Setting up a “Human Calibrated” Anisotropic Cost Surface for Archaeological Landscape Investigation

Michele De Silva and Giovanna Pizziolo

Dipartimento di Studi Storici e Geografici, Univesità degli studi di Firenze

Via S. Gallo 10, 50129 Firenze, Italy

e-mails: mdesilva@unifi.it, gpizziolo@unifi.it

Abstract

This paper presents an application of GIS tools for investigating one aspect of the archaeological landscape: movement through it. The authors would like to provide an experimental procedure to obtain cost surfaces related to human movement in a given geographical area, taking into consideration a settlement perspective. This research mainly focuses on the insertion of the concept of round trip movement from a given location in a calculation of cost surface through the adaptation of one function - available in the literature - related to human energy cost. After the explication of the procedure, the results and possible implications of this application are discussed using the Biferno Valley (Molise, Italy) as a case study.

Key words: GIS, cost distance, landscape archaeology, Prehistoric settlement, Neolithic, Molise

1. Introduction, research background and context

The context of this research lies within the landscape archaeology framework and it aims at investigating relationships between past human communities, their places and landscape in which they lived. Since spatial analysis was applied in archaeology, a number of different questions have arisen as regards a more in depth understanding of the relationship between archaeological sites and their contexts. Attention has been paid to methodologies which may evaluate this relationship. Within this framework, GIS applications have strongly participated in the development of Landscape Archaeology analysis, building up solutions on a cell based model, focusing on exploring different issues. These have been aimed at analysing natural resources related to site location and settlement pattern (e.g. Gaffney et al. 1995, Saile and Zimmerman 1996, Verhagen 1995), accessibility and mobility through the landscape and land subdivisions (Lock and Stančič 1995) or the influence of what is visible or perceivable in the landscape (Wheatley 1993, 1995, Llobera 1996). Based on various theories, different investigations have been undertaken, leading to a processual and post-processual debate (still currently underway) in which environmental or cognitive determinism is highlighted as an ever present risk (Van Leusen 1999). The interaction between several features of archaeological sites and the landscape which contain them has been explored in an attempt to understand the role, extension, position and other characteristics of areas surrounding -or (somehow) related to- past settlements. A wide range of elements play a role in the definitions of these portions of landscape. They may be either cultural and social elements -such as taboos, social relations at an inter and intra site level, sacred landscapes etc.- or natural elements, such as natural obstacles (slopes, streams and rivers, deserted areas), vegetation types, soil types, landscape morphology which constitute a process of complex interaction (Ingold 1986, Tilley 1994).

Despite this complexity, we can attempt to carry on landscape investigations through the use of GIS tools. In fact the GIS structure enables the correlation (and overlay) of data leading to possible comparison between different approaches, variables of a different nature and results (Stančič and Kvamme 1999). Indeed, through analyses which appreciate multiple interactions between different variables, ranging in qualitative and spatial aspects, it is possible to attempt a reconstruction of the landscape through a global approach. Consequently, if we desire to investigate a landscape archaeological theme e.g. the accessibility and use of areas related to archaeological sites, we have to confront more than one variable which are likely to be of different natures. Bearing this complexity in mind, investigations regarding what can be called an area of pertinence or interest on a site at a local scale could move from a “settlement” point of view to a territorial and landscape perspective. From among the range of variables participating in the process of interaction between communities and their territories, this work only focuses upon only one.

A particular emphasis is given to the role that movement can play in the interaction between settlements and the landscape. One may analyse movement according to different approaches but in this study our aims focus upon exploring human mobility through the landscape taking into consideration its topography in order to build up a human calibrated cost distance in relation to the slope. Thus we would like to focus upon only one of the themes related to the wide range of elements which may influence a complex human behaviour such as human mobility through the landscape.

At this experimental stage, our attention has been particularly oriented towards the methodological aspect of this issue. We then subsequently tested the methodology in different archaeological and geographical contexts.

We do not intend to propose an outright solution to the problem but simply to contribute to the methodological debate with regard to cost distance providing the setting up of a variable which can be taken into consideration during the investigation of the formation processes of settlement/landscape interactions.

