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Studies have demonstrated a relationship between plant species diversity within urban green spaces (UGS) and psychological restoration of visitors. However, the majority of "non ecologist" visitors are not able to perceive all the different plant species present within UGS. More work is thus needed to explore and better understand the underlying processes of this relationship. Recent studies have suggested that "non ecologist" visitors are able to perceive landscape heterogeneity within UGS, which is related to species diversity based on landscape ecology theories. The goal of this study was to test whether landscape heterogeneity can begin to elucidate the relationship between species diversity within UGS and psychological restoration of visitors. Within 13 UGS in Rennes (France) we tested if relationships can be established between i) measured landscape heterogeneity, ii) landscape heterogeneity perceived by visitors, and iii) psychological restoration of visitors. We measured landscape heterogeneity using different landscape-level metrics, and quantified psychological restoration and perception of landscape heterogeneity of 390 visitors using *in situ* questionnaires. Our results evidenced that within UGS visitors are able to perceive landscape compositional and configurational heterogeneity, and that they gain psychological restoration from landscape configurational heterogeneity. We advise that enhancing landscape configurational heterogeneity within UGS could help designers and managers increase both their environmental and social benefits.

1. Introduction

As the world becomes more urbanized (UN, 2014), urban green spaces (UGS) are becoming more and more important locus for biodiversity (Haaland & van den Bosch, 2015; Nielsen, van den Bosch, Maruthaveeran & van den Bosch, 2014). Meanwhile, numerous studies have evidenced that biodiversity within UGS, especially species diversity, can promote psychological well-being of visitors (Fuller, Irvine, Devine-Wright, Warren & Gaston, 2007; Irvine, Fuller, Devine-Wright, Tratalos, Payne, Warren, Lomas & Gaston, 2010; Jorgensen & Gobster, 2010). This has notably been addressed through Attention Restoration Theory (ART) (Carrus, Scopelliti, Lafortezza, Colangelo, Ferrini, Salbitano, Agrimi, Portoghesi, Semenzato & Sanesi, 2015; Hoyle, Hitchmough & Jorgensen, 2017). Psychological restoration is conceived in terms of recovery of directed attention from mental fatigue (Kaplan & Kaplan, 1989), and relaxation or stress reduction (Ulrich, 1981; Ulrich, Simons, Losito, Fiorito, Miles & Zelson, 1991).

However, it has been shown that the majority of “non ecologist“ visitors (i.e. with little or no knowledge of plants and animals) have poor species identification skills and do not perceive the full species diversity within UGS (Dallimer, Irvine, Skinner, Davies, Rouquette, Maltby, Warren, Armsworth & Gaston, 2012; Fuller et al., 2007; Shwartz, Turbe, Simon & Julliard, 2014). Their assessment of species diversity tends to under-estimate the actual richness (Leslie, Sugiyama, Ierodiaconou & Kremer, 2010; Lindemann-Matthies & Bose, 2008), or on the contrary to over-estimate it (Southon, Jorgensen, Dunnett, Hoyle & Evans, 2018). A study by Dallimer et al. (2012) concluded that psychological restoration of visitors isn’t related to the actual species diversity within UGS, but rather to the species diversity they perceive (i.e., believe to be present) (Dallimer et al., 2012). Southon et al. (2018) reported a lack of positive relationship between species diversity and psychological restoration of visitors within UGS. However, they showed significant associations between perceived site level biodiversity and feeling connected to nature, which has been associated to psychological restoration (Hand, Freeman, Seddon, Stein & van Heezik, 2016; Le Bot, 2013). Coldwell and Evans (2018) stated that perceived environmental conditions can have a greater influence than objectively measured equivalents, and that this form of cognitive bias could impact the psychological well-being experienced by visitors within UGS.

If a relationship has been demonstrated between species diversity and psychological restoration of visitors within UGS, more work is still needed to explore and better understand the underlying processes. One approach is to identify specific environmental parameters within UGS that are related to species diversity while also being perceivable by visitors and beneficial to their psychological restoration (Dallimer et al., 2012; Hand et al., 2016). Doing so could bring us a step closer to increasing both ecological and social benefits of UGS (Mc-Donnell & Hahs, 2013).

Recent studies suggested that "non ecologist" visitors perceive biological diversity within UGS on a structural level (Özgüner & Kendle, 2006; Qiu, Lindberg & Nielsen, 2013; Voigt, Kabisch, Wurster, Haase & Breuste, 2014). This implies that if visitors are not able to perceive the full species diversity within UGS, they are rather able to perceive landscape structural diversity (Dramstad, Fry, Fjellstad, Skar, Helliksen, Sollund, Tveit, Geelmuyden & Framstad, 2001; Schwartz et al., 2014; Voigt & Wurster, 2015). According to Fuller et al. (2007), landscape heterogeneity is the principle mechanism through which humans detect landscape structural diversity variations. Based on landscape ecology theories, landscapes with high heterogeneity are able to host more coexisting species due to a high number of available niches (Rocchini, Balkenhol, Carter, Foody, Gillespie, He, Kark, Levin, Lucas, Lu-oto, Nagendra, Oldeland, Ricotta, Southworth & Neteler, 2010). This landscape pattern has thus been identified as a key variable enhancing the diversity of species in a landscape (Burel & Baudry, 2003). Gobster, Nassauer, Daniel and Fry (2007) stated that the structure of a land-scape provides ecological information at a scale that is readily perceivable, and can act as a tool to connect humans with ecological phenomena. We hypothesized that within UGS land-scape heterogeneity could be an environmental parameter that is related to species diversity while also being perceivable by visitors.

In this paper, we tested whether landscape heterogeneity can begin to elucidate the re-lationship demonstrated by previous studies between species diversity and psychological restoration of visitors within UGS. In order to do so, we addressed the following research questions within 13 UGS in Rennes (France):

(1) Is there a correlation between landscape heterogeneity perceived by visitors and measured landscape heterogeneity, that is to say are visitors able to perceive landscape heterogeneity?

