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Relationship between landscape visual attributes and spatial pattern indices: A test study in Mediterranean-climate landscapes

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Abstract

The analysis of the relationships between landscape visual quality and landscape structural properties is an active area of environmental perception research. The aim of this study was to determine the relationship between landscape spatial pattern and the rating of visual aesthetic quality. Eight landscape photographs were evaluated for 11 visual attributes by 98 respondents. The scores obtained for these 11 attributes were subjected to principal components analysis in order to summarize the qualities used by the respondents and thus determine their visual preferences. For each photograph, three window sizes were defined (with respect to a landcover map) to cover the different areas corresponding to the visual field (foreground, mid-ground and background). The landscape spatial structure for each window was analyzed using spatial metrics. The correlation between each dimension and the spatial pattern indices of the landscape were then calculated. Positive correlations were obtained between visual aesthetic quality and a number of landscape pattern indices. The results suggest that landscape heterogeneity might be an important factor in determining visual aesthetic quality.

Keywords: Visual aesthetic quality; Spatial metrics; Landscape quality; Landscape structure

1. Introduction

1.1. Landscape visual quality assessment

In recent years, the scenic beauty of the landscape has become an important component of planning practices and management strategies (Daniel, 2001; Scott, 2002). Historically, scenic beauty has played an important role in the way landscape has been protected and in the conservation of places considered to be of singular beauty (Preece, 1991). Social concern for the degradation of the landscape has renewed the importance of scenic value as a key aspect of landscape management and planning.

Landscape visual quality can be defined as "the relative aesthetic excellence of a landscape" (Daniel, 2001) and examined in terms of observer appreciation (Lothian, 1999). Knowledge of the elements and processes that organize landscapes is indispensable, but so too are the perceptions, opinions and valuations of the

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public (Kline and Wechelns, 1998). Little is known, however, about the relationships between landscape structure and perception; better knowledge of them would be clearly advantageous (Litton, 1979).

The assessment of the visual aesthetic quality of the landscape has seen important developments in recent years. There are two main paradigms of the theory of landscape aesthetics, both of which are on the basis of landscape assessment methods: the "objective" paradigm (where visual quality is inherent to landscape properties) and the "subjective" paradigm (where landscape quality is "in the eye of the beholder") (Lothian, 1999).

With respect to these two paradigms, two approximations to landscape assessment can be differentiated. In the "expert-based" approach, the biophysical features of the landscape are transformed into formal parameters (form, line and variety), which are assumed to be indicators of landscape quality (Daniel, 2001). Some studies have emphasized the role of vegetation in landscape preferences (Bishop, 1996), as well as spatial diversity or complexity (understood as the variety of the landscape's constitutive elements) (Crawford, 1994), waterform (Bishop and Hulse, 1994), landform, topography and viewshed (Hammitt et al., 1994; Purcell and Lamb, 1998). Naturalness has been shown to have a positive effect on the aesthetic quality of scenery (Schroeder, 1987). Human influence, such as residential backgrounds (urban, suburban and rural), city streets (Baldwin et al., 1996) or industrial areas (Purcell et al., 1994), etc., can have a negative impact on preference (Strumse, 1994).

In the "perception-based" approach (Daniel, 2001), landscape visual aesthetic quality is considered to be a product of the visible features of the landscape interacting with psychological processes taking place in the human observer. This approach can be assessed through sensory–perceptual parameters or cognitive constructs. This relies on the idea that environments are sources of information and that humans are information-seeking animals actively pursuing knowledge. Kaplan and Kaplan (1982) proposed a model for landscape preferences in which landscape organization is understood as a source of information that satisfies the motivation to comprehend and explore and indicated the importance of the following factors in the determination of preference: coherence (logical placement, order), legibility (permeability of the scene, accessibility and ease of orientation), complexity (diversity of elements and visual richness) and mystery (the concealment of parts of the scene and the promise of more information that encourages exploration) (see review by Stamps, 2004). In this model, understanding is favored in environments that are coherent and legible and exploration is enhanced in those that are complex and mysterious. Appleton (1975) identifies two components of landscape aesthetic preference: the possibility of accessing the information harbored by the landscape, termed "prospect" and safety or the possibility of refuge termed as "refuge". Prospect is the opportunity to gain a clear view, refuge is the opportunity to hide from the view of others.

According to Bernáldez and Gallardo (1989), affective responses to landscape depend as much on visual characteristics as on the characteristics of the spectator; certain spectator attitudes appear to be correlated with landscape preferences. Formal configurations (the organization of components), such as shape, colors, pattern, etc., stand out as positive influences. Semantic characteristics (the process of recognition of the objects that compose the scene), such as diversity, viewshed, transparency, etc., are also important.

These models relate quantifiable aspects of landscapes with subjective landscape preferences, but they cannot be easily used to evaluate the scenic quality of large regions (Hunziker and Kienast, 1999). Further, they are not directly usable by planners and natural resource managers, who work primarily with maps and other aerial representations of the landscape rather than individual perspectives, thoughts and perceptions (Forman, 1995; Palmer, 2004). A synthesis of both approximations, i.e., of the "expert-based" and "perception-based" methods, would provide a more comprehensive approach to the study of landscape quality.

