Using viewsheds wisely: developing sound methodologies from spatial analyses of megalithic monuments in western Scotland

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Abstract: In a similar way to that of Fisher et al's 1997 paper, the aim of this project is to contribute to the quantitative analysis and development of testable hypotheses concerning archaeological sites in the landscape (Fisher et al, 1997:581). The initial intention of this project was to ensure that valid and reliable outcomes regarding the original use of the free-standing megalithic monuments of western Scotland were possible through its use of appropriate spatial and statistical analyses. Whilst this objective remains the same it is no longer the sole objective. Rather, more complex theories regarding the nature of the cosmology of those who built the monuments and the possible cosmological connections between them, other monuments and the environment are considered. Based upon the initial methodologies and outcomes, further development of sound hypotheses and robust experimental designs that could be used in conjunction with GIS data and applications was assured for the more complex considerations.

This paper outlines the overall project design and demonstrates the connection between the methodologies used to date and those to come. It is believed that the project design fulfills the minimum requirements for the incorporation of systematic project design and quantitative analysis in the application of viewshed technology.

Key words: landscape archaeology, archaeoastronomy, methodology, GIS, viewshed, spatial analysis, Scotland, megaliths

Introduction

Ultimately, this study investigates the cosmology of the megalith builders of western Scotland (see Figure 1). It was decided that an investigation into territory that had previously been studied, geographically and thematically speaking, was the most sensible approach to begin with. However, it was also recognised that new methodologies were required, in order to improve the state of research into prehistoric societies and archaeoastronomy in particular. What had appeared as a single télos of the study, became twin téloi: desire for the revelation of reliable conclusions through the development of sound methodological practices.

This study began by reassessing the orientation of free-standing stone monuments and their possible associations with astronomical phenomena (originally assessed by Ruggles and contributors in 1984). Whilst investigating the possible interest of the megalith builders in astronomical phenomena it became evident that a much more complex set of behaviours (deliberate or not) might be revealed. If discovered, these could provide a deeper understanding of the cosmological issues at stake for the builders, and perhaps even those who came before and were to come afterwards. From the beginning, the project was based upon conventional scientific methods with the belief that with proper project design, and the asking of appropriate questions, one can only enhance one's knowledge of the societies one is trying to understand.

The experimental design for the expanded study relied upon the outcomes of the first two phases of the project. Due to their nature, they provided us with valid hypotheses to be tested, and directed us towards appropriate methodologies to test them with. These newer methodologies, as well as those found within the first two phases of this study, are based upon considerations current within landscape archaeology and the application of GIS. More specifically, phase three of the study is dependent upon the use or modification of GIS software (GRASS[1] and ARCINFO[2]), primarily those involving viewshed procedures. It is the intention of this paper to discuss the methodology of the project in detail.

Some current considerations

Many of the criticisms in the field of Landscape Archaeology and, to some extent Archaeoastronomy, are well rehearsed. Nevertheless, we will briefly mention some of the general issues. In this way, we may later highlight how our own research attempts rectify some of the problems still inherent in the study of archaeological sites in the landscape, especially in the application of GIS viewshed analysis. The criticisms are aimed primarily at the lack of rigorous analysis. Though the project addresses a number of critical issues in methodological approaches in Landscape Archaeology, this paper will focus upon the development of sound viewshed analysis.

What many critics of GIS analysis are looking for is the connection between visualization and statistical analyses (Lock and Harris, 1992; Kvamme 1995:7) Kvamme summarises this quest:

> simple statistics cannot convey the essence of spatial pattern in the same way that an effective graphic can. At the same time, statistical tests can inform us of the existence of (a) pattern when it is difficult or impossible to visualise, and even if we can see (a) pattern we may wish to obtain objective measures of its (existence and of its) strength. Both approaches complement each other ... (1995:7).

To create such a complementary approach between vision and statistics we must begin with the creation of testable hypotheses, for this allows for the possible derivation of firm statements of significant associations (Fisher et al 1997:582).

Testable hypotheses

The advantage of designing testable hypotheses is that we can be more certain of both our results and their interpretation. Additionally, we will gain a greater understanding of the nature of our data, our methodologies and our enquiries by the sheer fact that we have had to produce very specific questions to provide very specific answers. Added to these, it allows us to determine further hypotheses which may help to disentangle more complex issues.

To create statistically testable hypotheses, certain properties of observed or gathered data are compared to those of a hypothesised (modelled) or real population (this may be a 'parameterised' real population). These latter populations are often called 'control groups', 'expected populations/ distributions' or 'background values'. The expected distribution is often that distribution which would occur if nothing other than an interplay of chance factors were responsible for its formation. When the resultant outcome of no significant difference is found between the control and the observed data in this case it is said that the observed data are also likely to be the result of chance factors.

