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Research Article

Does the management of woody edges in urban parks match aesthetic and ecological user perception?

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Abstract

In recent times, the focus in urban park management has shifted from mere aesthetics to the difficult task of striking a balance between ecology and the aesthetic outlay of those parks. Park managers design the spatial arrangement, the structure and the ecological diversity of vegetation to mimic natural ecosystems. However, the ecological benefit is often associated with a decrease in the aesthetic value for users. To better understand this trade-off, we eye-tracked 196 users in Rennes (France) to test if 'ecological' management of woody edges was in accordance with their aesthetic preferences and ecological perception. We identified which were the visual areas of interest for users in four types of managed woody edges and analysed which were considered as the most aesthetic and the most ecologically valuable. Finally, we analysed if both aesthetic user preferences and 'ecological' management of woody edges were compatible. Based on a classification of increasing management complexity of woody edges, we showed that users' aesthetic preferences were mainly focused on tree and shrub layers, while users identified the herb and shrub layers as the most favourable area for maintaining biodiversity. Thus, the more complex the edge, the more the relationship between aesthetic preferences and ecological management is for park management. More precisely, in complex woody edge structures, some vegetation layers such as shrub could represent a specific lever to fulfil both aesthetic and ecological purposes.

Key words: eye-tracking, scenic diversity, park management

Introduction

Over 54% of the total global population lives in cities since 2014 and the figure is predicted to rise to over 70% within 30 years (World Health Organisation 2016). Facing this increase of the urban world's population, urban parks supporting nature are identified as important landscape elements providing ecosystem services (Russo et al. 2017) and could support biodiversity (Kowarik 2011). In this context, urban parks are recognised as particularly useful to bring nature close to the people (e.g. Cox et al. 2017), thereby improving quality of life in the cities (e.g. Parsons 1995; Dallimer et al. 2012; Carrus et al. 2015). More precisely, the need for urban parks to foster physical and psychological well-being, therefore, became a key focus of urban policy (Dong and Qin 2017; Hoyle, Hitchmough, and Jorgensen 2017).

Landscape aesthetics (Gobster et al. 2007) notably in urban green spaces (Meyer et al. 2020) is known to contribute to the physical and psychological well-being of urban residents. More precisely, the preference of urban people for manicured, tidy landscapes has been well documented (Jorgensen, Hitchmough, and Calvert 2002; Gobster et al. 2007; Jorgensen and Gobster 2010; Hoyle et al. 2017). Relationships between human preferences and biodiversity are complex (Dong and Qin 2017; Southon et al. 2017); 'wild-looking' parks with the highest biodiversity are generally negatively perceived aesthetically compared to ornamental woodland park style with the lowest biodiversity (Qiu, Lindberg, and Nielsen 2013; Hoyle et al., 2017).

The management of woody edges is characterised by habitat sharpening, which is defined as the increase in contrast between woodland and adjacent landscape elements (e.g. lawn), and the consequent loss of edge habitat (Janzen 1987). This process has several direct and indirect consequences on biodiversity and human appreciation of parks (Parsons 1995; Jorgensen et al. 2002; Jorgensen and Anthopoulou 2007). There is a growing literature about how management of urban parks influences linear woody edge structure and their perception at local scales (Tyrväinen et al. 2003; De Chant et al. 2010; Hauru et al. 2012). One challenge for park management is thus to transform urban parks to be both ecologically diverse and aesthetically appealing (Parsons 1995) by considering the multiple dimensions of well-being. The aesthetic dimension of urban parks is related to a complex assortment of well-being dimensions including social and secure place (Jorgensen and Anthopoulou 2007), affordance (Samuelsson et al. 2018), restorative experiences (Kaplan and Kaplan 1989) or soundscapes (Watts and Pheasant 2015; Wang and Zhao 2019). Ecological purposes in urban areas concern mainly urban ecosystem services generated in a diverse set of habitats such as wetland, meadows or woodland, which provide, for example, microclimate and water regulation, pollution reduction and health benefits (Elmqvist et al. 2015).

Understanding the pattern of eye movement is a good means to understand how people assess scenes (Rayner and Pollatsek 1992). New technologies such as eye-tracking could help to study landscape perception (Holmqvist et al. 2015). It is a means of recording the visual perception of information. As explained by Henderson and Hollingworth (1998) and summarised in Duchowski (2009), there are at least three important reasons to understand eye movements in scene viewing. First, eye movements are critical for the efficient and timely acquisition of visual information during complex visual–cognitive tasks. Second, how we acquire, represent and store information about the visual environment is a critical question in the study of perception and cognition. The study of eye movement patterns during scene viewing contributes to the understanding of how information in the visual environment is dynamically acquired and represented. Third, eye movement data provide an unobtrusive, on-line measure of visual and cognitive information processing. More precisely, eye-tracking allows the abstraction of the gist of a scene using specific features such as fixations and eye movement analysis (Rayner 1992, 1998; Underwood 1998). There are two important issues for understanding eye movement control during scene viewing: where the fixation position tends to be centred during scene viewing and how long the fixation position tends to remain centred at a particular location in a scene (Henderson and Hollingworth 1998). In that sense, eye-tracking experiments are widely recognised and useful to study what element in a natural scene, and particularly, what vegetation element in a park captures attention (Holmqvist et al. 2015).

In urban areas, interactions between the spatial arrangement and the structure of the vegetation are key factors to explain aesthetics preferences of users in green spaces (Kaplan and Kaplan 1989; Southon et al. 2018). Southon et al. (2017) showed that species-rich meadows can provide a win–win strategy for biodiversity and human preferences, potentially improving connections between these two. Many examples showed that people generally dislike dense vegetation and bushes as they restrict visibility, accessibility and feeling of safety in forests (e.g. Tyrväinen et al. 2003; Gundersen and Frivold 2008). Therefore, natural woodlands could sometimes be considered as less attractive than well-maintained woodlands, particularly when they present multi-layer structures and dense edges (Parsons 1995; Jorgensen et al. 2002; Jorgensen and Anthopoulou 2007). Previous studies have focused on how residents perceive ecological management options [such as restoration management, Hauru et al. (2012)]. Some cases showed that natural woodlands often lacked a win–win strategy regarding biodiversity versus public preferences, even if more naturalistic vegetation can improve this relationship (Jorgensen et al. 2002; Jorgensen and Gobster 2010).