1.2. Landscape visual quality and spatial pattern

The possibility of relating landscape spatial metrics to quantitative measurements of landscape preference is an area of great theoretical and practical interest (Giles and Trani, 1999). Crawford (1994) and Palmer (1997) have suggested that the spatial metrics commonly used in landscape ecology could be used as indicators of visual aesthetic quality.

Several studies have recently been performed in this area. For example, in Salamanca (Spain), Saldaña et al. (1986) demonstrated a relationship between the perceived diversity of the landscape and landscape preferences. Hunziker and Kienast (1999) used several spatial metrics to analyze the structure and composition of a group of photographs with different degrees of afforestation. The results showed significant correlations between diversity and contagion and scenic value.

Franco et al. (2003) related scenic beauty ratings of photographs to the landscape metrics of the scenes represented (variables measured on the local and landscape scales) and found significant relationships between landscape metrics (such as diversity and circuitry) and preference. In a study to predict scenic perception in a changing landscape in Dennis, Massachusetts (USA), Palmer (2004) found approximately half of the variation in scenic perceptions to be explained by spatial landscape metrics.

Of all the spatial metrics of the landscape, diversity and heterogeneity are perhaps the easiest to relate to human perception of the environment. Greater homogeneity increases coherence, while fragmentation decreases it. Greater coherence is generally thought to be positively related to scenic value (Kaplan and Kaplan, 1982; Palmer, 2004). Subsequently, the fractal dimension should provide an indication of visible landscape complexity, which is thought to contribute to scenic value (Purcell et al., 2001).

In summary, landcover structure plays a significant role in the visual quality of the landscape. Linking landscape structure to landscape preferences should, therefore, be of the greatest interest in landscape planning and management.

1.3. Aim of the study

The aim of the present study was to explore the relationships between landscape visual quality and landscape spatial pattern. The first working hypothesis explored was that landscape visual quality can be decomposed into a limited number of independent attributes. The second was that some of these visual attributes may be correlated with landscape spatial structure.

To test these hypotheses, a two-phase experimental design was used:

Phase 1: Scores for eight landscape photographs were obtained with respect to the visual landscape attributes found in the existing literature. These were then reduced into a few independent attributes by principal components analysis (PCA).

Phase 2: The statistical relationships between these attributes and the spatial structure of the landscape mosaic, derived from landcover maps of the same area captured in the images, were examined by correlation techniques.

2. Methods

2.1. Study area

Two Mediterranean landscapes were examined (Fig. 1): the central sector of the Sierra de Guadarrama (Madrid, Spain) and the Andean foothills (Santiago, Chile). These two areas were selected since they are good representatives of Mediterranean mountain landscapes subject to high leisure activity demands (both are close to large urban areas).

2.2. Selection of landscape images

The study areas were overlain with a regular grid of sampling points to facilitate a series of landscape perception experiments. The distance between sampling points (50 for the Madrid site and 60 for the Santiago site) was 5 km. This grid was actually designed to be used in several different experiments—hence, its size. Four photographs of the landscape (facing north, east, west and south) were taken at each point. Points that were inaccessible were not covered. For the specific purposes of this experiment, four photographs were then randomly selected from the total pool for each study site (Fig. 2). The use of photographs for evaluating landscape aesthetics has been established as a valid method for most experiments (Steinitz, 1990; Strumse, 1994; Stamps, 1997).

To reduce the time of evaluation and prevent respondent fatigue (which could influence the results), the number of photographs to be examined was intentionally kept small (Hunziker and Kienast, 1999).

2.3. Assessment of landscape visual attributes

Many different attributes for assessing landscape quality can be found in the literature. To reduce vari-