The creation of expected distributions of viewsheds

"There is no predetermined method for finding the statistical significance of the area visible from one location as opposed to another"(Fisher 1997:584)

In GIS the influence of landscape factors cannot really be understood from a single model. This is because the topography of the landscape varies. Thus any model or expected distribution will be "dependent on site-specific terrain" (Fisher 1997:584).

Naturally, as viewsheds are affected by terrain, we have to determine "what is the likelihood that the observed pattern of visibility is an artefact of the surrounding landscape or topography, rather than anything else?" The most accurate, but time consuming, approach would be to create viewsheds for all locations within the Digital Elevation Model (DEM) through full intervisibility analysis. From these parameters the population of the viewsheds could be calculated. A more suitable, and still very reliable, approach would be to create viewsheds from randomly sampled viewing locations. This will allow one to build a representative sample of the viewsheds of the entire landscape (Lake et al, 1998:34) from which an expected distribution can be generated. An example of this applied technique can be found in Fisher et al (1997:584). Terrain must be seen, then, as a condition or a 'background visibility property' as referred to by van Leusen (1999:§3.2).

Lack of statistical analysis

Peter Fisher et al state categorically that "(if GIS used) ... then rigorous statistical analysis should and can be applied, but usually is not" (1997: 582). Added to this is the concern of misleading interpretations and conclusions caused by the use of GIS "without (the) understanding of the underlying spatial and statistical processes" (1997: 581). If one does not understand the mechanics of either the GIS software or data there could be a 'House of Cards' effect whereby the correct procedures and statistical analyses will not be applied, results will be irrelevant and interpretations ultimately of no consequence. One might even have to ask of oneself "have I designed my hypotheses around what I thought GIS software could do?"

Viewshed studies which have employed statistical analyses include Wheatley's (1995) and Mark Lake et al's (1998) applications of the Kolmogorov-Smirnoff test, Fisher et al's use of Monte Carlo testing (1997) and, for quantitative analyses without statistical tests, Wheatley and Gillings (2000).

The following briefly outlines the outcomes of the two completed stages of this project, namely Phase 1 and Phase II.

Phase I

Rigorous statistical analysis and testable hypotheses

The following hypotheses were tested upon 125 free standing stone monuments in western Scotland using the Z^2_m tests to test for the likelihood that sites were oriented towards the same directions (see Higginbottom and Clay, 1999 for a fuller description of phase I):

(i) clustering in orientation exists in the site database of the region of western Scotland as a whole.

(ii) clustering in orientation exists in the site database of western Scotland for each of the sub-regions of Mull, Argyll, Islay, Uist, Kintyre and Lewis/Harris.

The regions included the areas of Coll, Tiree and North Argyll with Mull, Jura with Islay, and Lorn with Argyll, Uist, Kintyre and Lewis/Harris. It was an *a priori* decision to test the second set of hypotheses only if the first hypothesis could be supported.

When looking at the entire sample, some statistical evidence for the rejection of the null hypothesis (uniformity) was found (Z^2_2= 8.58, n=166, $p < .1$). The alternative hypothesis of clustering, therefore, was accepted. It was decided from this that it was worthwhile to continue the investigation of the data using regional analyses. Very significant trends were found for the regions of Uist ($B = 15.93$; $p < .005$) and Mull ($B = 11.51$; $p < .025$). Trends of minor significance were detected for Argyll ($B = 8.99$; $p < .1$) and Islay ($B = 8.4$; $p < .1$). At this level of investigation Lewis/Harris and Kintyre were the only regions that did not reveal any evidence for the rejection of the null hypothesis (uniformity).

It should be noted that phase I of this project has addressed a demand of Wheatley and Gillings to test "whether (or not) we have grouped together ... those monuments that represent the same tradition ... rather than accept it uncritically" (2000: §4.6). We have indeed found support for the likelihood of a similar tradition within the database, that of the deliberate orientation of monuments. We can now use the same database to test for more complicated behaviour, namely the orienting of sites for the purpose of indicating celestial phenomena.

Phase II Conclusions

Landscape and visions

Our results of Phase II revealed that the placement of the free-standing stone monuments in western Scottish sites included a significant consideration of the horizon for three of the regions, Argyll, Mull and Islay (Higginbottom, Smith, Simpson, and Clay, 2000). The horizon may have even been seen as an extension of the sites.[3] These regions also revealed the possible due regard given to specific celestial phenomena. What is more, the regions appeared to focus upon differing phenomena, providing evidence for regional differences within a shared, broader cultural framework (See Table 1 for specific phenomena). Added to this, the even broader cultural behaviour of the orientation of monuments is shared by a fourth area, that of Uist. Though it is not yet clear in which events or objects the sites of Uist might be interested, it is now clear that the majority of alignment forms for Uist are intersite alignments rather than intrasite alignments.