Many examples of structurally diverse woody edges can be found all around the world (e.g. Fry and Sarlöv-Herlin 1997; Ferris and Carter 2000). In Europe and particularly in France, many urban parks were designed in the last and the penultimate centuries and present highly managed woodlands and woodland hedgerows. More recently, park management has developed management plans to favour biodiversity in urban woodland areas, particularly on woody edges (i.e. the interface between forest and open grounds) that could benefit species richness for some taxa such as insects (e.g. Gonzalez, Salvo, and Valladares 2017; Magura et al. 2017; Luppi et al. 2018) or plants (e.g. Vallet et al. 2010).

Whereas many studies have examined how urbanisation alters forest landscape structure at the landscape or regional scales, there is a growing literature about how management influences linear woody edge structure and their perception at local scales (Tyrväinen et al. 2003; De Chant et al. 2010; Hauru et al. 2012).

The novelty of our approach was to understand how a complexity gradient of managed woody edges was perceived in urban parks. Based on a classification of woody edge complexity and on landscape ecology theory (where ecotones are more diverse than single habitat, Burel and Baudry 2003), we hypothesised that the more complex the edge, the higher the biodiversity (Dronova 2017). Indeed, landscapes with high heterogeneity are able to host more coexisting species due to a high number of available niches (Rocchini et al. 2010). Landscape heterogeneity has thus been identified as a key variable enhancing the diversity of species in a landscape (Burel and Baudry 2003). The structure of a landscape provides ecological information at a scale that is readily perceivable and can act as a tool to connect humans with ecological phenomena (Gobster et al. 2007). We then tested whether 'ecological' management of woody edges by park management in urban parks was in accordance with users' perception and aesthetic preferences. More precisely, we used an eye-tracking experiment to identify (i) which were the visual areas of interest (i.e. tree, shrub or herb layers) for users in the four types of woody edges. Then, we analysed which areas of interest were considered as the most (ii) aesthetic and the most (iii) ecological by users. Finally, we analysed whether (iv) both users' aesthetics preferences and 'ecological' management of woody edges made in urban parks were possible to provide recommendations for park managers. In deciduous forests, species diversity generally increases with succession and reaches a maximum during the forest stage when structural diversity is highest (Bazzaz 1975). From an ecological point of view, in forests, shrub and herb layers are richer than tree layers (Gilliam 2007; Muñoz et al. 2009). In this study, we thus expected that users could identify these layers as more interesting from an ecological point of view than the tree layer. It is often stated, though less often in quantitative terms, that most plant biodiversity in forest ecosystems is found in the herbaceous layer (Gilliam and Roberts 2003; Roberts 2004; Whigham 2004) and the shrub layer (Zhongliang et al. 2000). For example, in a review, Gilliam (2007) mentioned that the herb layer averages more than 80% of the total plant species richness of a forest. In other words, from an ecological point of view, in forests, shrub and herb layers are richer than tree layers (Gilliam 2007) and

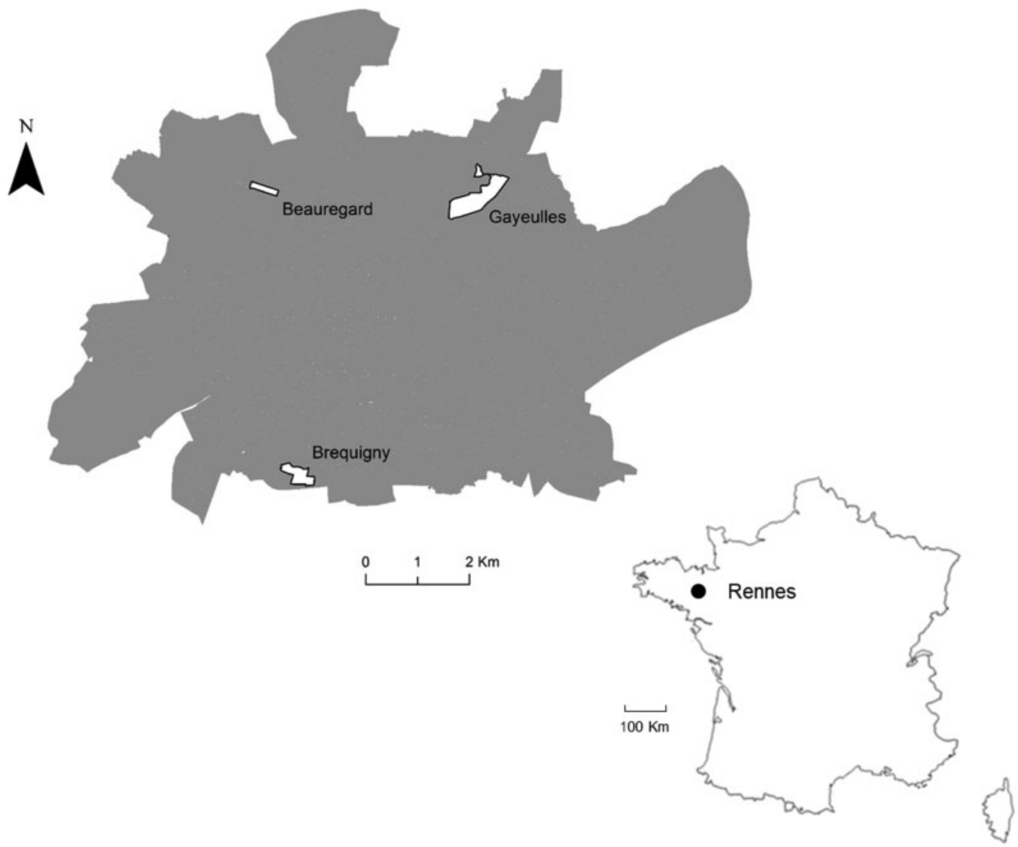

Figure 1: Map of the Rennes agglomeration and locations of the three parks sampled

enhance the ecological functioning of the forest (Muñoz et al. 2009).

Materials and methods

Photographs and site's selection

In the city of Rennes (France), park management distinguished four kinds of edges according to their structure (woody edges with tree layer only; woody edges with tree and shrub layers; woody edges with tree and herb layers; and woody edges with tree, shrub and herb layers). Photographs of managed diversity of woody edges were taken in three urban parks (Gayeulles, Brequigny and Beauregard) in Rennes (France). Photographs were taken in quite similar weather conditions and during the same season to assure consistency about the foliage stage (spring, 18–23 May 2016) (Fig. 1).

