Institut für Geodäsie und Geoinformation

The role of green infrastructure quality

for healthier and biodiverse cities

A One Health approach for reconciling people and wildlife needs

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Abstract

In the upcoming decades, urban areas are expected to undergo significant expansion and transformation in order to accommodate the growing proportion of the world's population living in cities. This challenge presents a unique opportunity to rethink our cities and to shift from development patterns that have resulted in urban environments associated with environmental degradation and disconnection to nature and instead embrace transformative changes that promote healthier and more resilient cities where people and nature thrive. Urban green infrastructure is one of the main strategies to achieve this goal, given the potential of various types of green spaces and structures for delivering several ecosystem services benefitting not only human health and wellbeing but also biodiversity conservation. However, limited knowledge remains on the quality necessary to effectively provide the range of benefits expected by green infrastructure and also on possible trade-offs among beneficiaries with different needs. This doctoral thesis addressed these research gaps through two main questions: a) which and how green spaces characteristics are associated with mental health and wellbeing and wildlife support outcomes, and b) what are the synergies and trade-offs between human health and wildlife dimensions in urban green spaces.

Through a systematic review, green space features that reportedly affected human mental health or wildlife support in previous studies were compiled. Then, the holistic One Health approach was used as a basis for the development of a framework connecting quality attributes of green spaces with human mental health and wellbeing and wildlife support in the urban context.

To apply this framework in a case study in Brazil, the first step required a cross-cultural adaptation of the selected psychometric scales for measuring psychological restoration in the target population. Specifically, the Perceived Restorativeness Scale and the Restoration Outcomes Scale were translated into Portuguese and validated using samples from Porto Alegre and São Paulo cities located in southern and southeastern Brazil. The psychometric properties of both scales presented adequate internal consistency and model fit indexes, which remained consistent across participants’ gender and city of residency. Besides the intended application in this doctoral study, the provision of these newly-validated versions of such measures creates opportunity for the expansion of research on restorative environments in the poorly studied Global South, particularly in Brazil.

In São Paulo, Brazil, a case study was carried out utilizing indicators and metrics identified in the systematic review to analyze the relationships outlined in the developed framework. The primary factors affecting user restorativeness were perceived safety and naturalness of parks. These perceptions were associated with park characteristics such as tree canopy coverage, presence of water bodies, and signs of vandalism. The presence of natural water bodies presented a clear mutual benefit for psychological restoration and support to birds (as representative of wildlife species). In contrast, whereas parks with higher tree canopy coverage offered greater potential for restoration to users, outcomes for bird assemblages were distinct depending on the metric selected. Summing up, the findings point out the necessity of a heterogeneous network of green spaces that are purposely planned and managed considering the synergies and trade-offs between human and wildlife requirements.

In conclusion, the results of this doctoral thesis confirm the important role of green space quality in providing benefits to humans and animals. It also stresses the advantage of applying the One Health approach also to the urban context and, more specifically, to green infrastructure, enabling the identification of mutually beneficial effects and potential trade-offs between the environment, humans, and animals, and ultimately the implementation of truly multifunctional spaces and solutions.

Zusammenfassung

In den kommenden Jahrzehnten ist davon auszugehen, dass sich Stadtgebiete signifikant erweitern und verwandeln werden, um den wachsenden Anteil der Weltbevölkerung, der in Städten lebt, aufzunehmen. Diese Herausforderung bietet eine einzigartige Möglichkeit unsere Städte zu überdenken und uns von Entwicklungsmustern zu lösen, die zu einer städtischen Umgebung geführt haben, die mit Umweltzerstörung und der Abkopplung von der Natur verbunden ist. Stattdessen sind transformative Veränderungen anzustreben, die gesündere und widerstandsfähigere Städte fördern, in denen Menschen und Natur gut leben und gedeihen können. Die Etablierung einer urbane grünen Infrastruktur ist eine der Hauptstrategien zur Erreichung dieses Zieles, da diverse Arten von Grünflächen und -strukturen das Potential haben, verschiedene Ökosystemleistungen zu erbringen, die nicht nur der menschlichen Gesundheit und dem Wohlbefinden zugutekommen, sondern auch der Biodiversität dienen. Allerdings ist das Wissen über die nötwendige Qualität, die erforderlich ist, um die von grüner Infrastruktur erwarteten Vorteile effektiv zu erbringen sowie über mögliche Zielkonflikte zwischen Nutznießern mit unterschiedlichen Bedürfnissen noch begrenzt. Die vorliegende Doktorarbeit befasst sich mit diesen Forschungslücken anhand zweier Hauptfragen: a) wie und welche Grünflächenmerkmale mit mentaler Gesundheit und Wohlbefinden sowie dem Schutz und Erhalt der Wildtiere zusammenhängen, und b) welche Synergien und Zielkonflikte zwischen den beiden Dimensionen mentale Gesundheit und Wildtiere in urbanen Grünflächen bestehen.

Im Rahmen einer systematischen Literaturrecherche wurden Grünflächenmerkmale mit ihrer Wirkung auf die mentale Gesundheit von Menschen und/oder dem Schutz und Erhalt der Wildtiere zusammengetragen. Anschließend wurde der holistische One-Health-Ansatz als Basis für die Entwicklung eines theoretischen Rahmens genutzt, der die qualitativen Aspekte von Grünflächen mit mentaler Gesundheit und Wohlbefinden und dem Schutz und Förderung der Wildtiere im urbanen Raum verbindet.

Um diesen theoretischer Rahmen in einer Fallstudie in Brasilien anwenden zu können, war in einem ersten Schritt die transkulturelle Anpassung der ausgewählten psychometrischen Skalen zur Messung der psychischen Erholung in der Zielpopulation notwendig. Insbesondere wurden die Perceived Restorativeness Scale und die Restoration Outcomes Scale ins Portugiesische übersetzt und anhand von Stichproben in den Städten Porto Alegre und São Paulo im Süden und Südosten Brasiliens validiert. Die psychometrischen Eigenschaften beider Skalen präsentierten adäquate interne Konsistenz und Modellanpassungsindizes, die über das Geschlecht und den Wohnort der Teilnehmer hinweg konsistent blieben. Neben der beabsichtigten Anwendung in

dieser Arbeit bietet die Bereitstellung dieser neu validierten Versionen solcher Maßnahmen die Möglichkeit, die Forschung zu erholsamen Umgebungen im wenig untersuchten globalen Süden, insbesondere in Brasilien, zu erweitern.

In São Paulo, Brasilien, wurde eine Fallstudie durchgeführt, bei der die in der systematischen Literaturrecherche ermittelten Indikatoren und Messgrößen verwendet wurden, um die im entwickelten Bezugsrahmen dargestellten Zusammenhänge zu analysieren. Die wichtigsten Faktoren, die die Erholung der Nutzer beeinflusst haben, waren die wahrgenommene Sicherheit und die Naturnähe der Parks. Diese Wahrnehmungen standen in Zusammenhang mit Parkmerkmalen wie der Baumkronenbedeckung, dem Vorhandensein von Gewässern und Anzeichen von Vandalismus. Das Vorhandensein von natürlichen Gewässern stellte einen eindeutigen Nutzen für die mentale Erholung und dem Schutz und Erhalt der Vögel (als representative Spezies für die Wildtiere) dar. Im Gegensatz dazu, boten Parks mit einer größeren Baumkronenbedeckung den Nutzern ein höheres Erholungspotential, während die Ergebnisse für die Vogelarten je nach gewähltem Kriterium unterschiedlich ausfielen. Schließlich weisen die Ergebnisse auf die Notwendigkeit eines heterogenen Netzes von Grünflächen hin, die unter Berücksichtigung der Synergien und Kompromisse zwischen den Bedürfnissen von Menschen und Wildtieren gezielt geplant und verwaltet werden müssen.

Zusammenfassend bestätigen die Ergebnisse dieser Dissertation die wichtige Rolle der Grünflächenqualität für den Nutzen für Mensch und Tier. Sie betonen außerdem den Vorteil der Anwendung des One-Health-Ansatzes auch auf den städtischen Kontext und insbesondere auf ihre grüne Infrastruktur. Dies ermöglicht die Identifizierung von wechselseitig vorteilhaften Auswirkungen und potenziellen Konflikten zwischen Umwelt, Menschen und Tieren und schließlich die Umsetzung von tatsächlich multifunktionalen Grünflächen und Lösungen.

Contents

Abbreviations

AIC	Akaike Information Criteria
BA	Being away dimension
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CI	Confidence interval
CO	Coherence dimension
FA	Fascination dimension
H-BRS	Hochschule Bonn-Rhein-Sieg
ISO	International Standards Organization
IZNE	International Centre for Sustainable Development
ME	Metric Model
MW	Minimum wage
NDVI	Normalized Difference Vegetation Index
PRS	Perceived Restorativeness Scale
RMSEA	Root Mean Square Error of Approximation
ROS	Restoration Outcome Scale
SC	Scalar model
SD	Standard deviation
SEM	Structural Equation Model
SRMR	Standardized Root Mean Square Residual
UGI	Urban green infrastructure
UNU-EHS	United Nations University – Institute for Environment and Human Security
VIF	Variance inflation factor
ZEF	Zentrum für Entwicklungsforschung

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1. Introduction

1.1 Background and motivation

By 2030, around 5 billion people will be living in cities, demanding the expansion of urban areas to triple the level at the beginning of this century (Seto et al., 2012). This significant and imminent expansion raises concerns about the continuous application of urbanization patterns that have created socio-ecological environments that impose many risk factors on physical and mental health (Gruebner et al., 2017; Prüss-Ustün et al., 2016). For instance, in comparison to their rural counterparts, urban dwellers are at higher risk of major mental illnesses such as anxiety, mood, and psychotic disorders, a phenomenon called the urban psychological penalty (McDonald et al., 2018). Recognizing the need for change, cities worldwide have been seeking new alternatives for building and transforming urban areas to provide healthier and resilient environments for their inhabitants. The integration of green infrastructure into urban planning has gained momentum as a strategy to make cities more livable (World Health Organization, 2016).

Green infrastructure is defined as natural, semi-natural, and artificially-created networks of multifunctional ecosystems located at multiple spatial levels within and around cities (Tzoulas et al., 2007). In the urban context, it is called urban green infrastructure (UGI) and comprises a variety of green spaces (e.g. parks, gardens, and cemeteries) and infrastructures (e.g. green walls, green roofs, and bioswales). Empirical research provides evidence of the role of UGI in providing several ecosystem services that benefit human health and well-being such as microclimate regulation (Iungman et al., 2023; Klemm et al., 2015), air purification and noise reduction (Cohen et al., 2014), and coping with mental disorders (Marselle et al., 2020). Besides the benefits to urban dwellers, UGI also provides habitat and resources for plants and animals. This is especially important because several urban areas overlap highly biodiverse regions, and therefore cities can also act as areas for biodiversity conservation, mainly through the preservation and implementation of green spaces that support local flora and fauna (Aronson et al., 2017; Beninde et al., 2015; Cornelis and Hermy, 2004; Ives et al., 2016).

The importance of UGI is reflected in the international agenda, especially in the Sustainable Development Goals (e.g. Goal 11 - Make cities and human settlements inclusive, safe, resilient and sustainable) (United Nations, 2015), the New Urban Agenda (United Nations, 2017), and the brand new Kunming-Montreal Global Biodiversity Framework (i.e. Target 12 - green and blue spaces in urban and densely populated areas) (CBD, 2022), all drawing attention to the role of green and public spaces for achieving environmentally sustainable and resilient urban development. Although many synergies can be found in the agendas, trade-offs also exist. In order to avoid urban sprawl into natural habitats, thus biodiversity and ecosystem services loss, there has been an increasing movement towards city densification and compaction (United Nations, 2017). However, this jeopardizes the preservation and creation of green spaces within cities as there is a global trend of green space reduction with the increase in human population density (McDonald et al., 2023). Additionally, a drawback exists in convincing decision-makers of the importance of preserving and investing in new green spaces because their implementation and management require a significant budget whereas not all the benefits of these areas are easy to quantify in economic value.

Considering that space for nature is becoming more limited and under pressure within cities, there is an increasing need for quality and multifunctional green spaces, which maximize benefits for human health and biodiversity conservation. Effective design and management may enhance the services provided and attach a higher value (not merely economic) to these places, consequently contributing to their preservation facing the pressure of urban development.

1.2 Theoretical framework and research gaps

1.2.1 Green spaces and human health

A large body of literature recognizes the benefits that nature exposure provides to human physical and mental health (see Sandifer et al. 2015 for a review). Although causality is still not fully comprehended, three pathways may connect green spaces to human health and well-being: harm reduction (mitigation of environmental stressors), capacities building (physical activities and social cohesion), and capacities restoration (cognitive and stress recovery) (Markevych et al., 2017). In this study, the capacities restoration pathway was selected to investigate the beneficial effect of green spaces on mental health and well-being. This is in line with the positive sense of mental health as not merely the absence of a mental disorder, but as the foundation for well-being and effective functioning for an individual and for a community (WHO, 2004). As determinants of mental health encompass environmental factors, improvements of the urban environment can potentially act as health-promoting public health interventions.

Studies on capacities restoration often belong to the restorative environments research field, which study how environments differ in their potential to recover depleted adaptive resources (von Lindern et al., 2017). Usually, they focus on comparisons between the potential of natural *versus* urban-built settings on cognitive restoration and well-being, usually considering natural settings as homogenous. Therefore, although research on urban green spaces has been rapidly growing, several studies emphasize the little attention directed to the quality of nature that people have been exposed to, which could be important in terms of assessing the most relevant components of these settings that are linked to mental restoration potential (Carrus et al., 2015; Hartig et al., 2014; Peschardt and Stigsdotter, 2013; Stigsdotter et al., 2017). Moreover, studies usually show limitations such as the use of pictures as stimuli to rate the settings (Nordh et al., 2009) which may not reflect the actual experience in the site (Negrín et al., 2017). In terms of environment characterization, some use only qualitative tools (Peschardt and Stigsdotter, 2013; Stigsdotter et al., 2017) or quantify design variables through a picture of the setting (Nordh et al., 2009). More objective knowledge about the specific attributes important for enhancing the restorative potential in urban settings should be gathered if this research area is to guide policies and design towards health and well-being promotion through access to opportunities for nature contact and exposure within cities (Hartig, 2011; Karjalainen et al., 2010; Peschardt and Stigsdotter, 2013).

Empirical evidence still suffers from geographical bias towards the Northern Hemisphere, especially Europe and North America. Considering that even among European countries different perceptions can be observed (Edwards et al., 2012), there is a knowledge gap on the potential role of geographic conditions, local demands, and cultural-specific perceptions and behaviors in shaping human-nature relationships (Hartig et al., 2014; Kabisch et al., 2015). This knowledge is important considering that the design and manage of green spaces have to be sensitive to local contexts (World Health Organization, 2016).

1.2.2 Green spaces and biodiversity

Three main aspects make green infrastructure an important strategy for biodiversity conservation: it provides habitat for local flora and fauna (biodiversity support), especially in urbanized landscapes, through the creation and maintenance of natural and semi-natural areas; it potentially enhances species movement by promoting connectivity among habitat patches; and its broad and plastic concept facilitates the understanding by different disciplines and stakeholders (Garmendia et al., 2016). In contrast, its broad definition may also contribute to UGI being often reduced to areas that are not built upon (Garmendia et al., 2016). The lack of minimal requirements for UGI quality combined with the consideration of biodiversity enhancement as a side effect or co-benefit jeopardizes urban biodiversity conservation since not all types of urban green spaces may provide the balance among habitat area, quality, and connectivity that is necessary for wildlife support (Hodgson et al., 2009).

Several studies provide evidence on urban green spaces supporting wild animal species (Estevo et al., 2017; Ives et al., 2016; Nielsen et al., 2014). These spaces can provide habitat, nesting, and food resources to non-domestic animals that can be found in human-dominated and non-agricultural areas, hereafter referred to as urban wildlife (Magle et al., 2012; Nielsen et al., 2014), However, the level of uncertainty involved in assuming that these areas will necessarily support significant biodiversity needs to be recognized and research should be carried out to determine the relative value of different UGI elements for urban wildlife support (Garmendia et al., 2016). Although mixed results on the effect of characteristics of urban green spaces on biodiversity richness can be found in the literature of different countries (e.g. Cornelis and Hermy, 2004; Fuller, et al., 2007), some general patterns indicate main effects at both patch/local (e.g. patch size, habitat heterogeneity, vegetation) and matrix/landscape scales (e.g. urban-rural gradient and patch isolation) (Beninde et al., 2015; Nielsen et al., 2014). Therefore, it is essential to understand the mechanisms involved in species distribution in urban habitats in order to plan and design green spaces that are effective for biodiversity conservation (Braaker et al., 2014).

1.2.3 Multifunctional green spaces

Multifunctionality is one main principle in UGI planning and should not be considered a mere compilation of as many functions (ecosystem services) as possible, but a strategy to create synergies among services that a place can offer in order to maximize benefits for social and ecological dimensions (Hansen and Pauleit, 2014). Synergies are established when ecosystem services improve each other simultaneously, whereas trade-offs imply that the enhancement of one service happens at the cost of another (Raudsepp-Hearne et al., 2010).

Planning for multifunctionality also implies dealing with many possible trade-offs. For instance, large vegetation areas have a high potential for habitat provision for fauna but may provide fewer drainage services (Dobbs et al., 2014) or even raise negative feelings in some people (Milligan and Bingley, 2007). Most of the studies on the benefits of urban green spaces focused on the assessment of a single ecosystem service, therefore synergies and trade-offs between services were not detected (Haase et al., 2014; Ziter, 2016). And usually, when detected, dealing with competing demands results in the prioritization of ecosystem services easily associated with economic benefits over biodiversity conservation concerns (Garmendia et al., 2016).

The One Health approach recognizes that the health of humans, animals, and the environment are interconnected, and promotes multidisciplinary and cross-sectoral collaborations to find solutions that benefit all dimensions (Queenan et al., 2017). In order to effectively integrate biodiversity and health concerns in UGI planning and management, such a holistic view is important to identify synergies between human use and biodiversity conservation in urban green spaces, as well as acceptance thresholds, and therefore offer spaces that benefit both (Aronson et al., 2017). Although the majority of the studies under the One Health approach has focused on zoonotic diseases and anti-microbial resistance, the present study aims to expand the One Health approach to health promotion along with biodiversity conservation, exploring the potential benefits that green spaces may offer in the human-wildlife-environment interface in urban areas.

1.3 Problem statement and research questions and objectives

The available literature on the effects of urban green spaces on human mental health and biodiversity support presents mixed results, strong geographical and taxonomic biases, and only broad orientations to decision-makers and planners. Additionally, studies that integrate these dimensions are exceptions in the field. Therefore, there is a need for studies that apply interdisciplinary approaches such as a socioecological framework that captures interactions among human, animal, and environment dimensions.

This study aims at identifying which and to what extent specific characteristics of urban green spaces may affect human health and wildlife support, and which are the synergies and trade-offs between these two dimensions. This thesis was constructed based on two main research questions and associated objectives:

RQ1: Which and how green space characteristics have been associated with mental health and wildlife support outcomes?

RO1: Identify and compile indicators reflecting green space quality that have reported associations with different measures of mental health and wildlife support in the literature.

RO2: Investigate relationships between selected green space indicators and metrics of mental health and wildlife support in the context of a megacity from the Global South.

These objectives address the research gaps regarding the consideration of nature as homogeneous, geographical bias, knowledge of the effect of individual park characteristics, and user real experience instead of photographs/videos.

RQ2: What are the synergies and trade-offs between human health and wildlife dimensions in urban green spaces?

RO3: Identify green space features that benefit both human and wildlife outcomes, as well as features that bring divergent outcomes to these dimensions.

RO4: Investigate the effect of actual and perceived biodiversity on mental health outcomes.

These objectives address the lack of studies integrating both dimensions and contribute to emerging evidence on biodiversity's effect on human health outcomes.

1.4 Research context

This PhD was conducted as part of the Forschungskolleg "One Health and Urban Transformation – identifying risks and developing sustainable solutions" funded by the Ministry of Culture and Science of North Rhine-Westphalia. This Forschungskolleg is jointly operated by the Center for Development Research (ZEF), the International Centre for Sustainable Development (IZNE) at the Hochschule Bonn-Rhein-Sieg (H-BRS), and the United Nations University – Institute for Environment and Human Security (UNU-EHS) Bonn, in collaboration with the Department of Geography (Faculty of Mathematics and Natural Sciences, University of Bonn), and the Institute for Hygiene and Public Health (Medical Faculty, University of Bonn).

1.5 Overview of doctoral thesis structure

This cumulative doctoral thesis comprises six chapters. Chapters 1 and 2 provide the theoretical and methodological framework applied in this thesis. Each of the three main chapters (3, 4, and 5) is included in the form of a manuscript prepared for publication in international peer-reviewed journals. Two manuscripts (chapters 3 and 4) were already published and the third (chapter 5) is currently in preparation for submission. Chapter 6 presents the main findings, potential implications of the findings, limitations and suggestions for future studies, and conclusion.

Chapter 3 addresses research objective 1 through a systematic review of urban green space factors affecting human mental health and wellbeing as well as wildlife support. The evidence compiled was used for the development of a conceptual framework and the selection of the human mental health and wildlife metrics used in this thesis. In chapter 4, the translation and validation of the metrics selected to assess mental restoration to the target population was conducted.

Chapter 5, addresses research objectives 2, 3, and 4, investigating relationships depicted in the conceptual framework (chapter 3) through a case study in São Paulo city, Brazil.

2. Methods and data

2.1 Overview of workflow and methods

This thesis is composed of three analytical chapters with different but interlinked objectives (Fig. 1). In the first phase of the research, a systematic review (chapter 3) was conducted to identify indicators reflecting urban green space quality that were already associated with human mental health and wildlife support outcomes, as well as the metrics most commonly used to assess human mental health and wildlife in the context of urban green spaces. Moreover, this work allowed the development of a framework considering potential mediators and moderators involved in the relationships between green space, human, and wildlife dimensions. As a follow-up step, a cross-cultural translation and adaptation of the most used instruments to assess mental wellbeing outcomes in the systematic review had to be conducted as no versions in the Portuguese language were available (chapter 4). The final versions were tested in a pilot study conducted in the cities of Porto Alegre and São Paulo and validated through psychometric analysis.

In the second phase, a case study (chapter 5) was conducted to investigate the interlinkages and relationships depicted in the framework product of the literature review. Through a general assessment of all eligible urban parks, we assigned them into groups according to the area, tree cover, and social vulnerability, from where representatives were selected to be surveyed. From the list of green space indicators product of the review, a selection of the most relevant and applicable indicators was conducted in a workshop with practitioners of São Paulo City Hall. Data on park indicators was collected on the ground and through secondary data and satellite images. The survey included the instruments validated in chapter 4, as well as relevant variables that were raised in the systematic review. Secondary data was retrieved to calculate the most used wildlife support metrics found in the review. Statistical analysis was performed to assess relationships depicted in the framework and identify synergies and trade-offs between human and wildlife dimensions.

The transdisciplinary character of this research required a diversity of methods, primary and secondary data acquisition, and the knowledge of best practices in several research fields such as urban ecology, environmental psychology, and urban planning. A table is provided below with details of each research step, specific objectives, methods, and data used (Tab. 1 and 2).

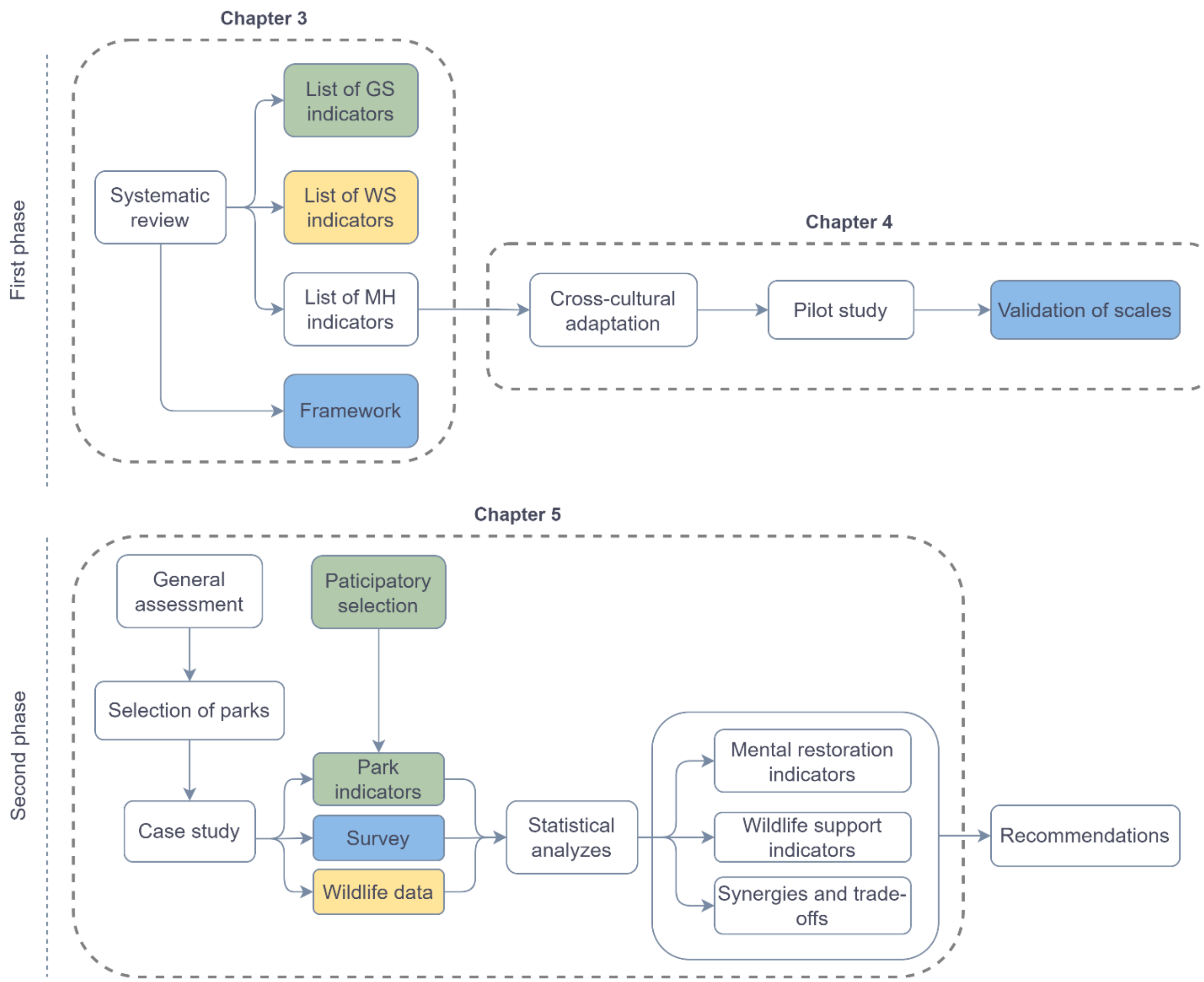

Figure 1. Overview of the working flow and delimitation of the analytical chapters of this doctoral thesis. Chapter 3 includes the systematic review which originated lists of indicators of green space (GS) quality, wildlife support (WS), and mental health (MH), as well as a framework depicting relationships between these dimensions. Chapter 4 is composed of the cross-cultural adaptation and validation of psychometric scales that measure mental restoration. Chapter 5 refers to the application of the framework to a case study using indicators selected from the systematic review and the validated scales.

Table 1. Main steps in the research process with objectives, methods, and data used.

Steps in the research process and main objective	Specific objectives	Methods and data
1. Literature review Collect indicators of green space quality and metrics of human mental health and wildlife support	a. Identify indicators of green space quality significantly related to human mental health and wildlife support outcomes; b. Identify the most used metrics of mental health and wellbeing; c. Identify the most used metrics of urban wildlife support; d. Identify potential synergies and trade-offs between human and wildlife dimensions; e. Develop a framework to guide future studies;	a. b. c. d. Systematic review of peer-reviewed literature; e. Framework development based on the results and the One Health approach Data: secondary data from studies published in a 10-years timeframe
2. Cross-cultural adaptation of scales Translate and validate scales selected to measure mental health outcomes	a. Translate and adapt scales to Portuguese (Brazilian) language b. Apply scales in a pilot study in Brazil c. Analyze the psychometric properties of the scales	a. Independent translations combined into single version and evaluated by an expert committee; a. Qualitative evaluation with the application of the instruments in a small sample; a. Back translations evaluated by the scales' authors; b. On-site questionnaire application with green space users in two Brazilian cities; c. Analysis of internal consistency, Confirmatory Factor Analysis, and multigroup confirmatory factor analysis; Data: primary data collected in surveys
3. General assessment and parks selection Ensure representativeness and relevant design variation among the selected parks	a. Categorize parks according to size and tree cover; b. Categorize parks according to sociovulnerability level;	a. b. Stratification of parks in groups followed by random selection inside each group Data: secondary data from municipality and satellite images
4. Participatory selection of indicators Ensure relevance and applicability of results	a. Identify indicators of green space quality that are relevant from the public agents point of view;	a. Workshop with public servants to rank indicators according to their relevance to mental health and wildlife, practical relevance, and availability/feasibility of data collection. Data: indicators list resulted from step 1

Table 2. Main steps in the research process with objectives, methods, and data used (Table 1 continued)

Steps in the research process and main objective	Specific objectives	Methods and data
5. Impact of park features on human mental health outcomes Identify characteristics that have a significant effect on mental restoration	a. Collect data on selected park indicators; b. Assess mental restoration of park users; c. Collect data on potential mediators/moderators; d. Assess the effect of park variables on mental restoration considering mediators/moderators factors;	a. GIS analysis and measurements on the field; c. d. On-site questionnaire survey; e. Statistical analysis (structural equation model, mixed-models) Data: primary data from survey and field measurements, and secondary data from municipality inventories on vegetation cover and bird species.
6. Synergies and trade-offs Identify park variables which similar and divergent effects on human and wildlife	a. Calculate wildlife diversity estimates for each park; b. Assess the effect of significant park variables on wildlife support c. Identify variables that benefit both human and wildlife (synergies) d. Identify variables that have divergent outcomes to human and wildlife (trade-offs)	a. Richness and Shannon-diversity estimation, urbanity index; b. Statistical analysis (spatial correlation analysis, linear regression models) c.d. Comparison with results from step 5. Data: secondary data from citizen-science platforms;

2.2 Study area

Chapter 5 of this thesis consists of a case study conducted in São Paulo City, Brazil. This is one of the four metropolitan regions focused on by the 'Forschungskolleg One Health and Urban Transformation', along with the Ruhr Metropolis (Germany), Ahmedabad (India), and Accra (Ghana).

São Paulo is a city of impressive numbers. Having an estimated 12 million inhabitants distributed over 1.521,110 km², of which almost two-thirds are built up, the city is the largest and most populous in Brazil and the fourth largest in the world (United Nations, 2018). Its territory is divided into 97 districts organized in 32 regional prefectures. Regarding climate, according to the Köppen classification, it is characterized by a humid subtropical climate with a cold and dry season from April to September (fall and winter), and a warm and wet season from October to March (spring and summer) in which the mean temperature is higher than 22°C (Alvares et al., 2013).

The territory of this megacity overlaps the Atlantic Forest biodiversity hotspot, the most endangered biome in Brazil with only 28% left of native vegetation cover (Rezende et al., 2018). Along with the area loss, its high diversity of endemic species is considered biotically compromised, with about 30% of species loss (Newbold et al 2016). São Paulo's original landscape was mainly degraded during the expansion of coffee production in the mid-19th century (São Paulo, 2017) and in the 1970´s industrial phase, with accelerated and unplanned growth and sprawl towards the surrounding regions (São Paulo, 2008).

Currently, about 21% of the city is still covered by vegetation however, it is concentrated in fragments of the secondary natural vegetation of the Atlantic Forest at the extreme south (Serra do Mar) and north (Serra da Cantareira) of the territory (São Paulo, 2017). The distribution of green areas within the city is insufficient and unequal. Of the 32 regional prefectures, only five meet the index of 15m² of green area per capita recommended by the Brazilian Society of Urban Forestry (SBAU, 1996), three of them having indices from 65 to 312 m²/per capita whereas half (16) has indices lower than 5 m²/inhab (Casimiro, 2018).

As an effort to improve the availability of public green spaces, the municipal government launched the program "100 Parques para São Paulo" (100 Parks for São Paulo): an ambitious plan to triple the number of municipal parks (34 sites at that time) which was implemented from 2005 to 2012. This short period in São Paulo´s history was the most relevant for the expansion of the green areas system, with the remarkable implementation of 53 out of the close to 100 municipal parks available until 2017 (Casimiro, 2018). Currently, the 111 parks under the municipality stewardship are categorized as urban, linear, and natural parks (São Paulo, 2022). Urban parks usually protect forest patches within the urban area and are characterized by the presence of administrative infrastructures, physical protection in the perimeter (grids), and focus on biodiversity protection, however, serving as leisure spaces as well. Linear parks have been implemented to protect river banks and may provide some leisure, but have no grids and less to no administrative infrastructure. Natural parks are conservation units created in more preserved areas with the main objective of protecting biodiversity.

The visible variation in parks' characteristics (Fig. 2) in terms of tree coverage, facilities, and size, makes the city of São Paulo a good case study to test the impact of green space features on human health and wildlife outcomes. However, such analysis must consider the unequal socioeconomic conditions present in this city. Social groups are highly spatially segregated, with the low-income population mostly located in the peripheral areas, which offer less accessibility to amenities and lower-quality services (Feitosa et al., 2021). Therefore, we addressed the issue in this research by selecting parks located in regions with different levels of vulnerability to poverty according to the São Paulo Social Vulnerability Index (SEADE, 2013) (Fig. 3). This index aggregates socioeconomic and demographic dimensions through several variables reflecting vulnerability to poverty: income (e.g. household income per capita, % households with per capita income up to ½ minimum wage), literacy (e.g. % of literate household heads), and family circle characteristics (e.g. % of female household heads from 10 to 29 years old, % of children from 0 to 5 years old).

	**Rio Verde Park** Small size Low tree coverage
	**Profa. Lidia Natalizio Diogo Park** Small size Medium tree coverage
	**Trianon Park** Small size High tree coverage

Figure 2. An example of the differences in park characteristics. Depicted are parks (and respective names) categorized as small in size but with different levels of tree coverage (low, medium, and high).

