The importance of landscape characteristics for the delivery of cultural ecosystem services

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Abstract

The importance of Cultural Ecosystem Services (CES) to human wellbeing is widely recognised. However, quantifying these non-material benefits is challenging and consequently they are often not assessed. Mapping approaches are increasingly being used to understand the spatial distribution of different CES and how this relates to landscape characteristics. This study uses an online Public Participation Geographic Information System (PPGIS) to elicit information on outdoor locations important to respondents in Wiltshire, a dynamic lowland landscape in southern England. We analysed these locations in a GIS with spatial datasets representing potential influential factors, including protected areas, land use, landform, and accessibility. We assess these characteristics at different spatial and visual scales for different types of cultural engagement. We find that areas that are accessible, near to urban centres, with larger views, and a high diversity of protected habitats, are important for the delivery of CES. Other characteristics including a larger area of woodland and the presence of sites of historic interest in the surrounding landscape were also influential. These findings have implications for land-use planning and the management of ecosystems, by demonstrating the benefits of high quality ecological sites near to towns. The importance of maintaining and restoring landscape features, such as woodlands, to enhance the delivery of CES were also highlighted.

Keywords: cultural ecosystem services; Public Participatory GIS (PPGIS); viewshed; landscape; protected areas; spatial

1. Introduction

The benefits we receive from the natural environment are essential to human life. These benefits, that people obtain either directly or indirectly from ecological systems, are referred to as ecosystem services and can be classified as provisioning, regulating and cultural services (CICES, 2017). Identifying and quantifying ecosystem services is increasingly important in land-use planning and the management of ecosystems (Braat and de Groot, 2012; European Comission, 2011; Tallis et al., 2008). A wide range of methods have been used to quantify ecosystem services, which can be relatively simple to apply in the case of provisioning services (e.g. timber production). However the often less tangible benefits arising from Cultural Ecosystem Services (CES), can be much more difficult to quantify and are therefore often assessed inadequately or not at all. For this reason, assessments of CES (Daniel et al., 2012) are underrepresented in ecosystem services studies (Boerema et al., 2016; Gee and Burkhard, 2010).

CES are the non-material benefits that people gain from ecosystems through cultural heritage, spiritual enrichment, recreation and tourism, and aesthetic experiences (Church et al., 2011; Millennium Ecosystem Assessment, 2005). They are considered central to wellbeing and are often central to arguments for the protection of ecosystems (Hirons et al., 2016). It is therefore important to assess CES, to improve our knowledge of interactions between social and ecological systems and the potential generation of wellbeing (Brown et al., 2011). Furthermore, benefits associated with CES are often key to assessing trade-offs between other ecosystem services (Cordingley et al., 2015) and management decisions (Daniel et al., 2012).

CES include a wide range of non-material benefits, which do not necessarily co-vary across landscapes. For example, Cordingley et al. (2015) found that recreational use of heathland habitats did not match stated differences in aesthetic preferences for these habitats. A number of methods have therefore been developed in response to the need for greater understanding and quantification of CES (Boerema et al., 2016). These range along a spectrum from quantifiable aspects of CES, such as tourist expenditure or number of visitors (Anderson et al., 2009; Chen et al., 2009; Neuvonen et al., 2010), to quantification of the "wellbeing" of individuals (Boerema et al., 2016). Mapping CES through place or landscape values has also been increasingly used in recent years. This can be achieved through direct stakeholder engagement (Brown and Fagerholm, 2015; Brown and Weber, 2012; Fagerholm et al., 2012) or by using social media data, including geotagged photographs from Flickr (Keeler et al., 2015; Wood et al., 2013) and Instagram (Zanten et al., 2016). Public Participation Geographic Information Systems (PPGIS) are increasingly being used as a method for gathering landscape values (Brown and Brabyn, 2012; Brown and Weber, 2012; Lowery and Morse, 2013; Riper and Kyle, 2014), with the aim of increasing public involvement in policy making and land use planning by capturing local spatial information (Kenter, 2016; Sieber, 2006).

A landscape feature could provide several CES including recreational, aesthetic, future, heritage, and spiritual values (Brown & Reed, 2000), but also have different values for different people. Studies investigating CES often only consider recreational value, since this tends to be easier to quantify than other values such as spiritual, educational and aesthetics (Boerema et al., 2016; Nahuelhual et al., 2013; Paracchini et al., 2014; van Riper et al., 2012). However, differences in the relative importance of landscape features can occur depending on the cultural values obtained (Brown and Brabyn, 2012). This highlights the need to explore the many types of CES individuals may receive from the landscape. A number of definitions have been developed for the term "landscape"; in this study we describe a landscape as a heterogenous area which interacts with its entities, including humans (Lepczyk et al., 2008; Sayer et al., 2013).

Mapping preferred locations in the landscape allows for statistical and spatial analysis to determine the relative importance of different factors for the delivery of CES. A range of landscape characteristics have been associated with CES values, including protected areas, land cover, landform and accessibility (Brown and Brabyn, 2012; Frick et al., 2007; Peña et al., 2015). The composition of land, including landscape diversity and naturalness are considered to be important (Brown and Brabyn, 2012; Peña et al., 2015), as well as the presence of particular habitats, such as woodland (Frick et al., 2007) and water (Brown and Brabyn, 2012). The distance travelled to visit a location in a landscape is essential to consider. Many studies report a distance-decay function for visitation, influenced not only by perceived benefits but also the ease and cost of travel (Liston-Heyes and Heyes, 1999; Neuvonen et al., 2007; Schipperijn et al., 2010). A significant proportion of research on CES has been carried out in protected areas (Neuvonen et al., 2010; Plieninger et al., 2013) where cultural benefits such as recreation and spiritual fulfilment have been reported (Daniel et al., 2012; Plieninger et al., 2013). However, it is essential to consider the importance of protected areas within the context of the wider landscape, where a number of characteristics, including landform and accessibility, may interact. These range of characteristics may also influence CES at different scales of perception, for instance through what is present at a location compared to what may be seen in the surrounding area.

Identifying and mapping landscape values provides decision makers with a better understanding about how the landscape functions (Meyer and Grabaum, 2008; Willemen et al., 2008). Recognising important landscape characteristics can be useful for revealing areas which offer a greater delivery of CES (“cultural hotspots”) and where gaps in the delivery of CES occur (“gap analysis”) in a landscape (Bagstad et al., 2017; Plieninger et al., 2013).

Influential landscape characteristics are useful to consider when providing further resources for improving existing CES hotspots, reducing CES gaps, and identifying trade-offs, so that overall delivery of CES can be enhanced and potential conflict among stakeholders reduced.

In this paper we investigated whether landscape characteristics such as protected areas, landform, land use and accessibility, were associated with the delivery of CES. To achieve this we used PPGIS to elicit information on outdoor locations important to respondents in a dynamic lowland landscape in southern England and analysed these in combination with spatial datasets of potential influential factors. The objectives of this study were to address the following questions:

(i) Do landscape characteristics such as protected areas, accessibility, land cover and landform influence the delivery of CES in a multifunctional landscape?

(ii) Do these landscape characteristics vary in relative importance depending on the type of cultural engagement (recreation, natural heritage, or cognitive)?

(iii) What is the impact of different spatial and visual scales on the characteristics affecting cultural service delivery?

2. Method

2.1 Study Area

The study was undertaken in southern Wiltshire in the South West of England (Latitude 50^{0}58'44"N - 51^{0}25'40"N; Longitude 1^{0}30'44"W - 2^{0}19'44"W), across the focal lowland landscape for the Wessex-BESS project (http://wessexbess.wixsite.com/wessexbess) studying a range of ecosystem services (Raffaelli et al., 2014) (Fig 1). The region covers 273 600 ha and has a population of around 1,080,000 (Office for National Statistics, 2014). Land cover is dominated by arable land (46%) and grasslands (41%, where 28% of this is agriculturally improved), with some woodland (9%) and a relatively low cover of urban land (4%). The study area contains the military training area of Salisbury Plain (SPTA) which contains around 14,000 ha of highly biodiverse semi-natural chalk grassland, the largest continuous extent of this habitat in Western Europe (Toynton and Ash, 2002). The area is drained by numerous chalk streams, which have high ecological value (Environment Agency, 2004), including the River Avon catchment. The study area is also a unique prehistoric ritual landscape with widespread Neolithic (circa 4000 – 2400 BC) and Romano-British (500-600 AD) earthworks and monuments, which include some of the best preserved in Southern England (Barnes, 2003) and UNESCO World Heritage sites such as Stonehenge and Avebury (UNESCO, 2016).

