

Using enhanced GIS surface analysis in landscape archaeology

A case study of the hillforts and defended enclosures on Gower, Wales

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Preface

My professional interest is primarily in teaching and supporting GIS users from undergraduates to postgraduates and researchers in geography and other disciplines at the University of Oxford. Archaeologists have become significant users of GIS at Oxford and this course has enabled me to build on my personal interest and knowledge of landscape archaeology in a way which will enhance my ability to advise and assist GIS users. I am grateful to Oxford University Library Services for their financial support and the help and advice from the University of Leicester School of Archaeology & Ancient History. I could not have carried out the research without access to digital Ordnance Survey data through the Digimap service provided by EDINA at Edinburgh Data Library and I acknowledge their support.

Finally, I have as always appreciated the support of my wife Jill who patiently waited around on wet and windy hillforts while I took photographs and tried to picture the scene 2000 years ago. I dedicate this to her with love.

Chapter 1 Iron Age Gower

The area included in this study covers approximately 150 square km and contains thirty-three Iron Age hillforts and defended enclosures. Nine sites are classed as defensive by the National Monuments Record of Wales (NMRW) with the remainder serving a dual defensive and domestic purpose. The distribution of these sites is shown in figure 1.

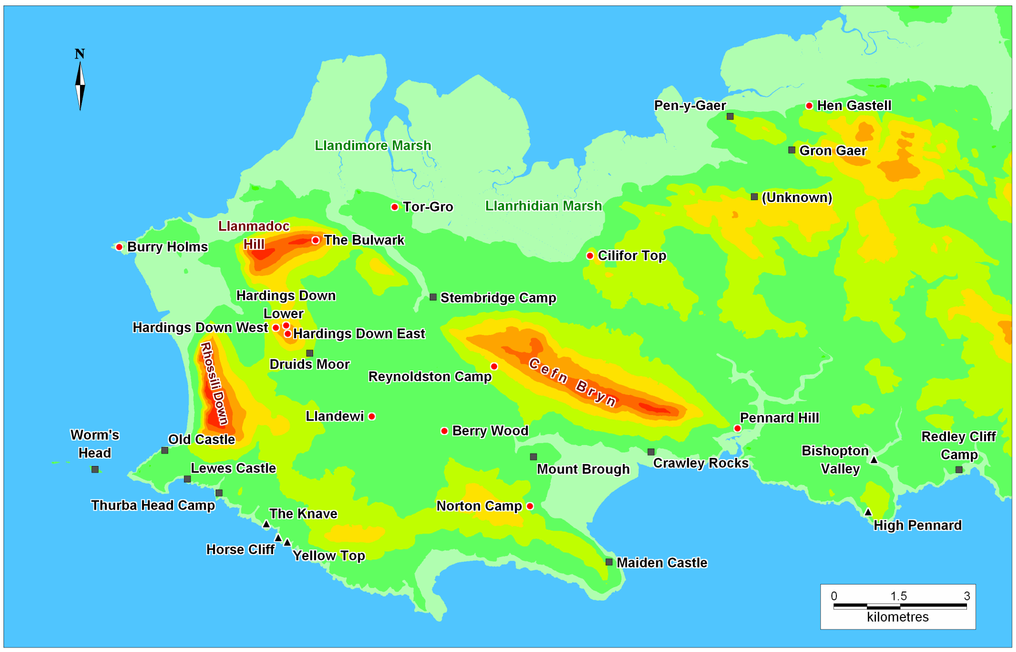

Figure 1: Iron Age forts and enclosures on Gower

(Relief generated from OS Landform-Profile DTM data.
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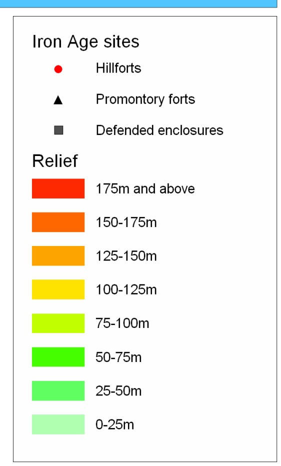

Name	Alternative Name	Type	OSNGR
Berry Wood		Hillfort	SS472884
Bishopton Valley		Promontory Fort	SS569878
Blue Pool Bay	Broughton Burrows	Enclosure	SS407928
Burry Holms		Promontory Fort	SS399925
Cil Ifor	Cilifor Top	Hillfort	SS505924
Crawley Rocks		Promontory Fort	SS518879
Druids Moor		Defended Enclosure	SS441901
Gron Gaer		Defended Enclosure	SS550947
Hardings Down East		Hillfort	SS437906
Hardings Down Lower	Hardings Down North	Hillfort	SS436908
Hardings Down West		Hillfort	SS434907
Hen Gastell	Dan y Lan Camp	Hillfort	SS554957
High Pennard		Promontory Fort	SS567866
Horse Cliff		Promontory Fort	SS434860
Lewes Castle		Promontory Fort	SS414873
Llandewi		Hillfort	SS455887
Maiden Castle	Main Castle	Defended Enclosure	SS509854
Mount Brough	Penrice Castle	Defended Enclosure	SS492878
North Hill Tor	Nottle Tor Camp	Promontory Fort	SS453938
Norton Camp		Promontory Fort	SS491867
Old Castle		Promontory Fort	SS409879
Pennard Hill		Hillfort	SS538885
Pen-y-Gaer		Hillfort	SS536955
Redley Cliff Camp	Caswell Cliff Camp	Promontory Fort	SS588875
Reynoldston Camp		Hillfort	SS483899
Stembridge Camp		Promontory Fort	SS469914
The Bulwark		Hillfort	SS443927
The Knave		Promontory Fort	SS422871
Thurba Head Camp	Pitton Camp	Promontory Fort	SS421870
Tor-Gro		Hillfort	SS461935
Un-named		Enclosure	SS541937
Worm's Head		Promontory Fort	SS393875
Yellow Top		Promontory Fort	SS436859

Figure 2: Iron Age forts and defended enclosures on Gower

Early Iron Age

The caves at Bacon Hole (GR) and Culver Hole (GR) contained evidence of hearths and the remains of shellfish and domestic animals. Excavations in 1856 and 1886 in Bacon Hole produced fragments of an Iron Age 'A' bowl. This suggests that occupation was occasional or seasonal but not necessarily permanent (Hughes 1999, 85).

The Iron Age 'B' period is characterised by the hillforts and defended enclosures. The hillforts on Gower can be classified into three groups:

i. The hill *top* fort, built on a summit with concentric defences.

ii. The hill *slope* fort, lying below the summit on the side of a hill.

iii. The *promontory* fort, which occupies a coastal position.

Hillforts

Gower has two large multivallate forts: Cil Ifor or Cilifor Top (SS505924) is a hill top fort (figure 3) and The Bulwark, on the eastern slope of Llanmadoc Hill (SS443927), a hill slope fort. These may have served as a regional focus (GGAT 2007, 6) or as large tribal villages (Rutter 1948, 65). Cil Ifor covers approximately 3ha and was excavated in 1910, the finds including two stone mortars, a round stone jar cover and iron scoriae, suggesting small-scale iron working (Rutter 1948, 65). The ditches are rock-cut and up to 2.5 m deep (Hughes 1999, 102). Cil Ifor appears to have been occupied through to the medieval period (although this may not have been continuous) as some of the defences appear to be ringworks of medieval date (GGAT 2007, 7). Large enclosures have been identified to the south-west of Cil Ifor from air photography, but their purpose and date have not been verified (GGAT 2006, 7).

Figure 3 Cil Ifor Hillfort from the south (source: author)

The Bulwark is smaller than Cil Ifor, with an internal area of approximately 0.9ha and appears to show evidence of development over several periods (Hughes 1999, 100). The inner enclosed area has an eastern entrance and an incomplete second line of defence. The outer defence is incomplete on the north-east - possibly the steep slope was regarded a sufficent protection. A sub-enclosure is located in the south-east corner which has been identified as a possible animal enclosure. Excavations in the 1870s uncovered animal bones, charcoal and stone implements. A later excavation in 1957 also suggested a second period of construction on the north-west.

Two kilometres south-west of The Bulwark on Harding Down are three sites in close proximity. The relationship and chronology of these sites is not clear. Hardings Down West is a hill-slope fort of approximately 0.4ha with outer defences on the south-east side. Hardings Down North (or Lower), is an enclosure covering approximately 800 sq m with an entrance on the north-west. To the east and near the summit of Hardings Down is the apparently unfinished Hardings Down East fort.

This group is an enigma. It is not clear which was built first – was construction of the East fort abandoned in favour of the West fort, for example? Excavation of the West fort in October-December 1962 showed evidence of substantial construction, with a rubble bank faced with a drystone wall. The entrance on the north-east side was protected by two sets of gates protecting an entrance passage 8 feet wide by 9 feet long and the excavated post-holes for these are still visible. A round hut was discovered near the north-west part of the fort, 7m in diameter and constructed from 6 or 7 posts, with Iron Age 'B' pottery discovered on the floor. Near the centre of the fort a larger (10m diameter) hut was discovered (Archaeology in Wales, 1962 and Hughes 1999, 89).

Promontory forts

The promontory forts appear to have been defended homseteads, as hut sites have been discovered within those sites which have been excavated. The Knave (SS422871) was excavated in 1938 (Hughes, 1999) and revealed Iron Age 'B' pottery, slingstones and a mace butt. The banks were found to be revetted with limestone blocks. Excavations at High Pennard (SS567866) in 1939 (Hughes, 1999) produced evidence of domestic occupation: a mortarium rim, clay spindle whorl, glass fragments and daub were among the finds. Slingstones suggested that the site was intended to be defended (Rutter 1948, 65). Evidence of a timber gateway was found and a drain appears to have been constructed to channel water from the rampart to a pit, possibly to store rainwater. Artifacts found in Bishopton Valley promontory fort during a 1939 excavation included an iron finger ring and iron nail, together with Samian ware and a bronze penannual brooch suggesting continued occupation into the Roman era (Hughes 1999, 104-105).

Defended enclosures

These sites are characterised by a single defensive ditch and rampart. Druid's Moor for example has a bank and ditch defence with a 3m wide entrance on the south-east side. They generally occupy lower ground and can be isolated, for example Mount Brough, or close to a hillfort, such as Hardings Down Lower and Druid's Moor (SS441901). None of the Gower defended enclosures have yet been excavated, although exavations elsewhere in south Wales have revealed evidience of substantial ditches and single defended.