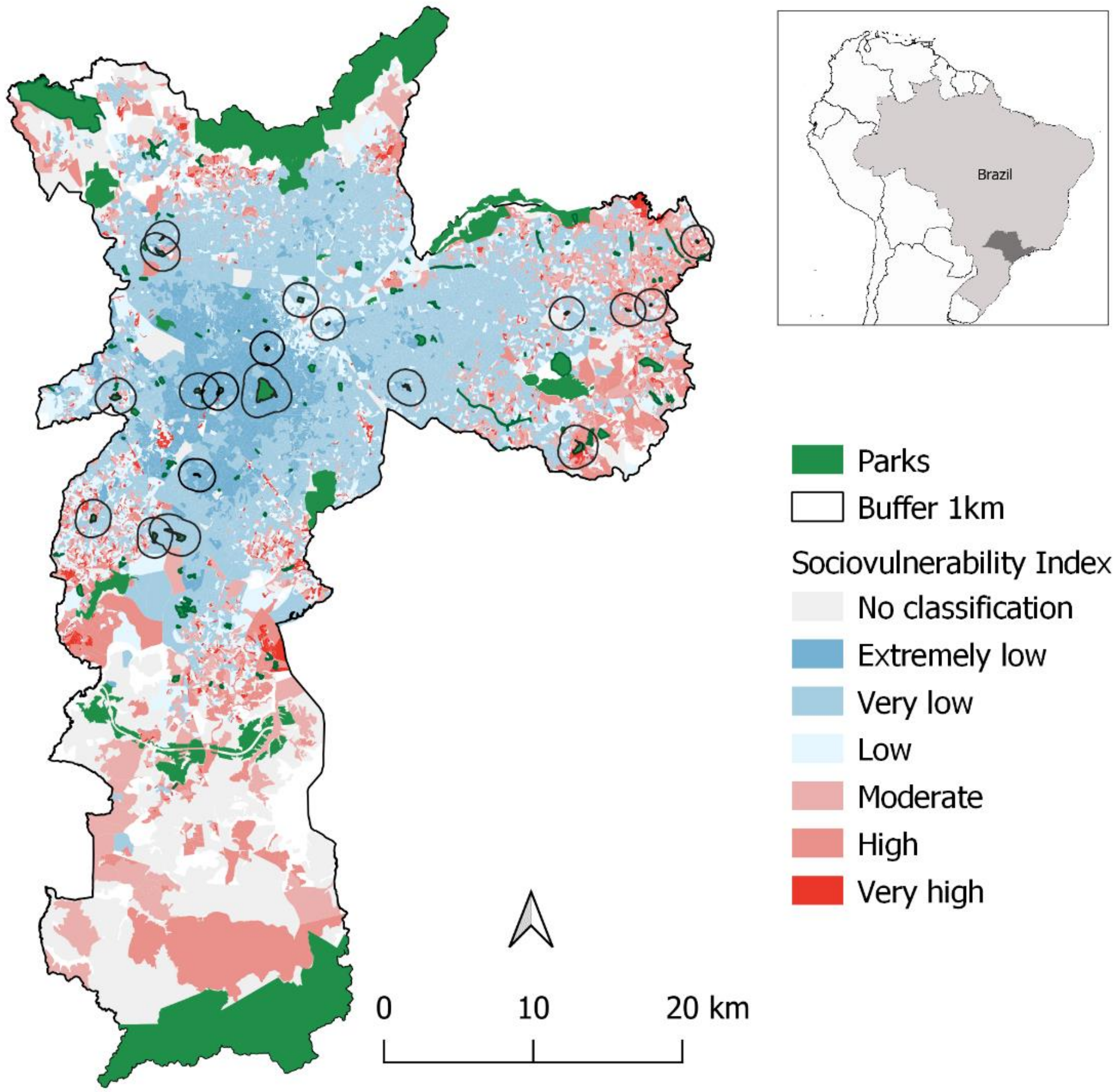

Figure 3. Map of São Paulo city showing the location of parks selected in this study in relation to the distribution of sociovulnerability levels in the territory. The sociovulnerability index layer is publicly accessible on the Geosampa platform (https://geosampa.prefeitura.sp.gov.br/) and was downloaded as shapefile. In the upper right, the location of São Paulo state in Brazil.

3 Systematic review and integrative framework uncovering synergies and trade-offs between mental health and wildlife support in cities[1] [2]

3.1 Introduction

Green infrastructure is associated with multiple benefits to physical and mental health however, mental health and its relation with the environment is still a neglected topic in urban planning despite its relevance in urban areas (Okkels et al 2018). Good practices in urban planning may counteract part of the urban psychological penalty (McDonald et al., 2018) by fostering the green in the city, such as large and pocket parks, street trees, backyards, and gardens, which have been increasingly associated with better mental health (Wood et al., 2017), life satisfaction (Houlden et al., 2019), mental restoration (Lindal and Hartig, 2015), and stress recovery (Hunter et al., 2019). However, several studies emphasize the little attention directed to the quality of green that people have been exposed to (Jorgensen and Gobster, 2010), which could promote or prevent green space use and consequently its benefits to people.

Urban areas also pose risks to wild animal populations, through the degradation and fragmentation of natural habitats (McDonald et al., 2018), exposure to pollutants, and parasites transmission (Murray et al., 2019). Nevertheless, cities have a surprisingly huge potential to harbor biodiversity, and even threatened species (Ives et al., 2016). In this regard, it is essential to identify green space characteristics that are determinant in providing the necessary conditions for urban wildlife support in order to avoid the collection of “green deserts” that do not contribute to biodiversity conservation (Hodgson et al., 2009).

On the one hand, green spaces are considered a strategy to provide improve health and biodiversity in urban areas. On the other hand, even sustainable urban development approaches such as the compact design threatens the preservation of existing green spaces (Haaland and van den Bosch, 2015). In such complex challenges, a holistic view is necessary if cities are to become places that promote health and biodiversity. The One Health approach consider that the

[1] A modified version of this chapter was originally published as: Felappi, J.F., Sommer, J.H., Falkenberg, T., Terlau, W., Kötter, T., 2020. Green infrastructure through the lens of “One Health”: A systematic review and integrative framework uncovering synergies and trade-offs between mental health and wildlife support in cities. Science of The Total Environment, Volume 748, 141589. https://doi.org/10.1016/j.scitotenv.2020.141589
[2] The numbering of figures and tables was changed to consecutive numbers.

health of humans, animals, and the environment depends on each other, and looking at these dimensions simultaneously can lead to more efficient solutions that benefit all (Queenan et al., 2017; Lebov et al., 2017). Green spaces can strategically combine different functions, maximizing benefits for social and ecological dimensions (Hansen and Pauleit, 2014) and therefore withstand urban development pressures. Therefore, the One Health approach may help to identify synergies to maximize and trade-offs to manage in truly multifunctional green spaces.

To contribute to urban green space planning in terms of ensuring the quality necessary for the provision of services to humans and wildlife, this paper aims to (a) review the existing evidence on how urban green space's quality has been associated with mental health and wildlife support outcomes; (b) compile a list of indicators of green space quality used in these studies; (c) identify potential synergies and trade-offs between the two dimensions; and (d) propose a framework based on the One Health approach to uncover interlinkages on the mental health-wildlife-environment interface in the context of urban green spaces.

3.2 Material and methods

3.2.1 Search strategy

A systematic review was conducted in order to identify studies that associated urban green space quality to mental health and wildlife support and to extract indicators used in their analyses. Two different searches were carried out on the Science Direct database. For the human mental health dimension, the selected keywords were ("green space" OR "park") AND ("mental health" OR "restoration" OR "restorative" OR "psychological"). The terms "green space" and "park" are widely used in studies on green areas in the urban context. The keywords "mental health" and "psychological" (regarding either psychological benefits or psychological well-being) were used to retrieve a broad range of studies in this dimension, while "restoration" and "restorative" were used to also capture studies on cognitive restoration and stress recovery related to restorative environments (Kaplan, 1995). For the wildlife dimension, we opted for three blocks of search terms: ("urban" OR "green space" OR "park") AND ("biodiversity" OR "wildlife" OR "fauna") AND ("distribution" OR "variable" OR "driver"). The third block of terms was included to direct the search towards studies that not only describe biodiversity but rather investigate its spatial patterns of distribution. In both searches, the terms were included in either the title, abstract or author-specified keywords. There was no restriction regarding geographic location, but we limited the searches to the period from January 2008 to December 2019. In order to expand the literature coverage, the so-called snowballing method was applied in a second step to screen the reference lists of the selected articles and identify additional promising studies.

3.2.2 Eligibility and selection criteria

Records were selected for full-text assessment based on the screening of titles and abstracts. Articles were excluded when incompatible with the definitions of green space, green space quality, mental health, or wildlife support adopted in this study and described below. Only records in English language were included. Articles were selected if they presented at least one significant effect of green space features on mental health-related or wildlife support-related measures and described how the indicator was measured (see Supplementary material S.1 for details in selection criteria[3]).

In this study, urban green spaces were considered natural, semi-natural, or artificial ecosystems within the urban and peri-urban matrix (Tzoulas et al., 2007), such as private gardens, woodlands and parks, except for green roofs and green walls. By green space quality, we mean the collection of geographic, ecological and anthropogenic characteristics of the setting that can somehow be controlled and modified by humans, comprising, for instance, human-made structures, land cover, and vegetation structure and maintenance (Beninde et al., 2015). Articles were excluded when the study sites were not located within urban or peri-urban areas, or green space characteristics were merged into principal component factors and the individual effects could not be assessed.

For mental health, we followed the World Health Organization definition as a “state of well-being in which the individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community” (WHO, 2004, p.10) and looked for a range of measurements related to mental disorders, psychological benefits and well-being, as well as mental restoration outcomes. We excluded articles that focused only on either children; mortality rates; availability and accessibility of green spaces.

Finally, for urban wildlife support, we considered response variables that are reflected in wildlife health, defined by the capacity of non-domestic animals to cope with changes and to satisfy daily living requirements as a result of interactions between biological, social, and ecological determinants (Stephen, 2014). Articles were excluded when sampling points were not restricted

[3] Supplementary material S.1 of this publication can be accessed in chapter i.a. in the appendices.

to green spaces, only impacts on vegetation or impacts of agriculture were considered, the focus was on variation across urbanization gradients or comparison between urban and rural areas.

3.2.3 Data extraction

From each study, we systematically extracted the following data:

(a) Indicators of green space quality that were statistically significant, and their description (independent variables);
(b) The measure used to quantify a mental health/psychological outcome or state; or the measure of wildlife support (dependent variables);
(c) The observed effect of the independent variable on the dependent variable. We only considered analysis with clear and significant results (i.e. p-value < 0.05 and 95% CI not overlapping with zero), and with the direction of the relationship (i.e. positive or negative effect for continuous variables, and the category with the strongest effect for categorical variables);
(d) The type of nature exposure (e.g. on-site experience, photographs, virtual reality) used on mental health studies or the animal group investigated in wildlife studies (e.g. mammals, birds);
(e) The country where the study was conducted.

3.2.4 Framework development

Although the dimensions that compose the One Health triad, i.e. environmental health, human health, and animal health, should be equally addressed, studies under this approach typically have focused on zoonotic and vector-borne diseases (Lapinski et al., 2015; Rabinowitz et al., 2018), neglecting the environmental dimension and having human health as the ultimate target. Here, we adapt and propose an expansion in the application of this concept in terms of (a) applying it to the urban context, (b) changing the negative focus of environment and animals as sources of diseases towards salutogenic approaches (Antonovsky, 1996), addressing prevention and maintenance of good health and well-being with urban green spaces and their biodiversity as potential health promoters, and (c) addressing wildlife conservation not only as a beneficial side-effect but also as a target.

For the purpose of this study, the environmental health dimension refers to the urban environment and is represented by the network of green spaces, which are known to provide important services such as microclimate regulation (Klemm et al., 2015), air purification and noise buffering (Cohen et al., 2014). The focus is on green space qualities, which are considered a critical factor for ecosystem functioning and the services provided (Aronson et al., 2017; Klemm et al., 2015). The human health dimension focuses on mental health benefits derived from green spaces. The animal health dimension is limited to non-domestic animals that can be found in the city (urban wildlife) and their health and conservation at the population level (Lerner, 2016).

Based on the data extracted from our systematic review, we elaborated a framework illustrating (a) pathways linking green space's qualities to mental health; (b) linkages between green space's qualities and wildlife support; (c) connections between the three dimensions; and (d) external drivers that potentially affect this system.

3.3 Results

A total of 1.428 articles were screened through the steps depicted in Figure 4, resulting in 72 articles included in this review. The search on the mental health dimension resulted in 541 records, comprising 491 research articles, 28 review articles, and 22 book chapters. After screening the titles and abstracts applying the selection criteria, 70 articles were selected for full-text assessment, and finally, 11 studies fulfilled the criteria and were included in this review. Through the snowballing process, 52 references were added. From these, 18 articles were assessed in full-text and 9 selected, thus a total of 20 articles (for the mental health dimension) were included in this review.

From all screened mental health articles, two mainstream study designs were identified. The first case comprises epidemiological studies in which health data gathered in national surveys or online/mailed questionnaires is correlated with green space availability (e.g. green coverage within buffers surrounding each participant residence) and/or green space accessibility (e.g. distance to the nearest green space). Due to the fact that this study design does not take into account green space quality, it fell outside the scope of this review. The second study design refers to experimental studies in the environmental psychology field and is characterized by the use of photographs, combined or not with audios, as stimuli to participants that should rate them according to perceptions or feelings. In this case, different attributes of the green spaces can be manipulated and several studies under this approach were included in this review. Additionally, the majority of studies on mental health screened did not collect objective measurements of green spaces quality, or calculated indices and composite scores, which does not allow the assessment of individual factors.

The wildlife dimension search resulted in 718 records, being 688 research articles, 24 review articles, and 6 book chapters. After this step, 66 articles remained for full-text assessment and 27 were selected. The snowballing process contributed 117 additional references, of which 50 were selected for full-text assessment, and 25 articles included, totaling 52 articles from this dimension included in this review.

In the screening process, we identified a transition from the typical approach that assesses biodiversity levels across the urban-rural gradient and assumes urbanization level as the main driver of variation, towards a more recent focus on the role of specific characteristics of the environment, at local and landscape levels, shaping urban biodiversity. Therefore, in contrast with mental health studies, the role of green space characteristics on wildlife support was extensively tested and consequently resulted in a higher number of indicators included in this review compared to the mental health dimension.

3.3.1 Overview of selected studies

As a general pattern, studies were mainly conducted in Europe and North America (67% of studies, Supplementary material S.2.[4]). Mental health studies were dominated by European countries (60%) and few studies in North America and Asia. For urban wildlife, studies from all regions were included, however, Europe and North America shared the majority of studies (61%), while South America and Africa were poorly represented (10%).

Seven different exposures or stimuli were identified in mental health studies. Most studies opted for on-site assessments or controlled exposure in a laboratory using photos as stimuli (40% and 30% of articles, respectively). Other forms were online or mailed questionnaires, photos combined with sounds, sounds solely, videos, and immersive virtual environment.

Wildlife studies covered a wide range of taxonomic groups of animals, comprising mammals, birds, reptiles, amphibians, molluscs, insects and invertebrates in a variety of green spaces such as parks, wetlands, gardens, woodlands, forest remnants, cemeteries and vacant lots. However, the majority of studies assessed bird communities (58% of articles), followed by insects (29%), in urban parks (33%) or more than one type of green space (21%). Only seven studies (13.5%) assessed two or more animal groups simultaneously.

[4] Supplementary material S.2 of this publication can be accessed in chapter i.b. in the appendices.

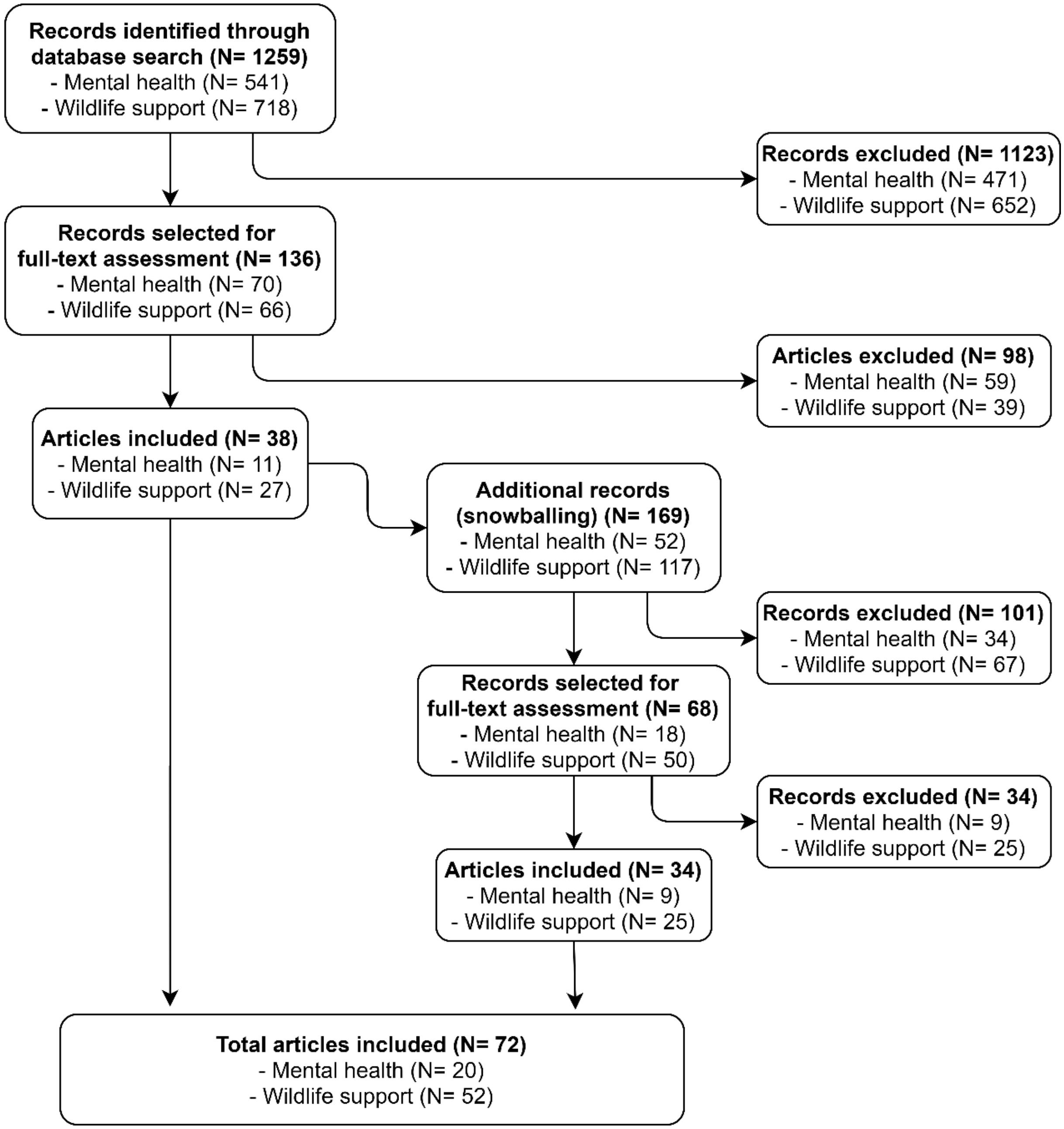

Figure 4. Flow diagram illustrating the selection process of studies included in the systematic review.

3.3.2 Mental health and wildlife support measures

The studies included in this review applied 22 different mental health-related measures, predominantly self-reported single-item rating scales and psychometric scales (multi-items). These psychometric instruments evaluate constructs (latent variables) that cannot be directly observed and allow the testing of empirical hypotheses and theoretical models (Hutz et al., 2015). Half of the studies used measures related to mental restoration (10 articles), followed by safety perception (6 articles), psychological well-being (6 articles), and test/physical measurements (3 articles). Four studies applied measurements from two or more of these dimensions. Due to the lack of green space quality assessment, studies applying the most commonly used methods of green space exposure assessment (i.e. availability and accessibility) were excluded, which may be directly related to the absence of measurements of chronic mental health outcomes, as these cannot be assessed in small-scale, short-term experimental studies.

The self-reported instruments applied in mental restoration studies were developed based on theories that explain the mechanisms by which contact with natural settings may recover our capacity to focus attention and reduce stress levels, thereby benefiting mental health and well-being (Kaplan and Kaplan, 1989; Ulrich, 1983). These instruments, i.e. Perceived Restorativeness Scale, Revised Restorativeness Scale, Likelihood of restoration, Potential for recovery from stress, Perceived Restorativeness Soundscape Scale, aimed to measure either the user's perception of restoration or the restorative potential of a setting, which largely depends on setting's characteristics.

Regarding wildlife support, a total of 20 types of measurements were applied. Species richness was the variable most widely used (38 articles), followed by abundance (21 articles), community composition parameters (16 articles), and diversity indices such as the Shannon or the Simpson index (13 articles). The majority of the studies (36 articles) considered two or more measures simultaneously.

3.3.3 Green space indicators

From the selected articles, we retrieved 33 significant green space quality indicators for mental health (Supplementary material S.3. and S.4.[5]) and 81 indicators for wildlife support (Supplementary material S.5. and S.6.[6]). We separated indicators into two domains - site-level

[5] Supplementary material S.3 and S.4 of this publication can be accessed in chapter i.b. in the appendices.
[6] Supplementary material S.5 and S.6 of this publication can be accessed in chapter i.b. in the appendices.

and landscape-level factors - and further classified them according to Table 3. Overall, indicators related to vegetation structure of green spaces were the majority but with a huge influence of the wildlife dimension (Fig. 5). In mental health studies, design (8 indicators) followed by spatial configuration and vegetation structure (6 indicators each) were the better-represented categories, while for wildlife support, they were vegetation structure (25 indicators), and management (17 indicators).

3.3.3.1 Landscape-level factors – urban matrix and connectivity

Only two studies tested the effect of landscape-level factors on mental health-related outcomes. No indicators regarding connectivity were identified. In the urban matrix category, land use in the surroundings of a green space affected the user's perceived safety, e.g. green spaces located in industrial areas invoked more fear of crime on visitors (Mak and Jim, 2018). Additionally, green space location was a factor influencing perceived restorativeness, with peri-urban areas being more restorative, probably due to less urban/human interference (Carrus et al., 2015). Although wildlife studies that purely investigated the variation of biodiversity in a gradient of urbanization were not the scope of this review, based on the literature available it is possible to consider that peri-urban green spaces are more favorable to native species (Nielsen et al., 2014), in synergy with restorative effects.

In the wildlife dimension, most of the indicators associated with urbanity levels, such as impervious surface and building cover, had a negative impact on wildlife support metrics. On the other hand, aspects related to the coverage of native tree species and green and blue areas, as well as their connectivity, positively affected wildlife support.

Population density around the green space may affect both dimensions but in different directions. While low-density residential areas were associated with lower safety perception of green space users (Mak and Jim, 2018), lower population densities increased the richness of bird and frog species (Fontana et al., 2011a; Hamer and Parris, 2011).

Table 3. Definition of each domain (site-level and landscape-level), the categories in which indicators of green space quality were classified, and examples of indicators for each category*.

Category	Explanation	Example of indicators
Site-level factors	Green space as the unit of analysis. Capture conditions at the microhabitat scale.	
Spatial configuration	Factors related to different types of land cover, size, and shape. A green space view from above.	Patch area; tree cover; grass cover; water cover; sealed area; shape
Vegetation structure	Aspects describing composition, complexity and spatial arrangement of different vegetation types.	Spatial arrangement; tree density; tree diversity; understorey coverage
Design	Refer to explicit decisions in the planning and implementation process in order to modify the original area for multiple purposes.	Accessibility to water; topography; habitat diversity; artificial structures
Management	Regarding maintenance of vegetation and facilities, and operation rules.	Vegetation maintenance; flowers; mowing height
Acoustic environment	Not limited to traffic noise level, but also considers other sources such as biological and geophysical sounds.	Noise level; bird songs; natural sounds
Biodiversity	Present only in the human health dimension. Comprises measures of plant and animal diversity.	Biodiversity level; bird richness; Bird density
Landscape-level factors	Buffer surrounding the green space in a specified radius as the unit of analysis. Capture conditions of the adjacent matrix.	
Urban matrix	Land use cover reflecting permeability to animal dispersion and qualities of the neighborhood.	Impervious surface; green coverage; adjoining landuse; water cover
Connectivity	Present only in the animal health dimension. Factors reflecting proximity to other areas of interest.	Connectivity/distance to other green spaces, wetlands, natural habitats

* The complete list of green space indicators is provided as Supplementary material S.3 to S.6.

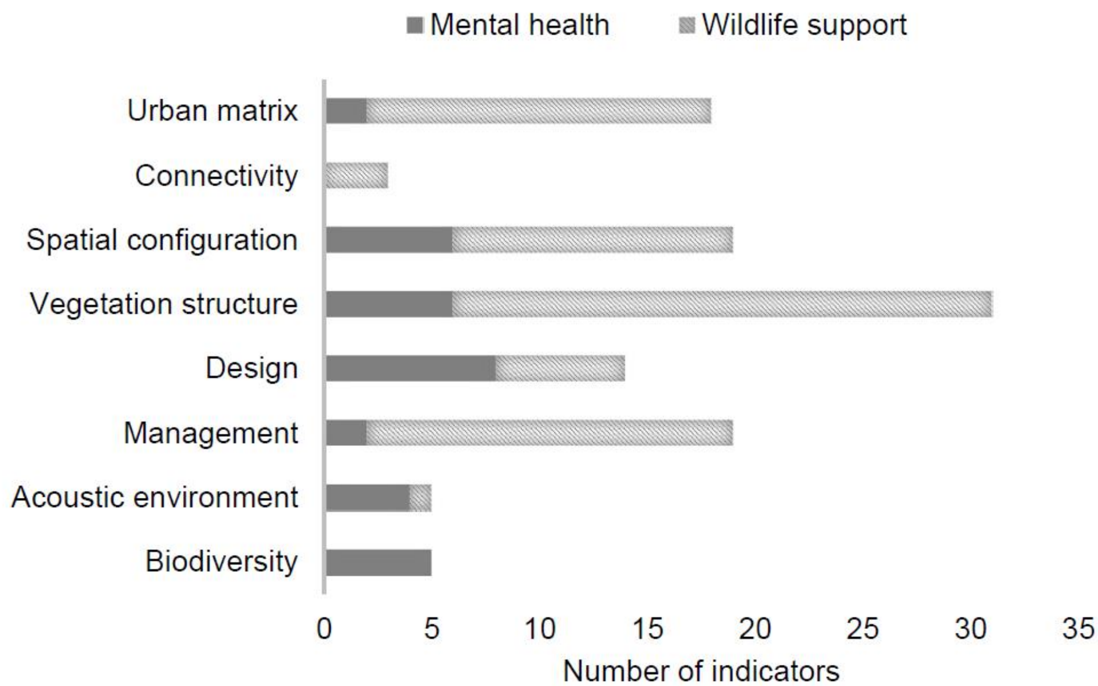

Figure 5. Number of indicators assigned to mental health and wildlife support in each category of independent variables. The complete list of green space indicators is provided as Supplementary material.

3.3.3.2 Site-level factors - Spatial configuration

Patch area showed a positive correlation with both mental restoration and wildlife support. Higher restoration potential was found in larger green spaces in European countries (Cervinka et al., 2016; Nordh et al., 2009), however, in a study conducted in a developing country, large parks invoked more fear of crime than smaller ones (Mak and Jim, 2018) and potentially impair the restorative experience. Green space area was the most commonly used indicator in the wildlife dimension and was consistently associated with positive effects on different types of measurements across animal groups.

Synergies were also found regarding vegetation cover and water. Bushes and trees coverage were positively associated with restoration and psychological well-being (Dallimer et al., 2012; Nordh et al., 2009), and with bird, butterfly and spider species richness (Fontana et al., 2011b; Kowarik et al., 2016; Shwartz et al., 2013). The presence of water bodies in green spaces improves their restorative potential (Nordh et al., 2009; Wang et al., 2019) and support to bird (Morelli et al., 2017; Yang et al., 2015) and invertebrate species (Johansson et al., 2019).

Grass cover had a positive effect on restoration (Nordh et al., 2013, 2009) but mixed results were found between and within animal groups. For instance, higher grass coverage was beneficial for butterfly abundance but had a negative effect on urbanophobe butterflies (Shwartz et al., 2013). As for birds, it had a negative influence on species richness but was positively related to nest occurrence of bird species associated with grasslands (Roche et al., 2016; Shwartz et al., 2008). These results illustrate that trade-offs may occur not only between human and animal needs but also within animal groups, depending on species' requirements.

3.3.3.3 Site-level factors - Vegetation structure

The effects of vegetation structure on restoration and psychological well-being measures are inconclusive. Whereas some studies found that more enclosed settings, with higher tree density, and vertical complexity similar to natural conditions were beneficial to restoration (Hauru et al., 2012; Hoyle et al., 2017; Wang et al., 2019), in other studies the restorativeness and other mental health-related outcomes were worse in settings with low prospect and high refuge potential or high tree density (Gatersleben and Andrews, 2013; Jiang et al., 2014). One factor that may influence the results is safety, since dense vegetation, with low permeability and visibility, was consistently linked to lower levels of safety perception (Andrews and Gatersleben, 2010; Baran et al., 2018; Jorgensen et al., 2012). In fact, when controlling for perceived safety, enclosed vegetation affected restoration positively (Tabrizian et al., 2018).

Interestingly, a negative relationship found between the actual number of plant species and psychological well-being may be an artifact of people's incapacity to estimate plant species richness since participants' perceived plant richness entailed positive results (Dallimer et al., 2012). This finding illustrates the relevance of analyzing not only objective indicators but also people`s perceptions of the settings.

Indicators of vegetation structure on the wildlife dimension were mostly positively correlated with several measures of urban wildlife support. Plant community diversity as well as horizontal and vertical vegetation complexity are favorable features for animal populations. In contrast, abundance of bird species was negatively correlated with some aspects of vegetation complexity mainly due to the contribution of alien species and specific guilds that benefit from open or more anthropic environments, as exemplified by the positive effect found when considering only native bird species (de Toledo et al., 2012). Additionally, the type of vegetation was an important factor, with non-native and invasive plant species negatively affecting avian and lepidopteran communities in contrast to native plant diversity (Amaya-Espinel et al., 2019; Burghardt et al., 2009; Dures and Cumming, 2010).

3.3.3.4 Site-level factors - Design

Presence of water bodies, and, more importantly, features that facilitate their accessibility and encourage activities linked to water may enhance user´s restoration (Zhao et al., 2018). Characteristics such as straight footpaths alignment, which allow a clear view ahead or behind, and sufficient number of gates are important factors to reduce fear of crime in green spaces (Mak and Jim, 2018).

Better restoration outcomes found in flat topography may also be related to user´s safety perception and the possibility to have a wide view of the surroundings (Zhao et al., 2018). On the other hand, flat topography may not be the most beneficial design for wildlife, since it often correlates with low habitat heterogeneity. Green spaces with higher diversity of habitats are more beneficial to wildlife, as retrieved in our review for butterflies and pollinator species (Shwartz et al., 2013), and as a general pattern already reported (Nielsen et al., 2014). Considering that settings with a higher number of natural features were also more restorative (Cervinka et al., 2016), designing spaces with a predominantly flat topography but ensuring a variety of habitats could have synergistic effects.

For birds, minimizing forest edges and designing trails with a significant distance from forest patches reduce the impact of human disturbance (Kang et al., 2012; Shwartz et al., 2008). However, the latter implies a trade-off between wildlife protection and people’s opportunity of immersion in nature, restricting the potential mental health and well-being outcomes.

3.3.3.5 Site-level factors - Management

Tended vegetation, with low amount of deadwood and brushwood, had a positive effect on mental health, strongly increasing “positive affect” and decreasing “negative affect” (Martens et al., 2011). For wildlife, however, intensive management is detrimental. The contrasting positive result on bird species abundance is actually an artifact of the increasing abundance of urban exploiter species (Shwartz et al., 2008). Green spaces that foster wildlife offer conditions more similar to nature adopting practices such as non-clearing of understory vegetation cover and aquatic vegetation, leaf litter and woody debris, covering of unpaved areas with mulch and peat, and maintaining longer grass height (Bryant et al., 2017; Heyman et al., 2011; Shwartz et al., 2013).

Human aesthetic preferences in green spaces have a potentially negative effect on urban wildlife support. This conflict is exemplified by urban ponds that were managed in a “clean” condition (emergent vegetation removal and mowing of surrounding vegetation) to favor human preferences (Noble and Hassall, 2014), and wood debris permanence in green spaces as a shelter for animals in contrast to aesthetics considerations (Barrett et al., 2016). Another potential trade-off identified is the presence of dogs in green spaces. While they can be detrimental to activity patterns of wildlife (Bryant et al., 2017), walking the dog is a common motivation for people to visit green spaces. Operating rules are important in this case to reconcile the allowance of pets and the minimization of their impact on wildlife.

A potential synergy between aesthetics and wildlife support is in relation to the management of decorative vegetation. The presence of flowers improved the restorative potential (Wang et al., 2019) as well as richness and abundance of bees and butterflies (Blackmore and Goulson 2014; Hoyle et al., 2018; Matteson and Langellotto, 2010).

3.3.3.6 Site-level factors - Acoustic environment

Biological sounds (i.e. birds and insects) and geophysical sounds (i.e. wind and water) positively affected restoration (Zhao et al., 2018), stress recovery (Alvarsson et al., 2010) and tranquility perception (Liu et al., 2019), whereas traffic noise had a negative effect (Evensen et al., 2016). Noise levels also affected bird communities, especially above a threshold of 50 dB, which increased the abundance of common species and reduced the presence of rare species (Patón et al., 2012). In another study, the results varied with the type of measurement adopted (i.e. presence or abundance) and the species analyzed. Altogether, nearly half of the bird species considered were not present with high levels of ambient noise (González-Oreja, 2017).

3.3.3.7 Site-level factors - Biodiversity

Only three studies selected in this review analyzed the influence of biodiversity on mental health and psychological well-being. Biodiversity was measured objectively through surveys (Dallimer et al., 2012), but also through subjective measures of user’s perceived species richness or expert evaluation (Carrus et al., 2015). The influence of the presence of birds and fish in green spaces’ images was also assessed (Wang et al., 2019). These studies observed positive effect of biodiversity/wildlife on mental health measures however, a fourth study retrieved did not find any correlation (Southon et al., 2018). Additionally, the relationship between actual and perceived levels of biodiversity was inconsistent across these studies.