The results of the study to date make it possible to observe the connection between monument, landscape and phenomena.

Indicated directions

We can now assume that the alignment of stones within sites, and possibly between sites, is of import and that the action of looking, as well as what could be seen from the monuments, played a part in their location. It is this very evidence that allows us to apply notions of alignment, vision and visibility to our hypotheses of the next phase. Further, it gives us confidence in any future reliance upon the notion of 'line-of-site', for an interest in using monuments as the backsite and the horizon as a foresite has been verified. Finally, our choice of methodologies, namely additional cluster analyses and the application of viewshed analysis, appear appropriate for the data we have.

Phase III - Orientation and visibility analysis

Though the experimental design for this phase is complete, the application is not. The following describes in detail the methodological reasoning behind this design. To proceed with the investigation two equally important questions demand to be asked. The first is, 'is the relationship we have seen between monument, horizon and astronomical phenomena a continuous one' across the landscape? That is, are there any other areas or objects between the monuments and the indicated phenomena that participate in this relationship? Putting forward the simplest hypothesis first, then, "a spatial relationship, in the form of clustering, exists between the Ruggles sites and other Neolithic or Bronze Age objects or places" (hypothesis 1). More specifically, "there is a possible alignment of the Ruggles sites, the indicated horizon or phenomena and other Neolithic or Bronze Age features"(hypothesis 2).

The second question asks "does the connection between monument, horizon and astronomical phenomena also contain a visual component?" Might there not be a visual connection between the free-standing stones, the phenomena, the horizon and other Neolithic or Bronze age features? The hypotheses here are: "there is a significant number of other Neolithic or Bronze age sites (Group2 sites) that might be seen from the locations of the Ruggles' sites (Group1 sites) (that is, found within the non-directional viewsheds of the Group1 sites)" (hypothesis 3) and "the Group2 sites are significantly located within the Group1's directional viewsheds, the axis of which is directed by the orientation of the Group1 sites (hypothesis 4).

Finally, the investigation requires that we query the visual connection between all Group1 sites within a specific region with their visually associated Group2 sites. The question being asked is "do the Group1 monuments within the same region share any specific view of the same Group2 monuments?" The general hypothesis here states: " a significant proportion of Group1 sites share the same viewshed area(s)". More specifically: " a significant proportion of Group1 sites share the view of the same Group2 sites" (hypothesis 5 – cumulative viewshed - CVA). Naturally the issues of amount and type of Group2 sites may arise.

The first set of hypotheses (1&2) is based upon the evidence of the importance of alignments to the culture(s) of the megalith builders in western Scotland. The second group of hypotheses (3&4) is reliant upon the line of sight drawn between the monument (backsight) and the horizon points (foresight), in which an interest was also verified. The latter is, in fact, a variant of the alignment hypothesis.

Ultimately, we are trying to determine the likelihood that these other Neolithic or Bronze age sites were connected to the same cosmological belief system(s) as the free-standing stone sites that were initially assessed.

The 'secondary sites'

The list of sites that was used to determine the data for the Group2 sites came from a Royal Commission of Ancient and Historical Monuments of Scotland (RCAHMS) database that itemised all sites regardless of age in western Scotland. Neolithic and Bronze Age monuments were extracted from this. For a detailed explanation of how sites were chosen as Neolithic or Bronze age see Higginbottom, Simpson, and Clay in preparation B. The result of the application of this *a priori* method was that only "large finds", usually considered to have ritual associations, were extracted. These could be summed up as 'monuments' or 'monumental' and 'grave sites'. The actual list is: Cairn with (cinerary)urn and/or cist, Cairn or cist with cremation, chambered cairn, cup and ring marking(s), henge, ring-ditch, stone alignment, stone circle, stone setting, standing stone (RCAHMS labels). The number of these Group2 sites is 1287.

It is clear to the authors that the Group2 sites are various in age and type. Despite the fact that we are looking at site layout in relation to Group1 sites, the hypotheses do not in any way propose or rely upon the order of the sites' appearance. The order of the sites' appearance on the landscape, therefore, is not at this point accounted for. As it was clear that age could not be strongly controlled for at this stage for the entire RCAHMS data set it was decided that an in-depth study of these issues must be considered later. However, site type in itself, and as a possible key to the order of appearance of sites, will be assessed at a later stage of Phase III.

