Title:

Mapping invisibility: GIS approaches to the analysis of hiding and seclusion.

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Abstract

Analyses of visibility have become a commonplace within landscape-based archaeological research, whether through rich description, simple mapping or formal modelling and statistical analysis, the latter increasingly carried out using the viewshed functionality of GIS. The research presented here challenges current obsessions with what is visible to focus instead upon the interpretative benefits of considering the invisible and the complex interplay of visibility and concealment that frequently accompany landscape movement and experience. Having highlighted the difficulties in analysing relational properties such as invisibility and hiding using traditional archaeological techniques, a series of new GIS methodologies are presented and evaluated in the context of an original study of a series of remarkably small, visually non-intrusive prehistoric megalithic monuments. The results serve to challenge dominant interpretations of these enigmatic sites as well as demonstrating the utility, value and potential of the GIS-based approaches developed.

Highlights

- The paper demonstrates that GIS-based viewshed calculations (and their obverse), carried out in sufficient number and within a clear theoretical framework, offer considerable potential for the analysis and exploration of invisibility and hiding.
- It shows that global indices of visual concealment and exposure independent of any single designated location, or group of such, can serve as powerful heuristics capable of opening up new interpretative pathways.
- Once mapped, landscape-wide patterns of hiding and exposure can be subject to further interrogation and analysis through metrics such as texture and rugosity that in turn open new directions for landscape research

- Despite being visually unobtrusive and notoriously difficult to find, the tiny prehistoric monuments of Exmoor were not deliberately hidden or concealed through their landscape placement.

Keywords

GIS, viewshed, hiding, concealment, affordance

1.0 Introduction

As expressed through the concepts of looking and seeing, visibility has become a commonplace within landscape-based archaeological research, incorporated in a plethora of different ways ranging from the simple to the more esoteric and complex (Jerpåsen 2009). For example, it can involve merely noting the presence of a commanding or distinctive view when describing a given locale and/or acknowledgement of the role of visual relationships in the structuring of given landscapes (e.g. Cummings and Pannett 2005; Bongers et al. 2012). It can also entail the mapping of visual zones, formal networks of visual connectivity and the statistical interrogation of observed (or claimed) visual phenomenon in order to seek to explain locational choices in the past (e.g. Lopez-Romero de la Aleja 2008; Lake and Ortega 2013; Wright et al. 2014; Brughmans et al. 2015). Visibility patterns and relationships also lie at the heart of avowedly experiential approaches to the interpretation of landscape and location, where visual perception is brought to the fore in attempts to tease out the metaphorical associations of certain landscape configurations (e.g. Tilley 2010).

Since their widespread adoption in the 1990s Geographical Information Systems (GIS) have increasingly been employed in order to explore visual phenomena through their viewshed and intervisibility functions (see Lake and Woodman 2003; Gillings 2009). Most commonly implemented using a raster spatial data model, these tools allow the user to either map the field-of-view associated with a given viewpoint (or group of viewpoints) or determine the presence of unbroken lines of sight between a series of locations respectively. The viewshed, in particular, has become a routine part of the landscape archaeologist's armoury. Although crude in its basic application - delineating as it does no more than a simple binary map of zones that are either in and out-of-view - since its introduction into archaeological research the viewshed function has been finessed through an on-going process of tweaking and refinement; a non-exhaustive list includes manipulation of view angles and parameters, fuzziness, visual acuity, visual prominence, horizon delineation and 3D visibility modelling (Zamora 2008; Rášová 2014; Ogburn 2006; De Reu et al. 2011; Bernardini et al. 2013; Paliou 2013). A parallel strand of research has focused on the heuristic value not of generating individual viewsheds, but instead generating and combining large groups of such. Variously termed Complete-Cumulative Viewshed Analyses (Lake et al 1998); Visualscapes (Llobera 2003), Affordance-viewsheds (Gillings 2009), Total/Inherent viewsheds (Llobera et al. 2010) and Visibility fields (Eve and Crema 2014) these seek to reveal and map global visibility patterns, independent of any single viewing location.

As a result of this on-going research, we now possess a sophisticated and powerful set of tools for answering questions structured around visibility, revealing hitherto unsuspected visual patterns on a global landscape scale, and verifying and assessing the veracity of such patterning in a rigorous and statistically verifiable fashion. The argument I would like to present here is that whilst undoubtedly stimulating, these developments have come at the expense of any sustained consideration of the flip-side of any viewshed calculation – what is out of view. Further that whilst invisibility is itself an interesting locational property to map and explore, the interplay between what is visible and invisible opens wholly new interpretative pathways for exploring past landscapes. In the discussion which follows I present a series of methodological approaches, grounded within a clear and explicit theoretical framework, that seek to bring these pathways to the fore. The potential is explored through the analysis of a group of late-Neolithic to Early Bronze Age standing stone settings on upland Exmoor in the southwest of Britain which have the property of seemingly having been deliberately hidden.

2.0 The Exmoor monuments

The upland landscape of Exmoor is characterised by broad, flat plateaus interspersed by a network of deeply cut stream channels called coombes. What makes the Exmoor monuments so interesting is their elusive, fugitive character – although over 60 have been recorded, they are incredibly hard to find (even when you know where to look) with new examples coming to light regularly as a result of accident and chance encounter (Gillings *et al*. 2010). This is undoubtedly due in large part to their diminutive size (with stones rarely exceeding 0.2 - 0.3m in maximum dimension and frequently much smaller). Yet larger stones were available if they had been required, and one is left with a strong sense that the lack of a substantive visual presence was deliberate. The lack of a visual signature also prompts the question as to whether this desire for seclusion or concealment was also reflected in the locations chosen to erect them. If so it not only implies intention on the part of those raising the stones but brings into question the validity of the interpretative frameworks we use to make sense of megalithic monumental structures of this period, that emphasise prominence (whether social, material or visual) (Gillings et al. 2010; Gillings 2015). The elusive, hidden character of the Exmoor monuments certainly has to be accounted for in any interpretations as to their purpose and placement, and in the most sustained treatment of the settings to date it is notable that as much emphasis is placed upon their chosen location as the tiny size of the component stones (Tilley 2010). In essence, the argument presented is that the settings marked locations that afforded concealed groups of hunters the optimum view of potential game (ibid, 335-346).

In order to assess the veracity of such interpretations as well as broader questions about the hidden character of the megaliths it is important to ascertain whether these diminutive monuments were indeed erected in secluded places or locations that afforded specific visual properties such as seeing-without-being-seen (e.g. hunting blinds). The challenge is one of recognising and interrogating these possible relationships – i.e. analysing invisibility.

3.0 Traditional approaches to determining invisibility and hiddenness

The work of researchers such as Tilley is based upon a sensitive and nuanced reading of the landscape gained through direct observation and experience of it (Tilley 2010). Yet the properties of invisibility, hiddenness and concealment are not kind to traditional experiential approaches to landscape interpretation which are invariably based upon the first-hand observations of a researcher 'in-place'. This is because whilst they are indeed perceptual affordances, they are ones that are impossible to judge and/or evaluate from the locations themselves. As any would-be fugitive can attest, the degree to which a given locale is truly hidden can only be ascertained from every *other* location within a given landscape – it is an evaluation that can only be made by those looking rather than those hiding. Further, if a location is truly hidden then there is a strong chance that it will neither be seen or noted even if subject-centred observations are taken across the broader landscape. Put simply, hidden locations are hard to find. As a result, if we are going to actively factor properties such as concealment, hiddenness and seclusion into our landscape interpretations, going and taking a look is not enough and an alternative set of methods are required in order to map and explore these properties.

4.0 GIS and the mapping of invisibility

It is argued here that one profitable way forward lies with the viewshed and map algebra functionality of GIS articulated within a clear and explicit theoretical framework. Two basic approaches have been adopted. The first is built upon the calculation of the converse of the traditional viewshed, i.e. mapping not the zone which is in-view but instead the area from which a given viewpoint can be viewed. The second begins with a traditional field-of-view calculation, but focuses attention not upon the viewshed (the in-view area) but instead the areas that fall outside of it (what might clumsily be referred to as the out-of-viewshed). In each case this is effected through an affordance approach (see Gillings 2009; 2012) that is based upon the generation and combination of large numbers of viewshed calculations to generate global heuristics independent of any single viewer location. What distinguishes affordance viewsheds from other cumulative visibility products is that rather than seeking to quantify visibility as a morphometric property of the Digital Elevation

Model (DEM), or land surface parameter (e.g. Olaya 2009) they instead treat it as a profoundly relational, or dispositional property that emerges through the practical engagement of animals (most commonly, though not exclusively, people) and topography. For example, an individual seeking to hide, or a group seeking to raise a monument in a covert or secluded location offering good views of potential game animals. The crucial point to make is that these specific properties (for example does a given location hide an individual or allow game to be observed whilst masking the observers?) only manifest themselves in the context of this specific activity and assemblage of actants; the same location may afford very different properties to individual or animals bound up in other tasks and doings, affordance being inexorably bound in the relation between the abilities of animals and situational features. In this sense the concept of affordance being promoted here is directly analogous to DeLanda's notion of relational capacities, properties that emerge from the interaction between people and environment, yet are irreducible to either (DeLanda 2013, 66-67) [1].