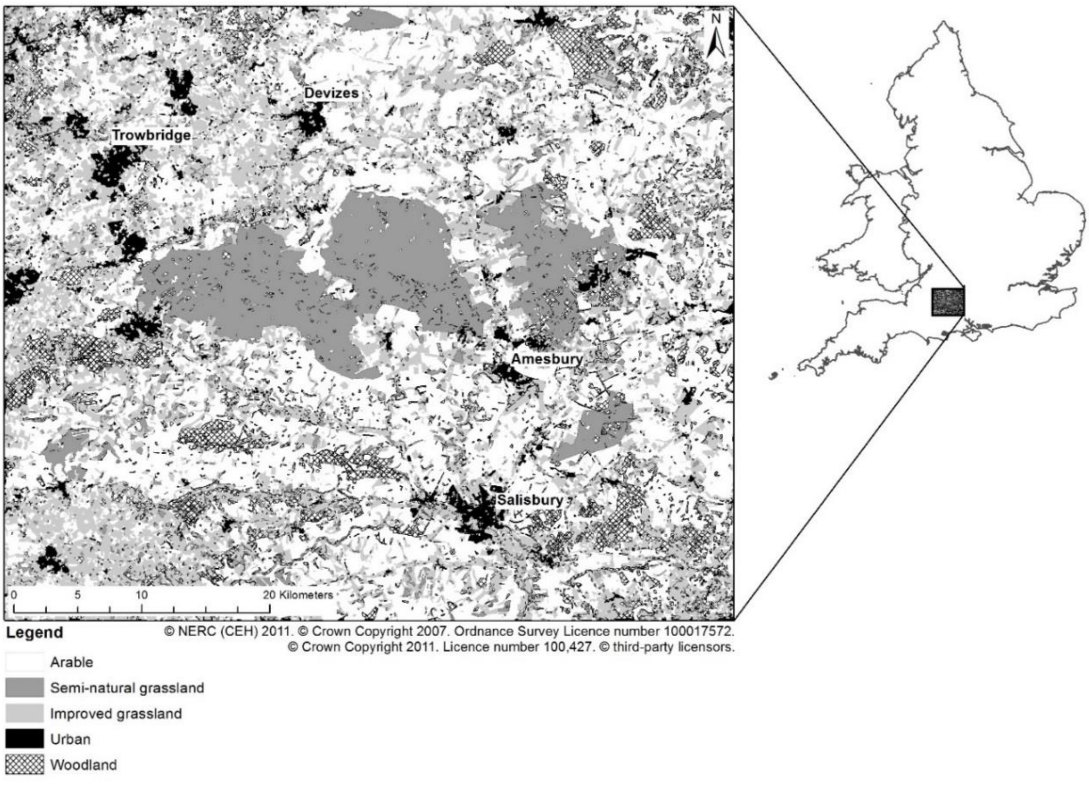

Fig 1. The study area located in southern Wiltshire in the South West of England (Morton et al., 2011).

2.2 Survey Data

In this study we use people's stated preference for locations in southern Wiltshire as an indicator of CES delivery. We assume that these selected locations provide cultural value and benefits to individuals, through recreation, for example, which can ultimately lead to increases in well-being (Brown et al., 2011). Survey data were collected using a PPGIS online survey from August 2014 until December 2015. Participants were recruited through advertisement via parish councils, local community groups and local newspapers in the Wessex region. The PPGIS survey website (http://www.ppgis.manchester.ac.uk/bess/) began with an introduction, followed by a research ethics note which had to be read before continuing. The subsequent screen contained an interactive application with Ordnance Survey (OS) maps of the study area. The OS maps could be zoomed in to different scales, and the participants could interact with the map and create digital markers (see Supplementary Material, Figure S1). Respondents were asked to "Mark on a map three outdoor places of personal importance to you". Up to three different markers could be placed per respondent. Once the markers had been placed, participants were asked to fill out text-based questions, to obtain information on the activities that participants carried out at these points along with socio-demographic characteristics. The survey was developed following a stakeholder workshop (see King et al., nd). We grouped the activities associated with each selected point to reflect types of CES engagement, namely recreation (outdoor swimming, horse riding, running, cycling, walking, playing, hunting, fishing) n = 433, natural heritage (conservation, wildlife) n = 275, or cognitive (spiritual, teaching, creative) n = 143, based on groupings reported in Plieninger et al. (2013). Respondents could select as many associated activities as they wished per point, thus some points fell into multiple CES engagement categories (96 points fell in all 3).

2.3 Spatial Data

The digital markers from the PPGIS survey were imported into ESRI ArcGIS v10.3 (© ESRI, Redlands, CA) for analyses. We refer to these markers as “selected points” throughout. An equal number of control points were randomly generated within the same bounding area given to the participants (Fig 2). This approach is comparable to the use of pseudo-absences in species distribution models, since a control point did not necessarily represent a non-important outdoor place, merely one which was not selected by PPGIS participants. Barbet-Massin et al. (2012) found that randomly selected pseudo-absences (i.e. control points) which were equally weighted to the sum of the presences (i.e. selected points), produced the most accurate predicted distributions. Other studies have applied similar approaches to survey data (Sherrouse et al., 2014; Whitehead et al., 2014). Although access to SPTA is often restricted due to live-firing or military training exercises, access can still be gained on certain days of the year by the public and thus has the potential to be visited and preferred by participants, as shown in Fig 2. For this reason, we allowed the generation of control points on the SPTA.

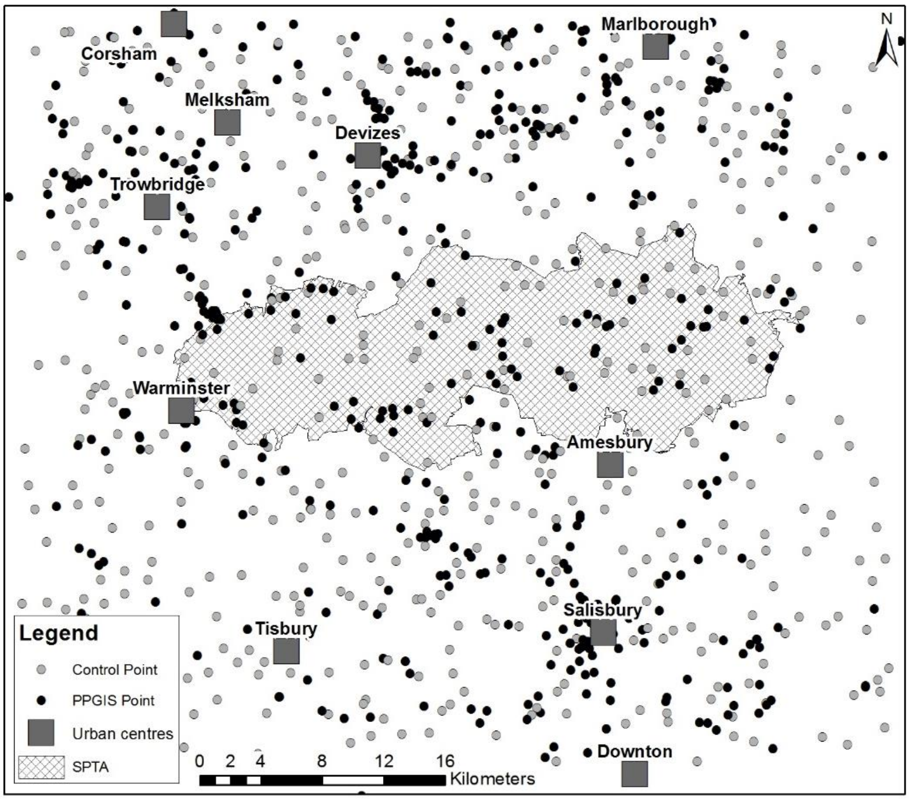

Fig 2. PPGIS points selected by respondents and control points generated in the study area, alongside the ten urban centres (defined by postcodes supplied) and the Salisbury Plain Training Area.