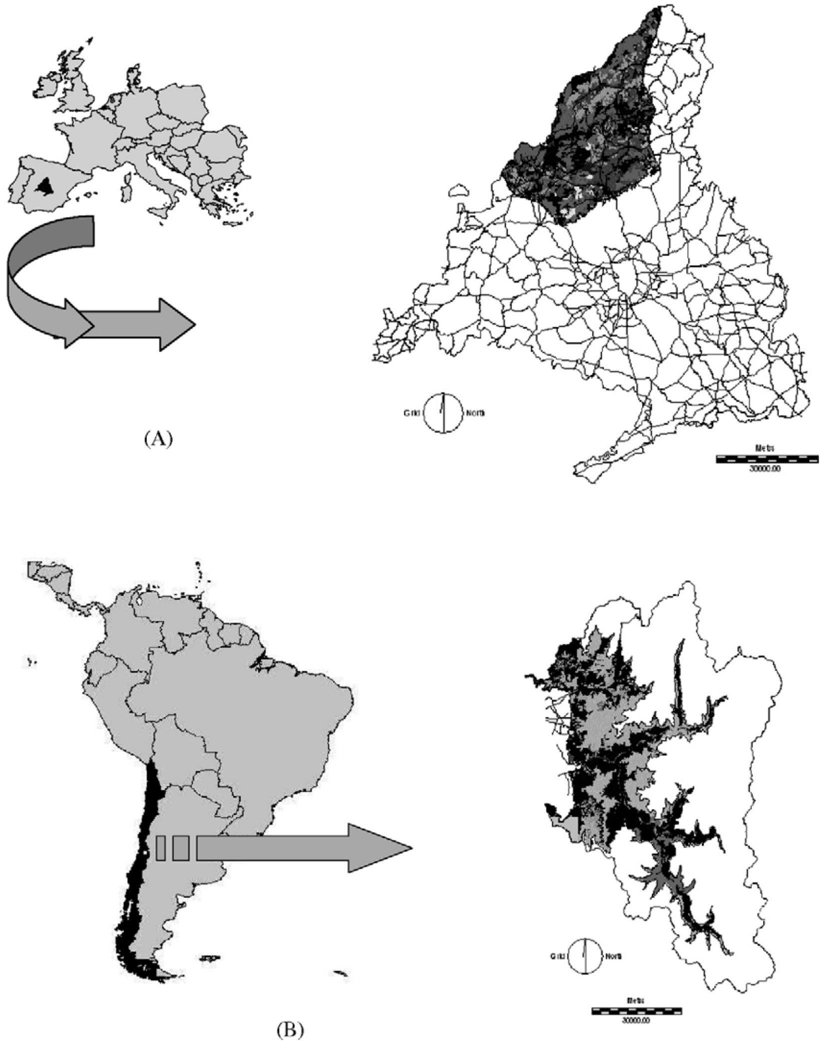

Fig. 1. (A) The Sierra de Guadarrama de Madrid (Spain) and (B) the Andean Precordillera de Santiago (Chile).

ability and maintain the internal coherence to the selected attributes, those associated with three main landscape aesthetics theories were selected:

(1) *The landscape perception model* (Kaplan and Kaplan, 1982): In this model, "perceived complexity", "coherence", "legibility" and "mystery" are informational variables related to landscape preference that are concerned with the organization of the landscape.
(2) *The prospect/refuge theory* (Appleton, 1975): The attribute selected was "perspective". This is defined in terms of the ease with which an observer situated within the landscape can obtain an extensive view of the surrounding area.
(3) *The landscape perception model* (Bernáldez and Gallardo, 1989): These authors defined "diversity", "risk", "colors", "pattern" and "patch-shape" as synthetic abstractions of physical landscape elements, meaning that physical features or properties of the landscape combine to form arrangements or compositional patterns in the eye of the observer.

In addition, "scenic beauty" was considered, since this is the attribute used by most preference studies and represents the sum of many visual attributes. In many

Fig. 2. Landscape photographs used in the experiment. Images (A–D) are of the Sierra de Guadarrama and (E–H) are of the Andean Precordillera.

preference studies it is the only attribute examined. Scenic beauty is normative and evaluative of landscapes and is used here as a measure of agreeableness.

In each of these 8 landscape photographs, visual quality was thus assessed by evaluating the following 11 variables: scenic beauty, coherence, legibility, complexity, mystery, perspective, diversity, risk, colors, pattern and patch-shape (Table 1).

Landscape photographs were evaluated by 98 respondents randomly selected from environmental and forestry science undergraduates. To reduce the possibility that other biases might affect the results, precautions were taken in the final selection of subjects. None of the subjects chosen had received any substantial exposure to design principles and the sample was balanced with respect to gender-factors that previous research has shown to influence preference ratings (Dearden, 1987; Gobster and Chenoweth, 1989). Each respondent was asked to award points (one to seven on an increasing scale) for each visual attributes in each of the eight landscape photographs. To obtain the maximum independence in the evaluation of the images, the attributes were evaluated separately, the full set of photographs being examined each time. This task generally took about 45 min to complete. Intra-group and inter-rater reliability indices were calculated for all visual attributes (see Palmer, 2000; Palmer and Hoffman, 2001).

2.4. Landscape windows

For each of the eight sites where the landscape photographs were taken, three square windows of different size were defined over a landcover map. These

Table 1
Overview of the visual attributes examined and the corresponding questions and measurement scales (all visual attributes were measured on seven-point scales) [adapted from Appleton, 1975; Kaplan and Kaplan, 1982; Bernáldez and Gallardo, 1989; Gobster and Chenoweth, 1989; Strumse, 1994]

Visual attributes	Question and scale
Scenic beauty	Assign a value to the scene in the picture according to its scenic beauty
Coherence	Indicate to what degree the picture is coherent. Assign a low value if there are strange elements that do not integrate with the rest of the landscape elements
Legibility	Assign a low value if you consider that the image is confused or difficult to interpret
Complexity	Indicate whether the spatial structure is simple or complex
Mystery	Assign a high value if you perceive the picture is hiding information, that there are elements hidden to the observer
Perspective	Assign a high value if you perceive the place in the picture has a wide or panoramic perspective
Diversity	Assign a high value if you perceive the image to have a lot of different elements and a low value if the picture has few different elements
Risk	Assign a high score if you perceive the components of the image to evoke hazards or dangers or a lower score if they present a hospitable, safe and sure appearance
Colors	Assign a high value if you perceive the image to have many different colors
Pattern	Assign a high value if you perceive the image to have regularly repeated elements or clear patterns
Patch-shape	Assign a high value if you perceive that the elements of the landscape have an irregular shape

windows covered three distance-zones: the area close to the observer or foreground (a 500 m × 500 m window, 0.25 km^2), the mid-ground (an intermediate area comprising the former and the mid-ground (1 km^2) and the background (5 km × 5 km window, 25 km^2) (Fig. 3) (Smardon et al., 1986; Bishop and Hulse, 1994; Baldwin et al., 1996).