2. Moving across the landscape

2.1. Setting up a framework

As we have briefly mentioned above, a range of variables should be evaluated if we are to deal with the role of movement on the perception of ancient human landscapes. This current work analyses movement from an energy consuming physical point of view, without evaluating other cultural, social or perceptive aspects which, as we know, may characterise or influence movement through space or any eventual choice of itinerary. In fact, what is considered nearby and/or easily reachable from the point of view of physical effort is not necessarily so from a social perspective. Nevertheless we believe that an evaluation of the cost of moving may provide information and additional data sets that may be subsequently compared with other kinds of variables thus constituting further discussion, and whether positive or negative key, for an interpretation of the archaeological landscape sets. In any case, within this physical framework we have introduced a cultural perspective in order to build up a model which takes into consideration one of the human needs within a settlement context. In particular we have chosen to modify the cost distance module provided by GIS software in order to be able to evaluate a variable which could be significant in a landscape archaeology investigation.

2.2. Problems of friction

Movement across space is hindered by friction. In the initial stages we can assess that from a physical point of view the natural features which may influence human movement in terms of friction can be divided into two categories: isotropic friction (i.e. independent of the direction of movement) such as vegetation density, soil types, wet or snowy areas etc. and anisotropic friction (i.e. dependent on the direction of movement) such as slope or streams. In this paper, we focus on the latter and we particularly explore how the topography of the landscape acts as anisotropic friction to movement. This work has been developed following the procedural structure provided by the software Idrisi for Windows (Eastman 1997).

It is possible to assess that the direction of movement crossing a slope does influence the intensity of friction with which one is faced. In fact, if we consider a person walking up a hill, along the line of maximum slope, they will be subject to the maximum friction, in other words friction acting at its fullest; on the other hand, if we consider a movement across the hillside the slope will, to some extent, not influence the friction which could be evaluated in terms of movement along a plain ground (figure 1).

2.3. One way movement and round trip movement

Generally, in cost distance analyses, movement is considered a one way direction, but if we are dealing with settlements, inhabited by a community, we must presume that some return trips will have to take place, perhaps in the context of daily movements there and back. Therefore, we accordingly, have to calculate the cost of a round trip movement instead of just a one way journey on which the calculation model is based.

Thus, in a one way movement from a village located in the middle of a slope (figure 2), it costs less to reach the place located at a lower altitude in relation to the village (B in figure 2) then the places located at a higher altitude (A in figure 2). But in a round trip movement through the landscape we have to take into account that people have to return to their village. In other words, we can say that an upward movement implies in itself a downward movement and *vice versa*. In this case, the cost to reach and

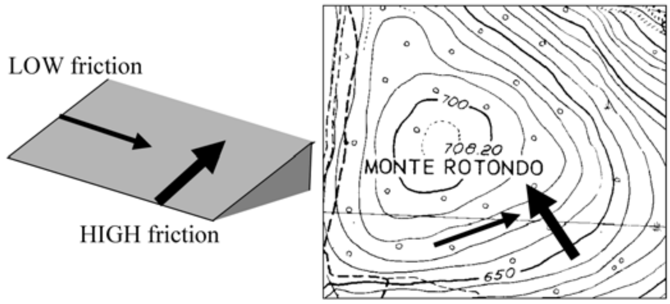

Figure 1: Topography acts as an anisotropic friction to movement, in fact friction intensity depends on the direction of movement.

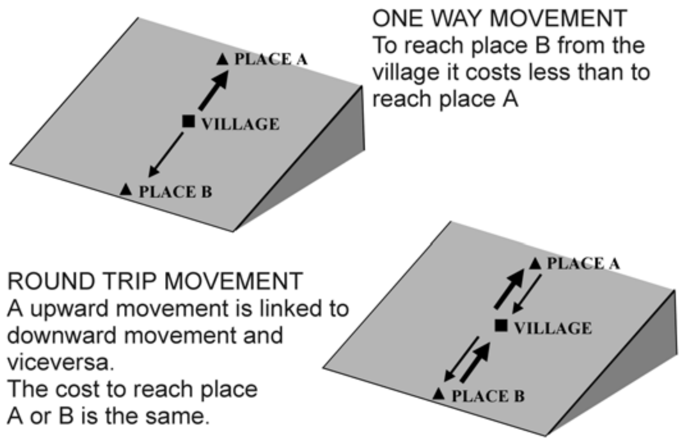

Figure 2: In the evaluation of cost to movement from a settlement we have to take into consideration a round trip movement.

come back from places at a higher or lower altitude is the same. From a settlement perspective it is clear that places at a lower altitude are not necessarily in a favourable position in relation to the village. In fact upon returning to the settlement the friction due to movement is no longer advantageous especially if one is laden down with goods to bring home.

