Settlement patterns modelling through Boolean overlays of social and environmental variables

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Abstract

Robust multivariate statistical methods frequently cannot be applied to model archaeological settlement distributions in contexts where the number of sites of certain types or periods is small. One alternative is to apply simple Boolean logic to combine variables that have been shown to have a bearing on settlement locations. This paper focuses on the modeling of archaeological settlement distributions through the use of simple Boolean overlays in GIS, a method that is by no means new. The sites investigated are a sample of Bronze Age hillforts from the island of Brac, in central Dalmatia, Croatia. What is new in this paper is that particular attention is paid to social variables as "predictors" of settlement location, a domain too frequently overlooked in modeling studies. A number of social variables are investigated and their importance is statistically tested. Of some importance, this paper does not sacrifice an environmental perspective at the same time, for multiple environmental correlates of settlement location are shown to exist as well. Consequently, this paper recognizes the importance of social and environmental domains to human location behavior and shows that models of high predictive power can only be achieved when variables from both domains are simultaneously considered.

1. Introduction and basic background

The main objective of this paper is to present and discuss performance of archaeological predictive modeling. Predictive models have a fairly long tradition in American archaeology. They have been intensively used for cultural resource management in USA. The main reason for their application is due to the fact, that American archaeologists are allowed to do archaeological surveys and excavations only on the state or federal owned lands. On the basis of very limited surface covered by archaeological prospection of the state or federal owned land predictive models were used to generalize the possibility for site locations on the wider areas (Allen et al.1990; Judge and Sebastien 1988; Kvamme 1992). Generally, the legislation which is determining archaeological field work in European countries is different and allows archaeologists to do their work easily on privately owned land.

Therefore, the applications of predictive modeling in Europe is very limited and often over simplistic. The second objective of this paper is to discuss how social variables could be incorporated into archaeological predictive model. Many similar applications in USA have been criticized that only natural environment data have been used in archaeological spatial analysis. We wanted to suggest several ways of quantifying social variables in the research and using the results in predicting archaeological site locations.

After the general description of the data and discussion of the data quality, a simple model for hillfort locations is presented. The advanced regression model for barrow locations follows with the discussion on their individual performance. In the final chapter modeling techniques are compared and general conclusions are drawn.

It is not within the scope of this paper to discuss in details theoretical approaches of predictive modeling. General, two different approaches can be defined: inductive and deductive. In the inductive model, one starts with the basic archaeological data and tries to build some conclusions based on this database. In the deductive approach one starts with the theoretical knowledge and understanding of archaeological data on the synthetically level and tries to deduce some conclusions on the logic of settlement patterns and land use in the past. More data on this issues can be found elsewhere, for example in Dalla Bona (1994). The technological problems when applying any of the above theoretical approaches should be briefly mentioned as well. Generally speaking, one can apply either techniques of the Boolean overlay of the variables for which it has been proved that they have in some way influenced location patterns or perform multivariate statistical regression. While the last approach is very powerful and gives a detail insight into the relationship between individual variables analyzed, regression analyses can perform only when the number of sites analyzed is large. Unfortunately this is not the case in many case studies, when the knowledge on land use or settlements is limited on several locations only.

2. Introduction in the study area and database

2.1.General introduction to the island of Brac

The data set used for the comparative analysis of different predictive modeling techniques and theoretical approaches was the one from the island of Brac in Central Dalmatia, Croatia. Central Dalmatian islands have been a subject of extensive field survey for more than a decade. The Adriatic Islands Project has conducted field surveys and excavations on several islands ranging from the small island of Palagruza in the center of Adriatic Sea through the islands of Solta, Vis, Hvar up to the largest island in the region, the island of Brac. The modeling techniques were tested on a part of the database of the island of Brac. In this part of the island there is a fairly large number of Bronze age hillforts so that one can expect that satisfactory statistical conclusions could be made when their locations are analyzed. It is also important to stress that islands are ideal for archaeological spatial analysis since they are well defined spatial entities where land territories can be easily established.

The island of Brac seemed to be very adequate for the kind of analysis we wanted to perform. The island of Brac is the largest of all Central Dalmatian islands and has a total surface of 395 km2. It is of elliptical shape with the longer axes oriented in the east-west direction and measuring around 36 km, while the shorter axis is 12 km long (figure 1). The entire Central Dalmatia is characterized by rather dramatical relief and Brac is no exception in that. The highest peak on Brac is Vidova gora measuring 778 m above sea level and is also the highest peak on all Adriatic islands. The geology of the island on the other hand is fairly monotonous. It is mostly comprised of cretaceous limestone and dolomite. Soft Eocene deposits can be found only in small areas on the southern coast, while quartar deposits can be found in most valleys and numerous karst dolinas. On these two geological basis the best soils were developed. The climate of the island can be described as a typical Mediterranean climate with mild winters and hot summers. Despite the island is fairly small there are some variations in the microclimate. First, because of the cold northern winds, the northern coast is a bit colder. The average summer temperature is 16 Co, however, the temperature drops for about 0.6 Co for every 100 meters of the elevation rise on the island. Similar impact has the relief on the precipitation, which are nearly all as rain. While on the western tip of the island the average rainfall is 799 mm per square meter yearly, in the highest locations with systematic measurements in Praznice 1320 mm of precipitation yearly is an average. Vegetation of the island is characterized by the black pine in the higher locations. Lower locations are often covered with the red pine or dense Mediterranean scrub. The best quality soils in alluvial valleys and dolinas are used for viticulture and agriculture, while many mild slopes are terraced and used for olive plantations. Due to intensive depopulation of the island which started at the end of the 19th century and continued till today, many fields have not been used for decades and are overgrown with the Mediterranean scrub.