‘Windows’ were used instead of viewsheds to assure that all indices were calculated for equal areas. This allows comparison of the results obtained at different

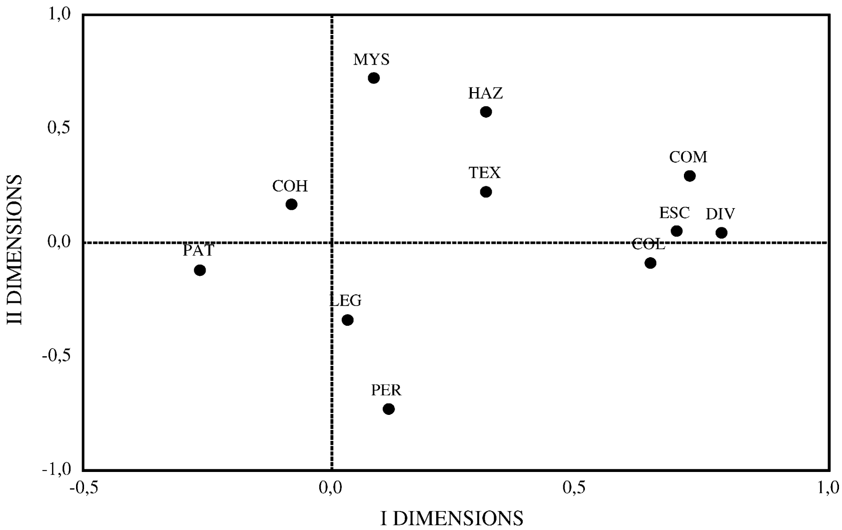

Fig. 3. Graphical representation of the mean values of PCA Axes I and II for scenic beauty (ESC), diversity (DIV), complexity (COM), coherence (COH), legibility (LEG), mystery (MYS), risk (RSK), perspective (PER), color (COL), shape (SHP) and pattern (PAT).

sampling points with different sized viewsheds (due to variations in topography) and allows calculations involving different window sizes to be performed in a comparable fashion.

2.5. *Landscape pattern indices*

Landscape ecologists have developed a number of spatial metrics, i.e., quantitative measures of landscape structure (Gustafson, 1998), which are used to characterize landscapes, their spatial and temporal variation and current condition (O'Neill et al., 1988; Turner et al., 2001; Herzog et al., 2001). These indices quantify several aspects of landscape pattern by taking into account the area and spatial distribution of landscape elements, i.e., patches of different landcover. Two main categories of indices have been suggested: composition indices (including the proportion of the landscape taken up by each patch type, patch richness, patch evenness and patch diversity), which quantify the variety and abundance of patch types within a landscape, but not their spatial arrangement and configuration indices (including mean patch-shape, fractal dimension, contagion, interspersion and juxtaposition), which quantify the spatial distribution of patches within the landscape (McGarigal and Marks, 1994).

Landcover maps of both regions were used to calculate landscape metrics. Both maps were of the same scale (1:50,000) and resolution (25 m) to ensure that measurements were comparable. This resolution is below the minimum size of landscape patches; it, therefore, allows the identification of all land use and

Table 2
Indices used to describe the spatial structure of the landscape

Indices	Acronym	Description
Number of patches	NP	This measures the number of patches in a landscape mosaic. The index does not consider the type of each patch. It is used as a measure of landscape fragmentation
Patch diversity	SIDI	Diversity of landcover types estimated by Simpson's index. The greater the value, the greater the likelihood that two randomly selected patches are different patch types. It, therefore, indicates landcover heterogeneity. Diversity values may be influenced by patch richness and evenness
Patch richness	PR	This measures the number of different types of patches, independent of the number of patches of each type. High richness values indicate a high number of different elements (patches or landcover types). Landcover richness is not affected by the relative abundance of each landcover type or the spatial arrangement of the patches. It can, therefore, be referred to as the compositional dimension of landscape diversity
Evenness	SIEI	Simpson's evenness index. This measures the distribution of areas among patch types and is independent of richness. Maximum evenness for any level of richness is based on an equal distribution among landcover types. Low evenness indicates that either one or just a few elements are dominant. High evenness values indicate an equiprobable distribution of landscape elements. Evenness is a structural component of diversity
Interspersion	IJI	This measures how landscape elements are interspersed. Higher values result form landscapes in which patch types are well-interspersed (equally adjacent to one another). Lower values characterize landscapes in which patch types are poorly interspersed
Contagion	CONT	This measures the extent to which landscape elements are aggregated. Higher values may result from landscapes with a few large, contiguous patches. Lower values generally characterize landscapes with many small and dispersed patches
Fractal dimension	DFLD	Mean fractal dimension for all patches. Quantifies the complexity of patch-shapes. For simple shapes, the fractal dimension is 1. As polygons become more complex, the fractal dimension approaches 2
Visibility	VIS	Measures of visibility of the landscape. Values may be higher when the landscape provides a general or panoramic view. Lower values generally characterize landscapes with a smaller or more enclosed view
Relief	VAR	Measure of topographic heterogeneity. Higher values may result from an abrupt surface. Lower values generally characterize landscapes with a flat surface

For more information on how these indices are calculated, see McGarigal and Marks (1994).

vegetation types. Landcover classifications reflecting those types distinguishable by human perception at the landscape scale were used in both maps (Palmer, 1997).

A set of landscape indices was calculated for each of the three window sizes, using Fragstats software (McGarigal and Marks, 1994). The landscape composition indices used included number of landcover types, diversity and evenness. Landscape configuration was measured according to the number of landcover patches, contagion, patch interspersion and patch-shape. Table 2 provides definitions of the indices (for all formulae, see McGarigal and Marks, 1994).