Two buffer sizes were generated around the selected points and control points, to take into account the different spatial scales at which landscape variables might impact upon CES. A buffer size of 500m was used to represent a local scale, whilst a buffer of 5km represented the wider landscape scale, similar to Willemen et al. (2008). Having the local buffer set at 500m, as opposed to an even finer scale, allows for some level of variation in the precision with which respondents placed their markers. For example, a participant may place a marker in the centre of an area of importance rather than the actual point of use or access. There are also likely to be differences in the precision with which participants selected points due to the adjustable scale on the PPGIS. In addition to the circular buffer, we also generated a 'viewshed' for each of the selected points and control points (Supplementary material, Figure S2). A viewshed is a raster surface which provides the locations visible in all directions from an observation point, calculated from a Digital Elevation Model (DEM), in our case with 5m horizontal resolution (Intermap Technologies, 2007) (Figure S2). The individual viewsheds were restricted to 500m and 5km, to give a local and a landscape scale view. Viewsheds were created to represent the landscape that could be seen by an individual at the marked point, whilst the circular buffers were created to signify what was present in the surrounding area, for example what an individual would experience if moving around within the buffer. The four buffer types created were thus; the local-visual area (500m viewshed buffer), local-total area (500m circular buffer), landscape-visual area (5km viewshed buffer) and landscape-total area (5km circular buffer). The four buffer types around the selected and control points were then used to extract predictor variables comprising broad categories of designated areas, landform, land cover and accessibility, using a range of spatial datasets (Supplementary Material, Table S3).

To examine the potential influence of protected areas in a multifunctional landscape, we included two variables; the area of land under protection, and the diversity of habitats within protected areas. In England the basic unit of statutory protection is the Sites of Special Scientific Interest (SSSI), which are areas of land selected for ‘special interest by reason of any of its flora, fauna, or geological or physiographical features’ (JNCC, 2015). We calculated the area of SSSI in each of the four buffer types and overlaid the SSSI layer with the Priority Habitats Inventory layer (i.e. those habitat types designated as being most threatened and requiring conservation action under the UK Biodiversity Action Plan (Natural England, 2013)) to calculate the diversity of protected areas. Accessibility to the point was represented by the average Euclidean distance between the point and the ten most common postcodes supplied by PPGIS respondents. These ten postcodes were used as proxies for urban centres and thus the home locations of most of the participants (Fig 2). Indeed, these ten postcodes represented 85% of the respondents (Supplementary material, Table S4). This approach allowed us to compute distances for the control points which had no associated point of origin and to include points for which the respondents had not supplied postcodes (<7%) in the survey questionnaire. To account for people’s valuing of historical sites (Beverly et al., 2008), we included the area of historic interest inside each of the four buffer types using polygon vector layers from Historic England (Historic England, 2015) (see Table S3). The digital elevation model (DEM) was used to extract the two landform variables: average altitude for each buffer type and the maxiumum viewshed area. The maximum viewshed area was restricted to a distance of 20km, since this is the likely maximum distance that can be seen on a clear day (ESRI, 2015). For each site, we also extracted land cover variables, including the area of semi-natural grassland (Neutral, Calcareous, Acid and Fen, Marsh and Swamp), woodland, urban area, river length and land cover diversity, inside each of the four buffer types using the Land Cover Map 2007 (Morton et al., 2011) (with the exception of river length, see Table S3). Semi-natural grasslands were selected, since these are a key landscape characteristic of the study area and they are important habitats across Europe (Duffey, 1974).

2.4 Data Analysis

The land cover categories were combined into ten aggregate classes (Morton et al., 2011). Diversity scores for ten land covers and twelve protected priority habitats were calculated using the Inverse Simpson diversity index in the *vegan* package (Oksanen et al., 2007) in R v3.0.2 (R Core Team, 2013).

To estimate the relative importance of the selected landscape variables for delivering CES, models were constructed using logistic regression, with selected points (1) and control points (0) as the dependent variable. We used a multi-model averaging approach, so all possible combinations of explanatory variables were modelled. All continuous predictor variables were z-standardised prior to analysis to facilitate comparison of model coefficients across variables. Sets of strongly inter-correlated variables (Pearson's $r > 0.6$ or < -0.6) were excluded as possible combinations within the same model by generating a subset of the full model (Supplementary Material, Table S5). Using this approach allowed for each member of pairs of correlated variables to appear independently in different candidate models. The twenty selected points that fell outside of the study area, along with the eight duplicate (defined as points in exactly the same location) selected points were removed from the analysis for simplicity.

Models were ranked using Akaike's Information Criterion for small sample sizes (AIC_c). The differences in AIC_c (Δ_{AICc}) were used to compare models for each of the four buffer types. In order to determine the relative importance of predictor variables, a model-averaging approach was used for models with $\Delta_{AICc} \leq 2$. This level was chosen since models with $\Delta_{AICc} \leq 2$ are considered to be as good as the best model (Burnham and Anderson, 2002). Models with $\Delta_{AICc} < 6$ can also be important, however a large number of models were included when using this value, which can be problematic (Symonds and Moussalli, 2011). The model.avg function of the *MuMIn* package (Barton, 2010) in R was used to calculate the model-averaged coefficients, standard errors and p-values. The relative importance of each variable was calculated by summing the Akaike weights (w_i) for each variable for every model in the $\Delta_{AICc} \leq 2$ set in which it was represented. The higher the total weight for a variable, the higher relative prevalence in the best fitted models for predicting CES delivery from landscape variables. However, to ensure that each variable is assessed fairly, the number of models which contain the variable must be balanced (Burnham and Anderson, 2002), thus the summed weight for each variable was divided by the number of times that the variable appeared in the set of models, giving an average variable weight (w_i). The same modelling procedure was repeated separately for each of the three CES engagement groups; recreation, natural heritage and cognitive, to examine whether characteristics associated with designated areas, accessibility, landform and land cover differed between cultural engagement types. For each group, an equal number of control points generated from the previous analysis were randomly selected.

To test for spatial autocorrelation between the variables in each of the four buffer types, Moran's I correlograms were produced (Legendre and Legendre, 1998), using the *ncf* package (Bjornstad, 2013) in R (Supplementary Material, Figure S6). As a result, we removed (and replaced with a random selection of new control points) isolated controls points generated on the far corners of the study area (n = 48), after which no evidence of spatial autocorrelation was detected.

3. Results

3.1 Sample sizes and socio-demographic data

The PPGIS survey was completed by 278 participants, with a total of 510 selected points returned. There were 478 control points and 466 selected points for analysis, as duplicates and selected points outside the study area were excluded. The most common activities associated with the selected points were walking without a dog (21%), followed by watching wildlife (18%), and walking the dog (12%) (Fig 3). Because hunting (1%) and fishing (1%) were only identified by a few participants, we excluded these points from our analysis. For socio-demographic data see Supplementary Material Figure S7.