(2) Is there a correlation between psychological restoration of visitors and measured landscape heterogeneity?

Following previous studies (Coldwell & Evans, 2018; Dallimer et al., 2012), we also asked:

(3) Is there a correlation between psychological restoration of visitors and their perception of landscape heterogeneity?

2. Methods

2.1. Selection of 13 UGS in Rennes

Rennes is the most populated city of Brittany, and the 11th most populated of France with 216 268 residents in 2016. For the past 10 years, it has been experiencing one of the highest growth rates in France with a population increase of 1.29% per annum since 2007, rising to a density of 4292 residents per square kilometer (National Institute for Statistics and

Economic Studies, 2016). This density varies across the 12 different neighborhoods of the city, ranging from about 13 351 in the center to about 6449 in the south west of the city (in the neighborhood of the "parc de Bréquigny"). The average income per household per annum is slightly higher than the national average, although this number differs across the different neighborhoods with the center being the richest. Rennes extends over 5000 hectares, of which 880 is public UGS. It is one of the greenest cities of France, with the first UGS created as early as the 19th century.

We selected 13 UGS based on ecological, landscape and socio-demographic criteria. We followed a two-step selection protocol. First, we selected a sample of 37 UGS among the 54 public UGS of Rennes based on their ability to support urban biodiversity (McDonnell & Hah, 2015). For this, we excluded those with an area of less than 5000 square meters and with less than 30% of vegetation within a radius of 500 meters around them. Second, we selected 13 UGS among the 37 in order to maximize a broad range of land-cover compositions using a Principal Component Analysis (PCA, Appendix A). Land-cover composition was defined as the proportions of five main land-cover types commonly present within UGS (woodlands, shrubs, herbaceous areas, water areas and mineral surfaces). The PCA was made using as dependent variables the proportions of those five land-cover types, which were computed using a land-cover map provided by the urban planning agency of Rennes (AUDIAR) and a GIS software (ArcMap 10.X). The goal of the PCA was to select 13 UGS as different as possible on a gradient of land-cover composition. With the intention of capturing the socio-demographic diversity across Rennes, the 13 UGS of study were sampled across the city by selecting at least one in each of the 12 different neighborhoods (Fig. 1).

2.2. Landscape heterogeneity measurement

Landscape heterogeneity of the 13 UGS was measured using five different landscape-level metrics commonly used to quantify specific spatial characteristics of landscape structure. Landscape heterogeneity is defined as the combination of diversity (composition) and complexity of spatial arrangement (configuration) of land-cover types (Li & Reynolds, 1995). A land-cover type represents an area of relatively homogeneous environmental conditions with specific biodiversity content, and can be translated as a habitat (Hand et al., 2016). We measured landscape compositional heterogeneity using the Shannon's Diversity Index SHDI (Shannon & Weaver, 1949). This metric provided information on the variety and abundance (i.e., richness and evenness) of land-cover types within each UGS of study. It is commonly used as a relative index for comparing different landscapes (Hand et al., 2016). We measured landscape configurational heterogeneity using four complementary aggregation metrics: (1) the Aggregation Index AI (He, DeZonia & Mladenoff, 2000), (2) the Contagion Index CONTAG (Li & Reynolds, 1993), (3) the Interspersion and Juxtaposition Index IJI (McGarigal & Marks, 1995), and (4) the Landscape Shape Index LSI (Patton, 1975).

The five landscape heterogeneity metrics were each computed based on five different land-cover maps using the software Fragstats (McGarigal & Marks, 1995). See description of the five different maps in Table 1 and Appendix B. In this paper, the symbol $_x$ will be used to indicate which map the metrics are based on (for example, the metric SHDI based on map 1= $SHDI_1$, the metric SHDI based on map 2= $SHDI_2$ and so forth). Those five different maps were created by adding in different ways four land-cover types to the map used to select the 13 UGS (i.e., Map 1) using the GIS software ArcMap 10.X. Map 1 represented the distribution of woodlands, shrubs, herbaceous areas, water areas, and mineral surfaces. We added the flower areas in Map 2-5 by distinguishing the flowering shrubs from the flower beds in Map 2 and Map 4, and we split the herbaceous areas into lawns and meadows in Map

2 and Map 3. Meadows were defined by a mowing height >1m (Hand et al., 2016). We added those four land-cover types because they influence the diversity of resources and refuge areas available for species, and thus favor species diversity within UGS (Harris, Kendal, Hahs & Threlfall, 2017; Hoyle et al., 2017; Southon et al., 2018). It thus seemed relevant to add them in order to measure landscape heterogeneity related to species diversity. By adding them in different ways generating five different maps, our goal was to identify if those four land-cover types also influence visitors' perception of landscape heterogeneity and psychological restoration within UGS.

2.3. On-site questionnaires

We used face-to-face questionnaires administered directly in the 13 UGS to collect and quantify perception of landscape heterogeneity and psychological restoration of individual visitors. We conducted a total of 390 questionnaires (30 per UGS) from June to September 2017. Visitors interviewed were chosen randomly and in different locations within each UGS. We carried out questionnaires at different hours (both within and outside working hours) and during weekends and weekdays in order to interview as many different visitors as possible. Questionnaires were self-completed and lasted 15 minutes each. The great majority of visitors approached (87.4%) were willing to complete our questionnaire. To test whether visitors understood the vocabulary we used and the meaning of our questions, we conducted preliminary questionnaires on a small number of visitors (20) under the same protocol. It led us to replace the term *heterogeneity* with the term *diversity,* which is more comprehensible for "non ecologist" visitors.

2.3.1. Structure of the questionnaire

The questionnaire developed for this study was organized in three sections. Visitors interviewed were first asked to evaluate and score their perception of landscape heterogeneity within the UGS in which they were on a scale from 1 = "I think it is not at all diverse" to 5 = "I think it is very diverse". It should be noted that visitors interviewed did not all necessarily experience the entire landscape of the UGS in which they were before answering our questionnaire. Our wide sample of visitors chosen randomly and in different locations within each UGS outweighed this limitation. Furthermore, we only interviewed visitors who had already been in the UGS a few times before, so they could have a relative overview of its landscape. Building a cognitive map takes time and repeated exposures (Kaplan & Kaplan, 2003).