The indices of visibility and relief for the two regions were obtained from a digital elevation model (DEM). The visibility at each of the sampling points was calculated taking into account the mean height of the vegetation and urban elements (see Table 2 for details).

2.6. Statistical analyses

To detect relationships among visual attributes, PCA was performed using the rotation varimax normalized procedure. The initial data matrix was formed by as many variables as there were visual attributes (i.e., 11). The usefulness of this approach in the analysis of scenic quality has been reported in previous studies (Strumse, 1994; Hanyu, 1997; Todorova et al., 2004). This method allows redundancies to be detected among variables (in this case, visual attributes) and shows which are the most important in explaining the variability of the data, i.e., which visual attributes have the highest loading factors.

The visual attributes with highest loading factors in each axis of the PCA were then selected. Correlations between the mean scores for these visual attributes and each of the landscape pattern indices were calculated. All correlations were performed using the non-parametric Spearman rank test. Since a high degree of redundancy has been reported in landscape indices (Turner and Ruscher, 1988), correlations among all the spatial pattern indices were also calculated.

3. Results

3.1. Reliability

Internal consistency reliability coefficients (Cronbach's alpha coefficient) were calculated for the 11 variables rated (Table 3). Intra-group reliability ranged from 0.89 for mystery to 0.98 for perspective. Inter-rater reliability ranged from 0.27 for coherence to 0.65 for perspective.

Table 3
Internal consistency reliability coefficients (intra-group and inter-rater) for the visual attributes variables

Visual attributes	Reliability	
	Intra-group	Inter-rater
Scenic beauty	0.94	0.34
Coherence	0.92	0.27
Legibility	0.93	0.29
Complexity	0.95	0.37
Mystery	0.89	0.20
Perspective	0.98	0.65
Diversity	0.97	0.49
Risk	0.96	0.42
Colors	0.96	0.40
Pattern	0.95	0.44
Shape	0.94	0.44

3.2. Relationships among visual attributes: principal components analysis

PCA analysis helped to reduce redundancies among the set of landscape attributes taken from the literature. This shows that, in different evaluations, some attributes reflect the same landscape features. The first four axes of the PCA analysis accounted for 59.13% of the variance in the original set of variables (Table 4). High loading factors (>0.5) for a visual attribute of any given axis indicate it to make a large contribution towards defining the axis. Different attributes with high loadings on the same axis show a high degree of redundancy among those attributes (Fig. 3). The results may, therefore, be interpreted as follows:

- Axis I showed high loading factors for diversity, complexity and color diversity. Complexity and diversity can be considered complementary attributes; the respondents found it difficult to differentiate between them. Further, they are related to the chromatic diversity of the perceived image. Scenic beauty also showed a high loading factor in Axis I, revealing a high correlation of these broad, normative concepts of landscape agreeableness with diversity, complexity and color diversity in the perceived landscape.

Table 4
Factorial analysis of scenic quality for the set of visual attributes

Visual attributes	Axes			
	I	II	III	IV
Scenic beauty	0.69[a]	0.05	0.33	0.07
Diversity	0.78[a]	0.05	−0.05	−0.14
Complexity	0.72[a]	0.30	−0.10	−0.11
Coherence	−0.08	0.17	0.82[a]	−0.01
Legibility	0.03	−0.33	0.69[a]	0.08
Mystery	0.31	0.72[a]	−0.12	0.05
Risk	0.08	0.58[a]	0.08	−0.13
Perspective	0.11	−0.73[a]	0.06	−0.19
Colors	0.64[a]	−0.09	−0.16	0.19
Pattern	−0.27	−0.11	0.26	0.68[a]
Shape	0.31	0.23	−0.16	0.69[a]
Variance accounted for (%)	23.72	13.82	12.21	9.35

[a] Indicates highest factor loading for a variable.

- Axis II distinguished mystery (high, positive loading) from perspective (high, negative factor loading) as two opposing attributes. Risk also showed a high and positive loading, revealing strong redundancy with mystery. Thus, high perspective landscapes are those with low mystery and vice versa.
- Axis III showed coherence and legibility to have high loading factors. These are redundant attributes, reflecting the same aspects of landscape visual quality.
- Axis IV showed high loading factors for patch-shape and pattern, both attributes being related to the distribution and configuration of the elements in the scenes.

3.3. Relationship between scenic quality and landscape spatial metrics

The relationship between landscape aesthetic quality and spatial structure was analyzed by determining the correlation between the mean values of the visual attributes that best characterized the PCA axes (those with the highest factor loadings) with the values for pattern indices derived from landcover maps at the three window sizes (Table 5).

The first axis of PCA analysis was characterized by scenic beauty. This was significantly correlated only to landcover evenness in the 1 km^2 window (Table 5), suggesting that the most appreciated landscapes were those where all landcover types were of nearly equal area.

Axis II showed the opposition of perspective and mystery. Perspective correlated strongly and negatively with altitude heterogeneity in the 1 km^2 window, suggesting that those scenes with the greatest perspective were those with low topographical heterogeneity (Table 5). Mystery was related to landcover heterogeneity (number of patches) both in the 0.25 and 1 km^2 windows and to landcover fractal dimension in the 25 km^2 window (Table 5). The more mysterious landscapes were those found to be highly heterogeneous, suggesting that a large number of patches and topographic variability creates a greater sensation of landscape mystery.