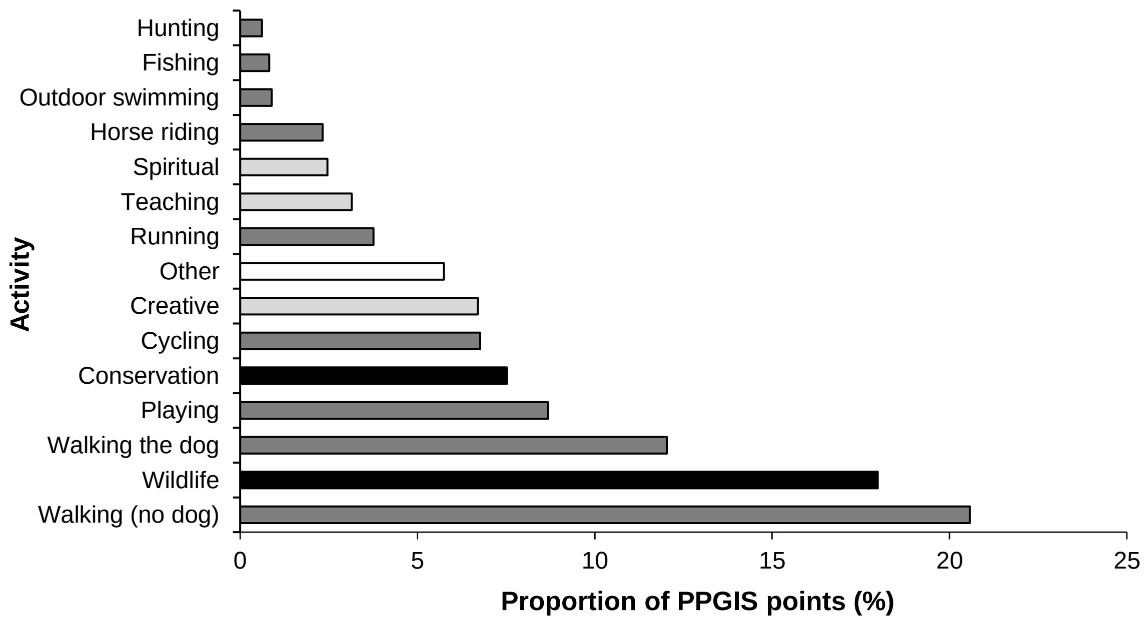

Fig 3. Cultural service activities associated with PPGIS points. Recreational activities in dark grey (n = 445), natural heritage in black (n = 284), cognitive in light grey (n = 149) and other (n = 106) activities in white.

3.2 Landscape characteristics associated with selected important locations (and the delivery of CES) at different spatial and visual scales

The spatial scale and buffer type with the most significant associations between different landscape variables and selected PPGIS points were the 500m circular buffer (seven variables at $p < 0.05$; Table 1) and the 500m viewshed buffer (five variables). Several landscape variables were not significant at any spatial scale or buffer type, including altitude, grassland, land cover diversity and the area of protected land. All other landscape variables tested were significant in between two to all four buffer types . Despite differences in significance and weightings for these variables, the direction of the effect was consistent across all fourbuffer types. The variables with the greatest average weight across buffer types ($W_i = 0.09$) were Euclidean distance to urban centres, urban area, protected area habitat diversity and maximum viewshed.

Euclidean distance showed consistently negative associations with selected points (significant at $p<0.05$ for three buffer combinations). This suggests that areas that are more accessible (i.e. closer to the ten urban centres in the study area) were more likely to be selected by survey participants. Urban area demonstrated a positive relationship with selected points, which was significant in all four buffer types. Positive associations were also revealed for the maximum viewshed area and protected area diversity (both significant in three buffer types), suggesting that locations with a greater visible area and a higher diversity of protected priority habitat types were more likely to be selected. The historic interest variable showed a significant positive relationship for the circular buffer types only, indicating that points are more likely to be found where there is historic interest in the surrounding area. The area of woodland also showed a significant positive association for differentiating selected points from control points in the local scale buffers (500m) only. Models created at the local scale had larger explanatory power (higher R^2 values) compared with the landscape scale. The same was true for the circular buffer models compared with the viewshed buffer model at their respective scales.

#Table 1 approximately here#

3.3 Variation in important landscape characteristics between cultural engagement groups

To identify differences between our three cultural engagement groups (recreation, natural heritage and cognitive) we focused on the effects of protected areas, land use, landform and accessibility, using the buffer type with the highest R^2 value in the previous analysis; the local-total area scale (500m circular buffer) (Fig 4). The same set of variables as before (altitude, grassland, land cover diversity and the area of protected land) were not significant in any cultural group. The only variables significant to $p<0.05$ in all three cultural groups were woodland, viewshed and urban area. The positive associations revealed for these variables suggests that locations were more likely to be selected for recreation, natural heritage or cognitive value where there was a larger area of woodland and urban area, with greater views. The Euclidean distance and river variables were both significant for recreation and natural heritage value. The negative association with Euclidean distance and the positive relationship with river, suggests selected locations were more accessible and had a greater length of river present. Compared to recreation and natural heritage, the cognitive group had less significant associations between different landscape variables and selected points, though the only significant positive association with the historic variable was revealed. This suggests participants were more likely to select a location for cognitive engagement where features of historical interest were present in the surrounding landscape.

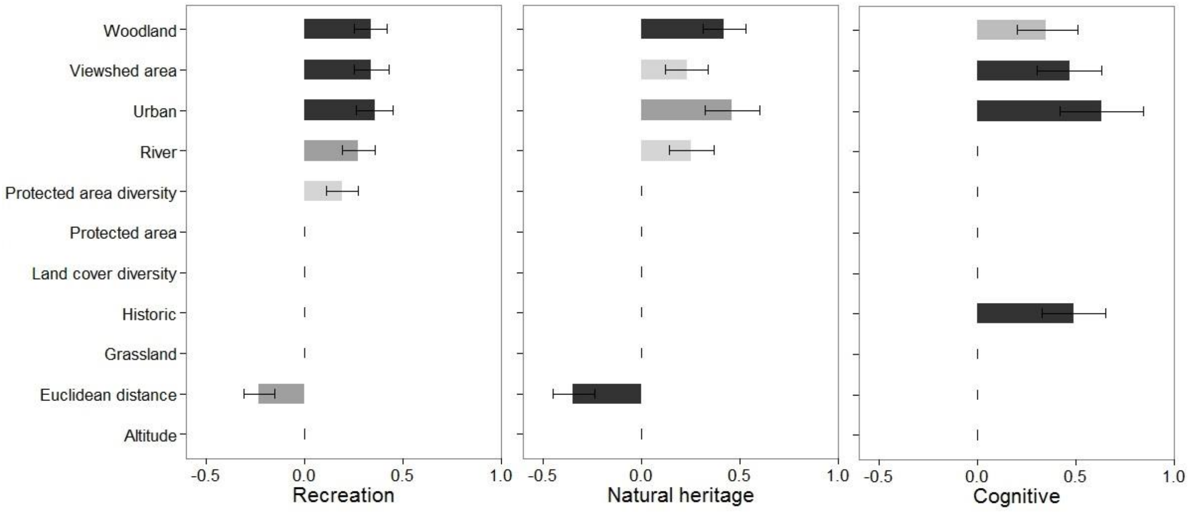

Fig 4. Model-averaged coefficients ± SE from logistic regression analyses for significant variables using a 500m circular buffer for the three different cultural engagement groups; recreation, natural heritage and cognitive, where black bars are significant at a level of <0.001, grey <0.01, and light grey <0.05.

4. Discussion

It is well known that CES provided by landscapes are challenging to examine (Church et al., 2011), but their importance to people is clearly recognised (Hirons et al., 2016). Here we have been able to investigate the relative importance of landscape characteristics for the delivery of CES, using locations identified through a PPGIS survey. In general terms our findings suggest that cultural services are more likely to be delivered from locations that are accessible, near to urban centres, with greater views (i.e. a larger area) and a high diversity of protected habitats. Interestingly, the habitat diversity of protected areas was identified as more important than the diversity of land cover, which suggests that people prefer high quality habitats rather than just the range of habitats available. Other important characteristics included a larger area of woodland and the presence of historic interest in the surrounding landscape.

