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AN APPLICATION OF CUMULATIVE VIEWSHED ANALYSIS TO A MEDIEVAL ARCHAEOLOGICAL STUDY: THE BEACON SYSTEM OF THE ISLE OF WIGHT, UNITED KINGDOM

1. Introduction

The fundamental strength of a Geographical Information System upon which this study draws, is its ability to acquire, visualise and generate spatially referenced data. Although the function of visibility analysis has a long pedigree before the widespread adoption of GIS, this form of spatial analysis not only has a valuable contribution to landscape studies but also towards the application of how data is managed within a CRM environment. Research in this area, carried out by the "Caere Project" (Moscati 1998), has shown that very few tests of spatial analysis are conducted throughout cultural management. In general, the various forms of visibility analysis have been applied within a research framework, testing hypothesis and facilitating studies in understanding ancient landscapes and the people who lived within them. Yet, a different paradigm in which viewshed analysis has a viable application is to test the accuracy of archaeological databases, particularly those of the Sites and Monuments Record.

Sites and Monuments Records are the databases of archaeological information used by Local Planning Authorities throughout the United Kingdom (UK) primarily as an aid to development control. They are virtually dedicated to CRM activities within the regional planning environment. Further, they represent the most comprehensive and frequently updated source of archaeological information available in the UK. The adoption of GIS within SMR management has meant that spatial and thematic components of the archaeological record can be integrated together with the ability of testing the classification of a site.

The obvious functions of a GIS in aiding the analysis of physical landscapes has recommended its application to archaeological survey (Witcher 2000, 13), and now many archaeological projects employ the use of GIS in some capacity. Yet, uniquely within medieval studies, this tool has largely only been used in a data management capacity, following basic procedures such as the overlaying of different data themes with various environmental variables and the creation of dynamic maps for the illustration of certain data in different points in time on a cartographic background. The application of spatial analysis techniques, which have particularly gained popularity with the widespread adoption of mainstream GIS software, where many of these tools, such as line-of-sight, cost distancing and viewshed analysis are simple built in functions, has meant there has been increasing testing of these techniques on archaeological data-sets, with the aim of drawing out new information based on environmental variables. Crucially, the data-sets upon which the majority of spatial analysis has been conducted have been either of the Prehistoric or Roman period.

A great wealth of criticism has been made of the application of visibility analysis to archaeological data, a significant problem being the testing of the data on a "barren landscape" (TSCHAN *et al.* 2000, 29). The existence of a risk of "technological determinism" (HUGGETT 2000, 8), brought about by limitations in software, where instances such as "the tree factor" (WHEATLEY, GILLINGS 2000, 6) cannot be considered within the generated viewshed, must also be noted. However, data-sets are rarely medieval, yet there is a broad scope for the application of this technique. This study focuses on one theme in particular, that of the construction and use of beacons in the medieval period. The data-set from which this study is drawn is taken from the SMR of the Isle of Wight, England's largest offshore island, which offers an opportunity to explore the usefulness of spatial techniques to archaeological data of the Middle Ages. The aim of this study is to illustrate how the technique of Cumulative Viewshed Analysis can be used in a CRM capacity to test the assessment of a site and to understand the functionality and success of the beacon system that was employed to protect the southern coast of England during the medieval period.

The study discussed in this article forms part of a wider research that is currently being undertaken on the Isle of Wight. It is within the design of the project that this analysis falls, as it forms part of a broad study in understanding the character of the medieval island.

