



Research

## What's biodiversity got to do with it? Perceptions of biodiversity and restorativeness in urban parks

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**ABSTRACT.** Understanding the mechanisms underlying the positive influence of urban biodiversity on dwellers' well-being is critical to inform sustainable management of urban greenspaces, but studies published to date on the role of biodiversity in mental restoration have provided contradictory results. Both urban greenspace biophysical characteristics and the emotional connection with the place may play a role in mental restoration. Using urban greenspace landscape and biodiversity metrics, and on-site observations and questionnaires to assess site quality and visitors' perceptions, we explore the influence of biodiversity (perceived and measured at different levels), urban greenspace characteristics, and visitors profiles in mental restoration. Our statistical analysis demonstrates that perception of biodiversity, along with satisfaction and connection to place, were the most important predictors of mental restoration. The proportion of broadleaf and evergreen tree species also had a positive influence on biodiversity perception and mental restoration. People perceive existing biodiversity through visual cues as the diversity of leaf forms in broadleaf species, with this process being almost completely mediated by the perception of tree diversity. These findings have direct translation into planning and management practices by acknowledging the importance of biodiversity and, above all, specific traits, namely of evergreen broadleaf species, in promoting restorativeness of urban parks for users. Our results highlight the importance of using standard ecological methods when assessing biodiversity in urban greenspaces and their influence on human well-being.

**Key Words:** *biodiversity perception; biological diversity; functional diversity; mediation; mental well-being; perceived restorativeness*

### INTRODUCTION

Living in cities can be very stressful. Crowding, high levels of noise, strong artificial lights and odors, pollution, and many other factors contribute to people becoming overloaded with undesired stimuli, which can have consequences for mental health and well-being (Galea et al. 2005). Interacting with nature may help to overcome these effects through a wide range of benefits. Reduced anxiety and stress, and improved cognitive abilities, self-esteem, happiness, and life satisfaction are just some of the benefits of interacting with nature (Frumkin et al. 2017, Hall and Knuth 2019a,b). According to previous research, mental restoration has been consistently associated with positive aspects of well-being (Marselle et al. 2019). This process is known as restorativeness, which is defined as the potential of the environment to re-establish certain cognitive capacities related to human information processing (Hartig 2004).

Natural environments in cities are representative of human intervention in the landscape over time. They can include remnant areas of natural habitats that may be more or less free of human intervention, as well as man-made or transformed habitats, with a multitude of designs, architectural elements, and vegetation structures. Natural environments are generally more restorative than urban ones, but built elements in urban greenspaces may also be a source of psychological restoration and well-being (Lindal and Hartig 2013, Hajrasoulih et al. 2018, Weber and Trojan 2018).

Urban greenspaces, specifically urban parks, are complex social-ecological systems that serve both as biodiversity repositories that perform ecological functions and as spaces for mingling that fulfill important social functions (Cattell et al. 2008, Elmqvist et al.

2013). Each urban greenspace has its own biological and cultural constellations that offer meaning and identity to the space (Andersson and Barthel 2016). People perceive, experience, and value a space according to their perceptions and attached emotions. Perceptions are crucial for interpreting and assigning meaning to the environment (Qiong 2017). A space recognized as meaningful and with which people can identify induces intangible, emotional, and cognitive bonds (Tuan 1975) that positively influence mental restoration and well-being (Ratcliffe and Korpela 2016, Knez et al. 2018). In addition, according to constructivist approaches, people construct objects of perception and thought that contribute to the cognitive process, and reality is an interpretation of the environment within this perspective (Wapner and Demick 2002). This assumption implies a distinction between the experienced and physical environment, and it highlights the importance of assessing people's perceptions when dealing with mental well-being. The effects of perceptions of naturalness, greenness, and aesthetic attractiveness on mental well-being have been investigated previously (e.g., Hidalgo et al. 2006, Marselle et al. 2015, Hipp et al. 2016), but to the best of our knowledge, no study has jointly considered the roles of biodiversity (which we define as the richness of species and variability of species traits), both objective and perceived, and the physical characteristics of parks in well-being.

Evidence supports the positive effect of experiencing nature on mental well-being (Houlden et al. 2018, Menardo et al. 2021), but little is known about the specific roles of different attributes of nature, i.e., biodiversity, or the mechanisms that might allow them to exert their influence (Botzat et al. 2016, Marselle et al. 2019). Few studies have investigated the relationship between biodiversity and mental well-being, and those that have often simply compared

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**Table 1.** List of park characteristics, including age, origin, and design.

Park	Park construction	Origin and design	Date of urbanization
Jardim da Estrela	1840s	English design	1800s
Jardins Gulbenkian	1960s	Modern Portuguese design	1900s
Mata de Benfica	1910s	Former farms	1900s
Tapada das Necessidades	1740s	English design, former game reserve	1800s
Mata de Alvalade	1950s	Former planted woodlands	1940s
Quinta das Conchas	1900s	Former planted woodlands	1990s
Vale Fundão	1970s	Former planted woodlands	1960s–1970s
Vale do Silêncio	1950s	Former planted woodlands	1940s–1960s
Parque do Calhau	1940s	Planted woodlands	Unknown
Keil do Amaral	1940s	Planted woodlands	Unknown
Montes Claros	1940s	Planted woodlands	Unknown
São Domingos de Benfica	1940s	Planted woodlands	Unknown