Other evidence for the Iron Age in Gower

The principal occupation of the Iron Age inhabitants is assumed to be farming, but little if any evidence exists to confirm the view (GGAT 2006, 7). The large enclosures noted above near Cil Ifor could be related to farming, either to protect crops from animals or to contain them. The slopes around Hardings Down could have been used for farming, but no evidence has so far been found and Iron Age field systems could have been absorbed into later Roman or Medieval systems.

Chapter 2 GIS surface analysis in archaeology

Historical background

The use of visibility and inter-visibility analysis in archaeology to attempt to understand the spatial pattern of site location has a long history. This was often a textual depiction of the view towards or from a particular site (Lock, 2003, 165) and the antiquary William Stukeley noted the significance in the location of barrows to create a 'false horizon' (Van Leusen, 2002, 6-9). The problem with the visual approach is the human impact on the landscape since the time the monuments were constructed. A simple visual assessment of the inter-visibility between locations is now often hampered by buildings and trees, preventing long-distance viewing except in undeveloped remote locations. In the past, attempts were sometimes made to circumvent this problem by removing obstructions. Sir Norman Lockyer's investigations into alignments centred on the Merry Maidens stone circle in Cornwall involved the removal of sections of walls (Mitchell, 1974, 63) but this is would probably be unacceptable today!

The GIS approach

The use of surface analysis in a Geographic Information System (GIS) provides a possible solution. The GIS approach has been criticised in the past, in particular the geographic nature of GIS which treats landscapes as an abstract geographic object (termed 'Cartesian space'), without the human and historic perspective (Van Leusen, 2002, 6-2), viewed as a revival of environmental determinism, advocated by the processualist approach to archaeology. The rigid nature of analysis using GIS was considered naïve and over-simplistic, reducing the nature of cognitive space to a binary visible/not visible area covering an infinite distance, yet despite these criticisms the use of binary viewsheds in archaeology has become well established. Published research appears to fall into two broad categories. The first uses binary viewshed analysis alone to test the possible reasons behind the location of monuments and structures in the landscape, using inter-visibility as a determining factor. The second approach uses viewsheds in combination with other physiographic data (such as slope and aspect of the area within the viewshed) to establish the influence of the landscape on location, as view alone is just one of many possible reasons for the choice of site.

An example using binary viewshed analysis for testing location is a study by Lock and Harris on the barrows of the Danebury area, cited by Wheatley (Wheatley, 1995) which suggested deliberate placement to *avoid* inter-visibility with other barrows. When applied to defensive structures such as hillforts, the limited overlap between viewsheds could indicate a planned distribution intended to maximise visual surveillance, by maintaining continuous observation with a minimum number of monitoring sites. It could also reflect the desire to create territories with boundaries at the limits of vision.

By combining the viewshed with other landscape data it is possible to move beyond the simple binary test of visibility to include other factors which could influence the choice of location. The Iron Age has left little evidence of farming and settlement outside the surviving forts and enclosures, but such land use could have been significant if the purpose of a hillfort was to overlook a territory. In this case the need for visibility was not just defensive but to observe and control the surrounding area and possibly act as an administrative focus and place of refuge for people and animals.

It is possible to suggest likely areas used for agriculture by analysis of slope and aspect, both of which can be determined from digital elevation data using a GIS. The maximum slope which is compatible with agriculture depends on the method of working the land, especially ploughing with animals. It has been proposed that a slope angle of up to 25% could probably be worked by human labour, but plough animals could not cope with this, so 13% would be their upper limit (Van Joolen, 2003, 28). A southerly aspect would be favoured to optimise solar exposure and this can be determined in a similar way to slope, but using the maximum rate of change in elevation between cells (Chapman, 2006, 83).

Visibility analysis methods in GIS: Line of sight and viewsheds

Inter-visibility between two sites can be determined by the use of *line of sight* analysis. The method is straightforward – the terrain profile along a straight line between two points is analysed using elevation data in a GIS. Inter-visibility is true if no intermediate points are higher than either the observer's position or the target. Figure 6 shows this is the case between The Bulwark and Cil Ifor :

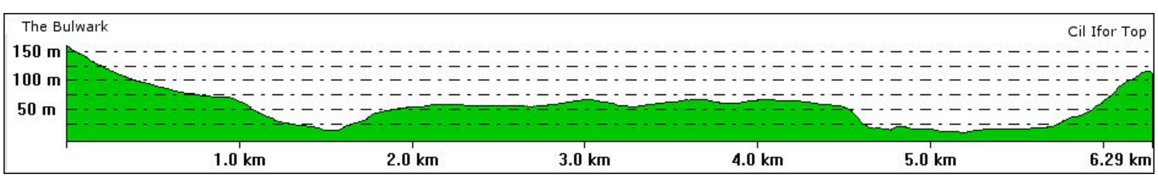

Figure 4: Line of sight profile between The Bulwark and Cil Ifor

Line of sight analysis helps to circumvent the problems noted earlier such as obstructions resulting from later development and changes in land cover, such as planting woodlands. Under favourable conditions the technique can be applied in field observations, but the limiting factor is the inability to test more than one target at a time. To explore the positional significance of a site it is necessary to consider the entire visual landscape surrounding the site. This can be from the point of view of observing (looking out from the site across the landscape) which would be an important factor for a defensive structure or sighting point used to observe solar or other astronomical events. Conversely the site may have been located for visual significance, in which case the area from which the site can be observed has to be determined. This requires the use of multiple line of sight tests to establish a *viewshed,* which determines visible and non-visible areas as viewed from the observer's position. The resulting pattern can then be superimposed on a cartographic representation of the landscape to reveal the visible areas.

Until the development of digital cartography and geographic analysis software (GIS) creating viewsheds was a laborious process. A viewshed examines the line of sight from an observer's location to a number of points in the landscape and without the use of computational methods this would have to be limited to sample points, or the manual plotting of points from contours (isolines linking points of similar height).

Modelling the terrain

Most GIS programs use surface data in a raster format to analyse surfaces. A raster consists of a regular grid of cells encoded with the height of the cell, which can then be used to compute the viewshed. If the source data is at a larger resolution than that required for the surface model, or the spatial distribution is irregular, interpolation is required to estimate values for cells which do not correspond to known values. Data can be derived from contours and using a GIS it is a straightforward process to extract points at regular intervals along a contour line. If this process is repeated for all contours within a defined area a set of source data points will be produced.

An alternative method of computing a surface from heights is the triangulated irregular network (TIN). This uses Delaunay Triangles (a method of triangulation using the three points which fall on the circumference of the smallest circle which contains the points). The result is a faceted surface which has the additional function of depicting slope and aspect (Chapman, 2006, 73). To examine the overlap between viewsheds (and conversely to see how many sites are visible for a given location in the landscape) the cellular structure of a raster surface is required to perform map algebra, which is not possible using TINs. The viewsheds are combined and the binary values summed (with 1 subtracted from each cell to allow for a site 'seeing itself') to create a single multiple viewshed.

Source data

The source elevation data used in this project is the Ordnance Survey Landform-Profile DTM data set. Although the Ordnance Survey refer to this as a DTM (digital terrain model), it is more accurately a D*E*M (digital elevation model). DTMs normally incorporate slope and aspect information (Albrecht, 2007, 62), whereas the Ordnance Survey product only has a height attribute.

The digital elevation data is in the form of a 10mx10m grid. Heights are given to 1cm but the source data (1:10,000 scale contour mapping and air survey) is not necessarily to this level of precision. The Ordnance Survey literature gives a root mean square error (the standard measure of error used in surveying) of +/- 1m (Ordnance Survey, 2001, 3.3). Ordnance Survey do not give further information as to whether the error varies by location and the single figure is effectively a nationwide calculation. The error in the height data will in turn affect the accuracy of any viewshed calculations, but this can be allowed for by calculating the probable accuracy of the result, for example by using Monte Carlo simulation. This uses a random value (in this case it would range from -1 to +1) which is added to each height value. The viewshed is then calculated using the modified values. The process will have to be repeated *n* times and the results averaged to obtain a probable viewshed (Kidner *et. al.*, 2001, 27). This process would be extremely time-consuming and beyond the scope of this project. The viewsheds from the Gower forts extend many kilometres and the effect of a 1 metre error will become insignificant with distance, so the DTM data will be used unmodified. A further characteristic of the DTM data is the smoothing effect of the 10m sampling grid. A cell size less than 10m can be interpolated to create cells with intermediate values which would model slope more realistically between grid points, but ridges or dips between the 10m points will not be recorded. Whilst this would be significant in small-area surface modelling, the surface model will have the same characteristics over the entire area of Gower, so it can probably be ignored for the scale of this project. Of more significance is the assumed certainty of visual state in a binary viewshed and this is addressed in the next section.

Introducing uncertainty into viewshed calculation

Simple binary viewsheds can have one state, visible or not visible. In reality this is over simplistic as view is affected by factors such as distance and viewing conditions. This cannot be modelled in a binary viewshed as values within a range from visible (1) through decreasing degrees of clarity to invisible (0) are required.

The effects of human visual acuity are complex and inter-related, resulting in psychophysical limits to vision (Ogburn, 2006, 406). There are three principal measures: detection acuity (the ability to see a small target against a dark background), resolution acuity (separating the elements of target) and recognition stimulus (recognising and identifying a target). These are measured by the angle subtended by the target object as seen by the observer. In simple terms this means that for a target of given size, the observer's ability to recognise, separate discrete parts or simply detect the object will depend on distance.

One approach to this problem is the use of Higuchi viewsheds, which replace the single viewshed with a series of zones or distance classes which reflect the observer's ability to recognise features in the landscape (Wheatley and Gillings, 2000, 12). Higuchi used the width of a tree as the observed object and proposed eight zones which represented the progressive reduction in the observer's acuity. For convenience these can be reduced to three, representing foreground, middle ground and distant ground. In the foreground zone the observer can see sufficient detail to recognise the tree species from shape and leaf type (recognition zone). With increasing distance this is reduced to a middle-distance view (resolution), where the number of trees can be detected but not in sufficient detail to identify the species) leading finally to a distant view (detection) where colour contrast might suggest trees but only as a contiguous group.