4.1 Landscape characteristics associated with selected important locations (and the delivery of CES) at different spatial and visual scales

A greater number of significant associations between landscape variables and selected PPGIS points were revealed at the local scale (500m) compared with the landscape scale (5km). Similar characteristics were discovered for what people view (represented by the viewshed) and use in the surrounding area (represented by the circular buffer) at the local scale, suggesting the differences were minimal between the two perceptions for the delivery of CES. This may be explained by the similarities between what people see and use at this scale, where on average the viewshed buffer accounted for 33.6% of the circular buffer. In contrast, greater differences were evident between the important characteristics identified for the two perceptions at the landscape scale, where a reduced coverage (an average of 8.5%) of the circular buffer by the viewshed occurred. It is important to remember that from the PPGIS we were only able to capture a single important point, while people are likely to be using a more complex area around this given location. We used circular buffers at different scales in an attempt to represent the used area, which has helped us to address this problem partly, however comparisons between what is visible and what is used may be prone to error. We also assume that the marking of important locations in the study area is strongly associated with people deriving CES at those points. However, the links between important places, cultural values, wellbeing and the delivery of CES are likely to be complex. The survey was largely carried out by highly-educated individuals (84%, Supplementary Material Figure S7), which is often a common representation bias in PPGIS (Brown, 2017).

Several landscape characteristics were suggested as not important for the delivery of CES in this landscape, including the altitude, area of semi-natural grassland, land cover diversity and the area of protected sites. As previously mentioned, the lack of influence for the diversity of land cover suggests that the quality of these different areas is important, not just the complexity of habitats available (King et al., n.d.). The lack of association between the area of protected habitats and selected locations also highlights the importance of habitat diversity. Interestingly, the area of semi-natural grasslands was not associated with selected points, despite many of these areas being important for wildlife (Vickery et al., 1999; WallisDeVries et al., 2002) which is known to be valued (Mace et al., 2012). Similar relationships with grassland were observed by Plieninger et al. (2013) who found grasslands were hardly related to perceived CES. However at a larger landscape scale the diversity of plant species in semi-natural grasslands is unlikely to be appreciated (Lindemann-matthies et al., 2010). The lack of influence of altitude suggests participants had no preference over whether they visited high places or lower altitude areas, as long as greater views were on offer, as indicated by the positive association between the maximum viewshed area and selected points.

The delivery of CES was consistently associated with accessibility, the quantity of urban area, the diversity of protected habitats and the size of the view from a selected point, at the majority of spatial and visual scales. Thus all four broad categories of potential influence (protected areas, landform, land use and accessibility) represented by the various characteristics were important. Participants were more likely to select a location with a high diversity of protected habitats, potentially due to the enhanced opportunities for watching and enjoying wildlife. The study area has the largest continuous extent of calcareous grassland in Western Europe (Toynton and Ash, 2002), home to numerous special and charismatic species of butterflies, bees and birds, which are known to be highly valued (Mace et al., 2012). The benefits people receive from connecting with nature are well established in the literature (Fuller et al., 2007; Maller et al., 2005; Sadler et al., 2010). A range of other activities may also be associated with protected areas and deriving CES, including guided tours, hiking, swimming and relaxing (Ament et al., 2016). Ament et al. (2016) also found that people visit different protected areas to benefit from different services. This may explain our findings, highlighting the importance of diverse protected areas in the local surroundings. This study showed the importance of diverse protected habitats being visible in the local area, which corresponds to that reported by Maller et al. (2005), where people like to view natural areas. This is also reflected at the landscape scale, where viewing, but not using, the diversity of protected areas was found to be important for the delivery of CES. This suggests the use of protected areas is more important in the local area, however participants still value the opportunity to be able to view these areas in the wider landscape. The findings have significant implications, which suggest that protection under SSSIs is not only beneficial for protecting biodiversity (Gazenbeek, 2005; Ridding et al., 2015), but that they are also important for the delivery of CES. Thus, in this multifunctional landscape, protecting biodiverse habitats may have multiple, non-conflicting benefits for biodiversity, CES and other services (Carvell, 2002) if managed effectively. The association between protected area habitat diversity and CES in this study may provide early indications of a relationship between biodiversity and CES, however further research in this area is required.

A greater expanse of built up areas and gardens, represented by the urban variable, was the only factor to influence the selected locations at all spatial and visual scales. However, when we examined the proportion of urban area found within each of the buffers, only 4% on average is found at the landscape scale and 5% at the local scale, suggesting that the increase in service delivery applies to small increases in built up areas in a predominantly rural landscape. This proportion of built up area is potentially beneficial for providing facilities and services to areas where cultural activities may be undertaken. Similar patterns have also been observed in other parts of the world, including Zanzibar where aesthetic places and CES were associated with areas of infrastructure, services and opportunities for shopping (Fagerholm et al., 2012). The significance of built up areas in this study could also be linked with the selection of important locations close to participants' homes, where the distance to travel is less, which also corresponds to a shorter Euclidean distance revealed in our models. This is consistent with other studies which report relationships between participation in cultural activities and greater accessibility (Cordingley et al., 2015; Neuvonen et al., 2007; Sen et al., 2010).

The creation of viewsheds, also done by Nahuelhual et al., (2013) and Peña et al. (2015), provides a sound methodology for quantifying scenic views and aesthetic appeal, which are often hard to assess and are consequently rarely quantified in studies. We found that areas which offer greater views over the landscape are more likely to deliver CES. This is consistent with Brown and Brabyn (2012), who found recreation and aesthetic values to be associated with high topography, open valleys and mountains.

4.2 Variation in important landscape characteristics between cultural engagement groups

The relative importance of the landscape variables was similar, regardless of whether all selected points were grouped, or split into recreation, natural heritage and cognitive groups. The set of landscape variables that were not significant in the previous analysis, also showed no association with any of the cultural engagement groups individually, suggesting that no important patterns were missed when the points from all groups were lumped. A larger area of woodland, with built up areas and greater views, was important for the delivery of CES across all three groups. The positive association of woodland on the delivery of CES has also been reported by Norton et al. (2012) for leisure and escapism. The findings also correspond to results presented in the England Leisure Visits Survey 2005, where walking occurred most in woodland (Natural England, 2006). In this particular study area, the preference of woodland may arise due to the desire for variety in a landscape where woodland is uncommon.

Fewer landscape associations were detected for cognitive engagement, however the sample size for this group was lower. Nevertheless, this is the only group where historic interest was important. It is well known that people value the maintenance of historically important places (Daniel et al., 2012) and so the findings in this study are not surprising given that the Wessex region has diverse and abundant historic interest, including one of the top ten attractions in the UK; Stonehenge (Mason and Kuo, 2008). King et al. (n.d.) found the importance of "sense of place" was associated with non-biotic features such as heritage, in the same study region.

Although the methodology has proved valuable in determining the relative importance of landscape characteristics for the selection of important areas in the study area, and hence the delivery of CES, the R^2 values calculated from the models produced are generally quite low. The R^2 values did increase when the points were focussed into a particular cultural engagement group (recreation, natural heritage and cognitive), which provides further evidence for the importance of being specific about which service is being quantified (Swetnam et al., n.d.). However, the highest R^2 value was still only 0.15. There are a number of reasons for this; firstly, participants have a wide range of choice in the landscape, followed by a variety of activities that may take place in a given location; secondly, individuals vary in age, gender and experiences, thus the perception of CES is highly variable (Hirons et al., 2016). Lastly, the control points selected for this analysis do not represent non-important outdoor locations. Instead they can be described as a background average, in comparison to selected points which are places of high cultural value, since all parts of the landscape, even those considered generally to be undesirable, may have value to someone (The Research Box et al., 2009). This illustrates the progress that is still required to be able to predict CES provided by landscapes and highlights the caution that needs to be taken when evaluating results from cultural service modelling software.

5. Conclusion

This study has provided a method for identifying the relative importance of landscape characteristics at different spatial and visual scales for the delivery of CES in a dynamic, complex region. We found that protected areas, accessibility, land cover and land form all influenced the delivery of CES in the study area, and this varied over different spatial and visual scales. Similar landscape characteristics were revealed for recreation, natural heritage and cognitive engagement groups. Overall, our results highlight the need for landscapes which are of high ecological quality, diverse and near to towns. This information is of interest to local communities, but also to environmental managers and landscape planners, by helping them to prioritise parts of the landscape and identify locations for restoration, to further enhance areas for obtaining cultural benefits (Peña et al., 2015). They are also useful to consider when targeting "cold spots" or areas that are currently not recognised as being culturally important. For example, the work by Scotland's Forestry Commission to create woodlands near urban areas (Forestry Commission Scotland, 2011), may increase the delivery of CES, based on the findings illustrated in this study. The methodology established in this paper could be benefical for implementing policies and international treaties such as

The European Landscape Convention (ELC). The ELC aims to promote the protection, management and planning of European landscapes, through engaging people in decision-making and ensuring all components of the landscape, including natural and man-made areas are accounted for (Déjeant-Pons, 2006). This methodology is thus highly revelant, particularly as it involves a PPGIS and models both natural and man-made characteristics in the landscape.