Hypotheses and the appropriate tests

For Hypothesis 1 we are asking:
(i) are there any clusterings of Group2 sites, about the Group1 sites?
For Hypothesis 2 we are asking:
(ii) are there any clusterings of Group2 sites, about the Group1 sites, in the directions indicated by the Group1 sites' orientations?
For Hypothesis 3 we are asking:
(iii) what is the percentage or proportion of Group2 sites that exist within the Group1 sites' 360 degree viewsheds? Or what is the number of Group2 sites "seen" within the hit cells versus the non-hit cells?
For Hypothesis 4 we are asking:
(iv) what is the percentage or proportion of Group2 sites that exist within the Group1's directional viewshed, as indicated by the Group1 sites' orientations?
For Hypothesis 5 we are asking:
(v)i what is the percentage of Group1 sites that share the same geographical view ?
(v)ii what is the percentage of Group1 sites that view common Group2 sites?"

Obtaining the observed data

Five sets of information are required:
(i) the orientations (azimuth values) of the Group1 sites'
(ii) the co-ordinates (eastings and northings) of the Group1 sites
(iii) the co-ordinates (eastings and northings) of the Group2 sites
(iv) a non-directional viewshed of each Group1 site.
(v) a directional viewshed of each Group1 site.

The first two sets of data were part of the original databases of Ruggles and RCAHMS. The third fourth and fifth, naturally, need to be created.

The orientations

The orientations obtained from the Group1 sites for Phase II will be applied to hypotheses 2, 4, 5. Group1 site data sets for hypotheses 2 and 4 will also be produced from the original Ruggles database but produced in the following way:

We have 276 orientations for the Group1 sites, often more than one orientation per site (n of sites=125). There are also two formats for the orientations: intersite or intrasite and one-way or two-way. From these one can code the orientations into four groups of: intersite/ one-way, intersite/two-way, intrasite/one-way or intrasite/two-way. Intersite is where the orientation is formed by the intervisibility of the two sites, and is usually "where two sites form an indication of two ranges of horizon, one in each direction"(Ruggles, 1984:66).

It was decided to use only the one-way orientations in the first instance for the following reasons:
(i) we could be sure of the intended direction that was to be sighted along;
(ii) they could be used to create future expected distribution(s), assuming that significant outcomes were obtained. We can then use all the 2-way alignments that were used in the very first set of cluster analyses in Phase I (where one of two alignments was chosen at random) and compare their distribution with that of the new expected distribution created from the 1-way alignments.

Here the expected distribution will be illustrating a situation where more than chance factors are responsible for the outcome. In relation to hypothesis 4 then, if it is found that the distributions are the same for the one-way and two-way orientations, the latter can also be said to display a significant percentage of Group2 sites in the directional viewshed areas. The testable hypothesis would be: there is no significant difference between the two distributions.

Hypothesis One

Testing hypothesis 1

To determine the occurrence, or not, of significant clusters of Group2 sites about the Group1 sites the family of tests was applied to the data for query (i), as stated under "Hypotheses and the appropriate tests".

The Z_m^2 test determines whether the observed pattern of orientations is consistent with the assumption that each orientation is equally likely to be anywhere between 0 and 360 degrees, or whether that assumption can be plausibly rejected. Thus the concept of expected distribution is built into the test.

Hypothesis Two

Testing hypothesis 2

Hypothesis 2 asks 'are there any clusterings of Group2 sites, about the Group1 sites, in the directions indicated by the Group1 sites' orientations'? We already have the location of the Group2 sites that 'fall' about the Group1. From this we need to make a data cut of those Group2 sites that fall close to the orientation line of the Group1 sites. We then compare the number of these Group2 sites that fall inside the nominated band width with the number that falls outside of this band. This allow us to test whether or not there is a significant difference between the two. If there is, then it would be fair to say that there is a significantly greater number of Group2 sites that are positioned in relation to the orientation of the Group1 sites than not. The determination of this angular value or band can be found in Higginbottom, Simpson and Clay, in preparation A)

The Viewsheds

A comprehensive report of the viewshed methodology and associated theoretical bases can be found in the paper Higginbottom, Simpson and Clay, in preparation B.

The viewsheds for hypothesis 3

To obtain the viewsheds GRASS 4.3 is to be used and the function employed is r.cva. It was explained by Mark Lake to the author that the use of the cumulative viewshed (CVA) routine (r.cva) for the line-of-site (LOS) analysis was preferable as LOS (r.los) routine in GRASS truncates the height of the observer to the nearest metre whereas r.cva doesn't (personal communication).

When using r.cva for LOS assessment each site file can only have 1 set of co-ordinates which represents a single site. The procedure is to run r.cva for every site, and with the "visibility from" rather than "viewsheds of" [= -f] option chosen. The non-directional LOSs, then, were created in this manner. The directional LOS creation incorporated this technique with some additions.