3.3.4 An integrative framework

Our review resulted in a list of potential synergies and trade-offs between human requirements and wildlife conservation in green spaces (Table 4) based on studies that considered the two dimensions separately. Here, we propose an integrative framework based on the One Health approach that summarizes the findings of our systematic review and identifies the main interlinkages between green space's quality (environmental health), mental health (human health), and wildlife support (animal health) (Fig. 6). In detail, it depicts relationships at local fine-scale levels, i.e. urban green spaces and their adjacent landscape, and is structured in such a way that all indicators and response variables extracted in this review can populate the framework and be assigned to a domain (e.g. site-level factors) and category (e.g. design) (Fig. 7).

Table 4. Potential synergies and trade-offs between wildlife support and mental health promotion in green spaces. The arrows indicate the directional trend of the relationship according to results compiled in this review and estimations based on additional theory: ↑ positive effect; ↓ negative; ↕ both; ↗ positive estimation; ↘ negative estimation*.

Indicator	Mental health	Wildlife support
Peri-urban location	↑	↑
Population/housing density	↑	↓
Patch area	↑	↑
Water bodies	↑	↑
Grass cover	↑	↕
Bush cover	↑	↑
Tree cover	↑	↑
Plant richness	↕	↑
Enclosed vegetation	↕	↑
Flat topography	↑	↘
Habitat diversity	↑	↑
Distance trail to forest	↘	↑
Intensive management	↑	↓
Flowers	↑	↑
Pets allowed	↗	↓
Ambient noise	↓	↓

* The complete list with green space indicators, mental health and wildlife support measures, and details about their relationships is available as Supplementary material S.3 to S.6.

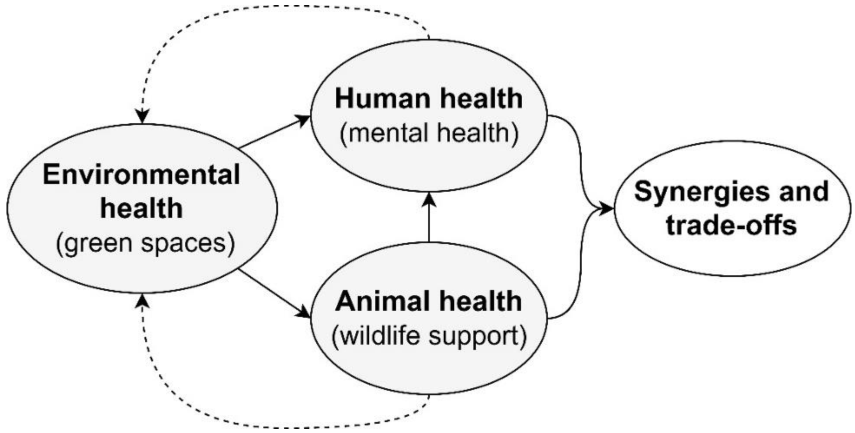

Figure 6. The integrative framework addresses the interlinkages between the three dimensions of One Health and the final outcomes as the synergies and trade-offs between human and animal health.

In the environmental health dimension, we identified green space's attributes that affected the human and animal dimensions and represented aspects of spatial configuration, vegetation structure, design, management, and acoustic environment. Aspects related to vegetation (e.g. plant species diversity and arrangements) are considered architectural or structural elements that can be purposely manipulated by humans in urban settings to maintain or promote certain functions (Tzoulas and James, 2010) and therefore, are green space features. Additionally, the characteristics of the adjacent surroundings (landscape level) may also interfere in the conditions and perceptions at the site level. Ultimately, besides environmental health being a driver of human health and animal health, a feedback loop exists when, for instance, animal diversity improves ecosystem functioning, and recognized benefits to human health may be translated into better care and improvement of green spaces.

According to the majority of findings included in our review, the human health dimension in this framework focuses on the role of mental restoration experienced in urban green spaces as a promoting factor of mental health and well-being (Hartig et al., 2014). The restorative experience of a green space visitor is the product of the environment's restorativeness combined with personal aspects. For the definitions of major framework elements, see Supplementary material S.7.[7]

We identified several characteristics of green spaces that might influence the user´s perception and restoration outcomes and thus the restorative potentials may differ from place to place. Most

[7] Supplementary material S.7 of this publication can be accessed in chapter i.c. in the appendices.

likely, green spaces' qualities affect indirectly the restorative experience of visitors through their perceptions of the environment. Therefore, these perceptions can be considered mediators on the relationship between green space´s qualities and user´s restorative outcomes and are combined in a domain called “environment-related factors”. They may also be affected by a combination of environment and wildlife dimensions. For instance, the soundscape is influenced by anthropogenic and geophysical sounds of the green space’s acoustic environment, as well as by biological sounds coming from the wildlife dimension.

Another linkage between animal and human health dimensions is the positive effect of wildlife measures on restoration and psychological well-being (Carrus et al., 2015; Dallimer et al., 2012). Most likely, this effect occurs indirectly through perceived biodiversity. The way visitors perceive biodiversity may not be fully correlated to the actual biodiversity levels of the site and may also be strongly influenced by setting characteristics such as tree cover (Dallimer et al., 2012).

Besides the setting’s attributes and perceptions, individual characteristics and behaviors of green space visitors may moderate the effects on the restorative experience. The so-called “People-related factors” comprise the use of the place, personality traits, pre-condition and sociodemographic variables (Carrus et al., 2015; Cervinka et al., 2016; Evensen et al., 2016). As an example, activities carried out in a park that depend more on the quality of the environment, such as walking and contemplating, were correlated with higher scores of perceived restorativeness and well-being than reading and socializing (Carrus et al., 2015). Additionally, interactions between this domain and environment-related factors may also be expected, such as the correlation between connection to nature and perceived biodiversity (Southon et al., 2018) and gender with perceived safety (Jorgensen et al., 2012).

For wildlife, intra-urban variation in support metrics can be explained by local factors (within site), which determine habitat suitability for survival and reproduction of a species, and landscape factors, which affect the permeability of the surrounding matrix to species dispersal and thus the colonization and migration capacity (Beninde et al., 2015; Croci et al., 2008). Our review compiles an extensive list of indicators that affect wildlife support in urban green areas and thus can contribute to a better design and management of biodiversity-friendly spaces.

Even though the human health and animal health dimensions have their own outcomes, the main goal of this framework is to uncover potential synergies and trade-offs between them. Understanding which and how green space’s characteristics affect human health and animal health may allow the design and management of spaces that maximize benefits and reduce conflicts.

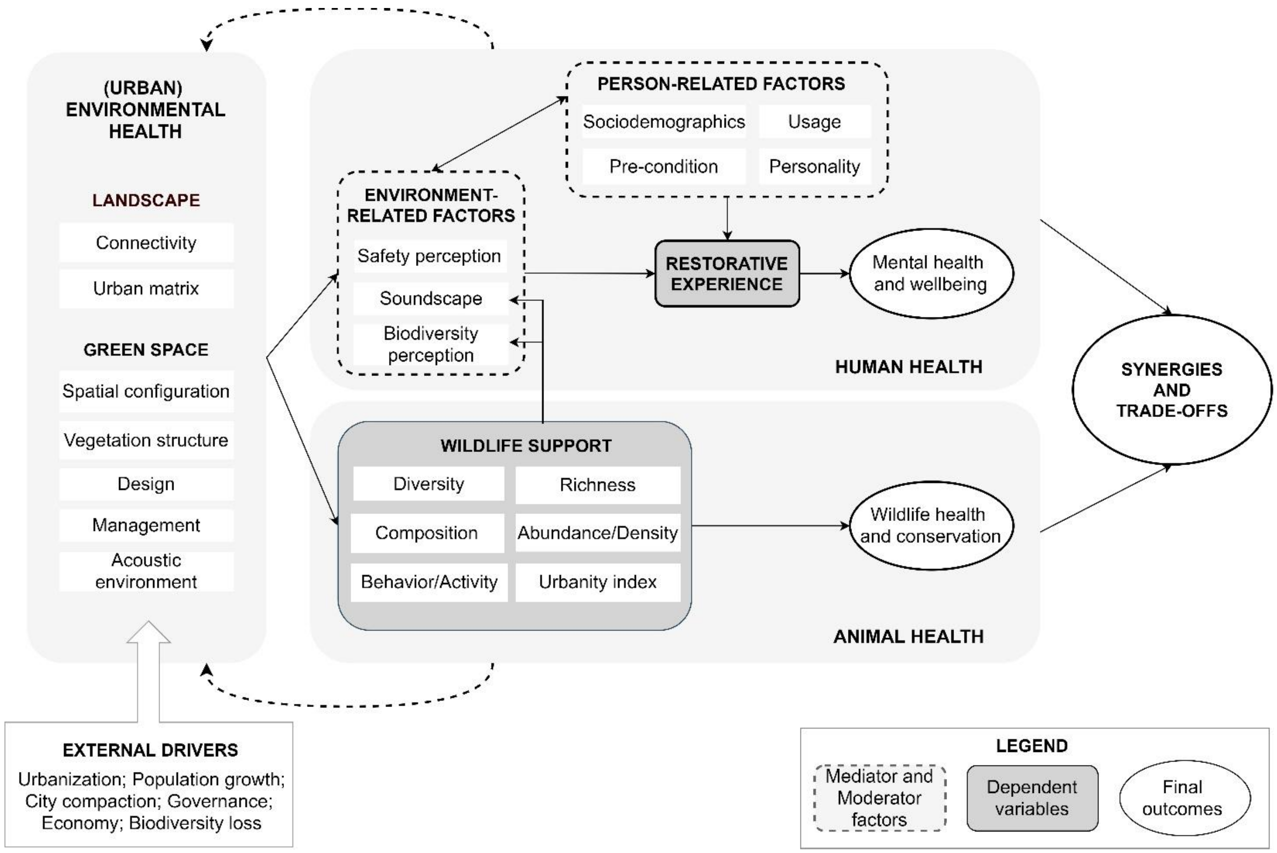

Figure 7. Relationships between the One Health dimensions in urban green spaces based in the findings from the systematic review.

3.4 Discussion

3.4.1 Study designs and geographical coverage

A big share of literature on green infrastructure effects on mental health looks into availability and accessibility to urban green at the residence surroundings. Although this type of study benefits from easier access to secondary data, it does not take into account the quality of the green areas and the perceived greenness, which was shown to be related to mental health outcomes (Sugiyama et al., 2008) but not correlated to the widely used metrics of green cover (Leslie et al., 2010). For instance, recurrently used remote sensing products, such as the Normalized Difference Vegetation Index (NDVI), may give the same value to an inaccessible lot with overgrown vegetation as to a public park (Markevych et al., 2017). The lack of quality assessment is a potential reason for the inconsistent evidence on epidemiological studies addressing green space effect on health (Nieuwenhuijsen et al., 2017), and therefore this study design provide limited contributions to the understanding of pathways and causalities in this relationship.

Likewise, studies that tested mental health outcomes under different scenarios of green space qualities may suffer from other sorts of limitations. On the one hand, conducting on-site studies may involve drawbacks in terms of time, funding, control of confounders, inability to assess long-term mental health outcomes, and generally small sample sizes. On the other hand, experiments conducted in laboratory conditions may lead to different results than in the field (Gatersleben and Andrews, 2013). In fact, these studies usually make use of only visual stimuli to assess mental health and restoration, and use students as participants, which does not fully represent either the reality of user experience in a green space or the socio-economic characteristics of the whole population (Negrín et al., 2017). Therefore, in order to better understand the effect of green on health outcomes, on-site studies that reflect real user's experiences and the effect of green space quality should be the focus of future research.

The lack of studies on urban green spaces in terms of wildlife support and mental health dimensions in developing countries is evident and pressing considering that almost 90% of expected future urban population growth will take place in Asia and Africa (United Nations, 2018). Empirical evidence collected mainly in the developed world cannot simply be transferred to other contexts with different socio-economic, cultural, and biogeographic conditions, which may result in distinct relationships in the human-animal-environment interface (Fischer et al., 2018; Kabisch et al., 2015). One example identified in this review is the role of perceived safety in green spaces, which can impair the restorative experience, requiring rather than recovering directed attention, and even prevent people from visiting these places in dangerous neighborhoods. Urban planning and policies should be tailored to the local context and therefore future studies in this field are especially needed in the developing world.

3.4.2 Mental restoration in urban green spaces

Restoration is one pathway linking exposure to nature and human health and well-being outcomes (Markevych et al., 2017), and is based on the integration of stress-oriented (Psychophysiological Stress Reduction Theory) and attention-oriented (Attention Restoration Theory) theories, which describe distinct but interacting benefits of restorative experiences (Kaplan, 1995). The first focuses on stress response suppression resulting in less physiological activation and more positive self-reported emotions (Markevych et al., 2017; Ulrich, 1983). The latter addresses the recovery of "directed attention", i.e. the capacity to focus attention, which plays a fundamental role in the effectiveness of daily activities and can become depleted in meeting the demands of everyday life or after prolonged mental effort (Kaplan and Kaplan, 1989; Kaplan, 1995). Through these mechanisms, restoration promotes health by reducing the risk of diseases related to chronic stress and boosting subjective well-being (Hartig et al., 2014).

The provision of places that enable restoration, i.e. restorative environments, has potential as a preventive health intervention especially relevant in the context of urban areas, where lifestyle imposes increased demand on cognitive resources (Kaplan and Berman, 2010) and opportunities for contact with nature are scarce. Urban green spaces are not natural environments by definition but they comprise natural elements and functions that make them eligible to act as “urban nature” (Hartig et al., 2014) and thus, as restorative environments. However, green spaces may offer different restorative potentials according to their capacity to fulfill the following dimensions: provide a sense of getting away of daily issues (being away), hold effortless attention (fascination), provide space and enough to see and experience (extent), and match the individual expectations (compatibility) (Kaplan, 1995). For this reason, it is crucial to advance the understanding on objective attributes of green spaces that enhance restoration and their relation with user’s perceptions, so that it could guide policies and design towards the promotion of urban restorative environments, as well as feed predictive models that may help in decision-making (Bratman et al., 2019). Furthermore, the effect of plant and animal diversity on restoration is promising and future research should be able to provide biodiversity indicators to be targeted in green space planning and management.

3.4.3 Wildlife support in urban green spaces

Urban green spaces can be considered “habitat islands” surrounded by the urban matrix, which suffer from disturbance, fragmentation, and isolation, in an adaptation of the island biogeography theory to urban areas (Davis and Glick, 1978). Considering that interactions with humans may be detrimental to animals, ranging from individual effects (e.g. stress responses) to changes in population size and distribution, some aspects of design and management of green spaces may decrease the disturbance level, especially through habitat characteristics that provide refuge and reduce human detection by the animals (Tablado and Jenni, 2015).

We retrieved a high number of indicators of green space quality associated with wildlife outcomes, but these results are influenced by outcomes in bird assemblages, the most studied group due to their conspicuousness and role as indicators of habitat quality (Fontana et al., 2011a). Patterns can be identified from similar findings among studies, however, one has to be careful when generalizing findings from one group of animals to wildlife as a whole. An indicator can produce different results depending on the wildlife metric (e.g. species richness versus abundance), animal group, or species' characteristics within the group (e.g. bird guilds). A comprehensive assessment of animal species is challenging and usually not feasible, and this is the reason why indicator species are used. Future work should, therefore, also address less studied animal groups, making use of standard metrics that can be compared and easily synthesized in future meta-analysis.

In addition, the inclusion of measures that assess qualitative aspects of community composition is important to account for potential high richness or abundance driven by urban exploiters, alien and invasive species, in comparison with native and sensitive species that reflect higher ecological quality (Lepczyk et al., 2017). Examples such as the urbanity index (Shwartz et al., 2013) allow the differentiation between habitat requirements for urban exploiters and specialist species. A better understanding of how different animal groups and species respond to urban green spaces qualities would allow the design of heterogeneous networks of spaces that provide requirements for multiple biodiversity targets.

3.4.4 Framework contributions

Although future studies in each dimension are necessary, we advocate for more holistic approaches and interdisciplinary work integrating humans, animals, and the environment, following the One Health approach, which proved to be useful in expanding the knowledge on socio-ecological systems in the context of urban green spaces. Currently, studies comparing requirements for both human use and biodiversity conservation in the context of green spaces are still exceptions (e.g. Heyman et al., 2011), and usually, when the two dimensions are considered in the same study, the focus is on the effect of biodiversity on human health. We compiled results from studies that considered the dimensions individually and combined them in an exploratory approach. Future studies should address both dimensions simultaneously to identify synergies and trade-offs under the same environmental and socio-economic conditions.

Trade-offs may arise not only between human and wildlife dimensions but also within humans and animals groups. Therefore, when seeking multifunctionality, we must also recognize that it is unlikely that a green space will supply all possible demands. In this sense, it is crucial to find synergies between services and between beneficiaries so that green spaces can be effectively developed to maximize specific targets. Overall, synergies between mental health and wildlife seem to overcome conflicts. However, many aspects are still not established or not even initially studied. The main conflict detected is related to the naturalness level of the vegetation, which is beneficial for wildlife but may have negative outcomes for perceived safety and attractiveness for humans. Design and management decisions (e.g. location of trails, vegetation maintenance) should either balance aesthetic preferences and perceived safety with wildlife requirements towards multifunctional spaces, or define priorities and target beneficiaries for each green space, aiming for a heterogeneous network of spaces with different functions.

3.4.5 Limitations

This review does not aim to comprehensively list all the available evidence in mental health and urban wildlife research fields but rather provide insights on the potential synergies and trade-offs that may arise when considering the integration of these dimensions. Therefore, we opted for general search terms that allowed us to retrieve records in different dimensions of mental health, from diseases to psychological states, as well as wildlife support across several animal groups and types of urban green elements. The limitation of using a single search database for the main literature review was partly counterbalanced with the snowballing process, which added a similar proportion of articles from different publication sources.

The studies and the list of green space indicators included were constrained to significant statistical results, excluding indicators that have been proven ineffective in other studies. Furthermore, we do not address potentially different perceptions according to specific age, gender, or ethnic groups, but reinforce that this distinction is important for the provision of more inclusive green spaces.

Due to the limited evidence on the effect of green space qualities on mental health, we included studies with different forms of nature exposure (e.g. on-site and photographs) even though this may lead to different outcomes, as already discussed. The findings of this review should guide future research, especially with real exposure to nature, rather than be generalized.

We acknowledge that our framework is biased towards positive effects of biodiversity on human health, which is not always the case. Other trade-offs may arise when enhancing biodiversity and natural ecosystems in urban areas, involving potential human health risks, such as zoonotic and vector-borne diseases. However, these negative effects are much better understood than the neglected intangible benefits of wildlife to humans (Soulsbury and White, 2015), and can be properly monitored and mitigated (Lõhmus and Balbus, 2015).

3.5 Conclusions

Meeting the demands of human use and biodiversity conservation in a limited space is a challenge not well investigated so far. To our best knowledge, this is the first review that combines mental health and wildlife support outcomes related to green space quality. We provide insights to the optimization of green space design and management identifying green space qualities that promote synergistic effects on mental health and wildlife support, as well as trade-offs that must be considered. Additionally, we contribute to the expansion of the research field applying the One Health approach to uncover parts of the multiple relationships involved in the green space-human-animal interface and providing a framework and a comprehensive list of indicators that allow its operationalization.

Finally, we argue that future research should address simultaneously multiple dimensions under a socioecological-systems perspective that captures the complexity involved in human-animal-environment relationships. The One Health perspective proved valid on expanding the knowledge on interconnections involved in human-animal-environment relationships in urban green spaces. Adopting this holistic approach in urban planning may allow us to build healthier urban environments, in which green spaces effectively reconcile human needs and nature conservation.

4 Translation and validation of two scales to measure psychological restoration[8] [9]

4.1 Introduction

Restorative environments are places that promote recovery of depleted psychological resources through a process called restoration (Hartig et al., 1996). The process of restoration promotes health by reducing the risk of diseases related to chronic stress and boosting subjective well-being (Hartig et al., 2014). The restorative experience is explained by two main theories based on stress-oriented and attention-oriented mechanisms (Kaplan, 1995).

The Stress Recovery Theory (Ulrich, 1983) states that attractive natural settings evoke aesthetic and affective responses linked to pleasant feelings. These settings are effective when it comes to capturing our attention and blocking stressful thoughts, ultimately promoting psychophysiological restoration. Restoration is more pronounced in individuals with an initial state of stress and excessive arousal.

The Attention Restoration Theory (Kaplan & Kaplan, 1989) states the capacity to focus attention, called “directed attention”, plays a fundamental role in the effectiveness of daily activities however, it is prone to fatigue after long periods of mental effort. Directed attention fatigue is associated with detrimental outcomes such as negative emotions, irritability, performance impairment, and accidents among others (Hartig et al., 1996). Restorative environments allow the recovery of mental competence through the restoration of directed attention (Kaplan, 1995, 2001). To be considered restorative, a setting must fulfill the following four dimensions: a sense of escaping daily issues (being away); ability to hold effortless attention (fascination); coherent richness of things to see and experience (extent); and the meeting of the individual’s expectations (compatibility) (Kaplan, 1995).

Psychometric scales were developed to measure the restorative potential of environments and restoration outcomes. Most studies on restorative environments applied these scales focusing on comparisons between the restorative potential of natural *versus* built settings. Although the

[8] A slightly modified version of this chapter was originally published as: Felappi, J.F., Bedin, L.M., Terlau, W., Kötter, T. 2022. Psychometric properties of two psychological restoration scales: translation, adaptation and validity evidences of the Brazilian versions (Propiedades psicométricas de dos escalas de restauración psicológica: traducción, adaptación y validez de las versiones brasileñas), PsyEcology, 13:1, 50-74. https://doi.org/10.1080/21711976.2021.1992871

[9] The numbering of figures and tables was changed to consecutive numbers.

number of studies investigating the role of natural settings on mental health and wellbeing has been increasing, they are concentrated in high-income countries (Collins et al., 2020; Felappi et al., 2020). Considering that even among European countries different perceptions can be observed (Edwards et al., 2012), there is little research into the potential role of geographic conditions, local demands and cultural-specific perceptions and behaviors in shaping human-nature relationships (Hartig et al., 2014; Kabisch et al., 2015). Therefore, it is necessary to investigate whether the empirical evidence accumulated so far compares to populations from the Global South.

Studies in Brazil did not use psychometric scales to measure restoration, meaning these scales should pass through a cross-cultural adaptation to be correctly applied in this country. This study aims at translating two instruments, Perceived Restorativeness Scale and Restoration Outcome Scale, to Brazilian Portuguese language, accounting for their adaptation to the local context and thereby ensuring the maintenance of content validity evidences and equivalence to the original version. Additionally, the psychometric proprieties and the convergent validity of these scales are analyzed.

4.2 Methods

4.2.1 Participants

This study was conducted in two capital cities located in the south and southeast regions of Brazil: Porto Alegre, Rio Grande do Sul State, which has nearly 1.5 million inhabitants, and São Paulo, São Paulo State, with more than 12 million inhabitants (IBGE, 2019). Eligible participants were adults (≥ 18 years old), residents of the city, who were visiting urban parks and squares.

4.2.2 Instruments

4.2.2.1 Perceived Restorativeness Scale (PRS)

One of the most frequently used scale in restorative environments studies (Han, 2018) is the Perceived Restorativeness Scale (Hartig et al., 1996). PRS assesses the environment’s restorative quality, or the potential of a certain environment to promote restoration (Negrín et al., 2017). It is considered a useful tool to address the dimensions required for restoration and to distinguish environments with different restoration potentials (Hartig et al., 1997). The original scale and subsequent versions were successfully applied in several countries, e.g. Austria, Canada, Italy, Spain, and Sweden.

The first version of the scale was composed of four dimensions reflecting the theoretical constructs of the Attention Restoration Theory, i.e. being away, fascination, coherence (a component of extent), and compatibility, with 16 items in total and seven response alternatives (0 = “Not at all” to 6 = “Completely”) (Hartig et al., 1996). The internal consistencies (Cronbach α) of the subscales varied across sites and study designs explored with this first version, being adequate for fascination (.75 to .94) and compatibility (.75 to .94), but more unstable for being away (.49 to .92) and, especially, coherence (.38 to .85). Additionally, a 2-factor solution was suggested, with coherence items loading in an independent factor and the three other dimensions being combined into a General Restorativeness subscale. In an effort to represent the extent construct beyond coherence and to solve the factor structure of the instrument, the scale was further developed with the revision and addition of items, resulting in a 26-items scale (Hartig et al., 1997). A 4-factor solution was then confirmed, but the included items intended to sample the extent construct aligned with compatibility and fascination, and the coherence factor was poorly correlated with the others. In subsequent studies that analyzed psychometric properties of the scale, the 4-factor structure was seldom achieved (Han, 2018) and issues with the reliability and factor structure related to the coherence dimension were reported (Perschardt et al 2013; Purcell et al., 2001; Marselle et al., 2016). Considering that this study does not aim to solve the mentioned issues with the extent construct but rather provide an adequate scale ready for application in Brazil, the PRS version adopted in this study, as suggested by the original author (T. Hartig, personal communication, September, 2018), is comprised by the consolidated three factors and 15 items from the 26-items version: Being away (items 1 to 5); Fascination (items 6 to 10); and Compatibility (items 18 to 22).

4.2.2.2 Restoration Outcome Scale (ROS)

The Restoration Outcome Scale (Korpela et al., 2008) focuses on perceived restoration resulted from contact with a setting. It integrates the stress-oriented and attention-oriented theories and assumes as outcomes of restoration aspects such as forgetting worries, recovering attentional focus, relaxation, and an increase in positive feelings whilst a decrease in negative feelings.

A first preliminary version of the scale (Hartig et al., 1998) aimed at measuring the extent to which participants experienced particular changes characteristic of restoration at home and near-home area. The scale consisted of 10 items divided into the factors “Relaxation” and “Reflection”. Subsequently, another version of the scale was applied to assess restorative experiences in favorite places (Korpela et al., 2008). It was composed of 6 items reflecting relaxation and calmness (items 1 to 3), attention restoration (item 4), and the clearing of one's thoughts (items 5 and 6), with a response scale ranging from 1 (Not at all) to 7 (Totally). Despite reflecting different constructs, the scale presented one single factor and a strong internal consistency (α = .92), thereby a mean summary score can be computed based on all items (Korpela et al., 2008). For this study, the full version of ROS from Korpela and collaborators was adopted.

4.2.3 Procedures

4.2.3.1 Cross-cultural adaptation

The cross-cultural adaptation of each instrument to the Brazilian Portuguese followed international guidelines (International Test Commission, 2017) and recommended steps (Borsa et al., 2012). First, two translations of the original instrument were conducted by independent translators who have Portuguese as their native language. Second, two authors of the present study revised and solved discrepancies in the two translations, reconciling them into a single version that presented the best semantic and conceptual equivalence with the original version. Third, an experts' committee was formed by three judges who evaluated the items in terms of semantic, idiomatic, and conceptual equivalence. Each item was evaluated as good, fair, or poor, and suggestions were provided in the case an item had a poor evaluation. The judges were academics who have conducted studies in the restorative environments field in Brazil. Two authors of this study reviewed the judge's evaluations and suggestions and made changes where necessary. Subsequently, a qualitative evaluation was conducted with the application of the instrument with a small sample of the target population (n = 10) to verify whether the instructions, the items, and the response scale were comprehensible and correctly corresponded to the original content. Finally, the back translation of the final version of the scale, which was performed by a third translator with English as native language, was evaluated by the scale's main author to ensure that the items retained the content of the original version.

4.2.3.2 Application of instruments

Nine places were selected in Porto Alegre for the application of questionnaires in December 2018, comprising urban parks, such as "Parque da Orla" and "Redenção", and squares, such as "Praca da Alfândega" and "Praca Macedônia". In São Paulo, ten urban parks were selected, among them "Trianon", "Guarapiranga", "Lajeado" and "Eucaliptos", and the interviews were conducted during March and April 2019.

Participants were randomly approached during their visit to these spaces. After accepting the terms and signing the informed consent form, a trained interviewer applied the questionnaire, which included the instruments (see Supplemental material[10]) and questions on socio-demographic variables. Participation was anonymous and the average time to complete the questionnaire was 15 minutes. This study was approved by the Brazilian National Committee on Research Ethics (CONEP, CAAE: 00239018.7.0000.5390), and all procedures complied with ethical guidelines on research with humans.

4.2.3.3 Data analysis

First, we conducted descriptive statistics of the sociodemographic characteristics and the instruments, for each study site and the total sample. This was followed by bivariate correlations between items (within each subscale, when applied) to test multicollinearity. Cronbach alpha was applied as a measure of internal consistency and values higher than .70 were considered adequate (Vaske, 2008). Convergent validity was tested through Pearson correlation between the scales. All the mentioned analyses were performed on IBM SPSS Statistics 24.

In order to verify if the observed and latent variables followed the theoretical model established, we performed Confirmatory Factor Analysis (CFA) on R software version 4.0.0 using the lavaan package (Rosseel, 2012). The weighted least square estimation (WLSMV) parameter was selected considering the use of measures with Likert-type scales. Indicators of good model fit were considered a Comparative Fit Index (CFI) value higher than .95, Root Mean Square Error of Approximation (RMSEA) lower than .06, and Standardized Root Mean Square Residual (SRMR) equal or below .08 (Schreiber et al., 2006).

To investigate whether the components of the model are equivalent between cities and genders, multigroup confirmatory factor analyses were performed to test configural (no equality constraints), metric (factor loadings constrained equal), and scalar invariance (both loadings and intercepts constrained equal). The evidence of invariance is detected when the difference between CFI values (ΔCFI) of the metric and scalar models in comparison to the configural model (baseline value) is smaller or equal to .01 (Byrne, 2016; Cheung and Rensvold, 2002; Coenders et al., 2005). This is a commonly used criterion to evaluate measurement invariance, avoiding the shortcomings of other fit indices like the χ^2 (Putnick & Bornstein, 2016).

[10] Supplemental material of this publication can be accessed in chapter ii.a. in the appendices.

4.3 Results

A total sample of 566 adults completed the questionnaire, comprising 166 people from Porto Alegre and 400 from São Paulo city. The total sample is well balanced in terms of participants' gender, being 50.7% male and 49.3% female, with ages ranging from 18 to 85 years old and an average age of 41.05 (*SD* = 15.30). The sociodemographic characteristics of the sample are described in Table 5.

The test of convergent validity resulted in a high correlation between PRS and ROS scales (r = .774 p =< .0001). This indicates that the two different assessment methods measure theoretically similar concepts.

Table 5. Sociodemographic characterization of the city samples and the total sample.

	Porto Alegre (*n* = 166)		São Paulo (*n* = 400)		Total sample (*n* = 566)	
Variable	*n*	%	*n*	%	*n*	%
Gender						
Male	78	47	209	52.3	287	50.7
Female	88	53	191	47.8	279	49.3
Age						
18-30	68	41	108	27	176	31.1
31-45	46	27.7	139	34.8	185	32.7
46-60	28	16.9	99	24.8	127	22.4
Over 60	24	14.5	54	13.5	78	13.8
Level of education						
Primary (incomplete)	4	2.4	32	8	36	6.4
Primary (complete)	14	8.4	39	9.8	53	9.4
Secondary	76	45.8	132	33	208	36.7
Technical degree	8	4.8	21	5.3	29	5.1
Superior	64	38.6	173	43.3	237	41.9
Did not answer	0	0	3	0.8	3	0.5

4.3.1 Perceived Restorativeness Scale

The mean score and standard deviation of each item as well as the general score of the scale obtained for both study sites are described in Table 6. The mean PRS score in Porto Alegre was 4.23 (*SD* = 0.96) with a range from 1.07 to 5.87, while São Paulo had a mean of 4.33 (*SD* = 0.91) and a range from 0.80 to 6.00. Multicollinearity tests resulted in no bivariate correlation higher than 0.61 (between items 1 “Being here is an escape experience” and 3 “It is a place to get away from it all” of the Being away dimension), therefore all items were retained for further analysis.

The internal consistency of the scale and its factors, represented by the Cronbach's alpha values, was satisfactory with a value of .90 for the whole scale, .81 for Being away dimension (BA), .80 for Fascination (FA), and .80 for Compatibility (CO). Considering the city samples separately, in Porto Alegre the value of the whole scale was .91, .87 for BA, .82 for FA, and .83 for CO. For São Paulo city, the values were respectively .89, .79, .80, and .78. All items contributed to the factors as the exclusion of any of them decreased the Cronbach alpha values of the subscales.

Table 6. Mean value and standard deviation of each scale item and the general Perceived Restorativeness score, for each study site.

Items PRS	Mean (standard deviation)	
	Porto Alegre (*n* = 166)	São Paulo (*n* = 398)
Being away Factor (BA)		
1. Being here is an escape experience.	4.21 (1.521)	4.50 (1.369)
2. Spending time here gives me a break from my day-to-day routine.	4.80 (1.318)	4.68 (1.292)
3. It is a place to get away from it all.	3.91 (1.617)	4.18 (1.683)
4. Being here helps me to relax my focus on getting things done.	4.16 (1.465)	3.94 (1.767)
5. Coming here helps me to get relief from unwanted demands on my attention.	4.60 (1.371)	4.73 (1.260)
Fascination Factor (FA)		
6. This place has fascinating qualities.	4.67 (1.157)	4.46 (1.346)
7. My attention is drawn to many interesting things.	4.13 (1.358)	4.17 (1.372)
8. I want to get to know this place better.	3.73 (1.604)	3.89 (1.629)
9. There is much to explore and discover here.	3.73 (1.514)	3.77 (1.596)
10. I want to spend more time looking at the surroundings.	4.52 (1.333)	4.48 (1.383)
Compatibility Factor (CO)		
11. Being here suits my personality.	4.42 (1.415)	4.73 (1.235)
12. I can do things I like here.	4.45 (1.328)	4.54 (1.321)
13. I have a sense that I belong here.	3.49 (1.733)	4.00 (1.557)
14. I can find ways to enjoy myself here.	4.19 (1.439)	4.27 (1.389)
15. I have a sense of oneness with this setting.	4.38 (1.500)	4.65 (1.252)
General PRS score	4.23 (0.960)	4.33 (0.914)

The results of the Confirmatory Factor Analysis indicate that the model established *a priori* with three factors (BA, FA, and CO) fits the data very well (Table 7). A first-order CFA of each study site and the total sample presented good fit indices but also moderate to high correlations between the three subscales (total sample, BA-FA = .68; BA-CO = .71; FA-CO = .86) indicating a potential second-order model. Therefore, we conducted a second-order CFA of the total sample, which obtained the same adequate parameters (CFI = .995, RMSEA = .024, SRMR = .054). As both models are adequate, the simpler model (first order) would be the reasonable solution. However, considering the theoretical and statistical correlation between the factors, the second-order model was the solution adopted as it contributes with a latent variable "Perceived Restorativeness" which aggregates the three factors and allows the calculation of a General Perceived Restorativeness Score (Figure 8). The items with higher standardized weights were "Being here is an escape experience" (.83) in the BA factor, "My attention is drawn to many interesting things" (.75) in the FA factor, and "I have a sense that I belong here" (.71) in the CO factor. The latter was the factor that best explained the Perceived Restorativeness (.94).