3. Building up a cost surface related to round trip movement

3.1. Basic steps

In order to build up a cost surface related to topography, using modules provided by Idrisi for Windows, we have to follow certain steps listed below:

1. build up a Friction Surface, in other words, an image which expresses the maximum friction exerted by each portion of landscape,
2. build up a Friction Direction Surface which is a layer that expresses in which direction the movement is subject to maximum friction,
3. formulate an algorithm to describe how friction changes in relation to the direction of movement,
4. define a set of one or more sites, for instance prehistoric settlements, from which to calculate the cost surface.

3.2. Step one: The friction surface

A Friction surface is a grid in which each pixel expresses the maximum friction factor determined by the slope in relation to a friction unit measure.

Friction Surface is derived from a slope surface although it is not exactly the same. Let us give an example. A pixel that expresses a slope value equal to 20% does not have a friction value increased by 20% as opposed to a pixel on the plain ground. It is, therefore, necessary to find the relation between slope and friction. Let us assume that the unit measure (the base cost) is the cost necessary to cross a pixel on the plain ground and it is equal to one. In our cost model, friction is expressed in terms of relative friction, using the base cost as a reference. For example, if it takes 100 calories to cover a given distance on a plain ground, and 200 calories to cover the same horizontal distance on a given slope, we may indicate that the slope has a friction of 2 (Eastman 1997:15-2).

We, therefore, have to find a function to obtain a friction surface derived from a slope surface.

3.2.1. Choosing a function to represent human effort in movement

How does the effort in movement in relation to slope change when we consider people walking through the landscape?

We have to find a function which expresses the relationship between slope and effort or "cost" in terms of energy consumption. A variety of functions are available in literature (Van Leusen 1999) although attempts are currently underway to find a more appropriate and all purpose definition. Different studies to model and measure the human cost of movement are undertaken in relation to time and energy consumption.

It is not the aim of this paper to discuss either the reliability of these formulas or which ones may provide more accurate and likely models. We are, however, more interested in evaluating the possible development of a procedure which takes advantage of using one of these functions. In particular, the authors would like to test the forming of an anisotropic cost surface in relation to topography according to human behaviour in a settlement perspective (i.e. going away and coming back) realised through the adoption of a formula based on the physical effort in movement. Due to the experimental phase of this work, attention has been focused on the mathematical aspect of the formula, choosing the one that fits better into our working framework. At a future stage of research, a specific study on the best function to be adopted will be undertaken.

Thus, we can initially try to adopt the function suggested by Ericson and Goldstein (1980:23-24) to calculate the cost distance along a route in relation to a linear path, in which:

Work (i.e. moving in a particular direction) is equal to:

horizontal distance + (3.168 * distance up) +

+ (1.2 * vertical distance down)

We would like to stress here that this function has not been adopted on the basis that we believe it to be the best or the most realistic, but simply because it fits best into our working framework in this experimental phase.

3.2.2. Adapting the Ericson and Goldstein's function to a raster grid related to round trip movement

The function presented above has been developed in relation to the movement of walking along a line, but since we are dealing with landscapes and according to our framework, we have to take into consideration surfaces instead of lines expressing linear movement. We therefore have to adapt this function to a raster grid. The first stage regards the difference in height calculated for a surface. Assuming 1 pixel to be a unit measure, we can directly work out the difference in height for every pixel from the slope surface expressed as a percentage.

For instance, a pixel with a slope of 20% represents a difference in height equal to 0.2.

For every pixel along the line of maximum slope we have:

Friction Factor going upwards is equal to

1 + (3.168 * the slope as percentage)

and

Friction Factor going downwards is equal to:

1 + (1.2 * the slope as percentage)

Now we have obtained two maximum friction surfaces: one to cross every pixel upwards and one to cross every pixel in a downward direction.

When we are dealing with our cost determination we have to take into consideration that in a return journey a man in movement crosses plain and sloping areas. Therefore, each individual segment, which is not in a plain position, will be alternately crossed once in the upward slope and once in the downward slope. We can, subsequently, evaluate their cost (and thus their friction) as if the surface were crossed once in the upward slope and once in the downwards slope along the maximum slope lines.