Table 5
Spearman correlation values for each visual attributes and landscape spatial structure indices at three window sizes: 0.25, 1 and 25 km^2 (see text for details) ($^*P < 0.05$)

Window (km^2)	Acronym	Visual attributes				
		ESC	LEG	MYS	PER	SHP
0.25	NP	0.30	−0.76*	0.73*	−0.58	0.63
	DFLD	0.42	−0.65	0.50	−0.47	0.72*
	SIDI	0.29	−0.74*	0.63	−0.59	0.65
	PR	0.29	−0.86	0.62	−0.29	0.49
	SIEI	0.29	−0.74*	0.63	−0.59	0.65
	IJI	0.09	−0.17	0.25	−0.08	0.25
	CON	0.51	−0.67	0.63	−0.66	0.78*
	VIS	−0.48	0.03	0.25	−0.33	0.23
	VAR	0.48	0.24	0.24	−0.57	0.48
1	NP	0.03	−0.54	0.78	−0.51	0.63
	DFLD	0.36	−0.54	0.47	−0.56	0.78*
	SIDI	0.60	−0.51	0.64	−0.62	0.88*
	PR	0.14	−0.54	0.55	−0.22	0.55
	SIEI	0.95*	−0.02	0.33	−0.40	0.76*
	IJI	0.55	−0.43	0.37	−0.42	0.75*
	CON	0.05	0.14	0.26	−0.19	0.31
	VIS	−0.24	−0.01	0.55	−0.57	0.50
	VAR	0.26	−0.06	0.21	−0.76*	0.50
25	NP	0.07	−0.25	0.34	0.32	0.00
	DFLD	−0.11	−0.30	0.87*	−0.42	0.56
	SIDI	−0.02	−0.51	0.31	0.33	−0.02
	PR	0.07	−0.46	0.21	0.48	−0.12
	SIEI	0.07	−0.15	0.34	−0.10	0.46
	IJI	0.11	0.01	−0.12	0.31	0.12
	CON	−0.10	0.18	−0.42	0.02	−0.38
	VIS	−0.24	−0.40	0.45	0.12	−0.02
	VAR	0.55	0.17	0.17	−0.52	0.45

Table 6
Spearman correlation values among indices of the spatial structure of the landscape for each of the three window sizes (see text for details) ($^{*}P < 0.05$)

Windows (km^2)	Acronym	Indices	NP	SIDI	PR	SIEI	IJI	CONT	DFLD	VIS
0.25	NP	No patches	1							
	SIDI	Diversity	0.95*	1						
	PR	Patch richness	0.96*	0.94*	1					
	SIEI	Evenness	0.85*	0.77*	0.94*	1				
	IJI	Interspersion	0.80*	0.78*	0.63	0.55	1			
	CONT	Contagion	0.38	0.40	0.40	0.39	0.11	1		
	DFLD	Fractal dimension	0.97*	0.90*		0.94*	0.77*	0.78*	0.40	1
	VIS	Visibility	0.30	0.31	0.43	0.31	0.16	0.50	0.18	1
	VAR	Relief	−0.17	−0.15	−0.5	−0.15	−0.41	0.11	−0.03	−0.32
1	NP	No patches	1							
	SIDI	Diversity	0.65	1						
	PR	Patch richness	0.89*	0.71*	1					
	SIEI	Evenness	0.08	0.71*	0.30	1				
	IJI	Interspersion	0.42	0.76*	0.70	0.60*	1			
	CONT	Contagion	0.09	−0.46	0.10	−0.72	−0.14	1		
	DFLD	Fractal dimension	0.70	0.69	0.79*	0.39	0.50	−0.53	1	
	VIS	Visibility	0.68	0.35	0.37	0.11	0.22	−0.01	0.49	1
	VAR	Relief	−0.12	0.19	−0.42	0.26	0.26	−0.54	0.14	0.11
25	NP	No patches	1							
	SIDI	Diversity	0.90*	1						
	PR	Patch richness	0.92*	0.83*	1					
	SIEI	Evenness	0.32	0.50	0.40	1				
	IJI	Interspersion	0.24	0.38	0.86*	0.86*	1			
	CONT	Contagion	−0.58	−0.69	−0.93*	−0.93*	−0.72*	1		
	DFLD	Fractal dimension	0.56	0.55	0.39	0.57	0.21	−0.74*	1	
	VIS	Visibility	0.77*	0.80*	0.67	0.33	0.26	−0.62	0.61	1
	VAR	Relief	−0.61	−0.71*	−0.25	0.37	−0.19	0.14	−0.23	−0.43

Legibility (Axis III) correlated with several spatial pattern indices (number of patches, diversity and evenness in the 0.25 km^2 window) (Table 5). Since these showed very high collinearity (Table 6), they may be interpreted in the same way as “landcover heterogeneity”. The more legible landscapes were those found to be less heterogeneous, suggesting that a smaller number of patches may create a greater sensation of landscape legibility. In addition, legibility comprises inspection and interpretation of the scene at close quarters, hence, its correlations at the 0.25 km^2 window level.