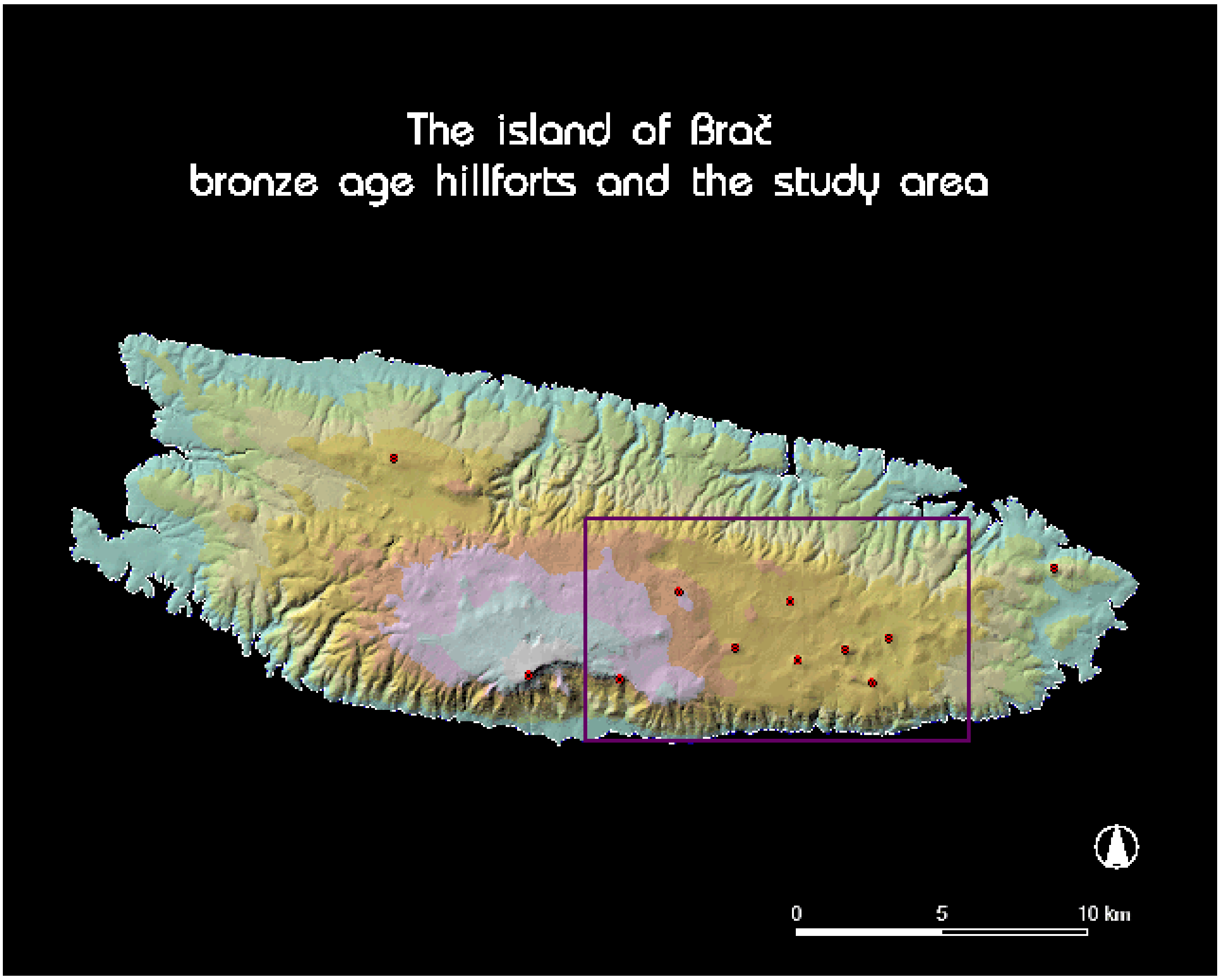

Figure 1: The island of Brac and the working area.

On the basis of relief, microclimate, vegetation, soils and geology, following physiographic regions can be defined: - coastland and low alluvial valleys, - intermediate hills with the western plateau at the Nerezisko polje, - higher hills with the upper eastern plateau between Praznice and Novo Selo. It seems that each of these physiographic regions attracted different human activities. Coastland and alluvial valleys are today most intensively used for agriculture and it comes with no surprise the majority of Roman settlement sites are located there as well. On the other hand, in the Bronze Age for example, higher hills with the upper eastern plateau were in the focus of human activities. This microregion is used today mostly for sheep and goat grazing with some limited agriculture mostly in smaller karst dolinas.

2.2. Field survey and the working area

After successful completition of the field survey projects on the islands of Hvar, Vis and Palagruza, where the survey techniques were tested and calibrated, it was decided to apply the same survey techniques on the island of Brac. The survey was based on surface artifacts collection. Considerable number of archaeological sites on Brac were excavated or recorded at the end of the 19th century and between 1950s and 1960s (Vrsalovic 1968). Unfortunately these sites were rather poorly recorded. Even their location was defined only descriptive or with toponym only, meaning that their spatial position could not be easily determined and used in the analyses. Therefore, all known sites were revisited and properly recorded. During the 1994 field survey a total of nearly 600 records were documented and input into the database. The number of sites compared to the previously known was more than doubled.

In the field survey sites from all archaeological periods were recorded, as wells as industrial sites like lime kilns or stone quarries. Total more then 90 Roman Age sites were recorded, of which around one third were settlements. During the field survey around 250 prehistoric stone barrows were recorded as well as nearly 20 prehistoric hillforts. This is a fairly large and consistent database and it was considered to be large enough for predictive modeling. Most of the hillforts are located in the higher hills with the upper eastern plateau between Praznice and Novo Selo. Here, on the surface measuring about one fourth of the entire island surface, nearly half of the Bronze Age hillforts and barrows are located. It is important to notice, that the entire working area had a surface of less than 120 km2. The working area started on the west close to Vidova gora, the highest peak of the island and finished east at the drop from the plateau to the fertile valley of Novo Selo and Selca. The southern and northern edge of the working area were set by the coast line and no substantial island surface has been cut off. Working area encloses what was considered to be the center of the Bronze Age activities. Here 107 barrows and nine hillforts are located.

2.3. Natural environment data and the archaeological data used

For the analysis and predictive model generation we needed extensive social and natural environment data. Here we would like just briefly to mention some natural environment data used in the research. One of the most important natural environment data in spatial research is usually digital elevation model (DEM) and its derivatives. As mentioned, the island of Brac has a rather dramatical relief and it must have influenced settlement patterns and land use. Therefore, a DEM was created using contour lines from photogrammetriacly produced maps in scale 1:25,000. Contour lines were digitized and used for the interpolation of the DEM. From the DEM a number of useful information on the terrain were derived and used in the analysis: slope, local relief and others as well as some social data like the size of hillfort territories and intervisiblity between sites. It was decided to use some other natural environment data like soil quality, which must have influenced land use patterns in past.

Before going into any details about the research there are several issues considering the data quality which we want to discuss here. First is the most elementary one and that is the question on the contemporality of the sites we are analyzing. The data used in this research was obtained through the archaeological field survey. On the entire island of Brac, only one hillfort was excavated and that one was on the western part of the island. Despite the results of the excavations remain unpublished (Marovic and Nikolanci 1977) it provided some limited insight in the Iron Age only. On the basis of comparable data from the Bronze Age sites on the neighboring islands and the mainland, all nine hillforts were identified as a major Bronze Age settlements. It could not be absolutely clear however, if all these sites were actually used simultaneously through the Bronze Age. Only extensive excavations could provide detail chronology of each individual site. Similar problems occurs when barrows are discussed. It is generally agreed that most of the barrows in the Central Adriatic are dated in Bronze Age. But, we can not assume that they were actually constructed in a short period of time. If we consider the extent of labor needed to built a 3 meters high and over 20 meters diameter barrow, it is clear that they were gradually built through longer period of time. The present distribution of barrows is therefore a result of their gradual construction and in Early Bronze Age, their distribution must have been very different compared to today. Last but not least there is problem of the function of barrows in the Bronze Age. Several function were assigned to them, from more obvious ones, like burials, through function of landmarks up to ritual (Gaffney and Stančič 1991). Some differentiation of hillfort probably due to their function and datation can be found if the distribution map of hillforts and barrows is observed (figure 2). It is clear that some hillfort sites are virtually surrounded by the numerous barrows. On the other hand, several hillforts seem to be rather isolated and only several barrows could have been assigned to them.