Friction factor for a round trip is equal to:

1/2 [1+(3.168*the slope as percentage)+

+1+(1.2*the slope as percentage)]

As we can see above the average of the friction factors of these two surfaces constitute the maximum friction surface for a round trip.

3.3. Step two: The friction direction surface

Now we have to evaluate the direction of frictions.

The friction direction surface expresses the direction (in terms of azimuth) of movement which would incur the greatest cost to movement, in other words, the opposite of the maximum slope direction (figure 3). As a consequence, we can derive the friction direction surface from the slope direction surface.

3.4. Step three: Setting up the algorithm

How does the effective friction and its cost to movement change in relation to the direction of movement?

The "effective friction" to movement depends on the difference between the direction expressed by the friction direction surface and the direction of movement. The angle between the direction of movement which incurs the maximum friction and the direction under consideration will be called $\Delta \alpha$.

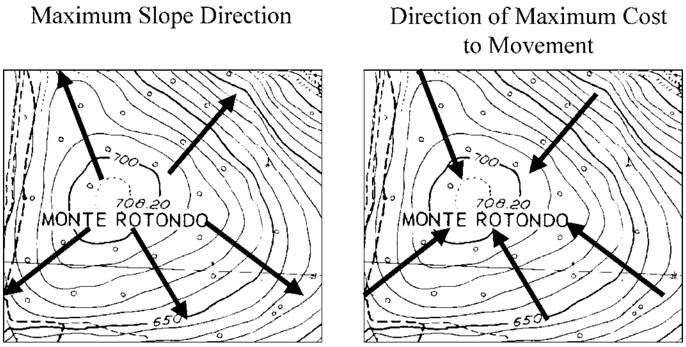

Figure 3: The direction of the maximum cost to movement is the opposite of the maximum slope direction.

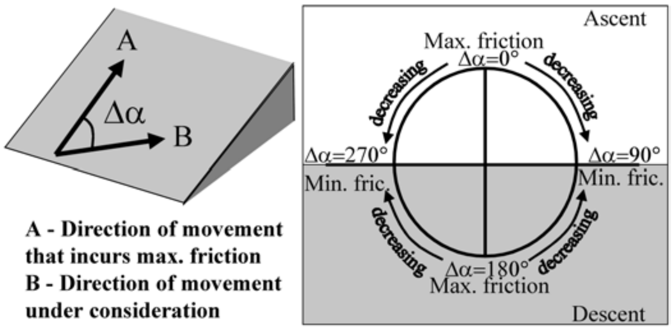

Figure 4: Assessment of how the effective friction changes in relation to the direction of movement.

In a one way trip we will have friction related to ascent that acts fully for $\Delta\alpha$ equal to zero progressively decreasing until reaching the minimum friction (i.e. horizontal plane) for $\Delta\alpha$ equal to 90° and 270°. Instead, the friction related to descent acts fully for $\Delta\alpha$ equal to 180° progressively decreasing till the minimum friction for $\Delta\alpha$ equal to 90° and 270° (figure 4).

But our "stated friction" i.e. the friction factor expressed by our friction surface, is calculated as the mean friction for a round trip.

In other words, the friction surface expresses the mean friction of each pixel along the line of maximum slope for a round trip (stated friction).

As a consequence, the effective friction has to be the same for the ascent and for the descent.

In order to satisfy our assumption, we have modified the default anisotropic function used by the module VARCOST provided by Idrisi. In fact, this algorithm evaluates friction for descent to be less than plane ground friction, that is to say as a force, and this is opposed to our above described assumptions.

The anisotropic function that we have used is the following:

effective friction = stated friction$^{|f|}$

where $f = \cos^k \Delta\alpha$
k = user defined coefficient (for a movement on foot we have chosen k = 2)
$\Delta\alpha$ = difference angle between the direction of movement that incurs the maximum friction and the direction of movement being considered.

3.5. Step four: Defining a set of points

As we have mentioned above, in order to calculate the cost surface we need a set of points from which we presume that the movement starts. Particular attention has to be paid to the choice of one or more sites from which to calculate the cost distance. If we choose more than one site it is necessary to operate a classification in order to compare homogeneous sites, especially if we are interested in defining a sort of accessibility catchment. In other words, it does not make sense to globally consider all archaeological evidence such as settlements, camp-site and off-site, artefact scatter etc. and then to investigate their reciprocal area of influence as if they played the same role in the landscape. Instead, it is fundamental to first of all set up the research goals and only then undertake the analyses. In order to obtain consistent results it is therefore necessary to stream the archaeological evidence through a classification process according to context specific criteria.