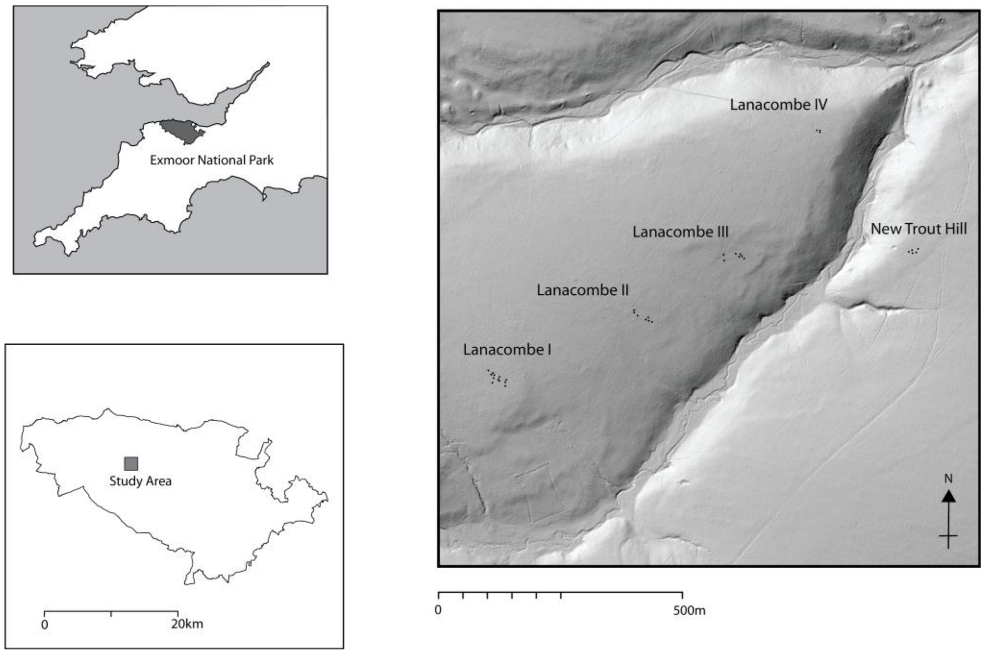

Figure 1 – Location of the Lanacombe stone settings, Exmoor (this figure contains data that is © Crown Copyright/database right 2015. An Ordnance Survey/EDINA supplied service and the Environment Agency).

The analyses were carried out within ArcGIS 10.1 and focus upon a $7km^2$ study area centred upon a group of five of the diminutive megalithic settings located on the plateau spur of Lanacombe (Figure 1). The basis for the various visibility calculations was a 10m resolution DEM encompassing the study area and a 6,880m buffer around its outer edge (Figure 2). The latter corresponded to the maximum viewing range used in the generation of visibility products (see below) and served to remove edge effects (i.e. the possibility that any component viewshed, and the metrics derived from it, might be artificially truncated by the edge of the DEM) [2]. As each analysis represents an individual (e.g. a human or prey animal) engaged in looking for a specific thing (a standing stone, a cluster of such, a human, an animal) it is crucial to control the distance at which recognition is possible. In practice two viewing ranges have been used in the analyses that follow based upon the standard limit of recognition acuity for a 1m wide object (Ogburn 2006, 409-10); the theoretical upper limit of human recognition acuity under ideal conditions (6,880m) and the limit of normal 20/20 vision (3,440m). The choice in each case has been dictated in part by the assumptions underlying each specific analysis (for example global analyses of visual exposure/concealment and distance/direction effects have used the theoretical maximum of 6,880m (Analyses 1, 3 and 5)) and partly as pragmatic consideration in ensuring the feasibility of the analysis in terms of the time taken to carry it out (e.g. Analysis 2). The parameters used for each analysis are detailed in Table 1. The viewpoints used in the various analyses were drawn from a vector point layer derived from the centre points of the DEM grid cells falling within the boundary of the $7km^2$ study area. This resulted in a total population of 70,531 viewing locations regularly spaced on a 10m resolution grid [3]. The approach taken is exploratory insofar as it seeks to assess the veracity of a range of explanatory frameworks that draw upon locational affordances through simple map overlay and visual inspection rather than rigorous probability testing. Whilst a statistical inference framework has not been adopted in the present study there is nothing to prevent such, and the heuristics generated could easily be incorporated into formal modelling procedures if required (e.g. Eve and Crema 2014).

Analysis	Viewpoints	Target cells	Viewpoint offset	target cell offset	viewshed range	Processing time
1 – views to	70,531	2,284,950	0	1.65	6,880m	286 hours
2 – Above Ground Level (AGL) analysis	70,531	805,834	0	1.65	3,440m	373 hours
3 – views from	70,531	805,834	1.65	0	6,880m	286 hours
4 – views to coombe bottom	2,576	805,834	0	1.65	3,440m	3.5 hours
4 – views from coombe bottom	2,576	805,834	1.65	0	3,440m	3.5 hours
5 - distance	493	7,860-212,038	0	1.65	from 0 to 7000 in 500m bands	25 hours
5 - direction	493	128,625	0	1.65	6,880	24 hours

Table 1 – affordance viewshed parameters

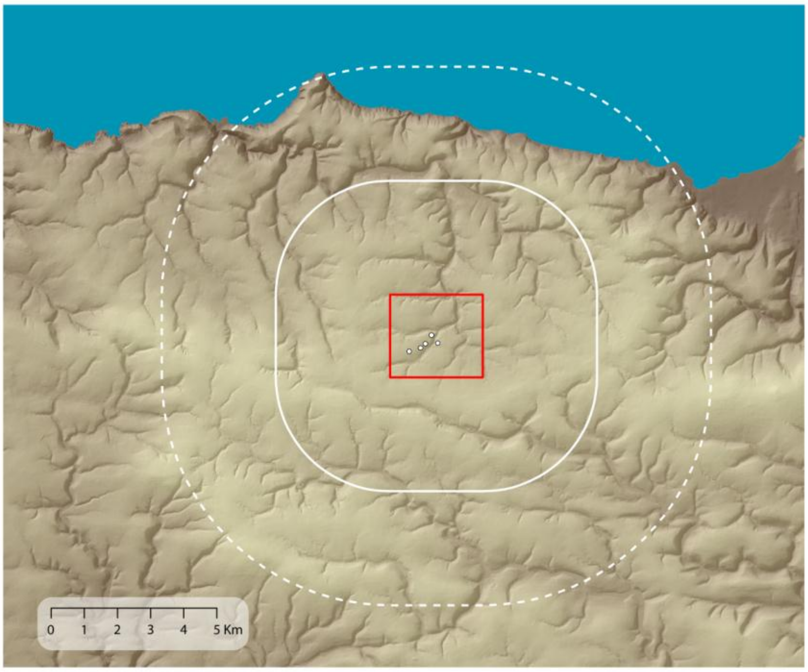

Figure 2 – the study area. The red box delineates the core study zone; the solid white line the 3,440m view limit; the broken white line the maximum 6,880m view extent (this figure contains data that is © Crown Copyright/database right 2015. An Ordnance Survey/EDINA supplied service).

4.1 Analysis 1 - Hidden places?

As hidden places gain their status by dint of being hard to see the most straightforward way of assessing degrees of concealment is to identify the least visible areas of the study zone; i.e. those that afford the lowest chance of being seen. To achieve this the full set of 70,531 viewing locations were taken and using a bespoke Python script, individual viewsheds were calculated for each of the viewpoints to a maximum range of 6,880m [4]. To ensure that the viewshed reflected views-to (i.e. how frequently the viewpoint was visible from the surrounding landscape) the height of each viewpoint was set to the ground surface level whilst an offset of 1.65m (the height of a notional observer) was then applied to the elevation of each target cell. Once calculated, the number of cells that could see the viewpoint was extracted and written back to the attribute table of the viewpoint layer. The final stage was to rasterise the grid of vector points on the basis of the calculated counts to generate an affordance map of global landscape exposure; the lower the cell value, the less often that particular location is seen (Figure 3).

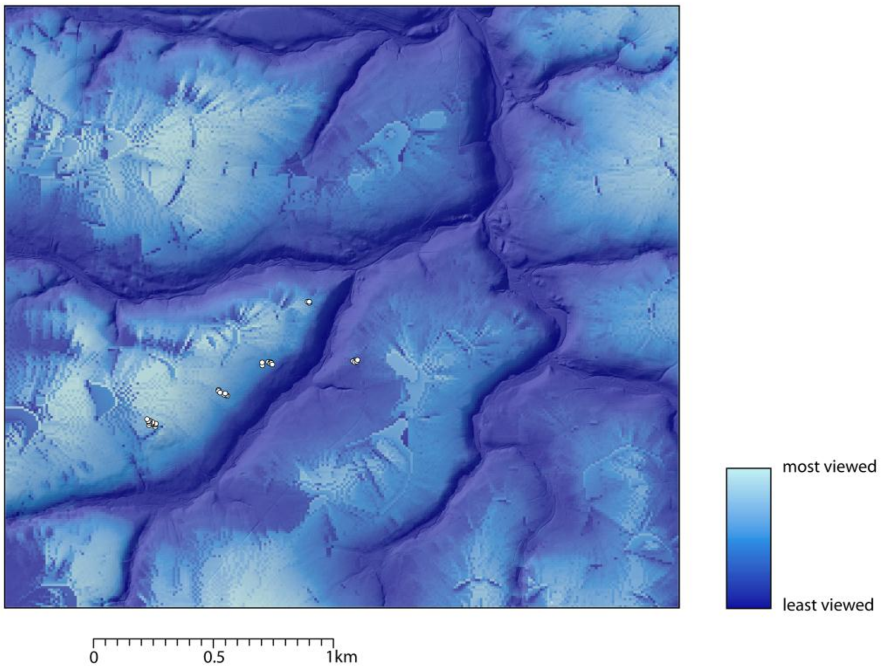

Figure 3 – an affordance viewshed encoding views-to the 70,531 study area viewpoints (this figure contains data supplied by the Environment Agency).

