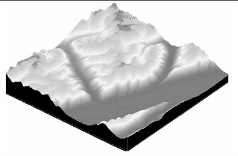
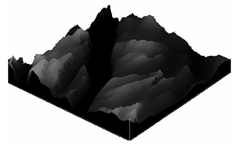
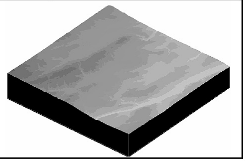
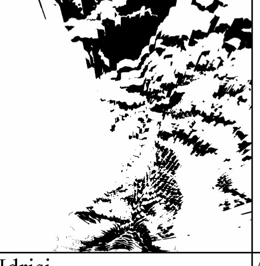
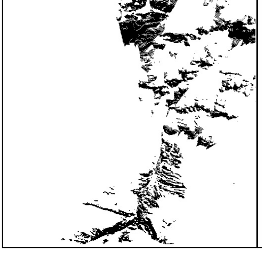
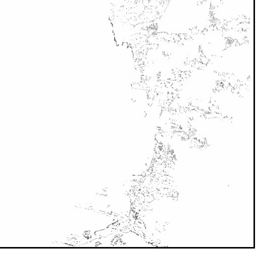
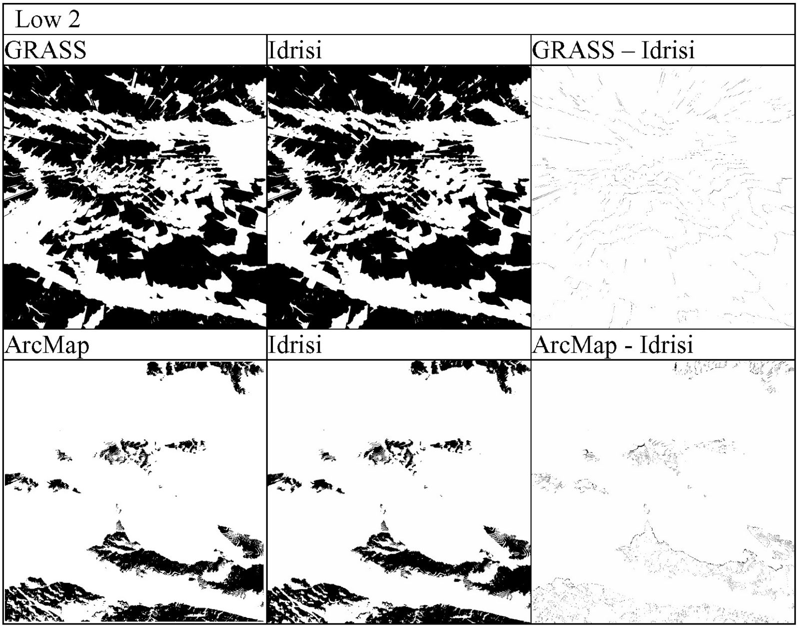
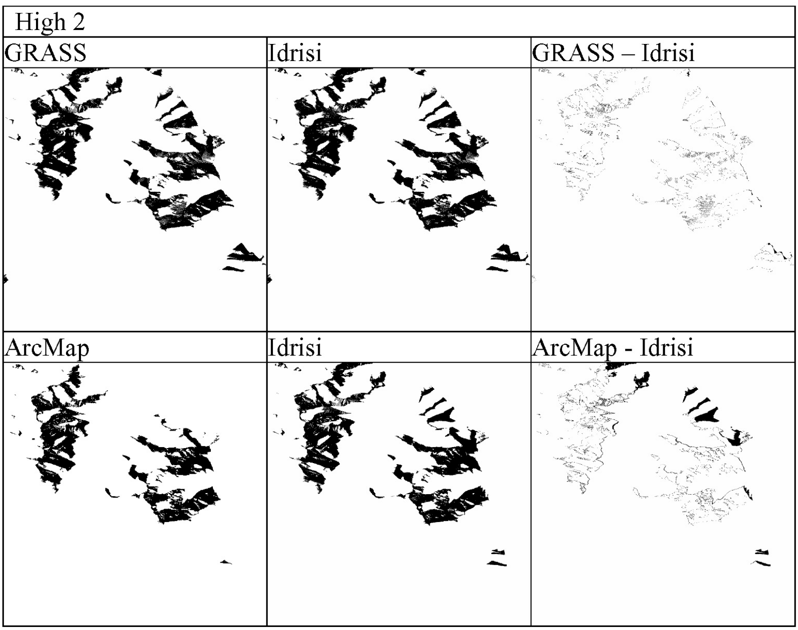
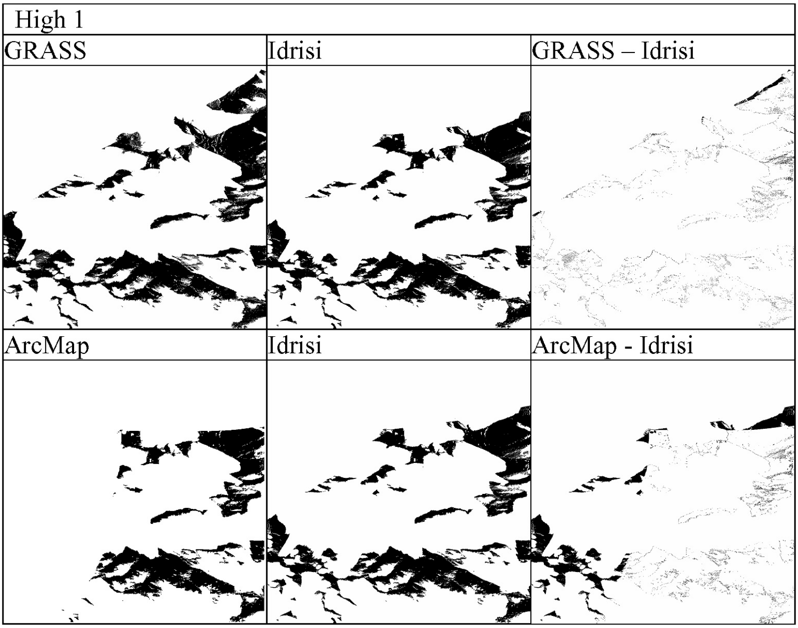
Appendix A