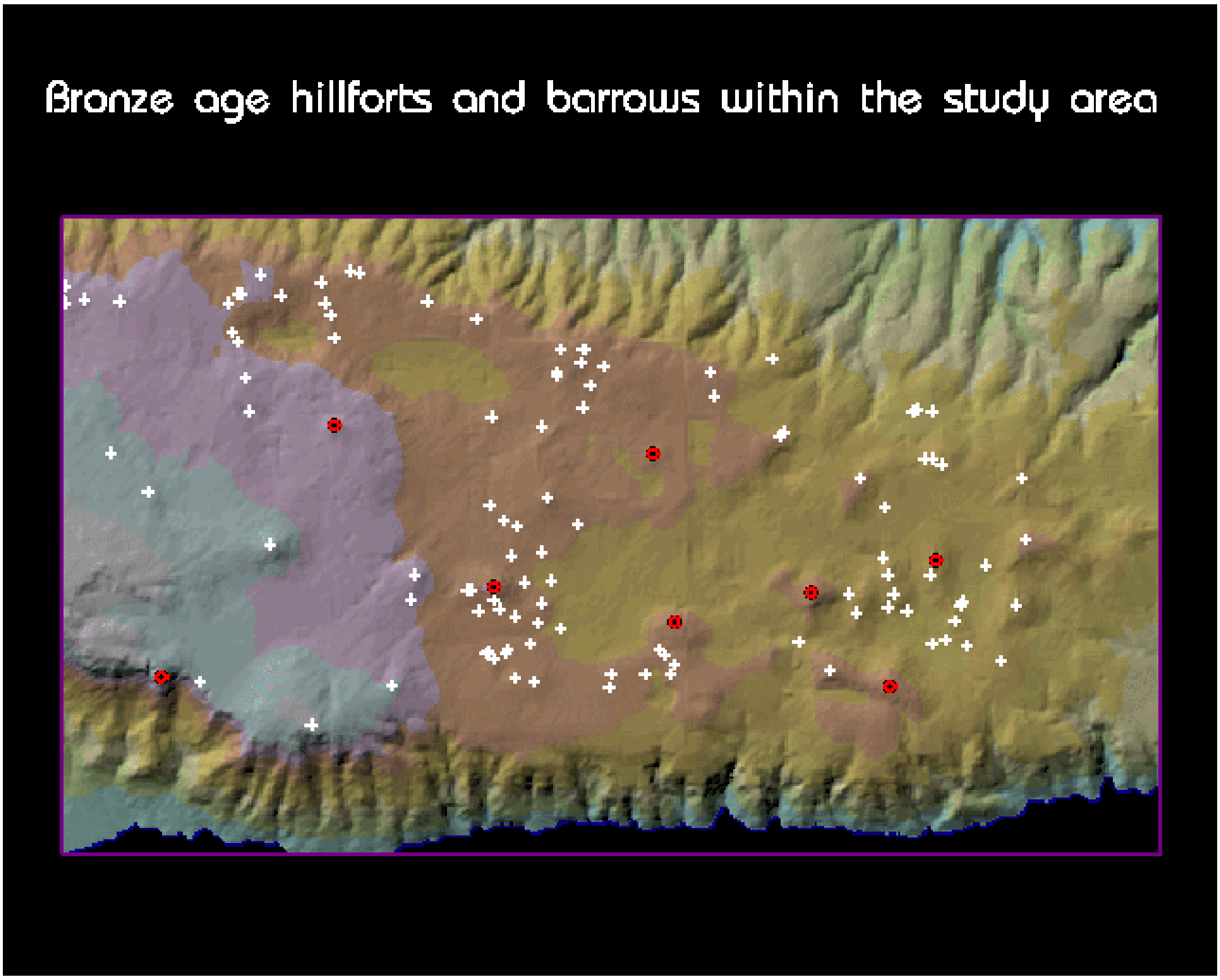

Figure 2: The general distribution of hillforts and barrows in the working area.

Despite these differences which mostly resulted in problems with datation and function determination, it was decided to treat all barrows and hillforts as sites which coexisted. All the barrows as well as all hillforts respectively were treated as sites with equal function.

The other problems encountered with the predictive model generation were those due to the fairly small number of hillforts presented. In the working area there were only nine Bronze Age hillforts and 107 barrows. While the number of barrows is fairly large providing good database for predictive modeling, nine sites is much more problematic. Therefore, it was decided to apply two different modeling techniques. First one would be more suitable for small number of sites, where advanced multivariate statistical methods could not applied. This would be based on the Boolean intersection of spatial information layers for which would be proved that must have influenced the distribution of sites. The advantage of this approach compared to the complex multivariate statistic based techniques is that its procedure is easy to perceive and that they can be applied even on smaller samples.

During the analysis another problem was encountered: the problem of site sizes and the accuracy of their recording. All the sites under consideration here are fairly large. The smallest barrows have surface of more than 20 m2 and can be up to 400 m2 large. But, since it was decided, that the spatial analysis would be performed in the raster based GIS using cell size of 30 x 30 m, the size of these sites can be neglected and they can be easily treated as points. However, this is not a case with the hillforts. Hillforts are by their mere definition fairly large sites, covering sometimes surface of several hectares. The problems occurred since the hillfort location was recorded using one spatial coordinate only. Unfortunately, this coordinate was not always he centroid or the highest point of the site. The location of some hillforts was recorded sometimes by the coordinate of the main entrance, centroid or the highest point. During the analysis this caused some problems. For example, when the slope of the hillfort sites was analyzed, it was found out that one site was located on the very steep terrain, with the slope measuring over 60 percents. Although the hillfort by its mere definition must have some flat terrain on its top, and same was of course with this site, the location of this hillfort must have been recorded on its southern ramparts which were at the edge of dramatic slope. This error did not influence much the intervisibility analysis since additional three meters were assigned as the elevation of the viewing point. Despite the problems like this could have been changed during the field work with a better decision on where the location of the site is to be recorded, or even during the GIS analysis, it was decided to leave the data unchanged. Otherwise, the location of each site would have to be compared to the DEM data and altered.

The natural environment data used in the analyses is the data on the present natural environment. One of the basic questions if the present environment data is used in the analysis is how does it represent the environment in the period analyzed. For some natural environment data, general conclusions could be drawn on the basis of comparative analysis with the other Central Adriatic Islands. There it was realized, that the relief did not change substantially since the end of the last glaciation. Therefore, it can be claimed that the modern relief is a fair representation of the relief in the Bronze Age. This can not be said for all other natural environment. Despite the data on water springs and natural ponds was recorded during the field survey, the preliminary analysis of their distribution showed to have very limited potential in our analysis. The distribution of the water resources was concentrated in several larger karst dolinas and alluvial valleys. It appeared that some hillforts existed without any water springs or ponds at all. It is obvious, that either substantial number of present water resources remained unrecorded, or that these have changed. The major reason for changes of water resources lies in the changes of the vegetation cover. And the vegetation was most dramatically changed during the prehistory and through history till today. Just a brief insight into the events at the end of the last century can prove so. At the end of the nineteenth century, the Central Dalmatian Islands have been intensively used for viticulture and agriculture. In the Western Mediterranean a vine disease philoxera was destroying vineyards. Originally Central Adriatic was speared from this fatal disease. Due to the increased demand for vine, previously unused land, covered with scrub and grass was cleared, terraced, and changed into vineyards. The vegetation cover was dramatically reduced. Since vegetation is a very important factor for controlling the water during the extreme rainfall, it happened several times in the end of the nineteen century, that during fall storms, when large quantities of rain felt, previously barely existing creeks flooded and killed several people. Today the land on the island of Brac is extensively covered with the dense Mediterranean scrub. This resulted in the lack of surface water and it is hard to believe that what appears today as a dry valley with no water at all through the year, grew to a substantial stream during the nineteen century storms, flooded and even took human lives. However, on the basis of these preliminary analysis it was decided, that the data on water resources would not be used in the analysis.

Finally, distribution of soils is the important natural environment data which must have played a crucial role in the establishment of Bronze Age settlement patterns. Unfortunately, the soils database was not as good as the soils database for the neighboring island of Hvar (Gaffney and Stančič 1991). The soil map was produced on the basis of very limited field work. The printed map was in the scale 1:200,000 which would be barely usable for any kind of regional analysis. It was decided therefore, to try to derive some information on the soil quality from the satellite imagery. Thematic Mapper image was used to produce the soil information layer, which despite the mixed signal from the vegetation, proved to be of the much better quality than the original map. However, the question of the changes of the natural environment when talking about the soil cover is a very important one. Comparative analysis in the mainland (Shiel and Chapman 1988) prove, that soils have been through important changes starting in the Bronze Age. Therefore it was suggested that the soil data should be used with extreme caution.

3. Boolean models and hillforts

3.1. Introduction

We wanted to start the case study for predictive modeling of prehistoric site locations with the type of data which we thought would be the most promising. The Bronze Age hillforts were thought to be the dataset from which the best results could be obtained. Beside that, they seemed to be a perfect example of sites on which the impact of different variables which have influenced their location could be tested and evaluated.

Bronze Age hillforts are interpreted to be important settlements located on the hilltops with some kind of defensive structures. They are supposed to present the highest hierarchy of settlements in the region (Marovic 1981). Of course, the settlement was not limited to hillforts only, and a number of smaller huts or even groups of huts must have existed on other locations. However, the hillforts were definitely the largest and most important settlements in the period analyzed. By its mere definition their location is limited by several natural environment factors. The hilltop position is the most obvious one, while there are a number of others, like the slope (hilltop must have some level slope to be adequate for the hillfort location), and others. On the other hand, there are a number of social factors which must have influenced their location. The most obvious one is the distance from the nearest contemporary hillfort. It is agreed that hillforts have territories of certain sizes within which there are not supposed to be any other hillfort present. All these and a number of other variables are constantly evaluated during the judgmental survey, when new hillfort sites are tried to be discovered. The main objective of the first case study was to test the relationship between hillfort site locations and some natural and social environment data. If statistical relationship between them could be proved, then these variables could be used for creating predictive model. The basic logic behind the predictive model is therefore rather simple. First, a set of variables which were considered to be influencing site location was to be defined. Then the values of each variable on hillfort locations had to be compared with the locations where no hillfort sites were recorded. On the basis of this comparison a threshold value for each variable was to be defined and that value would be used for creating a binary layer for each variable proved to be influencing hillfort location. Finally all these binary layers would be combined using Boolean logic and a result would be a simple location model for hillforts. This would also be a predictive model for hillforts.