Visitors were then asked to indicate their level of agreement with a list of 15 statements each measuring a different aspect of psychological well-being (Table 2) using a 5-point Likert scale (from 1 = I strongly disagree to 5 = I strongly agree). This scaling method has been widely used in different studies focusing on psychological well-being (Carrus et al., 2015; Dallimer et al., 2012; Fuller et al., 2007). The different aspects of psychological well-being measured by the 15 statements were derived from the literature, but the phrasing of the statements was devised for the purpose of this study. We identified main components of psychological well-being grounded in Attention Restoration Theory that have been the most broadly referenced in the literature, and translated them into 10 statements (Table 2, statements 1-10). Psychological restoration has been associated to a feeling of connection with "nature" (Hand et al., 2016; Le Bot, 2013). Inversely, it has been associated to a feeling of separation, or escape, from the surrounding urban landscape (Jennings, Jean-Philippe, Willcox, Zobel, Poudyal & Simpson, 2016; Özgüner & Kendle, 2006) and from the daily routine (Hoyle et al., 2017; Kaplan, 1995). A positive association has also been identified between restorative effect and landscape aesthetic experience, conceived as a feeling of pleasure attributable to perceivable landscape characteristics (Gobster et al., 2007). As landscape aesthetic experiences are fundamentally triggered by emotion-based processes, they can be facilitated by sensory inputs like smells or sounds (Grahn & Stigsdotter, 2010; Ulrich, 1986). We then identified main components of psychological well-being related to the use of UGS (i.e., without regards to its biodiversity) that have been the most broadly referenced in the literature, and translated them into five statements (Table 2, statements 11-15). UGS have been identified as places of socialization (Long & Tonini, 2012), which has been associated with a feeling of safety (Ulrich, 1981; Wolch, Byrne & Newell, 2014). The "sense of place" theory suggests that UGS can enhance psychological well-being through increased belonging and emotional place attachment (Dallimer et al., 2012; Devine-Wright, 2009). By facilitating outdoor physical and recreational activities, UGS have also been associated to enhanced psychological well-being conceived in terms of mental health (Kaplan & Kaplan, 2003).

The questionnaire also collected data on visitors' socio-demographic characteristics. We included questions on gender, age (15 to 34, 35 to 54 and 55 and more), and childhood environment (rural or urban). It also collected data on their frequency of site visit (frequent = once per day to once a week, or infrequent = 2-3 times a month to a few times per year).

2.4. Data Analysis

For each of the 13 UGS, we computed a total score of psychological well-being by summing up all the scores given on the 5-point Likert scale to the 15 statements by the 30 visitors. We computed two other scores of psychological well-being; (1) by distinguishing the scores given to the 10 statements of psychological restoration and (2) by distinguishing the scores given to the five statements of psychological well-being related to the use of UGS. As those two scores were not measured on the same number of statements, we normalized them in order to be able to compare them. A categorical PCA allowed us to ensure that the scores given to the 10 statements of psychological restoration and the scores given to the five statements of psychological well-being related to the use of UGS could be separated by different PCA axes (Appendix C). We also computed an individual score for each of the 15 statements by summing up all the scores given to each statement by the 30 visitors interviewed. We then computed for each of the 13 UGS a score of perceived landscape heterogeneity by summing all the scores given on the scale from 1 to 5 by the 30 visitors.

We then carried out Pearson correlations between the following data: the 13 total scores of psychological well-being, the 13 scores of psychological restoration, the 13 scores of psychological well-being related to the use of UGS, the 13 individual scores for each of the 15 statements, the 13 scores of perceived landscape heterogeneity, and the five landscape heterogeneity metrics. As the metrics were computed based on five different maps, we used five different "sets" of metrics. The Pearson correlations between these data were carried out independently two by two, and summarized altogether in matrices. Five correlation matrices were created, each using a different set of metrics. To analyze and discuss correlations we selected only high and significant Pearson correlation coefficients ($|R|>0.6$ and $p<0.05$). By selecting 13 different UGS of study on a gradient of land-cover composition by the mean of a PCA, we expect a clustering of the data into the 13 UGS.

It should be noted that our analyses could be improved at the level of individual respondents using a mixed model framework with site as a random factor. However, in the case of our study, those analyses would require a wider set of data to converge. We created histograms of the scores of perceived landscape heterogeneity for each of the 13 UGS, and performed multiple mean comparison tests of the scores of perceived landscape heterogeneity between each of the 13 UGS using a Kruskal-Wallis test (Kruskal-Wallis test, df=12, $\chi^2=84.29$, p-value<0.001) and posthoc tests (Critchlow & Fligner, 1984).

We analyzed the distribution of proportions of each social variable (i.e., gender, age group, childhood environment, and frequency of sites visit) across the 13 UGS using Chi-square tests. We then computed for each of the 13 UGS a total score of psychological well-being and a score of perceived landscape heterogeneity by distinguishing visitors based on the social variables that had a homogenous distribution across the 13 UGS. We performed Pearson correlations summarized in matrices between these scores taking into account the social variables and the five landscape heterogeneity metrics based on the five different maps.

Due to the large number of different combinations of metrics and scores that have been tested in our study, we carried out a false discovery rate method to test the risk of finding significant P-values by change. We used the Benjamin-Hochberg procedure with a discovery rate of 0.05 (Benjamin & Yekutielli, 2001).

All statistical analyses were conducted using R Software version 3.4.2 (R Core Team, 2017).

3. Results

3.1. Characteristics of visitors interviewed

Among visitors interviewed 37.69% were men and 62.31% were women, compared to 46.95% and 53.05% respectively for the average population of Rennes. The most represented age group, without reference to gender, was 15 to 34 years old (46.6%), while for the average population of Rennes it is 15 to 30 (33.7%) (National Institute for Statistics and Economic Studies, 2016).