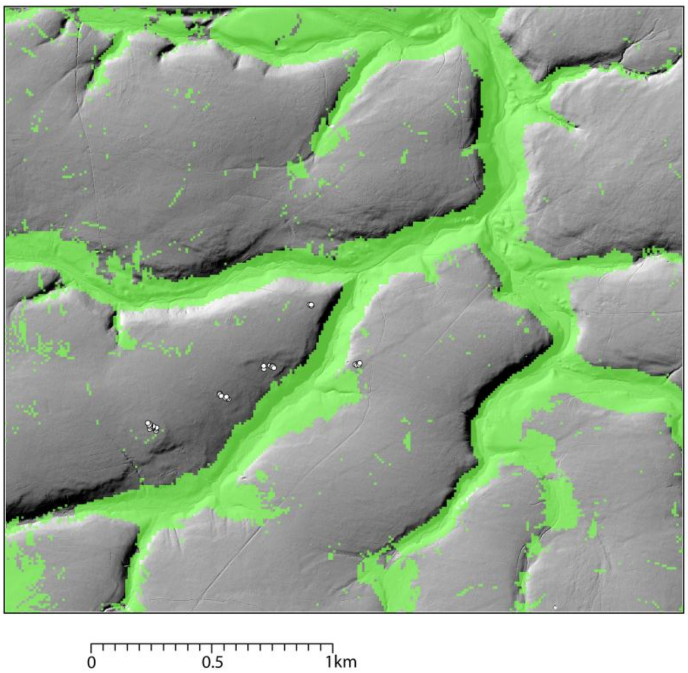

Figure 4 – *the least viewed (lower quartile) zone (this figure contains data supplied by the Environment Agency)*.

With the map in place, the relationship between the monument locations and visual exposure could be explored. At this point the question of thresholds arose in terms of how best to translate the raw count values into meaningful statements about levels of hiddenness or exposure. Whilst this could potentially be calibrated through fieldwork (e.g. of the kind pioneered by Hamilton et al. 2006) as this is a relative measure within any given topographical configuration the decision was taken to focus initially upon broad trends, using quartile values to reclassify the data and treating the upper and lower quartiles as least and most hidden respectively (Figure 4). Visually comparing the locations of the standing stones to the lower quartile it is immediately clear that the least frequently viewed locations fall predominantly within the coombes (deeply incised stream valleys) that cross the study area, below the level of the stone settings. If the intention had been to hide the settings from general view then we should expect to find them tucked away in the coombe bottoms.

4.2 Analysis 2 – a global index of invisibility?

An alternative approach to the analysis of invisibility is to focus exclusively upon the obverse of the binary viewshed; the areas that are out-of-view. This was achieved using the Above-Ground-Level (AGL) functionality of ArcGIS which offers an optional output to the traditional viewshed calculation which encodes for every out-of-view grid cell the number of metres of additional elevation that would need to be added to bring it into view (ESRI 2012) [5]. Although not described as such, what this effectively encodes is the depth-of-hiddenness of each out-of-view grid cell relative to a viewpoint or group of such. Needless to say, if AGL outputs are generated for every possible viewpoint in a study area and combined the result is a different kind of affordance layer - a location independent index of global invisibility where the value of each cell is its summed 'depth' in metres from the full population of study zone viewpoints – what might be termed an invisibility-field (see Eve and Crema 2014). Once again, a bespoke Python script was used to generate and combine 70,531 AGL layers on the basis of a maximum viewing distance of 3,440m (Figure 5). The result once again confirms the visually closed and restrictive character of the Coombe bottoms in comparison to the plateau tops. It also offers little support to the argument that the monuments were located in particularly concealed parts of the overall landscape, the 'hiddenness' values for the component stones falling below the median value for the AGL layer as a whole.

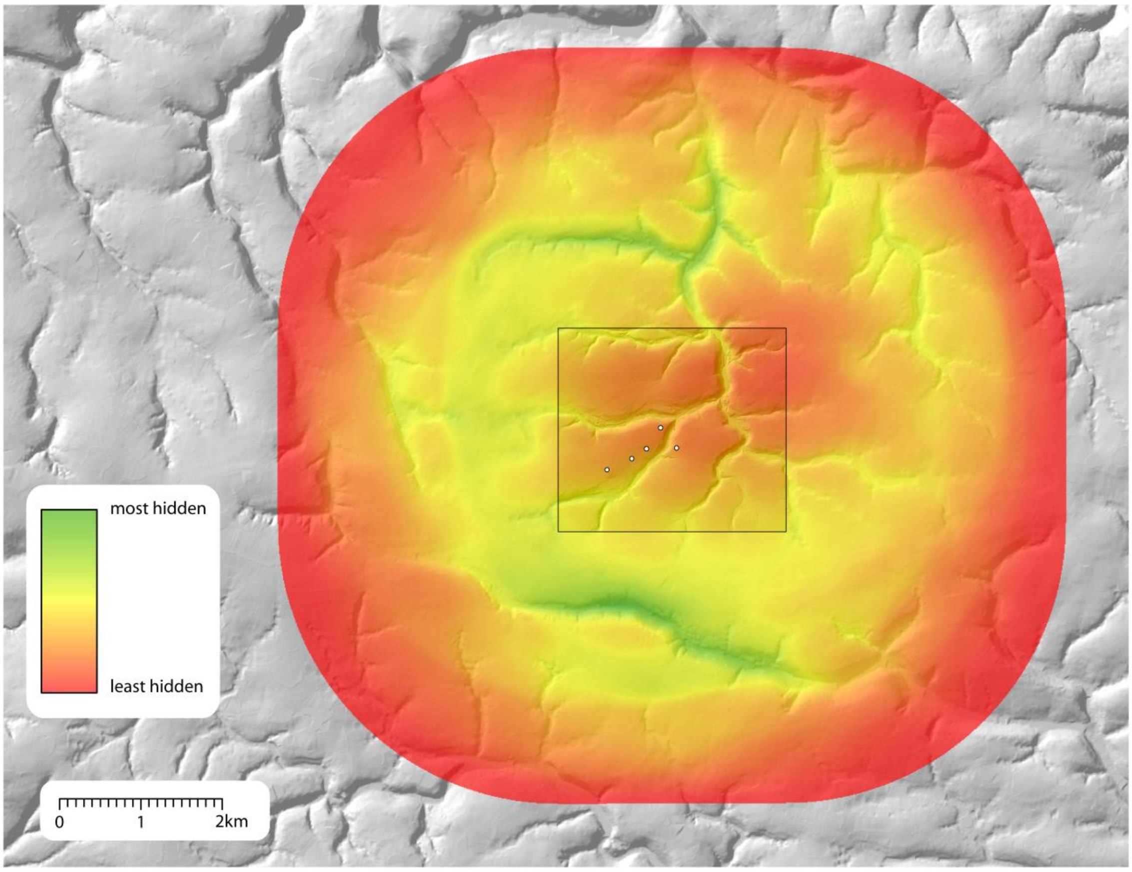

Figure 5 – the results of the AGL analysis of the study area. Please Note: the very low values (red) at the edges of the 3,440m buffered zone are an edge effect resulting from the reduced number of composite AGL layers generated on the perimeter of the buffered central study area i.e. the maximum view range is only reached by viewpoints on the very edges of this zone (this figure contains data that is © Crown Copyright/database right 2015. An Ordnance Survey/EDINA supplied service).

4.3 Analysis 3 - Covert spaces?

Central to the hunting interpretation (Tilley 2010, 335-346) is the interplay between seeing and being-seen that manifests itself at certain locations. This might take the form of covert places, that are hard to see yet afford expansive views (Tilley's hunting locales), or surveillance spaces, that exemplify the paradox of seeing little whilst being overseen (Foucault 1977, 200) that might constitute potential ambush sites. If the latter existed they could be extracted and the visual relationship of the settings to them assessed. To map such areas a second affordance viewshed was generated for the 70,531 core viewpoints, this time reversing the offsets to generate a raster layer where each cell encoded how much of the landscape could be seen from its corresponding viewpoint (Figure 6).

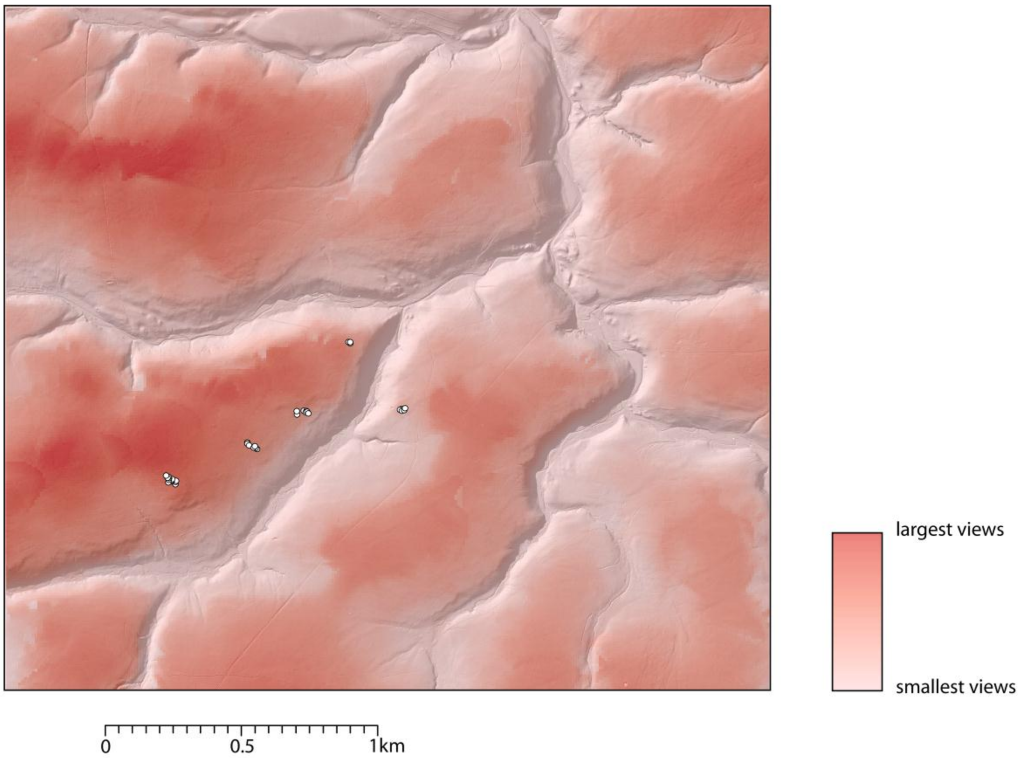

Figure 6 – an affordance viewshed encoding views-from the 70,531 study area viewpoints. The component standing stones of the settings are indicated by the white circles (this figure contains data supplied by the Environment Agency).