For an observer to be able to detect, resolve *and* identify a target object it has to occupy at least 1° of arc. As the arc decreases the object moves into middle zone until the arc is 3', at which point the distant zone commences. The limit of the distant zone for a person with normal vision is an arc of 1', in perfect conditions of visibility and 20/20 vision the minimum is 30" of arc, but this is the extreme limit and for an observer with average eyesight an arc of 1' is considered the minimum (Ogburn, 2006, 410).

From these visual arcs it is possible to define distances for the three zones, using the trigonometric relationship between the visual arc, distance from observer and object width:

$$\tan(\beta/2) = s/2d$$

where:

β = visual arc

s = object width

d = distance from observer

This can then be adapted to enable a distance multiplier *a* to be calculated, which multiplied by *s* gives the value of *d* for an object of given width:

$$a = \frac{1}{2\tan \beta / 2}$$

Source: Ogburn, 2006

It is clear that the value of ***a*** will vary according to target width. Ogburn used a target width of 1 metre for these calculations and the results are shown in figure 5:

Visual arc	Distance multiplier	Distance (m) for object of width			Notes
		1m	2m	5m	
30"	6880	6880	13700	34400	Limit of perfect acuity
1'	3440	3440	6880	17200	Limit of normal vision
3'	1150	1150	2300	5750	Limit of middle ground zone
1°	57	57	114	290	Limit of foreground zone

Figure 5: Distance Multipliers for a range of visual arcs and object sizes (source: Ogburn, 2006)

Wheatley and Gillings suggest using the *height* of the observed object (in their case, a tree) to calculate the distance multipliers, but visual arc is a horizontal angle (human vision has greater resolving power horizontally then vertically). This inconsistency was noted by Ogburn with an example of Californian Redwood trees, which by virtue of their height would create distance zones significantly larger than in deserts for example, even though the latter would have superior visibility with their lack of obstructions and clear climate (Ogburn, 2006, 408). To avoid this confusion I propose using the width of a person (rather than the height) which will be used to modify the parameters used to generate the initial binary viewshed. Taking a value of 0.7m for this, the recalculated distances are shown in figure 6:

Visual arc	Distance multiplier	Distance (m) from observer	Notes
30"	6880	4816	Limit of perfect acuity
1'	3440	2408	Limit of normal vision
3'	1150	805	Limit of middle ground zone
1°	57	39.9	Limit of foreground zone

Figure 6: Modified distance table for width of one person

Although the Higuchi zonal system improves on the binary viewshed, visibility would reduce progressively once the limit of clear observation was passed (the transition between the foreground and middle ground zones). An infinite number of zones are required to represent the change in visibility but in practice this problem can be addressed by introducing uncertainty (Gillings, 1998, 117). A method of modelling this is the introduction of 'fuzziness' to the result (Wheatley and Gillings, 2000, 9), by using the distance from the observer's position as a weighting factor to modify the visibility value. This produces a more realistic result than the fixed Higuchi ranges.

The notion of using fuzzy set theory to modify the viewshed was proposed by Fisher, who used it in conjunction with distance decay (Fisher, 1994 in Wheatley and Gillings, 2000, 8). It as been noted that Fisher initially misused the term "fuzzy viewshed", by applying it to RSME errors in the DEM, a problem better addressed by using Monte-Carlo Simulation. Fisher corrected this in subsequent work, but it has still been misapplied in archaeological studies (Ogburn, 2006, 408). The Fisher model for a basic fuzzy viewshed assumes that perfect clarity exists to the edge of the foreground zone (viewshed value = 1) and then progressively decreases with distance up to the edge of the middle zone, from which point visibility has little clarity and degrades further until extinction (viewshed value = 0). The formula used by Fisher was based on earlier work on fuzzy sets and is shown below:

$$\mu = \frac{1}{1 + \left(\frac{d - b_1}{b_2}\right)^2}$$

Fuzzy membership (visibility) is represented by μ, with b_1 and b_2 representing the limits of the foreground and middle zones respectively. Distance from the observer is represented by *d*. The value of μ will be 1 to the edge of the foreground zone and then decrease progressively towards 0. The value b_2 will be the distance at which $\mu = 0.5$. This defines the point at which visibility starts to fall noticeably and the observed object subtends an arc of 1'. Using the proposed value of 0.7, the progressive decrease in visibility is shown in figure 9, with the limit of perfect human acuity under clear conditions (0.1) occurring at a distance of between 7000 and 7500m.

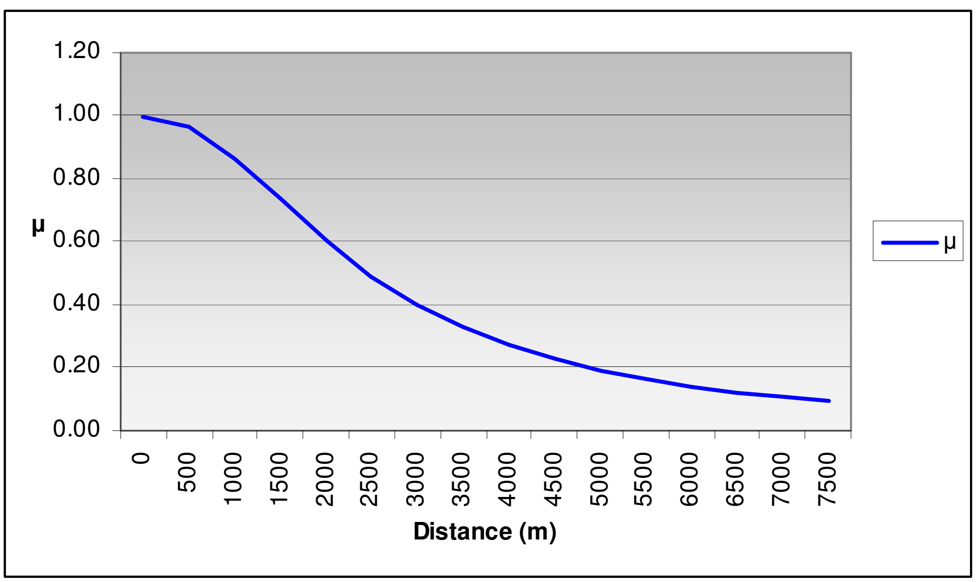

Figure 7: Decrease in visibility with distance where b2 gives a value of μ = 0.5

A problem identified by Ogburn is that the value of 0.5 is associated with a visual arc of 1', the limit beyond which a person with perfect vision can no longer identify an object.

He suggests a value of nearer 0.4 which would allow for less than perfect vision and/or viewing conditions. This requires a modification of Fisher's formula by including a multiplier (in this case 2) so a value of 0.33 for μ is achieved:

$$\mu = \frac{1}{1 + 2(\frac{d - b_1}{b_2})^2}$$

This will be used for the calculations in this project.

The graph of visibility using the modified formula is shown in figure 8:

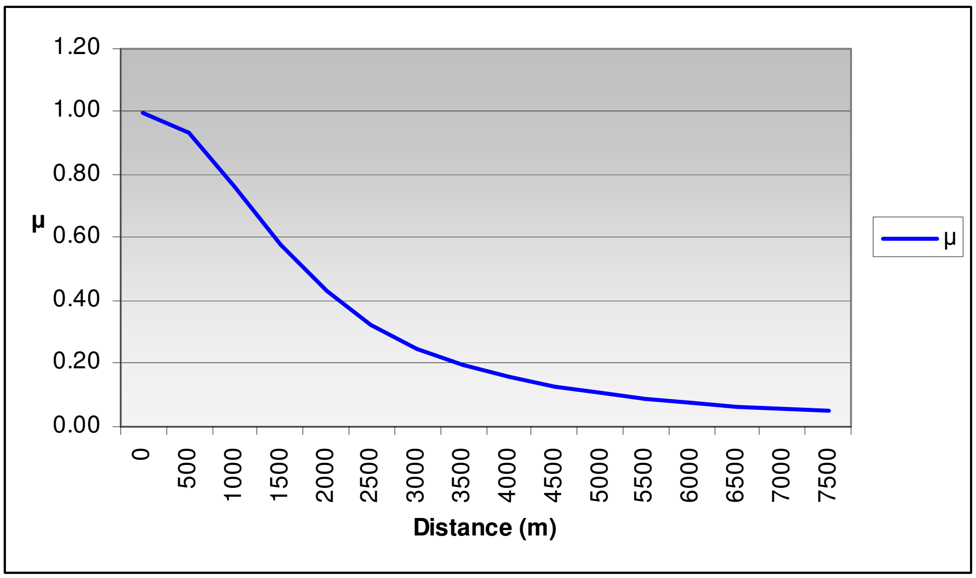

Figure 8: Decrease in visibility with distance where b2 gives a value of μ = 0.33

The use of $\mu = 0.33$ as the value which determines the distance b_2 results in a value of $\mu = 0.1$ at the extreme limit of visibility, the point at which an object subtends 30" of arc. This is a more realistic result than using $\mu = 0.5$ which produces a value for b_2 of between 7000 and 7500, far beyond the 30" limit.

Using these formulae the fuzzy viewsheds of the Gower hillforts can now be calculated and the methodology is described in chapter 3.