The distribution of proportions of visitor's gender (Chi-square test, df= 12, χ^2= 14.27, p-value = 0.283) and childhood environment (Chi-square test, df= 12, χ^2= 5.4959, p-value = 0.939) was homogenous across the 13 UGS. The distribution of proportions of visitor's age group (Chi-square test, df= 24, χ^2= 47.74, p-value = 0.002) and frequency of site visit (Chi-square test, df=12, χ^2= 48.90, p-value = 2.171e-06) was not homogenous across the 13 UGS.

3.2. Correlations between landscape heterogeneity perceived by visitors and measured landscape heterogeneity

The scores of perceived landscape heterogeneity were highly and significantly correlated with the landscape compositional heterogeneity metric $SHDI_{1-5}$ (Pearson correlation coefficients, $0.60 < R < 0.61$, $0.021 < p < 0.038$, Table 3), and with the landscape configurational heterogeneity metric IJI_3 (Pearson correlation coefficient, R=0.63, p=0.024, Table 3). The higher the metrics $SHDI_{1-5}$ and the metric IJI_3, the higher the scores of perceived landscape heterogeneity. The histograms (Appendix D) and the results of the mean comparison tests (Appendix E) showed that there wasn't a large variation in the individual scores of perceived landscape heterogeneity (19/78 comparisons). This implies that visitors to a UGS perceived its landscape heterogeneity in a similar manner, whatever the UGS. The site effect is thus low, and didn't play a main role on the correlation between perceived and measured landscape heterogeneity.

When taking into account the social variables, we found a high and significant positive correlation between the metrics $SHDI_{1-5}$ and IJI_3 and the scores of perceived landscape heterogeneity given by women and by visitors who grew up in a rural childhood environment. The full results are synthesized in Table 4.

3.3. Correlations between psychological well-being of visitors and measured landscape heterogeneity

We found a high and significant correlation between the total scores of psychological well-being and the landscape configurational heterogeneity metric IJI_3 (Pearson correlation coefficient, R=0.64, p=0.012, Table 3). The total scores of psychological well-being increased with the metric IJI_3. We found no significant correlation between the total scores of psychological well-being and the landscape compositional heterogeneity metric $SHDI_{1-5}$ (Pearson correlation coefficient, 0.14< R<0.33, 0.058<p<0.063, Table 3).

When taking into account the social variables, we found a high and significant positive correlation between the metric IJI_3 and the total scores of psychological well-being given by men and by visitors who grew up in a rural childhood environment. The full results are synthesized in Table 4.

3.4. Correlations between psychological well-being of visitors and their perception of landscape heterogeneity

We found a high and significant correlation between the total scores of psychological well-being and the scores of perceived landscape heterogeneity (Pearson correlation coefficient, R=0.76, p=0.002). The higher the total scores of psychological well-being, the higher the scores of perceived landscape heterogeneity.

When taking into account the social variables, we found a high and significant positive correlation between the scores of perceived landscape heterogeneity and the total scores of psychological well-being given by women and by visitors who grew up in a rural childhood environment. The full results are synthesized in Table 4.

3.5. Correlations between psychological restoration of visitors, their perception of landscape heterogeneity, and measured landscape heterogeneity

Results showed that the total scores of psychological well-being were highly and significantly positively correlated with the scores of psychological restoration (Pearson correlation coefficient, $R=0.97$, $p=0.001$, Table 5), but only significantly positively correlated (but not highly) with the scores of psychological well-being related to the use of UGS (Pearson correlation coefficient, $R=0.43$, $p=0.026$, Table 5). Results also showed that the total scores of psychological well-being were highly and significantly positively correlated with all individual scores of the 10 statements measuring psychological restoration (Pearson correlation coefficients, $0.60<R<0.89$, $0.002<p<0.037$, Table 6), but were not correlated with any of the five statements measuring psychological well-being related to the use of UGS (Pearson correlation coefficients, $0.19< R<0.48$, $0.055<p<0.072$, Table 6).

With the 5-point Likert scale assessment method we used, items of the list presenting scores that are not correlated with the total scores are considered not to have an influence on the total scores. Those items can thus be eliminated (Murphy & Likert, 1938). The total scores of psychological well-being can thus be directly associated to the scores of psychological restoration. Furthermore, with this scaling method, the establishment of high and significant positive correlations between the scores obtained for each item of the list (each statement in our study) and the total score verifies the internal consistency of the list of items, i.e., its reliability (Murphy & Likert, 1938).

Results also showed that the scores of perceived landscape heterogeneity and the metric IJI_3 were highly and significantly correlated with the scores of psychological restoration (Pearson correlation coefficients, $R=0.69$, $p=0.013$ and $R=0.60$, $p=0.029$, Table 5), but were not correlated with the scores of psychological well-being related to the use of UGS

(Pearson correlation coefficients, R=0.51, p=0.056 and R=0.43, p=0.062, Table 5). Those results confirm further that the correlations we established between the metric IJI_3, the scores of perceived landscape heterogeneity, and the total scores of psychological well-being can be directly associated to the scores of psychological restoration. We compiled those correlations in a general scheme (Fig. 2). The results of the Benjamin-Hochberg procedure confirmed that all the P-values of the high and significant correlations established were significant (Table 7).

4. Discussion

4.1. Are visitors able to perceive landscape heterogeneity within UGS?

We found a high and significant positive correlation between the scores of perceived landscape heterogeneity and the landscape compositional heterogeneity metric $SHDI_{1\text{-}5}$, as well as the landscape configurational heterogeneity metric IJI_3. These results allowed us to confirm a positive correlation between landscape heterogeneity perceived by visitors and measured landscape heterogeneity within UGS. In other words, these results suggest that visitors are able to perceive both landscape compositional and configurational heterogeneity within UGS. Landscape configurational heterogeneity is precisely perceived through the mixing of land-cover types (i.e., Interspersion and Juxtaposition IJI). Following previous studies (Dramstad et al., 2001; Fuller et al., 2007; Hand et al., 2016), these results validate our hypothesis that landscape heterogeneity is an environmental parameter within UGS that is related to species diversity while also being perceivable by visitors. This supports the work of Schwartz et al. (2014) who concluded that increasing structural complexity in UGS could be more effective at raising visitor’s awareness for biodiversity than increasing species diversity, which requires a higher level of identification skills.