Due to the small sample size this is in fact only possible approach. Despite being effective it obvious has some disadvantages compared to the more advanced, multivariate statistics approach. The most obvious one is that each variable is treated separately so at the end we can not quantify what has influenced more the site location: was the slope of the terrain playing more important role, or was the proximity to good soils more important. Much more intriguing would be the comparisement of the weights of natural environment variables with the social ones. This could have been an interesting approach in entering into the discussion of cultural vs. natural environment factors influencing site locations (Kvamme 1997).

3.2. Variables: environmental, social/environmental and social

The first stage in creating the predictive model is defining the variables needed for the analysis. However, one should be aware, that the list o variables is based on two basic facts. First, the model is always a simplification of the real world. Therefore, in the model of any kind some variables are always omitted because we do not know that they have influenced the real world. It also worth stressing that some variables are not used in the model because they would be hard or impossible to obtain.

On the basis of extensive knowledge on prehistoric hillforts in the region and relying on the experience obtained during the field work, a list of variables influencing hillfort location was made. It was attempted to incorporate in the model both, social and natural environment data. These variables are presented in Table 1 and will be described here only briefly.

Four variables fall in the group of social variables influencing hillfort location. The first one is the distance between hillforts. By merely observing the study area one can see that it appears that the hillforts are regularly distributed. The hillforts had to have some economic territories in which the presence of any other community would be exclusive. This meant that the other hillfort could exist only within a certain distance from another hillfort. There are several different ways of calculating these distance. The first one we tried was based on the measurement of linear distance from each hillfort to its nearest neighbor. The other option is based on the more refined measurements of distance which are based on the distances calibrated with the impact of the relief (Gaffney and Stančič 1991). Both of the options were used and they appear to perform very similar. Of course, the cost surface approach is much more realistic, specially in the case of the Vidova gora hillfort which is positioned just on the edge of the extremely steep drop south towards the coast. However, most of the other hillforts are located on the isolated hills which lie elevated above the fairly flat plateau. It was calculated that the minimum distance between two hillfort is about 1600 m, meaning that each hillfort would have at least 800 m exclusive buffer zone (figure 3).

Figure 3: Distance from hillforts bitmap as predictor for hillfort locations.

The second important social variable was considered to be the intervisibility between the hillforts. Hillforts are supposed to be positioned in such locations that they wold be able to maintain visual control over larger areas, including their territories and overlooking other hillforts. So, the hypothesis was set, that hillforts are set in such locations that from them it would be possible to see many other hillforts. This hypothesis was very easily tested. A visible area was calculated from each hillfort and then they were all added together creating a cumulative viewshed. Cumulative viewshed is a thematic representation of intervisibility from other hillforts. Each location in a landscape is assigned higher value if it can be seen from more hillfort locations and vice versa. It was found out that hillforts appear to be located in the locations which are highly visible. While the arithmetic mean of all locations within the study area was visible from 1.2 hillforts, the hillfort locations were visible from 3.9 hillforts. Therefore, the hypothesis was proved, meaning that this might be a good variable for predicting the hillfort site locations (figure 4).

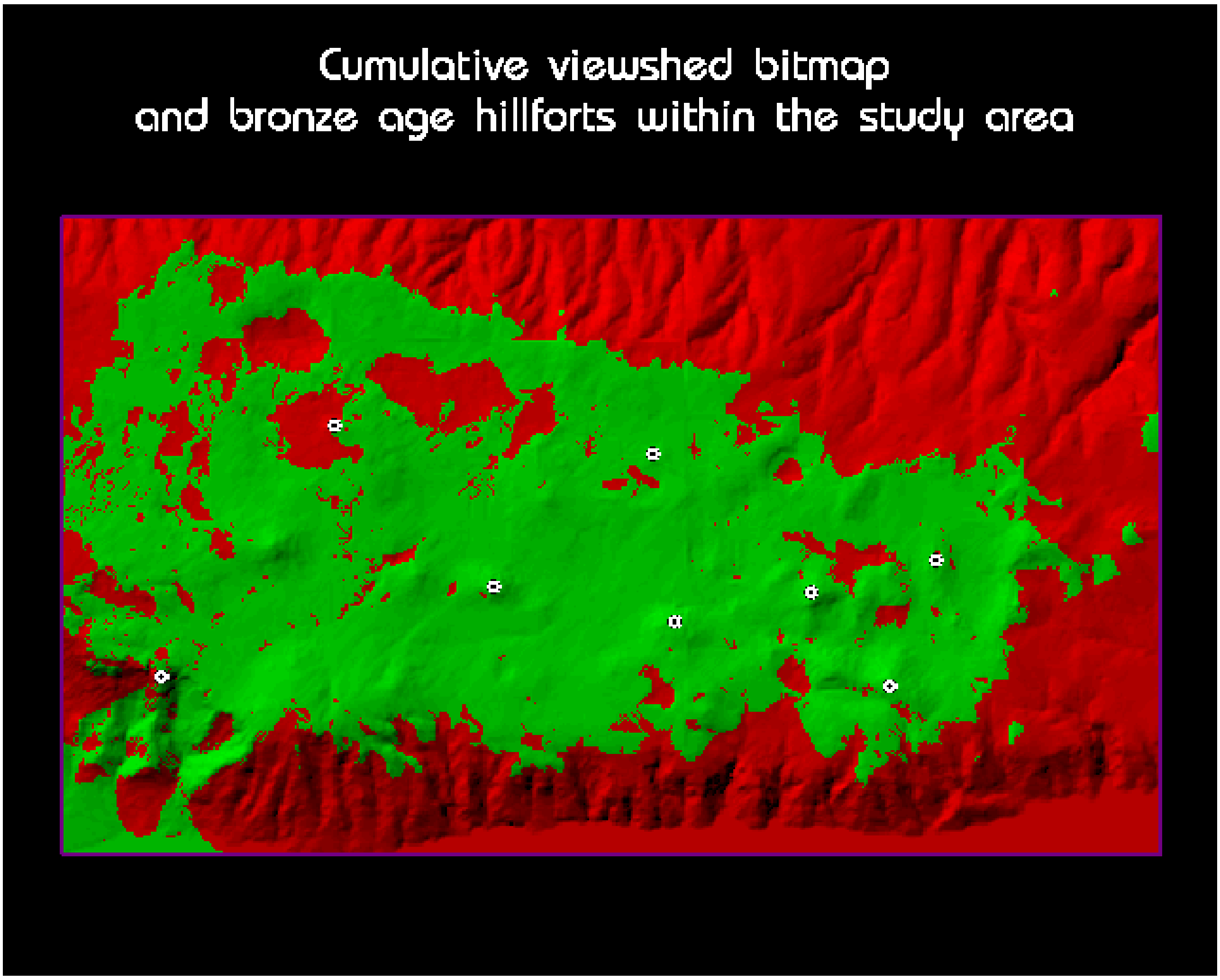

Figure 4: Intervisibility between hillforts as predictor for hillfort locations.

Third social variable which was decided to be tested is the distance from the sea. It appeared that all the Bronze Age hillforts were located on considerable distance from the coast. The main reason that the hillforts were located away from the coast is that larger distance from the coast meant more safety. The distance from the coast line can be tested in similar ways like the distance between the hillforts. Basically, two different approaches are possible, the first one being the linear distance and the second one being the distance modified with the steepness of the terrain. It should be stressed here, that the working area had to be enlarged here due to the coast line just north of the edge of previously established study area. Anyway, in both cases it was proved, that there is a relationship between the distance from the coast line and hillforts. While the average distance from the coast for the whole island is around 2300 m, the hillfort locations are appearing to be located more far away from the cast with the average distance of 3200 m. Similar patter is found if the cost surface approach is applied, calibrated for the equivalent of walking time. The average distance from the coast for the whole study area is around 3 hours walk, compared to the distance of hillfort locations from the coast which is around 4 hours and 30 minutes. While both approaches appear to be useful for predicting hillforts locations, it was decided to use the results from the cost surface approach since it is a better presentation of the real world circumstances (figure 5).