Chapter 3 Methodology

The processes involved in this project are shown as a workflow diagram in

Figure 9 below:

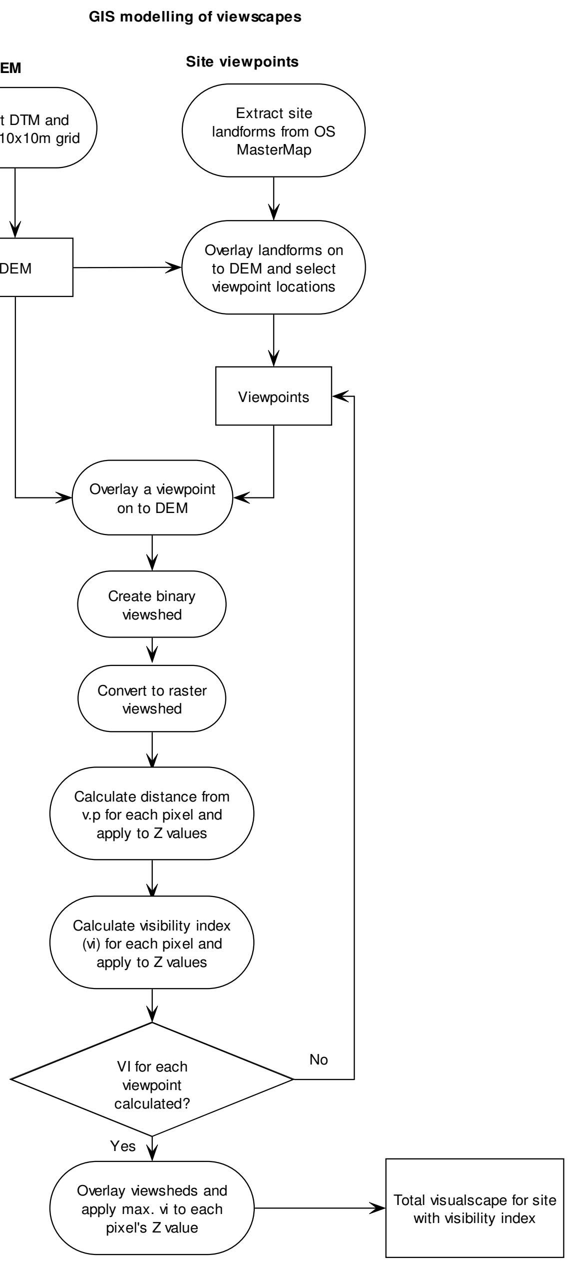

Figure 9: Workflow diagram of cartographic modelling of viewscape analysis. (Source: author)

The data processing and analysis was carried out using two GIS programs: Manifold GIS version 8.0 and Global Mapper version 9.0 (details are listed in appendix 1).

Creating the Digital Elevation Model (DEM)

To create the DEM, Ordnance Survey 1:10 000 scale Landform Profile DTM data was downloaded from Digimap (for details about the Edina Digimap service see the appendix). The data is supplied as 5x5km tiles in NTF format and twenty tiles were required to cover the Gower study area. The data tiles were imported into Global Mapper to create a composite DEM consisting of approximately 5,775,000 10m x 10m cells. The data was imported without interpolation or generalisation so that the optimum precision was maintained.

Selecting site viewpoints

The conventional approach to viewshed calculation has been to take a single viewpoint as the observer's position. This would suffice for a standing stone or summit location as the view would be as seen by an observer as they turned around on the same spot. The views from a hillfort however can change significantly as the observer moves around the site and so the use of multiple viewpoints is essential to build a composite viewshed which takes in the full range of views (Gillings and Wheatley, 2001, 12).

The number of viewpoints and their individual locations for each hillfort was determined by its size, aspect and structure. As a result the number of viewpoints per location ranged from four to ten. The viewpoints were selected from locations along the top of banks, both at the angles and at approximate mid-points, reflecting the variance in heights resulting from the sloping aspect of some of the sites, notably The Bulwark and Hardings Down. Initially the viewpoints were to have been selected by visiting each site and taking GPS readings, but difficulties over access and excessive vegetation growth made this approach impractical. An alternative method was therefore adopted, utilising Ordnance Survey MasterMap data. This is supplied as vector data at 1:2500 scale in multiple layers, one of which depicts landforms which include banks and ditches of the hillforts. MasterMap data for the hillfort areas was downloaded from Digimap and imported into MapInfo 8.0. The landforms for each site were extracted and imported into Global Mapper. The landform objects were then overlaid on to the DEM, which enabled the heights along and across the banks to be examined and suitable viewpoints selected. Figure 12 shows part of The Bulwark as depicted by the Landform Profile data overlaid on to MasterMap:

Figure 10: OS Landform Profile heights for part of The Bulwark

Generating the binary viewsheds

Using the viewpoints for each site, the initial binary viewsheds could then be generated. Global Mapper allows a number of input parameters to be entered and the following were used:

Observer elevation: 1.7m

Target height: 0.5m

Radius: 4.816 km

The observer height represents the eye-level of a typical Iron Age male and the target height was set to 0.5m above ground level to avoid excessive fragmentation of the viewshed which caused by small variations in the height of pixels. The radius was set to 4.816km as this represents the distance at which the visibility index reduces to 0.1 which as explained in chapter 2 represents the extreme limit of visibility.

The results for The Bulwark are a good example of the variation in viewshed area and direction from each viewpoint and these are discussed and illustrated in the following figures. The viewpoints occupy a range of positions, encompassing the overall layout of the site. They represent the changing aspect viewed by an observer moving around both the central part of the hillfort and the outer defensive banks. The separate viewsheds are illustrated in Figure 11 and the areas covered by each viewshed are compared in figure 12:

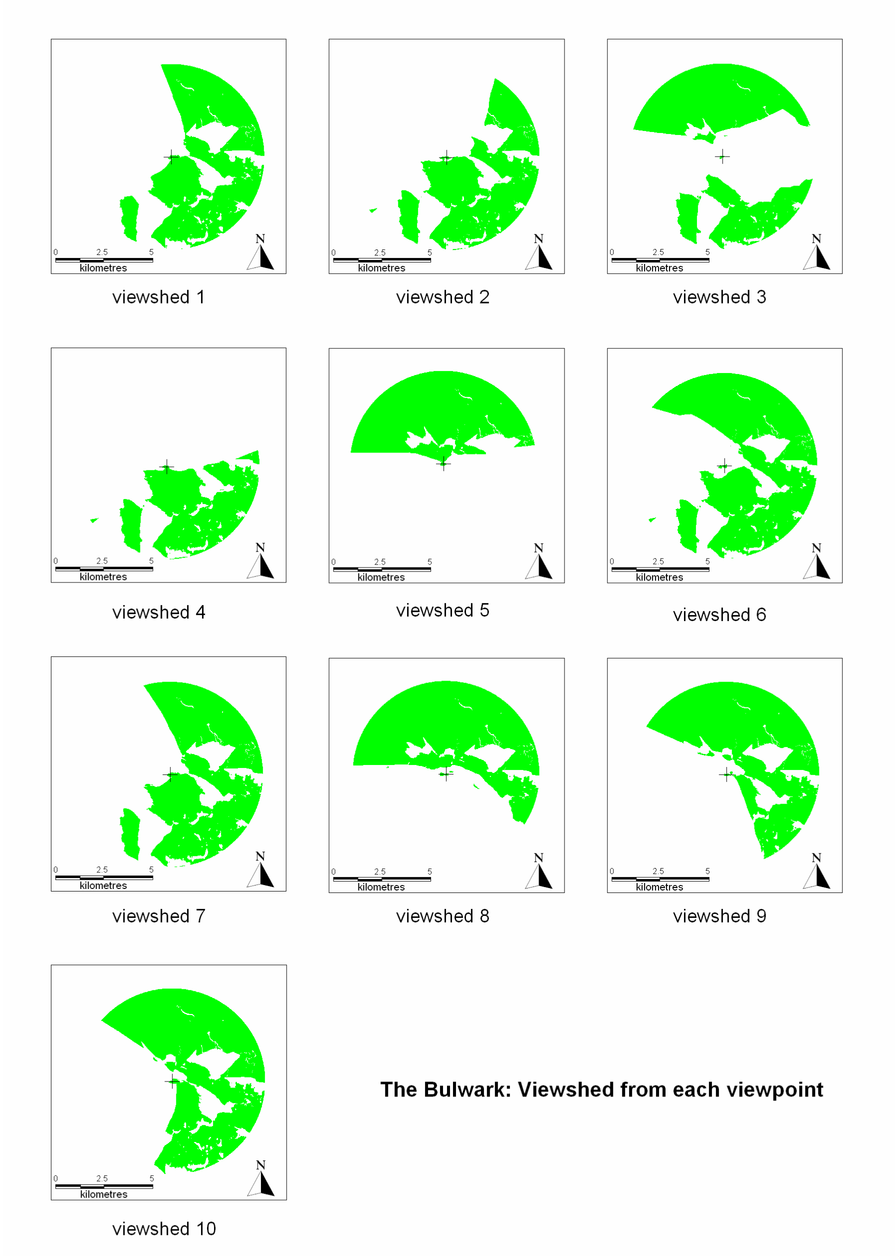

Figure 11: The Bulwark: variation in viewshed direction and area

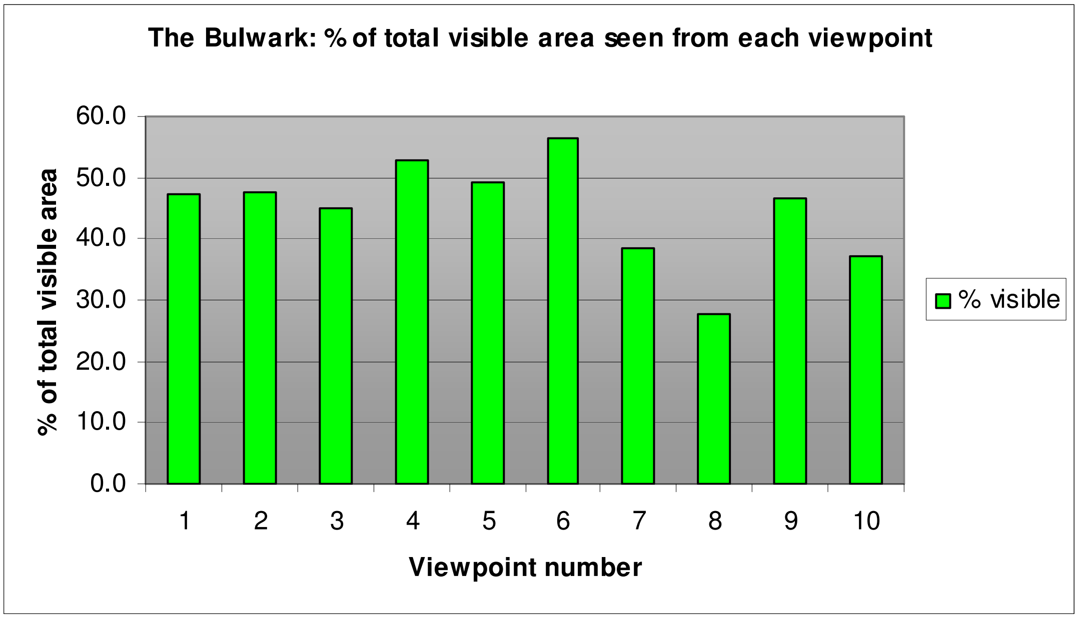

Figure 12: The Bulwark: Variation in % coverage

Figure 12 illustrates the wide variation in direction and coverage at each viewpoint. The average viewpoint coverage is 44.8% of the total area within a 4.816 km radius of the viewpoint. Interestingly even the highest viewpoint (no. 9: 173m) covers less than 50% of the total area, so taking a range of viewpoints is essential to create a realistic total viewshed.