The analysis conducted here has currently only been applied to this study area, however replication of this work in other regions, particularly with different landscape features, would provide validation for the important characteristics identified and may reveal further insights.

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Table 1. Model-averaged results from logistic regression analyses to explain the selection of important locations for each of the four buffer datasets; 500m viewshed buffer, 5km circular buffer, 500m circular buffer and 5km viewshed buffer.

	500m viewshed buffer				5km viewshed buffer				500m circular buffer				5km circular buffer			
	Coefficient	± SE		W_i	Coefficient	± SE		W_i	Coefficient	± SE		W_i	Coefficient	± SE		W_i
Altitude	0.02	0.05		0.07	0.01	0.03		0.09	0.05	0.08		0.08	#			
Euclidean distance	-0.23	0.07	**	0.08	-0.22	0.07	**	0.10	-0.24	0.08	**	0.09	-0.12	0.09		0.09
Grassland	-0.01	0.04		0.07	0.00	0.02		0.08	0.05	0.08		0.10	0.01	0.03		0.07
Historic	0.01	0.03		0.06	0.02	0.04		0.10	0.16	0.07	*	0.09	0.15	0.07	*	0.09
Land cover diversity	0.02	0.05		0.07	0.01	0.03		0.09	0.07	0.09		0.10	-0.03	0.06		0.07
Protected area	-0.01	0.04		0.06	#				0.02	0.05		0.06	0.10	0.09		0.09
Protected area diversity	0.25	0.08	**	0.08	0.18	0.07	**	0.10	0.19	0.08	*	0.09	0.02	0.05		0.08
River	0.06	0.08		0.08	0.00	0.02		0.07	0.25	0.08	**	0.09	#			
Urban	0.38	0.09	***	0.08	0.25	0.08	**	0.10	0.42	0.09	***	0.09	0.42	0.09	***	0.09
Viewshed area	0.27	0.08	***	0.08	0.10	0.09		0.11	0.29	0.08	***	0.09	0.23	0.07	**	0.09
Woodland	0.34	0.08	***	0.08	0.01	0.04		0.09	0.31	0.08	***	0.09	0.01	0.04		0.06
R^2		0.09				0.04				0.11				0.06		

* $p < 0.05$;
**$p < 0.01$;
***$p < 0.001$
Variable was not retained in top models

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Supplementary Material

Figure S1. Screen capture of the PPGIS survey for identifying important points within the Wessex landscape. Participants can zoom, drag and click markers onto the Ordnance Survey (OS) map. Each marker has a set of questions associated with the chosen location.

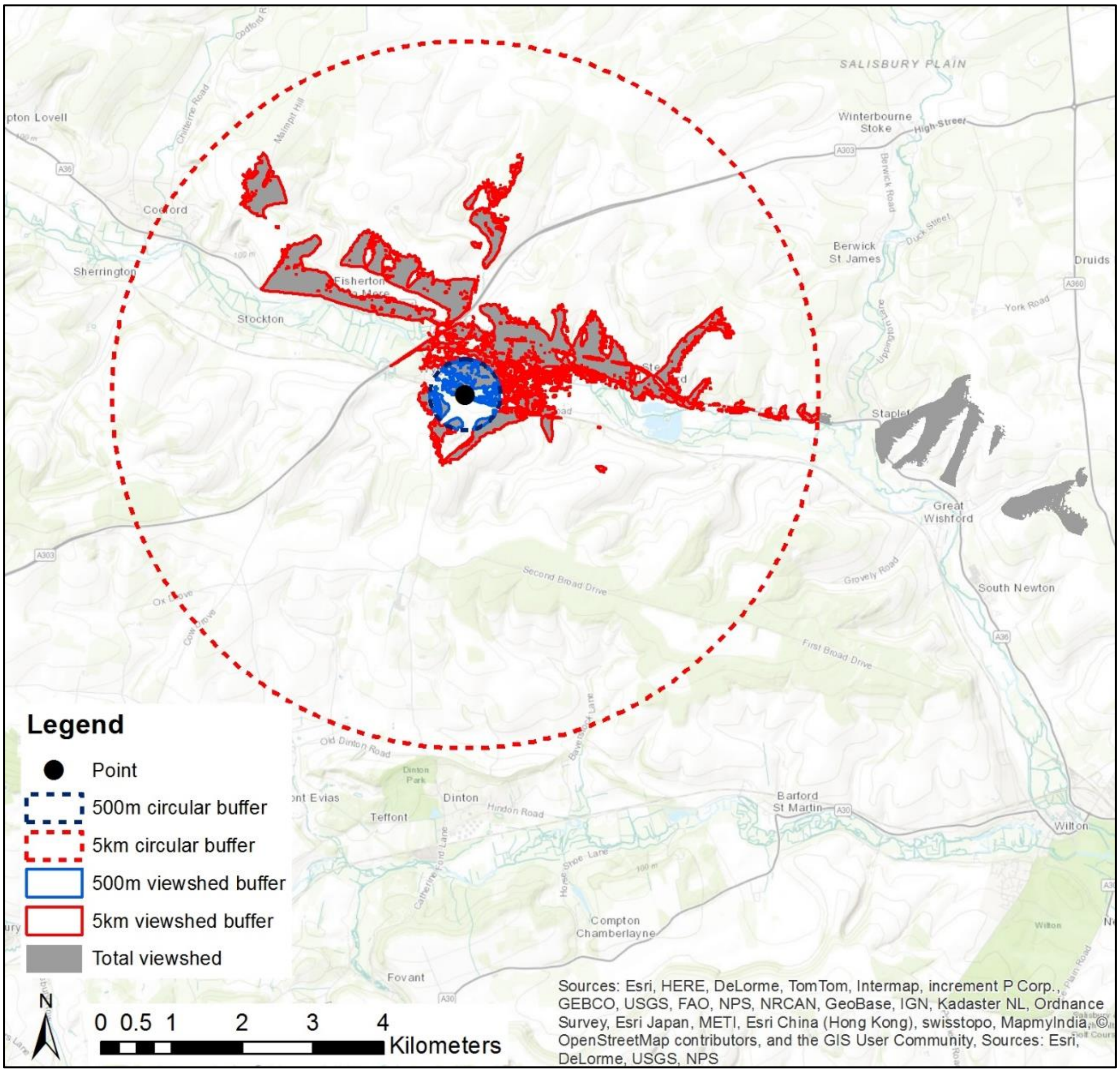

Figure S2. An example PPGIS point with the maximum viewshed and the four buffer types created; the local-visual area (500m viewshed buffer), local-total area (500m circular buffer), landscape-visual area (5km viewshed buffer) and landscape-total area (5km circular buffer).