2. THE ISLE OF WIGHT MEDIEVAL LANDSCAPE PROJECT

The Isle of Wight, the location of which is illustrated in Figs. 1 and 2, is unique in its character, geography and history. Since the Middle Ages the island has been significant because of its sensitive geographical position and yet only limited archaeological activity has been conducted. There is a wealth of archaeology ranging from Bronze Age round barrows to Roman villas and a medieval castle. The island has been described as a microcosm of the English lowland landscape (BASFORD 1980, 8), which offers a unique opportunity to study the medieval period and to apply spatial analysis techniques, as it is a contained landscape with clear barriers (the English Channel and Solent Water) the boundaries of the analysis can be clearly defined. Also, the full medieval SMR data-set provided to the project by the Archaeological Unit of the Isle of Wight County Council is of a substantial amount so as to offer a reasonably sized investigation. Further, since the island has been spared of

Fig. 1 – Geographical location of the Isle of Wight in the United Kingdom.

the worst of modern development and has large areas declared "Areas of Outstanding Natural Beauty", hence protected, much of the medieval character remains on the island.

In 1997 the Medieval Landscape Project was initiated with a particular focus on medieval settlement and agriculture, with the aim of extracting information concerning the population levels on the island during the Middle Ages. Fieldwork commenced in the same year, and since then three different sites have been the subject of archaeological investigation, ranging from possible deserted medieval villages (DMV) to a study of the only Cistercian Abbey on the island, that of Quarr on the north-east coast.

The range of data that has been collected by the project has been focused towards its integration into one resource and decision support management system, where the inclusion of British Ordnance Survey digital data forms the structure for the analysis. The decision to undertake visibility analysis on the beacon system was defined by Sly (1996, 4) in the research proposal where the aims of the Medieval Landscape Project were set out:

1. To try to establish the character of medieval settlement on the island. This is vital in answering questions of desertion on the island in the Middle Ages.

2. To establish the pattern of medieval land use as this may provide some clues as to the population of the island. This is based on the premise that

Fig. 2 – Detailed location of the Isle of Wight, United Kingdom (Map courtesy of Ordinance Survey; 1:500.000).

arable farming was more labour intensive in the medieval period, particularly compared to pastoral farming.

3. To try and establish where and when on the island individual medieval settlements were deserted.

4. To establish the pattern, and explain the causes of any depopulation on the island that occurred in the medieval period.

The important role which the island fulfilled in the strategic defence of the UK mainland was fundamental to its character in the medieval period. Historical documents continually note the movement of armed forces to the island and the stationing of a militia. Against a background of a declining population, brought about by a variety of causes, the continuous invasion of the island perhaps being the most significant, the suggested character of the island is one that is defined by preparation for invasion. To this end, in studying the functionality and success of the defensive warning system that comprised of these strategically located observation and warning points, a comprehension of the role of the beacons can be gained for in understanding the medieval character of the island.

Several important themes that are critical to the application of spatial analysis on the medieval beacon system on the island are the geography, geology and history of the island, as these combined to define the effectiveness of the beacons and ultimately their success.

3. Geography of the Isle of Wight

The Isle of Wight lies a mile off England's southern coast, in the mouth of Southampton Water. Covering an area of 94,146 acres, the island is an area of great natural beauty. Over 50% of the islands 60 miles of coastline have been declared "Heritage Coastline", and nearly 75% of the land use on the island is agricultural (Basford 1980). The dominant feature of the island is a chalk ridge, running east-west across the island cut by the valleys of the Medina and Yar.

The agriculture of the island is a mixture between pasture (36,100 acres) and tillage (23,500 acres), a direct result of the unique underlying geology of the island. A majority of the pasture can be found to the north of the Island as 60% of the farms that are dairy can be found in this area where there is a higher proportion of grass cover. Thus the island represents a typical view of the English lowland landscape, supporting an economy of agriculture, tourism and light industry.

Understanding the geography of the island is crucial to its study, as much of its history revolved around both its geographical position and its pattern of land use. With a suggested geographical pattern of higher land use to the north of the island and high chalk ridges dominating the south, the relevance of this towards the establishment and effectiveness of beacons is important. An expected pattern to be seen from the map calculation of the viewshed may be of greater inter-visibility in the north of the island.