Based on the presence of the different vegetation layers (herb, shrub and tree layers), four types of woody hedgerows were defined: tree layer alone (Fig. 2A), tree and shrub layers (Fig. 2B), tree and herb layers (Fig. 2C) and tree, shrub and herb layers (Fig. 2D). These layers were regularly found in management documents in many cities (e.g. Direction des jardins de la ville de Rennes 2008) and are easily distinguishable (Özgüner and Kendle 2006; Meyer et al. 2020). These four types of woody hedgerows represent a complexity gradient of managed woody edges corresponding to a specific management and planning measures. The higher the type, the less frequent and inclusive the measures are. In the Type 1, the vegetation is staged, structured, designed and constrained in its evolution. This means that spontaneous plants or weeds are not welcomed. Lawns are regularly mowed. Trees can be exotic as they are mostly selected for their aesthetic values (i.e. their volume, shape or colour). The vegetation in Types 2 and 3 woody edges is rather controlled. The composition of those woody edges is less strict and deliberately favours the development of the spontaneous expression of nature, especially in the herb layer for Type 2. The goal is to create more wild-looking and semi-natural woody edges. Herb layer is generally mown once per year, shrub layer is also pruned once per year. The Type 4 woody edge, the more complex, favours the apparition and development of spontaneous vegetation. Vegetation is left to naturally occupy the voids within and between the three vegetation strata, instead of systematically weeding or mowing as in other woody edges. The main objective of this measure is to allow the constitution of sustainable complex vegetation structures with a semi-natural dynamic, which are favourable to fauna. Effort is thus put on planting native plants as it promotes the development of spontaneous autochthonous vegetation leading to the development of herbaceous and shrubby undergrowths. Thinning can be applied when necessary in order to favour the development of interesting plants (e.g. Euphorbia and ferns in Brittany) and clarify the distinction between the shrub and herbaceous layer. The development of trees and shrubs is generally constrained and in order to keep a distinction between the layers, the volume of the shrubs is controlled in height and width by trimming the largest branches when necessary. The lowest branches of the trees are also cut when necessary.

Panoramic photographs of woody hedgerows were taken using the same Canon EOS 70 D Digital SLR camera, a wide-angle

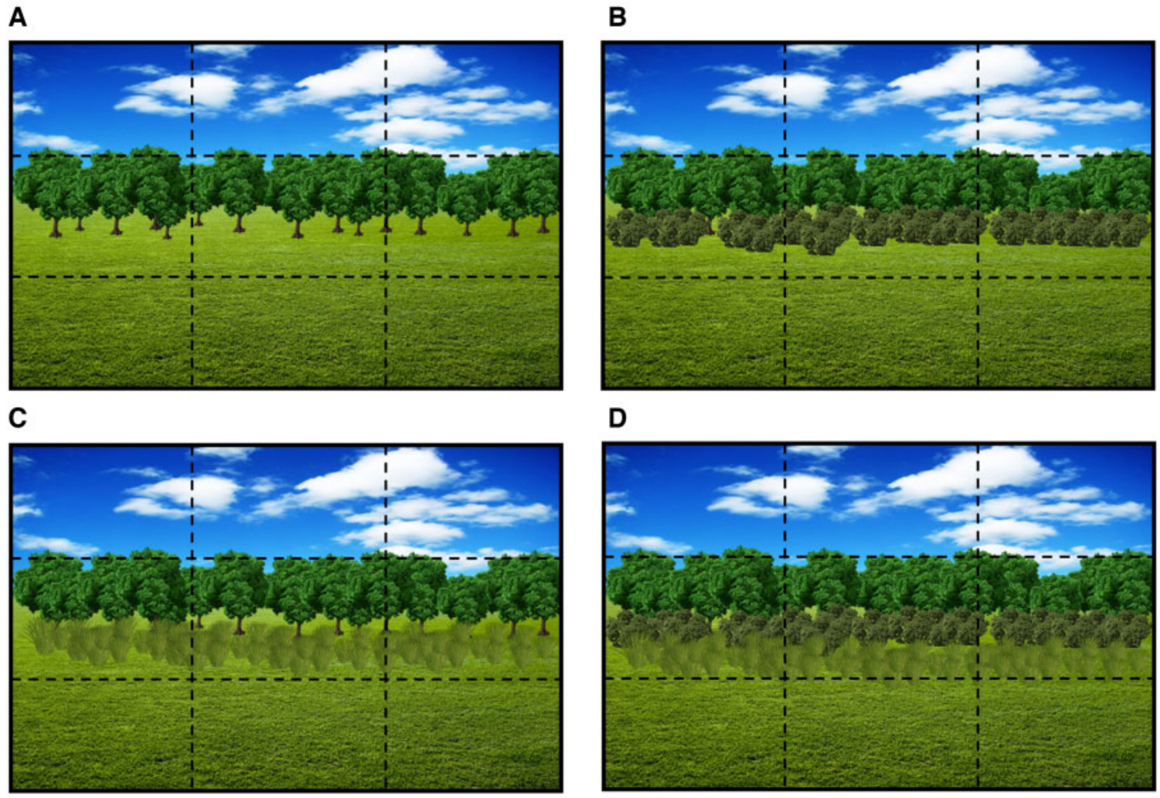

Figure 2: (A) Type 1 woody edge (i.e. tree layer only). (B) Type 2 woody edge with tree and shrub layers. (C) Type 3 woody edge with tree and herb layers. (D) Type 4 woody edge with tree, shrub and herb layers. Dotted lines were only represented to illustrate the aspect ratio of 1:3 for the sky, the woody edge and the lawn

objective (Canon EF-S 10–22-mm f/3,5-4,5 USM, focal length used: 10 mm) and a tripod to guarantee a constant shot height (1.6 m). Each photograph had an identical display size (3648 × 2432 pixels). Compared to 4:3, panoramic photographs allowed more extensive visual explorations and provided easier and more information extractions (Dupont, Antrop, and Van Eetvelde 2014). Each photograph was taken at a different distance of the tree layer to respect, as far as possible, an equal aspect ratio for the sky, the woody hedgerow and the lawn (Fig. 2). Four photographs of each woody hedgerow type were collected, as a result, 16 photographs were made (Supplementary Appendix A) and used during the eye-tracking experiment. For each photographs, we controlled the visual weighted balance to have homogeneous photographs without high contrast effects. We did not use specific algorithm to improve the visual weighted balance nor specific software to modify the composition of the photographs.