The viewsheds for hypothesis 3 - directional LOS

Directional viewsheds are not possible using a single function in GRASS, yet it is essential to take account of direction in LOS calculations when assumptions or evidence for specific bearings drive the investigation. The way around this is to use r.cva for single LOS analysis as above and use the binary viewshed output as the input for r.stats. The operation of r.stats allows one to output an ascii file with the x and y co-ordinates(x3,y3) of all the 'seen' cells (non-zero data values) for each site being tested (Group1 in this case). With these data one can use trigonometrical calculations to locate the cells' positions (x3,y3) in relation to the orientation line being accounted for (in this instance it is the orientation line of the alignment produced by a Group1 site (with co-ordinates (x1,y1) and the indicated 'point' on the horizon (with co-ordinates (x2,y2)). This method was suggested to the author by Mark Lake. Alternatively, one can convert the co-ordinates of (x2,y2) and (x3,y3), in relation to (x1,y1), to azimuths. Remember also that we already have the azimuth or orientation of the line (x1y1, x2y2) for the Group1 sites.

If one chooses to use the co-ordinates, trigonometry can be used to calculate the distance and position of the seen cells from the nominated azimuths or orientations of each Group1 one site, which will allow one to get a picture of the spatial patterning of which areas were seen and where they were. One can compare this information with the co-ordinates of the Group2 sites and their distances from the bearing. This will allow one to view or calculate the number of co-incidences that have occurred between the 'seen cells' and the Group2 sites. That is, how many Group2 sites can be seen. The advantage of doing this trigonometrically is that one can actually calculate the number of sites that might have occurred within the same cell. Remembering that the Ordnance Survey data gives elevation information every fifty metres, it means our raster map is composed of 50 by 50 metre cells. The site data, however, is more detailed and it is possible to have a number of sites located within a 50-by-50 metre cell. Using something like 'r.coin' in GRASS 4.3, therefore, only allows one to readily calculate the number of cells that have coincidences (or the number of cells that have coincided with a site(s)) not the number of times there are site coincidences for the same cell(s). 'r.coin' requires that one have a raster sitemap perhaps converted by 's.to.rast'; as a result, one's raster sitemap only records absence or presence of sites.

The main reason for obtaining the x and y co-ordinates of all the seen cells is, however, that they provide data for statistical analysis. So, although getting a picture of the spatial patterning can be useful, be it via histogram or mapping, to discover whether this pattern is significant or not a more rigorous method is required to "obtain objective measures of its (existence and) strength" (Kvamme, 1995:7). Regardless of the method, an *a priori* decision must be made that allows one to choose how much of the area on either side of the indicated orientation is included in the assessment. It requires a limited decision to be made about the idea or concept of boundaries and where they are to be drawn. The reasoning behind the *a priori* decision can be found in the section below.

Creating the inclusive area for the directional viewshed

Once one has created a 360 degree viewshed, one can literally take a 'cut' from this to create a directional viewshed. The idea is to create a viewshed given the observer's location and the direction in which they are looking. This is done by taking into account all the known variables that affect visibility and vision according to the situation being investigated. The creation of the 360 degree viewshed using CVA takes care of some of the general visibility issues, based on the assumption of a clear day, apart from the curvature of the earth[4]. What is needed now, is an estimation of the horizontal visual range (areas to the left and right) a person might have when purposely directing their gaze, or looking at, a particular phenomena on the horizon. Things to take into account include horizontal visual range when focusing upon a single direction, size of the phenomena, head movement to make the edges of the phenomena the centre of vision and distance of the horizon. For a first foray into the design of a directional viewshed the range of 30 degrees was chosen, that is ± 15 degrees either side of the line of orientation (Higginbottom, Simpson and Clay in preparation B), remembering that we are not investigating what we can see overall, but what else we can look at when we are observing, or keeping in visual range/contact, the phenomena on the horizon.

Obtaining the expected data

The creation of expected distributions for viewsheds

Remembering that the influence of landscape can not really be understood from a single model we need to create a number of models or expected distributions for each separate geographical region. This will allow the determination of the influence of landscape shape upon visibility, as well as the location of a site within that landscape. Determination of influence is considered by comparing the viewshed model, which represents a pattern that occurs when chance factors are dominantly responsible, with a viewshed based upon real archaeological site data, location and landscape. To derive significant results, or arrive at significant conclusions which have archaeological relevance, the latter viewsheds must be "sufficiently different from the background visibility properties (background values or expected distributions) of the study area" (van Leusen, 1999: §3.2).