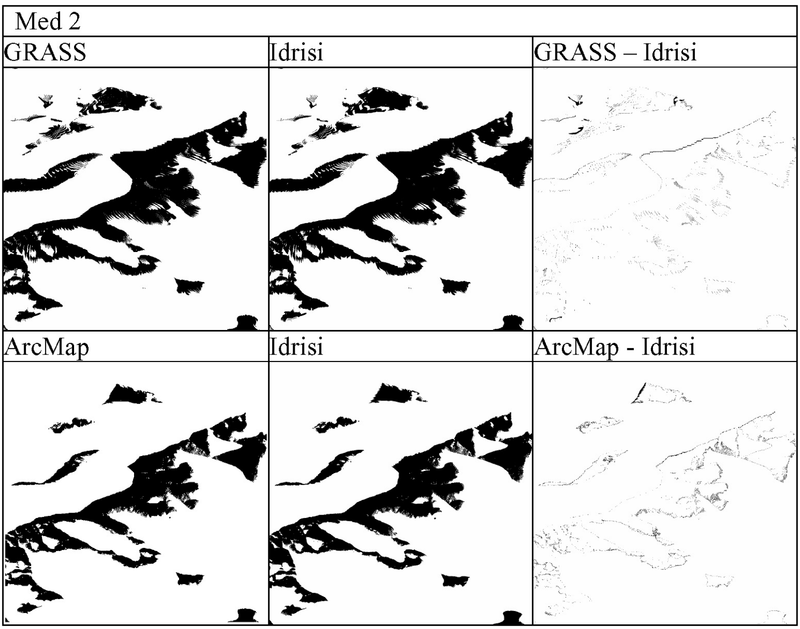
High 1	Med 1	Low 1
Range: 2365 meters	Range: 1340 meters	Range: 441 meters
		
High 2	Med 2	Low 2
Range: 2249 meters	Range: 1042 meters	Range: 168 meters
		

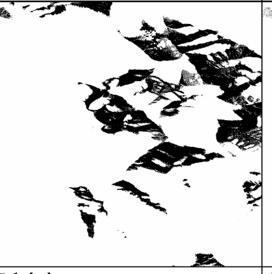
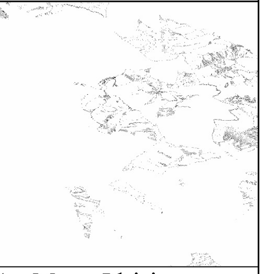
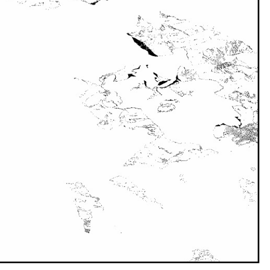
Low 1		
GRASS	Idrisi	GRASS – Idrisi
		