Eye-tracking protocol

Materials

In order to understand the complex relations between aesthetic preferences of users, ecological management carried out by park management on public woody edges and their perception by users, we developed a participative eye-tracking experiment based on 196 users in Rennes (France). The experiment was performed using a Tobii Pro X2-30 eye tracker developed by Tobii Pro (Stockholm, Sweden). This screen-based eye tracker captures gaze data at 30 Hz (i.e. is equal to 30 measurements per second), allowing a continuous registration of eye movements and the observer's scan path (Poole and Ball 2005). The record of human eye movements and the estimation of the point of gaze (i.e. where someone looks on the stimulus) is based on pupil and corneal reflection tracking of the observer using infrared light (Duchowski 2009). All the stationary gaze positions (i.e. fixations) and interconnecting eye movements (i.e. saccades) were recorded. In this study, according to Dupont et al. (2016) and Inhoff and Radach (1998), fixation points were determined when a position was stationary and were set at least at 100 ms.

The experiment was performed during the summer of 2016 in three parks (Gayeulles: 20–21 July 2016 and 16 August 2016; Brequigny: 13 and 18–19 July 2016 and 19 August 2016; and Beauregard: 11–12 July 2016 and 17–18 August 2016, Fig. 1). The parks were chosen with consideration for accessibility and visitors' frequentation. We used a van specially fitted to fulfil the eye-tracking experiment (including stationary table and chair, without windows to avoid infrared light by the sun and external disturbances, Holmqvist et al. 2015). During the experiment, the participants were seated 60–80 cm (depending on the optimal calibration position) in front of a 17-in. colour monitor on which photographs were displayed.

Protocol

Eye-tracking allowed the recording of direct quantitative metrics. It required no specific training or particular coordination but determined exactly and automatically where the user's interest was focused and was thus helpful in understanding user interaction with their environment (Duchowski 2009). The eye-tracking experiment was divided into three steps.

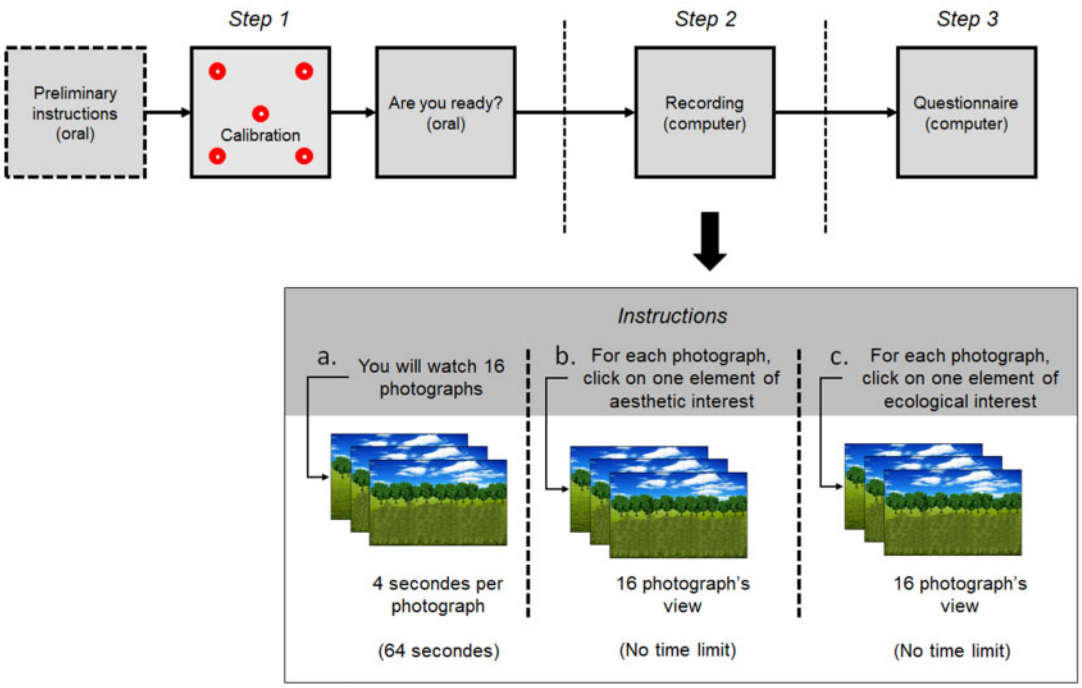

Figure 3: Eye-tracking protocol design. Step 1 aimed to identify which are the visual areas of interest in woody hedgerows. Step 2 aimed to identify aesthetic and ecological areas of interest (instructions were read directly on screen). Step 3 aimed to collect personal participant data by themselves

The first step aimed at preparing the participant for the experiment (Fig. 3, Step 1). During this step, the experimenter briefly gave the same oral preliminary instructions:

> This experiment aims at understanding the visual perception of wooded elements in urban parks. You will watch 16 urban park photographs taken in the city of Rennes. Please, try to watch them as normally as possible, without deliberately scanning the photograph as a whole. Please note that it is not a memory experiment, so be relaxed and enjoy the watching. I will not interact with you during the watching except in case of problems. Before viewing the photographs, the system needs to be calibrated to record what you are watching. Please follow the red point on the screen. Are you ready?

After the oral instructions, a 5-dot calibration was performed to assure accurate measurements over the entire screen. Just before Step 2, the experimenter asked again 'Are you ready?' to be sure that the participant was ready. Then, the experimenter launched Step 2.

Step 2 was divided into three sub-parts. Participants did not know the conduct of the sub-parts to ensure the reliability of the experiment. Participants first watched freely each photograph for 4 s (Step 2a, Fig. 3). This step aimed to identify which are the visual areas of interest in woody hedgerows managed by park managers (i.e. tree, shrub or herb). To examine scene perception on photographs, previous experiments have shown that participants get the gist of a scene very early in the process of looking, sometimes from a single brief exposure. Thus, it has been advocated that the gist of the scene is abstracted on the first few fixations, and the remainder of the fixations on the scene is used to fill in details (Rayner 1998). After laboratory tests, we calibrated the watching duration to 4 s to have approximatively 10–20 fixation points per participant for each photograph. The display order of the photographs was randomised to avoid the occurrence of effects that might originate from a fixed order (Dupont et al. 2016). The Step 2a was used to record visual patterns of participants (i.e. fixation points and saccades of participants).