Table 7. Results of the confirmatory factor analysis of the PRS: first-order model for each sample, and first and second-order models for the total sample.

	χ^2	*df*	*p*	CFI	RMSEA (CI)	SRMR
São Paulo (1st order)	92.194	87	.331	.998	.012 (0.001-0.031)	.057
Porto Alegre (1st order)	57.755	87	.993	.999	.001 (0.001-0.001)	.067
Total (1st order)	114.746	87	.025	.995	.024 (0.009-0.035)	.054
Total (2nd order)	114.746	87	.025	.995	.024 (0.009-0.035)	.054

χ^2 = chi-square, *df* = degrees of freedom, *p* = p value, CFI = Comparative fit index, RMSEA = Root mean square error of approximation, CI = Confidence interval 90%, SRMR = Standardized Root Mean Square Residual.

Regarding the invariance testing, the fit of the configural model was adequate for cities and genders, with all parameters within the reference values (Table 8). For cities, the constraints added by the metric and scalar models did not change the CFI values. For genders, CFI values were slightly reduced but still far below the ΔCFI cutoff value (ΔCFI= .005 and .006). These results provide evidence that the model holds invariance between cities and genders.

4.3.2 Restoration Outcomes Scale

The mean ROS score was 4.60 in São Paulo sample (score range from 0.33 to 6.00), and 4.42 in Porto Alegre (score range from 0.67 to 6.00) (Table 9). The reliability of the scale is adequate, as evidenced by Cronbach alpha values of .91 for the total sample, .92 for Porto Alegre, and .90 for São Paulo. The exclusion of any items did not improve the alpha value. Correlations higher than .7 were found between the items 1 (Being here is an escape experience) and 2 (After visiting this place, I feel refreshed and relaxed) (r = .74) and 2 and 3 (Being here renews my enthusiasm and energy for my daily routine) (r = .79). Therefore, we conducted a CFA using the whole scale and an alternative model excluding item 2, considering that it could represent multicollinearity. All models presented adequate fit indexes for a single factor scale (Table 10). Item 2 had the higher standardized weight (.86), closely followed by item 3 (.85) (Figure 9). Considering the explanation power of item 2, the lower alpha value without this item (.88), and the different content reflected in items 2 and 3, we decided to maintain the original structure of the scale with six items.

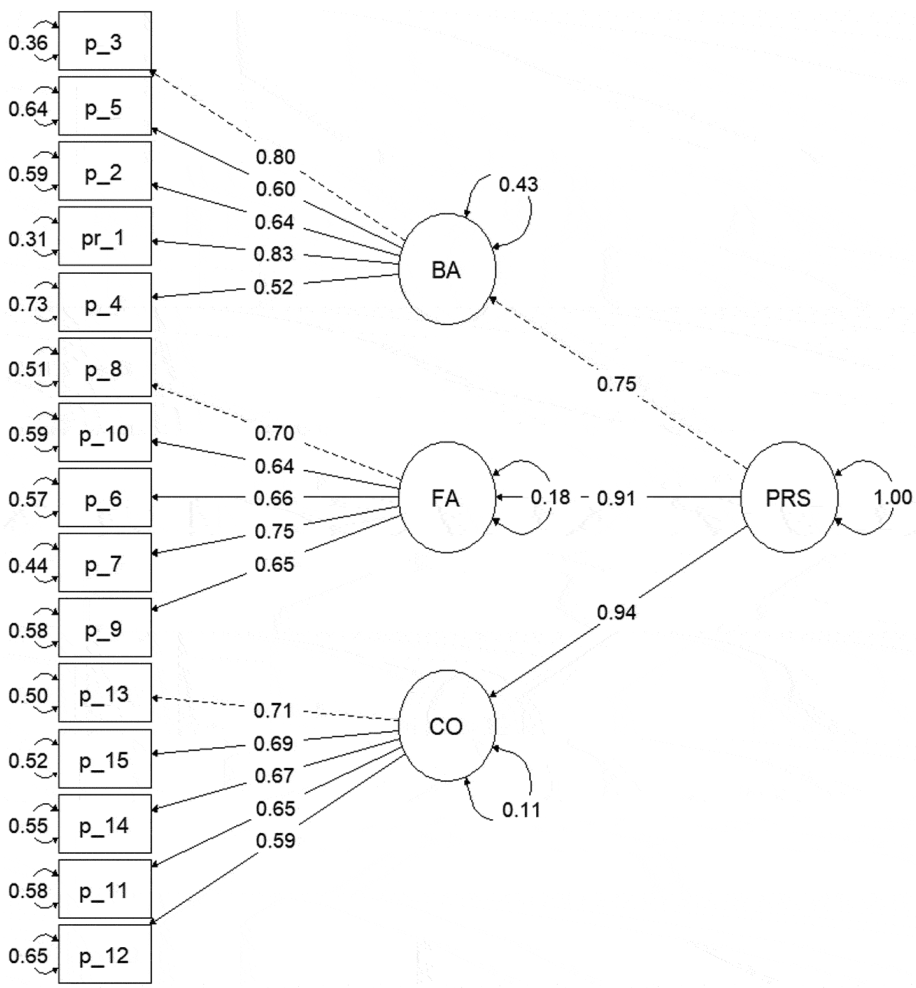

Figure 8. Confirmatory factor analysis (second order) of the Perceived Restorativeness Scale with 15 items, three factors and standardized weights. Note: The number after the prefix ‘p_’ indicates the item number according to Table 6.

Table 8. Multigroup factor analysis of the PRS between city samples and genders.

	χ^2	*df*	*p*	CFI	ΔCFI	RMSEA (CI)	SRMR
City							
CO model	149.949	174	.906	.999	-	.001 (0.001-0.012)	.057
ME model	181.438	188	.621	.999	.000	.001 (0.001-0.023)	.061
SC model	200.969	199	.448	.999	.000	.006 (0.001-0.027)	.063
Gender							
CO model	147.982	174	.924	.999	-	.001 (0.001-0.009)	.057
ME model	219.880	186	.045	.993	.006	.025 (0.004-0.038)	.068
SC model	228.803	198	.066	0.994	.005	.024 (0.001-0.036)	.069

χ^2 = chi-square, *df* = degrees of freedom, *p* = p value, CFI = Comparative fit index, ΔCFI = difference in CFI values between models, RMSEA = Root mean square error of approximation, CI = Confidence interval 90%, SRMR = Standardized Root Mean Square Residual. CO = configural model; ME = metric model; SC = scalar model.

Table 9. Mean value and standard deviation of each scale item and the general Restoration Outcome Scale score, for each study site.

Items ROS	Mean (standard deviation)	
	Porto Alegre (*n* = 166)	São Paulo (*n* = 399)
1. I feel calmer after being here.	4.84 (1.044)	4.86 (1.133)
2. After visiting this place, I feel refreshed and relaxed.	4.57 (1.327)	4.80 (1.191)
3. Being here renews my enthusiasm and energy for my daily routine.	4.63 (1.232)	4.80 (1.117)
4. My concentration and attention clearly increased here.	4.16 (1.505)	4.49 (1.210)
5. I forget about my daily concerns here.	4.11 (1.502)	4.24 (1.503)
6. Visiting this place cleansed and clarified my thoughts.	4.22 (1.355)	4.39 (1.356)
General ROS score	4.42 (1.127)	4.60 (1.033)

Table 10. Results of the confirmatory factor analysis of the ROS: first-order model for each sample and model for the total sample with and without item 2.

	χ^2	*df*	*p*	CFI	RMSEA (CI)	SRMR
São Paulo	3.285	9	.952	.999	.001 (0.001-0.001)	.034
Porto Alegre	2.459	9	.982	.999	.001 (0.001-0.001)	.038
Total sample	4.239	9	.895	.999	.001 (0.001-0.021)	.031
Total sample without item 2	0.753	5	.980	.999	.001 (0.001-0.001)	.015

χ^2 = chi-square, *df* = degrees of freedom, *p* = p value, CFI = Comparative fit index, RMSEA = Root mean square error of approximation, CI = Confidence interval 90%, SRMR = Standardized Root Mean Square Residual.

According to the results of the multigroup analysis (Table 11), the three levels of invariance tested fitted equally well, without changes in CFI values despite the equality constraints imposed on factor loadings and intercepts. This indicates that the model is equivalent across city samples and gender.

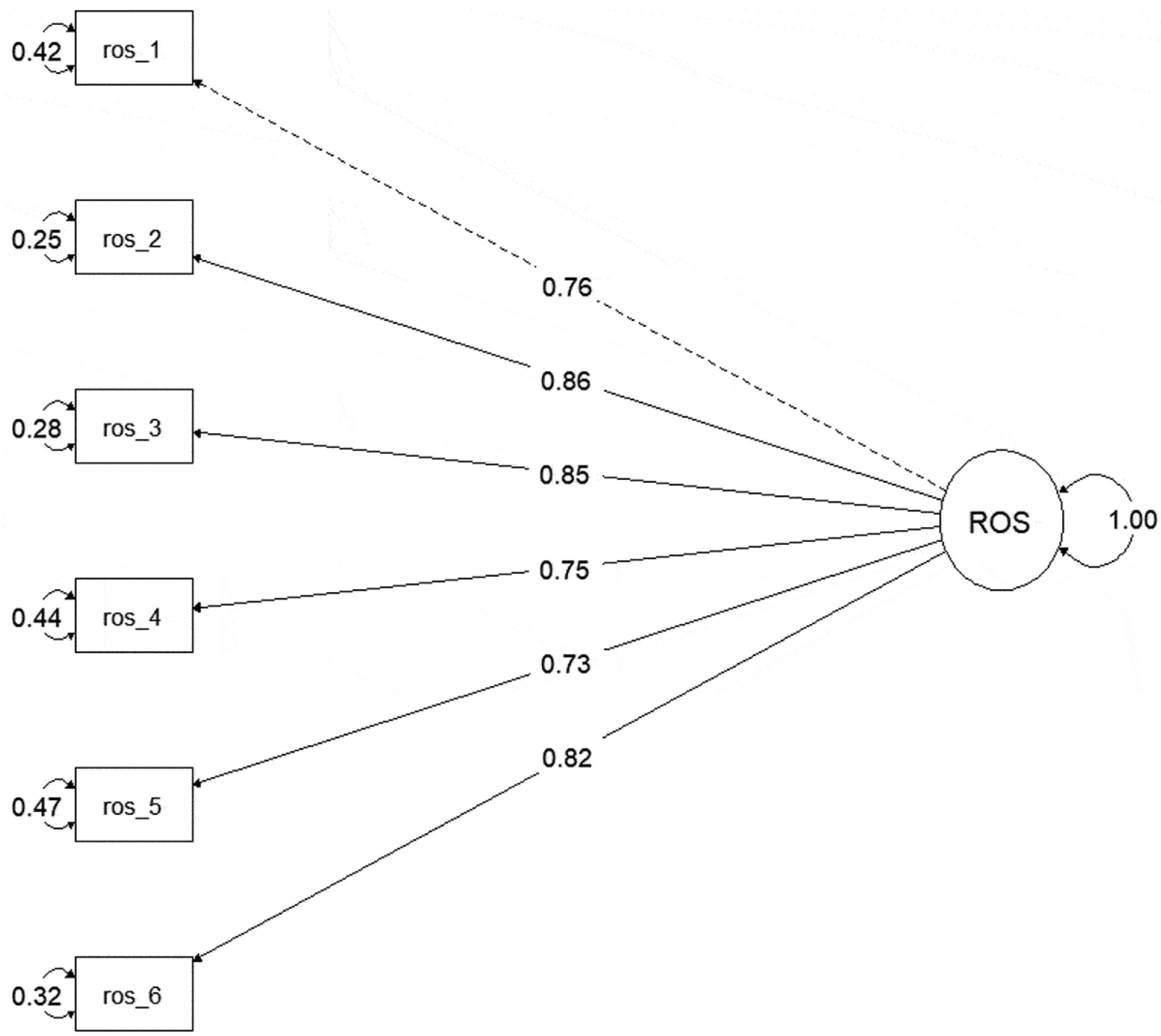

Figure 9. Confirmatory factor analysis of the Restorative Outcome Scale with six items and standardized weights. Note: The number after the prefix ‘p_’ indicates the item number according to Table 9.

Table 11. Multigroup factor analysis of the ROS between city samples and genders.

	χ^2	*df*	*p*	CFI	ΔCFI	RMSEA (CI)	SRMR
City							
CO model	5.744	18	.997	.999	-	.001 (0.001-0.001)	.031
ME model	19.360	23	.680	.999	0.000	.001 (0.001-0.040)	.056
SC model	22.719	28	.747	.999	0.000	.001 (0.001-0.034)	.058
Gender							
CO model	5.607	18	.998	.999	-	.001 (0.001-0.001)	.030
ME model	7.638	23	.999	.999	.000	.001 (0.001-0.001)	.035
SC model	8.921	28	.999	.999	.000	.001 (0.001-0.001)	.036

χ^2 = chi-square, *df* = degrees of freedom, *p* = p value, CFI= Comparative fit index, ΔCFI = difference in CFI values between models, RMSEA = Root mean square error of approximation, CI = Confidence interval 90%, SRMR = Standardized Root Mean Square Residual. CO = configural model; ME = metric model; SC = scalar model.

4.4 Discussion

Aiming at fostering research on mental health and wellbeing in the poorly studied low-middle-income countries, this study provides two psychometric scales to assess restorative experiences in the Brazilian population. Both instruments had adequate evidence of reliability and confirmed the factorial structure hypothesized *a priori* based on their theory and original development.

The satisfactory internal consistency of the subscales and the total PRS score combined with the good fit of the second-order model indicate that data can be analyzed either for each dimension or as a general restorativeness score. The item with higher weight was “Being here is an escape experience” (Being away factor), suggesting that the environments were efficient in diverting thoughts related to usual contexts and daily situations. Compatibility was the factor that best explained overall perceived restorativeness. This reinforces that not only the environment’s characteristics are important for promoting restoration but also that environment’s demands and provisions should be aligned with the individual’s purposes and inclinations at the time (Kaplan, 1995). A limitation of the adopted version of the PRS is the exclusion of the extent dimension, which could imply an incomplete sampling of the overall restorativeness. Therefore, we encourage future studies to develop and improve the representation of the extent construct in the PRS.

The item “After visiting this place, I feel refreshed and relaxed” had the higher weight in the ROS scale closely followed by the item “Being here renews my enthusiasm and energy for my daily routine”. Although these items were highly correlated, they were kept because they address different constructs. The first item reflects the relaxation involved in the restoration process while the latter focus on the recovery of vitality for the continuity of usual activities. However, the participants could have associated the word “refreshed” of the first item with this recovery of vitality, being a possible cause of the observed correlation. Therefore, a suggestion for future studies is to test the removal of the word “refreshed” from the first item.

One important characteristic of both instruments is that they have presented good fit indexes independently of participants’ gender and geographical region of residence. The fact that the proprieties of both instruments did not vary between the sampled cities of south and southeast regions is a good indication of their applicability to the whole country. However, considering the multiple cultures and geographical differences existent in this vast territory, it is recommended to check the validity evidences of the scales in future research conducted in the regions not included in this study. Additionally, studies that focus on gender roles in the perceived restorativeness are of great importance.

Studies on restorative environments are scarce in Brazil (Gressler & Günther, 2013) and did not apply psychometric scales but rather used semistructured interviews to assess the restorative experience (Felippe et al., 2017, 2020; Sousa et al., 2015). This qualitative method, however, is more limited in terms of testing hypothesis and comparing different settings or targets groups, which can be achieved when adopting psychometric scales that allow for quantitative analysis. Although PRS focuses on the restorative qualities perceived in the environment whereas ROS focuses on perceived changes in restoration states (Han, 2018), the convergent validity between the scales allows the selection of a shorter and convenient instrument or a longer and structured scale, according to the objectives and limitations of future studies. These instruments can be applied to assess the restorative potential and outcomes of existing places, and even of future settings, being a useful tool to inform the design of places that maximize restoration outcomes (Hartig et al., 1996) and overall mental health and wellbeing. Additionally, the application of these scales allows for comparing, to a certain point, findings from studies conducted worldwide, and testing hypothesis of the effect of different cultures, geographical conditions, and relationships with nature on restorative experiences.

5 Case study: the effect of park quality on the promotion of mental health and wildlife support in São Paulo, Brazil[11]

5.1 Introduction

Mental health disorders affected around 13% of the population in 2019 and have become a growing concern worldwide after the onset of the COVID-19 pandemic, with initial estimates showing up to 28% increase in cases (WHO, 2022). Nature has increasingly been acknowledged for its beneficial effect on human health and well-being and, more recently, "green prescription" has emerged as a nature-based health intervention typically designed to tackle non-communicable diseases and mental health issues through the exposure of patients to natural environments (Robinson and Breed, 2019). Even in anthropic environments, studies have demonstrated that urban nature (i.e. urban green infrastructure) can help to cope with mental disorders such as depression and anxiety (Cox et al., 2017; Marselle et al., 2020) as well as promote mental health and well-being through stress reduction (Hunter et al., 2019), and mental restoration (Lindal and Hartig, 2015),. However, evidence on the impact of urban green infrastructure quality in the provision of these benefits is still limited (Allard-Poesi et al., 2022; Felappi et al., 2020; Houlden et al., 2021; Knight et al., 2022).

Urban green infrastructure also plays a relevant role in biodiversity conservation, sustaining significant plant and animal species and functioning as stepping stones and corridors for wildlife (Villaseñor et al., 2021). Support to urban wildlife is affected by green space quality as aspects such as area, habitat diversity, and tree species richness have already been reported as predictors of animal diversity (da Silva et al., 2020; Yang et al., 2020). The knowledge of how animals respond to different characteristics of urban green infrastructure is essential to guide minimal requirements for green space design and management that effectively promote wildlife conservation (Garmendia et al., 2016).

Beyond the multifold benefits of green spaces to humans and biodiversity, the effect of biodiversity levels on human health and well-being outcomes has also been explored. Although studies have found mixed results, there is some initial evidence of a positive relationship (Cameron et al., 2020;

[11] A modified version of this chapter was published as: Felappi, J.F., Sommer, J.H., Falkenberg, T., Terlau, W., Kötter, T. 2024. Urban park qualities driving visitors mental well-being and wildlife conservation in a Neotropical megacity. Scientific Reports, 14, 4856, https://doi.org/10.1038/s41598-024-55357-2

Douglas and Evans, 2021; Nghiem et al., 2021). Nonetheless, requirements for human use and wildlife support may differ and a green space might not fulfill the demands for both dimensions at the same time. In order to maximize synergies and manage trade-offs between people and nature, interdisciplinary studies on the role of green space quality on outcomes for both dimensions are necessary.

In this study, we examine the indirect effect of urban park qualities on the perceived restorativeness of users, as well as their direct effect on wildlife support metrics. Additionally, we explore an indirect effect of park wildlife on restorativeness. We hypothesize that among synergies, some park characteristics, especially vegetation-related, may show opposite effects on humans and animals due to, for instance, local safety issues.

5.2 Theoretical framework

The relationships explored here are based on the One Health framework for urban green spaces (Felappi et al. 2020), which aims at understanding the interlinkages between the green space quality (environmental health), users' mental health and well-being (human health), and urban wildlife support (animal health). The focus is to investigate whether green spaces' characteristics affect outcomes for each dimension and, especially, to identify potential synergistic effects to be maximized and trade-offs to be managed in order to inform the design and management of multifunctional green spaces.

For this study, we selected urban parks as the green space type as they are freely accessible to the general population. From the multiple pathways linking green spaces to human mental health and well-being (Markevych et al., 2017; Marselle et al., 2021) we focus on the restorative experience. Perceived restorativeness is a known mediator in the relationship between settings experience and well-being outcomes (Nghiem et al., 2021), and it is usually associated with natural environments (Hartig et al., 2014). Characteristics of the setting may indirectly affect its restorative potential through users' perceptions of naturalness, soundscape, management, and safety (Felappi et al., 2020). Similarly, several environmental characteristics are known to potentially affect urban wildlife support (Beninde et al., 2015).

Here we explore how people's perceptions of the setting (i.e. environment-related factors) contribute to their restorative experience and how they are associated with objective indicators of the setting's quality and wildlife support (Fig. 10). Users' personal characteristics (i.e. person-related factors) are also considered to have an impact on the individual restorative experience.

Additionally, we analyze how the same objective indicators of the setting's quality affect wildlife support metrics. Finally, we identify and discuss potential synergies and trade-offs comparing the results for each dimension.

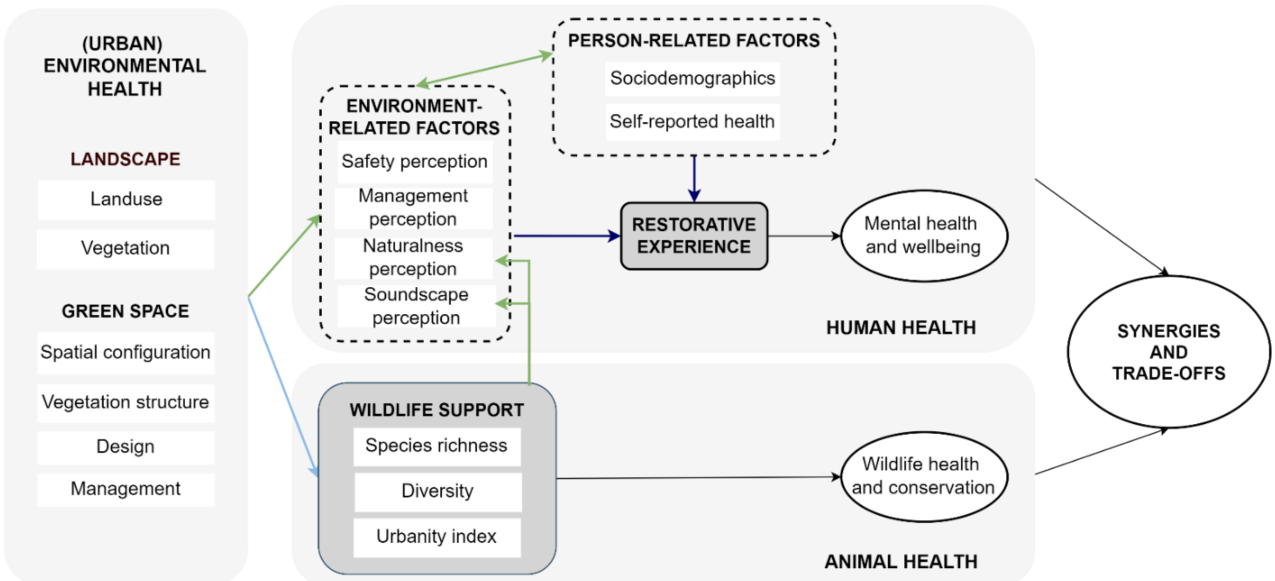

Figure 10. Theoretical framework depicting the relationships investigated in this study. Modified from Felappi and collaborators (2020). Colors refer to the three steps of the analytical approach: dark blue – first, green – second, and light blue – third step. A complete description of factors and interlinkages can be found in the original publication.

5.3 Methods

5.3.1 Study area

The city of São Paulo, located in southeastern Brazil, is the fourth largest urban agglomeration (22 million inhabitants) (United Nations, 2018), and has one of the highest prevalences of mental disorders (29,6%), with 10% of severe cases (Andrade et al., 2012). This megacity overlaps the Atlantic Forest biodiversity hotspot (Rezende et al., 2018) and 48% of its territory is covered by vegetation (of different types). Despite the high share of vegetation, it is unequally distributed across regions (Fig. 11b), with coverage ranging from 16% in the center to 62% in the southern region (São Paulo, 2020).

The existing 111 municipal parks are categorized as urban, linear, reserve, and natural (São Paulo, 2022). Reserves and natural parks are intended for biodiversity conservation, accordingly their accessibility for the public is restricted, and these were not considered in this study.

According to the municipality, urban parks are structured fenced spaces that protect biodiversity and provide recreational and sports facilities, whereas linear parks are riverside areas usually not fenced. The latter may or may not present recreational facilities as their main objectives are the protection of areas adjacent to water bodies and the connectivity between green areas. Looking at the characteristics of these spaces, there is a broad range of variation in aspects of the spatial configuration, vegetation structure, design, and management, making them a useful case to test the effect of park quality on our response variables.

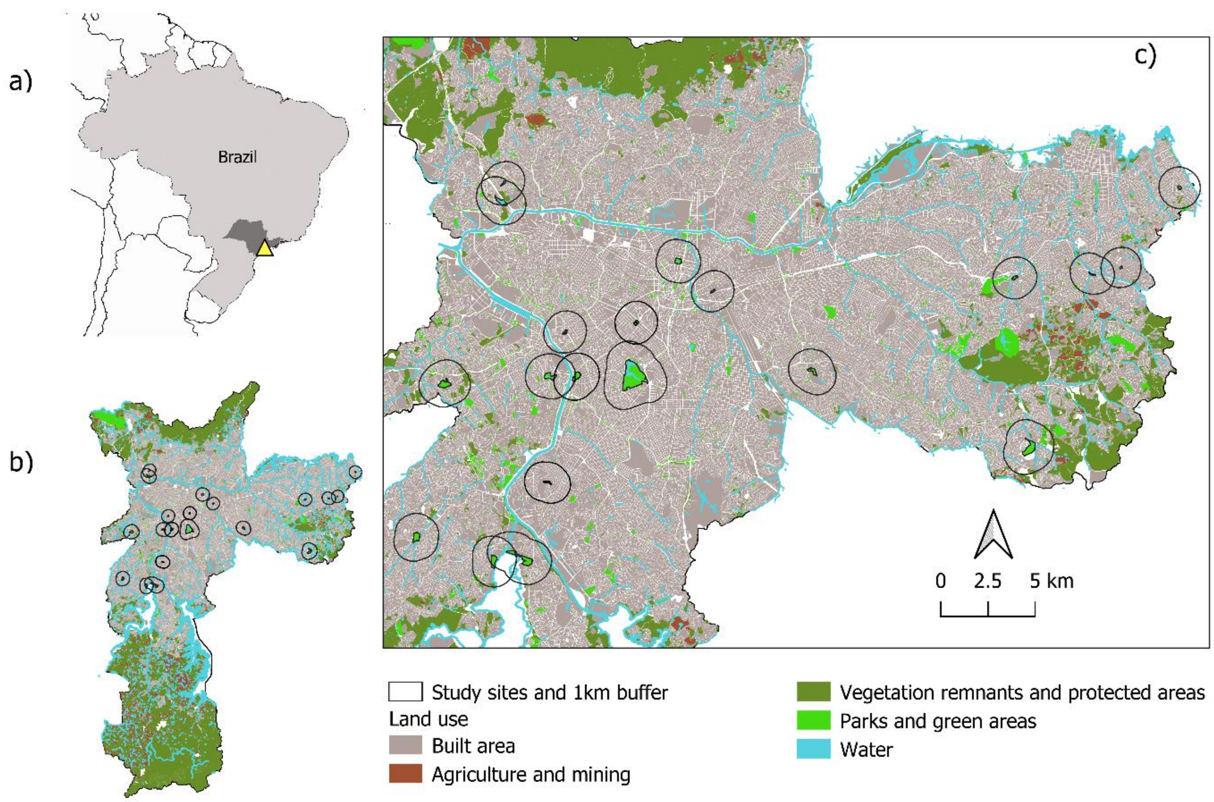

Figure 11. Maps showing the a) Location of the city of São Paulo (yellow triangle) within the state of São Paulo (dark gray) and Brazil. b) Land use map of São Paulo municipality showing the distribution of vegetation and green areas in relation to the build area, with study areas and their 1 km buffers in detail (c). Land use data downloaded from GeoSampa platform (https://geosampa.prefeitura.sp.gov.br/).

5.3.2 Research design

An observational study with cross-sectional data collection was conducted capturing ecological and social perspectives in the context of urban green spaces. Primary data was collected through a questionnaire elaborated to assess park users' perceptions and socio-demographic aspects. Secondary data was retrieved to compute green space indicators and biodiversity variables.

Our analytical approach comprised three main steps (Fig. 10). First, we investigated the effect of users' perceptions of the setting on restorativeness by conducting a structural equation model, as this analysis considers the particularities and errors attached to self-reported data and the use of psychometric and rating scales. In the second step, we used mixed models to assess associations between objective indicators of green space quality and users' perceptions of the setting. Finally, through linear regressions, we assessed the effect of green space indicators on wildlife support variables.

5.3.3 Selection of parks for survey

To enhance the representativeness of our set of study sites considering the variation found in city parks' characteristics, we adopted a stratified sampling approach to select sites from the total of 92 urban parks under the ownership of the municipal government that were legally created and qualified until 2019, and accessible to the general public. As 90% of these parks are below 20 ha in size, we set a cut point value of 10 ha to categorize them into smaller or larger parks. Six groups were created based on park area and visual estimation of tree canopy cover (low, medium, or high). Three parks from each group were selected representing, as much as possible, different levels of socioeconomic vulnerability (low, medium, or high) classified within a 1 km radius of park boundaries (Fig. 11c). Besides the selected 18 parks, the most popular city park (Ibirapuera) and a busy central square (Largo da Batata) were included representing best and worst cases (see Fig. 3 for a list of study sites). For this preparatory assessment, we obtained geo-referenced data on park boundaries and the Paulista Index of Social Vulnerability at the census tract level from the GeoSampa platform kept by the Municipality of São Paulo (geosampa.prefeitura.sp.gov.br) and combined them with Google Satellite images on QGIS 3.10.5.

5.3.4 Data collection

5.3.4.1 Questionnaire with park users

An on-site questionnaire survey[12] with visitants of each study site was conducted from March to June 2019, during the dry season. Each site was visited twice, on a workday and a weekend day, from 8 am to dusk, and under similar weather conditions. Respondents were randomly

[12] The full questionnaire can be accessed in chapter iii.c. in appendices.

approached among people that were visiting the park. Eligible participants were Brazilian adult (≥ 18 years old) residents of the city. Participation was anonymous and subjected to the signature of an informed consent form. The questionnaire was designed in a sequence aimed to reduce response bias and was applied by trained interviewers. Cards with response options for the questions were offered to avoid answer errors. The average time to complete the questionnaire was 15 minutes. This study was approved by the Brazilian National Committee on Research Ethics (CONEP, CAAE: 00239018.7.0000.5390), and all procedures complied with ethical guidelines on research with humans.

Data from four out of five sections of the questionnaire were used in this study: self-reported health and stress level, perceived restorativeness, setting and biodiversity perceptions, and sociodemographic factors. The first section comprised the individual health perception made up of three items (general health, mental health, and well-being) evaluated on a 5-point scale. In addition, stress perception in the last month was measured by the Perceived Stress Scale (Cohen, 1994), which is composed of 10 items evaluated on a 5-point scale validated to Brazilian Portuguese (Luft et al., 2007). The second section included a version of the Perceived Restorativeness Scale (Hartig et al., 1997) composed of 15 items evaluated on a 7-point scale, from 0 to 6, comprising the being away, fascination, and compatibility dimensions, and validated for the target population (Felappi et al., 2021). The third section comprised a scale to assess perceptions of the setting in three dimensions (3 items each, 7-point scale) built upon previous studies (Aletta et al., 2016; Derkzen, 2012): soundscape perception on pleasantness, eventfulness, quietness (e.g. “This park has a pleasant soundscape”); management perception regarding maintenance of facilities and vegetation, and overall cleanliness (e.g. “This park’s vegetation is well cared for”); naturalness perception in terms of similarity to nature and biodiversity (e.g. “This park looks like an untouched nature”). Additionally, single questions were used to measure the perception of safety (i.e. “This setting transmits a sense of safety“, 7-point scale), and biodiversity estimation (i.e. “About how many species of birds and trees would you say exist in this park?”). The response to the latter question consisted of five intervals of species estimation for trees (up to 50, 51-100, 101-150, 151-200, more than 200) and birds (up to 15, 16-30, 31-60, 61-100, more than 100) according to the range found in the pool of parks. The fourth section included socio-demographic questions such as sex, age, and income.

5.3.4.2 Wildlife data

Urban wildlife support in this study is represented by the bird assemblages observed in each park. Birds have been used as biodiversity indicators for several reasons, such as relatively easy identification and data availability, and are conservation flagships due to the interest and concern by the public (Gregory and Strien, 2010). We used two different sets of secondary data to obtain metrics for human perceptions and wildlife models.

The number of bird species observed in each park was used as an independent variable in the human perceptions models. Data were extracted from the Wildlife Inventory of São Paulo city (São Paulo, 2021b), which present a cumulative species list for each park, including observations since 1993. Surveys comprise transect counts, recording of birdsongs, and mist-net sampling. More recently, these lists also include observations collected in a structured citizen science program conducted by the municipality to promote bird watching in parks (i.e. “Vem Passarinhar”).

For the bird support models, we opted to use data from the citizen science platform eBird (https://ebird.org), which provides checklists including the abundance of each observed bird species, thus allowing the estimation of standardized bird species diversity estimates. eBird is a data source of bird observations from a global network of volunteers, which follow collection protocols and data quality checks through automated filters and experts review (Sullivan et al., 2014). Checklists from São Paulo state were obtained within the timeframe of January 2009 to July 2022.

5.3.4.3 Park quality indicators

Data on 40 indicators[13] reflecting park quality were collected for the sampled sites, comprising aspects of spatial configuration (e.g. proportion of tree canopy coverage), vegetation structure (e.g. proportion of native tree species), design (e.g. number of habitats), management (e.g. cleanliness), and adjacent landscape (e.g. vegetated area within 1 km radius). Indicators were selected from a previous study (Felappi et al., 2020) and in participatory consultation with practitioners from the São Paulo municipality through a workshop conducted in 2019. This consultation aimed at tailoring the analysis towards results that could be easily translated into practical recommendations on the planning and management of green spaces. A first filter was applied using a Pearson correlation matrix to identify and exclude indicators that were highly

[13] A table of indicators can be accessed in chapter iii.b. in appendices.

correlated (r>.80) with two or more indicators, leaving a total of 19 to be considered in the following analyzes (Supplementary material S.10[14]).

Data on vegetation coverage was obtained from the Digital Mapping of São Paulo Vegetation Cover (São Paulo, 2020). Vegetation patches were identified and classified into 15 categories on a 1:1.000 scale, based on orthophotos of the year 2017/2018 with 0.12 m of resolution and 3D digital mapping (LiDAR). Plant diversity metrics were calculated based on the Flora Inventories of Municipal Parks (São Paulo, 2021a). Indicators of park management and design (Tab. 12) were collected mainly on-site on the same days of the questionnaires' application.