Model creation and random samples

One needs to compare the observed pattern of sites within viewsheds with four different sets of randomly generated site data for each geographical region. Three of the four sets are made using the r.random site generator option. This makes a list of locations. We will make a minimum of 2760 sets for the 360 degree, or non-directional, viewsheds for comparison with the observed sites (hypothesis 3) and at least 560 to a 1000 randomly generated sets of data for the directional viewsheds (hypothesis 4). This is in order to determine a statistical confidence level for any apparent extreme result found in the real data set. Replacement with random sampling will be allowed.

The four sets of generated data to create the expected distributions are:

Hypothesis 3

Non-directional(1): a new randomly generated set of sites (locations), where n of sites=125. The created viewsheds will be 360 degrees. This is done a minimum of 1250 times. The number of sites within and without the viewsheds will be recorded.

Hypothesis 4

Directional sites(2): (i) use one of the randomly generated site sets from Non-directional(1).

(ii) Create 56 randomly generated orientations (equalling the number of randomly generated sites) and randomly assign them to one set of the previously listed random sites. (iii) Create directional viewsheds in the manner described above (or calculate same trigonometrically) for each of the randomly generated sites and its accompanying orientation. Do steps (i) - (iiii) 560 - 1000 times. The number of sites within and without the viewsheds will be recorded.

Directional sites(3): use randomly generated set of sites from Non-directional(1) above, and assign these new sites with the orientations from the original Ruggles' one-way data set (Group1 sites). The number of sites within and without the viewsheds will be recorded.

Directional sites(4): - use the original one-way Ruggles' site locations (Group1, n = 56) and randomly assign them one of the randomly generated directional orientations from Directional sites(2) 560 – 1000 times. The number of sites within and without the viewsheds will be recorded.

Note that the fourth set uses the locations of the Group1 sites but is given random orientations for their directional viewshed. Along with the first three sets, this ensures that all possible combinations of the location and orientation variables have been accounted for, further testing the hypotheses that either the location or the direction are statistically significant in the positioning of the Group2 sites in relation to the Group1 sites.

Comparing the observed and expected distributions

The general question we ask of each of our four expected distributions, is 'how many of the 560 random choices have more sites in view than that of our observed distribution"? So, if we discover that 30 expected sites have more Group2 sites in view than the observed then it is said to be significant at the 30/560 level or .048 % level. That is, we have discovered that the number of sites in the randomly generated, expected distribution are significantly less than that found in the observed distribution. Naturally we can express this in another way: the observed distribution has a significantly greater number of sites. Such a form of probability statistic is not distribution bound and is therefore suitable where we have no prior knowledge of how the expected distribution should display itself.

Hypotheses 5(i) and 5(ii) - Observed data, random samples and significance testing for CVA via r.cvs

The observed data are generated using r.cva for each of the 125 locations, but divided by region. CVA analysis differs primarily in that the generated viewshed types are of a cumulative nature (as described by Wheatley 1995). The same basic format for generating the random datasets above was used to create the random samples for CVA. Also there is only one form of random database created, a non-directional database. In this case a minimum of 1250 randomly generated sets of sites (locations) are used, where the n of sites for each set = 125, and the assessment of possible viewsheds is for a complete 360 degrees. The general format for testing is the same also.

Overview of treatise so far

This paper has so far reviewed the aims and methodology of the project. We have also presented the results of the first two phases. We now offer interpretative conclusions of these outcomes. The paper will close with remarks on the project's design

Interpretation of results to date

Both for our methodology and our interpretations we have assumed that belief systems guide, or influence, human action and thought, and that these are expressed by material culture. In our attempt to link material cultural to human action, and, finally, beliefs, we offer the following as a possible interpretation to date.

Overview

Primarily, this project has found that it was important for Neolithic and Bronze age peoples of western Scotland to purposely locate their structures to enable these sites to participate in a design of inter-relationship between themselves and the natural environment. (This raises the question whether any other recognisable entities might also be included). This suggests that it was of relevance to their belief systems to order their world in a very specific way. The patterns that we have found evidence for are 'simple' alignments. Alignments are where one or more arranged objects, or sites, are aligned with either another arranged object or site and/or a natural 'object'. What connects all these monuments is the possibility of a shared belief system across geographical space and time.

Simple alignments

In connection with these alignments is their direction and final destination. The assembling of the alignments (human action) produced distinct orientations or indicated directions to be viewed from a specific or definite place within the Landscape. For the free-standing stone monuments, in Mull, Argyll, Islay and Uist, these particular directions have been shown to be significant to the monuments as a regional group. These directions appear to be linked to celestial phenomena for the 3 regions of Argyll, Mull and Islay. To reiterate, these region titles include the areas of Coll, Tiree and North Argyll for Mull, Jura for Islay, and Lorn for Argyll. The geographical and chronological extent of these relationships, shows that the associated symbolic concepts held some weight. (that is, revealed the complexity of the relationships and the possible on-going nature of these relationships). The human action that is presented to us for each of these regions is that of forming configurations between and within structures.