Then, Step 2b (Fig. 3) was automatically launched with the sentence 'For each photograph, please click on one aesthetic (beautiful) element of interest'. During this step, the 16 photographs were seen again, randomly, and the participant could click on one aesthetic element using the mouse of the computer, without a time limit. This step was used to analyse which areas of interest (i.e. tree, shrub or herb layer) were considered as the most aesthetic.

At the end of Step 2b, Step 2c was also automatically launched with the sentence 'For each photograph, please click on one element of ecological interest (element favoring the biodiversity)'. During this step, the 16 photographs were seen again, randomly, and the participant could click on one ecological element with the mouse, without a time limit. This step was used to analyse which areas of interest (i.e. areas delimiting, shy, tree, shrub, herb and lawn) were considered as the most ecological.

Finally, a questionnaire was used in Step 3 (Fig. 3) to collect participant information regarding their sex (male, female) and age.

Participants

Park users were invited to participate. Each participant regularly visited (once a month) one of the three parks. Before they entered the van, we only introduced ourselves as university members performing a research experiment. Accompanying people (including adults accompanying children under the age of 16) could observe the experiment from the cabin of the van through a small window. During Step 1 (Fig. 3), all the participants were given the same brief instructions. To avoid influencing viewing patterns, no details were revealed with respect to the purpose of the study. Before starting the test, the participants were asked about any aberrations of their eyes vision (i.e. normal vision or if they wear glasses or contact lenses). All the selected participants had normal or corrected-to-normal vision. Human subject protocols and approval by the University of Rennes was done.

Data analysis

Metrics

Data recorded by the eye tracker were extracted using Tobii Pro Studio, the software supplied with the eye tracker. For each photograph, we defined three to five areas of interest, i.e. regions in the stimulus in which we were interested in gathering data (Holmqvist et al. 2015): sky, tree, shrub, herb (e.g. an uncut strip of grass) and lawn (e.g. regularly mowed strip of grass). The four edge types were based on physical vegetation structure. The major elements of vegetation structure as ecologically understood (height, projective foliage cover or density and floristic identity of the uppermost stratum) are likely to be the most visually perceptible (Lamb and Purcell 1990; Meyer et al. 2020).

Three metrics were extracted from the areas of interest and summarised. In this study, to identify which are the visual areas of interest in woody hedgerows (tree, shrub or herb, Fig. 3, Step 2a), we used specific fixation metrics: the number of fixations and their duration (in ms). Following Holmqvist et al. (2015), these two metrics related to basic position and duration measures allowed us to define where the participant fixed his eyes. We did not use saccades and their amplitude (degrees) because these metrics offer insight into the main observation pattern (Duchowski 2009), which was not the purpose of this study. To know where aesthetic and ecological areas of interest were located, we used the number of clicks per area of interest (Fig. 3, Steps 2b and 2c).

Analysis

Independent chi-squared tests were carried out to check if our sample was representative of the population of Rennes. These tests were done per gender and age.

After checking the distribution of variables using Shapiro–Wilk normality tests, the relationship between the number of fixations and their durations per photograph was analysed using the Pearson correlation test.

To test if the proportion of the different areas of interest (i.e. the number of pixels occupied by each area of interest divided by the total number of pixels) bias our results, four one-way analyses of covariance (ANCOVAs) were conducted to determine a statistically significant difference between the surface of the different areas of interest (in percentage) and the number of fixations, their durations, the number of aesthetic clicks or the number of ecological clicks controlling for the woody edge type as explanatory variables.

For each woody edge type, one-way analyses of variance (ANOVAs) were performed. After checking the distribution of residuals using Shapiro–Wilk normality tests, we analysed if the number of fixations and their durations (Objective 1), the number of aesthetic clicks (Objective 2) and the number of ecological clicks (Objective 3) varied according to the areas of interest. We performed Tukey honest significant difference (HSD) *post hoc* tests to identify significant differences between areas of interest (Table 1).

We then analysed (1) if the distribution of the fixation points and their duration in the different areas of interest followed the distribution of the aesthetic and ecological clicks and (2) if the distribution of the aesthetic clicks in the different areas of interest followed the distribution of ecological clicks (Objective 4, Table 2). We used multiple chi-squared parametrical tests with Bonferroni corrections to visualise where differences occurred (Table 1, last column).

All statistical analyses were carried out using R software version 3.4.2 (R Core Team 2017).

Results

One hundred and two men aged between 14 and 73 (35.80 ± 16.04, mean value $\pm$ standard deviation) and 94 women aged between 11 and 74 (35.95 ± 16.03, mean value $\pm$ standard deviation) voluntarily participated in the experiment ($N = 75$, 60 and 61 for Gayeulles, Brequigny and Beauregard, respectively). The refusal rate was 59.92%. Compared to 46.95% and 53.05% for the average population of Rennes (respectively for men and women, National Institute for Statistics and Economic Studies, 2015), no statistical differences were found (chi-squared test, $\chi = 0.83$, $df = 1$, P-value $= 0.36$) (Table 3). The sample of visitors interviewed for this study was also representative of the average population of Rennes in terms of age and gender (Table 3).

The number of fixation points (Shapiro–Wilk test of normality, $W = 0.93$, $P = 0.26$) and their duration (Shapiro–Wilk test of normality, $W = 0.95$, $P = 0.58$) were not significantly related (Pearson coefficient correlation test, $R = 0.47$, $P = 0.06$). No significant differences between the respondent's profiles were found when we analysed them separately.

Do areas of interest proportions influence the number of fixations and their durations?

There was a significant effect of the proportion of the different areas of interest on the number of fixations after controlling woody edge type (ANCOVA, $F = 795.8$, $P < 0.001$). In all woody edge types, the number of fixations increased significantly with the proportion of the different areas of interest (Pearson coefficient correlation tests, $R = 0.74$, $R = 0.53$, $R = 0.71$ and $R = 0.22$; all P-values < 0.001 respectively for woody edge Types 1, 2, 3 and 4).

There was a significant effect of the proportion of the different areas of interest on the duration of the fixations after controlling woody edge type (ANCOVA, $F = 645.9$, $P < 0.001$). In all woody edge types, the duration of the fixations increased significantly with the proportion of the different areas of interest (Pearson coefficient correlation tests, $R = 0.71$, $R = 0.52$, $R = 0.67$ and $R = 0.20$; all P-values < 0.001 respectively for woody edge Types 1, 2, 3 and 4).