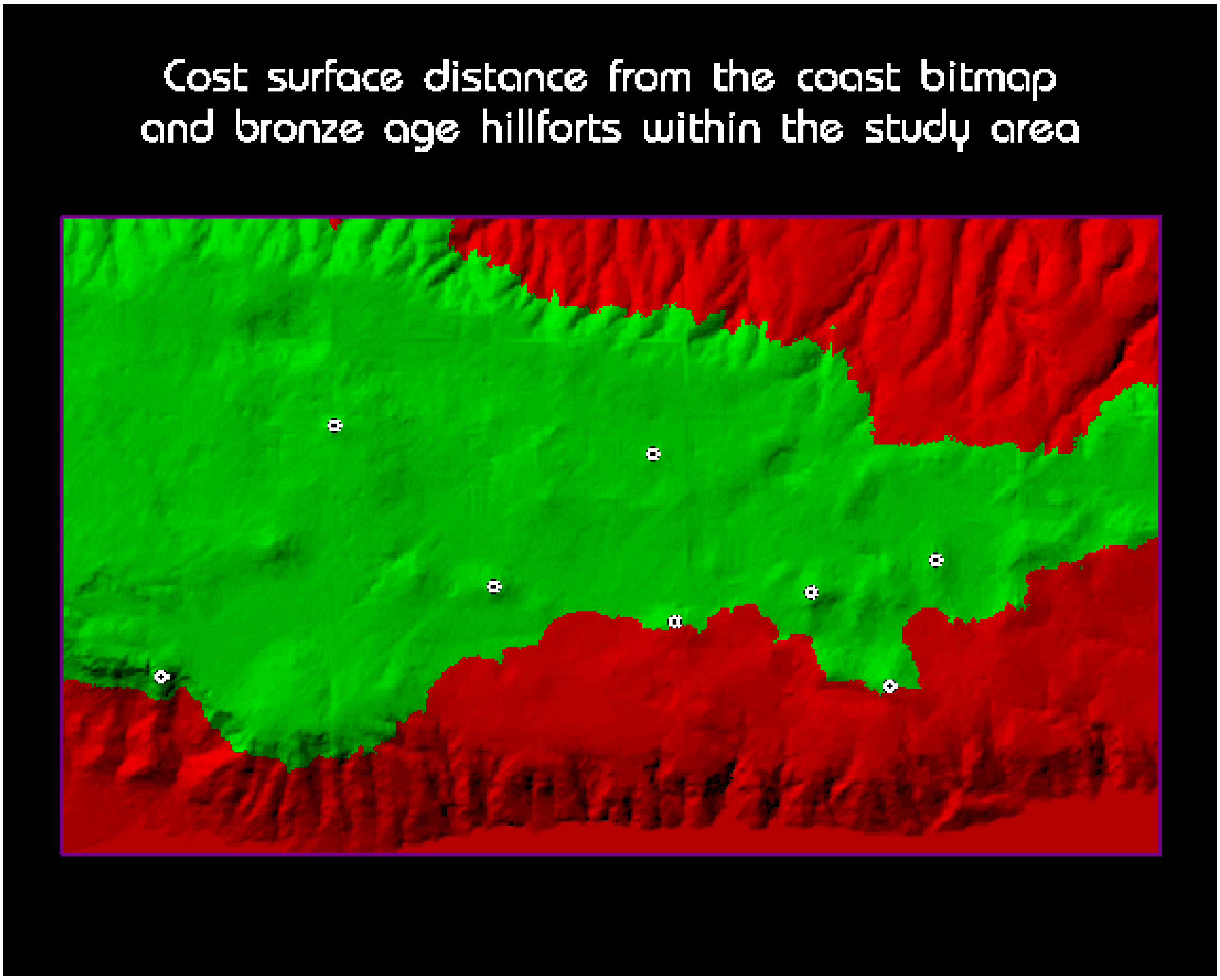

Figure 5: Distance from the sea as predictor for hillfort locations.

The last social environment data for which it was expected to be a good predictor of hillforts is based on the location of barrows. During the field work it was often found that barrows usually appear at certain distance from hillforts. Therefore, some kind of gravity model was made by Boolean overlay of cost surface distances from all barrows in the study area. More than 100 cost surface distances were combined and when hillfort locations were observed in this gravity model, it was found that they usually appear within some limited distance from barrows and still, not to close to them (figure 6).

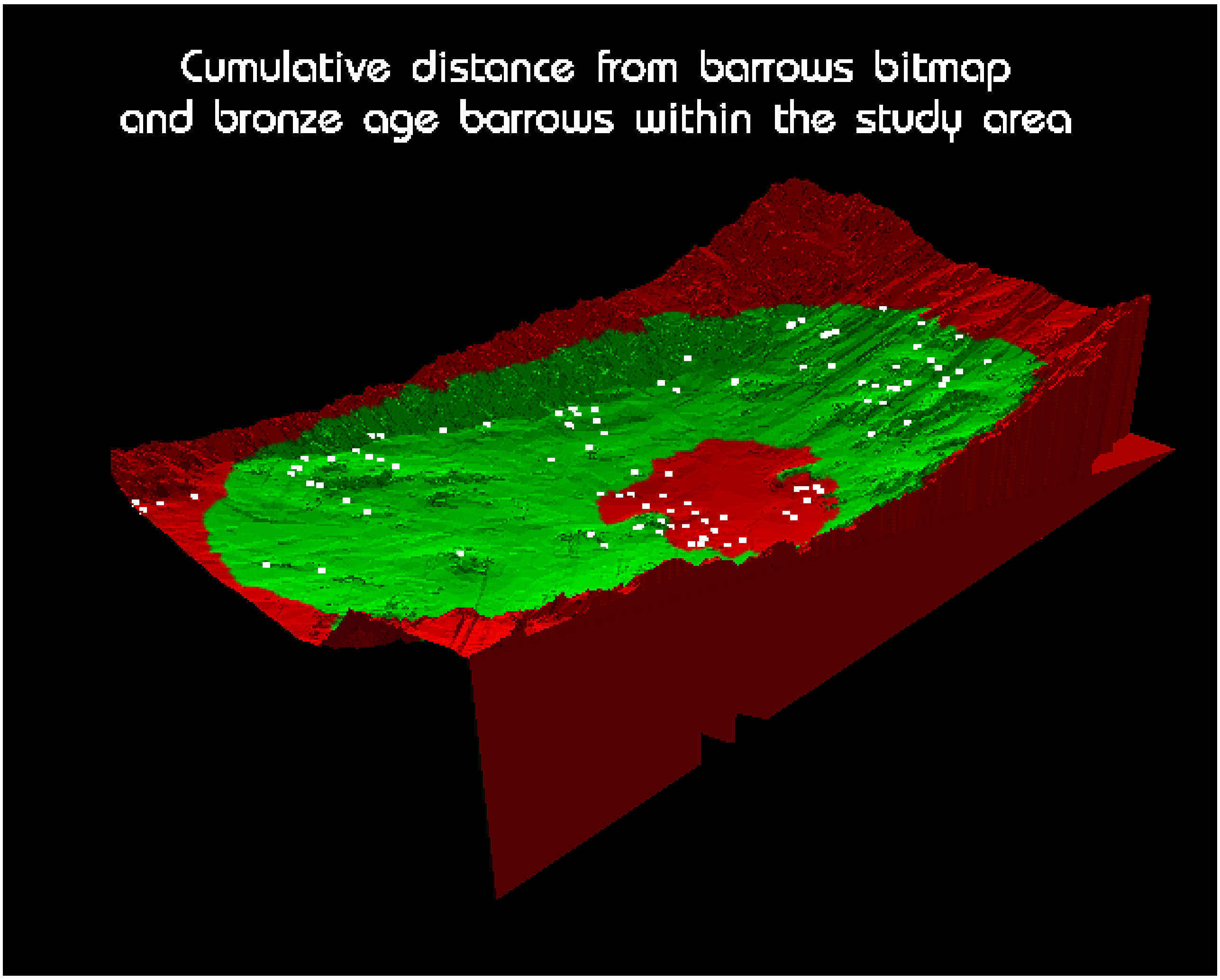

Figure 6: Distance from barrows as predictor for hillfort locations.