From the evidence to date, Mull, Argyll, Islay, and Uist appear to be linked to the same coherent, *fundamental* system. The spatial design that they all share may well be associated with, or represent, the same or similar elementary concept(s)

Possible associated belief systems

We have seen that both the moon and the sun were important entities to the builders of many of the sites researched to date in western Scotland. The material culture has revealed this to us via the purposely created alignment indications. The strength of these indications and the geographical extent of these also emphasise the weaving and integration of an important belief system that extends through-out much of western Scotland.

What can we know about their belief system from the evidence we have so far? The lunar phenomena that were of primary focus were the major and minor standstills, and of these two, the former was predominant for Mull and Argyll and the latter for Islay. This lunar position is when the moon reaches its maximum distance north or south of the equator during its 18.6 lunar period, before it then began its march back in the other direction. The minor standstill is when the moon's path is maintained inside that of the sun's and reaches its possible maximum distance north or south of the equator whilst staying within this boundary. Argyll also has an interest in the Sun at the winter solstice and Islay has an interest around the equinox. It is possible then, that the people of these monuments had a keen understanding of the cycles of the moon and sun. It is very likely that such changeable phenomena marked out, or mirrored, the equivalent changes in their immediate worldly landscape[5], such as tides and fishing, bird and other migration, parallel human movements and plant life. The sun and the moon for such peoples, then, were likely symbols of life-giving forces. Naturally, the great phenomena of light and warmth, regardless of whether they were associated with life-giving forces or not, would be worthy of appreciation and, perhaps, adoration. The major events in these bodies' movements, such the major standstills and solstices, may have represented times of great cosmological importance and may have implied 'magical' or 'powerful' moments in time.

Summary

Through the enormous investment of time and space, and the consistent patterns over the same, that the monuments, the horizons and the associated phenomena appear to be part of the same fundamental cosmological system. This system seems to be connected to astronomical phenomena and their cycles. Added to this, regions appear to have some cultural independence, for there are variations in the astronomical system they focus upon.

Conclusion

We have above the basis for the "ultimate design" of an investigation, as explored in the introduction. Here the connection between visualization and statistical analyses is made. This connection is not only made in the final section of the analyses, where viewsheds are constructed, but from the very start of the project where the importance of vision itself is tested using other methodologies and paradigms. In this way, the reasons for using viewsheds themselves are tested for soundness and applicability. So, too, is the complimentary creation of maps of site location, ground elevation and viewsheds, once the statistical analyses are done. Other visual aids include histograms and polar plots for understanding observed orientation patterns of sites.

The results of the viewshed analyses, when complete, will provide this investigation with additional information into the cosmological systems and monuments of western Scotland.

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End notes

[1] See http://www.baylor.edu/grass/ for information regarding this free GIS software.
[2] See http://www.esri.com/software/arcinfo/ for details about this GIS software.
[3] See the lighter shaded area for the delineation of the furthest horizon points for all the Ruggles' sites of Figure 1. The lighter shaded area allowed us to determine which, and how much, landscape data would be required to do a full horizon analysis of all sites.
[4] We will be using the script written by Jo Wood from the University of Leicester that will allow us to take into consideration the curvature of the earth when using Grass4.3. The module is r.xy.
[5] This is not attempt to define worldly as the opposite of otherworldy, but rather as tangible and immediate.. Along with these assumptions, symbolic concepts are seen as representative constructs of these belief systems.

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Tables

Region	Significant declination bin-widths in degrees	Possible astronomical phenomena	*p*	Ranges significantly avoided
Mull	¯30 -¯35 (southerly)	Lunar (Major standstill)	**0.025**	
	¯25 –30 (southerly)	Lunar (Major standstill)	0.095	
	25 – 30 (northerly)	Lunar (Major standstill)	0.077	
Argyll	¯20 -¯25 (southerly)	Solar (Winter solstice)	0.062	¯15 – ¯10 (southerly)
	25 – 30 (northerly)	Lunar (Major standstill)	**0.026**	15 – 20 (northerly)
	30 - 35 (northerly)	Unknown – but indicates densest part of Milky Way	**0.002**	
Islay	¯15 - ¯20 (southerly)	Lunar (Minor standstill)	0.051	¯20 -¯30 (southerly)
	¯5 - ¯10 (southerly)	Solar (flanking Equinox)?	**0.035**	
	0 - ¯5 (southerly)	Solar (flanking Equinox)	0.096	
	0 - 5 (northerly)	Solar (flanking Equinox)	0.095	
	15 - 20 (northerly)	Lunar (Minor standstill)	**0.005**	20 - 30 (northerly)