Creating the fuzzy viewsheds

The binary viewsheds were imported into Manifold for subsequent processing, as Global Mapper does not support sophisticated raster queries and calculations. Each binary viewshed was converted to a fuzzy viewshed in two steps. First the Z value of each pixel in the viewshed was changed from the height to the distance from the viewpoint, by using a geographic update query to modify the value. The process calculates the spherical distance (allowing for the curvature of the earth) from the viewpoint's X and Y coordinates to the centre X and Y coordinates of each pixel. Next, the formula given in chapter 2 was used to modify the Z distance value of each pixel to represent the visibility index. This was performed by a non-geographic update query (as this step is purely mathematical and does not use intrinsic spatial values) and the process repeated for each viewshed.

To create the composite total viewshed for the area the individual viewsheds were combined using a conditional argument which allocated the highest visibility value from each of the overlapping viewsheds to the Z value of the composite viewshed. The composite viewshed was then overlaid on the DEM, using graduated colours used to depict the visibility index. The colours were allocated to the visibility index range with green representing a value of 1.0, through yellow for a value of 0.33, to orange and finally red for the extreme limit where the value = 0.1.The results are presented and discussed in chapter 4.

Chapter 4 Results and discussion

The Bulwark

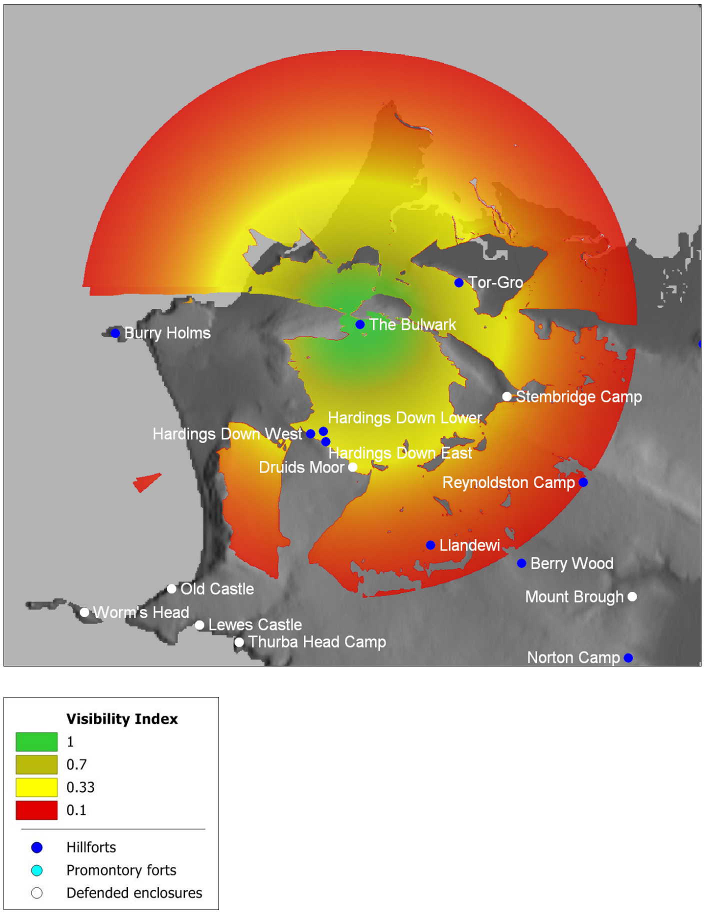

Figure 13: The Bulwark fuzzy viewshed

The Bulwark occupies a southeasterly aspect at the end of Llanmadoc Hill. This would suggest a corresponding viewshed, but as can be seen in figure 16 above it has almost a 270˚ view, with the westerly aspect obstructed by the summit of the hill. The multiple fort complex on Hardings Down is located where µ=0.33, the limit of visual recognition (p. 22), as is Stembridge Camp. Other sites are all beyond this range. The only other hillforts within the viewshed are Llandewi and Reynoldston Camp, but these are close to the maximum limit, over twice the distance to Hardings Down. Close to the fort the area of perfect acuity is interrupted by an area of dead ground directly to the northeast and is abruptly curtailed to the west. The limited view to the west and southwest suggests that this was not considered an area from which a potential attack might arise. The best view is to the southwest where there is little interruption and it could therefore be that the sloping land in this area was the primary area of interest.

Cil Ifor

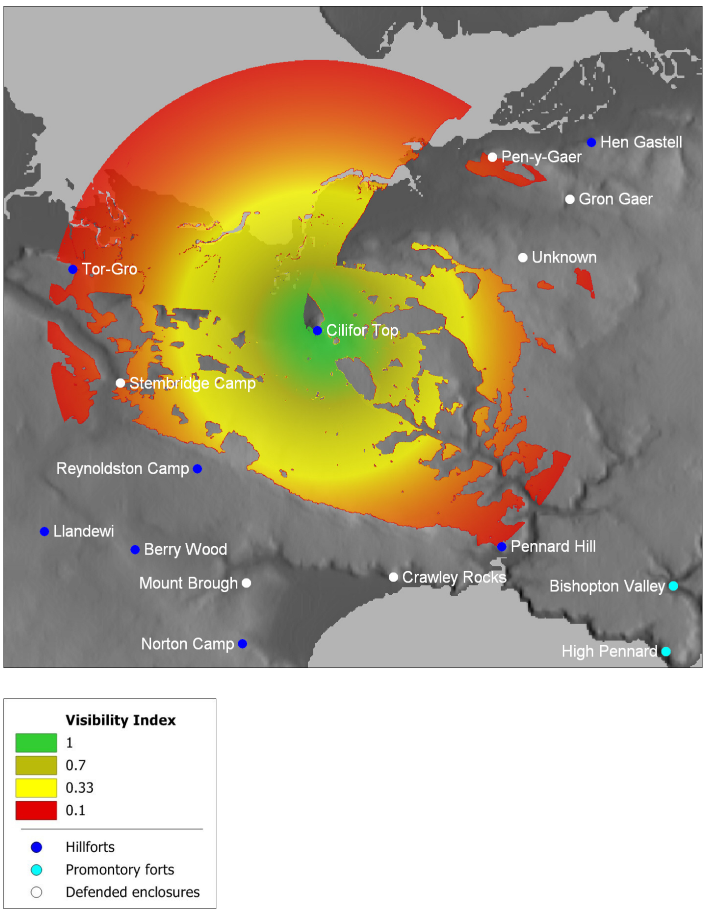

Figure 14: Cil Ifor fuzzy viewshed

Cil Ifor is probably the most defensive hillfort on Gower. It occupies a small ridge giving extensive views to the northwest and apart from the small area to the immediate north, has virtually all-round visibility up to the limit of clear acuity. The view is abruptly curtailed by the long ridge of Cefyn Bryn to the southeast, but it would be possible to see anyone crossing the ridge as they were outlined against the sky. There is also a good view of the coastal salt marsh which would permit easy observation of approaches from the sea. The view is more fragmented to the southeast, obstructed by areas of slightly rising ground.

Hardings Down

This complex of three structures, one apparently unfinished, will be considered as a group. Figures 15-17 below show the fuzzy viewsheds from each site:

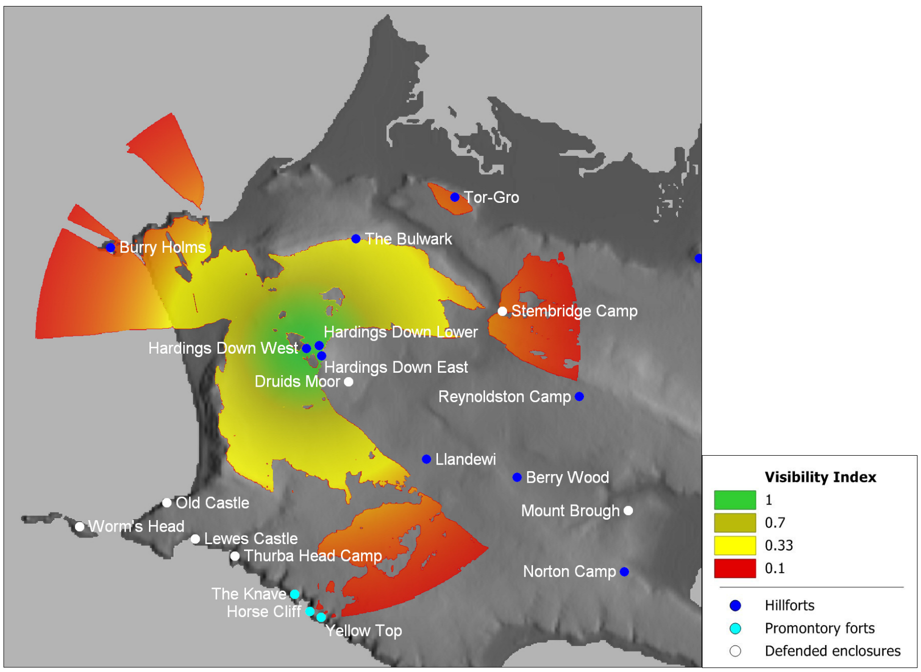

Figure 15: Hardings Down West fuzzy viewshed

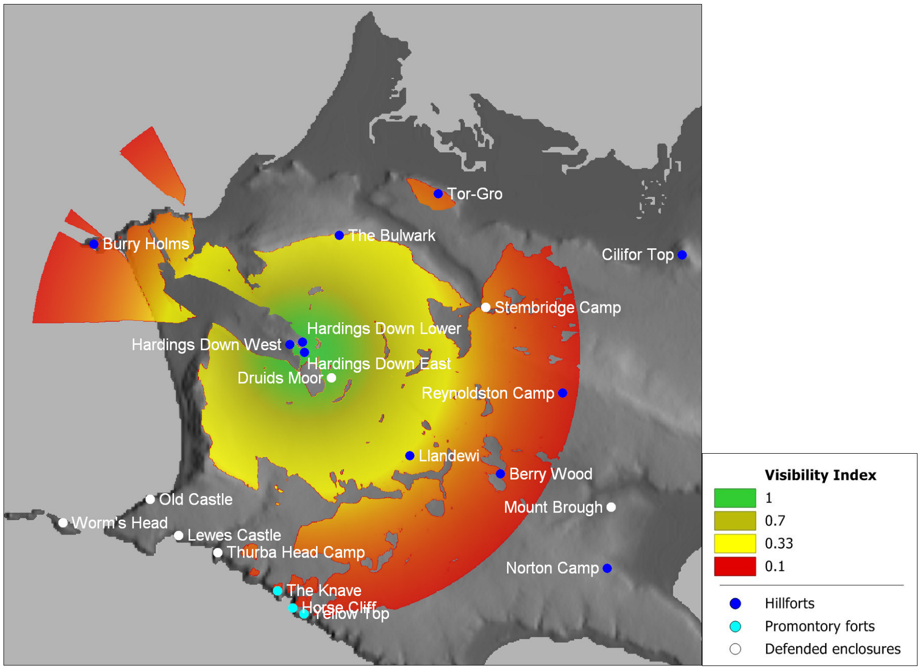

Figure 16: Hardings Down East fuzzy viewshed

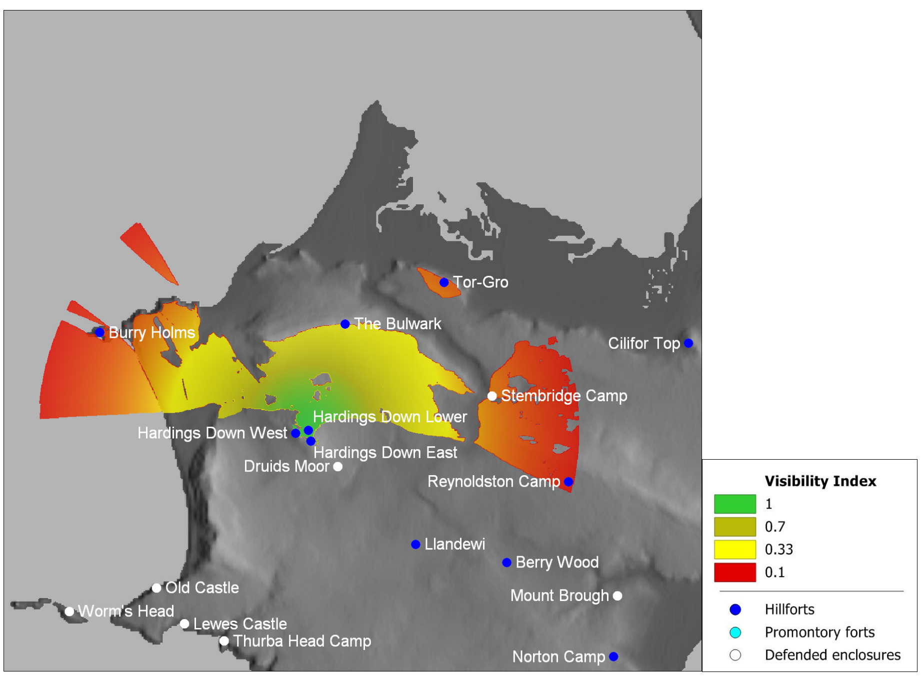

Figure 17: Hardings Down North fuzzy viewshed

Noticeable at Hardings Down West (figure 15) is the significant loss of view to the southeast, due to its position on the west slope of Hardings Down. Three other hillforts are within its viewshed, Tor-Gor, Burry Holms and The Bulwark, although only the latter is within the 0.33 v.i. limit. Apart from the gap at the north of Rhossili Down the view to the west is limited. The ridge of Rhossili Down would however expose anyone approaching from this direction through being silhouetted against the sky. The area of clear visibility extends around the whole of the visible area, so easily monitored, but the obstructed view to the east would be a serious vulnerability. The existence of two outer banks and ditches across this area suggests an attempt to improve defences, but even from here the view extends little beyond the eastern fort site.

Hardings Down East

Hardings Down East hillfort is unusual in that it appears to be unfinished. The eastern defences are fairly complete but to the west there are short lengths of unconnected bank and ditch which suggest a method of construction which was piecemeal and started at separate points. These presumably would have eventually been joined, but the method of construction is not the primary interest here. Rather it is to attempt to answer a question: Was the east site started and then abandoned in favour of the western one, or was it started *after* the west site had been constructed but for some reason not finished?

A clue may be in the viewshed, which as can be seen in figure 16 covers much of the west fort's view, but in addition provide an extensive view to the southeast. Five other hillforts are in view, including the three visible from the west fort. There is an area of dead ground to the northwest which is covered by the west fort, but apart from this the view is far superior. This suggests that the east fort was constructed *after* the west fort, either to enable the area to the east to be observed, or simply to improve the all-round defensive position. There seems little reason to abandon this site *in favour of* the west fort. It is possible that the west fort would be built as an additional outer defence or observation area, but there would then be no need for the defensive banks and ditches between the forts. The assumption here is of course that the purpose of the two ditches was defence, but they could possibly have served some other purpose, such as a demarcation between the two sites.

Hardings Down North

This small site appears to offer little advantage over the two larger forts. Its viewshed is overlapped by the west and east forts and the simple construction of a single bank and ditch could suggest an enclosure, either for religious or other ceremonial use as a defensive structure around a hut or farmstead.

Burry Holms

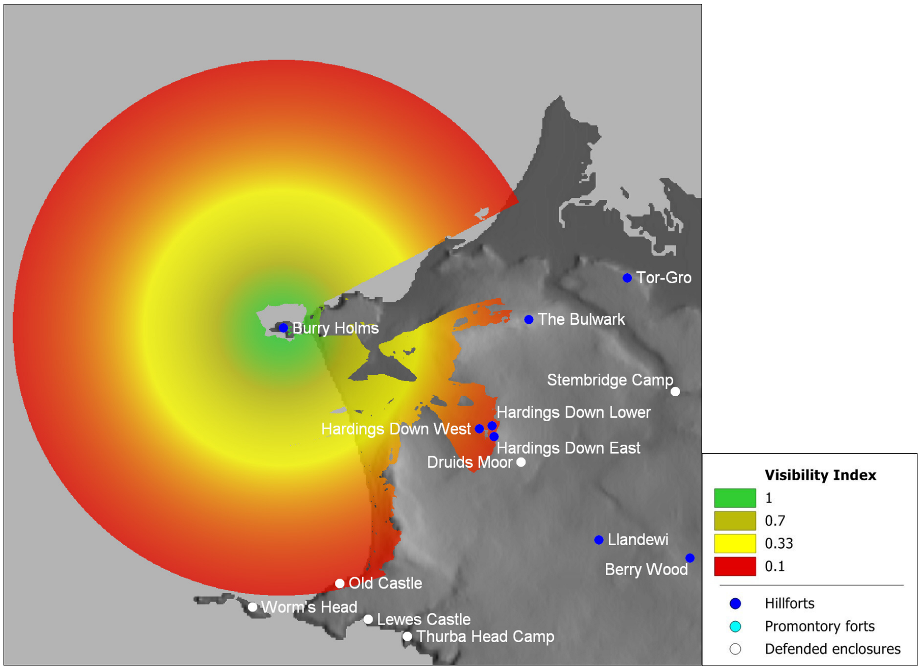

Figure 18: Burry Holms fuzzy viewshed

The site at Burry Holms has a strongly seaward orientation to its viewshed, which would suggest it should be classified as a promontory fort. Unlike the other promontory forts on Gower it also has an inland view and is the only fort which has a view along the coastal side of Rhossili Down. The Hardings Down complex is close to the periphery of the visible range, but apart from Old Castle (a defended enclosure) no other sites are within view. Its location suggests that the peninsula of Burry Holms (which is separated from the mainland at high tide) was chosen primarily for its defensive position.

Hen Gastell

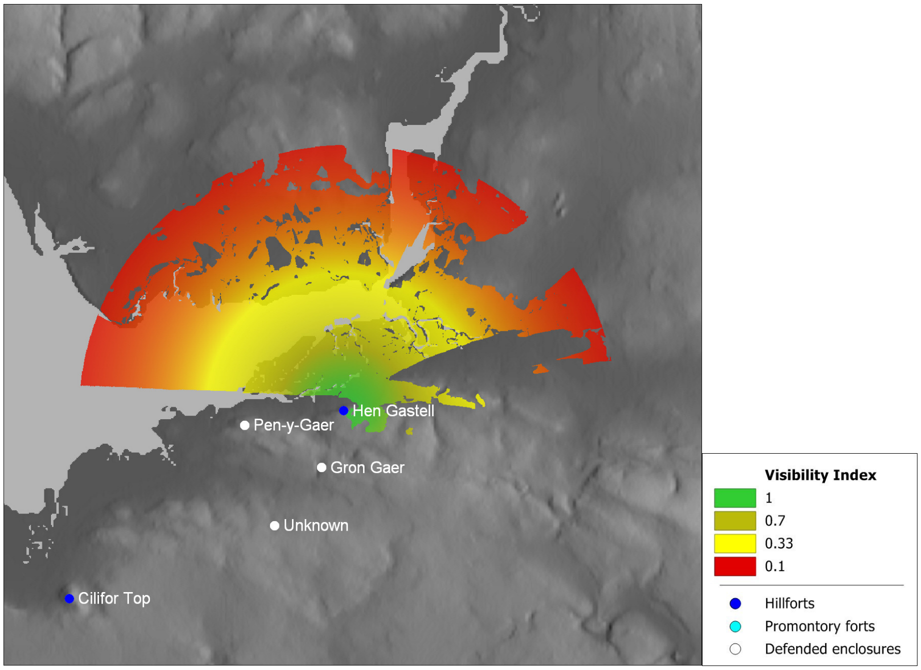

Figure 19: Hen Gastell fuzzy viewshed

The strongly coastal orientation of the viewshed with the area of clear visibility limited to the marshes directly to the north, suggests a promontory type fort rather than a hillfort. No other sites are within view, which indicates that it could alternatively be a defended enclosure rather than a fort.