The natural environment data which were decided to be used for creating predictive model are slope, ridge/drainage index, rim index and relief below index. Slope is a rather simple variable defining the slope of the terrain in the region. It was assumed, that hillforts are located on the terrain with fairly slope terrain. That means that the hillfort locations essentially have to have large quantities of slope terrain which would enable them to accommodate some houses. However, while the average slope of the working area is about 17 percent, the arithmetic mean of the slope for hillfort locations was 20 percent. It appeared, that the coordinate of some hillforts were recorded on the ramparts and not in the center of the hillfort. For these locations the steepness of the terrain was miscalculated. As mentioned, we decided to proceed with the modeling without changing the actual coordinates of the hillforts.

Remaining three variables used were defining hillfort like locations. All of them were derived from the DEM and are an attempt to quantify characteristic hillfort location: dominant elevation above a flat terrain (Kvamme 1992). Ridge/drainage index actually calculates the "viewing angle" at each location. While on drainage like locations a viewing angles appear to be smaller than 180 degrees, the viewing angles are bigger on ridge locations and closer to 360 degrees when the location is on the peak (figure 7). Rim index is a calculation of volume within a certain distance from the central point. If the point is in peak like or rime like location, it would have a higher index than if it is in a valley like location (figure 8). Finally, relief bellow is an indicator of the difference in the elevation of the surrounding area (figure 9). The faster relief drops from certain point, the higher value is assigned to the point. All these points are described in more details elsewhere (Kvamme 1992). A combination of these three values would be an ideal representation of a hillfort like natural environment location. A combination of all these values, including the low slope, would represent a hilltop location with sufficiently level terrain to sustain some housing.

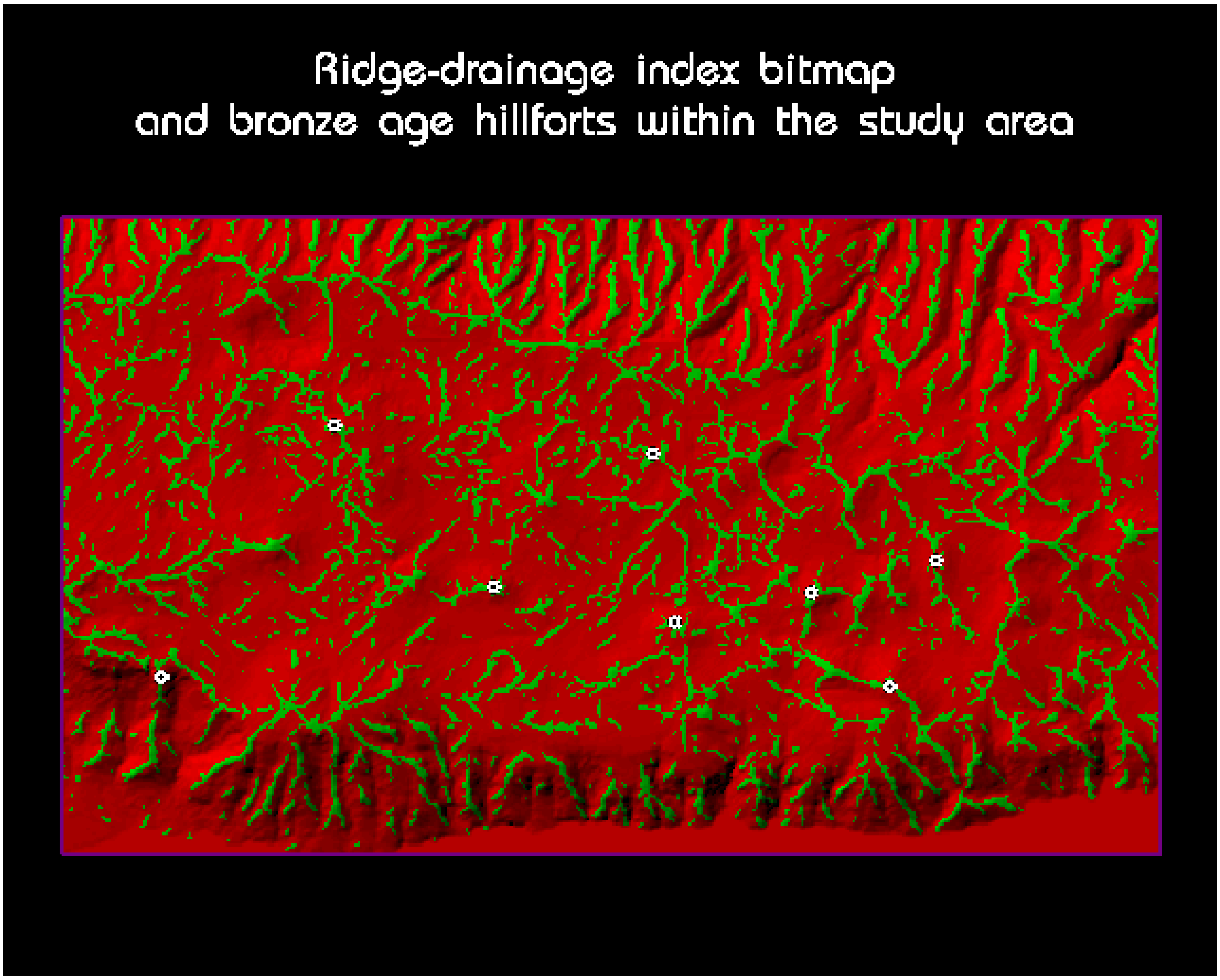

Figure 7: Ridge/drainage index as predictor for hillfort locations.