non-urban natural environments with urbanized environments or assessed nature in terms of naturalness, greenness, and other proxies. Only a minority of these studies assessed biodiversity using standard ecological methods and metrics (Botzat et al. 2016, Marselle et al. 2019), and the results were both mixed and varied across scales ranging from species to ecosystems. For example, some studies of habitat diversity and bird species richness found positive associations with mental well-being (Fuller et al. 2007, Luck et al. 2011, Johansson et al. 2014, Rantakokko et al. 2018), whereas the associations were not significant or inconclusive in other studies (Dallimer et al. 2012, Wheeler et al. 2015, Wolf et al. 2017). These contradictory results have led to some authors arguing that perceived biodiversity, rather than actual biodiversity, is responsible for mental well-being (Dallimer et al. 2012), and they have questioned the ability of lay-people to perceive variations in biodiversity accurately. Associations between perceived biodiversity and mental well-being were described as both positive (Dallimer et al. 2012, Schebella et al. 2019) and non-significant (Marselle et al. 2015, 2016), and the same contradiction was found when testing the ability of lay-people to assess existing biodiversity accurately (Fuller et al. 2007, Lindemann-Mathies and Bose 2008, Dallimer et al. 2012). Some authors have argued that large variations at the ecosystem level, such as habitat heterogeneity or vegetation cover, are more likely to be recognized than subtle variations in species diversity (Dallimer et al. 2012, Schebella et al. 2019). Many studies of the perception of biodiversity were also based on coarse definitions of biodiversity itself (e.g., greenness or naturalness) rather than species diversity. Perceived biodiversity is likely to depend on the visible traits of species that allow the discrimination of differences (de Vries and Snep 2019), but no previous study has explored the influence of visible functional traits on the perception of biodiversity or mental well-being. Thus, it is necessary to clarify the biodiversity elements that are responsible for mental well-being and the mechanisms that might allow these elements to contribute to well-being using standard metrics of landscape structure and biological and functional diversity, which are the most effective and accurate methods for achieving these aims.

In addition to natural elements, the facilities and amenities found in urban greenspaces contribute to the association between visiting greenspaces and mental restoration (Nordh and Østby 2013). Cultural and art elements with high aesthetic value also

have important restorative attributes (Deng et al. 2020). However, few integrated studies have considered the effect of both biodiversity and park characteristics on well-being (Wood et al. 2018).

Consequently, we aimed to understand two facets of urban greenspaces, specifically focusing on urban parks (including the qualities of both parks and biodiversity). First, how do the characteristics of urban greenspaces, the perceptions of these characteristics by users, visitation patterns, and connection to place contribute to mental well-being? Second, how is the perception of existing biodiversity related to objectively quantified biological and functional diversity?

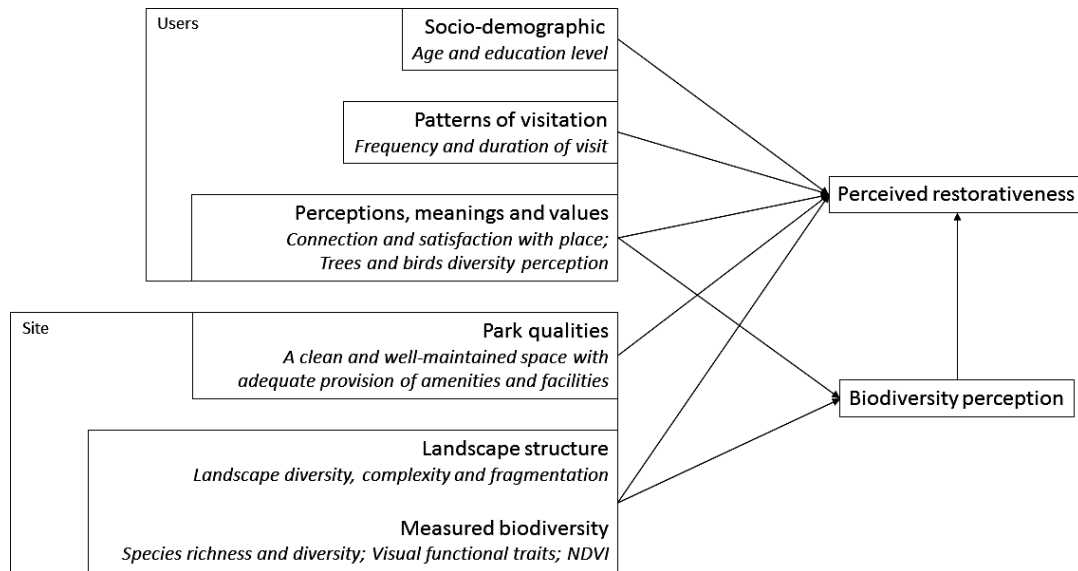
## METHODS

Twelve urban parks with public access in Lisbon, Portugal were studied as part of the EU FP7 GREENSURGE research project (<https://greensurge.eu/>). The parameters used to select the study parks included their location in the city, a diversity of designs and facilities, area  $\geq 4$  ha, and age  $> 40$  yr to ensure a completely developed vegetation structure (Table 1). A map showing the locations and pictures of each park may be accessed at [https://drive.google.com/open?id=1cFkuWVof\\_1DNxwBsj4sTq5kU-U9\\_pLT&usp=sharing](https://drive.google.com/open?id=1cFkuWVof_1DNxwBsj4sTq5kU-U9_pLT&usp=sharing). More detailed information about the characteristics of the parks, specifically the number of biotopes, vegetation structure, and presence of facilities and cultural artifacts, is provided by Vierikko et al. (2020).

## Data collection

Fifty face-to-face questionnaires were completed in each park to assess the users' perceptions of the parks' meaningfulness, attribute values, and biodiversity. The questionnaires were completed in the early morning or late afternoon during weekdays, and during any daytime hours on the weekends, while avoiding extreme weather conditions ( $> 30^{\circ}\text{C}$ ) and public events in the parks. Interviewers searched for respondents throughout the entire park to include people engaged in all possible activities and visitors with different stay lengths. In parks with low visitation rates, every visitor who entered the park was interviewed, whereas every fifth visitor was interviewed in other parks. We briefly explained the study's aim to each visitor we approached and asked them to participate. In total, 610 visitors (44.1% female and 55.9% male)  $> 18$  years old and currently living in the city responded to the questionnaire (each lasted at least 10 min), and 80 refused to

**Fig. 1.** Diagrammatic representation of the approach used to model perceived restorativeness and biodiversity perception, including user and site variables.



participate or did not complete it. The questionnaire covered several topics related to both visits and visitors, and further details are available in the study by Vierikko et al. (2020). The perceived restorativeness and biodiversity perception were evaluated using variables related to both the uses and the site as follows (Fig. 1).