The views-to (Analysis 1) and newly-generated views-from affordance viewsheds were then normalised to scale the values to between 0 to 1 and map algebra used to subtract the former from the latter (Figure 7). The possible range of values in the resultant raster layer are summarised in Table 2 where the expectation would be that covert places would be reflected in values close to 1 (++), whereas ambush spaces would lie closer to -1 (--). In practice the resulting values were positively skewed (2.678), ranging from -0.069 to 0.894 (Figure 8). This suggests that whilst there are no convincing ambush locations there are a number of covert places in the landscape with the properties you would expect of an effective hunting blind. Unfortunately these correspond exclusively to the flat plateau tops; areas free of standing stone settings.

		view-to		
	Values	High	Medium	Low
view-from	High	0	+	++
	Medium	-	0	+
	Low	--	-	0

Table 2- identifying optimum places for covert observation (++) and places of surveillance that are overseen without themselves seeing (--)

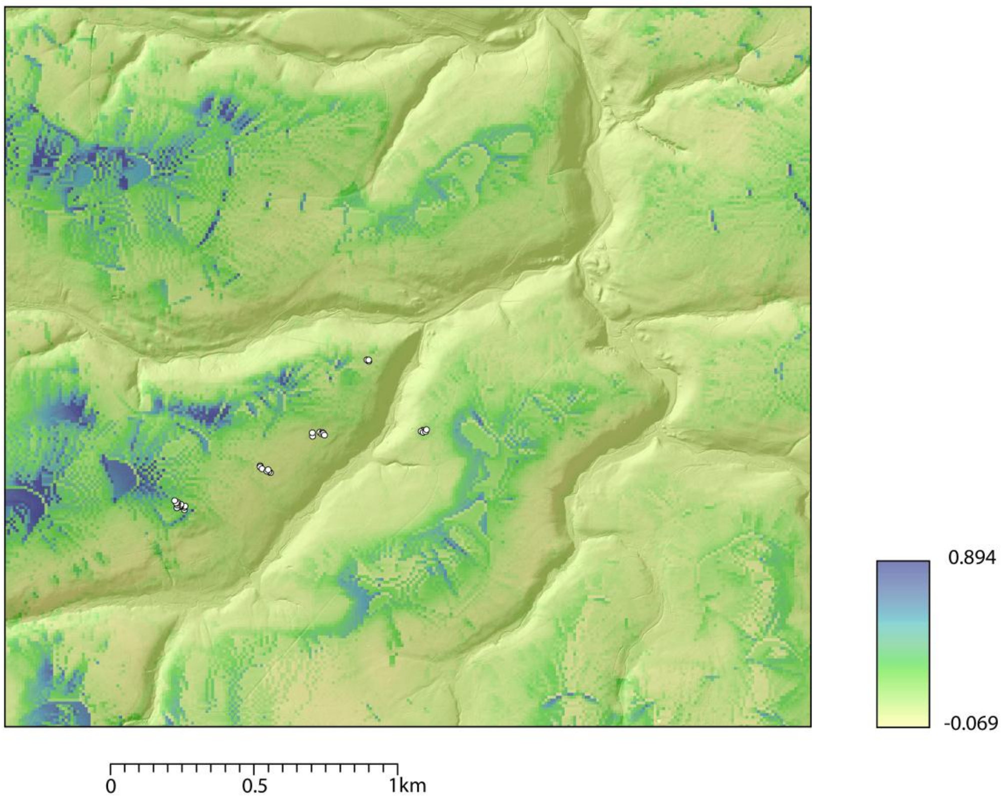

Figure 7 – subtracting the normalised views-from affordance viewshed from the views-to affordance viewshed (this figure contains data supplied by the Environment Agency).

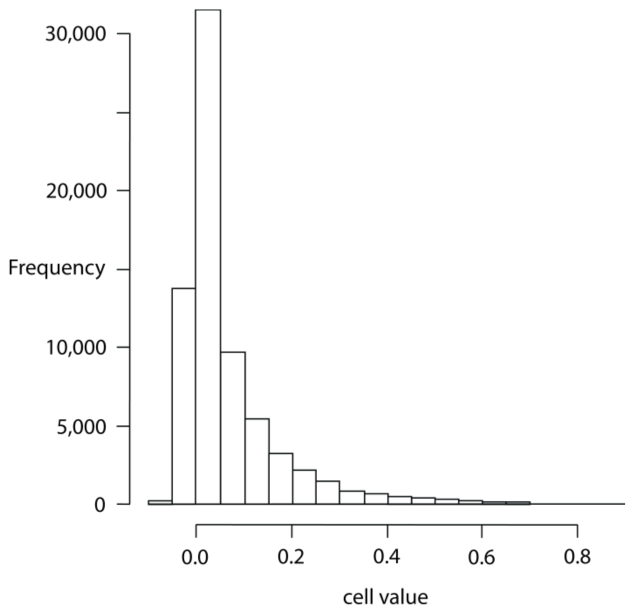

Figure 8 – the corresponding data values (histogram generated in R).

4.4 Analysis 4 – Spying on the coombes?

So far the analyses have been carried out with respect to the entire study area. However, the hunting blind interpretation is framed around the idea that the locations selected afforded specific visual properties (the simultaneous desire to view without being seen) with respect to specific parts of the surrounding landscape; the coombes through which the prey animals were funnelled. To explore this, coombe bottom locations were identified and a linked pair of affordance analyses carried out. To identify coombe bottoms, a raster slope layer was derived from the DEM (Olaya 2009, 144) and reclassified to extract all cells with values of less than 5^0 of slope. The contiguous areas of flat ground making up the coombe bottoms were then differentiated from the equally flat plateau tops and converted to generate 2,576 vector viewpoints (Figure 9).

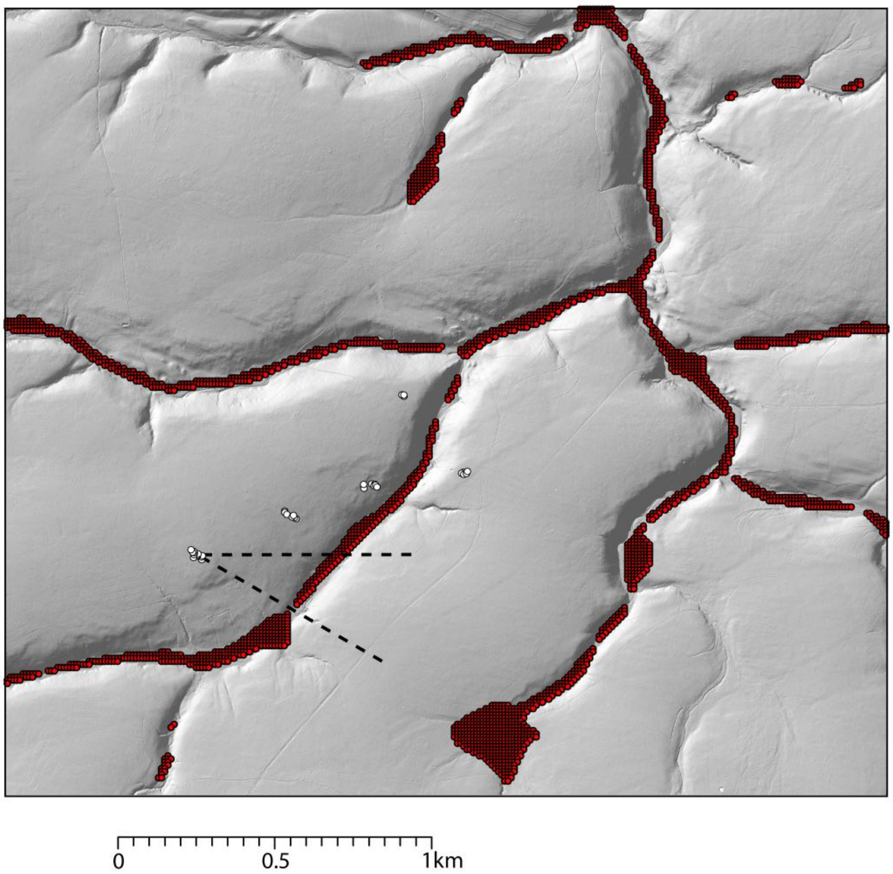

Figure 9 – the extracted coombe bottom viewpoints. The dashed lines indicate the 90 -120^0 directional wedge discussed in Analysis 5 (this figure contains data supplied by the Environment Agency).

Two affordance viewsheds were generated using a maximum viewing distance of 3,440m to encode views-to (as per Analysis 1) and views-from (Analysis 3) the coombe viewpoints. Overlay of the settings with respect to the upper quartile values of the views-to layer showed no consistent pattern, with some falling outside the zone (Lanacombe 1 and 2), some inside (Lanacombe 4 and Trout Hill New) and one straddling (Lanacombe 3) (Figure 10). Likewise the lower quartile of the views-from layer, which showed little evidence of any correlation with the setting locations (Figure 11).