There was a significant effect of the proportion of the different areas of interest on the number of aesthetic clicks after controlling woody edge type (ANCOVA, $F = 9.19$, $P < 0.001$). In woody edge Types 1, 2 and 3, the number of aesthetic clicks increased significantly according to the proportion of the different areas of interest (Pearson coefficient correlation tests, $R = 0.84$, $R = 0.66$ and $R = 0.69$; P-values < 0.01 respectively for woody edge Types 1, 2 and 3). In woody edge Type 4, there was no significant correlation between the number of aesthetic clicks according to the proportion of the different areas of interest (Pearson coefficient correlation test, $R = 0.33$, $P = 0.15$).

There was no significant effect of the proportion of the different areas of interest on the number of ecological clicks after controlling woody edge type (ANCOVA, $F = 1.74$, $P = 0.11$).

Table 1: Surface (%), number of the fixation points, duration (ms), number of aesthetic and ecological clicks according to predefined areas of interest for each woody edge type (mean ± SD)

Woody edge type	Areas of interest	Surface (%)	Fixation points (number)	Fixation duration (ms)	Aesthetic clicks (number)	Ecological clicks (number)	Aesthetic vs. ecological clicks
Type 1	Sky	26.84 ± 7.75	76.00 ± 23.11 (a)	18.37 ± 6.81 (a)	5.5 ± 2.65 (a)	1.75 ± 0.96 (a)	*
	Tree	46.89 ± 7.71	1855.25 ± 113.37 (c)	513.03 ± 31.46 (c)	160.0 ± 11.20 (c)	171.00 ± 6.78 (c)	NS
	Shrub	–	–	–	–	–	
	Herb	–	–	–	–	–	
	Lawn	26.27 ± 0.99	277.25 ± 69.32 (b)	67.09 ± 19.83 (b)	30.5 ± 9.75 (b)	23.25 ± 5.91 (b)	NS
			N = 8834	N = 2393	N = 784	N = 784	
Type 2	Sky	27.15 ± 4.89	75.00 ± 20.85 (a)	18.25 ± 7.52 (a)	17.75 ± 12.84 (a)	2.25 ± 0.50 (a)	*
	Tree	32.69 ± 13.02	1106.75 ± 533.69 (b)	317.50 ± 158.67 (b)	103.50 ± 50.47 (b)	71.75 ± 13.72 (c)	*
	Shrub	16.75 ± 11.62	664.25 ± 452.84 (ab)	176.46 ± 123.73 (ab)	46.75 ± 35.98 (ab)	100.50 ± 13.40 (b)	*
	Herb	–	–	–	–	–	
	Lawn	23.41 ± 0.71	337.50 ± 211.29 (a)	78.37 ± 52.02 (a)	28.00 ± 17.22 (a)	21.50 ± 10.79 (a)	NS
			N = 8734	N = 2362	N = 784	N = 784	
Type 3	Sky	27.68 ± 1.27	62.25 ± 18.26 (a)	15.69 ± 4.20 (a)	5.25 ± 3.95 (a)	0.75 ± 0.50 (a)	*
	Tree	44.17 ± 5.2	1630.50 ± 195.97 (c)	453.64 ± 53.76 (c)	134.50 ± 27.69 (b)	83.00 ± 42.98 (b)	*
	Shrub	–	–	–	–	–	
	Herb	8.88 ± 3.6	379.50 ± 176.44 (b)	102.66 ± 50.10 (b)	35.75 ± 19.57 (a)	106.75 ± 43.39 (b)	*
	Lawn	19.27 ± 3.9	134.75 ± 32.27 (ab)	35.28 ± 12.47 (ab)	20.50 ± 13.82 (a)	5.50 ± 1.91 (a)	*
			N = 8828	N = 2429	N = 784	N = 784	
Type 4	Sky	28.55 ± 1.22	82.25 ± 22.25 (a)	20.60 ± 4.88 (a)	18.75 ± 10.21 (a)	1.25 ± 0.50 (a)	*
	Tree	23.89 ± 7.16	671.75 ± 312.87 (b)	190.73 ± 91.58 (b)	66.75 ± 23.53 (b)	28.25 ± 20.56 (ab)	*
	Shrub	19.04 ± 5.36	947.50 ± 178.74 (b)	267.96 ± 52.59 (b)	71.00 ± 16.99 (b)	68.75 ± 23.77 (bc)	NS
	Herb	5.86 ± 2.19	233.75 ± 123.54 (a)	59.53 ± 32.47 (a)	14.00 ± 9.02 (a)	87.00 ± 46.31 (c)	*
	Lawn	22.66 ± 0.93	240.75 ± 66.97 (a)	54.85 ± 17.20 (a)	25.50 ± 8.10 (a)	10.75 ± 4.92 (a)	*
			N = 8704	N = 2374	N = 784	N = 784	

Letters represent significant differences (inside column of each woody edge type) provided by one-way ANOVA and Tukey HSD *post hoc* tests. The last column represents the results provided by multiple chi-squared tests with Bonferroni corrections to analyse if the distribution of aesthetic and ecological clicks per areas of interest vary. NS: non-significant. For each woody edge type and based on the four corresponding photographs, *N* represents the total number of fixation points for all areas of interest (e.g. 8834 points for the Type 1), the total fixation duration for all areas of interest (e.g. 2393 ms for the Type 1) and the total number of aesthetic and ecological clicks for all areas of interest (784 for each, 196 participants × 4 photographs with one click per photograph per participant).

*When $P < 0.016$ for woody edge Type 1; $P < 0.008$ for woody edge Types 2 and 3; $P < 0.005$ for woody edge Type 4.

Table 2: Results of the chi-squared tests for each woody edge (WE) type

		Number of fixation points	Fixation duration (ms)	Number of ecological clicks per WE type
WE Type 1	Number of aesthetic clicks	$\chi = 7.09^{*}$; df = 2	$\chi = 15.02^{***}$; df = 2	$\chi = 44.01^{***}$; df = 2
	Number of ecological clicks	$\chi = 16.04^{***}$; df = 2	$\chi = 12.48^{**}$; df = 2	–
WE Type 2	Number of aesthetic clicks	$\chi = 84.64^{***}$; df = 3	$\chi = 100.61^{***}$; df = 3	$\chi = 606.20^{***}$; df = 3
	Number of ecological clicks	$\chi = 164.89^{***}$; df = 3	$\chi = 175.55^{***}$; df = 3	–
WE Type 3	Number of aesthetic clicks	$\chi = 27.82^{***}$; df = 3	$\chi = 34.00^{***}$; df = 3	$\chi = 588.35^{***}$; df = 3
	Number of ecological clicks	$\chi = 769.30^{***}$; df = 3	$\chi = 790.32^{***}$; df = 3	–
WE Type 4	Number of aesthetic clicks	$\chi = 93.81^{***}$; df = 4	$\chi = 118.22^{***}$; df = 4	$\chi = 1516.10^{***}$; df = 4
	Number of ecological clicks	$\chi = 950.40^{***}$; df = 4	$\chi = 1047.60^{***}$; df = 4	–

The first two columns analysed if the distribution of the fixation points in the different areas of interest followed the distribution of the aesthetic and ecological clicks in the different areas of interest. The last column analysed if the distribution of the aesthetic clicks in the different areas of interest followed the distribution of ecological click (χ represents the value of the chi-squared test statistic and df represents the degrees of freedom).