Table S3. A summary of variables used to explain the selection of important locations in the study region, with their source, scale/resolution and description

Type	Variable name	Source	Scale/Resolution	Description
Accessibility	Euclidean distance	OS Meridian (Ordnance Survey, 2014), Population Data (Office for National Statistics, 2014)	1:50 000	Average Euclidean distance to each of the 10 proxy locations
Designated areas	Protected area	SSSI layer (Natural England, 2014)	1:1250 – 10 000	Area of Sites of Special Scientific Interest (SSSI)
	Protected area habitat diversity	Priority Habitats Inventory (Natural England, 2013), SSSI layer (Natural England, 2014)	10 – 100m	Diversity index for priority habitats which are designated as Sites of Special Scientific Interest (SSSI)
	Historic	World Heritage Sites, Scheduled Monuments, Parks and Gardens (Historic England, 2015)	1:1250 – 10 000	The area of historic sites including world heritage sites, scheduled monuments and parks and gardens
Land cover	Grassland	Land Cover Map 2007 (Morton et al., 2011)	Minimum Mappable Unit for land cover parcels: 0.5ha	The area of semi-natural grassland (Neutral, Calcareous, Acid and Fen, Marsh and Swamp). Excludes Improved grassland and Rough grassland.
	Land cover diversity	Land Cover Map 2007 (Morton et al., 2011)	Minimum Mappable Unit for land cover parcels: 0.5ha	Diversity index for land cover
	River	OS Meridian (Ordnance Survey, 2014)	1:50 000	Total length of river
	Urban	Land Cover Map 2007 (Morton et al., 2011)	Minimum Mappable Unit for land cover parcels: 0.5ha	Area of built-up areas and gardens
	Woodland	Land Cover Map 2007 (Morton et al., 2011)	Minimum Mappable Unit for land cover parcels: 0.5ha	The area of coniferous and broadleaved woodland
Landform	Altitude	Digital Elevation Model (Intermap Technologies, 2007)	5m	Average altitude
	Viewshed area	Digital Elevation Model (Intermap Technologies, 2007)	5m	The maxiumum area which is visible from the point

Table S4. The top ten most commonly surveyed postcodes from the PPGIS survey with the population (calculated from the Office for National Statistics, 2014) and percentage of participants surveyed from each location.

Location	Postcode	Population	% of participants
Salisbury	SP1/2	50,800	17
Warminster	BA12	28,508	12
Trowbridge	BA14	48,138	11
Marlborough	SN8	24,018	10
Devizes	SN10	31,544	10
Downton	SP5	22,361	9
Tisbury	SP3	11,303	4
Melksham	SN12	25,211	4
Corsham	SN13	16,529	4
Amesbury	SP4	31,111	4
			Total: 85%

Table S5. Correlation matrix of landscape variables for (a) 500m circular buffer, (b) 500m viewshed buffer, (c) 5km circular buffer or (d) 5km viewshed buffer model.

(a) 500m circular buffer

	Protected area diversity	Protected area	Altitude	Viewshed area	Euclidean distance	Historic	Land cover diversity	Grassland	Woodland	River	Urban
Protected area diversity	1.00	**0.58**	0.09	0.15	-0.11	0.07	0.11	0.37	0.11	0.06	0.02
Protected area	**0.58**	1.00	0.22	0.12	-0.14	0.12	-0.23	**0.74**	0.15	-0.19	-0.14
Altitude	0.09	0.22	1.00	0.26	0.09	0.13	-0.16	0.22	0.13	-0.49	-0.28
Viewshed area	0.15	0.12	0.26	1.00	-0.12	-0.08	0.09	0.06	-0.01	-0.22	-0.10
Euclidean distance	-0.11	-0.14	0.09	-0.12	1.00	0.05	0.06	-0.26	0.23	-0.04	-0.07
Historic	0.07	0.12	0.13	-0.08	0.05	1.00	0.07	0.01	0.20	-0.11	-0.09
Land cover diversity	0.11	-0.23	-0.16	0.09	0.06	0.07	1.00	-0.28	0.21	0.24	0.14
Grassland	0.37	**0.74**	0.22	0.06	-0.26	0.01	-0.28	1.00	-0.11	-0.20	-0.16
Woodland	0.11	0.15	0.13	-0.01	0.23	0.20	0.21	-0.11	1.00	-0.10	-0.12
River	0.06	-0.19	-0.49	-0.22	-0.04	-0.11	0.24	-0.20	-0.10	1.00	0.28
Urban	0.02	-0.14	-0.28	-0.10	-0.07	-0.09	0.14	-0.16	-0.12	0.28	1.00

(b) 500m viewshed buffer

	Protected area diversity	Protected area	Altitude	Viewshed area	Euclidean distance	Historic	Land cover diversity	Grassland	Woodland	River	Urban
Protected area diversity	1.00	**0.59**	0.05	0.12	-0.12	0.06	0.07	0.39	0.14	0.11	0.01
Protected area	**0.59**	1.00	0.07	-0.03	-0.11	0.08	-0.15	**0.72**	0.22	-0.09	-0.09
Altitude	0.05	0.07	1.00	0.20	0.08	0.07	-0.15	0.10	0.00	-0.30	-0.17
Viewshed area	0.12	-0.03	0.20	1.00	-0.12	-0.11	-0.06	-0.06	-0.10	-0.19	-0.08
Euclidean distance	-0.12	-0.11	0.08	-0.12	1.00	0.06	0.06	-0.24	0.18	-0.05	-0.05
Historic	0.06	0.08	0.07	-0.11	0.06	1.00	0.09	0.02	0.13	-0.06	-0.04
Land cover diversity	0.07	-0.15	-0.15	-0.06	0.06	0.09	1.00	-0.20	0.24	0.28	0.18
Grassland	0.39	**0.72**	0.10	-0.06	-0.24	0.02	-0.20	1.00	-0.08	-0.09	-0.11
Woodland	0.14	0.22	0.00	-0.10	0.18	0.13	0.24	-0.08	1.00	0.01	-0.08
River	0.11	-0.09	-0.30	-0.19	-0.05	-0.06	0.28	-0.09	0.01	1.00	0.22
Urban	0.01	-0.09	-0.17	-0.08	-0.05	-0.04	0.18	-0.11	-0.08	0.22	1.00

(c) 5km circular buffer

	Protected area diversity	Protected area	Altitude	Viewshed area	Euclidean distance	Historic	Land cover diversity	Grassland	Woodland	River	Urban
Protected area diversity	1.00	-0.27	-0.22	-0.13	0.19	0.07	-0.01	-0.30	0.09	0.24	0.29
Protected area	-0.27	1.00	0.19	0.02	-0.33	0.05	-0.01	**0.97**	-0.21	-0.55	-0.26
Altitude	-0.22	0.19	1.00	-0.07	0.11	0.33	-0.22	0.20	0.11	**-0.63**	-0.64
Viewshed area	-0.13	0.02	-0.07	1.00	-0.12	-0.14	0.10	0.01	-0.08	0.08	0.06
Euclidean distance	0.19	-0.33	0.11	-0.12	1.00	0.05	0.07	-0.41	0.55	-0.11	-0.14
Historic	0.07	0.05	0.33	-0.14	0.05	1.00	-0.16	0.02	0.04	-0.23	-0.21
Land cover diversity	-0.01	-0.01	-0.22	0.10	0.07	-0.16	1.00	-0.03	0.41	0.12	0.40
Grassland	-0.30	**0.97**	0.20	0.01	-0.41	0.02	-0.03	1.00	-0.32	-0.55	-0.26
Woodland	0.09	-0.21	0.11	-0.08	0.55	0.04	0.41	-0.32	1.00	-0.17	-0.19
River	0.24	-0.55	**-0.63**	0.08	-0.11	-0.23	0.12	-0.55	-0.17	1.00	0.70
Urban	0.29	-0.26	-0.64	0.06	-0.14	-0.21	0.40	-0.26	-0.19	0.70	1.00

(d) 5km viewshed buffer

	Protected area diversity	Protected area	Altitude	Viewshed area	Euclidean distance	Historic	Land cover diversity	Grassland	Woodland	River	Urban
Protected area diversity	1.00	0.12	0.04	0.08	0.01	0.07	0.14	0.07	0.16	0.18	0.10
Protected area	0.12	1.00	0.07	0.13	-0.07	0.12	-0.13	**0.89**	0.23	-0.09	-0.08
Altitude	0.04	0.07	1.00	-0.13	0.12	0.18	-0.16	0.09	-0.01	-0.21	-0.28
Viewshed area	0.08	0.13	-0.13	1.00	-0.12	0.04	0.04	0.17	0.23	0.53	0.32
Euclidean distance	0.01	-0.07	0.12	-0.12	1.00	0.06	0.23	-0.20	0.38	-0.13	-0.09
Historic	0.07	0.12	0.18	0.04	0.06	1.00	-0.01	0.10	0.10	-0.01	0.02
Land cover diversity	0.14	-0.13	-0.16	0.04	0.23	-0.01	1.00	-0.16	0.43	0.10	0.37
Grassland	0.07	**0.89**	0.09	0.17	-0.20	0.10	-0.16	1.00	0.02	-0.06	-0.03
Woodland	0.16	0.23	-0.01	0.23	0.38	0.10	0.43	0.02	1.00	0.17	0.09
River	0.18	-0.09	-0.21	0.53	-0.13	-0.01	0.10	-0.06	0.17	1.00	0.42
Urban	0.10	-0.08	-0.28	0.32	-0.09	0.02	0.37	-0.03	0.09	0.42	1.00

