Quantifying how visibility-based land cover and wilderness measures relate to perceived scenicness of landscape

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Abstract

Landscape Character Assessment (LCA) was designated to describe, classify and identify what makes a landscape unique and distinctive. This task is, however, challenging given the multi-faceted and complex nature of human-environment interactions. With the emergence of crowdsourced data, a more integrated framework for LCA is needed to accommodate these diverse sources. This paper as a precursor study evaluates how public perceptions of landscape scenicness are related with landscape features (i.e. visibility-based land cover and wilderness components) and also compares with the result derived from the cell-based percentage of land cover. The result provides evidence of a stronger link between the aesthetic pleasure and the visibility-based totality of land cover than the simple grid-based characterisation. In addition, the variations in three dimensions of wilderness quality (biophysical naturalness, apparent naturalness and remoteness from access) have significantly positive relationships with public perceptions of scenicness. An amount of future work is discussed to develop a more appropriate spatial framework for LCA.

Keywords: Landscape Character Assessment, *Scenic-Or-Not*, Voxel-based Viewshed Analysis.

1 Introduction

Landscape can be regarded as an assemblage of human and natural phenomena that is multi-faceted reality (Palka, 1995). It can be understood as the totality of its physical attributes (e.g. landform, land cover and ecology) and the human interactions with these attributes over centuries (e.g. land use and perceptions) factors (Appleton, 1994; Scott, 2002; Symons *et al.*, 2013) These shape the variability of characteristics and make a landscape unique and distinctive. Landscape Character Assessment (LCA) was designated to describe, classify and identify these characteristics at a range of scales (Symons *et al.*, 2013) and has been applied in both the UK (Swanwick and Land Use Consultants, 2002) and European contexts (Wascher, 2005). These approaches benefit from recent advances in geospatial techniques such as GIS and Remote Sensing and could be profitably directed towards adopting a 'bird's eye' landscape view' (with cartographic representations) (Symons *et al.*, 2013; Butler and Berglund, 2014). However, it is still challenging for such approaches to quantify or model landscape aesthetic quality in a large scale given the subjective nature of the process and the complexity of people's perceptions. As a result professional views hold, notwithstanding the advent of more public involvement in improving local landscapes planning process (Scott, 2002).

Recent practice places more emphasis on the incorporation of cultural characteristics (i.e. patterns of human activity) such as settlement and field patters into the LCA process (Turner, 2006; Symons *et al.*, 2013) to enable a more clear interpretive landscape typology, as guided by the European Landscape Convention (ELC). The formal measures for the wilderness quality of landscape, by contrast, have an implicit focus on the absence of human impact which may provide a supplementary information for the characterisation. With the proliferation of citizen science initiatives, the crowdsourced scenic ratings from the *Scenic-Or-Not* website (http://scenic.mysociety.org/) describe people's aesthetic landscape judgments through georeferenced ground level photos. It allows the landscape aesthetic quality to be evaluated and compared with other crowdsourced and traditional data (Jeawak, Jones and Schockaert, 2017). Meanwhile, such data also open avenues for understanding human interactions with the environment such as their health (Seresinhe, Preis and Moat, 2015) and conceptualisations of scenicness (Chesnokova, Nowak and Purves, 2017). All these call into question whether an integrated framework that combines these data as part of the characterisation and mapping process can result in a better informed decision-making (Warnock and Griffiths, 2015).

In landscape studies, many attempts have been to find the correlation of a set of landscape features with measures of perceived scenic beauty for conservation and enhancement purposes (Dramstad *et al.*, 2006; Han, 2009; Simensen, Halvorsen and Erikstad, 2018). However, these studies commonly neglect the importance of the surrounding within the totality of a landscape, and how it contributes to the aesthetic merits. In this sense, more concerns need to be raised over what people could perceive in the visual limited extent at their location.

Visibility analysis or viewshed is one of the core functions in many GIS tools. It has been used in a wide range of applications, such as landscape (Brabyn and Mark, 2011) and military (VanHorn and Mosurinjohn, 2010). The scalability of visibility analyses can, however, be the bottleneck for all these applications that requires a time-consuming computation (Wang *et al.*, 2017). A fast and simple computation framework, therefore, was devised by (Amanatides and Woo, 1987) to efficiently estimate viewshed and could be used in support of large scale landscape visualisation and assessment (Washtell, Carver and Arrell, 2009) though a recent study found that the foreground feature had more influence than those in the background on perceived landscape beauty (Stadler, Purves and Tomko, 2011).