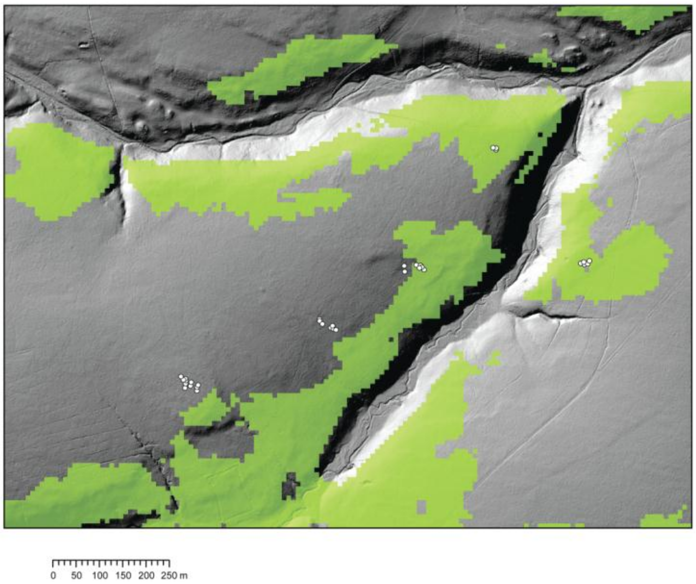

Figure 10 – views-to the coombe bottom (upper quartile) (this figure contains data supplied by the Environment Agency).

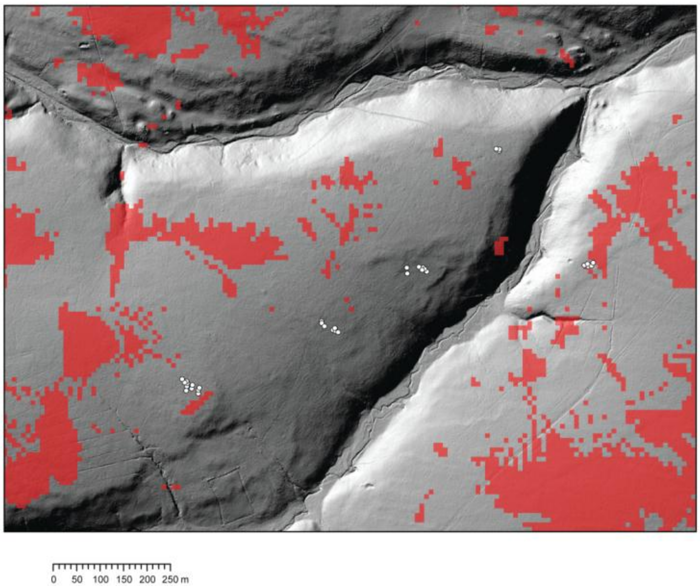

Figure 11 – views-from the coombe bottom (lower quartile) (this figure contains data supplied by the Environment Agency).

Using map algebra, these quartile zones were combined to identify areas fulfilling both criteria (i.e. those offering the most expansive views of the coombes whilst being concealed from them) and thus eminently suitable for hunting blinds. That such areas do exist is clear, as is the fact that the settings are not located within them, the New Trout Hill setting coming closest; sitting to the immediate southwest of such a zone but outside it (Figures 12 and 13). This raises questions regarding the veracity of any locational claims for the settings articulated around visual relationships with the coombe bottoms.

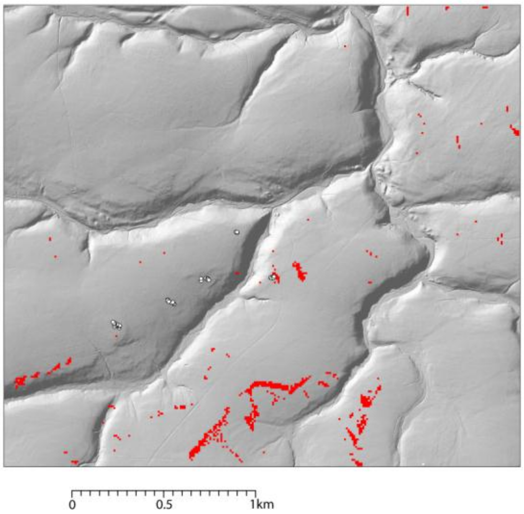

Figure 12 – the zone of overlap (this figure contains data supplied by the Environment Agency).

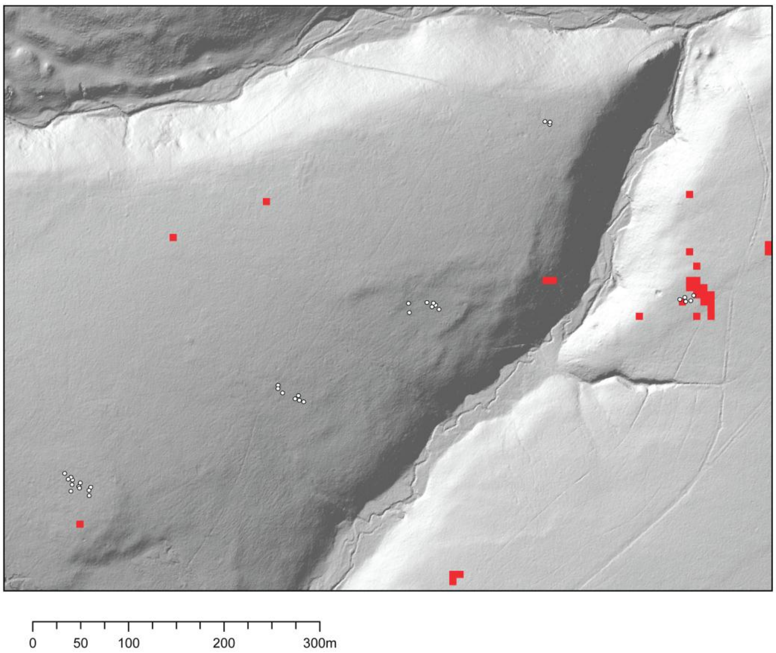

Figure 13 – detail of overlap zone in relation to the stone settings (this figure contains data supplied by the Environment Agency).

4.5 Analysis 5 - is invisibility distance and/or direction dependant?

The analyses of concealment and hiding discussed above have either been global (insofar as the heuristics generated are independent of any specific viewing location) or expressed with respect to particular topographical zones (such as the coombe bottoms). Yet a number of locational studies of prehistoric monuments have stressed that direction of approach, and mobility more generally, can be critical in considering whether the assemblage of monument, observer and topographical location manifested certain visual affordances or not (e.g. Lock et al. 2014; Murrieta-Flores 2014). For example, in the case of early Neolithic long mounds in the British Isles – substantial earthen monuments – direction of approach has been cited as an important determinant in assessing their degree of visual prominence (Field 2006, 109). Further, distance can be critical, with different locations coming in and out of view as you approach or retreat from them, suggesting that the degree to which a given location within a landscape affords invisibility may depend in part upon the distance from which it is viewed. That this property was recognised and actively exploited is once again suggested by the locations of a number of long mounds, which deliberately favour false crest locations that result in the monuments coming in and out of view upon approach (Darvill 2004, 87-88, 92; Field 2004, 107-9). It is important to stress that this is not scale dependency in the geomorphometric sense of different surface parameters manifesting at different scaled catchments (e.g. Wood 2009) nor is it fuzziness with regard to the progressive loss of visual clarity with distance (Wheatley and Gillings 2000; Ogburn 2006). Instead it refers to mobility and the propensity for places to pop in and out of view as an individual moves towards or away from them.

To investigate the impact of viewing distance a variant of the methodology discussed in Analysis 1 was developed which has been termed a ripple study. This involves carrying out a series of affordance analyses on a series of radiating distance bands away from the centre of the selected viewpoints(Figure 14A). The resulting affordance viewsheds can then be compared and contrasted in order to highlight pattern instability indicative of a given location or group of such flipping in and out of view. As a proof-of-method, a 125m radius area was selected centred upon the Lanacombe 1 stone setting resulting in 493 viewpoints. A series of view-to analyses were carried out limiting the viewable area in each case to a discrete 500m band or hoop (the first 0-500m, second 500-1000m etc. up to a maximum of 7000m) (Figure 15). The decision to use 500m intervals was arbitrary and this range can easily be modified dependent upon the required sensitivity of any analysis. In each case the number of cells that could see each viewpoint was stored and a view-to raster layer was generated for each band to allow comparison. To compensate for the fact that the number of potential viewing cells increased with increasing distance and thus make direct comparison meaningful, the recorded counts were divided by the total number of potential viewing cells for each band allowing the values to be expressed as a percentage of the maximum possible view frequency.

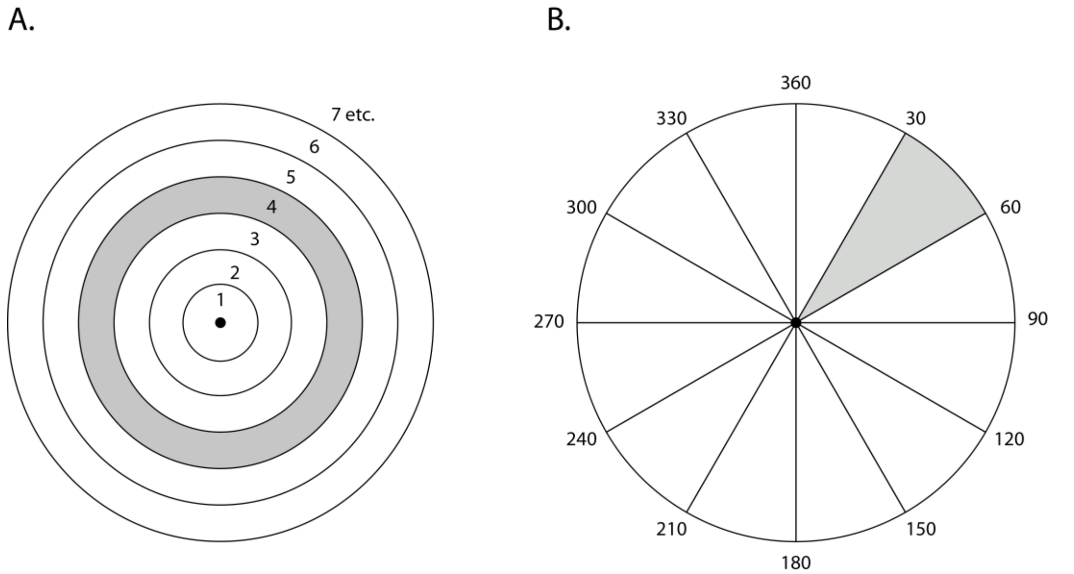

Figure 14 – A. Ripple analysis where a series of separate affordance viewsheds are generated sequentially for radiating 500m bands away from the viewpoint. In this figure the 4^{th} of these bands (1500-2000m) has been shaded by way of illustration. B. Wedge analysis where a series of separate affordance viewsheds are generated sequentially for 30^0 wedges radiating from each of the viewpoints. In this figure the 2^{nd} of these wedges (30^0 - 60^0) has been shaded by way of illustration.