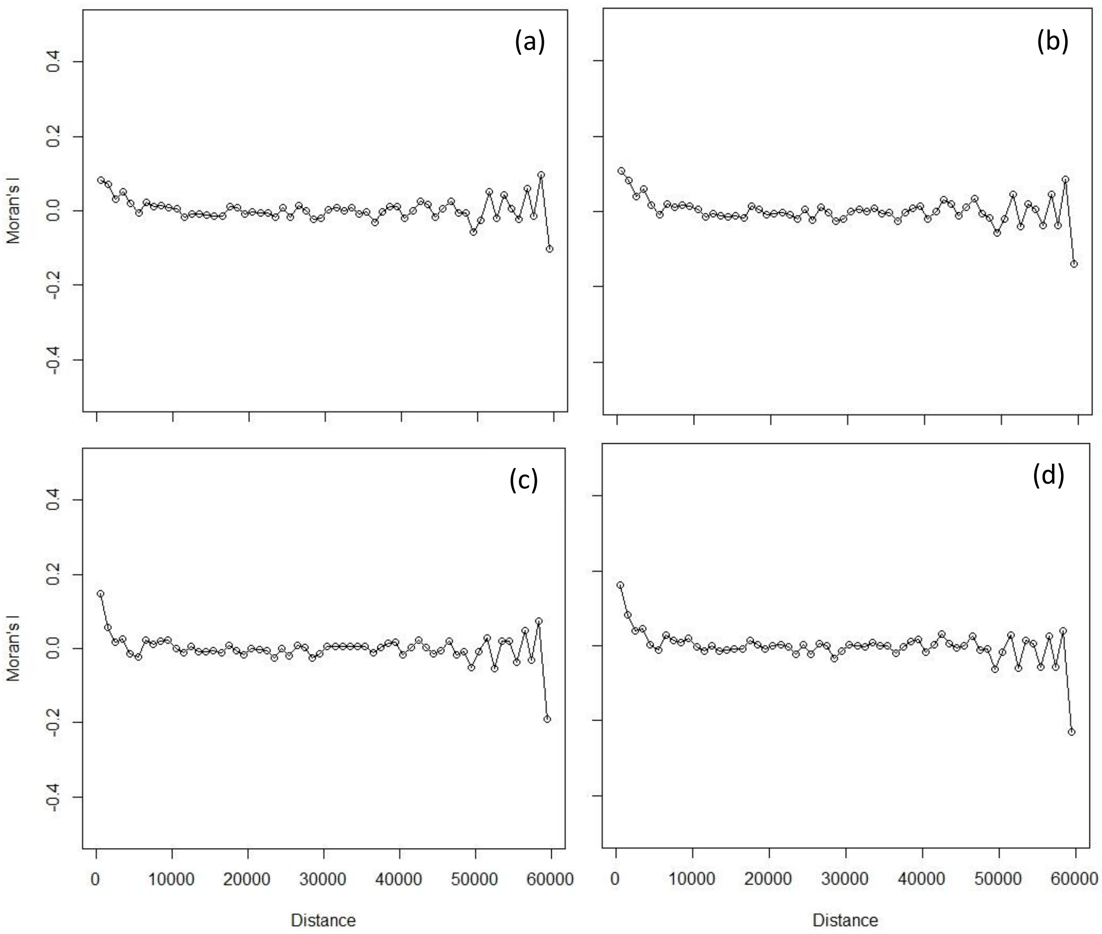

Figure S6. Moran's I correlograms showing no spatial autocorrelation between variables in the (a) 500m circular buffer, (b) 500m viewshed buffer, (c) 5km circular buffer or (d) 5km viewshed buffer model.

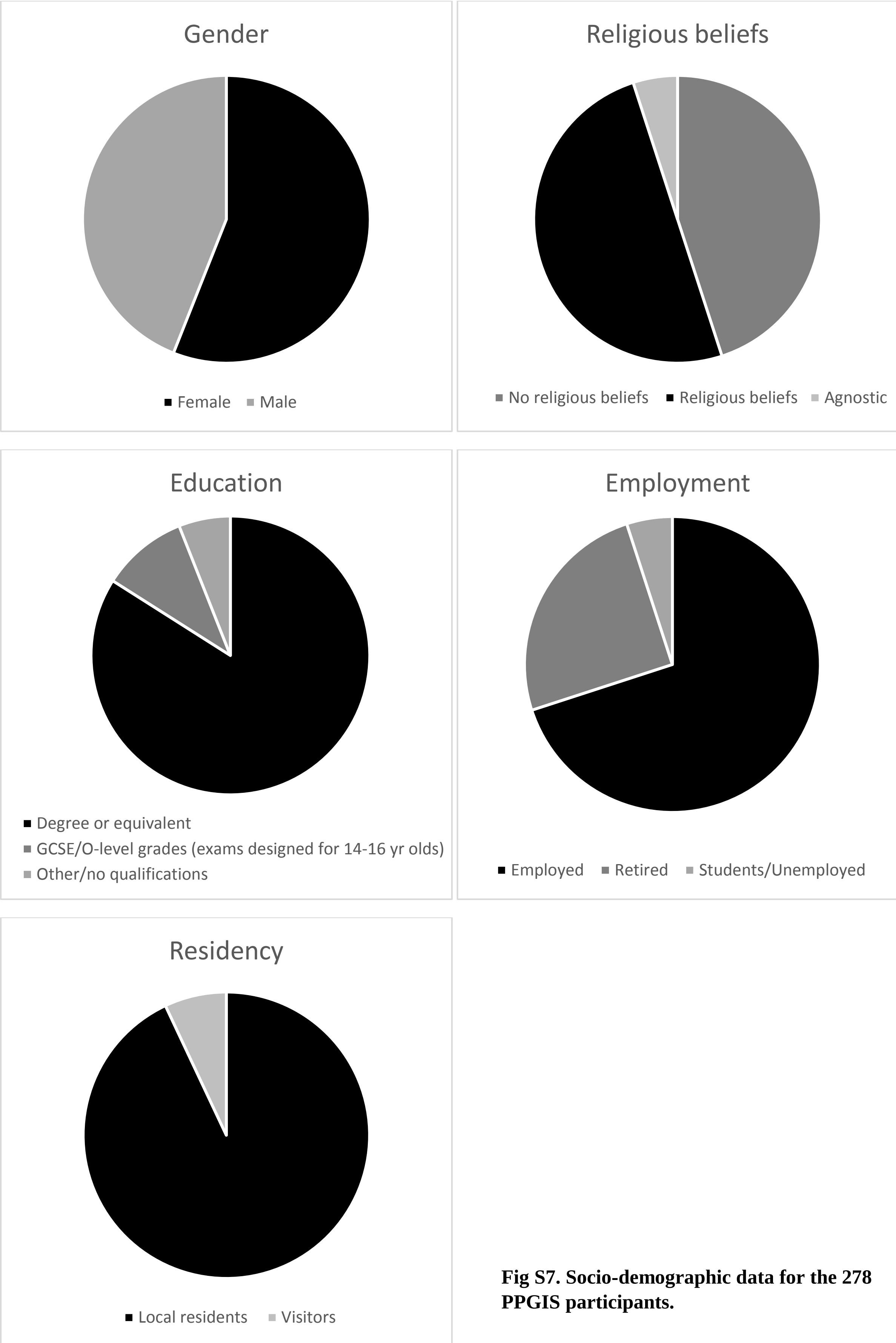

Fig S7. Socio-demographic data for the 278 PPGIS participants.