ArcMap	Idrisi	ArcMap – Idrisi
		


Low 2
GRASS
Idrisi
GRASS – Idrisi
ArcMap
Idrisi
ArcMap - Idrisi


High 2
GRASS
Idrisi
GRASS – Idrisi
ArcMap
Idrisi
ArcMap - Idrisi


High 1
GRASS
Idrisi
GRASS – Idrisi
ArcMap
Idrisi
ArcMap - Idrisi


Med 2
GRASS
Idrisi
GRASS – Idrisi
ArcMap
Idrisi
ArcMap - Idrisi

Med 1		
GRASS	Idrisi	GRASS – Idrisi
		
ArcMap	Idrisi	ArcMap - Idrisi
		

A Virtual Heritage Centre for Rome

The city of Rome is recently interested by a strongly dynamic phase, for what concerns the use of Information Technology (IT) applied to the management of cultural heritage. In this note the main players and general aim will be briefly described.

The players

In 2004 the **Municipality of Rome** has promoted a feasibility study for the creation of a Virtual Heritage Centre, that should be deployed in three steps. After the feasibility study, delivered in October 2004, an international exhibition gathering the best applications of digital technologies applied to the Roman civilization is planned for the fall 2005 (15^{th} of September to 15^{th} of November). Finally, a permanent centre should be created at the beginning of 2006 in the Imperial Fora, for providing visitors with a highly technological support in their cultural experience of Rome. This project will make use of state-of-art technologies like virtual reality reconstructions, artificial intelligence for the management of conceptual knowledge, advanced user profiling techniques for delivering the right type of content to individual visitors, together with the use of wireless networks and devices for allowing a contextualized fruition in motion.

The **COTEC** foundation, created in Spain under the auspices of King Juan Carlos, aims at stimulating the technological innovation of enterprises. The Italian branch of COTEC, that provides the higher institutional level (the president is, since October 2004, Carlo Azeglio Ciampi, President of the Republic of Italy) has recently promoted the realization of an Observatory on digital technologies applied to cultural heritage. The COTEC foundation intends to represent an institutional point of reference for the definition of policies for innovating the cultural heritage sector. The first concrete action consists in the publication of a white book, that should work as a pointer to a web portal for stimulating the aggregation of a new community and defining new synergies between researchers from different fields (archaeology, computer science, economics, marketing, etc.), public administrations (at local and national level), enterprises, and final users.

FILAS is the Financial Investment Agency of the Regione Lazio, founded in 1974 to foster the development of innovative business practices in Lazio region enterprises. FILAS manages measures to promote technologically advanced services in SMEs and identifies standards, solutions and common technological platforms to devise programmes for specific sectors. Furthermore FILAS promotes relations between research and industry in Lazio and stimulates entrepreneurship through the development of innovative models – as well as models that have proved successful in the most advanced European countries – in order to promote start-ups and new entrepreneurial activities through venture capital and other forms of financing. FILAS sustains and strengthens new initiatives capable of creating added value and new employment through financial support and managerial know-how and participates in the definition of new services for citizens and enterprises by bringing local authorities, research institutions and enterprises closer together. FILAS is a key component of this scenario as it has decided to support the definition of a multi-regional model for the creation of cultural districts and education activities, aimed at producing the new, interdisciplinary skills required for implementing innovative content, services, business models for the heritage sector.

The outlined scenario looks very promising and Rome can become a laboratory for the design, testing and deploy of new ways of conceiving the management of cultural heritage contents and resources.

The overall aim

The objective of the outlined synergy is to produce a blueprint for a European multi-regional infrastructure characterised by a tight cooperation between public administration, academia, and the industrial sector. Such cooperation is vital for designing new ways of managing cultural heritage, making extensive use of digital technologies and emerging economic models. At present, in fact, the heritage management is still at a very immature stage, due to lack of entrepreneurial skills that characterise cultural resources' managers.