Llandewi

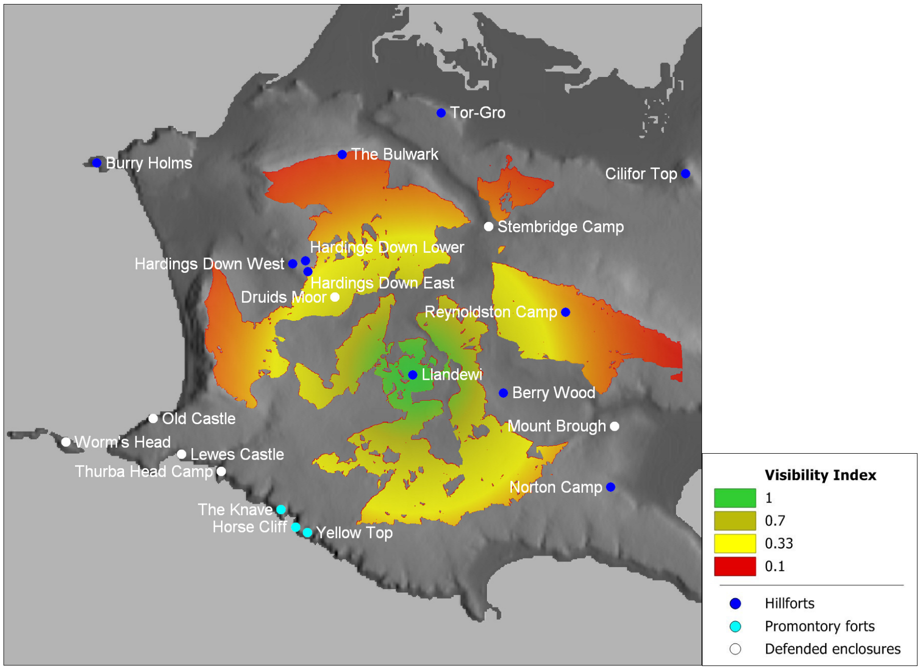

Figure 20: LLandewi fuzzy viewshed

An extensively fragmented view surrounds this location. The area of clear visibility is noticeably isolated and only the forts of Reynoldston Camp and The Bulwark are in view, along with the small Druid's Moor enclosure.

Norton Camp

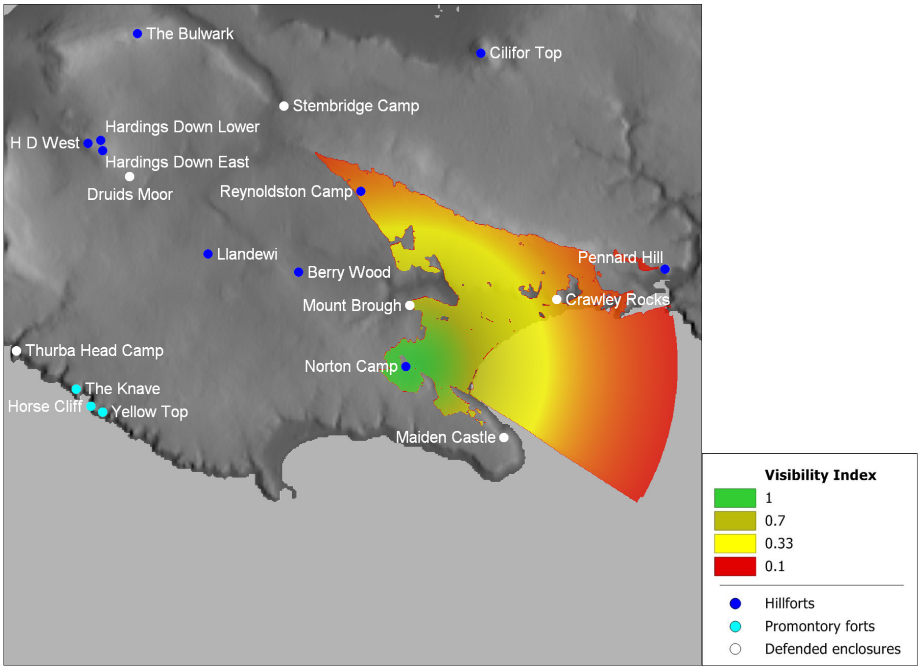

Figure 21: Norton Camp fuzzy viewshed

Whilst the view is clear to the ridge of Cefyn Bryn to the north and east, with Reynoldston Camp on the periphery to the north, this does not suggest a significant fort. The fort at Pennard Hill is barely in sight and none of the sites to the west and northwest are visible. This could be more of a defended enclosure, as in the case of Llandewi.

Pennard Hill

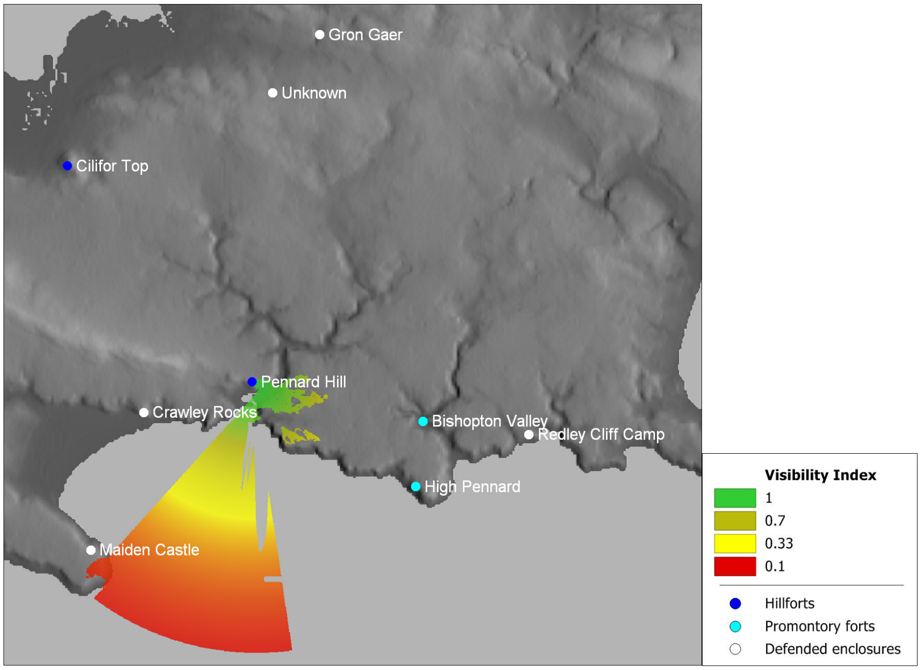

Figure 22: Pennard Hill fuzzy viewshed

Another site with a severely limited view, Pennard Hill again suggests a defensive position with characteristics more like an enclosure. No other sites are within view and the land area extends little beyond the clear zone of visibility.

Reynoldston Camp

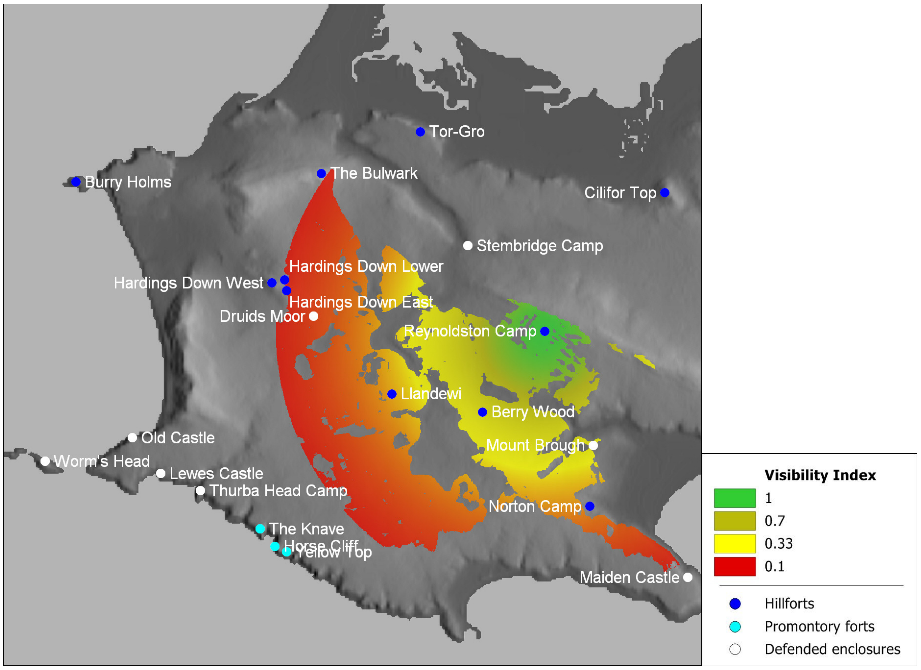

Figure 23: Reynoldston Camp fuzzy viewshed

The view from this site is constricted on the northeast by the ridge of Cefyn Bryn, but extends westwards to Hardings Down and The Bulwark at the limit of visibility. The sites at Llandewi and Berry Wood are within the 0.33 limit, as are the enclosures at Mount Brough and Druid's Moor. As with the sites at Hardings Down and The Bulwark, the main viewshed covers the area bounded by the slopes of Rhossili Down and Cefyn Bryn, but no part of the coast is visible.

Combining the Fuzzy viewsheds – the progression from viewshed to *visualscape*

Before discussing the result of combining fuzzy viewsheds, it will be useful to consider briefly the result of creating a simple binary cumulative viewshed. This can then be compared with the more sophisticated result obtained by using fuzziness. To create the binary viewshed, each separate viewshed is converted to a raster where the viewshed pixel values = 1 and all other pixels = 0. Using a simple update query the rasters can be added together. Each pixel will have a value in the range 0 (not visible from any hillfort) to 12 (visible from all hillforts). In this case the maximum number of overlapping viewsheds is 7. Figure 24 shows the result of combining the binary viewsheds for each of the twelve hillforts.