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

Which were the areas of interest for users in the four types of woody edges?

During the Step 2a (Fig. 3), 35 100 fixation points were recorded (Table 1), with a mean value of 11.19 ± 3.27 fixation points per photograph and per participant.

For each woody edge type, one-way ANOVAs were performed. The number of fixations and their durations varied significantly according to the areas of interest (*P*-values <0.001 for all ANOVA). We performed Tukey HSD *post hoc* tests to identify significant differences between areas of interest (Table 1, Columns 4 and 5). More precisely, Tukey HSD *post hoc* tests (Table 1, codification by letters) showed that, for the woody edge Types 1 and 3, tree layer was the main area of interest for users. The tree layer had significantly more fixation points and

Table 3: Average population of Rennes (%) and in this study ($N = 196$) per age breakdown according to the National Institute for Statistics and Economic Studies (2015)

Age breakdown	Rennes (%)	Sample (%)
0–14	14.3	3.06
15–29	33.7	34.18
30–44	18.4	36.22
45–59	15	16.84
60–74	11	9.70

was watched longer than other woody edge layers. For the woody edge Types 2 and 4, both tree and shrub layers had significantly more fixation points and were watched longer than woody edge layer. Conversely, the sky and lawn layers were the least area of interest for users whatever the woody edge type.

Which area of interest was considered as the most aesthetic and ecological by users?

In total, 3136 aesthetic and 3136 ecological clicks were recorded during Steps 2b and 2c, respectively (Table 1, Columns 6 and 7).

For each woody edge type, one-way ANOVAs were performed. The number of aesthetic and ecological clicks varied significantly according to the areas of interest (P-values <0.001 for all ANOVA). We performed Tukey HSD *post hoc* tests to identify significant differences between areas of interest (Table 1, Columns 6 and 7).

More precisely, Tukey HSD *post hoc* tests (Table 1, codification by letters) showed that, for the woody edge Types 1 and 3, tree layer was the most clicked aesthetic area of interest for users. For the woody edge Types 2 and 4, both tree and shrub layers were the most clicked aesthetic areas of interest.

For the woody edge Types 1 and 2, tree layer was the most clicked ecological area of interest for users. For the woody edge Type 3, tree and herb layers were the most clicked ecological areas of interest. For the woody edge Type 4, shrub and herb layers were the most clicked ecological areas of interest.

Aesthetic versus ecological areas of interest

If the proportion of the different areas of interest had an effect on the number of fixation points and their durations for woody edge Types 1, 2 and 3, results showed that the distribution of the fixation points and their duration did not follow the distribution of aesthetic and ecological clicks in the different areas of interest (Table 2). Moreover, the distribution of the aesthetic clicks in the different areas of interest did not follow the distribution of ecological clicks (Table 2). Aesthetic areas of interest differed from ecological areas of interest for users. Multiple chi-squared tests with Bonferroni corrections were performed to analyse the differences between the distribution of the number of aesthetic and ecological clicks per woody edge type and per area of interest (Table 1, last column). In low complex woody edge type (Type 1), the distribution of aesthetic and ecological clicks between trees and lawns did not differ. In more complex woody edge types (Types 2 and 3), users significantly increased the number of clicks in shrub and herb layers when they had to select ecological areas of interest compared to aesthetic areas of interest. Users significantly decreased the number of clicks in sky and tree layers, and partly in lawn layer (for Type 3 only). In the most complex woody edge type (Type 4), users significantly increased the number of clicks in the herb layer, significantly decreased the number of clicks in lawn, tree and sky layers and no significant difference was noticed in shrub layer.

These results showed a significant change in aesthetic and ecological perceptions of areas of interest by users, particularly in more complex woody edges (i.e. Types 2, 3 and 4).

Discussion

The novelty of our approach was to understand how a complexity gradient of managed woody edges was perceived in urban parks. We hypothesised that the more complex and diverse the edge was (i.e. with four vegetation layers), the more ecological it became (Gilliam 2007; Muñoz et al. 2009).

Areas of interest for users in the four types of woody edges

In this study, we showed that for the woody edge Types 1, 2 and 3, tree layer was the main area of interest for users. The tree layer had significantly more fixation points and was watched longer than other woody edge layers. Conversely, the sky layer was the least area of interest. For the woody edge Type 4 (the more complex), the tree layer was the main area of interest after the shrub. More precisely, the shrub layer had significantly more fixation points and was watched longer than other woody edge layers. The sky layer was the least area of interest. These results were not surprising considering visual attention and particularly when given a stimulus such as a photograph, because the entire scene is first seen mostly in parallel through peripheral vision and at low resolution. Then eyes are quickly repositioned to the first region that attracted attention. Finally, if the eye has enough time, which is not the case during the first step of the experiment (Step 2a), attention is engaged to perceive features at high resolution and in fewer proportions (Duchowski 2009). The human visual system strongly responds to a specific type of stimuli (e.g. contrasted areas of interest) and weakly to others (e.g. homogeneous areas of interest). We thus expected that woody edges had significantly more fixation points and were watched longer than sky or lawn layers (Duchowski 2009). Moreover, unconsciously, due to the subject of the study presented, users could also focus their attention on woody edges (Appleyard 1979; Haddad 1997). It was interesting to note that users did not focus on the most aesthetic or ecological areas of interest (Step 2a). This could be explained by the human visual system (Duchowski 2009) because when we asked users to click on one aesthetic and ecological element (Steps 2b and 2c), users had time to focus their attention and so took time to analyse the photograph, with lesser consideration to contrasted and homogeneous areas of interest (Dupont, Antrop, and Van Eetvelde 2015).