#### *Perceived restorativeness*

We assessed mental restoration using a reduced version of the Perceived Restorativeness Scale, which is a tool developed by Hartig et al. (1997) for assessing the restorative qualities of environments based on attention restoration theory (Kaplan and Kaplan 1989). This theory posits that nature offers a bottom-up stimulus that allows fatigued directed attention to rest and restore by capturing one's involuntary attention. To achieve this effect, the natural environment must provide the feeling of being away and distant from daily routines, provide sufficient area to explore and experience a visually organized and harmonious environment, be compatible with one's needs and desires by offering the opportunity to engage in enjoyable and meaningful activities, and be fascinating and attract direct attention in an effortless manner. We used eight items (Table 2) from the previously tested Perceived Restorativeness Scale survey instrument (Pasini et al. 2009), which were shown to be valid in previous studies (e.g., Scopelliti et al. 2012, Carrus et al. 2013). Two items from each of the Perceived Restorativeness Scale dimensions were used, and visitors were asked to score their opinion on a Likert scale ranging from 1 (do not agree) to 5 (completely agree). The individual scores were summed and averaged (final aggregated score) and then treated as a continuous variable in subsequent analyses (Norman 2010). Perceived restorativeness (PR) was used as a composite measure to assess the four experiential restorative qualities. The internal consistency of the measure was confirmed by a Cronbach's alpha score of 0.73.

**Table 2.** List of items used to assess perceived restorativeness.

Component	Item
Compatibility	Being in this place is in accordance with my personal interests
	I can do things I like here
Being away	Spending time here gives me a break from my day-to-day routine
	Coming here helps me to get relief from unwanted demands on my attention
Fascination	This place is fascinating
	There is much to explore and discover here
Extent and coherence	It is as if this place has no boundaries
	It is easy to see how things are organized

#### *Biodiversity perception*

To assess overall biodiversity perception (BDP), visitors were asked whether they perceived high levels of biodiversity (yes or no). Most visitors answered "yes" or "no," but some provided intermediate answers such as "so-so," "not so much," or "only plants, not animals." These responses were pooled together with the negative answers, and BDP was analyzed as a binary variable. To understand whether biodiversity, either real or perceived, was an important attribute of PR, the same taxa were used for comparison in both assessments. Vascular plants, butterflies, and birds were selected because they are the most conspicuous taxa in parks and are readily recognized by lay-people, as demonstrated by citizen science databases (e.g., iNaturalist <https://www.inaturalist.org/>), and the interviewees were also asked to score the perceived diversity of each taxon separately on a scale from 1 (very low) to 5 (very high).

### *User variables*

Patterns of visitation were determined by asking how often respondents visited a space and how long they stayed. Frequency of visitation (“frequency”) was classified according to two categories comprising occasional (less than once a week) or regular visitors (at least once a week). Duration of visit (“duration”) was classified according to five groups: passing by, < 30 min, 30 to 90 min, 90 to 180 min, and > 180 min. The “age” and “education” of users were requested to determine basic sociodemographic strata. The perception of satisfaction with a space was assessed based on the number of “complaints” reported about park maintenance and state of preservation. The meaningfulness attributed to a place, which was determined as the existence of an emotional connection, was assessed by asking visitors whether the park was special for them (“yes” or “no”).

### *Site variables*

We evaluated each park’s overall quality by assessing a set of on-site conditions, including the number and variety of amenities and facilities, their state of preservation, overall cleanliness, and absence of vandalism. Each item was scored from 1 (low variety/condition of amenities/facilities and visible signs of litter/incivilities) to 5 (high number/condition of amenities/facilities and no visible signs of litter/incivilities) and summed to obtain a final space quality score (“park quality”).

The biological characteristics of the parks included land cover and structure mapping, biodiversity assessments, and the visible functional traits of tree species. The land cover in parks was mapped on-site with MapItGIS for Android (MapitGIS Walk-Through <http://mapit-gis.com/walk-through-sample-survey>). Patches were delimited and classified according to cover type: trees with or without shrubby understory in various densities, grass or lawn, social areas (e.g., playgrounds, cafeterias, sport courts), water bodies, and paths. Patches with tree cover were also classified according to the dominant tree species. A geographic information system project was built in QGIS 2.18.18 (QGIS Development Team 2019), and land-cover metrics were calculated for parks with FRAGSTATS software (McGarigal et al. 2012) using two sets of classifications based on the cover type and dominant tree species. Four metrics for measuring landscape fragmentation, complexity, diversity, and evenness were computed for both classifications. The normalized difference vegetation index (“NDVI”) was computed based on Sentinel2A images with a spatial resolution of 10 m for the summer months.

Vegetation assessments were conducted according to a stratified sampling scheme based on the cover types and their area of occupancy in which transects were drawn in the patch centroid along the longest length. The area sampled for each cover type was at least 5% of its occupancy area. Trees were sampled along the transect using the point-centered quadrat method (Elzinga et al. 2001). Butterflies were sampled along fixed transects that covered all different cover types according to the Manual of Butterfly Monitoring issued by Butterfly Conservation Europe (Van Swaay et al. 2012). Parks were visited once each month from June to August, and all butterflies detected within 2.5 m on either side of a transect and 5 m in front of the observer were identified and recorded. Bird sampling was conducted during the breeding season (April–June) in the first hours after sunrise based on 10 min point counts in the park centroid and several extra points in

proportion to the park’s size (Sutherland 2006) up to a maximum of three extra points. The species richness, Shannon diversity, and evenness indexes were calculated for each taxon.

Visible traits of trees were compiled from various databases such as the TRY Plant Trait database (<https://www.try-db.org/TryWeb/Home.php>; Kattge et al. 2011) and the Botanical Information and Ecology Network (<https://biendata.org/>; Enquist et al. 2016). These traits were used to calculate the functional structure and diversity of trees based on the community weighted mean (CWM) and functional dispersion (Laliberté and Legendre 2010) using the R package “FD” (Laliberté et al. 2014). The CWM provides information about the dominant traits in the community by calculating trait values weighted by species abundances; it represents the percentage of each trait in the community for categorical traits. Functional dispersion reflects the degree of dissimilarity within the community, whereby a higher value denotes a greater diversity of traits in the community. Functional diversity indexes were calculated for leaf type and phenology, and flower and fruit showiness and phenology.

All of the variables collected, as well as their descriptions, units, and *P*-values for univariate analysis, are provided in Appendix 1.