5.3.5 Data analysis

5.3.5.1 Psychometric scales

We tested construct validity of the scales through reliability and factorial validity analysis. We adopted recommended thresholds indicating adequate parameter values and good model fit as Cronbach's alpha (α) higher than 0.70 (Vaske, 2008), Comparative Fit Index (CFI) higher than 0.95, Root Mean Square Error of Approximation (RMSEA) lower than 0.06, and Standardized Root Mean Square Residual (SRMR) equal to or below 0.08 (Schreiber et al., 2006). These analyses were performed in IBM SPSS Statistics 24 and R software version 4.0.0 using the 'lavaan' package (version 0.6-12, Rosseel, 2012).

For the Perceived Stress Scale and Perceived Restorativeness Scale we conducted confirmatory factor analyses (CFA) since their structures were analyzed before (Felappi et al., 2021; Luft et al., 2007). Both scales confirmed their one-factor and second-order structures with adequate internal consistency and fit indices (α= 0.81 and 0.92, respectively, Supplementary material S.11[15]). The factorial structure of the Perceived Restorativeness Scale enables the calculation of a perceived restorativeness score (PRS score) based on the average of items from the being away, fascination, and compatibility dimensions. We then tested the sensibility of the PRS score to differences across sampled sites estimating margins of responses and 95% confidence intervals for each site and performing pairwise comparisons of the predicted margins. For this analysis, we used the software STATA 16.1.

The three items referring to self-reported health status were combined into a latent variable "Perceived health", which presented adequate internal consistency (α= 0.76). For the settings

[14] Supplementary material S.10 can be accessed in chapter iii.a. in appendices.
[15] Supplementary material S.11 can be accessed in chapter iii.a. in appendices.

perception scale, we conducted a Principal Components Analysis with three fixed factors, which confirmed that the items loaded in the proposed dimensions (soundscape, management, and naturalness), each of them with adequate internal consistency (α= 0.73, 0.88, 0.70, respectively, Supplementary material S.11). We then calculated an average score from the three items of each perception to be used as dependent variables in the regression models.

5.3.5.2 People-related factors affecting perceived restorativeness

After confirming the robustness of our scales, we investigated how visitants' perceptions of safety and the setting affected restorativeness. Considering the nature of this subjective data, we conducted a structural equation model (SEM) with the latent variable perceived restorativeness (made up of its three dimensions) as the response variable, and the latent variables of settings perceptions (soundscape, management, and naturalness), as well as safety perception as predictors. In this analysis, we did not consider the park effect, but rather relationships at the individual level, and therefore we included the effect of control variables sex, age, income, and self-reported health (latent variables of health perception and stress perception). Income and safety perception were transformed into the dummy variables “up to (0)/more than four minimum wages (1)” and “safe (0)/unsafe (1)” (unsafe merged scores from 0 to 2).

The SEM analysis was conducted with the Weighted Least Squares Means and Variances (WLSMV) estimation method, which is more appropriate and with superior performance than Maximum Likelihood for the ordinal level of scale items and large sample sizes (Li, 2016). The model was subsequently optimized with the exclusion of non-relevant pathways. Indicators of good model fit followed the same thresholds mentioned for the psychometric tests (Section 5.4.7). Analyzes were performed in R software using the ’lavaan’ package (version 0.6-12, Rosseel, 2012).

5.3.5.3 Park indicators' effect on setting perceptions

To understand how park characteristics affected respondents’ perceptions of the setting, we first tested the necessity of multilevel analysis to account for the non-independency of observations (respondents clustered in parks) running null models (without predictors) including a random-effect (park) and checking a significant effect on intercepts and intraclass correlation (Garson, 2019, p. 58). As all models were significantly different from one-level linear models and intraclass correlation ranged from 0.158 to 0.367, we conducted mixed-effects linear models for each perception score (naturalness, soundscape, and management) as dependent variables, park indicators as fixed factors, and park name as random factor. Potential green space indicators for each perception were selected based on theory and evidence accumulated in the field (Supplementary material S.10). The number of bird species observed in each park was included as fixed effect in the models of naturalness and soundscape perception. Observations collected in the site 'Largo da Batata' (N= 50) were excluded in all models, and observations in 'Benemerito Jose Bras' (N= 56) were excluded in models of soundscape and naturalness, both due to incomplete biodiversity data.

As preliminary analyzes showed a poor correlation between the actual number of bird and tree species with respondents' estimation of richness (see Results section), we contrasted models using only objective indicators (model 1) with models replacing objective indicators of species richness by respondent's estimation of richness (model 2). For the species richness estimation variables, we used the mean number of species of the interval selected by the respondent in the questionnaire.

Additionally, we explored green space predictors of safety perception using a mixed-effects ordered logistic regression, considering that the response variable is a Likert-scale item (Rabe-Hesketh and Skrondal, 2021). We compared a model including only park predictors (model 1) with a model including control factors that could influence safety perception in the setting (model 2). These comprised significant personal factors resulting from the SEM analysis and an indicator of criminality level in the region (number of thefts registered in the closest police station to each park during the year 2018, source: Site Sou da Paz Analisa).

For all models, we checked multicollinearity between predictors and adopted a full model approach, constructing models that included all variables with acceptable variance inflation factor (VIF< 10) (Table 12). Models were run with robust estimation of standard errors of regression coefficients, which account for data heteroscedasticity and other violations of distributional assumptions (Rabe-Hesketh and Skrondal, 2021, pg. 48, 72). Model diagnostics included the exclusion of influential values based on Cook's distance and residual plots to check the normality and homoscedasticity of residuals. We compared model performance through the Akaike Information Criteria (AIC), with lower values indicating a better fit. We further explored relevant variables of the models calculating predictive margins for different levels of the response variables keeping all covariates constant. All analyzes were conducted in STATA 16.1. Visualization of models' results in the form of coefficient plots (with standardization of continuous and ordinal variables using z-scores) was elaborated with the 'dotwhisker' package (version 0.7.4, Solt and Hu, 2015) in R.

Table 12. List of green space indicators used in the final models of setting perceptions.

Variable	Mean(range)/Frequency	Definition
Landscape		
Landuse	68% mixed	Dominant land use type surrounding the park: residential - 0, mixed (residential and commercial or industrial) - 1
Prop green 1 km	21.9% (8.8-47)	Percentage of area covered by vegetation within the total 1km buffer area surrounding the park
Spatial configuration		
Area	162,315.6 m^2 (14,164-1,241,740)	Total park area
PA ratio	0.023 (0.005-0.049)	(Perimeter-area ratio) perimeter divided by total area
Prop canopy	61.9% (0-99.7)	Proportion of park area covered with closed tree canopy (trees' crowns predominantly touch each other)
Prop open veg	20.2% (0-76)	Proportion of park area covered with herbaceous strata with or without sparse trees
Vegetation structure		
Tree species	112.6 (40-329)	Total number of tree species
Tree sp/ha	18.0 (1.72-49.42)	Number of tree species divided by park area (in ha)
Prop native trees	52.9% (27.8-84.9)	Proportion of species categorized as native out of the total richness
Prop native bushes	52.6% (0-100)	Proportion of bushes categorized as native out of the total richness
Design		
Water score*	1.21 (0-4)	Multiplies the presence of water body (no-0/yes-1) and its accessibility (no-0/yes-1), plus water body naturalness (artificial-0/natural-1)
Number habitats	2.2 (1-4)	Number of microhabitats within the park
Topography	79% flat	Predominant topography: Flat or slightly undulating - 0, uneven - 1
Management		
Understorey	58% no	Presence of vegetation layer(s) beneath the tree canopy: no - 0, yes - 1
Cleanliness	58% with trash	Reflect the presence of trash in the days of survey: clean - 0, with trash - 1
Vandalism	74% no vandalism	Presence of signs of vandalism in park facilities: No vandalism – 0, vandalism - 1
Wildlife		
Bird species	69.4 (17-223)	Total number of bird species listed in each park

*for wildlife models, water score did not consider accessibility.

5.3.5.4 Park indicators' effect on wildlife support

We constructed models of bird species support based on three different response variables calculated from the eBird dataset. We followed recommended steps for data clearing and filtering (Strimas-Mackey et al., 2020) using only complete checklists, stationary or traveling protocols, and merging duplicate lists according to sampling event identifier. A dataset with checklists for each park was created intersecting geographic coordinates from the checklists with the shapefiles of park boundaries. A reference sample for each park was selected based on the following criteria: observation period ranging from 60 to 100 minutes, number of observed specimens available for all species reported (removal of lists in which bird species were reported as “X” - no count), and finally, the higher number of species reported. The definition of the range of observation period aimed to reduce variability in sampling effort while allowing enough time for observation of a high number of species (Johnston et al., 2021). We used a sample of 30 parks according to data availability on park characteristics and compliance with sampling effort criteria. A matrix with individual counts for each species by park was used as input to estimate species richness and Shannon diversity index on the ‘iNEXT’ package (version 3.0.0, Hsieh et al., 2016) in R. Using the ‘estimateD’ function, these diversity estimates were computed by standardizing samples by coverage (Roswell et al., 2021), at the minimum sample coverage level among all sites.

Additionally, we calculated the urbanity index of each park’s checklist. This index (adapted from the urbanophobe index, Shwartz et al., 2013) considers the degree of vulnerability of species to anthropic disturbance, commonly found in urban environments. The level of sensibility of each bird species (low, medium, high) was assessed in available literature (Parker III et al., 1996) and the index is calculated as the share of species with low sensibility out of the total number of bird species. A high index reflects a bird assemblage composed of a majority of species more tolerable to human disturbances instead of species that require a higher level of habitat quality.

Firstly, we tested if our response variables were spatially correlated through the Moran’s I test using the package ‘ape’ (version 5.6-2, Paradis and Schliep, 2019) in R. As spatial auto-correlation was not significant for all outcomes variables, we proceeded to run three linear regression models including all predictors that were statistically significant in the analysis of setting perceptions. This is in concordance with the aim of the study of analyzing potential synergies and trade-offs between human and animal dimensions using the same indicators. As park area was not correlated with bird richness ($r=0.30$, $p=0.103$) and diversity ($r=0.28$, $p= 0.137$), we did not include it as a control variable in the models. However, we tested concurrent models by adding the sampling effort time (duration of bird survey) as a covariate. Due to the limited sample size, we used 'lasso' command to select the best predictive variables to be included in the final models. We adopted model selection and diagnostic approaches already mentioned in section 5.4.9. Apart from investigating the main effects of variables, we ran additional regressions testing an interaction effect between proportion of canopy and the presence of understorey on all three independent variables. All analyses were conducted in STATA 16.1 and the coefficient plot in R.

5.4 Results

A total of 994 questionnaires were collected with the sample being well balanced in terms of sex (Table 13), but females are less represented than males, in contrast to the general population of São Paulo (52.6% female; IBGE, 2012). The higher proportion of respondents belonged to the range between 25 and 34 years old and the less represented age class was above 65 years old, similar to the general population (24.8% and 10.8%, respectively, IBGE, 2012). Household income lower than two minimum wages was the most represented class in the sample, although this class represents a lower proportion in the general population (29%, IBGE, 2012).

Table 13. Sociodemographic aspects of the sample. MW refers to minimum wage, which was equivalent to 998,00 Brazilian reais in 2019.

	n	%
Sex		
Female	486	48.9
Male	508	51.1
Age		
18-24	168	16.9
25-34	266	26.8
35-44	213	21.4
45-54	156	15.7
55-64	122	12.3
65+	69	6.9
Family monthly income		
< 2 MW	353	35.5
2-4 MW	285	28.7
4-10 MW	217	21.8
10-20 MW	66	6.6
> 20 MW	22	2.2
Did not answer	51	5.1

The Perceived Restorativeness Scale had a mean score of 4.02 (SD= 1.13) and was sensible to park conditions, showing statistically significant differences in PRS score among sites (Fig. 12). The predicted PRS score values of Rio Verde park (2.95, CI= 2.56-3.34) and Largo da Batata square (3.00, CI= 2.61-3.39) are lower than the others ($p<0.04$) except Guaratiba park ($p= 0.112$ and $p= 0.169$, respectively). Alfredo Volpi park shows the highest value (4.95, CI= 4.76-5.14) in comparison to all parks ($p<0.02$), not differing ($p= 0.360$) only in relation to Ibirapuera park (4.83, CI= 4.65-5.01).

Although the overall means of perceived naturalness, soundscape, and management scores were similar (3.09, SD=1.34; 3.31, SD=1.37; 3.31, SD=1.66, respectively), they significantly varied among sites too. Soundscape perception score is lower in Largo da Batata square (1.45, CI= 1.13-1.76, $p= 0.000$) achieving the highest score in Alfredo Volpi park (4.26, CI= 3.88-4.63). For management perception, Rio Verde has the lowest value among all parks (1.06, CI= 0.71-1.41, $p<0.01$) except Guaratiba (1.52, CI= 1.18-1.85, $p= 0.063$), and Povo park the highest score (4.77, CI 4.55-4.99, $p<0.02$) not being different only from Alfredo Volpi (4.58, CI= 4.26-4.91, $p= 0.357$). Finally, for naturalness perception, Alfredo Volpi park shows the highest value (4.26, CI= 4.00-4.51, $p<0.04$) not being different only from Guarapiranga (4.17, CI= 3.93-4.42, $p= 0.643$) and Severo Gomes (4.06, CI= 3.75-4.37, $p= 0.340$). The lowest value is found in Largo da Batata square (1.45, CI= 1.18-1.73). Overall mean safety perception was 3.48 (SD=1.8), with the lowest values found in Rio Verde (1.9, CI= 1.38-2.42) and Largo da Batata (2.08, CI= 1.67-2.49), and the highest values in Severo Gomes (2.6, CI= 4.32-4.88) and Alfredo Volpi (4.5, CI= 4.04-4.96).

5.4.1 Personal factors and perceptions affecting restorativeness

The first structural equation model (full model) showed moderate fit indices (model 1, Supplementary material S.12) and was followed by optimized models excluding the control variable age (model 2), which had an irrelevant effect on perceived restorativeness, and the exclusion of the additional non-significant pathways of health and stress perceptions (model 3, Supplementary material S.12[16]).

Safety perception was the variable with the largest standardized regression weight in the model, meaning that feeling unsafe in the setting had the strongest effect on perceived restorativeness, affecting it negatively (Fig. 13, Supplementary material S.13[17]). Feeling unsafe was positively correlated with being female and lower household income (less than 4 minimum wages). Higher

[16] Supplementary material S.12 can be accessed in chapter iii.a. in appendices.
[17] Supplementary material S.13 can be accessed in chapter iii.a. in appendices.

household income and being female affected positively the perceived restorativeness, however, with weaker effect sizes than setting perceptions variables.

Respondents' evaluation of the park as close to original nature and biodiverse (naturalness perception) was the most relevant setting perception, followed by management perception, and soundscape perception (Fig. 13). Naturalness perception was also correlated with management and soundscape perceptions. Self-reported health condition, stress level, and age were not relevant in the model due to small effect sizes and non-significant p-values.

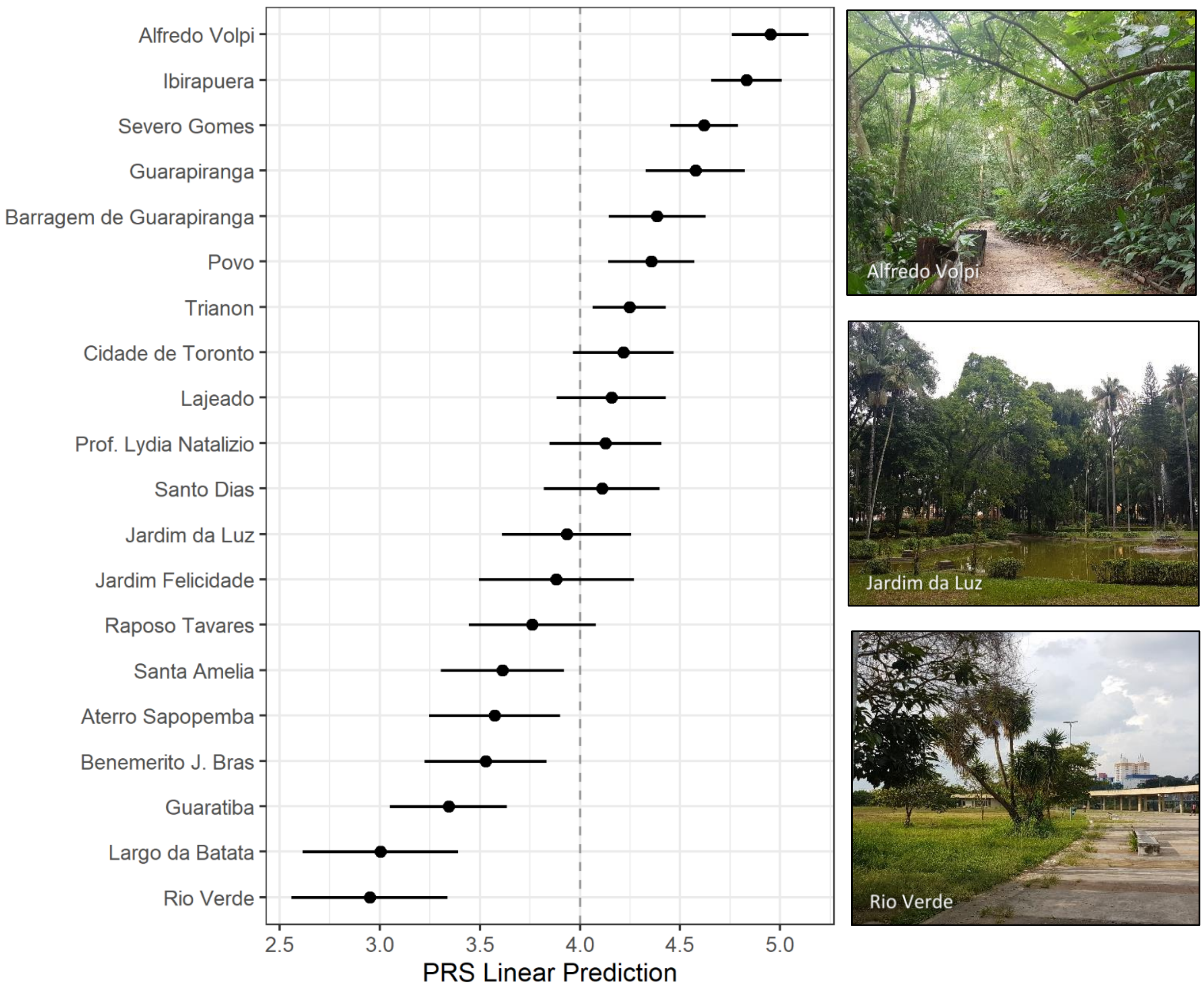

Figure 12. Adjusted predictions of perceived restorativeness scores (PRS) for each park and 95% confidence intervals. The dotted line represents the mean perceived restorativeness score of the total sample. The pictures provide an idea of the different parks' configuration and were taken from Alfredo Volpi (upper right), Jardim da Luz (middle), and Rio Verde (bottom).

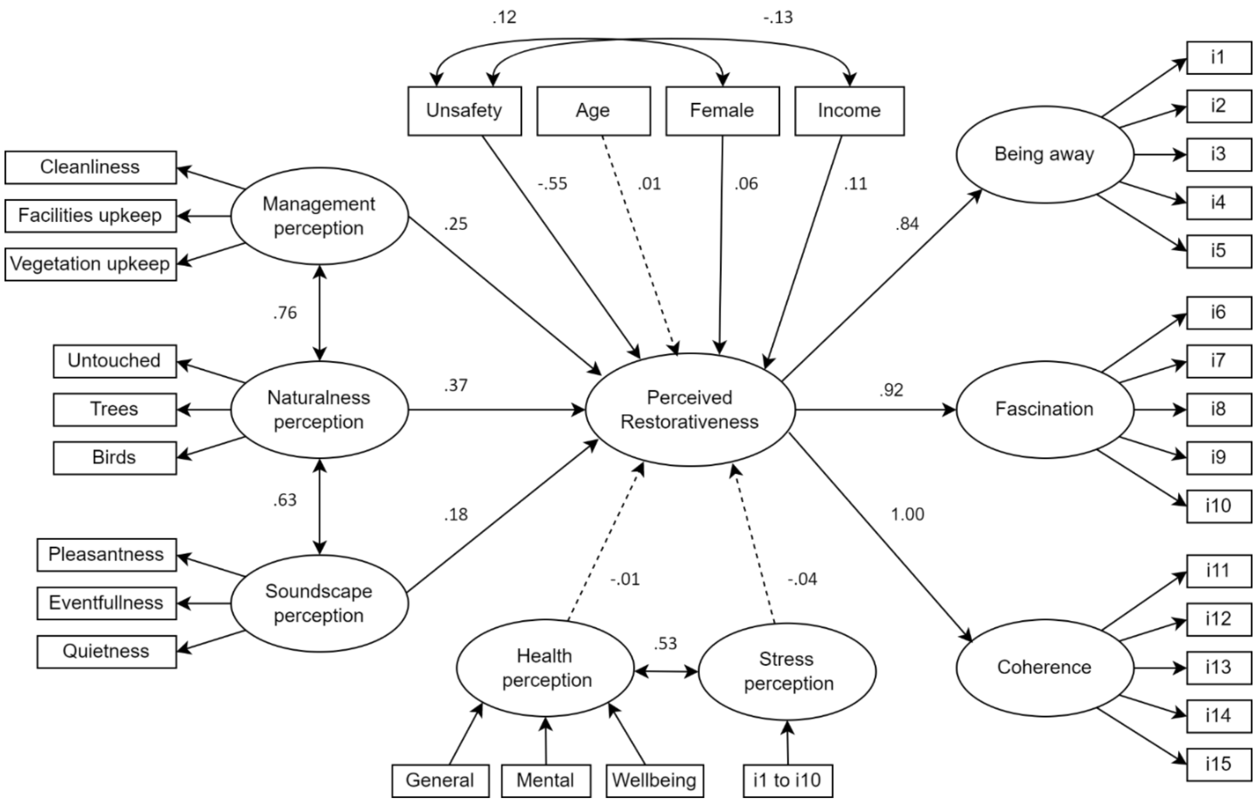

Figure 13. Path diagram of the perceptions and control variables affecting perceived restorativeness (full model, model 1 in Supplementary material S.13) with standardized coefficients. Dotted lines depicture pathways that were not significant (p> .05). Regression estimates within the measurement models were omitted in this picture for simplification.

5.4.2 Park qualities effect on setting perceptions

As a preliminary analysis, we explored whether people correctly perceived the actual number of bird and tree species. The correlation between the actual number of bird and tree species and respondents' estimation was low (r= 0.214, p=0.000; r= 0.40, p=0.000, respectively). Taking birds species richness estimation as an example, when respondents (N= 888) were asked about the range of bird species present in the park, 85.7% (N= 761) perceived fewer species, and only 8.1% (N= 72) perceived the correct range of species. More than half of respondents (55.5%, N= 493) estimated the presence of up to 15 species and 77.5% of up to 30 species, whereas 15 study sites reportedly have bird richness higher than 30 species with reported numbers for all study sites between 17 and 223 species per park. These results made us further investigate whether the respondents' estimation of bird and tree richness instead of the actual number of species would produce different outcomes in the setting perceptions models. For that, we compared and reported both models below.

In the naturalness perception model with objective predictors, only the proportion of tree canopy (p=0.000) and the presence of understorey vegetation (p= 0.040) were significant predictors, showing positive and similar effect sizes (Fig. 14). The concurrent model (model 2, Fig. 14), which replaced the actual number of bird and tree species with the estimated mean number by the respondent, yielded a lower AIC value (2567.097 versus 2592.133). In this improved model, the proportion of canopy (p= 0.000) and understorey presence (p= 0.003) remained as significant factors with higher effect sizes on naturalness perception however, birds (p= 0.000) and trees (p= 0.000) species estimations, as well as water score (p= 0.028), were relevant predictors with lower effect sizes.

Based on the best model (model 2), we further explored the effect of different levels of canopy coverage on naturalness perception. Keeping all covariates constant, our model indicates that the mean predicted value of naturalness starts to increase further than the overall mean (3.09) from 60% of canopy coverage (3.19, 95% CI= 3.10-3.27), achieving the higher predicted mean at near 100% coverage (3.53, CI= 3.39-3.67). In terms of water elements, sites without or with non-accessible water bodies show a predicted mean value lower than the naturalness perception overall mean (3.05, CI= 2.84-3.25), whereas the presence of accessible artificial water bodies (3.27, CI= 3.18-3.35) and, especially, access to natural water bodies (3.49, CI= 3.26-3.71) increased the predicted values.

Respondents' management perception was negatively affected by the presence of signs of vandalism (p= 0.002), followed by positive associations with the presence of understorey vegetation (p= 0.003) and tree species richness (p= 0.001) (model 1, Fig. 14). The proportion of native trees showed a lower and negative effect size (p= 0.037). In the alternative model (model 2), only vandalism (p= 0.004) and the estimation of tree richness (p= 0.000) remained significant predictors, the first with the strongest effect size. The second model yielded a lower AIC value (3151.417) than model 1 (3178.294).

The objective model for soundscape perception resulted in four significant predictors. Water score (p= 0.000) and bird species number (p= 0.000) had the strongest effect on the perception of soundscape however, the latter showed a negative relationship. The proportion of canopy (p= 0.000) and proportion of green within 1 km radius (0.004) followed with significant but lower positive effect sizes. Alternatively, in the second model, in which we replaced the actual number of bird species with the respondents' estimation, the direction of the relationship reversed to a positive effect, and only the estimation of bird species' number is a significant predictor of soundscape (p= 0.039). The water score was only marginally significant (p= 0.052). The second model performed better according to AIC values (2807.002 versus 2833.303).

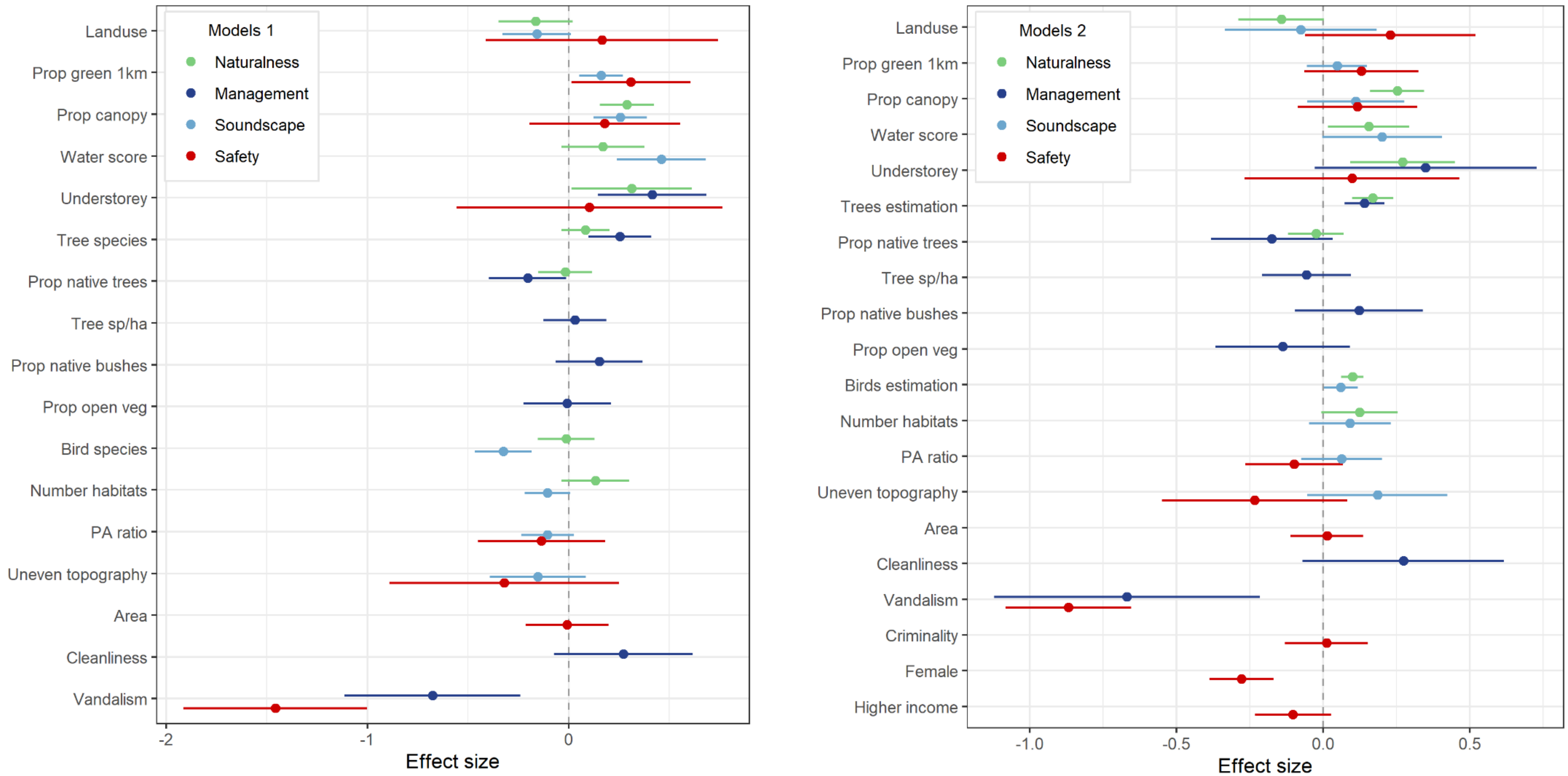

Figure 14. Effect sizes (standardized coefficients) of each variable included in the final models of setting perceptions (naturalness, management, and soundscape) and safety perception. The plots represent the models with objectives variables only (models 1, left side), and the models replacing biodiversity perception in the setting perceptions and including control variables in safety perception (models 2, right side). Variables with standard errors (bars) that do not cross 0 are statistically significantly. See Table 1 for definition of variables.

Regarding safety perception, in model 1 the presence of signs of vandalism had a strong negative effect on people's perception of safety (p= 0.000), followed by a smaller positive effect of proportion of green within a 1 km radius (p= 0.004). We proceeded by adding to the model the control variables sex and income (significantly associated with safety in the SEM model), and the objective indicator of criminality. In this second model, which performed better (AIC 3029.772 versus 3188.77), vandalism kept the strongest effect on safety perception (p= 0.000), followed by the participant's sex, with being female having a smaller and negative effect (p= 0.000). Proportion of green within 1 km radius lost relevancy, as well as income.

5.4.3 Park qualities effect on wildlife support

The lowest number of observed bird species in the reference samples from the eBird dataset was found at Independencia park, with 7 species, and the highest number was observed in Nove de Julho park, with 64 species. The mean urbanity index was 0.85 (0.58-1.0). Effort time (minutes of observation) did not have a relevant effect on the outcome variables, and the models that included it as a covariate resulted in higher AIC values. Therefore, only the best models (without this covariate) are reported.

Higher estimates of bird species richness are associated with a lower proportion of tree canopy (p= 0.000) and higher water score (p=0.036) (Fig. 15). Shannon diversity is negatively affected by proportion of canopy (p=0.003) and the presence of understorey vegetation (p=0.043). A high urbanity index is associated with a high proportion of vegetation within 1 km (p=0.018). The interaction effect between proportion of tree canopy and presence of understorey was relevant only in the urbanity index model, showing a negative relationship with urbanity (p=0.002). Sites with 80 to 100 percent of tree canopy and with understorey vegetation are predicted to show a significantly lower urbanity index than sites with the same canopy proportion but without understorey (p=0.003 and p=0.001 respectively, Fig. 16).

5.5 Discussion

5.5.1 Park quality and user restoration

Our findings reveal that urban parks can show significant variation in their restorative potential, and may in some cases not even differ to a busy city square. The quality of these spaces plays a decisive role in the provision of psychological restoration opportunities linked to improved well-being.

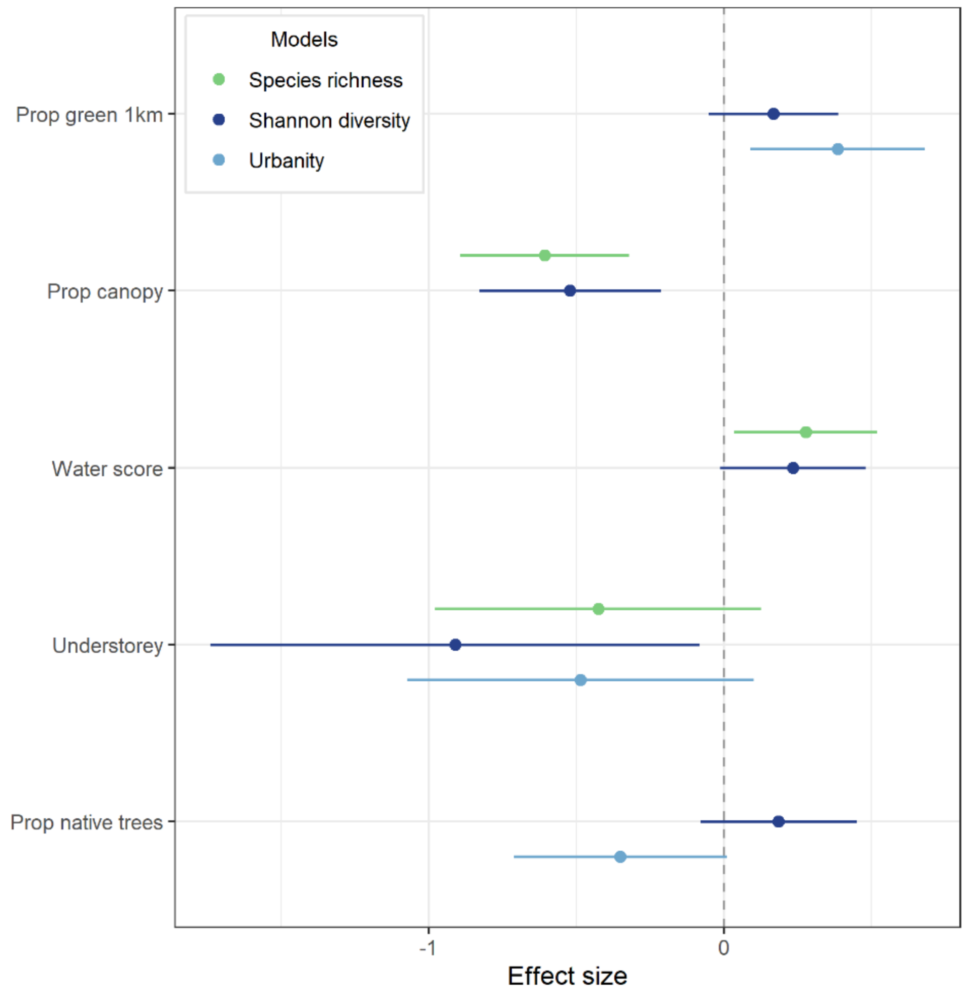

Figure 15. Effect sizes (standardized coefficients) of each variable included in the final models of bird community support (species richness, diversity, and urbanity). See Table 1 for definition of variables.