Once we have undertaken the above mentioned four steps, we can finally use an anisotropic cost distance module (in this case VARCOST provided by Idrisi for Windows) and build up a "human calibrated" cost surface related to orography.

4. Application to case studies

Once the procedure is set, we can then apply it to specific archaeological landscapes. However, it is important to remember that this cost distance due to topography may provide just one - and probably not the most important - of the variables which participate in the shaping of the human behaviour in and through the landscape. It is, therefore, necessary to integrate these results with the ones obtained from different analyses.

So far our applications have been oriented to assessing the reliability of the procedure and in evaluating its routine problems. After this phase some variation of the procedure will be attempted in order to further calibrate it.

This analytical methodology has been tested in three different archaeological contexts: Neolithic sites in the Biferno Valley (Central Italy), Calcolithic sites in Wadi Ram area (Southern Jordan) and Neolithic sites in the Altoribatejo area (Central Portugal). We have chosen contexts which are mainly related to the Neolithic culture as it is very stimulating for a settlement perspective implication. In fact, we may explore the interaction with landscape in a phase in which the concept of territory may be modified by new needs of the established communities. Needs related to round trip movements may likely become substantial when permanent activities are undertaken somewhere. In other words, in a "local to territory" perspective, movement linked to every day activities may be influenced by the "round trip" idea.

4.1. A case study in the Biferno Valley

4.1.1. Geographical context

The procedure developed so far has been applied to the Biferno Valley archaeological context, and in particular to the area surrounding the territory of Larino (Campobasso, Molise). The area selected is one of the ending structures of the Biferno lower basin and it constitutes a sort of geographical unit located on the right hand side of the valley. This area offers a range of morphological variations of hills and floodplains varying from heights of 575 m down to 25 m above sea level. However, this study area is characterised by a hilly landscape devoid of any dramatic breaks. Here the effects of past modifications are not significantly extensive