The results show that from a distance of 3km the area slips into what might be termed a less-visually-obtrusive background, though to assess the degree to which this background was typical or atypical with respect to the study area as a whole the ripple study would need to be extended to the full 70,531 viewpoints. Interestingly, applying Ogburn's multiplier of 3440 for 1 degree of arc (normal 20/20 vision) to the 0.2 – 0.3m typical stone width gives a recognition distance range of 688 - 1032m (Ogburn 2006, 409-410) which corresponds closely to the distance band of 500-1000m at which the chunk of landscape containing Lanacombe 1 was most visible.

To explore the question of directionality, a variant upon the above termed a wedge study was developed where rather than sequential radiating bands, the affordance analyses were repeated for a series of angular wedges radiating out from the centre of the study area (Figure 14B). Once again an arbitrary threshold was selected (30 degree slices) and the maximum viewing distance limited to the 6880m maxima (Figure 16). There is a marked directionality to the results with the area containing the Lanacombe I settings most visible from the 90-120^0 wedge corresponding to the area of the coombe bottom through which animals would presumably be moving (Figure 9).

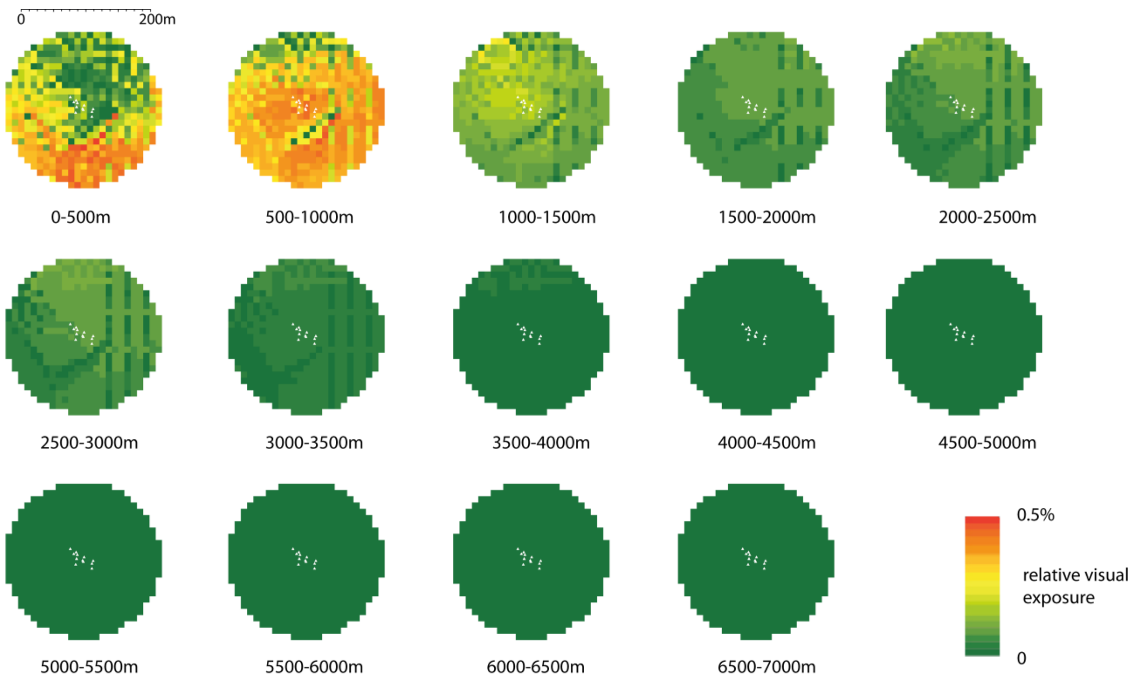

Figure 15 – results of the ripple analysis. The regular vertical banding is caused by artefacts in the DEM (see discussion of Figure 17)

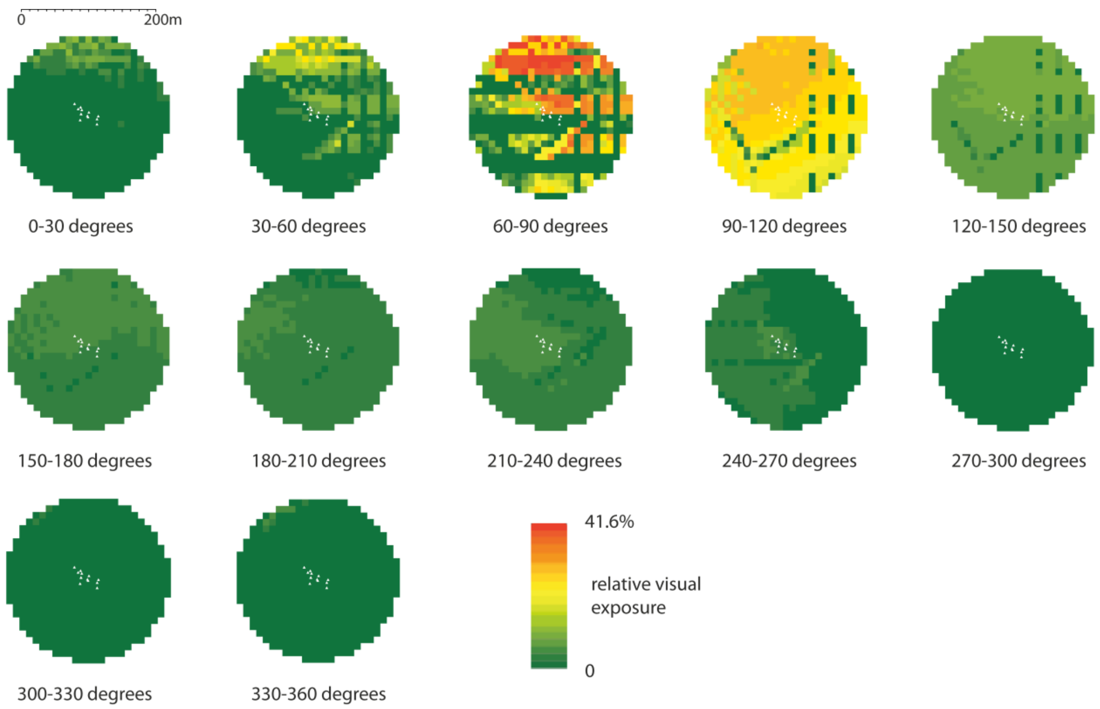

Figure 16 – results of the wedge analysis. The regular vertical and horizontal banding are caused by artefacts in the DEM (see discussion of Figure 17)

Taken together, these preliminary results can be read as challenging the possibility that their diminutive character was reinforced or accentuated by placing them in either deliberately out-of-view places or places hidden from view from certain areas (in particular the coombe bottoms). Instead they are located in an area of the landscape which becomes most visible at the same range at which the stones themselves (and presumably hunters clustered around them) become most prominent from precisely the direction of approaching game [6]. Whilst this method may ultimately be better suited to the investigation of visually imposing structures, the feasibility studies carried out here do allow changing patterns of landscape visibility/invisibility to be charted that can be folded into interpretative frameworks. Although not attempted, the two analyses could also be combined to explore changing directional affordances with distance.

5.0 Discussion

Whilst the interpretative value of a focus on invisibility, explored through an explicitly relational framework is significant, a number of issues remain with regard to the routine application of such approaches. The most straightforward , yet intractable, is the time taken in order to generate them. Whilst viewshed algorithms are computationally simple, they are time-consuming to calculate in large numbers (Table 1). For example, each of the Analysis 1 affordance viewsheds took 286 hours of run time whilst Analysis 2 ran for 373 hours, and these on the basis of a rather crude 10m resolution DEM [7]. Whilst 0.5m LiDAR data for the study area is available, analysing such is simply not feasible. For example the number of viewpoints alone would increase from 70,531 to 28 million and, assuming a maximum range of 6,880m, potential target cells from 2,284,950 to 914,109,032. Whilst research into optimised viewshed algorithm development continues apace, alongside the potential of Graphics Processing Unit (GPU), High-Performance Computing (HPC), distributed and parallel computational approaches to improve calculation speed (e.g. Wu et al. 2007; Llobera et al. 2010; Warn 2011; Toma 2012; Zhao et al. 2013; Ferreira et al. 2014), to date there been little in the way of consensus as to which offers the best way forward and no rigorous formal comparison with regard to the accuracy of the solutions tendered (e.g. Fisher 1993; Kaučič, B. and Žalik 2002). These remain key areas for future research. It could also be countered that quantitative determination of the degree to which a given location is hidden or not completely misses the point of traditional experiential analyses, insofar as what is important is whether a given location *feels* (or is perceived as being) hidden from the perspective of an observer seeking to hide there. In this sense the actual degree of success might be deemed of less importance than the sense of security a location affords. Needless to say, given the latter manifests as a restricted view from the prospective place of refuge it can easily be mapped using the approaches discussed above.