### **Data analysis**

Because of the hierarchical structure of the data collected (parks and surveys within parks) and specific characteristics of each park, we constructed an initial generalized linear mixed model without predictors for both PR and BDP with “park” as a random effect to account for the variability associated with parks. No variance in PR was associated with park, so the variance associated with park was not significant when variables were added to the BDP model. Thus, we employed generalized linear models in subsequent analyses to test the effects of the biophysical features of parks on PR and BDP. PR was modeled as a gamma distribution with an inverse link, and BDP was modeled as a binomial distribution with a logit link. To build the generalized linear models, the significance of each variable was first assessed by univariate analysis, in which variables with *P* < 0.25 were selected for multivariate analysis (Hosmer and Lemeshow 2000). A Pearson’s correlation matrix was generated, and the correlated nature of our data set demanded a highly conservative approach to assure the non-collinearity of the predictors. If a correlation was significant (*r* > 0.6), we selected the variable that was least correlated with the remaining variables, with higher biological or social significance, with lower residual deviance according to univariate analysis, or with a variance inflation factor < 10 (Tabachnick and Fidell 1996).

The final set of variables used to build the models for PR and BDP was selected after all of the previously defined assumptions were satisfied and preliminary univariate analysis was performed (Table 3). We used the same set of variables for both models, except those related to park quality and patterns of visitation were not included in the BDP model, which was focused on biodiversity. For each model, all significant, non-collinear, and suitable variables were included in the initial model, and a backward stepwise procedure was employed to select the best model based on the lowest Akaike information criterion. Scatter plots were checked to confirm the adequacy of residuals, homogeneity of variance, linearity of predictors, and goodness-of-fit of model analysis (Hosmer and Lemeshow 2000). Partial regression and

**Table 3.** List of the final set of variables used to model perceived restorativeness (PR) and biodiversity perception (BDP).

Variable	Description	PR		BDP	
		$r^{\dagger}$	$P$ univ. <sup>‡</sup>	$r^{\dagger}$	$P$ univ. <sup>‡</sup>
<i>Biodiversity and landscape metrics</i>					
Species richness	Total number of tree, butterfly, and bird species	0.129**	0.003	0.147**	0.001
N_Tree	Tree species richness	0.05	0.238	0.062	0.142
N_Butterfly	Butterfly species richness	0.171**	< 0.001	0.121**	0.004
H_Birds	Shannon diversity index for birds	0.087*	0.041	0.041	ns
E_Trees	Evenness of tree species	-0.188**	< 0.001	-0.03	0.004
E_Butterflies	Evenness of butterfly species	0.058	0.167	0.148**	0.001
E_Birds	Evenness of bird species	0.058	0.176	-0.023	ns
PRDcov	Patch richness density of land-cover types (lawns, trees, water)	-0.099*	0.019	0.048	ns
PRDsp	Patch richness density of dominant tree species	-0.106**	0.012	-0.025	ns
SHDIsp	Shannon diversity index for dominant tree species	0.137**	0.001	0.142**	0.041
MSIEIsp	Modified Simpson's evenness index for dominant tree species	-0.043	ns	-0.087*	0.045
CWM_evergreen	Community weighted mean of evergreen species	0.214**	< 0.001	0.191**	< 0.001
CWM_broadleaf	Community weighted mean of broadleaf species	0.136**	0.001	0.104*	0.014
CWM_fruitshowy	Community weighted mean of showy fruits	-0.067	0.118	-0.083*	0.051
NDVI	Normalized difference vegetation index in summer	0.093*	0.026	0.181**	< 0.001
<i>Users perceptions</i>					
Complaints	Disturbing features referred to by park users	-0.177**	< 0.001	-0.083	0.053
Special	Connection to place (Is this place special? Yes/No)	0.177**	< 0.001	0.006	ns
BDP	Perception of high levels of biodiversity	0.286**	< 0.001	—	—
Tree diversity perception	Perception of diversity of tree species	0.161**	< 0.001	0.410**	< 0.001
Bird diversity perception	Perception of diversity of bird species	0.137**	0.002	0.310**	< 0.001
<i>Visiting profile</i>					
Frequency of visit	Classes: occasional (< once/week), regular (≥ once/week)	0.092*	0.031	0.012	ns
Duration of visit	Classes: passing by, < 30 min, 30–90 min, 90–180 min, > 180 min	-0.046	0.015	0.103*	ns
<i>Park qualities</i>					
Park quality	Availability and quality of facilities, amenities, and space cleanliness	0.118**	0.005	—	—

<sup>†</sup>Pearson correlation coefficient, with significance: \* $P < 0.05$ , \*\* $P < 0.01$ .

<sup>‡</sup> $P$  value of univariate regression; ns = not significant.

partial correlation coefficients were also calculated to measure the effect of each individual predictor in the PR model and the strength of the relationship, respectively, while keeping the other variables constant (Freund et al. 2010).

The absence of significant biodiversity-related variables in the final models for both PR and BDP led us to investigate whether any of the biodiversity metrics influenced PR or BDP through indirect pathways mediated by the perceptions of users. Mediation is a cause-effect model that aims to explain the intermediary process that allows an external event (independent variable) to influence the internal psychological significance (dependent variable) through a mediator (Baron and Kenny 1986). The effect of the independent variable on the dependent variable must be reduced or eliminated (partial or complete mediation) when the mediator is kept constant to demonstrate mediation (Hayes and Rockwood 2017). To qualify for mediation, in addition to theoretical support for the proposed mechanism, there must be significant relationships between the independent variable and mediator, and between the mediator and the dependent variable. Based on the constructivist approach for establishing a distinction between the measured and perceived environment, we used variables comprising the species richness; the richness, diversity, and evenness of tree species; CWM\_broadleaf, CWM\_evergreen, PRDsp (patch richness density of dominant tree species), and NDVI; as well as the mediators BDP, PR, and tree diversity perception to test the effects of perceptions in mediating the path between measured

and perceived biodiversity (BDP), and between perceptions and PR. The analysis was performed using the R package “Psych” (Revelle 2018), which calculates the partial regressions and tests for the existence of mediation by using bootstrap methods to compute confidence intervals.