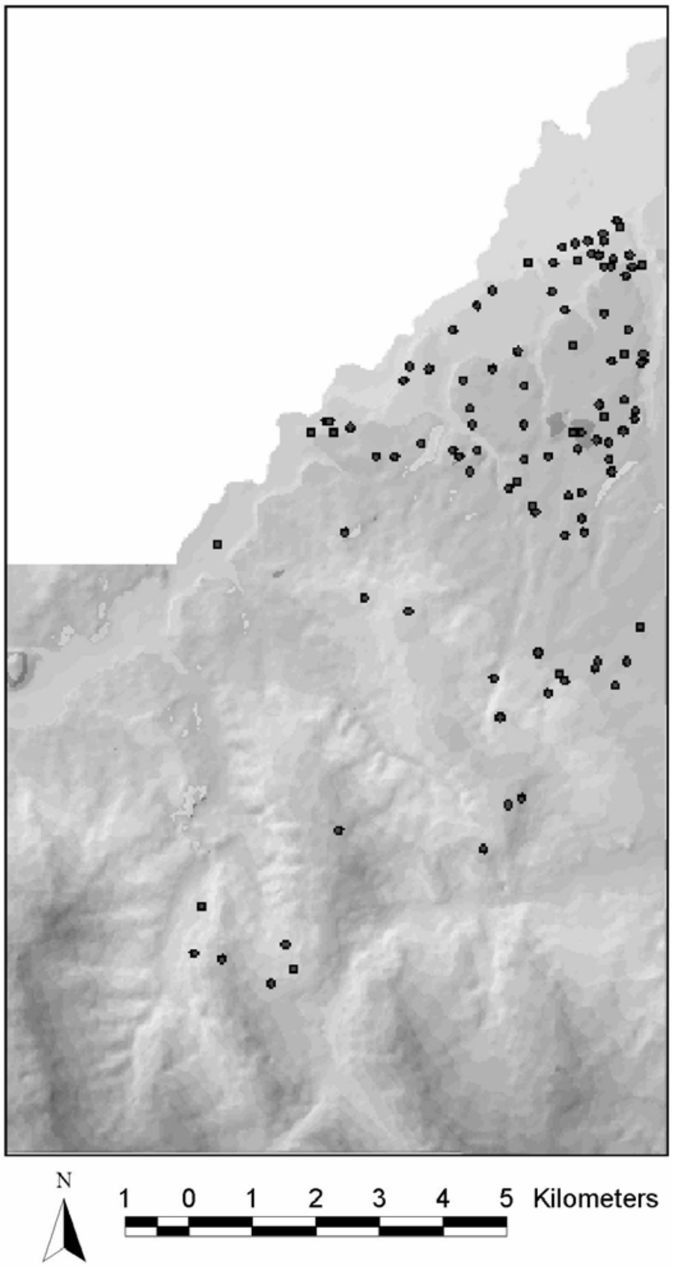

Figure 5: The geographical and archaeological context: the DEM and the distribution of Neolithic evidence.

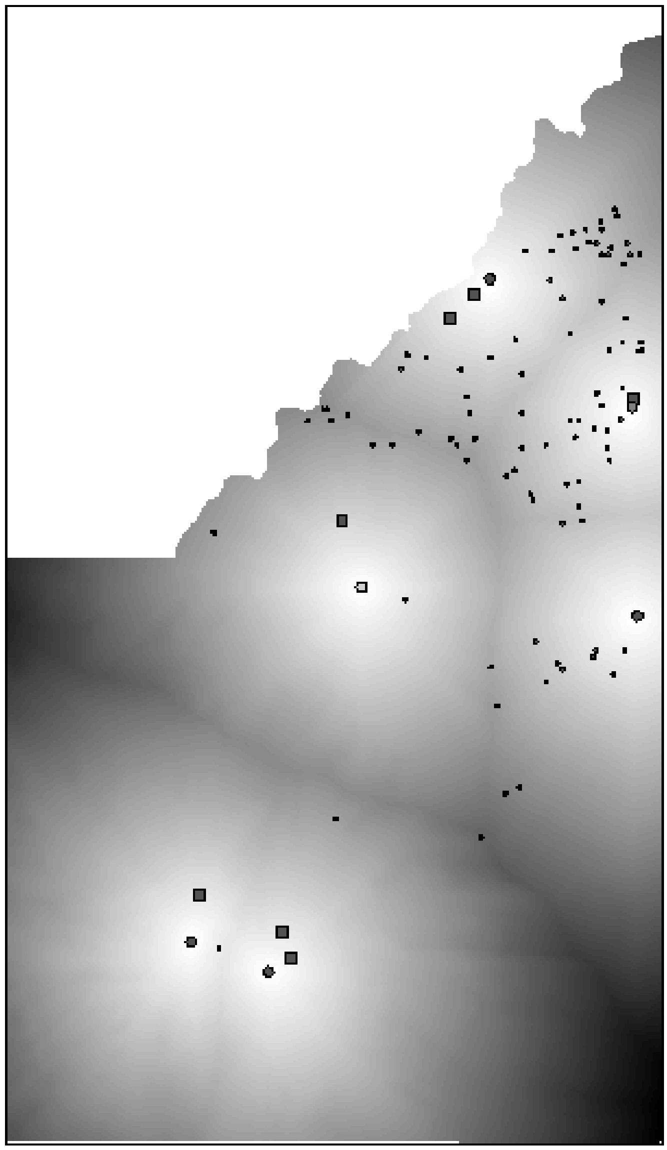

Figure 6: The cost distance surface calculated from the main Neolithic settlements (big dots in the map). Here it is visualised in a greyscale palette where the darkest tone represents the highest cost to movement.

(Barker 1995b:59) thus we can consider the morphology of the ancient landscape very similar to the actual one. By taking into consideration the study area we can observe an interesting variety of geomorphologic conditions. A DEM (figure 5) has been built originated from contour lines and spot heights derived from 1:25,000 scale topographic maps.

4.1.2. Archaeological context

As regards the archaeological context information has been derived from different sources (Barker 1995a, 1995b, De Felice 1994) resulting from systematic and non-systematic surveys conducted in the area. In the first stage a process of standardisation of archaeological data has been undertaken followed by a selection of prehistoric evidence. Then a classification of Neolithic sites has been carried out in terms of their rank, typology and chronology, taking into account the quantity, quality, type and density of archaeological evidence found in each site. As a consequence, we have streamed the sites into three categories of main settlements, associated settlements - in which evidence of domestic activities are less significant or less prosperous than the one in the main settlements - and off-sites (respectively represented as big dots, squares and small dots in the figures).