What the study has demonstrated is that factors such as concealment and invisibility can profitably be investigated using GIS. The AGL in particular has considerable potential not least in that having identified the least visible locations within the study area it is a relatively trivial task to extract them and use them to carry out affordance analyses (of the kind carried out in Analysis 4) to identify precisely where they are visible from. Perhaps more intriguingly, it also allows us to extract derivatives, such as roughness and rugosity, that in turn can be used to characterise the texture of a given landscape in terms of hiddenness and concealment [8]. For example, is a given landform characterised by frequent, isolated pockets of hidden ground or more continuous zones that are more frequently out-of-view, and how do these patterns articulate with factors such as mobility, inhabitation and monument placement? A feasibility study was carried out for precisely this purpose, extracting surface roughness and rugosity metrics for the AGL of the study area (Figure 17). Unfortunately the results were dominated by contour artefacts in the source DEM and rather than shedding light upon the nature of hiddenness in this landscape pointed instead to the need to pre-process the DEM prior to any further viewshed-related analysis (Reuter et al. 2009). Despite this, the approach itself is robust and the formal analysis of the parameters of the AGL surface is an area that would merit further research.

6.0 Conclusions

In the preceding discussion I have argued that not only is invisibility a potentially important heuristic, but it is one that computational approaches are uniquely placed to investigate. Using the example of a group of visually underwhelming prehistoric stone settings, a series of analytical methods have been proposed in order to determine whether the sense of deliberate concealment engendered by the diminutive scale of the stones used to construct them was further reinforced by careful choice of hidden locales within which to erect them. To explore this a series of computational methodologies have been proposed to analyse invisibility, concealment and hiding based upon simple GIS-based viewshed calculations, albeit generated in very large numbers and carefully controlled using offset, angle and distance parameters. The analyses carried out have demonstrated that by careful use of map algebra, the affordance layers that are generated by the various studies can be further compared and contrasted in order to explore the tensions that exist between states of seeing and being seen. Further, by focusing upon factors such as distance and direction questions of movement and mobility can begin to be addressed; indeed the AGL mapping would make a very interesting input into the generation of view-paths (e.g. Lock et al. 2014) and visibility fields (Eve and Crema 2014) not to mention cost-surfaces more generally (Wheatley and Gillings 2002, 151-159). Whilst very much a proof-of-method, the analyses of roughness and rugosity also open up the possibility of applying the full suite of geomorphometric tools to the interrogation and exploration of the visibility surfaces generated. This in turn has theoretical implications with respect to our ability to delineate and map not only a richer and more nuanced set of relational capacities, but through these begin to develop methodologies for realising the potential of powerful new frameworks and heuristics such as assemblages and affective fields (e.g. Fowler 2013, 20-58; Harris and Sørensen 2010).

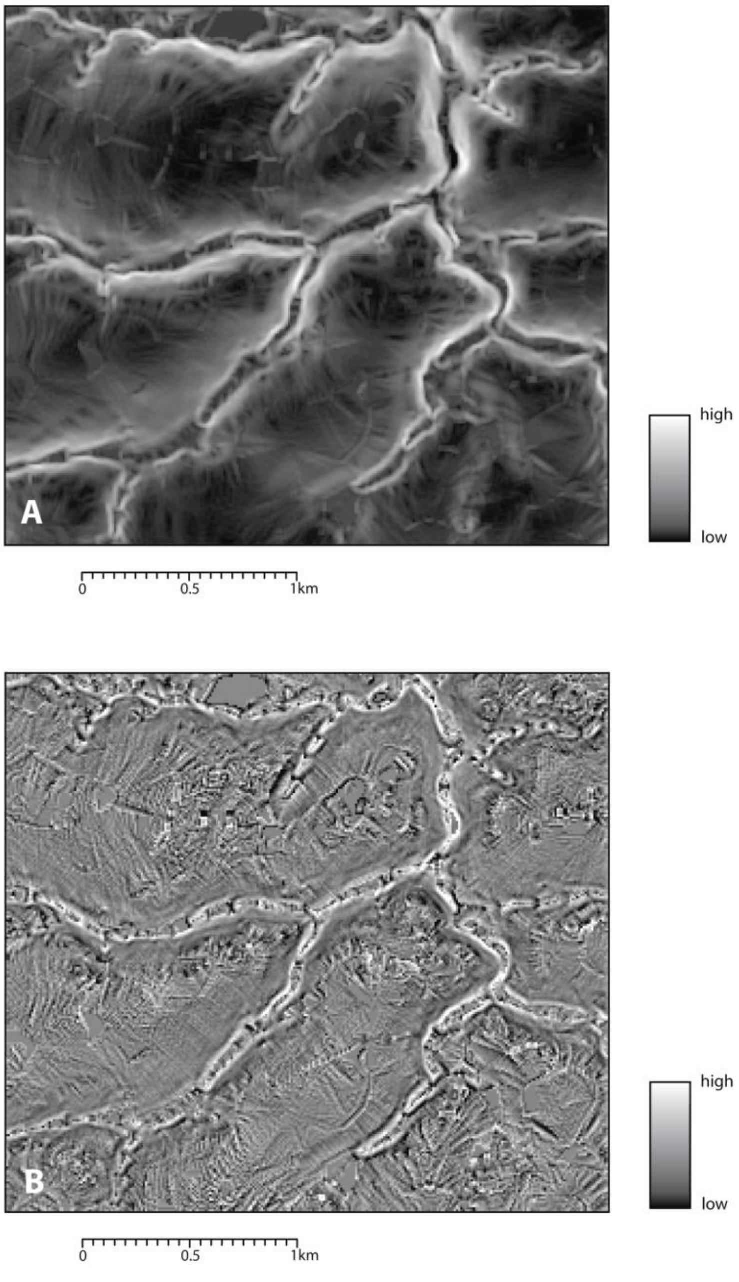

Figure 17 – results of the roughness (A) and rugosity (B) analyses of the AGL affordance data for the study zone.

That the results of the case-study analyses were negative should not detract from the broader utility of the tools developed. But where does this leave Exmoor and its enigmatic scatters of standing stones? We can now state with some confidence that they are neither visually prominent or show any evidence of being concealed, hidden or deliberately tucked out of view. Nor do they occupy parts of the landscape which afford good views coupled with high levels of concealment. Although such places clearly exist (and the analyses have successfully identified and mapped them) we do not find the monuments there. This is not to say that the structures were not deliberately hidden, merely to stress that if this was the case then this hiddenness was effected through their material properties alone rather than in conjunction with the locations they were created in. For example, regardless of how visually exposed a location was, the settings could be rendered inconspicuousness through their size, colour and texture with respect to the background. Needless to say, through careful framing in terms of affordance, such deliberate hiding of monuments in plain sight (e.g. abandoning the proverbial haystack to hide a needle in a pile of needles or conceal a distinctive face in a crowd) could also be investigated using the approaches discussed here. It may well be that visibility (in all of its manifestations) is the least relevant aspect in seeking to account for this practice of assembling small groups of tiny stones and setting them upright. They were small for other reasons and to approach them through the lens of visibility (undoubtedly a legacy of the use of the term 'monument' to describe them and the experiential modes of field-craft that have informed their interpretation) simply blinds us (no pun intended) to other possibilities. Instead they were always intended to be stumbled upon; their placement carefully attuned to, and emerging from, pathways of human and animal movement between and across the steeply incised combes and upland plateaus (see Gillings (in press) for a full discussion of the implications of these results).

What the analyses have hopefully demonstrated is that GIS-based viewshed calculations need not only shed light upon visibility. Invisibility, concealment and seclusion are equally interesting and providing we generate and combine enough viewsheds, and do so in a theoretically sensitive fashion, they are eminently amenable to analysis and investigation.

Endnotes

1.Indeed the term relational capacities is in many ways preferable to affordance insofar as it unshackles the concept from the field of ecological psychology within which it was first crafted, removing the concomitant pressure to ensure that its application conforms to the orthodoxies and tenets of that theoretical framework (for example see Knappett 2005: 51; Gillings 2012).

2. All of the raster layers used in the analyses comprise Ordnance Survey Landform Profile DTM data which has a 10m horizontal resolution, a vertical precision of 0.01m and a vertical accuracy of +/- 2.5m. It is interpolated from 5m interval contour data taken from 1:10,00 scale mapping (Ordnance Survey 2012). © Crown copyright and database right 2015.

3. The discrepancy between area and number of viewpoints is a result of the inexact correspondence between the 10m resolution DEM and the vector study area bounding box.

4. Copies of all of the Python scripts developed for this research are freely available from the author.

5. This was introduced to the ArcGIS package in version 10.1.

6. It could be argued that scent and wind direction are even more pertinent in a hunting context and it would be interesting to factor dominants winds into this analysis (I am indebted to Douglas Mitcham for this observation).

7. The analyses were run in ArcGIS 10.1 SP1, using bespoke Python scripts on a modestly specified PC - Intel Core 2 Duo, 3.00Ghz, 4GB RAM, Win 7 (64 bit) SP1. To minimise the impact of seemingly random crashes – particularly in the case of Analysis 2 - the data was chunked into 2,000 point blocks with log files cleared and the machine rebooted between runs. This introduced a significant down-time debt that has not been factored into the quoted run-times.

8. These are in many ways analogous to what are termed visibility surfaces in the field of military GIS research (e.g. Caldwell et al. 2003). Roughness and Rugosity were calculated using Jeffrey Evan's Geomorphometric and Gradient Metrics Toolbox.
http://evansmurphy.wix.com/evansspatial#!arcgis-gradient-metrics-toolbox/crro

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Bibliography

Bernardini, W., Bamash, A., Kumler, M. & Wong, M. 2013. Quantifying visual prominence in social landscapes. *Journal of Archaeological Science* 40(11), 3946-3954.

Bongers, J., Arkush, E. and Harrower, M. 2012. Landscapes of death: GIS-based analyses of chullpas in the western Lake Titicaca basin. *Journal of Archaeological Science* 39, 1687-1693.