## RESULTS

Significant positive correlations were found between PR and some of the biological diversity indexes such as total species richness ( $r = 0.129$ ), butterfly species richness ( $r = 0.171$ ), and diversity of birds ( $r = 0.087$ ), whereas a higher evenness of tree species was negatively correlated with PR ( $r = -0.188$ ; Table 3). Except for the diversity of tree patches (SHDIsp), which was positively correlated with PR ( $r = 0.137$ ), the remaining land-cover metrics (PRDcov and PRDsp) had negative correlations with PR ( $r = -0.099$  and  $r = -0.106$ , respectively). The visible functional traits related to leaf shape (CWM\_broadleaf) and phenology (CWM\_evergreen) were also significantly correlated with PR ( $r = 0.136$  and  $r = 0.214$ , respectively), and NDVI was positively correlated with PR ( $r = 0.093$ ). Users' perceptions of existing biodiversity were all positively correlated with PR (BDP,  $r = 0.286$ ; tree diversity perception,  $r = 0.161$ ; bird diversity perception,  $r = 0.137$ ) as well as the special connection with the place (special,  $r = 0.177$ ). By contrast, when the number of complaints regarding the space was higher, the value of PR was lower ( $r = -0.177$ ). According to the visiting profile, only the frequency of visit had a significant positive correlation with PR ( $r = 0.092$ ). Correlation analysis for BDP also found some positive associations with

**Table 4.** Generalized linear model for perceived restorativeness (scaled variables). BDP = biodiversity perception, PRDcov = patch richness density of cover types, CWM\_evergreen = community weighted mean of evergreen species.

Variable	Estimate	Standard error	P-value <sup>†</sup>	Partial correlation	Partial regression
Intercept	1.2744	0.0471	< 2e-16 ***		
<i>Perceptions, meanings and values:</i>					
Special	0.0390	0.0102	0.0001 ***	0.164	0.027
Complaints	-0.0271	0.0076	0.0004 ***	-0.142	0.020
BDP	0.0632	0.0116	8.5e-08 ***	0.247	0.061
<i>Patterns of visitation:</i>					
Frequency	0.0380	0.0216	0.079 ·	0.073	0.005
Duration	0.0547	0.0202	0.0069 **	0.101	0.010
Park_quality	0.0505	0.0232	0.0298 *	0.111	0.012
<i>Biodiversity and landscape metrics:</i>					
PRDcov	-0.0269	0.0105	0.0109 *	-0.114	0.013
CWM_evergreen	0.0812	0.0287	0.0045 **	0.128	0.016

<sup>†</sup>\* $P < 0.05$ , \*\* $P < 0.01$ , \*\*\* $P < 0.001$ ; · $P < 0.1$ .

diversity indexes such as total species richness ( $r = 0.147$ ), butterfly species richness ( $r = 0.121$ ), butterfly evenness ( $r = 0.148$ ), and diversity of dominant tree species (SHDIsp,  $r = 0.142$ ). Evenness of tree species (MSIEIsp) was negatively correlated with BDP ( $r = -0.087$ ). CWM\_broadleaf and CWM\_evergreen were also positively correlated with BDP ( $r = 0.104$  and  $r = 0.191$ , respectively), whereas fruit showiness was negatively correlated ( $r = -0.083$ ). Among the perceptions of users, only the perceived tree and bird diversities were positively correlated with BDP, and both variables had large correlation coefficients ( $r = 0.410$  and  $r = 0.310$ , respectively).

Among the biodiversity variables, only the patch richness density of cover types (PRDcov) and CWM\_evergreen remained significant in the final model for PR (Tables 3 and 4). PRDcov is a measure of patch richness and also landscape fragmentation, whereby a higher value denotes a higher number of smaller patches. CWM\_evergreen represents the proportion of evergreen tree species in a park. Thus, PR was negatively influenced by a fragmented landscape with a higher number of small patches and positively influenced by a higher proportion of evergreen species. The remaining significant predictors were related to pattern of visitation by users (frequency and duration of visit) and perceptions, whereby higher frequency and duration of visits both had positive effects on PR. Perceiving high levels of biodiversity (BDP) and having an emotional connection with the place (special) also had positive effects on PR, whereas a higher number of complaints about the space was associated with lower PR. Park quality, measured based on cleanliness and the variety and state of preservation of facilities and amenities, also had a positive effect on PR. The variables related to user perceptions (special, complaints, and BDP) had the greatest effect, and they had stronger relationships with PR according to the higher partial regression and correlation values. The measures of park quality and biodiversity (PRDcov and CWM\_evergreen) had weaker effects and correlations with the variables related to visitation patterns, and they were also less influential predictors with weaker correlations (Table 4).

The perception of high levels of biodiversity had an important effect on PR, even when combined with other predictors, so we built a model for BDP based on the same set of biodiversity-related variables but excluding those related to park quality and

visitation patterns. Many diversity-related variables had significant correlations according to univariate analyses, except for the proportion of evergreen species, but none of the other taxonomical, functional, or landscape diversity variables were retained in the final model. BDP was primarily determined by people's perceptions of tree and bird diversity (Table 5), whereby tree diversity was the most significant predictor with the greatest influence and strongest correlation according to partial regression and the correlation coefficients.

We then tested whether any of the biodiversity metrics had an indirect effect on restorativeness through the perception of biodiversity, and whether this effect was mediated by the perception of tree species diversity. Because of the correlated nature of BDP and PR, we also tested the mediating role of PR in BDP (Table 6 and Fig. 2). For the indirect effect of biodiversity on restorativeness through BDP, we only found partial mediations ranging between 18% and 32% for species richness, tree evenness, and percentage of evergreen and broadleaf species, and NDVI had the highest mediation proportion (53%). The inverse pathway was also tested, and partial mediations (15–42%) were found for tree species evenness, percentage of broadleaf and evergreen species, and NDVI. However, for BDP, full mediation through tree perception was found only for CWM\_broadleaf. All of the other tested mediations were not significant, according to the assumptions of the analysis (Hayes and Rockwood 2017).

Our results showed that mental restoration was primarily determined by the user perceptions, meaning, and value associated with parks, rather than by the biophysical attributes of the parks themselves, including their biodiversity. The main determinant for mental restoration was the perception of biodiversity, which was not directly influenced by any of the quantified metrics. BDP was indirectly determined by the amount of broadleaf species through the mediation of perceived tree species diversity.