4.1.3. Building up a cost surface

Adopting the procedure described in the previous paragraphs we have produced, using Idrisi for Windows, the friction surfaces and consequently the cost distance surface. The latter has been built up from the set of the main Neolithic settlements (figure 6).

In this way the relationship between the different categories of sites has been explored in terms of cost distance. A membership subdivision has been carried out among the main sites, for each pixel establishing which is the nearest settlement in terms of cost. Furthermore, the maximum “cost consuming distance” between main settlements has been calculated. This test enables us to evalu-

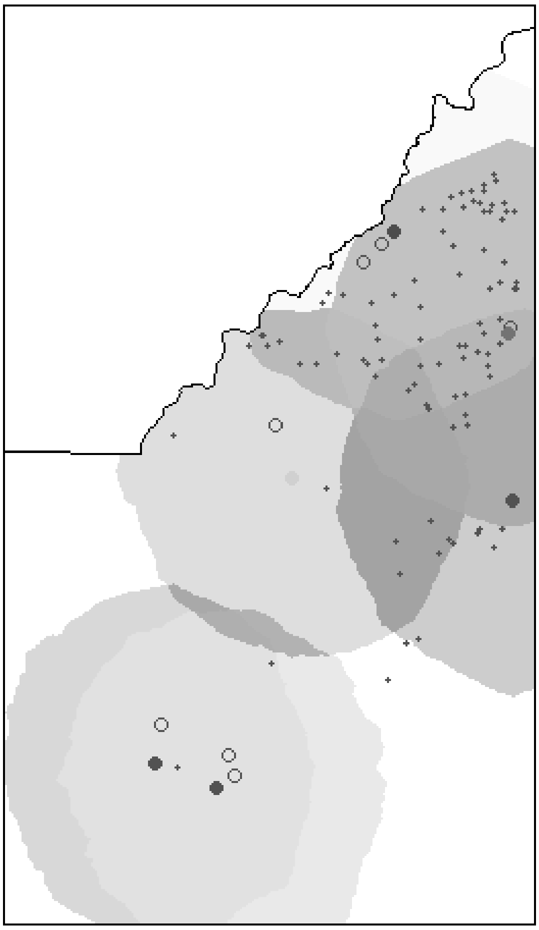

Figure 7: Cost distance buffers from the main settlements (filled dots) indicating areas reachable within a cost equivalent to the work necessary for a travel of 8 km (including a there and back journey) on plain ground.

ate a cost distance buffer for each of them (figure 7). The boundaries of buffers indicate the cost of movement equivalent to the work necessary for a travel of 8 km (including a there and back journey) on plain ground. The potential of their overlapping areas has then been explored. Subsequently, we have observed which parts of the landscape have an exclusive relationship with the settlements and which are shared by more than one. From the interpretation of this data compared with other information, we can imagine different possible scenarios. If all the settlements were of a similar rank and performed a similar territorial control, the hypothetical sharing of common areas would highlight the possible reciprocal negotiation of these small "tribes" (Alling Gregg 1987) over access to land, and/or the fact that their landscape might focus on different characteristics. On the contrary, in an alternative scenario the main settlements would play a different role over the landscape organisation and perception. The sharing of possible common territories would be planned by the main settlements and particularly exerted by the one located on the river terrace (i.e. the upper part of figure 7) in which occurred the longest and most substantial occupation. Other variables have been taken into consideration with regards to this hypothesis evaluating the presence of specific structures in the settlements, their intervisibility, the evidence of subsistence activities undertaken in the sites, the presence of artefact scatters in the hinterland of the settlements and the presence of specific geographical and morphological elements in the landscape. Regarding the latter elements we could also evaluate that despite their influence in the cost to movement they may also play a role in marking and perceiving land rights or spatial subdivisions of territories. As far as accessibility to natural resources it is quite possible that the inhabitants of the major settlement exploited the easily reachable area, represented by the soft and light soil of the river terraces, for agricultural purposes. However, it is not the aim of this paper to present a detailed report on all the different interpretations. We would simply like to present some of the problems and hypothetical interpretations connected to this application.