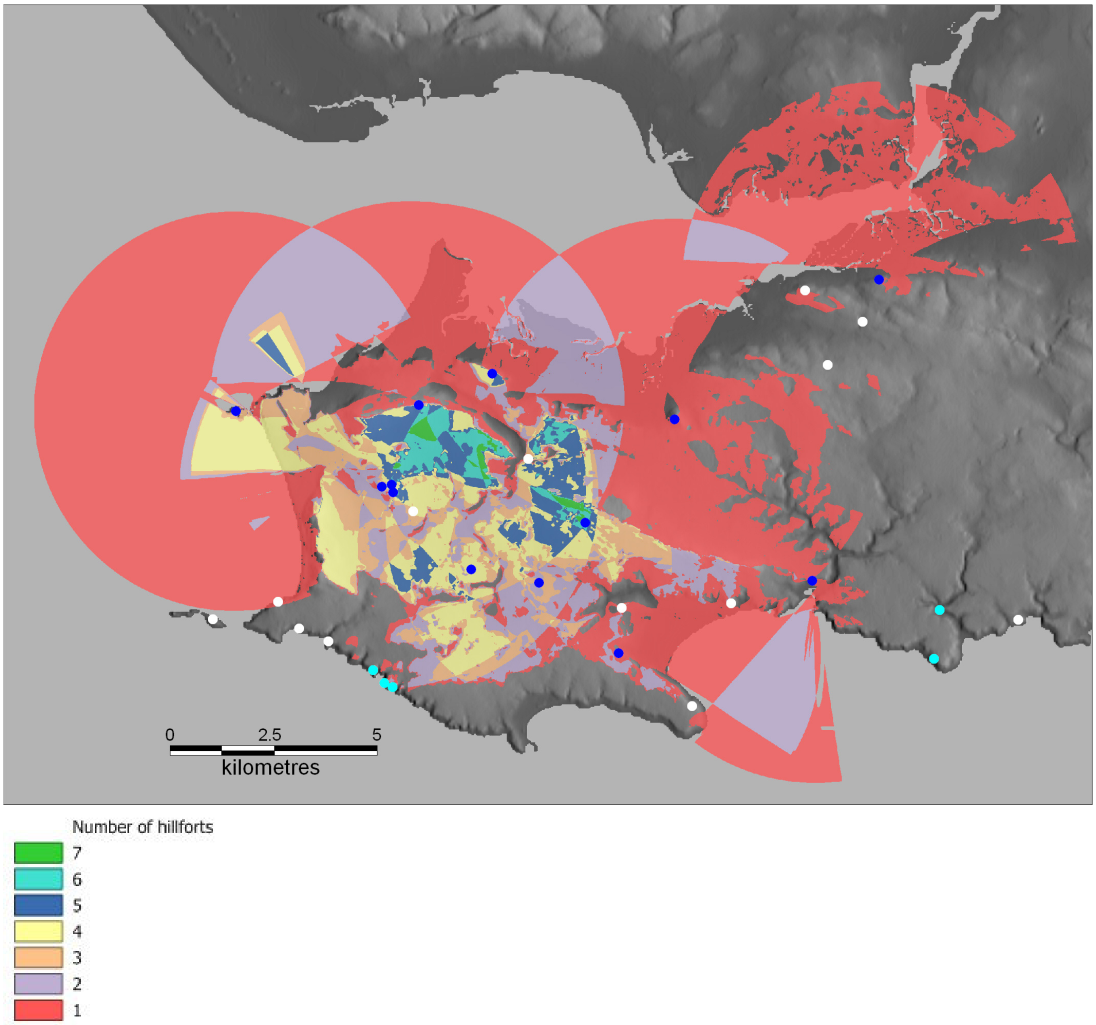

Figure 24: Cumulative binary hillfort viewshed map (number of overlapping viewsheds)

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The map in figure 24 clearly shows an area in central western Gower which is visible from several hillforts and this could suggest an area of settlement and farming. This does not however take into account the distance from each hillfort, so the fuzzy approach would be more appropriate. A similar map can be created by combining the separate fuzzy viewsheds, but in this case simply adding the pixel values will give a meaningless result. The pixel value in the fuzzy viewshed is an index, so an area covered by two overlapping viewsheds where both visibility indexes are for example 0.5 does not mean the area has a value of 1.0. The visibility is still the same from each hillfort. If however one viewshed has a value of 0.3 and the other 0.5, the visibility index will be 0.5 as one hillfort is closer than the other. This means that rather than the summed value, the maximum value of all overlapping viewsheds will be used. The result is shown in figure 25.

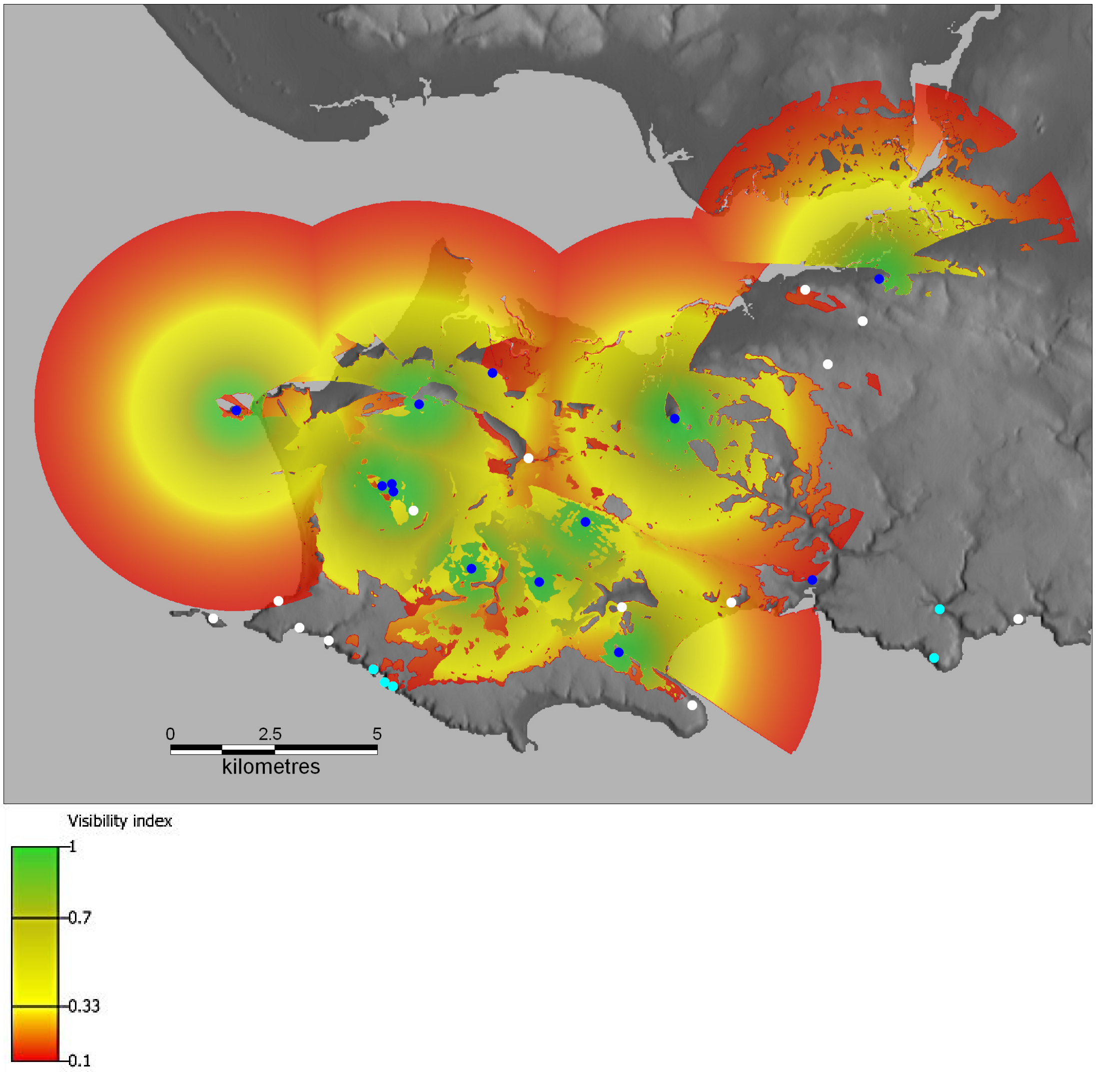

Figure 25: Combined fuzzy hillfort viewshed map

The result is a less fragmented coverage and a number of observations can be made. Each hillfort clearly shows its own area of clear visibility and there are clear zones of separation between them. With the exception of the Hardings Down group, each individual hillfort appears to be beyond the clear visual range of its neighbours, but within the limit of human acuity. There are a few scattered areas which fall beyond the 0.33 value, but much of the area of western Gower is within the visual range of 0.7 and this area is much larger than the binary viewshed map would suggest. It is most noticeable in the area to the north, which although it is visible from only one or two sites is nevertheless under good visibility. These areas could be significant for both defensive and administrative reasons. The former requires a clear view to avoid surprise attack and the latter enables farming and other activities to be monitored. People working and living within the region would be aware of at least one hillfort maintaining a watch almost wherever they were. Interestingly the areas of poor visibility are mostly on the east or north-easterly slopes which would offer poor farming and so less likely to be settled.

Conclusion

The aim of this project was to explore new approaches to the use of landscape analysis in a GIS to explore the pattern of hillforts and other defended sites on Gower. Rather than attempt to defend the traditional binary viewshed approach which has been criticised as being unrealistic and misleading, a more sophisticated methodology has been proposed and demonstrated. A further criticism which often occurs in the literature is that the human aspect is lacking from landscape analysis. Too much emphasis is placed on the physical landscape (height, aspect and slope, for example). This project proposes that the issue of human acuity should be considered when performing viewshed analysis through the application of mathematical processing to apply a 'fuzziness' factor to the result.

This approach suggests new ways of interpreting the landscape are possible which can introduce more uncertainty. That may seem a backward step which contradicts the urge to produce ever more accurate and precise data. There is the danger however that GIS removes that human factor in archaeology by reducing everything to spatial data existing in a virtual model of the landscape. The ability of a GIS to extract considerable quantities of spatial data from surfaces and terrains through its ability to use spatial queries makes it a powerful tool, but it should be used with caution. This project shows there is the potential to further understand the way Iron Age people used their landscape by enhancing the modelling power of GIS through the addition of human characteristics and uncertainty.

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Appendix

Digimap

Digimap is a collection of EDINA services that deliver maps and map data of Great Britain to UK tertiary education. http://edina.ac.uk/digimap

GIS software

Global Mapper

Global Mapper 9.0. Global Mapper Software LLC. http://globalmapper.com/

Manifold GIS

Manifold® System Release 8. Manifold Net Ltd. http://manifold.net