4.2. Does landscape heterogeneity within UGS have a positive impact on visitors' psychological restoration?

The scores of psychological restoration were highly and significantly positively correlated with the landscape configurational heterogeneity metric IJI_3. However, contrary to what we expected they were not correlated with the landscape compositional heterogeneity metric $SHDI_{1-5}$. This result confirms a positive correlation between psychological restoration of visitors and only measured landscape configurational heterogeneity within UGS. Visitors' psychological restoration is precisely related to the mixing of land-cover types. This result supports previous studies showing that visitors' feeling of well-being within UGS is related to the whole landscape rather than to a number of species or elements (Dramstad et al., 2001; Voigt & Wurster, 2015). Our finding that visitors' psychological restoration is related to the spatial arrangement of land-covers types rather than their diversity can be explained by previous studies suggesting that visitors experience UGS as a green atmosphere apprehended as a whole (Le Bot, 2013), and not through attention to specific details (Leslie et al., 2010). With our findings, we were able to identify that within UGS the mixing of land-cover types is a landscape heterogeneity parameter that is perceived by visitors and beneficial to their psychological restoration. This suggests that landscape heterogeneity can indeed begin to elucidate the relationship demonstrated by previous studies between species diversity and psychological restoration of visitors within UGS.

However, it should be noted that the relationship established by landscape ecology theories between species diversity and landscape heterogeneity is not always positive (Costanza, Moody & Peet, 2011). As increasing landscape heterogeneity can inversely decrease habitat patch size, it can have potential negative consequences for specialist species (Redon, Bergès, Cordonnier & Luque, 2014). Urban species have been shown to be mainly generalists (Clergeau, 2015), which might outweigh this limitation. Furthermore, if species diversity is favored by landscape heterogeneity, i.e., diversity and spatial arrangement of habitats, species diversity is also positively influenced by habitat type. Different habitats can have different impacts on species diversity, e.g., lawns are relatively poor at supporting species diversity compared to meadows (Southon et al., 2018). It is thus plausible that psychological restoration of visitors within UGS is more strongly associated with the ability of habitats at supporting species diversity rather than habitat diversity per se. Exploring this hypothesis in subsequent studies could bring further the understanding of the psychological well-being experienced by visitors within UGS.

4.3. Is psychological restoration of visitors within UGS related to their perception of landscape heterogeneity?

The highest significant correlation we evidenced was between the scores of psychological restoration and the scores of perceived landscape heterogeneity. This result confirms a correlation between psychological restoration of visitors and their perception of landscape heterogeneity within UGS. Following previous studies (Coldwell & Evans, 2018; Dallimer et al., 2012), it also implies that visitors' psychological restoration is more influenced by landscape heterogeneity they perceive than by measured landscape heterogeneity. Yet, our results evidenced that visitors are able to perceive measured landscape heterogeneity. This suggests that there are other aspects than landscape heterogeneity as measured within the field of ecology that may influence its perception by visitors, and thus the psychological restoration they gain from landscape heterogeneity within UGS.

Studies have shown that landscape perception can be influenced by personal and cultural particularities or experiences (Priego, Breuste & Rojas, 2008; Kaplan & Kaplan, 1989). When taking into account visitors' gender, we found a relationship between perceived and measured landscape heterogeneity, as well as between psychological well-being and perceived landscape heterogeneity merely for women. This could partly be explained by studies showing that women have a tendency to prefer natural over designed vegetation (Lindemann-Matthies, Junge & Matthies, 2010). However, the underlying factors remain unclear, as a relationship between psychological well-being and measured landscape heterogeneity was found merely for men. When taking into account visitors' childhood environment, we found a relationship between perceived and measured landscape heterogeneity, as well as between psychological well-being and landscape heterogeneity (perceived and measured) merely for visitors who grew up in a rural childhood environment. This supports studies showing that lack of nature exposure during childhood diminishes perceptual experiences of natural landscapes and emotional connection to nature (Lindemann-Matthies & Bose, 2008), which has been associated with reduced psychological well-being (Shanahan, Fuller, Bush, Lin & Gaston, 2015).

A larger set of socio-demographic variables would have increased our understanding of the relationships between landscape heterogeneity and psychological well-being of visitors within UGS. For example, educational qualifications, income and employment status have especially been shown to have a significant impact on individual psychological well-being (Hoyle et al. 2017; White, Alcock, Wheeler & Depledge, 2013). It should also be noted that as this study is confined to a site specific context, the scores of perceived landscape heterogeneity could have been influenced by geographical and local specificities, and a possible shared cultural background (Voigt & Wurster, 2015).

4.4. Do all land-covers mapped influence visitor's perception of landscape heterogeneity and psychological restoration within UGS?

The scores of perceived landscape heterogeneity and the scores of psychological restoration were both highly and significantly correlated with the landscape configurational heterogeneity metric IJI_3. The Map 3 represented the distribution of six land-cover types: woodlands, shrubs, herbaceous areas, flower areas, water areas and mineral surfaces (see Table 1 and Appendix B). This means that, within the 13 UGS, visitors perceived and gained psychological restoration from the mixing of precisely these six land-cover types. Therefore, the four land-cover types we mapped distinctly because they favor species diversity within UGS (i.e., lawns, meadows, flowering shrubs, and flower beds) do not all as well influence visitors' perception of landscape heterogeneity and psychological restoration. The fact that visitors perceived flower areas distinctly, but not the flowering shrubs from the flower beds, supports a recent study showing that visitor's perception of flowers within UGS is influenced by color diversity rather than species diversity (Hoyle, Norton, Dunnett, Richards, Russell & Warren, 2018).