The interaction with enterprises is considered fundamental for designing educational paths closer to requirements of the heritage sector. In particular, the following projects will be developed:

– **Observatory on digital technologies applied to cultural heritage**. The Observatory, promoted by COTEC, is designed for providing a benchmarking with the objective of extracting best practices on technologies and management models for the cultural heritage.
– **White Book**. The first practical activity of the Observatory is the annual edition of a White Book. This initiative, thought as a space for monitoring, evaluating, and discussing, rather than a simple paperwork, should allow to trigger a systematic debate on a fruitful use of digital technologies and management models for the valorisation of the cultural heritage.
– **Web Portal**. For its intrinsic nature, a book presents strong limitations, e.g. the impossibility to transmit multimedia contents; therefore, it has been decided to design the White Book as a pointer to a web portal. The project is divided in three phases, the first of which is tightly connected to the publication of the White Book, while the following should support the creation of a community of reference. Such community should gather users from a wide spectrum of backgrounds like arts, economics, IT, marketing, to name but a few, that today do not have opportunities to meet and exchange information and experiences, or to share activities and projects.
– **Virtual Heritage Centre**. Besides the mentioned initiatives, a permanent centre is planned for promoting further areas of development. Among those we can list:

– *Communication*. It is necessary to design user-cultural offer interaction models that insure user satisfaction providing contents and services starting from a suitable segmentation of user profiles.
– *Cultural Districts*. It is vital to activate infrastructures for enabling cooperation and promote synergies, involving the industrial sector, for allowing smaller or scattered entities to reach a sufficient weight to undertake innovation processes.
– *Training*. A particularly delicate and relevant aspect consists in the design of new educational paths, deriving from the interaction with enterprises operating in the domain, with the aim of producing skills required by the market.

The integration of all mentioned activities should provide a template to be proposed to other countries after testing and deployment in Italy.

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Computer Applications and Quantitative Methods in Archaeology UK Chapter University of Southampton - UK, 20-21 January 2005

The CAA UK 2005 Chapter Meeting was held in the Department of Archaeology at the University of Southampton in January. Attendance was high, with more than 80 delegates representing a broad spectrum of archaeological computation, including field units and other members of the commercial sector, university departments, regional and national bodies.

Papers were similarly diverse, considering such areas as XML-based data management and presentation tools, graphics and visualisation, theory and the place of computation, standards and data capture. A number of EPOCH showcases were also presented during the two day meeting.

On the first day of the meeting (Heritage Management and Public Presentation), the following papers were presented: R.J. Legg, *Environmental influences on the distribution of ring forts in Ireland*. S.D. Stead, *The CIDOC CRM*. J. Mitcham, *Somewhere between black and white - Grey literature and the OASIS project*. R. Gant, *Real world use of XML, XSLT and Web services in archaeology*. V. Ivrou and I.-A. Kotopoulos, *Towards a common approach for describing archaeological data*. A. Smith, B. Fuchs and L. Isaksen, *Virtual Lightbox for Museums and Archives (VLMA)*. M. Sifniotis and M. White, *Uncertainty in archaeological reconstructions: A 3D gaming approach*. M. White, P. Petridis and M. Sifniotis, *Augmented representation for cultural objects*. R.J. Legg, *Tools for stratigraphic data recording*. K.D. Strutt, *Using conventional geophysical survey techniques in an urban context: Survey at the Plaza de la Encarnación, Seville*. P. Cripps, *'Archaeological tower blocks' – computational and theoretical ghettos*.

On the second day of the meeting (Research Computation) the following papers were presented: T.R. McLaughlin, *Palaeodiet on the cusp: engaging dental microwear data using R and SQL*. K. Davison, P. Dolukhanov, G. Sarson and A. Shukurov, *Spatial modelling of Neolithic dispersal in a non-uniform environment*. E. de Gaetano, *The analysis of movement through space using two and three-dimensional techniques: A case study from southern Spain*. P. Cripps, *Visibility analysis in the Stonehenge and Avebury world heritage site*. U. Rajala, *Digging digitally tombs - pros and cons of digital documentation at Crustumerium (Rome, Italy)*. V. Gaffney, *Remote Sensing and the HP Visual and Spatial Technology Centre at Birmingham (UK)*. M. Addis, *Creating, searching and navigating multimedia collections in cultural heritage*. P. Rauxloh, *Interrogating a Medieval cemetery: GIS aids to interpretation*. T.A. Goskar, *Visualising 3D laser scans*. P. Longhurst and A. Chalmers, *Recent laser scanning work in South Africa and Libya*. I. Trinks, M. Díaz-Andreu, R. Hobbs, A. Blanshard, K. Sharpe, *Visualising archaeological rock art using 3D laser scanner data*. A. Carty, *Research?*.