Table 1. Possible specific astronomical phenomena for which evidence has been found. Poisson statistics were used to compare the actual horizon ranges of focus with those of the expected. The expected pattern being a normal distribution within *bin-widths. Above are Poisson - distribution outcomes showing significant results of individual bin analyses, where* p is the probability *of outcome. Probabilities in bold are where* $p < 0.05$*, others are where* $p < 0.1$*.*

Figures

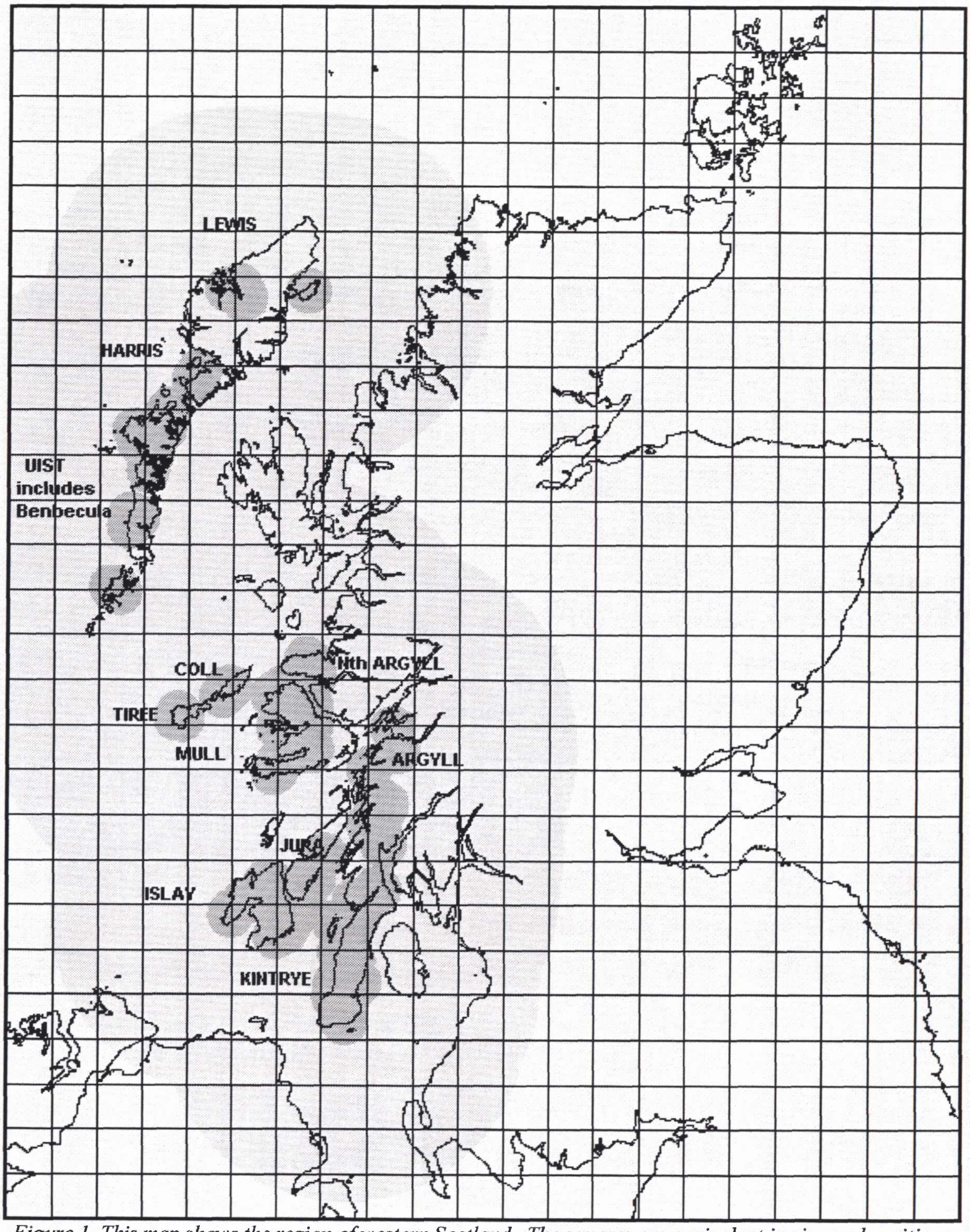

Figure 1. This map shows the region of western Scotland. The squares are equivalent in size and position to the Ordnance Survey 20 by 20 km LANDFORM® PANORAMA data tiles. The darker shaded areas are where the sites from Ruggles' data base are to be found. Map created by Andrew Smith.