This result also implies that visitors perceived flower areas and herbaceous areas as a whole, i.e., did not distinguish flowering shrubs from flower beds, and lawns from meadows. This brings up the question of scale when exploring visitors' perception of landscape heterogeneity within UGS. We used metrics based on a land-cover map, as it has been evidenced to provide good estimates of landscape heterogeneity (Jorgensen & Gobster, 2010; Rocchini et al., 2010). But studies have pointed out the difficulty in translating a two-dimensional world view into a ground-level representation that relates to the human "perceptible realm" (Dramstad et al., 2001; Gobster et al., 2007). In a UGS, each individual areas of land-cover type has its own internal structure and spatial specificities (Hoyle et al., 2017), which could be perceived by visitors more intensely than the overall heterogeneity. This could notably depend on their activity and movement around the site (sitting *vs.* running), or the extent to which they use it fully (Carrus et al., 2015). Exploring at which scales visitors perceive landscape heterogeneity within UGS the most, especially through a more nuanced understanding of the specific form, composition and character of different land-cover types, might bring our findings further.

5. Conclusion

Our results demonstrated that visitors are able to perceive both compositional and configurational heterogeneity within UGS. They perceive configurational heterogeneity precisely through the mixing of woodlands, shrubs, herbaceous areas, flower areas, water areas and mineral surfaces. We found that visitors' psychological restoration is related merely to landscape configurational heterogeneity, precisely to the same landscape pattern that they are able to perceive. We thus identified that the mixing of different land-cover types is an environmental parameter within UGS that is related to species diversity while also being perceivable by visitors and beneficial to their psychological restoration. Our results also suggested that visitors' psychological restoration is more influenced by landscape heterogeneity they perceive than by measured landscape heterogeneity. This highlights the importance of the subjectivity of human perception in exploring the relationships between landscape heterogeneity and psychological restoration of visitors within UGS.

Based on our results and on the positive relationship stated by landscape ecology theories between landscape heterogeneity and species diversity, we propose that the relationship demonstrated by previous studies between species diversity and psychological restoration of visitors within UGS could be the consequence of a relationship between landscape configurational heterogeneity and psychological restoration of visitors. As stated by Jorgensen and Gobster (2010), landscape heterogeneity may be one of the most promising UGS measures, with the potential to integrate various disciplinary perspectives and scales.

Such research should be instrumental for planning and management of UGS. One of the current main challenges is to understand how to shape their vegetation in order to increase both biodiversity and psychological well-being of visitors (Harris et al., 2017; Jennings et al., 2016; Wang, Palazz & Carper, 2016). Based on our results, we identified that a step towards this goal would be to mix woodlands, shrubs, herbaceous areas, flower areas, water areas and mineral surfaces on the whole site. A way to do so could be to plant vegetation taking into consideration the hierarchy of different heights to increase volume in the scene and create visual depth and complexity (Kaplan & Kaplan, 1989), or to create fluid transitions between different vegetation layers (Nassaeur, 1995).

Furthermore, according to Gobster et al. (2007), attention to the ecological value of a landscape can be influenced by the impact of this value on its perceived aesthetic quality. Therefore, our results could partly be explained by previous studies evidencing that within UGS aesthetic qualities often emerge from landscape structural diversity (Goodness, Andersson, Anderson & Elmqvist, 2016; Sahraoui, Clauzel & Folt, 2016), and from flowering (Goodness et al., 2016; Nassauer, 1995). This suggests that visitor's ability to perceive design and management actions in favor of landscape heterogeneity within UGS could be enhanced if those actions had a positive impact on its aesthetic quality.

More research is needed to better understand the intricate relationships between psychological restoration of visitors and perceived *vs.* measured biodiversity within UGS, and how these insights can be applied to planning and management practices. Following our study and others (Dramstad et al., 2001; Hunter & Luck, 2015; Nassaeur, 2012), we judge that there is especially a need to identify more landscape metrics related to species diversity within UGS that include human perception and psychological well-being.

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Table 1
Description of the land-cover types composing the five maps created for this study. “X” indicates that the land-cover type was mapped distinctly. Please also refer to Appendix B.

	Land-cover types							
	Woodland	Shrub	Lawn	Meadow	Flowering shrub	Flower bed	Water area	Mineral surface
Map 1	X	X	Herbaceous area				X	X
Map 2	X	X	X	X	X	X	X	X
Map 3	X	X	Herbaceous area		Flower area		X	X
Map 4	X	X	Herbaceous area		X	X	X	X
Map 5	X	X	X	X	Flower area		X	X

Table 2
List of the 15 statements used in our questionnaire to assess visitors' psychological restoration and psychological well-being related to the use of UGS.