4. Geology of the Isle of Wight

As mentioned previously, the island has a unique geological structure that consists of two distinct parts, defined by the northern margin of the central chalk ridge, clearly seen in Fig. 3. To the south the matrix is cretaceous and to the north it is made up of palaeogene geology

The south is characterised by light sandy soils, suitable for tillage and so is perceived to have been more densely populated in the Middle Ages. Large areas of the southern island have a lower greensand geology, yet there are outcrops of gault and wealden, leading to heavier clay soils, suitable for use in brick, tile and pottery production. The south of the island is also characterised by the underlying chalk, seen in the white cliffs of its coast. The steady erosion of these cliffs has lead to many archaeological finds, especially dating to pre-history.

North of the central chalk ridge the soils are characterised by Oligocene clays, more suited to pastoral farming which became more popular in the Middle Ages due to the rising price in wool, the declining population and the drop in demand for corn.

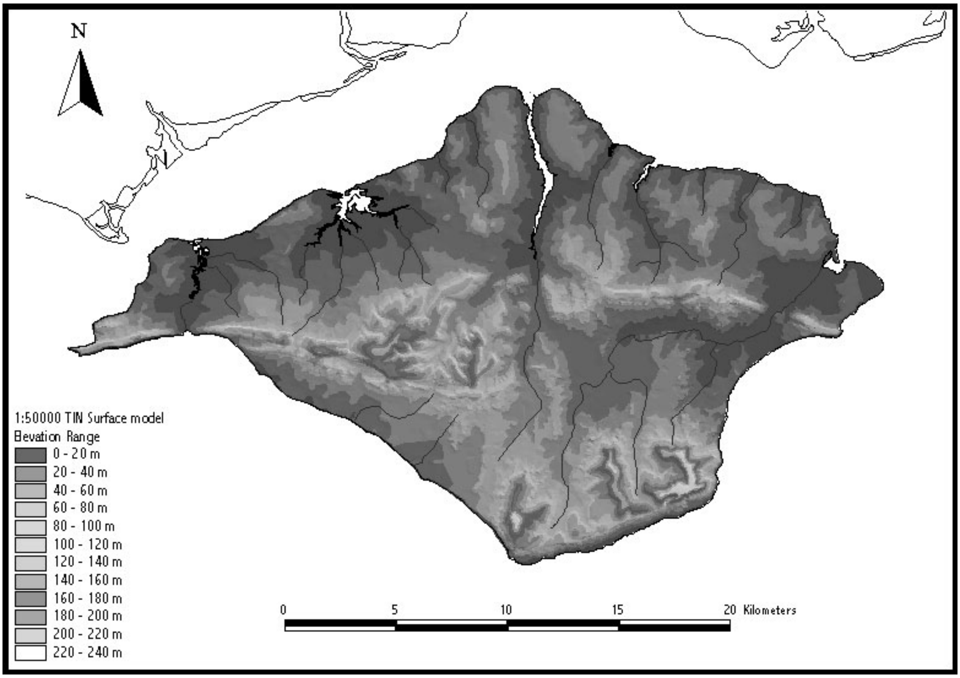

Fig. 3 – Elevation model of the Isle of Wight. The elevation range varies from sea level (dark grey) to 240 metres above sea level (light grey).

An awareness of the geology of the island goes some way to understanding its pattern of land use, as the geology directly controls the landscape and therefore in some manner influences the pattern of human activity in the past. Whilst the medieval population may have migrated towards the soils more suited to the demand from agriculture at that time, the geology of the island clearly dictated the pattern of movement of people.

5. The medieval beacon system

The Isle of Wight, whilst isolated from some events in England during the Middle Ages, had a significant role in the defence of the country, particularly because of its sensitive geographical position. From the early 11th century it was recognised as being of strategic importance as part of a front line defence against French invasion. Throughout the Middle Ages, the island was subject to continual raiding from across the channel, to the extent that the first militia and beacon system was established on the island in the 14th century. Raiding continued until the 16th century as successive kings sought to strengthen and consolidate the island with a series of forts and castles, Carisbrooke being the most significant. The island was kept under control of lords until 1583 when governors appointed by the Crown were placed in charge, emphasising its strategic importance to the nation.