Details of papers presented can be found at: http://www.caauk.org/. Discussion during and subsequent to the conference was fruitful, and we all look forward to the development of collaborative research resulting from it. The CAA UK 2006 Chapter Meeting will be announced in October, with details disseminated via the website.

CAA UK Organising Committee
Department of Archaeology
University of Southampton UK

Forthcoming conferences

Heritage Impact 2005: Socio-Economic Impact in Cultural Heritage

Brighton, UK. July 7th-8th

For information visit: `http://www.brighton.ac.uk/bbs/heritageimpact/index.php?page=programme`

DRH 2005: Digital Resources for the Humanities

Lancaster, UK. September 4th-7th

For information visit: `http://www.drh.org.uk`

UbiComp 2005: The Seventh International Conference on Ubiquitous Computing

Tokyo, Japan. September 11th-14th

For information visit: `http://ubicomp.org/ubicomp2005`

XX CIPA (International Committee for Architectural Photogrammetry): Symposium - International Cooperation to Save the World's Cultural Heritage

Torino, Italy. September 27th-October 1st

For information visit: `http://www.cipatorino2005.org`

VSMM 2005: The 11th International Conference on Virtual Systems and Multimedia

Ghent, Belgium. October 3rd-7th

For information visit: `http://www.vsmm.org`

International Conference on Computer Animation and Social Agents

Hong Kong, Japan. October 17th-19th

For information visit: `http://www4.comp.polyu.edu.hk/~casa2005/index.cgi`

CoDaWork'05 – the 2nd Compositional Data Analysis Workshop

Girona, Spain. October 19th - 21st

For information visit: `http://ima.udg.es/Activitats/CoDaWork05`

DIGITS FUGIT! Preserving Knowledge into the Future
33rd Annual Museum Computer Network Conference

Boston, Massachusetts, US. November 2nd - 5th

For information visit: `http://www.mcn.edu/Mcn2005/mcn2005index.htm`

International Congress "Cultural Heritage and New Technologies"
Workshop 10 "Archäologie & Computer"

Vienna, Austria. November 7th - 10th

For information visit: `http://www.stadtarchaeologie.at`

New books

Radiocarbon and Archaeology: Fourth International Symposium, St Catherine's College, Oxford (9-14th April 2002). Edited by T. Higham, C. Bronk Ramsey and C. Owen. Oxford University School of Archaeology, Monograph 62, 2004.

New Frontiers of Archaeological Research. Languages, Communication, Information Technology. Archeologia e Calcolatori, 15, 2004. Edited by P. Moscati (http://soi.cnr.it/archcalc/indice/iyear.htm).

The Future Digital Heritage Space. DigiCULT Thematic Issue 7. December 2004. Edited by G. Geser and J. Pereira (http://www.digicult.info/pages/themiss.php).

Core Technologies for the Cultural and Scientific Heritage Sector. DigiCULT Technology Watch Report 3. January 2005. Edited by S. Ross, M. Donnelly, M. Dobreva, D. Abbott, A. McHugh and A. Rusbridge (http://www.digicult.info/downloads/TWR3-lowres.pdf).

Predictive Modelling for Archaeological Heritage Management: A Research Agenda. Edited by M. van Leusen, M. and H. Kamermans, Nederlandse Archeologische Rapporten 29. Amersfoort, ROB, 2005.

Interdisciplinarity or the Best of Both Worlds. The Grand Challenge for Cultural Heritage Informatics in the 21st Century. Selected papers from VAST2004. Edited by K. Cain, Y. Chrysanthou, F. Niccolucci, D. Pletinckx, N. Silberman (http://www.epoch-net.org/?sid=&wsid=2&rub=338&lg=1).

Digging Numbers: Elementary Statistics for Archaeologists, Second edition. Edited by M. Fletcher and G. Lock. Oxford University School of Archaeology, second edition, forthcoming 2005.