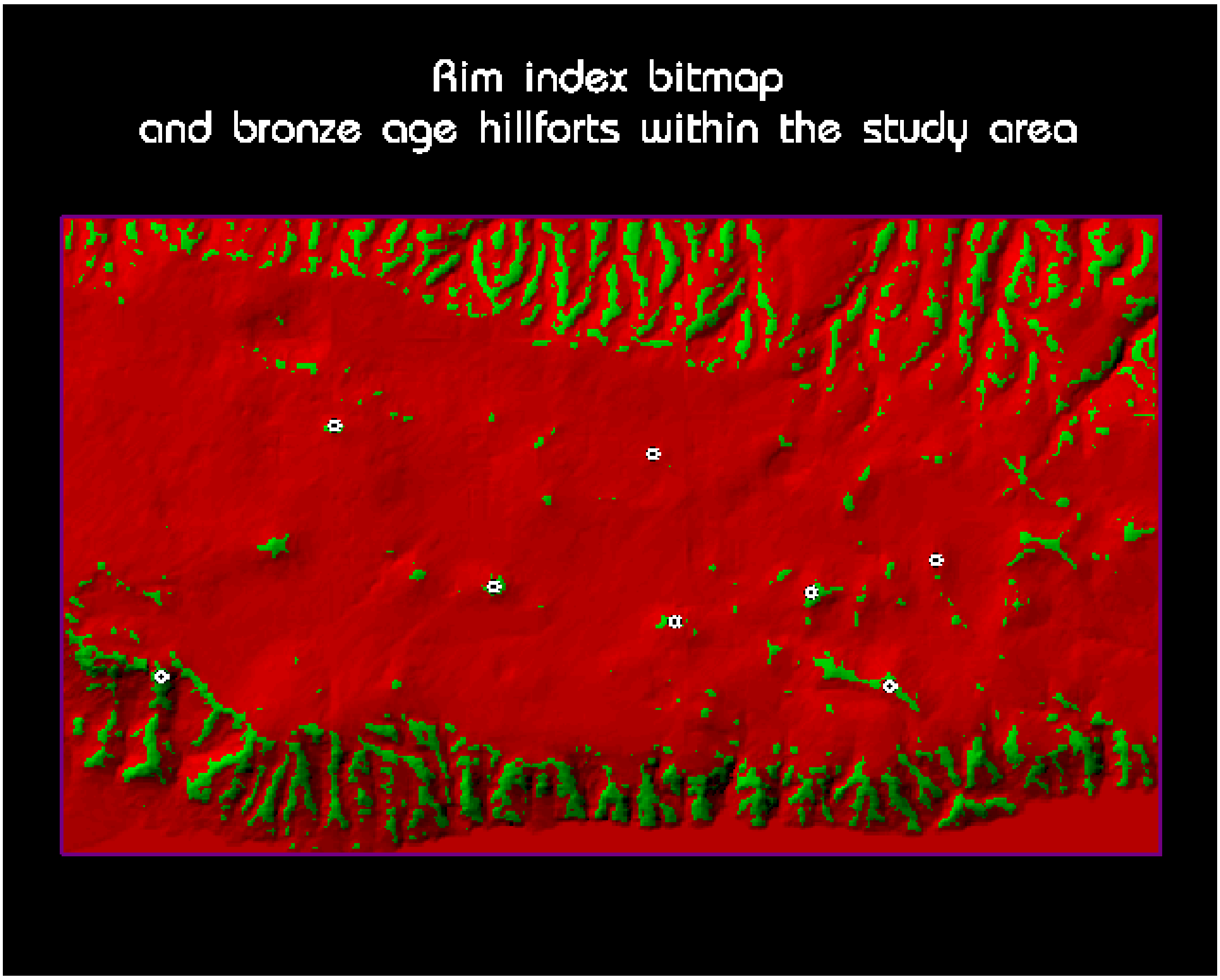

Figure 8: Rim index as predictor for hillfort locations.

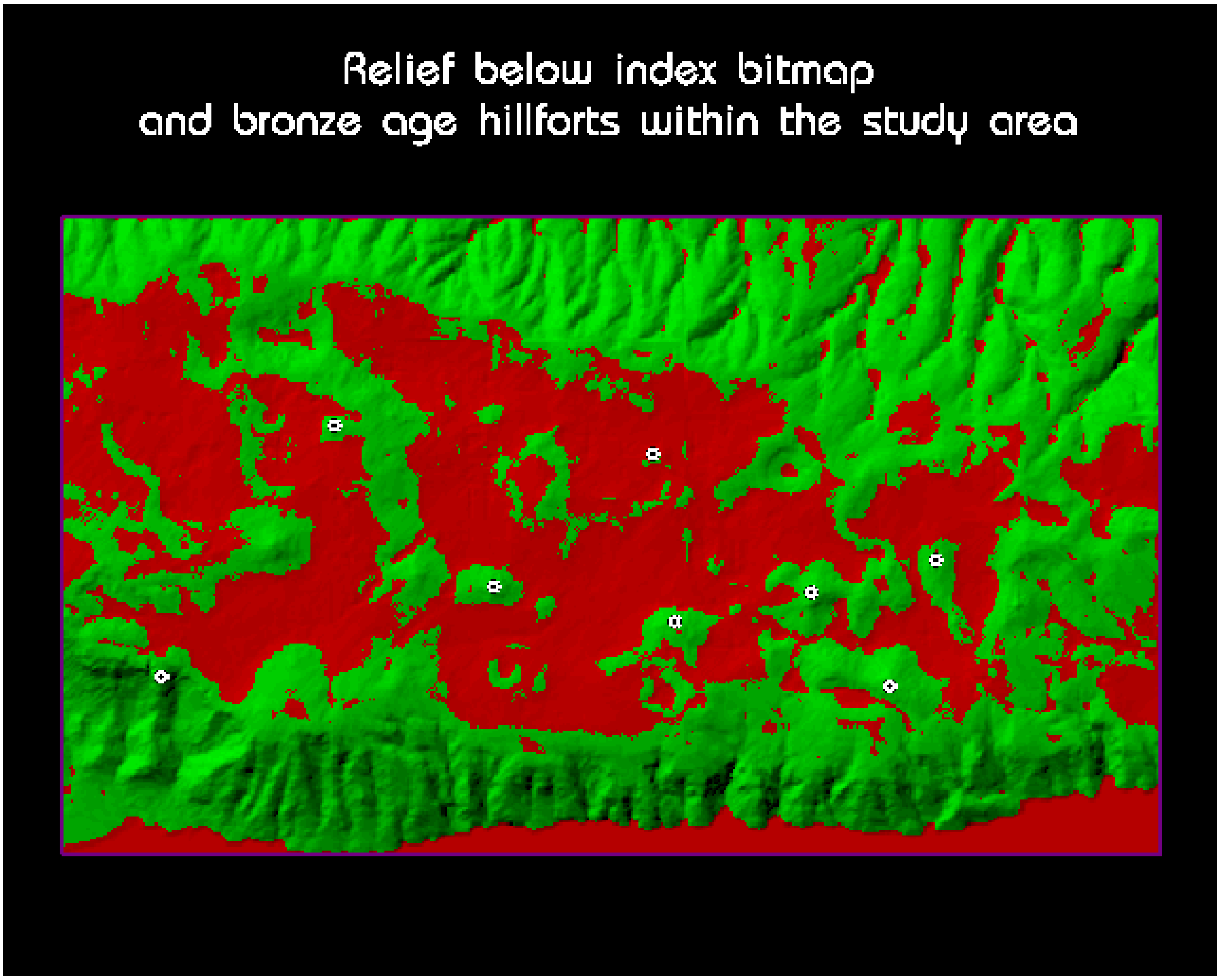

Figure 9: Relief below index as predictor for hillfort locations.

Finally, we wanted to test the relationship between the soils and hillfort locations. Availability of adequate soils providing resources for agriculture are important limiting factor in distribution of settlements in the Central Adriatic. Good quality soils are limited on karst dolinas, alluvial valleys and some minor areas on Eocene geology. As mentioned earlier, no good soil map was available. Therefore our research was based on the results of the classification of Thematic Mapper image from July 1993. On this image several classes of soils were rather easily interpreted. The good quality soils which are intensively used today for agriculture were easily identified. Same stands for the areas with very poor soils, which are mostly abandoned and have very scare vegetation. However, most of the intermediate soils were rather difficult to interpret. It often happens that a dense Mediterranean scrub has overgrown very good quality soils and it was then rather problematic to separate them from the poor quality soils with the same vegetation cover. However, the general hypothesis was, that each hillfort contains some good quality soils within its catchment. The catchments were defined as 800 m buffers. Having only nine sites and a weak pattern it was decided to use Monte Carlo simulation comparing the soil quality within territories of nine hillforts with a 99 times randomly generated territories of nine locations. It was proved that there is a correlation on 5 percent significance level. Later on, due to the poor quality of soil data and a rather weak correlation, it was decided not to use the soil data at all.

variable	background mean	background st.dev	location mean	location st.dev

distance between hillforts				
intervisibility	1.2	1.6	3.9	1.7
linear distance from the coast	2300m	1500	3200m	1300
cost distance from the coast	190 min	110	270 min	50
barrows gravity model	28759	10081	22131	5602
slope	17%	16	20%	18
ridge/drainage index	181	28	257	57
rim index	870	80	1065	97
relief below	27	22	43	25

Table 1: Comparisement of the characteristics of variables for the hillfort locations and background.