Patch-shape (Axis IV) was strongly correlated with landcover heterogeneity indices (fractal dimension and contagion) in the 0.25 km^2 window (Table 5). It also correlated with several spatial pattern indices in the 1 km^2 window, which, in turn, correlated with landcover heterogeneity (diversity, evenness and interspersion) and patch-shape complexity (fractal dimension) (Table 6). The more shape-rich landscapes were those that were highly heterogeneous, suggesting that a larger number of patches with irregular contours create the sensation of there being greater landscape irregularity.

4. Discussion

The aim of this experiment was to determine how landscape preference is related to landscape spatial patterns. Although preliminary, the results show that landscape preference is correlated to certain spatial metrics. These correlations suggest that differences in landscape pattern might play an important role in visual aesthetic quality.

4.1. *Visual attributes*

The PCA results showed the relationships among the visual attributes to be consistent with previous reports (Gobster and Chenoweth, 1989; Strumse, 1994; Hanyu, 1997; Hagerhall, 2000). These relationships can be summarized as four components of preference.

The main principal component (Axis I) was characterized by scenic beauty, which, in turn, was related to complexity and diversity. These attributes were related to the evaluation of the variety of elements in the landscape, which agrees with that reported by Hanyu (1997). Heterogeneity, variety, diversity and complexity are attributes consistently interpreted by subjects in a similar way (Francès, 1968; Stamps, 1997; Herzog and Shier, 2000). The high loading factor of scenic beauty in Axis I shows that it is related to these structure-associated visual attributes. In fact, complexity and diversity have been found to be the most significant predictors of preference (Francès, 1968; Wohlwill, 1976).

The second principal component (Axis II) showed perspective to oppose risk and mystery. Risk was strongly related to mystery; both these variables are related to the 'challenge to explore'. The perception of risk in a landscape is ambivalent and can evoke either the idea of imminent danger or of challenges to be met, depending on the observer (Bernáldez, 1985). Kaplan and Kaplan (1982) found the most preferred scenes to reflect greater mystery. Perspective is the sensation of the depth of the viewshed, is inversely related to mystery (mysterious landscapes should have low perspective) and is important for properly understanding and interpreting the spatial characteristics of the landscape. A deep, wide viewshed has been shown of great importance in determining visual quality (Appleton, 1975).

The third principal component (Axis III) was associated with coherence and legibility. Both these variables are related to the understanding of the environment and play an important role in the interpretation of landscape structure (Kaplan and Kaplan, 1982). Herzog and Leverich (2003) argue that the most preferred scenes in many studies are those with greater legibility.

The fourth principal component (Axis IV) corresponded to landscape pattern and patch-shape. Both these are related to the aptitude for finding regularities in the landscape and play an important role in interpreting its spatial structure (Bernáldez and Abelló, 1989).

4.2. Relationship between visual attributes and landscape metrics

The present results are consistent with those previously reported for agricultural (Hunziker and Kienast, 1999; Franco et al., 2003) and rural landscapes (Palmer, 2004) and suggest that some aspects of visual aesthetic quality might be expressed in terms of spatial structure. They also demonstrate interesting relationships in the way visual attributes are perceived and valued and explain how the spatial pattern facilitates or impedes the comprehension and exploration of the landscape.

The results also show that only a few landscape pattern indices are related to scenic beauty; indeed, only the correlation with evenness was significant for the 1 km^2 window. Greater perceived scenic beauty was attributed to landscapes with greater spatial evenness (landscapes with a mixture of different landcover types of approximately equal area providing variety). This result supports those of Palmer (2004) who reports the positive contribution of dominant land uses in landscape preference. Hunziker and Kienast (1999) also found diversity and evenness to be correlated with scenic beauty, although when a certain level of diversity is reached, scenic beauty may decrease. The present results show that, although landscape diversity has a positive influence on preferences (Schutte and Malouff, 1986; Scott, 2002), the relationship is not simple. To perceive high scenic value, a certain overall order has to be discovered (Staats et al., 1997) and a limited number of elements or colors must be present in the landscape (Peterson, 1974; Todorova et al., 2004), allowing the observer to understand the scene (Birkhoff, 1933).

Legibility showed significant negative correlations with number of patches, patch diversity and evenness in the 0.25 km^2 window. This suggests that greater perceived legibility is attributed to landscapes with less spatial heterogeneity. A strong relation has been found between visual legibility and visual complexity by other authors (Berlyne, 1960; Wohlwill, 1976). Any variation in spatial complexity (either increasing or diminishing) produces a positive response up to the point at which the scene becomes too monotonous or too complex to be legible (Wohlwill, 1976). This suggests that landscapes with high diversity could have low perceived legibility if their components cannot be understood in a coherent form. In this respect, Herzog and Leverich (2003) found visual access to be a major component of legibility in a forest setting. The correlation of legibility with landscape pattern indices in the foreground and mid-ground also suggests that legibility is arrived at via the observer's interpretation of his/her immediate surroundings (Smardon et al., 1986).

Perspective and mystery were found to be opposing attributes. The results show that landscapes valued as mysterious are those with high topographic variability and a large number of irregular-shaped different patches producing a sense great spatial heterogeneity. Landscapes with high perspective values are those with wide, open spaces providing a full view. Perspective and mystery are related to the exploration of the landscape. In making preference decisions, there appears to be a conflict between a clear view and easy interpretation of the landscape (perspective) and the need to be stimulated by the promise of additional information (mystery). A high spatial heterogeneity, landcover diversity and the sensation of being inside the scene are properties that have been found to confer a high degree of mystery (Gimblett et al., 1987; Lynch and Gimblett, 1992). In the "prospect/refuge" theory of Appleton (1975), topography plays an important role in interpreting the spatial structure of the landscape. This is closely linked to the feeling of having a general or panoramic view of the landscape (Hagerhall, 2000).