	Statements	Components of psychological well-being measured by the statements
		Grounded in Attention Restoration Theory
1	This UGS gives you mental energy	Recovery from mental fatigue
2	This UGS makes you feel more focused and motivated	
3	In this UGS you can relax	Relaxation and stress reduction
4	In this UGS you can unwind	
5	This UGS offers you opportunities to feel connected and close to nature	Connection with nature
6	In this UGS you can escape from the city	Escape from the surrounding urban landscape
7	In this UGS you feel like you can breathe and escape from the city's heat	
8	In this UGS you can escape from your daily routine	Escape from the daily routine
9	This UGS has aesthetics landscapes, you find it beautiful	Aesthetic experience
10	This UGS stirs up your senses	Sensory well-being
		Related to the use of UGS
11	This UGS is a place for meeting new people and spending time with friends and family	Socialization
12	In this UGS you feel safe	Safety
13	In this UGS you feel as part of a community	Belonging
14	This UGS brings back good memories, you feel close to it	Emotional place attachement
15	In this UGS you can easily practice physical and recreational activities that enhance your mental well-being	Mental health
	Initial statements in French	
1	Cet espace vert urbain vous procure de l'énergie mentale	
2	Cet espace vert vous permet de vous concentrer et de vous motiver	
3	Dans cet espace vert urbain vous pouvez vous relaxer	
4	Dans cet espace vert urbain vous pouvez vous reposer	
5	Cet espace vert urbain vous permet de vous sentir connecté et proche de la nature	
6	Dans cet espace vert urbain vous vous sentez coupé de la ville	
7	Cet espace vert urbain vous permet de vous oxygéner et de fuir la chaleur de la ville	
8	Dans cet espace vert urbain vous pouvez vous échapper de votre routine quotidienne	
9	Cet espace vert urbain contient des paysages esthétiques, vous le trouvez beau	
10	Cet espace vert urbain stimule vos sens	
11	Cet espace vert urbain est propice à la rencontre avec d'autres personnes, et vous pouvez y passer du temps en famille et entre amis	
12	Dans cet espace vert urbain vous vous sentez en sécurité	
13	Dans cet espace vert urbain vous vous sentez au sein d'une communauté	
14	Cet espace vert urbain vous rappelle de bons souvenirs, vous vous en sentez proche	
15	Dans cet espace vert urbain vous pouvez facilement y pratiquer des activités récréatives ou des pratiques sportives qui améliorent votre bien-être mental	

Table 3
Results (|R| values) of the Pearson correlations made between i) the scores of perceived landscape heterogeneity, ii) the total scores of psychological well-being, and iii) the five landscape heterogeneity metrics based on the five maps. Significance of the correlations (p-values) are symbolized as 0.01<p<0.05=*, 0.001<p<0.01=**, p<0.001=***.

Scores computed with the questionnaires	Landscape heterogeneity metrics				
	$SHDI_1$	IJI_1	AI_1	LSI_1	$CONTAG_1$
Scores of perceived landscape heterogeneity	0.60*	0.20	0.011	0.38	-0.29
Total scores of psychological well-being	0.33	0.39	0.33	0.38	-0.10
	$SHDI_2$	IJI_2	AI_2	LSI_2	$CONTAG_2$
Scores of perceived landscape heterogeneity	0.60*	0.38	0.060	0.33	-0.41
Total scores of psychological well-being	0.17	0.41	0.42	0.24	0.054
	$SHDI_3$	IJI_3	AI_3	LSI_3	$CONTAG_3$
Scores of perceived landscape heterogeneity	0.61*	0.63*	0.016	0.39	-0.46
Total scores of psychological well-being	0.24	0.64*	0.30	0.38	-0.16
	$SHDI_4$	IJI_4	AI_4	LSI_4	$CONTAG_4$
Scores of perceived landscape heterogeneity	0.60*	0.41	0.059	0.33	-0.44
Total scores of psychological well-being	0.14	0.37	0.42	0.24	0.022
	$SHDI_5$	IJI_5	AI_5	LSI_5	$CONTAG_5$
Scores of perceived landscape heterogeneity	0.60*	0.55	0.015	0.39	-0.41
Total scores of psychological well-being	0.25	0.57	0.30	0.38	-0.10

Table 4
Results (|R| values) of the Pearson correlations made between i) the scores of perceived landscape heterogeneity and ii) the total scores of psychological well-being both taking into account gender and childhood environment of visitors, and iii) the 5 landscape heterogeneity metrics based on the 5 maps. Significance of the correlations (p-values) are symbolized as 0.01<p<0.05=*, 0.001<p<0.01=**, p<0.001=***.

Gender

Scores computed with the questionnaires	Landscape heterogeneity metrics					Scores computed with the questionnaires	
						Scores of perceived landscape heterogeneity	
	SHDI$_{1-5}$	IJI$_3$	AI$_3$	LSI$_3$	CONTAG$_3$	given by men	given by women
Scores of perceived landscape heterogeneity given by men	0.47<R<0.59	0.44	0.01	0.50	-0.45	1	_
Scores of perceived landscape heterogeneity given by women	0.63*<R<0.64*	0.63*	0.031	0.24	0.29	_	1
Total scores of psychological well-being given by men	0.015<R<0.20	0.63*	0.12	0.40	0.033	0.47	_
Total scores of psychological well-being given by women	0.14<R<0.27	0.42	0.47	0.51	-0.012	_	0.73**

Childhood environment

Scores computed with the questionnaires	Landscape heterogeneity metrics					Scores computed with the questionnaires	
						Scores of perceived landscape heterogeneity	
	SHDI$_{1-5}$	IJI$_3$	AI$_3$	LSI$_3$	CONTAG$_3$	given by visitors who grew up in an urban environment	given by visitors who grew up in a rural environment
Scores of perceived landscape heterogeneity given by visitors who grew up in a urban environment	0.45<R<0.46	0.49	0.015	0.32	0.40	1	_
Scores of perceived landscape heterogeneity given by visitors who grew up in a rural environment	0.62*<R<0.63*	0.62*	0.17	0.20	0.35	_	1
Total scores of psychological well-being given by visitors who grew up in a urban environment	0.20<R<0.36	0.57	0.35	0.24	0.11	0.53	_
Total scores of psychological well-being given by visitors who grew up in a rural environment	0.12<R<0.29	0.64*	0.19	0.49	0.025	_	0.75**

Table 5
Results (|R| values) of the Pearson correlations made between i) the total scores of psychological well-being, ii) the two distinguished scores of psychological well-being, iii) the scores of perceived landscape heterogeneity, and iv) the five landscape heterogeneity metrics based on the Map 3. Significance of the correlations (p-values) are symbolized as 0.01<p<0.05=*, 0.001<p<0.01=**, p<0.001=***.

	Scores computed with the questionnaires		Landscape heterogeneity metrics				
	Total scores of psychological well-being	Scores of perceived landscape heterogeneity	$SHDI_3$	IJI_3	AI_3	LSI_3	$CONTAG_3$
Scores of psychological restoration	0.97***	0.69*	0.11	0.60*	0.42	0.27	0.0042
Scores of psychological well-being related to the use of UGS	0.43	0.51	0.54	0.43	0.31	0.50	-0.58

Table 6
Results (|R| values) of the Pearson correlations made between the total scores of psychological well-being and the individual scores of the 15 statements. Significance of the correlations (p-values) are symbolized as 0.01<p<0.05=*, 0.001<p<0.01=**, p<0.001=***.