4.1.4. Least cost pathway

In this work the general agreement on the absence of stratified hierarchies in these first Neolithic communities has been taken into consideration. In fact our hypothetical scenarios do not deal with complex hierarchies but have only singled out a settlement located on the river terraces as the major one. Questions, therefore, arise pertinent to the investigation of the interaction between all types of archaeological evidence found in the area through the interpretative framework described in the above paragraph. Subsequently, we have attempted to analyse this issue from a movement perspective, highlighting the possible presence of itineraries or networks connecting the main sites with the major settlement. In order to investigate the reciprocal relationships between the latter and other settlements, a least cost pathway based on our cost surface has finally been calculated. The images, obtained using the module provided by Idrisi for Windows, have been performed for every main site connected to the major one and, subsequently, a sum of all the pathways has been obtained in one single image (figure 8). This highlights an interesting relationship between the position of the secondary settlements and their proximity to the least cost pathway. In other words, we can say that the pathways pass very close to the sites, or that the secondary sites are located along the least cost pathways that link the major Neolithic settlement to the main ones within the same area. Moreover, there is an interesting coincidence between two pathways connecting two main settlements to the major one. However, the interpretation of a settlement pattern or network cannot be based only on this kind of analysis notwithstanding this the above mentioned least cost pathway may constitute a source of information and provide stimulating ideas. The observations presented so far may help us to undertake further analyses and to further explore any potential in depth interpretations of the Neolithic Landscape.

5. Conclusions

We hope that this paper has succeeded in presenting some aspects related to our experimental work in its initial stages, aiming to offer further tools relevant to the exploring of the Prehistoric Landscape and in particular of the relationship between settlements and their area of interest.

In a research field as complex as this, we believe in the importance of a multivariate approach with the hope that it will lead to further investigation and potentially stimulating results.

Although we are still far from any global reconstruction of the past human landscape we can attempt to improve our understanding through a comparison and correlation of different approaches, but work is currently still underway.

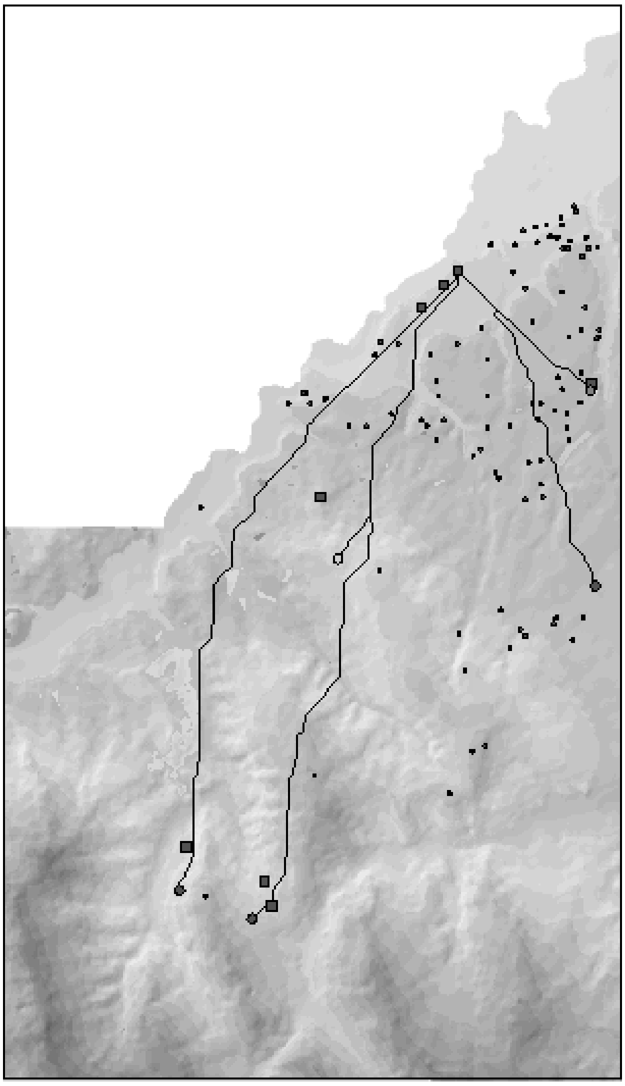

Figure 8: Least Cost Pathway (black line) connecting the major settlement located on the river terraces and the other main settlements (big dots). It is noticeable that the pathway passes by some associated settlements (squares).

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Note

This work has been carried out in full collaboration by the authors. In particular paragraph 1and 4 have to be attributed to Giovanna Pizziolo and paragraph 2 and 3 have to be attributed to Michele De Silva.