Safety perception was the most relevant factor affecting the perceived restorativeness of park users. Feeling safe in the environment is a basic condition to permit the rest of directed attention (Kaplan and Kaplan, 1989) and this finding reflects that vulnerability to criminal acts in such open spaces may hinder green space benefits. Naturalness perception - the similarity with a natural and biodiverse environment - had the second strongest effect on perceived restorativeness. Nature fulfills two main components of the restorative experience: “fascination” towards living beings and processes, and “being away” to a setting with a different content than everyday life (Kaplan and Kaplan, 1989). Provided safety conditions, high naturalness perception is the main factor to be aimed for in park design for improved restorative potential.

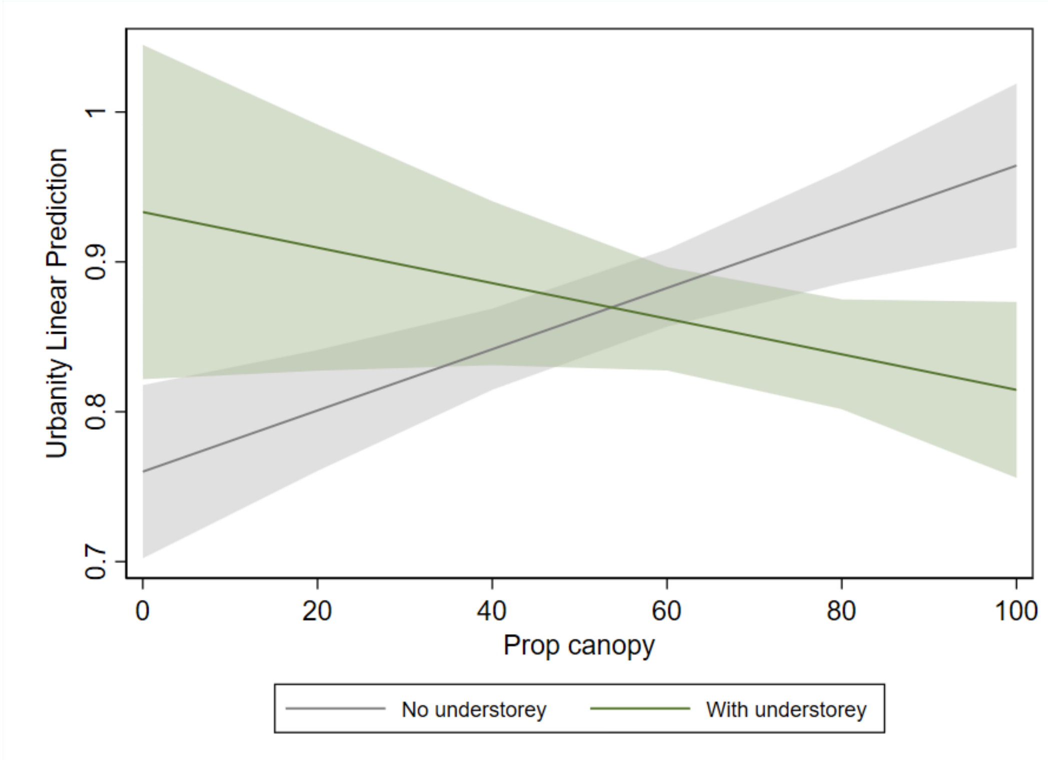

Figure 16. Relationship between proportion of tree canopy (Prop canopy) and urbanity index in the presence or absence of understory vegetation. Shaded area represents the 95% confidence interval.

Vegetation coverage within and adjacent to park boundaries indirectly affected users' perceived restorativeness through their perceptions of naturalness and soundscape. The beneficial effect of higher levels of tree canopy cover can be associated with the effectiveness of tree belts and street trees as barriers to environmental noise, and even beyond, vegetation may also induce a greater perception of noise reduction than the actual values (Han et al., 2018; Ow and Ghosh, 2017). A park with high tree canopy coverage may evoke familiarity with the original environmental condition as São Paulo is embedded in the Atlantic Forest biome, in which mature forests are made-up of big trees, an abundance of epiphytes, and multiple vegetation layers (Barretto and Catharino, 2015). This forest density is also a potential explanation for the positive effect of understorey vegetation on naturalness and management perception, suggesting that it did not create a perception of overgrowth and unmanaged vegetation but rather an intentional decision to foster the natural aspect of the vegetation patch. Contrary to our expectations based on previous studies (Jansson et al., 2013; Zhao and Huang, 2021), perceived safety was not associated with park configuration or vegetation aspects. This means that management actions such as the removal of understorey vegetation for improved visual permeability (Zhao and Huang, 2021), in this case, actually weaken restorative outcomes and do not necessarily improve the user's sense of safety in the park.

Additionally, aspects of vegetation composition affected the way people perceived park management. Higher perceptions of management were associated with a higher number of tree species (objective and perceived) but in a lower proportion of native in comparison to exotic species. This finding can be associated with previous studies showing that park users are more attentive to ornamental and emblematic species, which are usually exotic species intentionally cultivated by gardeners (Muratet et al., 2015). This effect is more likely associated with their attractiveness than with the identification of their "nativeness" by the general public, as non-native species may be seen as unusual, more colorful, and interesting (Fischer et al., 2011; Hoyle et al., 2017). Therefore, park users correctly associated the increasing presence of ornamental/exotic trees with higher levels of intervention and vegetation care.

The presence of water features is known to positively affect nature (Luo et al., 2022) and soundscape perceptions (White et al., 2020), and the degree to which water benefits restoration depends not only on its presence but also its accessibility (Zhao et al., 2018). In our study, a combination of accessibility (possibility of visual, acoustic, and/or physical contact) and the natural condition of the water body yielded the best outcomes for restoration through greater naturalness and soundscape perceptions. This aspect is highly relevant in a context where water bodies are often present in parks but, due to their poor ecological condition, are isolated or hidden from users through physical barriers or a design that does not encourage contact with this feature. In this sense, efforts in the ecological restoration of water bodies within parks are highly recommended.

An aspect of site management is of high relevancy for parks' restoration potential. Visible signs of vandalism in park facilities have the greatest effect on management and safety perceptions. The effect on management perception is related to the evidence of the inability of the administration to repair or replace damaged facilities. The presence of clear signs of vandalism in the park such as graffiti and broken facilities are the main predictors of safety perception whereas a quantitative indicator of criminality in the region is not relevant, which can be explained by the "Broken Windows Theory" (Wilson and Kelling, 1982). The theory states that when signs of disorder are left unrepaired the feeling of carelessness raises fearfulness in residents, which may not be associated with an actual increase in crime rates. Our findings also suggest that park quality may reflect neighborhood socioeconomic level, as respondents' income is not associated with perceived safety when accounting for park characteristics. In this regard, focusing financial resources on parks' maintenance would be an effective measure to improve safety perception and consequently boost their restorative potential.

An additional important factor for safety perception is gender disparity. Even when accounting for park quality and other control factors, sex remained a relevant factor with being female positively associated with unsafety perception, similar to findings in urban green spaces of other Global South countries (Zhao and Huang, 2021). The lower share of female respondents in our sample compared to the general population of São Paulo suggests that females might be underrepresented in these spaces in a reflection of safety issues. Considering that females are at higher risk of developing mental health issues than males, and may benefit more from urban green spaces (Fernandez Núnez et al., 2022), it is essential that public policies promoting the use of open (green) spaces also focus on women's safety, ensuring that they have equal opportunity to enjoy the whole potential of urban parks for their health benefits.

5.5.2 Park quality and wildlife support

Not only the presence but also the naturalness of parks' water bodies matters for bird species support in terms of overall richness. Microclimate effects such as milder temperatures close to water elements, as well as the habitat and food resources provided by natural water bodies, were proposed as possible reasons for the positive relationship between water and bird richness already reported in São Paulo city (Barbosa et al., 2020). On the other hand, the negative effect of higher levels of closed canopy on bird species richness and diversity contradicts previous studies in urban areas (Shwartz et al., 2013) but is in line with Jasmani et al. (2017). The positive effects of water presence and lower proportion of tree canopy suggest that bird richness in these urban parks is driven by habitat heterogeneity. Green spaces that provide multiple microhabitats such as forest patches, open vegetation, and water bodies, offer a broader range of resources and can attract bird species with varying habitat and foraging requirements (Jasmani et al., 2017). The association between understorey vegetation and bird diversity may be explained by an unbalanced presence of forest-dependent species in parks with forest remnants and larger forest patches. Notably, these results were influenced by the high diversity estimates in parks located at wetlands on the border of Guarapiranga water reservoir, which present the lowest canopy proportions in our sample (around 20%) but are habitats of good ecological quality. This also indicates that tree canopy cover alone may not be used as a proxy of ecological quality for the bird assemblage, at least in the environmental configuration of São Paulo city's parks.

When looking at a qualitative aspect of the bird assemblages in each park, the interaction between vegetation aspects was relevant and resulted in distinct outcomes. While higher canopy proportion and the presence of understorey negatively affected diversity estimates, the combination of these aspects reduced urbanity levels of the bird assemblage. This means that bird species more sensitive to human disturbances - and of higher conservation value - are benefitting from higher park tree canopy proportion when accompanied by understorey vegetation. The presence of understorey vegetation improves the ecological quality of urban forest patches in terms of providing nesting sites, increased forage availability, protection against predators and domestic animals, and is especially important to small-body and ground/understorey-nesting species, which are more sensitive to anthropogenic disturbance (Heyman, 2010; Joyce et al., 2018).

It is important to emphasize that this analysis did not aim to investigate all relevant features driving bird diversity estimates in urban parks, therefore our results must be interpreted in the context of comparison with the human dimension. Several green space features that are known to affect urban wildlife were not considered due to their irrelevancy for psychological restoration outcomes. Additionally, the analysis could not take into account green spaces with very low ecological quality due to either the lack of bird checklists or insufficient sampling effort in such areas. Bird watchers are usually attracted to more natural-like areas where the potential for bird encounters is higher. The inclusion of bird surveys in parks of lower ecological quality would contribute to the clarification of the tree canopy effect, especially in sites with lower than 40% of tree coverage.

5.5.3 Parks for humans and wildlife

We identified synergies and trade-offs between relevant green space indicators for users' mental restoration and bird assemblage support. A clear synergy is the presence of water bodies, especially with a natural aspect, which improved bird richness as well as restoration through higher perceptions of naturalness and soundscape. Therefore, this is a feature that should receive high relevance in the design and management of green spaces.

On the other hand, proportion of canopy cover presented both synergies and trade-offs depending on quantitative or qualitative aspects of bird species support. While higher tree canopy proportions with understorey vegetation provide higher restorative potential to users and benefit bird species of higher conservation value, it also reduces bird diversity estimates. However, birds where the only animal group considered in this study, and it is likely that other groups (from larger mammals to arthropods) do respond differently to canopy proportions and understorey vegetation features. Although the positive effect of lower tree canopy on diversity estimates may be a trade-off with psychological restoration, it could be considered a synergy with other human benefits, as a park with different habitats may provide more opportunities for recreational activities.

Our results contribute to the emerging evidence of the beneficial effect of biodiversity on human health and well-being (Cameron et al., 2020; Fisher et al., 2021; Nghiem et al., 2021), through the psychological restoration pathway. Regardless of the actual number of bird and tree species, people´s estimation of biodiversity was of high relevance to the three domains of setting perceptions related to restoration potential. Higher estimation of bird species by users was associated with better soundscape perception as the single relevant factor in the best model, in opposition to actual bird richness. The mismatch between people's perception of biodiversity and objective indicators was reported before (Muratet et al., 2015) and the general underestimation of bird richness in our case may be due to either short visit duration that does not allow the encounter with many species, the lack of knowledge on local biodiversity, or because respondents could not differentiate bird songs. In this sense, investment in environmental education of the population on local biodiversity could lead to enhanced benefits to mental well-being. As urban parks are the logical places for connecting with nature in urban areas, simple interventions such as guided tours and biodiversity-focused signage can improve visit quality and hence boost the restorative experience. Furthermore, future studies could explore bird richness perception in more detail carrying out bird surveys on the same days as questionnaire application.

5.6 Conclusions

This is the first study to provide quantitative evidence on the restorative potential of urban parks in Brazil, contributing to the understanding of pathways linking the environment to human health benefits. The findings highlight that urban parks can play an important role in mitigating the urban psychological penalty, or the negative effects of city on mental health and well-being, offering opportunities to recover from depleted psychological capacities and stress. To maximize this potential, safety perception should be prioritized as a fundamental condition for restoration in São Paulo’s urban parks, while design and management should focus on features that enhance the naturalness perception of users, the second key factor contributing to perceived restorativeness of users.

We show that park quality is crucial in determining its restorative potential for visitors. Settings of high restorative potential should have a forest-like appearance with abundant tree canopy (>60%) and multiple vegetation layers, and feature numerous tree species (including exotic ones). Additionally, the presence of easily accessible natural water bodies can enhance the restorative experience further. In terms of management, financial resources should be prioritized for the repair of signs of disorder such as graffiti and broken facilities, avoiding the depreciation of park benefits due to safety concerns.

Interdisciplinary socio-ecological studies are important to shed light on potential synergies and trade-offs between different beneficiaries of green spaces. Through a holistic approach, we were able to provide recommendations for the design and management of urban parks considering benefits to both human well-being and urban wildlife conservation. Taken altogether, our results suggest that incorporating natural water bodies into park design maximizes benefits for both dimensions. “Forest-like” parks provide higher restorative potential to users while benefiting bird species of higher conservation value. On the other hand, more heterogeneous parks may provide better bird diversity estimates and, despite lower restorative outcomes, they could provide more diverse recreational opportunities to users.

Besides the intrinsic value of nature, the evidence that higher biodiversity level is also a relevant factor influencing human well-being reinforces the importance of investing in urban nature. We underscore that attention to green space quality is essential to effectively provide the expected benefits for human health and biodiversity conservation. Our findings support efforts towards healthier and biodiverse cities through the provision of a heterogeneous green infrastructure consisting of a network of spaces that are purposely designed and managed to reconcile both human and wildlife needs.

6 Discussion, implications, and conclusion

6.1 Main findings

The systematic review (chapter 3) demonstrated the geographical bias towards European and North-American countries in both mental health and urban wildlife research fields and therefore the necessary effort to close the knowledge gap of Global South countries. The role of green space characteristics on wildlife support was more explored in comparison to mental health studies. The most used measures of wildlife support were species richness and abundance, and the majority of the studies considered two or more measures simultaneously. For mental health, measures were predominantly self-reported single-item rating scales and psychometric scales. This reflects the selection of studies explicitly linking green space characteristics to mental health outcomes, as other outcomes such as depression and anxiety are usually associated with green space exposure assessment in terms of availability and accessibility.

Several potential synergies and trade-offs between mental health and wildlife support outcomes were identified in the systematic review such as the beneficial effect of the presence of flowers for both dimensions and the contrasting effect of flat topography. Part of these synergies and trade-offs could be evaluated in the case study (chapter 5). As indicated in the review, the presence of water bodies was a synergy confirmed in the case study. Although the beneficial effect of tree coverage on mental health was corroborated, for birds (as representatives of wildlife) it revealed a more complex and nuanced effect. Another unexpected result is that enclosed vegetation (or the presence of understorey vegetation) was not a negative factor affecting restoration through the perceived safety in urban parks, and did not show a straight positive effect on bird support measures. Further synergies or trade-offs could not be evaluated either due to the lack of a statistically significant effect or due to multicollinearity of model variables. The potential effect of biodiversity - in terms of plant and wildlife richness - on restoration was demonstrated in line with the previously identified relevance of analyzing not only objective indicators but also people`s perceptions of biodiversity levels. Additionally, the suggested inclusion of measures that assess qualitative aspects of animal community composition proved valuable in disentangling the responses of birds to green space features taking into consideration their sensibility level to anthropogenic disturbances.

A framework was developed linking the three One Health dimensions in the urban context, with green spaces' quality (environmental health) affecting both wildlife support (animal health) and the restorative experience of users (human health). Furthermore, the effect on restoration depends on the individual perceptions of the setting (environment-related factors) as well as their personal characteristics (person-related factors), and the animal dimension can also contribute to people's perception of the setting. This proposed framework was improved and validated by the work developed in chapters 4 and 5. Based on the experience with the interviews for the validation of psychometric scales (chapter 4), the environment-related factors were further developed with the addition of the management perception and the slight change of the biodiversity perception into naturalness perception including the general natural aspect of the setting (chapter 5). The environment-related factors identified in the review and the additional management perception were significantly associated with the restorative experience of urban park users in Sao Paulo. Furthermore, the results confirmed the effect of wildlife on perceptions of soundscape and naturalness (biodiversity), which in turn affected users' restorativeness, demonstrating a pathway linking the animal and human health dimensions under the One Health approach.

The use of psychometric scales as metrics of mental health linked to green space qualities was highlighted in the systematic review. The selection of the Perceived Restorativeness Scale and the Restoration Outcomes Scale for application in Brazil aimed at allowing a comparison with studies already conducted in other countries. The good model fit indices achieved in both scales combined with their structural consistency in regards to sex and location (Porto Alegre and São Paulo) allow the implementation of quantitative assessments of mental restoration in the Brazilian population.

The case study conducted in São Paulo city, Brazil, unveiled significant differences in the restorative potential among urban parks, measured by the perceived restorativeness score, as well as in the mean scores of setting perceptions (naturalness, soundscape, and management). This indicates that park quality plays an important role and the scales used were sensitive enough to capture a range of user perceptions.

The restorative experience of urban park users in São Paulo was primarily dependent on a feeling of safety. Interestingly, unsafety was not associated with a criminality indicator, but with signs of vandalism inside the park. The impression of being in a place similar to a natural habitat with diverse animals and plant species (naturalness perception) was the main setting perception contributing to restorativeness, being more relevant than management and soundscape perceptions. This finding suggests that the design and management of parks that maximize the restorative potential should focus on promoting nature rather than overly manicured spaces. User perception of naturalness was associated with higher tree canopy proportion, presence of understorey vegetation, and presence of water bodies (ideally of natural aspect). An additional relevant park characteristic was linked to improved management perception of users - the second strongest setting perception – in terms of an overall higher quantity of tree species, and a positive contribution of exotic species. This is probably related to aesthetic reasons and/or familiarity with species commonly used in urban streets and gardens. A higher proportion of green within 1 km radius contributed to better perceptions of soundscape and safety, indicating that the presence of street trees and other green areas in the immediate vicinity of the park are also relevant for the restorative experience. Therefore, parks that offer higher restorative potential in Sao Paulo have better ecological quality in terms of vegetation and water body aspects while caring for maintenance of facilities.

With regards to similar or distinct responses of mental restoration and bird species support to green space features, as previously mentioned, a clear synergy existed in water body's presence. Other aspects that at first indicated trade-offs (i.e. the negative effect of higher canopy proportion and understorey presence on bird richness and diversity *versus* the positive effect on restoration) were better comprehended with the analysis of a metric reflecting a qualitative aspect of bird assemblage. Although heterogeneous green spaces with diverse habitats may benefit a wider range of bird species of different requirements, sites of high ecological quality with predominantly forested area may contribute especially to species more sensitive to anthropic disturbance. Therefore, green spaces should be planned, designed, and managed with clear purposes. According to findings from this case study, forest-like green spaces foster users' restoration potential and conservation of bird species of higher conservation value, whereas more heterogenous spaces may attract more bird species and offer more opportunities for different uses by people.

This study highlights the importance of considering the quality of green spaces for the effective delivery of expected services and identifying and managing synergies and trade-offs between services and between potential beneficiaries. Due to the increasing relevance of green spaces as nature-based solutions to tackle several urban issues, cities should aim at implementing a heterogenous network of green spaces that are adequately planned, designed, and managed according to local necessities and priorities, and that promote multifunctionality as its full concept.

6.2 Recommendations and potential implications of the findings

6.2.1 Recommendations for urban planning

In the expansion and transformation of urban areas, urban planning should integrate and mainstream health and biodiversity concerns. The solid evidence of the benefits of green spaces for human health and biodiversity makes these spaces an important feature to be promoted in new developments and interventions in built-up areas. Green spaces in adequate quantity and size should be available so that they can absorb the demand without compromising benefits due to overcrowding. Their equitable distribution within the city is essential to ensure that the whole population can access quality green spaces, which is of particular relevance in deprived neighborhoods. Therefore, the development of urban forestry/green infrastructure master plans at the local and regional levels is highly suggested to set clear targets and action plans (including their timeframes), to prioritize areas underserved, and to document areas to be preserved in face of pressures from housing and infrastructure developments.

Parks should be designed and managed to maximize synergistic functions, considering that different characteristics result in different outcomes for humans and animals. According to the present study, the green infrastructure network should comprise forest-like parks that maximize restoration of users and benefit birds of higher conservation value, and parks with diverse habitats that improve bird species richness and may offer additional recreational opportunities. Beyond the beneficial effects for mental health and wildlife support, green spaces are expected to provide other several ecosystem services which also involve synergies and trade-offs. Restorative green spaces, which feature water bodies and a high proportion of trees, can also help cities in climate change mitigation - with the cooling effect and mitigation of heat island effects - and reduction of air and noise pollution. Alternatively, more heterogeneous spaces, which include open vegetated areas for example, can be very useful, particularly in areas prone to flooding events.

Therefore, the establishment of a heterogeneous green infrastructure network is important, including not only parks with different characteristics but also multiple elements such as green roofs, gardens, greenways, and street trees, so that connectivity is enhanced allowing for the movement of people, wildlife, and ecological processes. For instance, greenways and green streets facilitate and make it more pleasant people’s movement, promoting physical activity and less dependence on transportation. Furthermore, they act as stepping stones for birds and other wildlife, benefiting urban biodiversity.

Besides general recommendations for the design and management of urban green spaces, the results from the systematic review and case study were combined to provide additional guidance on individual green space features (Table 14). Generalizability of results may be limited to different cultural backgrounds and local contexts. However, the results of the present case study were mostly in line with findings from other countries.

Table 14. Recommendations for green space design and management focused on mental restoration and wildlife support based on general findings from the systematic review (SR) or/and results in the local context - the case study (CS) in São Paulo, Brazil.

Green space feature	Recommendation	SR	CS
Proportion of green within 1 km radius	Increasing vegetation in the site vicinity (e.g. street trees, grass strips next to streets, squares, pocket parks) improves restoration of park users through better perceptions of soundscape and safety, as well as enables connectivity between green areas benefiting biodiversity.		X
Patch area	Larger areas are ideal to maximize positive effects on restoration and across animal groups. It also enables habitat diversity and multiple uses without compromising enough space for restoration. Safety should be provided to not invoke a higher fear of crime.	X	
Proportion of tree canopy coverage	For a higher restoration potential, most of the park area (over 60% in the local context) should be covered with trees. A large forest patch is better than several small ones as it minimizes the forest edge effect (unfavorable to biodiversity) and maximizes the feeling of immersion in nature.	X	X
Understorey vegetation	Tree patches should maintain underlying vegetation layers (understorey) improving the perception of naturalness. Safety must be provided to avoid that the lower visibility and high refuge potential lead to user unsafety feeling. Insects and birds (especially more sensitive species) are benefited by the provision of habitat, resources, and refuge.	X	X
Proportion of native tree species	Although native species should be prioritized for biodiversity conservation, the presence of exotic (non-invasive) species in strategic places may be welcomed as they improve user perception of management.	X	X
Water bodies	The presence of water bodies is important for both restoration and bird species and should be a highlighted feature. Ideally, they	X	X

	should be of natural aspect, clean, and accessible to users. Ponds/lakes and rectified canals can be designed or ecologically restored to improve user naturalness perception and provide habitat for birds, and invertebrates species.		
Biodiversity	Strategies to protect the existing species and attract/cultivate additional ones should be considered to maximize user contact with nature. Environmental education actions are suggested as a means to improve people's knowledge of local biodiversity.		X
Topography	Flat topography may benefit restoration through improved safety perception with the possibility to have a wide view of the surroundings. However, it may not be the most beneficial design for wildlife, since it often correlates with low habitat heterogeneity. A balance should be aimed to reconcile wide views with levels of the land that enable different habitats and an overall perception of naturalness.	X	
Trails	Straight footpath alignment, which allows a clear view ahead or behind, was linked to reduced fear of crime. The main trails in forested areas should be located close to the borders, minimizing disturbance to wildlife and allowing people to connect to nature without compromising safety perception. However, at least one path should offer cross the forest, giving opportunity to those who prefer a more immersive experience in nature.	X	
Facilities maintenance	Signs of vandalism such as graffiti and broken facilities or equipments should be repaired as soon as possible, as they were associated with unsafety perception and lack of management.		X

6.2.2 Potential implications to green space governance in São Paulo city

Considering the city of São Paulo's context and policies in place, the findings of this thesis could be translated into the following implications for policy and governance of urban parks and green spaces:

Not all park typologies provide the same restorative potential - Linear parks (i.e. Guaratiba and Rio Verde) sampled in this study presented poorer mean scores on perceived restorativeness. These parks are characterized by higher perimeter-area ratios and lower tree canopy coverage, and despite their association with rivers, these are artificially rectified and hidden from users. According to the municipality, the main objective of linear parks is to protect water bodies (this was not assessed in this study) and therefore they should not be expected to fulfill all potential services to users. However, our results of lower restoration potential suggest that this type of park should not be considered at the same level as other urban parks when assessing, for example, quantitative indicators of population accessibility to green space in terms of potential benefits for mental health and well-being. Efforts in increasing tree canopy and especially in the ecological restoration of the water bodies could significantly increase their restorative potential.

Prioritization of restorative-deprived areas - The eastern region of São Paulo concentrates areas of medium and high socioeconomic vulnerability and this condition is reflected in park quality and usage. Four out of five parks studied in this region showed perceived restorativeness scores lower than the overall mean, suggesting that this could be also an area with fewer opportunities for psychological restoration (restorative-deprived area). As green spaces have the potential to reduce the effects of social inequalities it is important to improve park quality and safety, especially in this vulnerable region, in order to provide adequate restorative experience potential to users. It is important to note that efforts towards improving green space quantity and quality, especially with the aim of benefiting deprived regions, must be aligned with strategies to avoid "green gentrification" and the displacement of the poorer residents and the consequent aggravation of social inequality and environmental injustice (Anguelovski et al., 2022).

Prioritization of management budget – The limited financial resources allocated to park management should be prioritized for the repair of signs of disorder/vandalism such as graffiti and broken facilities, avoiding the depreciation of park benefits due to safety concerns of users.

Mental health benefit as an economic incentive for opening up private green areas - São Paulo has recently approved the 'Plano Municipal de Conservação e Recuperação de Áreas Prestadoras de Serviços Ambientais' (Municipal Plan for the Conservation and Restoration of Ecosystem Services Providers Areas), which includes an instrument of Payment for Ecosystem Services that compensates landowners who protect or recover ecosystem services provider areas. The multiple ecosystem services offered by trees such as temperature regulation, noise, and air pollution reduction, made urban forests an eligible category for payment for ecosystem services as areas of local importance. However, under this scheme, vegetated private areas eventually selected for this instrument do not necessarily become open to the public. Considering the significant contribution of green areas to citizens' mental health and well-being, this policy could include this as an additional paid service given as an incentive to owners to open up their private vegetated lots to public use. Consequently, the adoption of such a scheme would have the potential to substantially increase the availability of open green spaces for the population with the contribution of these private areas.

Environmental education – as users underestimated plant and bird species richness present in parks, actions to promote local biodiversity knowledge have the potential to boost nature connectedness during the park visit and consequently the user restorativeness. Itinerant programs such as the successful “Vem Passarinhar” - monthly birdwatching events in different parks that promote citizen science – could be complemented with programs with focus on plants and insects, as well as with the provision of educational materials (e.g. biodiversity-focused signage and brochures) in all parks according to their respective biodiversity.

6.3 Limitations and future research

The systematic review (chapter 3) only considered statistically significant associations between urban green space features and outcomes to health or wildlife found in previous studies. This means that it does not provide all possible relationships and indicators that could be involved in the green space-mental health-wildlife interface. It was conceived as an evidence-based guide to inform the next steps of this doctoral thesis and future research in general.

In the analysis of users’ perceptions in chapter 5, the soundscape model could be improved with the inclusion of objective measures of the noise level. Actually, the measurement of the sound level was contemplated in this project and was performed during the application of questionnaires however, the equipment crashed halfway through fieldwork and it was not possible to transfer the stored data to the computer’s software. Therefore, this variable was unfortunately not considered in this thesis.

The wildlife analysis could not consider green spaces of low ecological quality due to the lack of citizen science data. The promotion of citizen science campaigns that include such non-sampled spaces would be of great importance for comparative purposes. Alternatively, conducting standardized wildlife sampling simultaneously with questionnaire application would be the gold standard for assessing the relationships between actual and perceived biodiversity. Despite being of difficult practical implementation, it could be feasible in larger projects involving more researchers and resources.

Due to the already complexity of the relationships studied, this thesis could not dive deep into different aspects of the human population. Although age and/or sex factors were included in the analysis of chapters 4 and 5, this research generally focused on the adult population, without distinctions regarding ethnic groups, gender identity, or disabilities for example. Restorative outcomes might vary when those aspects are taken into account and, in some cases, even the lack of accessibility to green spaces by some groups prevents them from enjoying this benefit. This consideration in future studies is of extreme importance in order to offer more inclusive restorative green spaces.

One main takeaway from this doctoral experience is that conducting a real transdisciplinary study as a one PhD project is quite challenging and may lead to one or more dimensions being less well represented. A suggestion to overcome this by being able to assess each relationship of the system in more detail and robust data would be to design entire PhD programs around a single context, with each PhD project addressing one specific part of the system in detail and the final aim of combining findings from all projects to have a big picture of interactions in the whole system.

6.4 Conclusion

Due to its holistic approach, this thesis provides contributions to different disciplines such as urban ecology, environmental psychology, urban planning, and public health. It extends the use of the One Health concept beyond the zoonotic diseases and antimicrobial resistance fields (both disease-focused), towards a health-promoting approach applying it to the core of our urban areas and their green areas system where the three One Health dimensions have the greater interaction potential.

The innovative framework integrating the three One Health dimensions in the context of urban green spaces, alongside the extensive lists of green space indicators associated with mental health and with wildlife support outcomes, offer theoretical and methodological guidance to future studies on the role of environmental quality on human health and wildlife dimensions, especially taking into consideration potential synergies and trade-offs between them.

The thesis contributes to the restorative environments research field in Brazil, with the validation of widely used psychometric scales to assess restorative outcomes. This may help, for instance, to fulfill the research gap on the cultural and contextual variations of human-natural settings relationships, since the currently available evidence is strongly biased toward studies in the Global North.

Finally, applying the outcomes from previous chapters in a case study conducted in a megacity of the Global South (São Paulo, Brazil), this study was able to identify specific characteristics that improve the restorative potential of urban parks and how these characteristics also affect outcomes in an animal assemblage (birds). The results were translated into suggestions for planning and managing green spaces taking into account the synergies and trade-offs between humans and birds. Furthermore, the scale developed to assess setting perceptions could be used in future studies of green infrastructure elements.

Taken altogether, this thesis contributes to the growing literature on the beneficial effect of urban green spaces and biodiversity on human health and well-being through the capacities restoration pathway. Importantly, it promotes an integrative view of the environment-human-animals interface and its interconnections to address multiple issues simultaneously aiming at maximizing benefits for all while managing trade-offs. This research highlights that green space quality affects its restorative potential to users and support to bird assemblages. Therefore, attention to green space quality during its design and management is essential in order to achieve the expected benefits for human health and wildlife conservation.

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Appendices

i. Supplementary material for chapter 3: Systematic review and integrative framework uncovering synergies and trade-offs between mental health and wildlife support in cities.

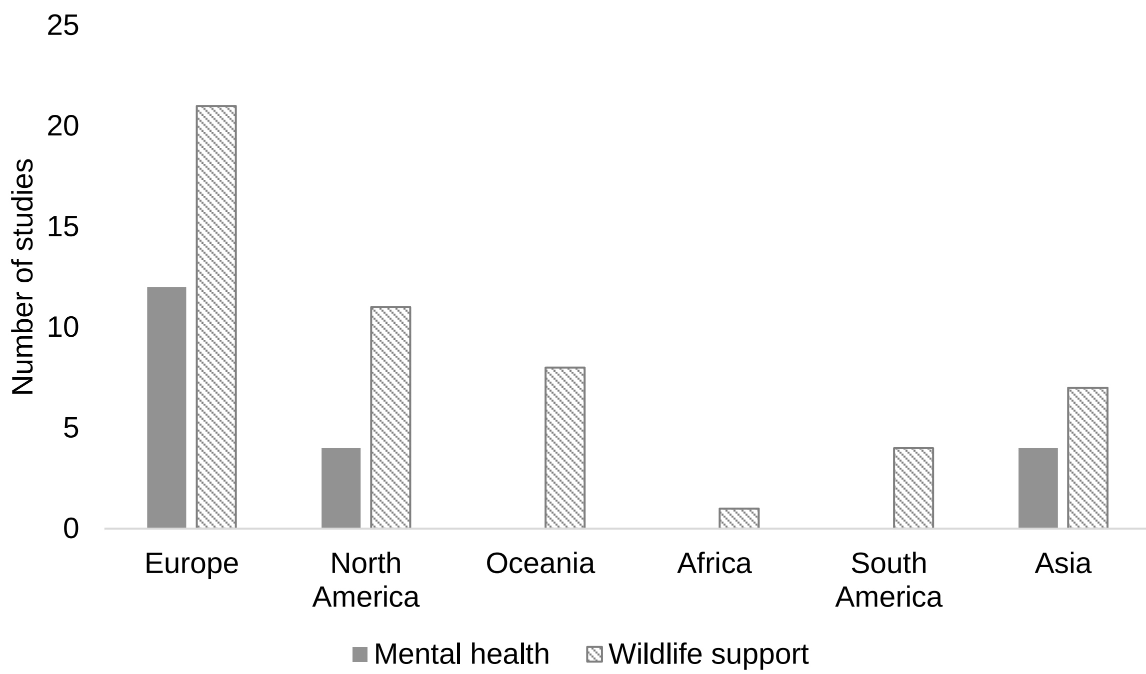
The following material was submitted as supplementary material A supporting the publication that constitutes chapter 4 of this doctoral thesis. It is available online through the following link: https://www.sciencedirect.com/science/article/pii/S0048969720351184#s0140

a. Inclusion and exclusion criteria

Supplementary material S.1. List of criteria for inclusion and exclusion of studies adopted in the systematic review.