The purpose of describing the geography, geology and medieval history of the island is to illustrate the perceived importance of the beacon system. A fuller understanding of its success and functionality can be assessed through Cumulative Viewshed Analysis.

5.1 *Viewshed analysis: a medieval scenario*

The purpose of visibility analysis is to explore the visual organisation of features across a landscape, where the concept of visibility has both cognitive and perceptual implications (Wheatley, Gillings 2000, 3). The strengths of the application have merited its wide spread adoption within Prehistoric and Roman studies, where applications are very different to those experienced when investigating medieval historical data.

In general, viewshed studies are applied upon a "barren landscape", disregarding vegetation, a factor that «can drastically alter the outcome of visibility studies in GIS» (Tschan *et al.* 2000, 29). Yet rather than dismiss viewshed analysis as a work of fiction (Tschan *et al.* 2000, 29) it is important to note the valuable role which it may perform in the assessment of medieval beacon functionality.

The purpose of medieval beacons was such that they required impressive fields of view, both for observation and signalling, which in turn dictates their construction in places of high visibility, such as on ridges and cliff-tops. When located at these prominent sites, the long sightlines afforded suggest that little prior knowledge as to the existence and location of the target point is needed, as beacons are highly visible features in a landscape (Fraser 1983). The influence exerted by vegetation coverage is thus limited as lines of sight are at a high altitude.

Viewshed analysis, and its related techniques, is a tool closely associated with the human capacity of sight (Tschan *et al.* 2000, 33) as it attempts to explore past cognitive acts which had in turn structured and organised the location and form of cultural features. The construction of beacons is a particular act where these visual phenomena can be seen to have significant meaning to the societies who constructed them. Their individual locations are important, as each forms part of a complex scheme of visual pathways providing a link in a chain of similar structures.

For a beacon system to perform its role and to its full potential, individual sites must be visible at the minimum with one other site. Viewshed analysis offers the opportunity to test the functionality of a system and to test if the locating of each site is correct. Where a beacon falls outside the chain, the archaeological interpretation of this site should be re-assessed, or the factor that the complete network may not yet be known be taken into account.

In investigating this "architectural space" (Tilley 1994) of beacons within a landscape, it is useful to consider how important it is to be able to see a particular site or monument, as opposed to knowing or being aware of its presence or location (Van Leusen 1999, 215). This theme is very central to many applications of viewshed analysis, as attempts are made to understand the cognitive landscape. The archaeological question here is one that is focused on the success of such a system, particularly in this scenario as it is the first known medieval beacon system and thus a pioneering defensive undertaking. Where as prehistoric studies, which in Britain are usually focused around the Salisbury Plains, due to their rich data-sets, seek to determine passages of movement and perceptions of the ancient landscape, this challenge in the understanding of the construction of a cognitive landscape is not a focus within this individual study. A current awareness of the purpose and functioning of defensive beacons answers many of the concerns that are raised, as visibility is a vital part of the functioning of such a system.

5.2 *Methodology*

The unique position of the Isle of Wight as the foremost bastion against invasion of England meant that the island was subject to constant foreign invasion over a three hundred year period. Its strategic importance meant that in 1324 the earliest known beacon system of the medieval period was built on the island. It saw considerable use during the invasions of 1338, 1340 and again following the Black Death in 1369 and 1403. The success and use of this beacon system is unknown, but through viewshed analysis it is possible to estimate the success of its positioning and appraise its usefulness to the Islanders. As a first system it clearly would have been innovative in its design, so through viewshed analysis it is possible to assess how inter-visible the beacons were.

5.3 *Data-sets*

The known locations of beacons was extracted from the SMR database through a query which drew out:

1. The SMR No.: to enable cross-referencing.
2. Site Name: for labelling purposes.
3. Period: to check fields extracted were only medieval.
4. Co-ordinates: spatial positioning.
5. Site Type: to verify as a Beacon.