Perceived patch-shape was correlated with several indices in the foreground and mid-ground windows, all related to landscape heterogeneity. High values of perceived shape correlated with landscape diversity and fractal dimension (landscapes with a large number of landcover classes and irregular shapes). Purcell et al. (2001) noted empirically how the fractal geometry of different types of natural scene was associated with preference (greater preference being associated with higher fractal values). Bovill (1996) found that judgments concerning ruggedness were positively associated with fractal dimension. The results suggest that landscapes with irregular shapes offer a sensation of high visual complexity, while those with homogeneous shapes have appear less complex.

In summary, landscape structure seems to be related to perceived visual aesthetic quality. From the perspective of the analysis adopted here, spatial structure is an informative dimension of the landscape with strong implications in the perceived quality of the scene.

Apparently, this condition implies that the perceptual qualities of landscapes of a certain structural heterogeneity, have a profound effect on well-being and aesthetic satisfaction (Lynch, 1960). Some researchers suggest relationships exist between heterogeneity and the perception of the landscape and that this may have an evolutionary basis (Appleton, 1975; Kaplan and Kaplan, 1982; Bernáldez, 1985). These authors argue that humans have an innate standard of beauty which has had (and still has) enormous adaptive and/or welfare implications. Thus, humans prefer and/or asses as beautiful those landscapes that include a series of features (in terms of spatial configuration and specific content) which would have provided survival benefits to our ancestors (Orians, 1986).

It makes sense that environments with intermediate levels of complexity should be preferred over both simpler and more complex environments since the range of resources present in an environment (and the ability to find and use them) probably peaks at intermediate levels of complexity. Simple environments have too few resources, while complex ones have so many that choosing among them becomes difficult (Orians, 1986). The influence of unity and variety (Berlyne, 1960) and order and complexity (Birkhoff, 1933) may be similar. The findings reported here suggest that in the free and voluntary framework that characterizes the observation and contemplation of the landscape, there is a more or less conscious search for these elements.

4.3. Some remarks about the methodology

Although the proposed methodology shows promise for helping determine the relationships between landscape preference and landscape structure, it nevertheless has certain limitations (which might be improved upon in subsequent work):

(1) The small sample-size reduces the reliability and extrapolability of the results. A larger number of photographs would be advisable, especially if the results are to be extrapolated to entire territories. Reducing the number of attributes to avoid respondent fatigue might be advisable.
(2) The low inter-rater reliability observed might be due to reduced variability among the images (Palmer, 1997). A sample of photographs with

greater landscape variability should make the results more reliable.

(3) The square windows used for the landscape pattern indices might not coincide exactly with viewsheds and areas not visible from the sample point might be included within a window. However, this problem would mainly affect the 5 km × 5 km window although its effect should be small since the foreground and mid-ground play the most significant roles in judging spatial relationships and understanding the perceived landscape (Smardon et al., 1986); landscape elements in the background are of little or no importance in terms of landscape perception (De Veer and Burrough, 1978; Palmer and Roos-Klein, 1998). The use of viewsheds could be helpful, although precautions need to be taken when comparing the viewsheds of different areas (Turner et al., 2001).

5. Conclusions

This work shows how the rating of landscape visual attributes might be related to landscape structure. Scenic beauty shows a limited correlation with landscape pattern indices, revealing inherent difficulties in predicting such a broad and normative concept using spatial metrics. However, a number of visual attributes, notably legibility, shape, perspective and mystery, show clearer correlations with landscape spatial pattern indices. These correlations are in agreement with those in related theories concerning the content of available information in the perceived landscape and the pleasure or scenic attraction produced. This reinforces the importance of incorporating theories of landscape perception into the development of programs for the protection of ecological quality and biodiversity and in conventional landscape management strategies and planning. Landscape heterogeneity, considered as a scenic resource, has an important role in visual aesthetic quality and the psychological benefit of a landscape. Landscape homogenization may not only obstruct satisfaction being drawn from the perception of a landscape but also have a negative influence on psychological well-being. Some authors suggest that the greater the homogeneity of agrarian landscapes, the lower their perceived visual beauty mainly due to the lack of color contrast caused by the reduction of crop diversity (Weinstoerffer and Girardin, 2000; Arriaza et al., 2004). These observations indicate the need for further investigations that replicate and improve upon this line of research and which address the following question: can visual aesthetic quality change depending on the composition and configuration of the landscape (see Nohl, 2001)?

The results also suggest that spatial metrics might be useful for explaining visual quality in landscape evaluation and assessment. In the management of many landscapes, great difficulty exists in reaching a consensus that guarantees results to be environmentally sustainable, appropriate and socially acceptable, easily comprehended and economically feasible. Several investigations have demonstrated that visual factors are important in the adoption of conservation practices (Nassauer, 1992; Sullivan et al., 2004) and that conflicts appear when the visual appearance of the landscape opposes public preferences. The use of landscape spatial metrics offers the advantage of availability and their easy comprehension might have a positive effect on future work on landscape preference.

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