The aim of this study was set up to evaluate firstly whether the landscape features (i.e. thematic land covers and wilderness quality components) are related to public perceptions of scenincess, and secondly to determine the extent to which the spatial framework of visibility analysis and scale impact on this relationship. The Discussion section includes areas of future work and suggests the need for a more appropriate spatial framework and the incorporation of additional data for LCA in the long run.

2 Material and Methods

To reduce the computational load of visibility analysis, a subset of *Scenic-Or-Not* data within the Lake District National Park was used as a precursor study (Figure 1). There were 2,305 geo-located *Geograph* images in this region and images were selected for which at least 3 ratings had been collected up to February 2015.

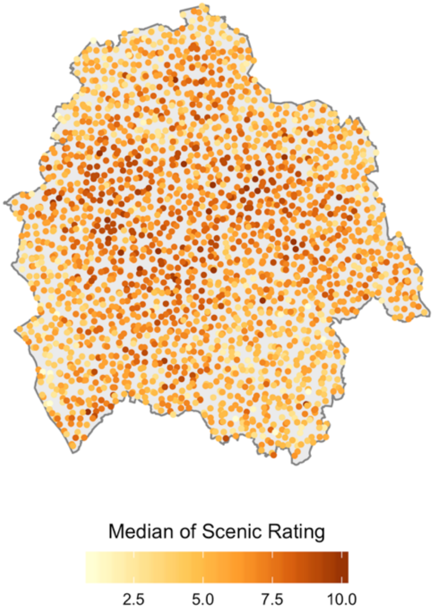

Figure 1 The spatial distribution of median *Scenic-Or-Not* ratings in the Lake District National Park

The land cover and elevation data adopted in this study were the 25m raster and 1km percentage cover with 10 aggregate classes of the Land Cover Map 2015 (LCM2015) created by the Centre for Ecology & Hydrology (Rowland *et al.*, 2017) and a 25m resolution Digital Elevation Model (DEM) download from Digimap Ordnance Survey respectively. Some data pre-processing was applied for further viewshed analysis—the 21 land cover classes of 25m raster were reclassified into 7 broad categories (Table 1). To evaluate the effect of visibility and scale, the proportion of broader land cover features for each 1 km^2 grid cell was used and reclassified as the same categories for comparison.

The predictor variables also included the components of wilderness quality in accordance with the definition of wilderness continuum regarding remoteness and naturalness advocated by (Nash, 1982) and developed by (Carver et al., 2002): *biophysical naturalness*, *apparent naturalness*, *remoteness from access* and *remoteness from population* using a multi-criteria evaluation (MCE) framework. The voxel-based viewshed tool employed herein was developed by (Carver and Washtell, 2012) where the visibility algorithm behind is similar to the R2 algorithm described by (Franklin and Ray, 1994).

Table 1 reclassification matrix.

1km raster (10 classes)	**25m raster (21 classes)**	**Reclassified class**	**Label**
broadleaf woodland	broadleaved woodland	broadleaved woodland	LCM1
coniferous woodland	coniferous woodland	coniferous woodland	LCM2
arable improved grassland	arable and horticulture improved grassland	agriculture	LCM3
semi-natural grassland	neutral grassland calcareous grassland acid grassland fen, marsh and swamp	grassland	LCM4
mountain, heath, bog	heather heather grassland bog inland rock	moor	LCM5
saltwater freshwater	saltwater freshwater	water	LCM6
coastal	supra-littoral rock supra-littoral sediment littoral rock littoral sediment saltmarsh	coast	LCM7
built-up areas and gardens	urban suburban	settlement	LCM8

In this voxel surface model, each pixel of DEM is projected as a series of vertical columnar elements whose vertical and horizontal surfaces can be independently checked for partial visibility together with calculating the distance decay effect. Within the visibility surface in the circle of 20 m radius, the proportional viewshed of each feature for each pixel was calculated and normalised using a logarithmic scale. Then the land cover covariates were extracted from the 8 normalised feature surfaces derived from the voxel-based viewshed analysis.

Then, a global Ordinary Least Squares (OLS) regression was applied to model the relationships between predictor and target variables. The OLS model can be expressed as follows:

$$y_i = \beta_0 + \sum_{j=1}^{m} \beta_j x_{ij} + \varepsilon_i \qquad (1)$$

where for observations indexed by $i = 1, \dots, n$, y_i is the target variable, x_{ij} is the value of the j^{th} predictor variable, m is the number of predictor variables, β_0 is the intercept term, β_j is the regression coefficient for the j^{th} predictor variable and ϵ_i is the random error term.