Exclusion criteria	Inclusion criteria
• Records not in English language • Sampling/study site is not a green space according to the definition adopted • Study site not located within urban or peri-urban areas • Do not assess green space characteristics/features (green space qualities) • Assess only availability and accessibility of green spaces • Green space characteristics merged (e.g. principal components, composite scores) • Focus only on children; mortality rates; physical health; attractiveness or preference • Assess impacts only on vegetation • Focus on variation across urbanization gradients or comparison between urban and rural areas • Purely qualitative studies	• Quantitatively or qualitatively assess green space characteristics (green space qualities) • Assess mental-health OR/AND wildlife support-related outcomes according to the definitions adopted • Use statistical analysis to test the relationship between green space characteristics and mental health or wildlife support-related measures • Report at least one significant relationship between green space features and outcomes of interest

b. Number of studies and list of indicators



Supplementary material S.2. Number of studies included in the systematic review divided on mental health and wildlife support per region of the world.

Supplementary material S.3. Urban green space indicators related to mental health and well-being at the landscape-level category. CA= categorical variable.

Indicator	Description	Type	Mental health variable	Observed effect	Reference
Urban matrix					
Location	Located in the urban or peri-urban area (categories: urban or peri-urban)	CAT	Perceived Restorativeness Scale	Positive (peri-urban)	Carrus et al 2015
	Categories: busy or quiet area	CAT	Perceived safety scale	Negative (quiet)	Mak and Jim 2018
Adjoining landuse	Type of residential land use that surrounds the park (categories: low-density residential or high-density residential)	CAT	Perceived safety scale	Negative (low-density)	Mak and Jim 2018
	Type of land use that surrounds the park (categories: industrial or office)	CAT	Perceived safety scale	Negative (industrial)	Mak and Jim 2018

Supplementary material S.4. Urban green space indicators related to mental health and well-being at the site-level category. CAT= categorical variable, and CON= continuous variable.

Indicator	Description	Type	Mental health variable	Observed effect	Reference
Spatial configuration					
Patch area	Size of the study site (categories: small or large)	CAT	Perceived safety scale	Negative (large)	Mak and Jim 2018
	Patch area categorized into intervals (categories: 0 - 200 m^2, 201 - 500 m^2, 501 - 800 m^2, 801 - 1200 m^2, >1200 m^2)	CAT	Perceived Restorativeness Scale	Positive	Cervinka et al 2016
	Perceived park size (categories: small, medium or large)	CAT	Likelihood of restoration, Being away and Fascination (PRS)	Positive	Nordh et al 2009
Water	Presence or absense of water (categories: water, no water)	CAT	Likelihood of restoration, Being away and Fascination (PRS)	Positive (presence)	Nordh et al 2009
			Restorative potential	Positive (presence)	Wang et al 2019
Grass cover	Percentage of the ground surface of the patch image covered by grass	CON	Likelihood of restoration, Being away (PRS)	Positive	Nordh et al 2009
	Relative dwell time across park components measured in eye-tracking experiment (categories: hardscape, grass, lower ground vegetation, flowering plants, bushes, trees, water, etc)	CAT	Likelihood of restoration	Positive (only for grass)	Nordh et al 2013
Lower ground vegetation cover	Percentage of the ground surface of the patch image covered by lower ground vegetation (not grass)	CON	Likelihood of restoration, Being away and Fascination (PRS)	Positive	Nordh et al 2009
Bush cover	Percentage of bushes coverage in the patch image	CON	Likelihood of restoration, Being away (PRS)	Positive	Nordh et al 2009
Tree cover	Percentage of tree cover in the patch image	CON	Likelihood of restoration, Being away and Fascination (PRS)	Positive	Nordh et al 2009
	Proportion of tree cover within 50 m radius	CON	3 dimensions of psychological well-being	Positive	Dallimer et al 2012

(continued)

Supplementary material S.4. (Continued).

Indicator	Description	Type	Mental health variable	Observed effect	Reference
Vegetation structure					
Permeability	Number of trees and shrubs on each edge of the scene (categories: low (six), medium (three) and high (one))	CAT	Perceived safety Perceived Restorativeness Scale	Positive (high permeability) Negative (controlling for safety)	Tabrizian et al 2018
Spatial arrangement	Number of vegetated edges in a picture (categories: 1-sided, 2-sided and 4-sided)	CAT	Perceived safety Perceived Restorativeness Scale	Negative (4-sided) Positive (controlling for safety)	Tabrizian et al 2018
Level of enclosure	Calculated through visible arc and visible area (categories: low, medium, and high)	CAT	Perceived safety	Negative (high)	Baran et al 2018
	Concealment level (categories: low and high)	CAT	Fear of crime	Positive (high)	Jorgensen et al 2012
	Level of closure of view, so that the urban matrix could not be seen through the vegetation, at the edge, at the edge zone, and in the forest interior (categories: open, semi-closed and closed)	CAT	Perceived Restorativeness Scale	Positive (closed)	Hauru et al 2012
	Level of prospect-refuge condition assessed through the extent of unobstructed view, the number of potential hiding places and opportunities for concealment, and accessibility to move through	CAT	Perceived danger and fear	Positive (low prospect-high refuge)	Andrews and Gatersleben 2010; Gatersleben and Andrews 2013
	the scene (categories: high prospect-low refuge, medium prospect-medium refuge, and low prospect-high refuge)		Perceived restoration	Negative (low prospect-high refuge)	Gatersleben and Andrews 2013
			Positive affect (Inventory of Personal Reactions - ZIPERS)	Positive (high prospect-low refuge)	Gatersleben and Andrews 2013
			Feelings of sadness (Inventory of Personal Reactions - ZIPERS)	Positive (low prospect-high refuge)	Gatersleben and Andrews 2013
			Anger/aggression (Inventory of Personal Reactions - ZIPERS)	Negative (high prospect-low refuge)	Gatersleben and Andrews 2013
			Attention (Necker Cube Pattern Control Task - NCPCT)	Positive (high prospect-low refuge)	Gatersleben and Andrews 2013
			Physiological restoration (heart rate)	Positive (high prospect-low refuge)	Gatersleben and Andrews 2013

(continued)

Supplementary material S.4. (Continued).

Indicator	Description	Type	Mental health variable	Observed effect	Reference
Tree density	Number of pixels in each panoramic photo identified as associated with trees divided by the number of pixels in the entire photograph, and multipling this number by 100	CON	Stress reduction (skin conductance and salivary cortisol)	Inverted U-shaped curve (after 35% stress reduction decreases)	Jiang et al 2014
	Amount of trees in a photograph (categories: low= single tree, middle= three trees, high= continuous tree canopy)	CAT	Restorative potential	Positive	Wang et al 2019
Planting structure	Structural similarity to natural vegetation in terms of the manner in which plants are layered through the third dimension (categories: least natural, moderately natural, most natural)	CAT	Restorative effects	Positive (moderately and most natural)	Hoyle et al 2017
Plant richness	Number of plant species (all forbs and woody plants) in 40 × 10 m plot	CON	3 dimensions of psychological well-being	Negative	Dallimer et al 2012
	Participants estimate the number of different types of plants at the study location in a scale from 1 to 5 (perceived species richness)			Positive	Dallimer et al 2012
Design					
Accessibility to water	Access to water bodies (categories: no water=0; difficult to access=1; neutral to access=2; easy to access=3)	CAT	Revised Restoration Scale	Positive (easy access better)	Zhao et al 2018
Footpath alignment	Alignment of footpaths categorized into straight or curved/winding	CAT	Perceived safety scale	Negative (curved/winding)	Mak and Jim 2018
Road cover material	Categories: more hard-paved or more soft vegetated areas	CAT	Perceived safety scale	Negative (hard-paved)	Mak and Jim 2018
Park gates	Provision of park gates (categories: sufficient or insufficient)	CAT	Perceived safety scale	Negative (insufficient)	Mak and Jim 2018

(continued)

Supplementary material S.4. (Continued).

Indicator	Description	Type	Mental health variable	Observed effect	Reference
Park layout	Parks with small, isolated and enclosed pockets or with large and open sites (categories: small isolated and enclosed pockets or large and open space)	CAT	Perceived safety scale	Negative (small, isolated and enclosed pockets)	Mak and Jim 2018
Natural features	Relative number of natural features (e.g., lawn, flowery meadow, water)	CON	Perceived Restorativeness Scale	Positive	Cervinka et al 2016
Landscape type	Photographs of relatively homogeneous landscape types according to landscape characteristics, spatial perception, and degree of artificialization (categories: forest lawn, forest road, forest lake, forest settlement, peak landscape, understory landscape, and forest canyon)	CAT	Tranquility rating	Positive (peak landscape and understory landscape)	Liu et al 2019
Topography	Type of predominant topography (categories: almost flat=0; slightly undulating=1; much more undulating=2, violently undulating=3)	CAT	Revised Restoration Scale	Positive (flat)	Zhao et al 2018
Management					
Vegetation maintenance	Amount of deadwood and brushwood (categories: 0= wild (high), 1= tended (low)).	CAT	Scales of mental state	Positive (tended)	Martens et al 2011
Flowers	Yellow flowers (Coreopsis grandiflora) were added to photographs (categories: presence, absense of flowers)	CAT	Restorative potential	Positive (presence)	Wang et al 2019
Acoustic environment					
Bird sounds	Song of a bird (Garrulax canoru) which is very popular and is often kept as a pet in China combined with photographs of parks, compared with other combinations of sounds and silence.	CAT	Revised Restoration Scale	Positive	Zhao et al 2018

(continued)

Supplementary material S.4. (Continued).

Indicator	Description	Type	Mental health variable	Observed effect	Reference
Natural sounds	A mixture of sounds from a fountain and tweeting birds.	CAT	Skin conductance level	Negative	Alvarsson et al 2010
	Combination of bird twittering, insect chirping and water flowing	CAT	Tranquility rating	Positive	Liu et al 2019
Wind sounds	Sounds of wind combined with photographs of parks, compared with other combinations of sounds and silence.	CAT	Revised Restoration Scale	Positive	Zhao et al 2018
Traffic noise level	A-weighted equivalent CON sound pressure levels from road and rail traffic (tram) (categories: <55 dB, 55–65 dB and >65 dB)	CAT	Perceived Restorativeness Soundscape Scale	Negative	Evensen et al 2016
Biodiversity/Wildlife					
Biodiversity level	Experts rating considering plant species and structural diversity as well as other species such as insects and birds (categories: low or high)	CAT	Perceived Restorativeness Scale	Positive (high)	Carrus et al 2015
	Participants estimate the number of different types of birds, butterflies, and plants at the study location in a scale from 1 to 5 (perceived species richness)	CON	3 dimensions of psychological well-being	Positive	Dallimer et al 2012
Bird richness	Number of all species recorded at each site	CON	3 dimensions of psychological well-being	Positive	Dallimer et al 2012
Birds density	Total (cross-species) bird density (birds per hectare) at each site	CON	3 dimensions of psychological well-being	Positive	Dallimer et al 2012
Fish	Addition of some fishes to the images containing water (categories: presence or absence of fishes)	CAT	Fascination and extent dimensions of restoration	Positive	Wang et al 2019
			Being-away dimension of restoration	Negative	
Birds	Addition of some birds on the lawn to the images (categories: presence or absence of birds)	CAT	Fascination dimension of restoration	Positive	Wang et al 2019

Supplementary material S.5. Urban green space indicators related to wildlife support at the landscape-level category.

Indicator	Description	Type	Wildlife variable	Observed effect	Reference
Urban matrix					
Urban area	Percentage of urban area calculated within a 200 m radius from each study site	CON	Birds community equitability, frequency of occurrence of insectivores and granivores, and foliage-foraging birds	Positive	Imai and Nakashizuka 2010
Impervious surface	Proportion of impervious surfaces (e.g. buildings, roads, industrial areas) at three radii of 300, 500 and 1000 m centred at the midpoint of each study site	CON	Bumble bees species richness	Negative	Ahrné et al 2009
	Proportion of sealed area within radius of 500 m centered on the centroid of each site	CON	Bird species richness and functional divergence	Negative	Schütz and Schulze 2015
Road coverage	Sum of the total length of roads in a 1000 m radius around a site (km/km2)	CON	Probability of local extinction of an amphibian species	Positive	Hamer 2018
	Percentage of area covered by asphalt in 100 m width buffers around study site	CON	Bird species richness (winter community)	Positive	Carbó-Ramírez and Zuria 2011
	Percentage of the landscape occupied by sealed roads at 1 km extent	CON	Reptile species richness	Negative	Garden et al 2010
	Percentage of the landscape occupied by sealed roads at 4 km extent	CON	Mammal species richness	Negative	
	Percentage of roads coverage within 200 m radius of each site	CON	Bird species richness and abundance	Negative	Amaya-Espinel et al 2019
Distance to highway	Distance from the centroid of each study site to the highway	CON	Probability of occupancy by an amphibian species	Positive	Hamer 2018
Distance to city center	Minimum distance to the commercial and administrative center of the city	CON	Seasonality in bird species composition	Positive	Leveau and Leveau 2016
Distance to city border	Minimum distance from site to the defined city limit	CON	Bird specialist and mutual species richness Bird mutual species abundance	Negative Positive	MacGregor-Fors and Ortega-Álvarez 2011

(continued)

Supplementary material S.5. (Continued).

Indicator	Description	Type	Wildlife variable	Observed effect	Reference
Building coverage	Percentage of total area of the matrix covered by buildings at 2 km outward from the edge of the study site	CON	Squirrels population density	Positive	Parker and Nilon 2012
	Number of buildings within a 200 m buffer surrounding each site divided by site area	CON	Bird species richness	Negative	Hudson et al 2009
	Percentage of area covered by buildings in 100 m width buffers around study site	CON	Bird species richness	Negative	Carbó-Ramírez and Zuria 2011
	Percentage of buildings within 200 m radius of each site	CON	Bird species richness Bird species abundance Insect species richness	Negative Positive Negative	Amaya-Espinel et al 2019
	Proportion of buildings with more than two stories surrounding the immediate limits of each site	CON	Bird species richness	Negative	Heino et al 2017 Leveau and Leveau 2016
Building height	Average building height within 200 m radius of each site	CON	Bird species richness Bird species abundance	Negative Positive	Amaya-Espinel et al 2019
Population density	Density of human residents in census collection districts within a 1000 m radius of each site	CON	Frog species richness	Negative	Hamer and Parris 2011
	Surveyed points plotted over a digital map containing the information on human population from the city's demographic census	CON	Bird species richness	Negative	Fontana et al 2011b
Tree cover	Total area of the matrix covered by trees divided by the total area of the matrix (2 km outward from the edge of the site)	CON	Squirrels population density Squirrels population behavior (aggression)	Negative Positive	Parker & Nilon 2012

(continued)

Supplementary material S.5. (Continued).

Indicator	Description	Type	Wildlife variable	Observed effect	Reference
Green cover around each site	Average green proportion (NDVI) for six buffer zones (100–500, 1000 m)	CON	Butterfly abundance	Positive	Shwartz et al 2013
	Proportion of land mapped as green open space within a 1000 m radius of each site	CON	Frog species richness	Positive	Hamer and Parris 2011
Native vegetation cover	Percentage of native vegetation cover within 200 m and 2000 m buffers around each site	CON	Quenda (small mammal) foraging dig activity score	Positive (200m buffer)	Bryant et al 2017
	Percentage of native vegetation (mixed-wood forest and shrubland) within 100 m surrounding each wetland	CON	Frog species occupancy	Positive	Scheffers and Paszkowski 2013
	Percentage of the landscape occupied by forest habitat at the 1 km extent	CON	Reptile species richness	Positive	Garden et al 2010
	Percentage of the landscape occupied by forest and rural habitat at the 5 km extent	CON	Mammal species richness	Positive	
	Average size of forest habitat patches at the 4 km extent	CON	Reptile and mammals species richness	Positive	
Accessible habitat	Total area of extant native vegetation within a 1000 m radius of a wetland that could be reached without crossing a highway (barrier)	CON	Probability of occupancy by an amphibian species	Positive	Hamer 2018
			Probability of colonization by an amphibian species	Negative	Hamer 2018
Water	Percentage of open water (lakes and rivers) area within 1 km from each study site	CON	Frequency of occurrence of granivorous birds	Positive	Imai and Nakashizuka 2010
	Percentage of wetlands cover (natural and constructed) within 100 m surrounding each wetland	CON	Frog species occupancy	Positive	Scheffers and Paszkowski 2013
	Percentage of water cover within a 200-m radius of each site	CON	Insect species richness	Negative	Heino et al 2017

(continued)

Supplementary material S.5. (Continued).

Indicator	Description	Type	Wildlife variable	Observed effect	Reference
Visibility level	Percentage of open land use (land cover other than urban and wooded areas, including high structures such as buildings or tall trees) calculated within a 1km radius	CON	Frequency of occurrence of foliage and ground-foraging birds	Positive	Imai and Nakashizuka 2010
Shape complexity	Area-weighted mean patch fractal dimension of the built component (patch shape complexity)	CON	Butterfly richness and abundance	Negative	Lizée et al 2012
Connectivity					
Green space	Number of joinings between matching patch types divided by the total number of possible joinings between matching patch types	CON	Semi-aquatic turtle occupancy	Positive	Guzy et al 2013
	Distance to the nearest neighboring green space	CON	Bird species richness (invasive and urban-dweller)	Positive	Amaya-Espinel et al 2019
			Seasonality in bird species composition	Negative	Leveau and Leveau 2016
Other areas	Distance to the next adjacent protected area (edge to edge)	CON	Bird species richness	Negative	Bräuniger et al 2010
			Ground nesting birds richness	Positive	
	Minimum distance to another natural habitat	CON	Proportion of endangered butterfly species	Negative	Jarosik et al 2011
			Butterfly species richness	Negative	Lizée et al 2012
	Connectivity of each site to other wetlands with 1000 m radius as the neighbourhood region (see formula)	CON	Probability of occupancy by an amphibian species	Negative	Hamer 2018
			Probability of colonization by an amphibian species	Positive	
	Geographic distance between ponds.	CON	Odonata species beta diversity	Positive	Johansson et al 2019
	Area and cost-weighted distance between each pair of fragments in the study system (Ti metric)	CON	Prairie dog local extinction	Negative	Magle et al 2010
	Isolation of the target green area in relation to other sites within 1 km (isolation index)	CON	Frequency of occurrence of granivorous birds	Positive	Imai and Nakashizuka 2010
			Frequency of occurrence of omnivores and ground-foraging birds	Negative	
Other populations	Proportion of prairie dog colonies within a 2 km buffer around each site	CON	Prairie dog colonization	Positive	Magle et al 2010

Supplementary material S.6. Urban green space indicators related to wildlife support at the site-level category.

Indicator	Description	Type	Wildlife variable	Observed effect	Reference
Spatial configuration					
Patch area	Total patch area	CON	Birds species abundance	Positive	Shanahan et al 2011; Biaduń and Zmihorski 2011; Leveau and Leveau 2016; Amaya-Espinel et al 2019
			Bird species richness	Positive	Bräuniger et al 2010; Shwartz et al 2013; Biaduń and Zmihorski 2011; Carbó-Ramírez & Zuria 2011; Hudson et al 2009; Patón et al 2012; Zhou and Chu 2012; Peris and Montelongo, 2014; Schütz and Schulze 2015; Liu et al 2019
			Bird species diversity (Shannon)	Positive	Biaduń and Zmihorski 2011; Zhou and Chu 2012
			Birds functional diversity	Positive	Liu et al 2019
			Birds functional richness and functional divergence	Positive	Schütz and Schulze 2015
			Songbirds presence/absence	Positive (for 6 sp., non-sig for 7)	González-Oreja 2017
			Songbirds abundance	Positive (5 sp.), negative (2 sp.), non-sig (6 sp.)	González-Oreja 2017
			Squirrels population density	Negative	Parker and Nilon 2012
			Wood frog species occupancy	Positive	Scheffers and Paszkowski 2013
			Pollinator species richness	Positive	Shwartz et al 2013
			Butterfly species richness	Positive	Bräuniger et al 2010; Jarosik et al 2011; Shwartz et al 2013
			Butterfly species abundance	Positive	Shwartz et al 2013
			Bee species richness	Positive	Matteson and Langellotto 2010
			Snails species richness	Positive	Bräuniger et al 2010
Water cover	Percentage of area covered by water within a 100 m radius around each bird sampling point	CON	Bird species richness	Positive	Morelli et al 2017
Pond area	Water surface area	CON	Odonata species diversity and evenness	Positive	Jeanmougin et al 2014; Johansson et al 2019
			Macroinvertebrate species richness and diversity	Positive	Hill et al 2015

(continued)

Supplementary material S.6. (Continued).

Indicator	Description	Type	Wildlife variable	Observed effect	Reference
Pond depth	Water depth was measured with a ruler in the deepest part of the pond.	CON	Insect species richness	Positive	Heino et al 2017
Shape	Perimeter-area ratio	CON	Bird species richness	Positive	Bräuniger et al 2010
			Tree nesting bird species richness	Negative	
Altitudinal range	Difference between the maximum and minimum altitude values for each park.	CON	Bird species richness and phylogenetic diversity	Positive	Liu et al 2019
Grass cover	Area of lawn cover	CON	Butterfly species abundance and pollinator richness	Positive	Shwartz et al 2013
			Butterfly urbanity index	Negative	
	Percentage of total area covered by lawn	CON	Bird richness and urban adapter bird richness	Negative	Shwartz et al 2008
	Area of grass per site	CON	Lapwings (bird) nest ocurrence	Positive	Roche et al 2016
	Relative coverage of short grass, long grass and native flowers within 50 m radius from wildlife sampling point	CON	Bird species richness	Positive	Fontana et al 2011
Bush cover	Bush cover formed of species with several stems and smaller than 3 m	CON	Butterflies species richness and abundance	Positive	Shwartz et al 2013
	Relative coverage of woody plants (<5m high) within 50m radius from wildlife sampling point	CON	Bird species richness and diversity (Simpson)	Positive	Fontana et al 2011a
	Visual estimation of the percentage of shrub layer within 10 x 10 m plots	CON	Spider species richness and diversity	Positive	Kowarik et al., 2016
	Percentage of bushes coverage (50–200 cm height) quantified along 40 points on the borders of each plot (every 2.5m along 4 transects of 50 m)	CON	Bird species abundance (avoiders)	Positive	Amaya-Espinel et al 2019
			Bird species abundance (utilizers)	Negative	
	Percentage of area covered by shrubs within a 100 m radius around each bird sampling point	CON	Bird functional richness	Negative	Morelli et al 2017
Tree cover	Proportion of tree cover formed of species with a single trunk and higher than 3 m	CON	Bird species richness	Positive	Shwartz et al 2013; MacGregor-Fors 2008
			Butterfly urbanity index	Negative	
	Relative coverage of woody plants (>5m high) within 50m radius from wildlife sampling point	CON	Bird species richness and diversity (Simpson index)	Positive	Fontana et al 2011
	Visual estimation of the percentage of tree layer within 10 x 10 m plots	CON	Spider species richness	Positive	Kowarik et al., 2016

(continued)

Supplementary material S.6. (Continued).

Indicator	Description	Type	Wildlife variable	Observed effect	Reference
	Mean percentage of tree cover calculated from visual estimation of 20 x 20 m plots distributed along transects	CON	Bird species richness	Positive	Peris and Montelongo, 2014
	Percentage of land covered by forest within 30 m buffer of wildlife sampling point	CON	Presence of magpie's (bird) nest	Positive	Kang et al 2012
	Percentage of tree cover within 25 m radius from wildlife sampling point	CON	Bird mutual species richness and abundance	Negative	MacGregor-Fors and Ortega-Álvarez 2011
	Proportional surface area of coniferous cover (ha)	CON	Bird species richness	Positive	Hudson et al 2009
	Percentage of trees coverage (> 200 cm height) quantified along 40 points on the borders of each plot (every 2.5m along 4 transects of 50 m)	CON	Bird species abundance (avoiders)	Positive	Amaya-Espinel et al 2019
			Bird species abundance (utilizers)	Negative	
Sealed area	Relative coverage of asphalted surfaces (roads, spots), diverse anthropogenic features (i.e. gazebos, statues, fountains) within 50m radius from wildlife sampling point	CON	Bird species richness	Negative	Fontana et al 2011
	Percentage of cemented area within 25 m radius from wildlife sampling point	CON	Bird mutual species richness and abundance	Positive	MacGregor-Fors and Ortega-Álvarez 2011
			Bird specialist species abundance	Negative	
	Coverage of biologically inactive surfaces such as paths, squares, grave sites and others (categories: up to 5%, 5–25%, 25–50%, over 50%)	CAT	Bird species number and abundance	Negative	Biaduń and Zmihorski 2011
Buildings	Relative coverage of buildings within 50m radius from wildlife sampling point	CON	Bird species diversity (Simpson)	Negative	Fontana et al 2011
Distance from water source	Distance from each wildlife sampling point to the closest permanent water source within site (including pond, lake or river)	CON	Urban adapter bird species richness and alien bird species richness	Negative	Shwartz et al 2008
			Bird species diversity, richness and abundance	Negative	Yang et al 2015
Connectivity of vegetated areas	Total vegetated area connected to the patches with different maximum distances of cleared land (10 m, 20 m, 30 m, 40 m and 50	CON	Bird species richness	Positive (at maximum 50 m)	Shanahan et al 2011
			Bird species abundance	Positive (at maximum 30m)	

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Supplementary material S.6. (Continued).

Indicator	Description	Type	Wildlife variable	Observed effect	Reference
Vegetation structure					
Basal area	Total basal area (diameter at breast height) of site`s trees	CON	Squirrels population behavior (aggression)	Positive	Parker and Nilon 2012
	Diameter at Breast Height (DBH) of woody vegetation (trees and bushes with height>50 cm and DBH>2 cm) within a plot of 50×50m at the center of each bird point count was measured to calculate a basal area per plot	CON	Bird species abundance (avoiders)	Positive	Amaya-Espinel et al 2019
			Bird species abundance (insectivorous)	Negative	
Tree height	Maximum tree height per plot	CON	Bird species richness	Positive	MacGregor-Fors 2008
Tree stand age	Age of the tree stand (categories: up to 30 years old, 30–50 years, 50–70 years, over 70 years old)	CAT	Bird species number, diversity (Shannon) and abundance	Positive	Biaduń and Zmihorski 2011
Crown width	Percentage of trees with crown width above 5 m within a 100 m radius around each bird sampling point	CON	Bird species richness and functional richness	Positive	Morelli et al 2017
Canopy cover	Average percentage of canopy cover across all quadrats sampled (spherical densitometer to measure the percentage of canopy cover for each quadrant)	CON	Squirrels population behavior (wariness)	Negative	Parker and Nilon 2012
	Percentage of canopy cover estimated in 10 × 10 m quadrat located at the approximate centre of each area		Quenda (small mammal) foraging dig activity score	Positive	Bryant et al 2017
	Percentage of canopy trees calculated from horizontal photos at 1.5m high		Frequency of occurrence of ground-foraging birds	Positive	Imai and Nakashizuka 2010
	Percent canopy closure (vegetation > 1.5 m) within 10 m radius from the point at which the animal was found and from a paired point	CON	Onychophora species presence	Positive	Barrett et al 2016
Tree diversity	Shannon–Wiener diversity index of the tree layer vegetation in each sampling plot	CON	Bird species richness Bird species abundance	Positive Negative (1.434 < DIVt < 1.940)	Yang et al 2015
	Total number of grass trees (Xanthorrhoea spp.) paperbarks (Melaleuca spp.) within each site	CON	Mammal species richness	Positive	Garden et al 2010
Tree richness	Total number of species of the tree layer vegetation in each sampling plot	CON	Bird species diversity (Shannon)	Positive	Yang et al 2015
	Total number of trees (including trees/large bushes >2 m) in the study site	CON	Bird species richness, total and native species abundance	Positive	Toledo et al 2012
Woody species richness	Total number of woody species in a 50m radius from wildlife sampling point	CON	Bird species richness and alien bird species richness	Positive	Shwartz et al 2008

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Supplementary material S.6. (Continued).

Indicator	Description	Type	Wildlife variable	Observed effect	Reference
Vascular plants richness	Number of species of vascular plants	CON	Butterfly and beetles species richness	Positive	Bräuniger et al 2010
Tree density	Woody vegetation taller than 2 m estimated within 50 m of each point count (Categories: 0 (zero to 3 individuals), 1 (4-8 individuals), 2 (9–15 individuals), 3 (15–20 individuals) and 4 (>20 individuals)	CAT	Bird species richness	Positive	Fontana et al 2011b
Tree abundance	Abundance of trees (including trees/large bushes >2 m) in the study site	CON	Bird species richness and total abundance	Negative	Toledo et al 2012
			Native bird species abundance	Positive	
Forb species diversity	Two levels of forb species diversity in meadows (categories: low 4–7 spp., high: 9–17 spp.)	CAT	True flies, true bugs, and thrips abundance	Negative	Hoyle et al 2018
Native plant diversity	Simpson's diversity index	CON	Lepidopteran species abundance	Positive	Burghardt et al 2009
			Avian species abundance	Positive	
	Shannon index based on the richness and abundance of native trees and bushes found in each plot of 50×50m at the center of each bird point count	CON	Bird species richness, and abundance of avoiders and granivorous species	Positive	Amaya-Espinel et al 2019
Non-native plant diversity	Simpson's diversity index	CON	Lepidopteran species abundance	Negative	Burghardt et al 2009
			Avian species abundance	Negative	
Invasive species density	Density of Acacia saligna within a 20 m quadrat was measured by randomly selecting 10 acacia stems at distances greater than 5 m apart and taking the average distance to the nearest neighbour to obtain an estimate of overall density	CON	Bird species richness	Negative	Dures and Cumming 2010
Plant communities	Number of plant communities (1–25), defined as associations of the phytosociological classification system	CON	Butterfly species richness and proportion of endangered species	Positive	Jarosik et al 2011
Coniferous/ Deciduous	Ratio of the relative coverage of coniferous woody plants and deciduous woody plants within 50m radius from wildlife sampling point	CON	Bird species richness	Positive	Fontana et al 2011

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Supplementary material S.6. (Continued).

Indicator	Description	Type	Wildlife variable	Observed effect	Reference
Horizontal coverage of the shrub layer	Coverage of woody plants with heights between 0.5 and 2.5 m, calculated from photographs taken by horizontal photography	CON	Bird species diversity (Shannon)	Positive (<21.7%) and negative (>21.7%)	Yang et al 2015
	Percentage of shrub vegetation calculated from horizontal photos at 1.5m high	CON	Frequency of occurrence insectivorous birds species	Positive	Imai and Nakashizuka 2010
			Frequency of occurrence ground-foraging birds species	Negative	
Vertical coverage of the shrub layer	Average percentage of shrub sampling points covered by the shrub layer vegetation in each sampling plot	CON	Bird species diversity (Shannon)	Positive	Yang et al 2015
Diversity index of the shrub layer	Shannon–Wiener diversity index of the shrub layer vegetation in each sampling plot	CON	Bird species richness and abundance	Positive	Yang et al 2015
Shrub richness	Total number of species in the shrub layer vegetation in each sampling plot	CON	Bird species diversity (Shannon)	Positive	Yang et al 2015
Horizontal coverage of the grass layer	Percentage of ground surface vegetation calculated from horizontal photos at 1.5m high	CON	Frequency of occurrence of omnivorous birds, foliage and ground-foraging guilds	Negative	Imai and Nakashizuka 2010
Height of herbaceous plants	Methodology in Carbó-Ramírez, 2008	CON	Bird species richness	Positive	Carbó-Ramírez and Zuria 2011
Foliage height diversity	Presence/absence of foliage in each height classes (from <0.5 to >10.0 m above ground) within 11m radius centered on each census point. FHD calculated based on the equation of Shannon diversity index	CON	Granivores bird species richness	Negative (wintering season)	Zhou and Chu 2012
Understorey coverage	Proportion of understorey coverage (categories: up to 5%, 5–10%, over 10%)	CAT	Bird species number and diversity (Shannon)	Positive	Biaduń and Zmihorski 2011
			Birds species abundance	Negative (over 10%)	

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Supplementary material S.6. (Continued).

Indicator	Description	Type	Wildlife variable	Observed effect	Reference
Design					
Habitat diversity	Shannon–Wiener index of habitat diversity per site: proportion of cover of each the sub-habitats types (tree cover, bush cover,flowerbed and lawn cover, cover of water, unmanaged areas, and flower meadows – areas seeded with wild flowers and high grasses)	CON	Butterfly species abundance and pollinator species richness	Positive	Shwartz et al 2013
	Shannon diversity index based on the percentage cover of broad habitat types recorded in 40 x 10 m plots	CON	Bird species richness	Positive	Dallimer et al 2012
Distance from trails	Distance from each wildlife sampling point to the nearest walking trail (m)	CON	Bird urban adapter species richness	Positive	Shwartz et al 2008
Forest edge	Distance from wildlife sampling point to the nearest forest edge (m)	CON	Presence of magpie's (bird) nest	Negative	Kang et al 2012
Artificial structures	Percentage of artificial structures (buildings, towers, and other human-made structures) calculated from hemispherical photos.	CON	Bird species richness and frequency of occurrence (diet and foraging guilds)	Negative	Imai and Nakashizuka 2010
Asphalt	Percentage of ground surface paved with asphalt calculated from horizontal photos at 1.5m high.	CON	Bird species diversity	Positive	Imai and Nakashizuka 2010
			Insectivorous bird species richness and frequency of occurrence of foliage-foraging birds species	Negative	
			Frequency of occurrence of granivores and ground-foraging birds species	Positive	
Natural perimeter	Length of study site perimeter formed by other than built-up area	CON	Butterfly species richness	Positive	Jarosik et al 2011

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Supplementary material S.6. (Continued).