## DISCUSSION

This is the first study to integrate actual park attributes (biodiversity and park facilities) with user perceptions of these attributes and user visitation profiles. Our results showed that individual perceptions, or lived experiences, had more important effects on restorativeness than actual attributes. Perception-

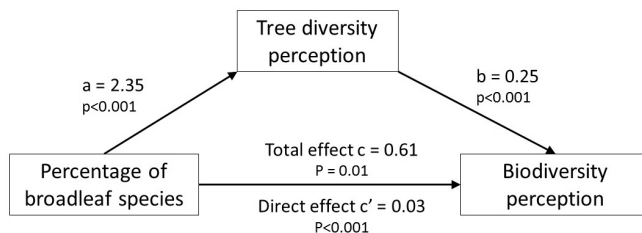
**Table 5.** Generalized linear model for biodiversity perception (scaled variables). CWM\_evergreen = community weighted mean of evergreen species.

Variable	Estimate	Standard error	P-value†	Partial correlation	Partial regression
Intercept	-8.2456	0.9663	< 2e-16 ***		
Tree perception	5.2074	0.7071	1.78e-13 ***	0.381	0.144
Bird perception	2.5602	0.4964	2.50e-07 ***	0.257	0.066
CWM_evergreen	2.0266	0.5496	0.000227 ***	0.191	0.036

†\*\*\**p* < 0.001.

related variables, including BDP, emotional connection with the space, and complaints were most significant in the PR model. Moreover, the amount of variation explained by these variables was more than double that explained by the remaining set of variables related to biophysical measurements and visitation patterns according to the partial regressions.

**Fig. 2.** Schematic diagram of mediation analysis results. Path *a* represents the effect of broadleaf species on tree diversity perception, path *b* represents the effect of tree diversity perception on the perception of biodiversity, and together they represent the indirect (mediated) effect of broadleaf species in biodiversity perception through the perception of tree diversity. Path *c'* represents the direct effect of broadleaf species on biodiversity perception when the indirect, mediated effect is controlled, and path *c* represents the total (mediated and direct) effect of broadleaf species on biodiversity perception. The requirements for a mediation effect are satisfied: paths *a*, *b*, and *c* are significant, and path *c'* is significantly smaller than path *c*, demonstrating that the perception of high tree diversity almost completely mediates the effect broadleaf species on users' perception of biodiversity.



Park quality, assessed based on amenity and facilities numbers and state of preservation as well as the level of park cleanliness, also contributed positively to PR, but to a much lesser extent. The presence of amenities and facilities that meet the needs and desires of visitors may contribute to a better appreciation of parks, and thus, to restorativeness (Nordh and Østby 2013, Wilkie and Stavidrou 2013). By contrast, evidence of litter or degraded furniture elicits undesired stimuli that attract attention, thereby impeding the feeling of being away, which is important for mental restoration according to attention restoration theory (Kaplan and Kaplan 1989). Cleanliness is one of the most desirable attributes in urban parks (Nordh and Østby 2013, Madureira et al. 2018), and the presence of litter is a major cause of the disturbances reported by users, as well as the lack of adequate management and complaints about the misbehavior of other users, including littering (Vierikko et al. 2020).

People seek urban greenspaces for many different reasons, and their needs and preferences for specific park features vary accordingly (Peschardt et al. 2016). The multiple uses, meanings, and needs regarding a single space will clearly lead to conflicts (Dinnie et al. 2013), especially if the space area and design do not adequately separate these multiple interests. Larger parks or those with a design that leads to a perception of large dimensions are related to a higher capacity for restoration (Nordh et al. 2009). A highly fragmented pattern with diverse land-cover types represented by high patch richness density may favor close contact with less desired environments and impair the ability to feel immersed (extent) in a pleasant environment that is adequate for the purpose of the visit (compatibility). Our results support the importance of large patches dedicated to a single function with a design that offers the possibility for seclusion and privacy, or the need to allocate specific functions to smaller parks connected in a multifunctional network of greenspaces in contrast to networks of one-size-fits-all multifunctional greenspaces. Lee et al. (2008) found a similar relationship with patch density regarding the existence of street trees and neighborhood satisfaction, whereby residents were more satisfied with large and well-connected tree patches than highly fragmented and isolated patches. Lu et al. (2018) showed that street greenery promoted walkability and visits to greenspaces, and Astell-Burt and Feng (2019) found that a higher tree canopy was associated with better mental health. These findings demonstrate the importance of greenways and green corridors as connectors of greenspaces to create multifunctional networks and to contribute to enhancing restorativeness.

In terms of the biodiversity in parks, the proportion of evergreen species was identified as a driver of PR. Evergreen species are associated with a perception of higher visual and aesthetic quality (Eroglu et al. 2012, Du et al. 2016) and are preferred to deciduous species (e.g., Camacho-Cervantes et al. 2014, Kuper 2015), and landscape preferences are associated with a higher likelihood of mental restoration (Pazhouhanfar and Kamal 2014, Lindal and Hartig 2015). The color green is known to elicit positive emotional responses in terms of relaxation and calmness because of its association with nature (Hemphill 1996, Kaya and Epps 2004), and virtual scenes containing evergreen species were shown to have a higher restorative potential than defoliated scenes (Paddle and Gilliland 2016, Kuper 2020).

The perception of high levels of biodiversity and the emotional connection to the place had stronger effects on PR than land cover and the taxonomical or functional diversity indexes. BDP was indirectly determined by the diversity of tree leaf types, and this effect was completely mediated by the perception of tree species diversity. Trees are usually the most prominent feature of a park,

**Table 6.** Analysis of the mediation role of biodiversity perception (BDP) and tree diversity perception in the effect of biodiversity metrics on perceived restorativeness (PR) and of PR and tree perception on BDP. CWM\_broadleaf = percentage of broadleaf species, CWM\_evergreen = percentage of evergreen species, NDVI = normalized difference vegetation index (a measure of greenness).