3 Results

Overall, both of the results (Table *2* and 3) are fairly loose model ($R^2 = 0.264$ for percentage raster of 1 km land cover and $R^2 = 0.236$ for the voxel-based features of 25 m land cover). Counter intuitively, the former model fit was not improved by the use of finer land cover features with considering the visibility counter. However, more predictor variables were found statistically significant in the latter regression mode where 5 of the 12 explanatory variables—broadleaved woodland (LCM1), agriculture (LCM4), moor (LCM5), coast (LCM7), biophysical naturalness (Rug), apparent naturalness (Nat) and remoteness from access (Acc) are statistically significant (p-value < 0.05). Among them, the coefficient estimates of broadleaved woodland (LCM1), moor (LCM5), biophysical naturalness (Rug), apparent naturalness (Nat) and remoteness from access (Acc) suggest positive relationships with the response variable. Particularly the variations in biophysical naturalness (Rug) are most strongly associated with changes in public perceptions of scenicness.

While mapping the distribution of the outlier for the voxel-based model, there is no obvious pattern but some clutter, for example, the green circle region (Figure 2) may suggest a need of Moran's *I* test for spatial autocorrelation and further examining local spatial structures by using simultaneous autoregressive (SAR) or conditional autoregressive (CAR) models (Cliff and Ord, 1981; Anselin, 1988; Haining, 2003).

4 Discussion

The results showing a more statistically significant model estimate while considering the surrounding features by using a voxel-based viewshed analysis provide evidence a stronger link between the aesthetic pleasure and the visibility-based totality of landscape. This may suggest the use of visibility-based framework is more informative than a simple grid-based characterisation while carrying out a landscape assessment. The limitation of the OLS model used herein is, however, to ignore substantive spatial interaction which could lead to biased and inconsistent estimates.

An amount of future work is laid out in order to suggest a more appropriate framework for LCA. Firstly, the residual spatial autocorrelation ought to be examined by the Moran's *I* test. If so, the covariate effects on connectivity structures could be estimated by using the spatially explicit models (i.e. SAR and CAR). Secondly, more spatially explicit indices can be included as additional predictor variables, for example, the terrain indices (e.g. overall openness) and the ecological indices (e.g. biodiversity). Also, different spatial resolution of data could be included to evaluate the effect of spatial scale.

Table 2 Results using grid-based land cover covariates

Parameter	Estimate	Std. Error	t value	p value
Intercept	3.809	1.252	3.041	0.002
LCM1	0.008	1.227	0.006	0.995
LCM2	0.127	1.238	0.103	0.918
LCM3	0.135	1.222	0.110	0.912
LCM4	1.519	1.215	1.251	0.211
LCM5	1.200	1.232	0.973	0.330
LCM6	1.863	1.250	1.491	0.136
LCM7	0.265	1.359	0.195	0.846
LCM8	-2.055	1.488	-1.381	0.168
Rug	1.652	0.173	9.568	0.000
Nat	0.182	0.072	2.511	0.012
Acc	0.033	0.010	3.285	0.001
Rem	0.000	0.000	-1.803	0.071

$R^2 = 0.264$; AIC = 8536.017

Table 3 Results using visibility-based land cover covariates

Parameter	Estimate	Std. Error	t value	p value
Intercept	3.076	0.217	14.194	0.000
LCM1	0.031	0.009	3.470	0.001
LCM2	0.004	0.007	0.472	0.637
LCM3	-0.007	0.010	-0.733	0.464
LCM4	-0.021	0.010	-2.072	0.038
LCM5	0.020	0.008	2.607	0.009
LCM6	0.011	0.010	1.075	0.283
LCM7	-0.070	0.018	-3.803	0.000
LCM8	-0.002	0.008	-0.233	0.815
Rug	1.930	0.170	11.337	0.000
Nat	0.530	0.060	8.833	0.000
Acc	0.041	0.010	4.013	0.000
Rem	0.000	0.000	1.434	0.152

$R^2 = 0.236$; AIC = 8621.694

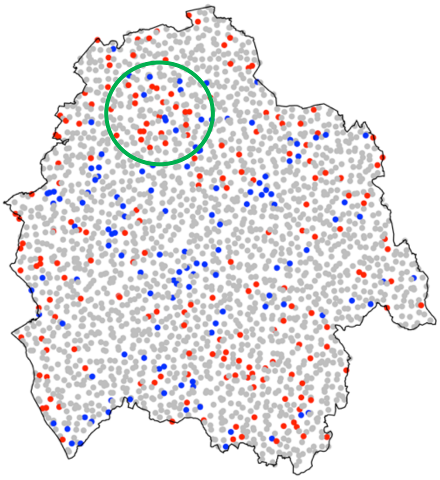

Figure 2 The distribution of outliers
(blue: underestimation; red: overestimation)

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