The data set of 28 records was imported in to the ESRI GIS software package ArcView 3.2. Combining this data-set and a generated TIN, which was calculated from 1:50.000 contour data, at an interval of 10 metres, the viewshed operation was performed across the island. At a resolution of 50 metres, the visibility for each of the individual beacons was calculated. The process of determining the cumulative viewshed from these results is outlined below, as is the process by which ArcView calculates a Viewshed.

5.4 *Viewshed analysis*

GIS based visibility analysis provides a natural course whereby to examine the success of the Isle of Wight medieval beacon system. A GIS can rapidly determine how many beacon sites can be seen from any point on the island, as well as provide a comparative sample for statistical testing. The aim of the test is outlined in the ESRI ArcView Manual as follows: "Viewshed analysis identifies the areas on a surface that are visible from one or more observation points. It answers the question: What can I see from these locations?".

The methodology that was followed is that outlined by WHEATLEY (1995, 5) when describing an analysis on long barrows of the Neolithic in Southern England. In order to create a viewshed map, the calculation requires that, for each cell in the raster, a straight line be interpolated between the source point and each other cell within the elevation model. The heights of all the cells which occur on the straight line between the source and largest cells can then be obtained in order to ascertain whether or not the cell exceeds the height of the three dimensional line at that point.

The result of each of these calculations is either a positive (1) or negative (0) result, whereby 1 equals a visible cell and 0 for that which is not visible. Once performed for the entire island, the result is a binary image map.

This process relates to the calculation made for each individual beacon site. In order to create a cumulative viewshed distribution, the process was run individually for each of the 28 sites. Summing all the resulting viewsheds for each beacon created a cumulative viewshed for the complete data-set. Since viewshed maps are matrices of zeros and ones, summing a series of georeferenced viewsheds on a cell-by-cell basis has the effect of increasing the value, by one, for each cell, whenever that particular cell is in a viewshed. Using this equation to construct a cumulative viewshed, the value in each cell thus corresponds to the number of beacons that could be seen from that cell.

One variable that was not considered in this process was the height of the beacon. As this value is as yet unknown and may only be hypothesised, it was decided to use the height value of the beacon location above sea level, as provided in the SMR database.

The resulting image map of this cumulative viewshed calculation may be seen in Tav IIIb. The cells, for the purposes of illustration, have been reclassified to the values of 0 and 1, whereby those areas of the island which have a direct line of sight from the target cell are dark green in colour and those with no line of sight are coded red.

5.5 Initial results

The analysis appears to show that the beacon system established on the island was successful in its placement as a majority of the island was protected. The areas that are invisible to beacons are limited and represent pockets of low lying areas between much higher areas, which perhaps were not inhabited or where beacon sites have yet to be located. Several sites are brought to attention that are indicated as a beacon sites within the SMR, yet appear to have no visibility when explored through the analysis. An explanation for this result is that these beacons, which mostly lie on the north coast of the island, formed part of a network with the mainland. In order to investigate this finding, a future direction of the study will be to conduct viewshed analysis in relation with the mainland and the island.

The binary map calculation, that forms the result of this viewshed analysis, on visual inspection shows a high percentage of inter-visibility. The study would however clearly benefit from a statistical investigation to establish whether the visual cartographic output does contain significant results.

6. The Kolmogorov-Smirnov test of significance

The Kolmogorov-Smirnov test is a non-parametric statistical test that measures the difference between the cumulative proportions of two samples (Kvamme 1990). It was used to test the significance of the results from the viewshed, which appear to illustrate a high proportion of the beacons were visible and had inter-visibility with a majority of the landscape. A pair of testable hypotheses were constructed as follows:

H0: beacons are distributed irrespective of the number of other sites which are visible.

H1: beacons are <u>not</u> distributed irrespective of the number of other sites which are visible.