Predictor	Response	Mediator	Direct effect <sup>†</sup>	Indirect effect <sup>‡</sup>	Total effect <sup>§</sup>	% mediation <sup>  </sup>	Confidence interval <sup>¶</sup>
Species richness	PR	BDP	0.26	0.12	0.38	0.32	0.05–0.2
Evenness trees			–0.61	–0.13	–0.74	0.18	–0.23–(–0.05)
CWM_broadleaf			0.80	0.22	1.02	0.22	0.04–0.42
CWM_evergreen			0.57	0.17	0.74	0.23	0.09–0.26
NDVI			0.32	0.37	0.69	0.54	0.18–0.6
Species richness	BDP	PR	0.26	0.08	0.34	0.24	0.02–0.15
Evenness trees			–0.22	–0.16	–0.38	0.42	–0.25–(–0.09)
CWM_broadleaf			0.39	0.22	0.61	0.36	0.08–0.41
CWM_evergreen			0.36	0.15	0.51	0.29	0.09–0.23
NDVI			0.88	0.15	1.03	0.15	0.02–0.3
Species richness	PR	Tree perception	0.27	0.11	0.38	0.29	0.04–0.19
Evenness trees			–0.67	–0.07	–0.74	0.09	–0.13–(–0.02)
CWM_broadleaf			0.77	0.25	1.02	0.25	0.09–0.43
CWM_evergreen			0.70	0.04	0.74	0.05	0–0.09
NDVI					0.42	0.27	0.69
Species richness	BDP	Tree perception	0.09	0.25	0.34	0.74	0.17–0.34
Evenness trees			–0.22	–0.16	–0.38	0.42	–0.26–(–0.06)
CWM_broadleaf			0.03	0.58	0.61	0.95	0.36–0.82
CWM_evergreen			0.42	0.09	0.51	0.18	0.01–0.18
NDVI			0.48	0.55	1.03	0.53	0.35–0.77

<sup>†</sup>Effect of the independent variable (X) on the dependent variable (Y) when the mediator (M) is held constant.

<sup>‡</sup>Conjunction of the effect of X on M and the effect of M on Y.

<sup>§</sup>Effect of X on Y without controlling for M.

<sup>||</sup>Percentage of reduction in total effect when M is controlled.

<sup>¶</sup>Obtained by bootstrapping; significant mediations have confidence intervals that do not include zero.

so it is easy to conceive that people might associate biodiversity with tree species diversity and, thus, with the diversity of leaf forms, specifically the percentage of broadleaf species. Broadleaf species have a large variety of readily distinguishable leaf shapes and tree habits, whereas those with needle and scale leaves, mostly highly similar-looking conifers, are difficult to distinguish without a deeper analysis of their morphology (Welch 1991). Different leaf shapes and tree habits present various visual stimuli that attract attention and provide cues regarding the meaning of an object, which are essential in the perceptual process (Lindsay and Norman 1977). Preference for broadleaf species has been reported (Lee 2001), especially in regions where they predominate (Schraml and Volz 2009) such as the Mediterranean region, where the native vegetation is dominated by broadleaf evergreen shrubs and trees, but also in other regions, including Australia (Williams 2002). Broadleaf species mostly have oval and spreading canopies, which are also preferred to the conical or pyramidal shapes that are common for conifers (Summit and Sommer 1999, Lohr and Pearson-Mims 2006).

We also found partial mediation of the effects of species richness, NDVI, and tree evenness on BDP, and these mediating processes meant that people perceived differences in biodiversity essentially through visual cues. This finding supports the statement by de Vries and Snep (2019:167) that “perceived biodiversity is likely to depend strongly on the visibility of the different species, and on the extent to which they are perceived as being different.” Mediation analysis was used in several previous studies of the mechanisms that allow different environmental qualities (existing

or perceived) to influence mental well-being outcomes (e.g., Nordh et al. 2009, Carrus et al. 2015, Lindal and Hartig 2015, Hipp et al. 2016, Marselle et al. 2016, Knez et al. 2018, Tabrizian et al. 2018, Wang et al. 2019). However, to the best of our knowledge, none of these previous studies conducted analyses to determine the mechanisms that influenced the actual perception of biodiversity or restorativeness.

Emotions play important roles in how humans perceive and categorize the surrounding environment (Brosch et al. 2010, 2013), and emotionally significant stimuli are more easily recognized and identified than neutral stimuli (Zeelenberg et al. 2006, Zadra and Clore 2011). It is important to understand how emotions and perceptions mediate the interactions between tangible biophysical features and mental restoration. A regular and continuous interaction with a space is important for creating meaning and a sense of belonging (place identity), which translates into an emotional connection to the place, i.e., so-called place attachment (Tuan 1975, Williams and Vaske 2003, Smaldone 2007). In our study, the emotional connection with a place had a positive effect on PR whereby regular users who visited spaces at least once a week and those who visited for longer periods scored higher for PR. These findings indicate that psychological restoration takes time and does not “just happen” as soon as one enters a greenspace. Previous studies obtained similar results and showed that quick visits (< 15 min) to greenspaces did not stimulate physiological restoration (Tyrväinen et al. 2014). A positive effect of personal association with a place on restorative perceptions has been described



previously (Korpela and Ylén 2009, Menatti et al. 2019), and place identity as a dimension of place attachment also has mediating roles between naturalness and well-being (Knez et al. 2018) and between memory and mental restoration (Ratcliffe and Korpela 2016). In our study, emotional connection with a place did not have any significant mediating role between biodiversity or its perception and restorativeness.

Thus, promoting restorativeness in an urban greenspace requires the provision of clean greenspaces with evergreen and/or broadleaf tree species and well-preserved amenities and facilities that are compatible with the needs and desires of visitors, which should be inviting and welcoming for people who visit a place. Considering tree functional traits and not only tree species is important for allowing park managers to decide which species to use locally by combining visible traits with local preferences and ecological contexts. Participatory governance processes involving local communities and other stakeholders are important for understanding their preferences and needs, but also for truly involving them in the cooperative design of nature-based approaches to mental health restorativeness. This approach may be particularly important in less developed countries with more recent urbanization processes and less acculturated urban populations, which may tend to import solutions that are not adapted to the local situation. The importance of this approach for these countries is indicated by the small amount of evidence accumulated from low and middle-income countries (Shuvo et al. 2020) compared to the growing volume of research into greenspace-health relationships in high-income countries in Europe, North America, and Australia (Markevych et al. 2017). Citizen science may provide a useful tool for understanding local preferences (Krasny et al. 2014), particularly in communities with fewer resources, where conducting social surveys to advance scientific knowledge might not be feasible.

Our findings highlight the need for the close integration of ecological and social values in urban greenspace planning and management. A next step may involve assessing how different origins and cultural constructs influence preferences, meanings, and values, and thus, the perception of biodiversity and restorativeness. This type of approach may help to address questions regarding environmental justice and equity and to bring these issues into governance processes.