The most aesthetic and ecological areas of interest

For low and medium managed woody edges (Types 1, 2 and 3), tree layer was the most aesthetic area of interest for users. For the woody edge Type 4, the more complex, the tree and shrub layers were the main aesthetic areas of interest for users. For users, the most ecological areas of interest were herb, shrub and tree layers in that sequence. To our knowledge, no empirical ecological survey was made in the different layers of the woody hedgerows concerned by this study. However, many studies showed that herbs (e.g. Josefsson et al. 2013; Garbuzov, Fensome, and Ratnieks 2015) and shrubs (e.g. Bolger et al. 2000), associated with permanent landscape features (e.g. Mazalova et al. 2015) such as hedgerows, positively affect specific richness, particularly for the invertebrate community. Moreover, when ecological benefits were brought up, users associated items with invertebrates benefits (Hoyle et al. 2017), particularly pollinators such as bees, wasps and butterflies. The fact that herb and shrub layers were significantly identified by users as ecological areas of interest present an encouraging example of the user's knowledge about the ecological interests of herb and shrub layers. Even if they found it less aesthetic, they already knew the ecological role of herb and shrub layers as beneficial to insects, showing the interest of this type of management (Qiu et al. 2013).

We showed that users' perception of complex hedgerows underlined the importance of the shrub layer. It supported the view that ecological management practices were appreciated by users. In complex woody edges, by increasing the ecological diversity of the shrub layer, we could promote both ecological benefits and subjective aesthetic preferences (i.e. with a variety of colours and textures, Dronova 2017; Hoyle et al. 2017; Southon et al. 2018; Meyer et al. 2020). However, care should be taken as vertical cover by shrubs can be perceived as physical obstruction and so negatively perceived (Nielsen, Gundersen, and Jensen 2018). Roovers et al. (2006) showed that a vegetation height of at least 54 cm could be identified as having significant obstructive features. Another way to enhance both ecological and aesthetic management of woody hedgerows in urban parks could be the creation of sown wildflower strips associated with the 'unaesthetic' herb layer to improve its aesthetical value. This would also increase biodiversity and associated ecological services (e.g. Haaland, Naisbit, and Bersier 2011) and aesthetic preferences of users (e.g. if strips presented more wildflower blooms and colourful planting, Garbuzov et al. 2015; Hoyle et al. 2017).

Study limitations

Even if we tried to respect, as far as possible, an equal aspect ratio for the sky, the woody hedgerow and the lawn, we saw that the larger the area of interest, the greater the number of fixation points, their duration and the number of aesthetical and ecological clicks. However, in complex hedgerows, when users had time to analyse ecological features, results suggested that user behaviour was not related to the spatial arrangement of the vegetation structure (Jorgensen et al. 2002). An untested bias in our analyses could be due to the use of areas of interest itself. Our goal was to measure the whole effect of layers, not a specific element effect. Based on our hypotheses and hedgerow structure, we defined between three and five areas of interest per photograph (Supplementary Appendix A). However, we were quite confident about the reliability of our results based on visual perceptions by taking into account specific elements known to potentially bias the measures (e.g. our photograph presented <27% colourful planting, Hoyle et al. 2017). Specific elements on photographs could also bias results and so the understanding of the visual pattern associated (Duchowski 2009). In this study, we checked if bare stripes (Supplementary Appendix A, Type 2, Photograph 1) and clouds (which represent >50% of the sky for 8/16 photographs) did not affect significantly visual patterns in terms of number of fixation points and clicks (P-values > 0.05 for all ANOVA).

In the current study, we used an eye-tracking experiment to measure what people watched. Eye-tracking experiment allowed to record directly and with efficiency the perception of users (e.g. Dupont, Antrop, and Van Eetvelde 2014; Dupont et al. 2016). We also used this method to better understand the complex relationships between human aesthetic preferences and ecological interest. This method allowed us to gain time (the overall experiment time was 5.46 ± 1.73 min). However, it could be interesting to analyse preferences using questionnaires (e.g. Jorgensen et al. 2002; Jorgensen and Anthopoulou 2007; Dong and Qin 2017; Hoyle et al. 2017) or photographs (e.g. Jorgensen, Hitchmough, and Dunnett 2007; Qiu et al. 2013), areas for expression of subjective experiences or photographs (e.g. Jorgensen, Hitchmough, and Dunnett 2007; Qiu et al. 2013) to better understand the underlying process. Moreover, as we did not vary the presentation order between aesthetic and ecological parts, we could not control if results would be different by using a random process, and more particularly between those who were asked to click on ecological first with those who did it after aesthetic part. Another limitation of this experiment was that only one sense was considered (i.e. visual). More researches need to be done by integrating non-users in order to have a general overview of population perception.

In this study, we did not control for all display factors (e.g. type of lawns and shape of trees). We decided to work on natural scenes and not to break down the scene into these detailed features (Meyer et al. 2020). By homogenising the photographs, we thus expected that this is the scene that drives our results rather than detailed features (Holmqvist et al. 2015). However, whatever the protocol, surveys using photographic criteria and eye-tracking tests had already confirmed the validity of using photographs as surrogates for real landscapes (e.g. Junker and Buchecker 2008; Dupont, Antrop, and Van Eetvelde 2014, 2015).

Conclusions

In Rennes, as in many other cities in Europe (e.g. Bruxelles and Strasbourg), park management distinguished different kinds of woody edges according to their structure from the simplest (woody edges with tree layer only) to the most complicated (woody edges with tree, shrub and herb layers). The management of structurally diverse woody edges is ecologically more valuable than the simplest woody edges for ecosystem services. Our results showed that shrub layers were found both aesthetic and ecologically sound in complex woody edges. To enhance both ecological and aesthetic management of woody hedgerows in urban parks, more consideration should be given to the shrub layer to enhance both aesthetics and ecological management. This layer could thus be used to bridge ecological and aesthetic purposes. We also need communication supports to provide information about the usefulness of shrub and herb layers for ecological purposes. Our approach could be extended to other profiles of structurally diverse and graduated edges all over the world and may help the development of sustainable management (i.e. by integrating both social, ecological and economic constraints). More studies aiming to identify the aspects of perceived landscape and their characterisations in relationship with various psychological dimensions are needed. To decipher relationship between a perceived landscape, well-being and the relationship with nature in urban areas, research hypothesis with psychological dimensions needs to be stayed and tested, particularly to consider the overall representation of the urban green space rather than only woody edges.

Supplementary data

Supplementary data are available at *JUECOL* online.

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