Using the GIS capability to summarise the characteristics of the cumulative viewshed map (population) and the site (sample number), it is possible to construct a one sample hypothesis test, at the appropriate confidence interval of 0.05, to accept or reject this hypothesis. The pairs of samples – that were subjected to the one-sample Kolmogorov-Smirnov test to determine if the differences between them were significant – were the complete data-set and a sample site, that of Appuldurcombe (the location of which may be seen in Tav. IVa, listed as number 20). The Kolmogorov-Smirnov test locates the point at which the two samples are farthest apart. It then subtracts the lesser proportion from the greater proportion and returns this number as the test statistic. Significance at the five percent level is reached if the maximum difference (*dmax*) between the samples is greater than the value *d* obtained from the sample size, using the following equation:

$$d \approx 1.36 / \sqrt{n}$$

In this formula *n* is the site sample 28. However, a note of caution should be added here as, because the square root of *n* serves as the denominator in this equation, sample size greatly affects the point at which the difference between samples becomes significant. A large sample size lessens the difference necessary for significance to be reached, while a small sample increases it. With a sample size of 28 for beacon sites, the difference (*dmax*) must be greater than 0.257 (*d*) for significance at the 5% level. In fact, the maximum difference between these samples was 0.368, indicating that the H0 hypotheses can be rejected. This result indicates that the locating of beacon sites was completed in respect to where other beacons were placed, suggesting that visual communication was a significant factor for deciding where to construct the medieval beacons.

7. Conclusions

This study has attempted to integrate techniques already present within the capabilities of the GIS with a diverse area of research, that of medieval landscape investigation. In exploring the avenue of research of applying viewshed analysis to a medieval data-set, significant results have been achieved, which in turn feed back into the areas of CRM. Limitations in this study have been noted, especially the exploration of the island as a single entity, taking it out of context with its surrounding landscape. Yet in treating the island as a unique area, it has been possible to explore the application of spatial analytical tools within a controlled environment.

The technique applied within this research has had notable success, and should dispel the reluctance to analyse medieval data within a GIS. Analysis of the beacon system has useful exposed where the faults in the positioning of it lie and where it can be clearly seen that the visual pathways were explored prior to construction.

7.1 *Future directions*

The Cumulative Viewshed Analysis conducted on the available data-set for the Isle of Wight medieval beacons has indicated that the SMR locations are mostly correct and that the siting of these visual phenomena was carefully considered in order to maximise island visibility. Yet whilst these results can be considered significant, some questions remain unanswered, especially the areas not covered by beacon visibility and those identified as having no inter-visibility.

The future direction of this study is therefore to consider the role of the beacons in relation to the mainland defence system. For example, the site of Fort Victoria, identified in the study as having limited visibility lies only 6.5 kilometers across the Solent Water from Hurst Castle on the UK mainland. In fulfilment of the wider research aims of the project, 5 metre contour coverage for the south coast of England and Isle of Wight has been obtained from the British Ordnance Survey, provided from the Land-Form Profile 1:10000 range. This increased accuracy and detail will aid a larger study of the beacon system on the island and its relationship with those on the UK mainland.

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The study forms part of an on-going research program on the Isle of Wight, being conducted by the Department of Archaeology, University of Southampton, with the aim of understanding Medieval settlement and agriculture on the island. Investigations have been conducted on a range of sites, varying from Deserted Medieval Villages to the Cistercian Abbey of Quarr. The initial results of this research indicated a strong pattern of movement of people to and from the island, a probable result of the strategic military importance the island had during the Middle Ages. Therefore, in collaboration with the Isle of Wight County Council Archaeological Unit, an investigation was launched into the success of the medieval beacon signalling system on the island, in order to appraise its success, the choice of positioning and the identification of sites. The results collected through the application of Cumulative Viewshed Analysis were then tested for their statistical significance in order to fulfil the CRM aspect of this research.

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