The biocultural diversity (BCD) concept provides a valuable and much needed social-ecological lens through which to study the dynamics of urban greenspaces, whereby it addresses the interrelatedness between people and nature, and it is expressed by the diverse ways people live, experience, perceive, and value their natural environment. BCD can be recognized easily in cities (Elands et al. 2019) where human activity has shaped urban nature over time, and the materialized BCD and lived BCD represent two dimensions of that interaction. Materialized BCD is related to tangible manifestations represented by quantifiable discrete objects as ecological communities or cultural artifacts, and lived BCD is concerned with the ways that people relate to the biophysical environment through their experiences, emotions, and perceptions. Our results fully agree with this concept because they show that restorativeness and BDP are closely interlinked, with both dependent on the characteristics of place (materialized BCD) and on its perception and evaluation (lived BCD). By

recognizing the mutual influences and interconnections between natural and cultural realms and the need to integrate social dynamics in urban ecosystems management, we consider that the BCD concept is useful for assisting the planning, designing, and management of greenspaces that are ecologically sound and that also provide locally adapted solutions to address a population's well-being. To help implement the BCD framework in urban contexts, we recently proposed an innovative indicator-based tool to assist decision making (Gonçalves et al. 2021).

## CONCLUSION

According to our results, the biophysical characteristics and user perceptions of parks were important for PR. The presence of large land-cover patches, evergreen tree species, and an adequate number of well-maintained amenities were considered the most restorative features. However, the personal experience of a space and its qualities, as well as the emotional connection with a space and, importantly, the perception of its biodiversity were crucial for this process. People perceived the existing biodiversity based on visual cues such as the diversity of leaf forms in broadleaf species, and this process was almost completely mediated by the perception of tree diversity. These findings can be directly translated into planning and management practices by acknowledging the importance of biodiversity-related attributes of greenspaces, i.e., tree functional traits, as well as promoting restorativeness for users of urban parks and recognizing the importance of using standard ecological methods for assessing biodiversity in urban greenspaces and its influence on human well-being.

*Responses to this article can be read online at:*  
<https://www.ecologyandsociety.org/issues/responses.php/12598>

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## Data Availability:

*The data that support the findings of this study are available on request from the corresponding author, PG. The data are not publicly available because it they are still under analysis.*

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**Appendix 1.** List of all variables used in statistical analysis with P-value for GLM univariate analysis. Blank cells correspond to variables with p-value > 0.25 and those that were not used either because they had outliers, were correlated > 0.60 or were not adequate to the analysis (e.g. amenities for biodiversity perception).

List of variables used in the univariate analysis to build the Generalized Linear Models			P-value univariate analysis	
Variable	Description	Units	Perceived Restorativeness (PR)	Biodiversity Perception (BPD)
<i>Biotic</i>				
H_TBB	Shannon diversity index of trees, butterflies and birds	NA		
H_Trees	Shannon diversity index of trees	NA	0.024	
H_Butterflies	Shannon diversity index of butterflies	NA	<0.001	
H_Birds	Shannon diversity index of birds	NA	0.041	<0.001
E_TBB	Evenness of trees, butterflies and birds	NA		0.004
E_Trees	Evenness of tree species	NA	<0.001	
E_Butterflies	Evenness of butterfly species	NA	0.167	
E_Birds	Evenness of bird species	NA	0.176	<0.001
Species richness	Total tree, butterfly and bird species	Number	0.003	0.190
N_Tree	Tree species richness	Number	0.238	0.020
N_Butterfly	Butterfly species richness	Number	<0.001	
N_Bird	Bird species richness	Number		0.004
LSIcov	Landscape Shape Index of land cover types	NA		
PRDcov	Patch Richness Density of land cover types	NA	0.019	0.248
SHDIcov	Shannon Diversity Index of land cover types	NA		0.028
MSIEIcov	Modified Simpson's Evenness Index of land cover types	NA	0.137	
LSIsp	Landscape Shape Index of dominant tree species	NA		
PRDsp	Patch Richness Density of dominant tree species	NA	0.0123	<0.001

SHDIsp	Shannon Diversity Index of dominant tree species	NA	0.001	0.041
MSIEIsp	Modified Simpson's Evenness Index of dominant tree species	NA		0.004
FDis_leafphen	Dissimilarity of tree eaf phenologies	NA	<0.001	0.019
FDis_leaftype	Dissimilarity of tree leaf types	NA	0.001	0.007
FDis_flowseason	Dissimilarity of tree flowering seasons	NA		<0.001
FDis_fruitphen	Dissimilarity of tree fruit phenologies	NA	<0.001	
FDis_flowshow	Dissimilarity of tree flower showiness	NA	0.200	0.001
FDis_fruitshow	Dissimilarity of tree fruit showiness	NA	0.212	<0.001
CWM_evergreen	Community Weighted Mean of evergreen species	NA	<0.001	0.014
CWM_broadleaf	Community Weighted Mean of broadleaf species	NA	0.001	
CWM_flowshowy	Community Weighted Mean of tree showy flowers	NA		0.051
CWM_fruitshowy	Community Weighted Mean of tree showy fruits	NA	0.118	
NDVI Summer	Normalized Difference Vegetation Index in summer	NA	0.026	<0.001
<i>Socio-demographic</i>				
Age	Age	Years		
Education	Education	Years		<0.001
<i>Visiting profile, park attributes and users perceptions</i>				
Frequency of visit	Classes: Occasional (less than 1x/week); Regular ( $\geq$ 1x/week)	0-1	0.031	
Duration of visit	Classes: Passing by; < 30 min; 30-90 min; 90-180 min; > 180 min	Score 1-5	0.015	0.036
Park quality	Availability and quality of facilities, amenities and space cleanliness	Number	0.005	
Biological salient features	Biological elements with historical, cultural, aesthetic value	Number		
Cultural artefacts	Built elements of cultural interest	Number		
Safety	Abundance of gardeners or security staff, and adequate lighting	Number		



Complaints	Disturbing features referred by park users	Number	<0.001	
Special PR	Connection to place (is this place special?) Perceived Restorativeness	Yes-No Score 1-5	<0.001	0.053
Biodiversity perception	Perception of high levels of biodiversity	Yes-No	<0.001	<0.001
Tree diversity perception	Perception of diversity of tree species	Score 1-5	<0.001	<0.001
Butterfly diversity perception	Perception of diversity of butterfly species	Score 1-5		
Bird diversity perception	Perception of diversity of bird species	Score 1-5	0.002	

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