Now, after it was statistical proved that each variable plays an important role in defining hillfort site location they could be used for generating predictive model. On the basis of these analysis a threshold value has to be defined which would be then used to define locations which fulfil certain demands for the hillfort locations. On the basis of these threshold values a binary information layer has to be made, where all locations in the study area, which fulfil some conditions would have value one, and all the others would have a value zero. This routine must be done for all seven variables for which it was proved that there is some statistical significance for defining hillfort site locations. These threshold values could be defined on a 5 percent level, however, we decided, to have the threshold defined on such level, that all the known site locations would be included in the binary layer. It simply means, that it was observed which is the lowest value recorded on the site and that one was chosen as a threshold. For example, if the slope layer is observer, the average slope on site locations was 20% with the standard deviation of 18, meaning, that value 38 could be used for the threshold. This would lead to the situation when the locations with the highest slope recorded would be located in the binary slope layer on locations recorded with a zero value meaning that they do not fulfil conditions for the hillfort site locations. As mentioned, we used the value on which the highest slope was recorded despite we knew that these values were to high. During the creation of these binary layers it was observed to how large areas the value zero was assigned. Larger these areas are, more they contribute to eliminating locations with low potentials for hillfort like locations. In the table 2 the threshold values as well as the performance of each predictor is presented. It is clear that the best predictors for the hillfort like locations are the rim index and the ridge/drainage index. Using any of these two descriptors for describing hilltop like positions we loose 80% or more of the landscape. From the natural environment variables the slope performs the worst due to the already mentioned inaccuracy of data. The threshold steepness value is 60% what is very high and enables us to reduce the possible site locations for only 3% of the study area. Social variables appear to be rather strong predictors as well. Each of them enables us to reduce the area of possible site locations for some 50%, what can be considered as a good performance.

variable	threshold value	performance
distance between hillforts	x>1600m	
intervisibility	x>1	52%
cost distance from the coast	x>220 min	57%

barrows gravity model	16000<x>32000	43%
slope	<60%	3%
ridge/drainage index	>198	80%
rim index	>950	86%
relief below	>14	30%

Table 2: Variables used in hillfort predictive model with the threshold values and performance.

The predictive model for hillfort locations is made by adding each of these binary layers together. The resulting information layer has attributes ranging from eight to zero. If all eight conditions are fulfilled then the locations attribute is value eight and if none of the conditions is fulfilled the attribute on that location is zero. Combining all these eight conditions is a rather easy and straight forward procedure. The result of this routine is presented in figure 10. The locations with the highest attributes could be interpreted as most likely to have additional hillforts. The performance of this model seems to be satisfactory. All known hillforts are within the areas with the highest possibility of containing hillforts. Total surface with the highest possibility for hillfort locations is reduced to 0.22% of the entire surface of the study area. However, it should be stressed that some of the locations predicted are very small. This means that smaller areas with the total surface of some 1000 m2 do not provide enough space to contain a hillfort. If this additional restriction is applied, the number of possible new hillforts is reduced to a handful of site locations which can be easily tested in the field.

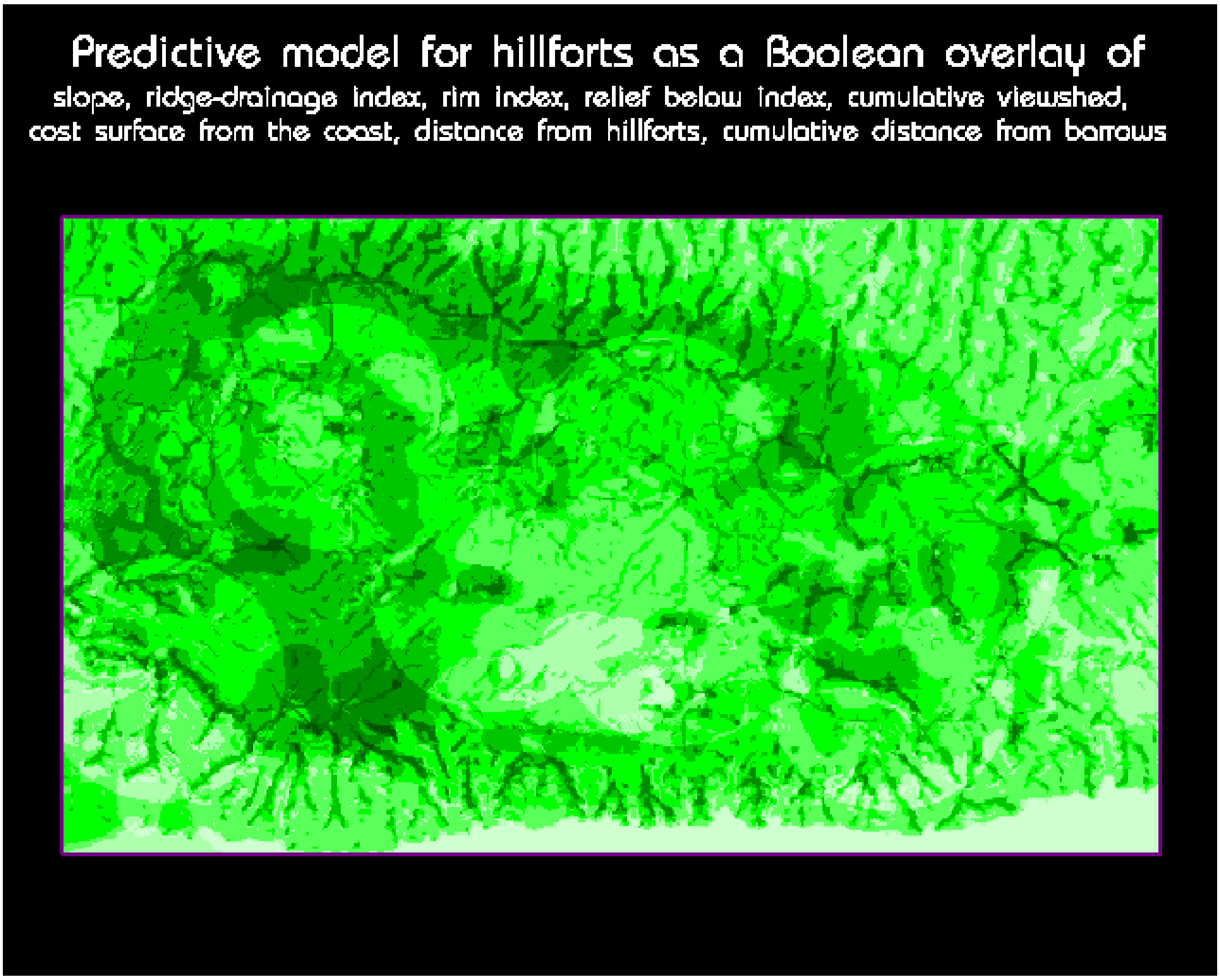

Figure 10: Predictive model for hillfort locations as a Boolean overlay of eight social and natural environment variables (darker green areas fullfil more conditions for hillfort locations).

The Boolean logic for producing predictive models is straight forward and very simple. Each variable assumed to be able to contribute to predicting new sites has to be statistical tested so that the significance is proved. On the basis of threshold values derived from the statistical analysis binary layers for each variable are produced. Predictive model is essentially a combination of these binary layers. This simple procedure has the advantage compared to complex multivariate statistics based procedure that it is very easy to understand. Overall performance of each variable is measurable by the amount of the space it helps to reduce for possible site locations. However, the it lucks the detail insight into the possible overlapping of some variables used. For example, rim index might considerably overlap with the ridge/drainage index and maybe same results could be obtained with using much smaller number of variables. The real advantage of this procedure is that it can be used in the cases with the smaller number of sites. Due to its simplicity and good performance even on smaller datasets, Boolean logic is an effective tool for creating predictive models.

4. Summary and conclusions

In this paper two possible modeling techniques were presented: a Boolean based intersection of variables and a regression model. While each of them has some strengths compared to the other one, we can generalize that they are all very useful technique for modeling and analyzing settlement and location patterns. The importance of predictive models was stressed on several occasions for cultural resource management (Judge and Sebastian 1988). Especially in the North American archaeology, predictive models have been intensively used to determine locations with adequate natural environment conditions for certain type of sites. However, it is generally true, that by proving that certain sites prefer locations which fulfil some natural environment and social conditions, predictive models still do not provide insight into theoretical understanding of the development of settlement patterns. Predictive models are often criticized that they lack archaeological theory and that they do not contribute to theoretical understanding of the location patterns. It is our opinion, that they can be used in more innovative ways in testing different hypothesis. Evaluation of the impact of individual natural and social environment variables for some location patters is only one possible approach. With the widespread of the geographical information systems and computerization of archaeological sites and monuments records on one side and the growing demand for archaeological sensitivity maps on the other, one can expect, that predictive modeling will be one of the fastest developing fields of the quantitative archaeology or even the entire discipline.

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