Brughmans, T., Keay, S. and Earle, G. 2015. Understanding Inter-settlement Visibility in Iron Age and Roman Southern Spain with Exponential Random Graph Models for Visibility Networks. Journal of Archaeological Method and Theory 22(1), 58-143.

Caldwell, D.R., Mineter, M.J., Dowers, S. and Gittings, B.M. 2003. *Analysis and Visualisation of Visibility Surfaces (Poster)*. http://www.geocomputation.org/2003/Papers/Caldwell_Paper.pdf. Accessed 29th April 2015.

Cummings, V. and Pannett, A. 2005. Island views: the settings of the chambered cairns of southern Orkney. In C & P (eds). Set in Stone: new approaches to Neolithic monuments in Scotland, 14-24. Oxford: Oxbow

Darvill, T. 2004. *Long Barrows of the Cotswolds and surrounding areas*. Stroud: Tempus.

DeLanda, M. 2013. *Intensive Science and Virtual Philosophy*. London: Bloomsbury.

De Reu, J., Bourgeois, J., De Smedt, P., Zwertvaegher, A., Antrop, M., Bats, M., De Maeyer, P., Finke, P., Van Meirvenne, M., Verniers, J. and Crombé. 2011. Measuring the relative topographic position of archaeological sites in the landscape, a case study on the Bronze Age barrows in northwest Belgium. *Journal of Archaeological Science* 38, 3435-3446.

ESRI. 2012. *ArcGIS Desktop Help 10.1 – Viewshed (Spatial Analyst)* http://resources.arcgis.com/en/help/main/10.1/index.html#//009z000000v3000000 Accessed: 23/4/2015.

Eve, S. and Crema, E. 2014. A house with a view? Multi-model inference, visibility fields, and point process analysis of a Bronze Age settlement on Leskernick Hill (Cornwall, UK). *Journal of Archaeological Science* 43, 267-277.

Ferreira, C.R., Andrade, M.V., Magalhães, S.V.G., Franklin, W.R and Pena, G.C. 2014. A Parallel Algorithm for Viewshed Computation on Grid Terrains. *Journal of Information and Data Management* 5(2), 171-180.

Field, D. 2006. *Earthen Long Barrows: the earliest monuments in the British Isles*. Stroud: Tempus.

P.F. Fisher. 1993. Algorithm and implementation uncertainty in viewshed analysis. *International Journal of Geographical Information Systems* 7 (4), 331-347.

Foucault, M. 1977. *Discipline and Punish*. London: Penguin.

Fowler, C. 2013. *The emergent past: a Relational Realist Archaeology of Early Bronze Age Mortuary Practices*. Oxford: OUP.

Gillings, M. 2009. Visual affordance, landscape and the megaliths of Alderney. *Oxford Journal of Archaeology* 28 (4), 335-356.

Gillings, M. 2012. Landscape Phenomenology, GIS and the Role of Affordance. *Journal of Archaeological Method and Theory.* 19(4), 601-611.

Gillings, M. 2015. Betylmania? Small standing stones and the megaliths of south-west Britain. *Oxford Journal of Archaeology* 34(3), 205-231.

Gillings, M. (in press). Fugitive monuments and animal pathways: explaining the stone settings of Exmoor. *Proceedings of the Prehistoric Society 81*.

Gillings, M. , Pollard, J. and Taylor, J. 2010. The Miniliths of Exmoor. *Proceedings of the Prehistoric Society* 76, 297-318.

Hamilton, S., Whitehouse, R., Brown, K., Combes, P., Herring, E. and Seager-Thomas, M. 2006. Phenomenology in Practice: Towards a p Methodology for a 'Subjective' Approach. *European Journal of Archaeology* 9(1), 31-71.

Harris, O.J.T. and Sørensen, T.F. 2010. Rethinking emotion and material culture. *Archaeological Dialogues* 17 (2), 145-163.

Jerpåsen, G.B. 2009. Application of Visual Archaeological Landscape Analysis: some results. *Norwegian Archaeological Review* 42(2), 123-145.

Kaučič, B. and Žalik, B. 2002. Comparison of Viewshed Algorithms on Regular Spaced Points. In A. Chalmers (ed). *Proceedings of the 18th Spring Conference on Computer Graphics*, 177-183. ACM, New York, NY, USA.

Knappett, C. 2005. *Thinking through Material Culture*. Philadelphia: UPP.

Lake, M and Ortega, D. 2013. Compute-intensive GIS visibility analysis of the settings of prehistoric stone circles. In A. Bevan & M. Lake (eds) *Computational Approaches to Archaeological Space,* 213-42. Walnut Creek: Left Coast Press.

Lake, M., Woodman, P. & Mithen, S. 1998. Tailoring GIS Software for Archaeological Applications: an example concerning viewshed analysis. *Journal of Archaeological Science* 25, 27–38.

Lake, M. and Woodman, P. 2003. Visibility studies in archaeology. *Environment & Planning B: Planning and Design 30, 689-707.*689–707.

Llobera, M. 2003. Extending GIS-based visual analysis: the concept of the visualscape. *International Journal of Geographical Information Science* 17(1), 25-48.

Llobera, M., Wheatley, D., Steele, J., Cox, S., Parchment, O. 2010. Calculating the inherent visual structure of a landscape (inherent viewshed) using high-throughput computing. In F. Niccolucci and S. Hermon (eds) *Beyond the artefact: Digital Interpretation of the Past: Proceedings of CAA2004, Prato, 13-17 April 2004*, 146-151. Archaeolingua: Budapest, Hungary.

Lock, G., Kormann, M. and Pouncett, J. 2014. Visibility and movement: towards a GIS-based integrated approach. In S. Polla and P. Verhagen (eds). *Computational Approaches to the Study of Movement in Archaeology,* 23-42. Berlin: de Gruyter.

Lopez-Romero Gonzalez de la Aleja, E. 2008: Characterising the Evolution of Visual Landscapes in the late Prehistory of south-west Morbihan (Brittany, France). *Oxford Journal of Archaeology* 27(3), 217-239.

Murrieta-Flores, P. 2014. Developing computational approaches for the study of movement: assessing the role of visibility and landscape markers in terrestrial navigation during Iberian Late Prehistory. In S. Polla and P. Verhagen (eds). *Computational Approaches to the Study of Movement in Archaeology,* 99-131. Berlin: de Gruyter.

Ogburn, D.E. 2006. Assessing the level of visibility of cultural objects in past landscapes. *Journal of Archaeological Science* 33, 405-413.

Olaya, V. 2009. Basic Land Surface Parameters. In T. Hengl and H.I. Reuter (eds). *Geomorphometry: Concepts, Software, Applications*, 141-169. Amsterdam: Elsevier.

Ordnance Survey. 2012. *Land-Form PROFILE User guide and Specification*. Southampton: Ordnance Survey.

Paliou, E., 2013. Reconsidering the concept of visualscapes: Recent advances in three-dimensional visibility analysis: In Bevan, A. and Lake M. (eds) *Computational Approaches to Archaeological Spaces*, 243-263. Walnut Creek: Left Coast Press.

Rášová, A. 2014. Fuzzy viewshed, probable viewshed, and their use in the analysis of prehistoric monuments placement in Western Slovakia. In J. Huerta, S. Schade and C. Granell (eds). *Connecting a Digital Europe through Location and Place. Proceedings of the AGILE'2014 International Conference on Geographic Information Science, Castellón, June, 3-6, 2014*. http://www.agile-online.org/Conference_Paper/cds/agile_2014/agile2014_114.pdf (Accessed 19th February 2015).

Reuter, H.I., Hengl, T., Gessler, P. and Soille, P. 2009., Preparation of DEMs for Geomorphometric Analysis. In T. Hengl and H.I. Reuter (eds). *Geomorphometry: Concepts, Software, Applications*, 87-120. Amsterdam: Elsevier.

Tilley, C. 2010. *Interpreting landscapes. Geologies, topographies and identities. Explorations of landscape phenomenology 3*. Walnut Creek: Left Coast Press

Toma, L. 2012. Viewsheds on Terrains in External Memory. *SIGSPATIAL Newsletter* 4(2), 13-17.

Warn, S. 2011. *High performance Geospatial Analysis on Emerging Parallel Architectures*. Unpublished PhD thesis: University of Arkansas.

Wheatley, D. and Gillings, M. 2000. Vision, Perception and GIS: developing enriched approaches to the study of archaeological visibility. In G. Lock (ed.). *Beyond the Map: Archaeology and Spatial Technologies*, 1-27. Amsterdam: IOS Press.

Wheatley, D. and Gillings, M. 2002. *Spatial Technology and Archaeology: the archaeological applications of GIS*. London: Routledge.

Wright, D. K., MacEachern, S., & Lee, J. 2014. Analysis of Feature Intervisibility and Cumulative Visibility Using GIS, Bayesian and Spatial Statistics: A Study from the Mandara Mountains, Northern Cameroon. *PLoS ONE*, *9*(11), e112191. doi:10.1371/journal.pone.0112191

Wood, J. 2009. Geomorphometry in Landserf. In T. Hengl and H.I. Reuter (eds). *Geomorphometry: Concepts, Software, Applications*, 333-349. Amsterdam: Elsevier.

Wu, H., Pan, M., Yao, L. and Luo, B. 2007. A partition-based serial algorithm for generating viewsheds on massive DEMs. *International Journal of Geographical Information Science* 21(9), 955-964.

Zamora, M. 2008. *Improving Methods for Viewshed Studies in Archaeology: The Vertical Angle*. http://proceedings.caaconference.org/files/2008/CD82_Zamora_CAA2008.pdf (accessed 19th February 2015).

Zhao, Y., Padmanabhan, A., and Wang, S. 2013. A Parallel Computing Approach to Viewshed Analysis of Large Terrain Data Using Graphics Processing Units. *International Journal of Geographical Information Science*, 27 (2), 363-384.