	Individual scores of the 10 statements measuring psychological restoration								
	Stat. 1	Stat. 2	Stat. 3	Stat. 4	Stat. 5	Stat. 6	Stat. 7	Stat. 8	Stat. 9
Total scores of psychological well-being	0.89**	0.88**	0.60*	0.84*	0.83*	0.74*	0.72*	0.82**	0.86**
	Individual scores of the five statements measuring psychological well-being related to the use of UGS								
	Stat. 11	Stat. 12	Stat. 13	Stat. 14	Stat. 15				
Total scores of psychological well-being	0.43	0.19	0.48	0.005	0.20				

Table 7
Results of the Benjamin-Hochberg procedure with a discovery rate of 0.05.

Correlations between...	Original P-values (sorted from smallest to largest)	Benjamini-Hochberg P-values
total scores of psychological well-being and scores of psychological restoration	0,001	0,024666667
scores of perceived landscape heterogeneity and total scores of psychological well-being	0,002	0,024666667
total scores of psychological well-being and statement 2	0,002	0,024666667
total scores of psychological well-being and statement 10	0,003	0,02775
scores of perceived landscape heterogeneity and total scores of psychological well-being given by women	0,004	0,0296
total scores of psychological well-being and statement 1	0,005	0,030833333
total scores of psychological well-being and statement 9	0,006	0,031714286
total scores of psychological well-being and statement 8	0,008	0,035878788
scores of perceived landscape heterogeneity and total scores of psychological well-being given by visitors who grew up in a rural childhood environment	0,009	0,035878788
total scores of psychological well-being and IJI3	0,012	0,035878788
total scores of psychological well-being and statement 4	0,012	0,035878788
scores of perceived landscape heterogeneity and scores of psychological restoration	0,013	0,035878788
total scores of psychological well-being and statement 5	0,016	0,035878788
scores of perceived landscape heterogeneity and SHDI1	0,021	0,035878788
scores of perceived landscape heterogeneity given by women and IJI3	0,021	0,035878788
scores of perceived landscape heterogeneity and SHDI4	0,023	0,035878788
scores of perceived landscape heterogeneity given my women and SHDI4	0,024	0,035878788
scores of perceived landscape heterogeneity and IJI3	0,024	0,035878788
total scores of psychological well-being given by men and IJI3	0,024	0,035878788
scores of perceived landscape heterogeneity and SHDI5	0,025	0,035878788
scores of perceived landscape heterogeneity given by women and SHDI1	0,026	0,035878788
total scores of psychological well-being and statement 7	0,026	0,035878788
scores of perceived landscape heterogeneity given by visitors who grew up in a rural childhood environment and SHDI1	0,027	0,035878788
scores of perceived landscape heterogeneity given by visitors who grew up in a rural childhood environment and SHDI2	0,028	0,035878788
scores of perceived landscape heterogeneity given by women and SHDI3	0,029	0,035878788
IJI3 and scores of psychological restoration	0,029	0,035878788
scores of perceived landscape heterogeneity and SHDI2	0,03	0,035878788
scores of perceived landscape heterogeneity given by women and SHDI2	0,031	0,035878788
scores of perceived landscape heterogeneity given by visitors who grew up in a rural childhood environment and SHDI3	0,031	0,035878788
scores of perceived landscape heterogeneity given by visitors who grew up in a rural childhood environment and SHDI4	0,031	0,035878788
scores of perceived landscape heterogeneity given by visitors who grew up in a rural childhood environment and SHDI5	0,031	0,035878788
scores of perceived landscape heterogeneity given by visitors who grew up in a rural childhood environment and IJI3	0,032	0,035878788
total scores of psychological well-being and statement 3	0,032	0,035878788
total scores of psychological well-being given given by visitors who grew up in a rural childhood environment and IJI3	0,035	0,038088235
total scores of psychological well-being and statement 6	0,037	0,039055556
scores of perceived landscape heterogeneity and SHDI3	0,038	0,039055556
scores of perceived landscape heterogeneity given by women and SHDI5	0,041	0,041

Figure 1. Location map of the 13 UGS throughout the 12 neighborhoods of Rennes (Brittany, France).

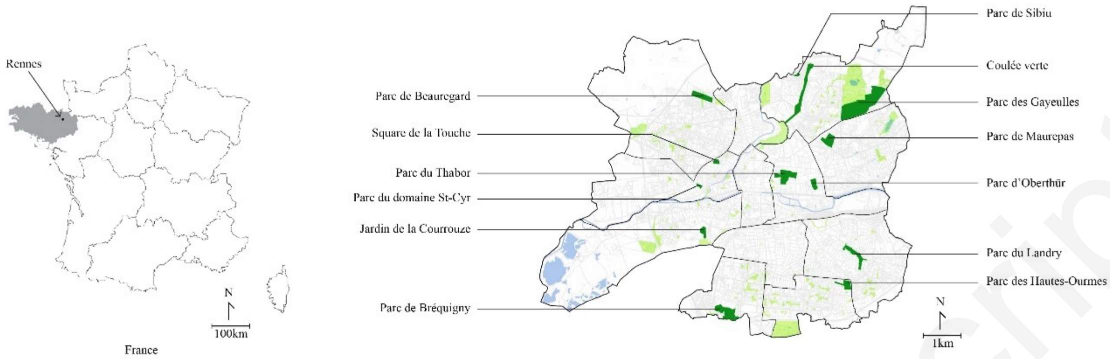

Figure 2. General scheme of the compiled correlations established between i) the landscape heterogeneity metrics $SHDI_3$ and IJI_3, ii) the scores of perceived landscape heterogeneity, and iii) the scores of psychological restoration.