Indicator	Description	Type	Wildlife variable	Observed effect	Reference
Management					
Management intensity	Visual estimation of management regime based on the level of landscape management, human activity and apparent vegetation characteristics (categories: intensive, moderate, light and	CAT	Bird species richness Bird species and urban exploiters species abundance	Negative (intensive) Positive (intensive)	Shwartz et al 2008
	Assessment related to uprooting of wild grown tree saplings as the prevailing management approach (categories: unmanaged, irregularly managed (up to 50% cover), or regularly managed (<5% cover))	CAT	Spider species richness	Negative	Kowarik et al., 2016
	Estimated clearance of understory vegetation in each experimental plot (categories: complete clearance (about 90% of the bushes, shrubs and small trees were cleared in the whole plot), patchy clearance (plot was divided into patches, every other patch was cleared and the rest was left unmanaged), and control (plots were left untreated)	CAT	Bird species density	Negative (complete clearance)	Heyman et al. 2011 (and Heyman 2010)
Vegetation condition score	Subjective estimate in 10 × 10 m quadrat located at the approximate centre of each area (categories: excellent = 1, good = 0.75, mediocre = 0.5, degraded = 0.25, poor = 0)	CAT	Quenda (small mammal) foraging dig activity score	Positive (excellent)	Bryant et al 2017
Pesticides	Two-level factor indicating the presence/absence of pesticides (categories: 0=no, 1=yes)	CAT	Bird species richness	Negative	Shwartz et al 2013
Quantity of mulch	Range of quantity of mulch coverage (from 0 (no mulch) to 6 (mulch covers most unpaved parts of the gardens, except lawns))	CAT	Bird species richness, bird urbanity index and butterfly species abundance	Positive	Shwartz et al 2013
Quantity of peat	Range of quantity of peat coverage (from 0 (no peat) to 5 (covers most unpaved parts of the public gardens excluding lawns))	CAT	Bird and pollinator species richness, bird urbanity index	Positive	Shwartz et al 2013
Woody debris	Percentage of woody debris coverage in 5 × 5 m quadrat located at the approximate centre of each area	CON	Quenda (small mammal) foraging dig activity score	Positive	Bryant et al 2017
	Number of cover objects such as logs, trees, rocks, and rubbish on a 10 m transect	CON	Onychophora species presence	Positive	Barrett et al 2016

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Supplementary material S.6. (Continued).

Indicator	Description	Type	Wildlife variable	Observed effect	Reference
Leaf/plant litter depth	Average depth of leaf and plant litter measured at two random points within the sampling plots	CON	Invertebrates species diversity	Positive	Kazemi et al 2009
Flower cover	Percent cover of flowering plants in small study plots	CON	Bumblebees species abundance	Positive	Ahrné et al 2009
	Percentage of the study site covered by flowers	CON	Butterfly and bee species richness	Positive	Matteson and Langellotto 2010
Flower density	Plots of grassland mowed at variable intervals (control) compared to plots sown with wildflowers seeds	CAT	Bumblebees and hoverflies species abundance	Negative (control)	Blackmore and Goulson 2014
Flower colour diversity	Two levels of flower colours diversity in designed meadows (categories: low colour diversity, high colour diversity)	CAT	Bumblebees abundance	Positive	Hoyle et al 2018
			True flies, true bugs, and thrips abundance	Negative	
Soil compaction	Average measure of soil hardness at each site measured as: number hits (B20) required to drive a weighted soil probe 20 mm into ground	CON	Reptile species richness	Negative	Garden et al 2010
Termite mounds	Total number of terrestrial termite mounds within each site	CON	Reptile species richness	Positive	Garden et al 2010
Mowing height	Height of mowing ranging from 4 to 8.5 cm	CON	Bird species richness	Negative	Shwartz et al 2013

(continued)

Supplementary material S.6. (Continued).

Indicator	Description	Type	Wildlife variable	Observed effect	Reference
Aquatic vegetation	Percentage of the pond covered by floating vegetation	CON	Aquatic insects species richness	Postive (at intermediate vegetation cover)	Blicharska et al 2016
	Proportion of the wetland surface covered by aquatic vegetation (i.e., emergent, submerged vegetation and floating vegetation)	CON	Probability of local extinction of an amphibian species	Negative	Hamer 2018
			Insect species richness	Positive	Heino et al 2017
	Percentage of pond surface area covered by submerged vegetation/macrophytes	CON	Odonata species diversity and evenness	Positive	Jeanmougin et al 2014
			Macroinvertebrates species richness and diversity	Positive	Hill et al 2015
	Amount of submersed aquatic vegetation within a 1 m^2 area at four points for each wetland	CON	Frog species occupancy	Positive	Scheffers and Paszkowski 2013
	Percentage of pond surface area covered by emergent vegetation/macrophytes	CON	Macroinvertebrate families richness	Positive	Noble and Hassall 2014
			Macroinvertebrates species richness and diversity	Positive	Hill et al 2015
			Odonata species beta diversity	Positive	Johansson et al 2019
	Percentage of emergent vegetation at each wetland (categories: 1 (no plant cover) to 5 (abundant plant cover, >75%)	CAT	Wood frog species occupancy	Positive	Scheffers and Paszkowski 2013
Shade on water body	Proportion of the pond that is not sunny	CON	Odonata species richness	Negative	Jeanmougin et al 2014
Visitor rate	Average number of people that passed within 25 m of the observer while conducting simultaneously the wildlife survey	CON	Seasonality in bird species composition	Negative	Leveau and Leveau 2016
	Number of visitors passing by the census area per minute (during the 10-min period of the bird census)	CON	Bird species richness (wintering season)	Negative	Zhou and Chu 2012
			Migrant bird species and insectivores species richness (wintering season)	Negative	
			Bird species density (breeding season)	Positive	

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Supplementary material S.6. (Continued).

Indicator	Description	Type	Wildlife variable	Observed effect	Reference
Presence of dogs	Presence or absense was scored as: no dogs = 0, or dogs = 1 (allowed off lead, allowed on a lead, or there being no signage precluding dogs and evidence of dogs recorded)	CAT	Quenda (small mammal) foraging dig activity score	Positive (no dogs)	Bryant et al 2017
Acoustic environment					
Noise level	Noise value exceeded for 90% of the measurements at each green space (L90)	CON	Songbird species presence/absence	Negative (6 species), positive (1 sp.), non-sig (6 sp.)	González-Oreja 2017
			Songbird species abundance	Negative (2 species), positive (1 sp.), non-sig (7 sp.)	
	Average level of noise (dB) measured over 5 min (categories: 25–35 dB; 35–45 dB; 45–55 dB; 55–65 dB; 65–75 dB and 75–85 dB)	CAT	Bird species abundance	Positive (above 50 dB)	Patón et al 2012
			Bird species composition	Rarest species (<50 dB), common species (>50 dB)	
	Average noise level (dBA) from eight measurements during each visit at each census point	CON	Granivores bird species richness	Positive (wintering season)	Zhou and Chu 2012
	Maximum noise recorded (in decibels) during the 8 min of the duration of the point count.	CON	Bird species richness	Negative	Fontana et al 2011b

c. Definition of framework elements

Supplementary material S.7. Definition of framework elements that are not included in the main article text.

Framework element	Definition
Environment-related factors	
Safety perception	Related to how aspects of the setting may increase or reduce the feeling of unsafety and fear in the visitors.
Soundscape	"Acoustic environment as perceived or experienced and/or understood by a person or people, in context" (ISO 12913-1, 2014, Part I)
Biodiversity perception	How a visitor perceive the variety of plants and animals present in the setting.
Person-related factors	
Sociodemographics	Variables such as age, gender, education, and income.
Usage	Aspects related to how the place is used. For example: type of activity carried out, frequency and length of the visit.
Pre-condition	State of the person before the visit to a green space. For example: stress level.
Personality	Aspects related to personal experiences and personality. For example: background of nature experiences, nature connectedness.
Restorative experience	Restoration is the process through which the contact with nature may help in either stress mitigation or prevention through the recovery of directed attention, i.e. the capacity to focus attention, that have become depleted in meeting the demands of everyday life or after prolonged mental effort (Hartig, 2011; Kaplan, 1995). Restorativeness is the potential of a certain environment to promote restoration (Negrín et al., 2017). Restorative experience combines the environment's restorativeness and personal factors that affect the individual's restoration.
Wildlife support	Metrics that aim to measure how a population of wild animals perform in a certain setting reflecting the ability to find shelter, food and partners.

ii. Supplementary material for chapter 4: Translation and validation of two scales to measure psychological restoration

The following material (S.8 and S.9) was submitted as supplemental material supporting the publication that constitutes chapter 4 of this doctoral thesis. It is available online through the following link: https://www.tandfonline.com/doi/suppl/10.1080/21711976.2021.1992871?scroll=top&role=tab

a. Final version of the scales in the Brazilian Portuguese language

Supplementary material S.8. Perceived Restorativeness Scale in the Brazilian Portuguese language.

Indique o quanto cada uma das seguintes frases desceve a sua experiência no ambiente em questão. Utilize a escala de resposta: 0= De jeito nenhum, 1= Muito pouco, 2= Pouco, 3= Nem pouco nem muito, 4= De certa forma, 5= Bastante, 6= Completamente. Os itens 1 a 5 pertencem a dimensão “Afastamento”, itens 6 a 10 “Fascinação”, e itens 11 a 15 “Compatibilidade”.

1. Aqui eu me distancio do dia-a-dia.
2. Passar o tempo aqui me dá uma folga na rotina do dia-a-dia.
3. Aqui é um lugar para ficar longe de tudo.
4. Estar aqui me ajuda a tirar o foco das coisas que tenho que fazer.
5. Vir aqui me ajuda a aliviar minha atenção de demandas indesejadas.
6. Este lugar tem qualidades fascinantes.
7. Minha atenção é atraída para muitas coisas interessantes.
8. Tenho vontade de conhecer melhor este lugar.
9. Há muito para explorar e descobrir aqui.
10. Eu quero passar mais tempo olhando o que está à minha volta.
11. Estar aqui combina com a minha personalidade.
12. Eu posso fazer coisas que eu gosto aqui.
13. Eu tenho a sensação de que pertenço a este lugar.
14. Eu posso encontrar formas de me divertir aqui.
15. Eu tenho uma sensação de unidade/união com este ambiente.

Supplementary material S.9. Restorative Outcome Scale in the Brazilian Portuguese language.

Indique o quanto cada uma das seguintes frases desceve a sua experiência no ambiente em questão. Utilize a escala de resposta: 0= De jeito nenhum, 1= Muito pouco, 2= Pouco, 3= Nem pouco nem muito, 4= De certa forma, 5= Bastante, 6= Completamente.

1. Eu me sinto mais calmo(a) depois de estar aqui.
2. Depois de visitar este lugar, eu me sinto renovado(a) e relaxado(a).
3. Estar aqui renova meu entusiasmo e energia para a minha rotina diária.
4. Aqui minha concentração e atenção claramente aumentaram.
5. Aqui eu me esqueço das preocupações diárias.
6. Visitar este lugar limpou e clareou meus pensamentos.

b. Ethical approval

First page of the final report with the research approval. This approval refers to the surveys conducted in chapters 4 and 5.

COMISSÃO NACIONAL DE
ÉTICA EM PESQUISA

PARECER CONSUBSTANCIADO DA CONEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Conciliando a promoção da saúde mental e a conservação da fauna silvestre em uma megacidade: a importância da qualidade dos parques urbanos.

Pesquisador: JESSICA FRANCINE FELAPPI

Área Temática: Pesquisas com coordenação e/ou patrocínio originados fora do Brasil, excetuadas aquelas com copatrocínio do Governo Brasileiro;

Versão: 4

CAAE: 00239018.7.0000.5390

Instituição Proponente: Zentrum für Entwicklungsforschung

Patrocinador Principal: Rheinische Friedrich-Wilhelms-Universität Bonn

DADOS DO PARECER

Número do Parecer: 3.184.560

Apresentação do Projeto:

As informações elencadas nos campos "Apresentação do Projeto", "Objetivo da Pesquisa" e "Avaliação dos Riscos e Benefícios" foram retiradas do arquivo Informações Básicas da Pesquisa (PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1212036.pdf, de 14/01/2018) e/ou do Projeto Detalhado (Projeto_Jessica_Felappi_portugues.pdf, postado em 07/09/2018).

INTRODUÇÃO

Garantir um desenvolvimento urbano sustentável é um dos maiores desafios das próximas décadas. Em2030, cerca de 5 bilhões de pessoas estarão vivendo em cidades, implicando em uma expansão de três vezes a área urbana existente no início desse século (Seto et al., 2012). Essa significativa e iminente expansão causa preocupação em relação a contínua aplicação de padrões de urbanização que criaram ambientes que impõe riscos para a saúde física e mental dos habitantes de cidades (Gruebner et al., 2017;Prüss-Ustün et al., 2016). Reconhecendo a necessidade de mudança, cidades do mundo inteiro vêm procurando alternativas para construir e transformar áreas urbanas de forma a promover ambientes mais saudáveis e resilientes para seus habitantes. A integração da infraestutura verde ao planejamento urbano vem ganhado destaque como uma estratégia para tornar as cidades mais habitáveis (World Health Organization, 2016). Infraestrutura verde é definida como "uma rede estrategicamente planejada de áreas naturais e

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iii. Supplementary material for chapter 5: Case study: the effect of park quality on the promotion of mental health and wildlife support in São Paulo, Brazil

a. Supplementary information on models and tables of estimates

Supplementary material S.10. List of variables originally included in each of the perceptions models before selection for final model analysis (according to multicollinearity).

Naturalness perception = landuse + proportion green 1km + area + perimeter-area ratio + proportion canopy[1] + proportion open vegetation[2] + tree species + tree species/ha + proportion native trees + bushes richness + proportion native bushes + water score + topography + number of habitats + understorey + bird species[3]

Management perception = proportion open vegetation + tree species + tree species/ha + proportion native trees + exotic trees[4] + bushes richness[5] + proportion native bushes + understorey + cleanliness + vandalism

Soundscape perception = landuse + proportion green 1km + area + perimeter-area ratio + proportion canopy + proportion open veg + water score + topography + number of habitats + bird species

Safety perception = landuse + proportion green 1km + area + perimeter-area ratio + proportion canopy + topography + understorey + vandalism

[1] Proportion canopy: consider categories 2, 3, 5, 9, 10, 13 of the Digital Mapping of Sao Paulo Vegetation Cover.

[2] Proportion open vegetation: consider categories 11 and 14 of the Digital Mapping of Sao Paulo Vegetation Cover.

[3] Bird species: data from Sao Paulo Municipality Wildlife Inventory.

[4] Exotic trees: Number of tree species classified as exotic.

[5] Bushes richness: Number of bushes species.

Supplementary material S.11. Parameters used to check the validity of scales.

Scale	Mean (SD)	Cronbach's α	χ^2 (df)	CFI	RMSEA	SRMR
Perceived Restorativeness Scale	4.02 (1.13)	.92	133.453 (87)*	.997	.023 (.015-.031)	.041
Being away (5 items)	4.14 (1.22)	.80				
Fascination (5 items)	3.83 (1.30)	.83				
Compatibility (5 items)	4.10 (1.26)	.84				
Perceived Stress Scale (10 items)	16.99 (6.88)	.81	144.116 (35)*	.968	.056 (.047-.066)	.057
Perceived health		.76	648.849 (3)*	.999	.0001	.0001
General health (1 item)	2.75 (0.98)					
Mental health (1 item)	2.75 (1.04)					
Wellbeing (1 item)	2.71 (0.97)					
Setting perceptions			74.104 (24)*	.991	.046 (.034-.058)	.043
Soundscape (3 items)	3.31 (1.37)	.73				
Management (3 items)	3.31 (1.66)	.88				
Naturalness (3 items)	3.09 (1.34)	.70				

* p≤ .001

Supplementary material S.12. Fit indices of the structural equation models.

Model	χ^2	df	CFI	RMSEA	SRMR
1. Full model (Perceptions + controls)	3176.218	755*	.935	.059 (.057-.061)	.065
2. Exclusion of non-signif control variable (age)	2805.352	719*	.943	.056 (.054-.058)	.063
3. Exclusion of all non-signif variables (age + health perception + stress)	1760.786	312*	.954	.071 (.067-.074)	.073

*p value= .000

Supplementary material S.13. Standardized coefficient, standard error, and significance level of each pathway in models 1 and 3 (Supplementary material S.12).

	Model 1			Model 3		
	Estimate	Std error	P value	Estimate	Std error	P value
Regressions						
PRS ← Safety (unsafe)	-.548	.104	.000	-.547	.104	.000
PRS ← Naturalness	.371	.079	.000	.369	.079	.000
PRS ← Management	.254	.056	.000	.255	.056	.000
PRS ← Soundscape	.183	.047	.001	.192	.047	.000
PRS ← Income (high)	.111	.076	.000	.109	.075	.000
PRS ← Sex (female)	.063	.075	.035	.060	.075	.044
PRS ← Stress perception	-.037	.084	.364	-	-	-
PRS ← Age	.011	.002	.696	-	-	-
PRS ← Health perception	-.008	.091	.857	-	-	-
Correlations						
Soundscape ↔ Naturalness	.627	.099	.000	.628	.098	.000
Management ↔ Naturalness	.760	.108	.000	.762	.108	.000
Health ↔ Stress	.531	.022	.000	-	-	-
Safety(unsafe)↔Sex(female)	.116	.007	.000	.116	.007	.000
Safety(unsafe)↔Income(high)	-.127	.007	.000	-.126	.007	.000

b. Supplementary material on indicators

Description of green space indicators collected for each park.

Dimension	Variable name	Type	Values	Description
Landscape	landuse	categorical	0 or 1	predominant land use type surrounding the park, 0 mixed, 1 residential
	green_1km	continuous		amount (ha) of vegetated areas within 1km from the park limits
	prop_green_1km	continuous		percentage of area covered by green within the total 1km buffer area
Spatial configuration	area	continuous		park total area
	perimeter	continuous		park perimeter
	pa_ratio	continuous		perimeter divided by area
	shape index	continuous		formula: SI = P / [2 × (π × A)$^{0.5}$], where P is park perimeter and A is park area
	water_presence	categorical	0 or 1	presence of water bodies (1)
	veg9	continuous		area of urban forest, preserved vegetation
	veg11	continuous		area of low tree coverage, crowns do not touch
	veg13	continuous		area of high tree coverage, crowns touch
	veg14	continuous		area of grass and shrubs coverage
	veg_total	continuous		total area of vegetation (sum of 15 categories)
	prop_veg	continuous		proportion of the park area covered by vegetation (all categories)
	canopy_cover	continuous		area covered by trees, calculated by summing areas of veg9 and veg13
	prop_canopy	continuous		proportion of park area covered with trees (canopy_cover)
	open_veg	continuous		area of open vegetation, calculated by summing areas of veg11 and veg14
	prop_open	continuous		proportion of park area covered with open vegetation
Vegetation	plant_richness	continuous		number of tree and bushes species
	native_plants	continuous		number of native tree and bushes species
	tree_richness	continuous		number of tree species
	native_trees	continuous		number of native tree species
	exotic_trees	continuous		number of exotic tree species
	prop_native_trees	continuous		proportion of native trees in comparison to exotic species
	tree_families	continuous		number of tree families
	bushes_richness	continuous		number of bushes species
	native_bushes	continuous		number of native bushes species
	exotic_bushes	continuous		number of exotic bushes species
	prop_native_bushes	continuous		proportion of native bushes in comparison to exotic species
Design	water_access_dummy	categorical	0 or 1	no access (0) or access to water (1)
	water_natural_dummy	categorical	0 or 1	0 for artificial and 1 for natural
	water_score	continuous		water_presence * water_access_dummy + water_natural_dummy resulting in scores 0, 1, 2
	topography	categorical	0 to 3	predominant topography, 0=flat; 1= slightly undulated; 2= uneven; 3= steep
	topography_dummy	categorical	0 or 1	combines 0 and 1 into 0= flat or slightly undulating, cat 2 and 3 into 1= uneven
	n_habitat	continuous		number of habitats
Management	cleanliness	categorical	0 to 3	0= no litter; 1= few litter; 2= litter and animal feces; 3= lot of litter and/or feces
	clean_dummy	categorical	0 or 1	combines cat 1 , 2 and 3 into 0; 1 park without litter
	vandalism	categorical	0 to 3	0= no signs; 1= grafitti, 2= broken equipments; 3= grafitti and broken equipments
	vandalism_dummy	categorical	0 or 1	combines cat 1 to 3 into 1 (signs of vandalism); 0 no signs
	understorey	categorical	0 or 1	presence of vegetation in the lower strata (1)

c. Full questionnaire

The questionnaire in Brazilian Portuguese language was developed and coded in the open source software KoBoToolbox (https://www.kobotoolbox.org/) and applied in face-to-face interviews. This PDF version shows the skip options in light grey color.

Questionario_SP_v3

Local

- ◯ Alfredo Volpi
- ◯ Barragem de Guarapiranga
- ◯ Cantinho do Céu
- ◯ Chácara das Flores Cidade
- ◯ de Toronto Eucaliptos
- ◯ Guabirobeira Guarapiranga
- ◯ Guaratiba
- ◯ Jardim da Conquista Jardim
- ◯ da Luz
- ◯ Jardim Felicidade
- ◯ Povo
- ◯ Prof. Lydia Natalizio Diogo
- ◯ Rio Verde
- ◯ Santa Amélia Sapopemba
- ◯ Trianon
- ◯ Outro
- ◯
- ◯
- ◯
- ◯

Outro local

____

Setor do parque

____

ID do respondente

____

1. Qual o seu SEXO?

- ◯ Masculino
- ◯ Feminino
- ◯ Outro/Prefere não informar

2. Qual a sua IDADE?

____

3. Em geral, como você avaliaria a sua saúde:

	Excelente	Muito boa	Boa	Razoável	Ruim
a. sua saúde (em geral)	◯	◯	◯	◯	◯
b. sua saúde mental	◯	◯	◯	◯	◯
c. seu bem-estar	◯	◯	◯	◯	◯

4. As próximas questões perguntam sobre seus sentimentos e pensamentos durante o último mês. Em cada caso, será pedido para você indicar o quão frequentemente você tem se sentido de uma determinada maneira. Embora algumas das perguntas sejam similares, há diferenças entre elas e você deve analisar cada uma como uma pergunta separada. A melhor abordagem é responder a cada pergunta razoavelmente rápido. Isto é, não tente contar o número de vezes que você se sentiu de uma maneira particular, mas indique a alternativa que lhe pareça como uma estimativa razoável entre as seguintes: 0=Nunca, 1= Quase nunca, 2= Às vezes, 3= Quase sempre, 4= Sempre.

○ Ok

4. Neste último mês, com que frequência...	0	1	2	3	4
1. você tem ficado triste por causa de algo que aconteceu inesperadamente?	○	○	○	○	○
2. você tem se sentido incapaz de controlar as coisas importantes em sua vida?	○	○	○	○	○
3. você tem se sentido nervoso e estressado?	○	○	○	○	○
4. você tem se sentido confiante na sua habilidade de resolver problemas pessoais?	○	○	○	○	○
5. você tem sentido que as coisas estão acontecendo de acordo com a sua vontade?	○	○	○	○	○
6. você tem achado que não conseguiria lidar com todas as coisas que você tem que fazer?	○	○	○	○	○
7. você tem conseguido controlar as irritações em sua vida?	○	○	○	○	○
8. você tem sentido que as coisas estão sob o seu controle?	○	○	○	○	○
9. você tem ficado irritado porque as coisas que acontecem estão fora do seu controle?	○	○	○	○	○
10. você tem sentido que as dificuldades se acumulam a ponto de você acreditar que não pode superá-las?	○	○	○	○	○

5. Com que FREQUÊNCIA você visita ESTE parque?

○ Diariamente
○ 3 a 6 vezes por semana 1 ou
○ 2 vezes por semana 2 a 3
○ vezes por mês
○ 1 vez por mês
○ A cada 2 ou 3 meses
○ 1 ou 2 vezes por ano Nunca/
○ Primeira vez
○

6. Quanto TEMPO você passa NESTE parque?

○ De passagem (menos de 15 minutos) Entre
○ 15 e 30 minutos
○ Entre 30 minutos e 1 hora
○ Entre 1 e 2 horas
○ Entre 2 e 3 horas
○ Mais de 3 horas
○

7. De que local você veio até este parque?

- ◯ Casa
- ◯ Trabalho
- ◯ Escola/Faculdade
- ◯ Outro

8. Quanto tempo você leva para CHEGAR a ESTE parque?

◯ Cerca de 5 minutos Entre 5 e
◯ 15 minutos Entre 15 e 30
◯ minutos Entre 30 minutos e 1
◯ hora Entre 1 e 1h30 minutos
◯ Mais de 1h30 minutos
◯

9. Por qual meio de TRANSPORTE?

- ◯ A pé
- ◯ Ônibus
- ◯ Metrô/Trem
- ◯ Carro/Táxi
- ◯ Bicicleta/Skate/Outro

10. Você poderia me informar o CEP ou bairro da sua residência?

____

11. Qual a sua PRINCIPAL MOTIVAÇÃO para vir a este parque? Por que você vem aqui?

◯ Atividade fisica
◯ Relaxar (mentalmente)
◯ Descansar (fisicamente)
◯ Passear com cachorro/pet
◯ Passear com criança/idoso
◯ Contemplar a natureza
◯ Curtir a natureza/Me aproximar de animais e da natureza Buscar um
◯ lugar silencioso/tranquilo
◯ Refletir sobre a vida
◯ Encontrar amigos/familiares
◯ Ir a um evento/atividade específica
◯ Ficar sozinho
◯ Refrescar do calor
◯ Respirar ar puro
◯ Se distrair/Observar outros visitantes
◯ Caminho mais curto para meu destino
◯ Outro
◯
◯
◯

11.a. Outra motivação

____

12. Qual a PRINCIPAL ATIVIDADE que você realiza NESTE parque? O que você faz aqui?

- ◯ Caminhar
- ◯ Correr
- ◯ Pedalar/Skate
- ◯ Fazer ginástica
- ◯ Esportes coletivos
- ◯ Yoga ou outras práticas introspectivas
- ◯ Observar animais/paisagem
- ◯ Brincar com criança
- ◯ Brincar com cachorro/pet
- ◯ Ficar sentado
- ◯ Conversar/Socializar
- ◯ Pegar sol
- ◯ Lanche/Picnic/Churrasco
- ◯ Meditar/Filosofar
- ◯ Ouvir música
- ◯ Dormir/Descansar
- ◯ Ler/Escrever
- ◯ Outro

12.a. Outra atividade

____

13. Você frequenta outros parques ou praças?

- ◯ Sim, eu frequento outras áreas verdes. Não, eu não
- ◯ frequento outras áreas verdes.

13.a. Qual o nome do outro local que você mais frequenta?

____

13.b. Entre o local em que estamos agora e o outro local que você mencionou, em qual você preferiria ir para relaxar e se recuperar do cansaço mental?

- ◯ Este lugar O
- ◯ outro lugar
- ◯ Os dois da mesma forma
- ◯ Nenhum dos dois

14. Estamos interessados na sua experiência NESTE lugar. Para nos ajudar a entender sua experiência, lhe apresentamos as seguintes afirmativas (frases) para você responder. Para cada frase se pergunte: Quanto esta afirmativa se aplica ou reflete a minha experiência neste lugar? Para indicar a sua resposta, selecione apenas um dos valores da escala que lhe foi fornecida.

◯ Ok

14. Quanto esta afirmativa se aplica ou reflete a minha experiência neste lugar?	0	1	2	3	4	5	6
1. Passar o tempo aqui me dá uma folga na rotina do dia a dia.	◯	◯	◯	◯	◯	◯	◯
2. Vir aqui me ajuda a aliviar minha atenção de demandas indesejadas.	◯	◯	◯	◯	◯	◯	◯
3. Há muito para explorar e descobrir aqui.	◯	◯	◯	◯	◯	◯	◯

4. **Eu quero passar mais tempo olhando o que está à minha volta.**

5. **Eu posso fazer coisas que eu gosto aqui.**

6. **Eu tenho uma sensação de unidade/união com este ambiente.**

7. **Este lugar tem qualidades fascinantes.**

8. **Aqui é um lugar para ficar longe de tudo.**

9. **Eu posso encontrar formas de me divertir aqui.**

10. **Aqui eu me distancio do dia-a-dia.**

11. **Estar aqui combina com a minha personalidade.**

12. **Minha atenção é atraída para muitas coisas interessantes.**

13. **Tenho vontade de conhecer melhor este lugar.**

14. **Estar aqui me ajuda a tirar o foco das coisas que tenho que fazer.**

15. **Eu tenho a sensação de que pertenço a este lugar.**

14. Quanto esta afirmativa se aplica ou reflete a minha experiência neste lugar?

0 1 2 3 4 5 6

1. **Eu me sinto mais calmo(a) depois de estar aqui.**

2. **Depois de visitar este lugar, eu me sinto renovado(a) e relaxado(a).**

3. **Estar aqui renova meu entusiasmo e energia para a minha rotina diária.**

4. **Aqui minha concentração e atenção claramente aumentaram.**

5. **Aqui eu me esqueço das preocupações diárias.**

6. **Visitar este lugar limpou e clareou meus pensamentos.**

15. Da mesma forma que na questão anterior, para cada uma das seguintes frases se pergunte: Quanto esta afirmativa se aplica a minha experiência neste lugar? Utilize a mesma escala da questão anterior.

0 1 2 3 4 5 6

16. Pense nos sons que você ouve neste ambiente. Na sua percepção, quais são os sons dominantes neste parque em ordem de importância?

Primeiro som

- Sons de pássaros
- Sons de outros animais
- Sons de água, vento, folhas
- Sons de veículos, buzinas
- Pessoas conversando, se exercitando, gritos, latidos
- Sons de aviões, máquinas, música
- Nenhum
- Silêncio
- Outro

Segundo som

- ◯ Sons de pássaros
- ◯ Sons de outros animais
- ◯ Sons de água, vento, folhas
- ◯ Sons de veículos, buzinas
- ◯ Pessoas conversando, se exercitando, gritos, latidos
- ◯ Sons de aviões, máquinas, música
- ◯ Silêncio
- ◯ Outro
- ◯ Nenhum

Outro som

____

17. Utilizando a escala oferecida, indique o quanto cada uma das seguintes frases reflete a sua percepção deste lugar:

	0	1	2	3	4	5	6
a. **Este parque possui um ambiente sonoro agradável.**	◯	◯	◯	◯	◯	◯	◯
b. **Este parque possui um ambiente sonoro agitado.**	◯	◯	◯	◯	◯	◯	◯
c. **Este parque é silencioso.**	◯	◯	◯	◯	◯	◯	◯
d. **Este parque me transmite uma sensação de segurança.**	◯	◯	◯	◯	◯	◯	◯
e. **Este parque e suas instalações são limpos.**	◯	◯	◯	◯	◯	◯	◯
f. **As instalações e equipamentos do parque são bem conservados.**	◯	◯	◯	◯	◯	◯	◯
g. **A vegetação do parque está bem cuidada.**	◯	◯	◯	◯	◯	◯	◯
h. **Este parque se assemelha a uma natureza intocada.**	◯	◯	◯	◯	◯	◯	◯
i. **Este parque tem uma grande quantidade de árvores e plantas.**	◯	◯	◯	◯	◯	◯	◯
j. **Este parque tem uma grande quantidade de animais.**	◯	◯	◯	◯	◯	◯	◯
k. **Eu sei reconhecer diferentes espécies de plantas e animais.**	◯	◯	◯	◯	◯	◯	◯
l. **Neste parque eu percebo o entorno urbano.**	◯	◯	◯	◯	◯	◯	◯

18. Percepção da biodiversidade

	1	2	3	4	5
a. **Cerca de quantos tipos diferentes (espécies) de aves você diria que existem neste parque?**	◯	◯	◯	◯	◯
b. **Cerca de quantos tipos diferentes (espécies) de árvores e plantas você diria que existem neste parque?**	◯	◯	◯	◯	◯

19. Considerando a escala fornecida de 1 a 10, onde o número 1 representa uma pessoa completamente voltada à natureza e 10 uma pessoa completamente voltada à vida urbana, responda: Você se considera mais ligado(a) à natureza ou à vida urbana?

____

20. Você passou a maior parte da sua infância em um ambiente urbano ou rural?

- ◯ Urbano
- ◯ Rural

21. Qual a sua escolaridade? Qual foi o curso de nível mais elevado que você concluiu?

- Não alfabetizado
- Alfabetização de jovens e adultos
- Ensino fundamental (1º Grau, Primário + Ginásio) incompleto Ensino
- fundamental (1º Grau, Primário + Ginásio)
- Ensino médio (2º Grau, Colégio)
- Curso técnico
- Ensino superior
- Não quero responder

22. Qual categoria melhor definiria a renda mensal média da sua família?

- Até 2 salários mínimos (até R$1.996)
- Mais de 2 a 4 salários mínimos (até R$3.992)
- Mais de 4 a 10 salários mínimos (até R$9.980)
- Mais de 10 a 20 salários mínimos (até R$19.960)
- Mais de 20 salários mínimos
- Não quero responder. *esta informação é importante para comparar percepções entre diferentes classes econômicas/sociais

iv. Publications and presentations

a. Peer-reviewed journal articles

Felappi, J.F., Sommer, J.H., Falkenberg, T., Terlau, W., Kötter, T., 2024. Urban park qualities driving visitors mental well-being and wildlife conservation in a Neotropical megacity. Scientific Reports 14, 4856, https://doi.org/10.1038/s41598-024-55357-2

Felappi, J.F., Bedin, L.M., Terlau, W., Kötter, T. 2022. Psychometric properties of two psychological restoration scales: translation, adaptation and validity evidences of the Brazilian versions (Propiedades psicométricas de dos escalas de restauración psicológica: traducción, adaptación y validez de las versiones brasileñas), PsyEcology, 13:1, 50-74, DOI: 10.1080/21711976.2021.1992871

Felappi, J.F., Sommer, J.H., Falkenberg, T., Terlau, W., Kötter, T., 2020. Green infrastructure through the lens of "One Health": A systematic review and integrative framework uncovering synergies and trade-offs between mental health and wildlife support in cities, Science of The Total Environment, Volume 748, 141589, https://doi.org/10.1016/j.scitotenv.2020.141589.

Lembi, R. C., Cronemberger, C., Picharillo, C., Koffler, S., Sena, P. H. A., **Felappi, J. F.**, Moraes, A. R. de ., Arshad, A., Santos, J. P. dos ., & Mansur, A. V. (2020). Urban expansion in the Atlantic Forest: applying the Nature Futures Framework to develop a conceptual model and future scenarios. Biota Neotropica, 20(Biota Neotrop., 2020 20 suppl 1). https://doi.org/10.1590/1676-0611-BN-2019-0904

b. Book chapter and policy brief

Yasobant, S., Arredondo Perez, A.M., **Felappi, J.F.**, Ntajal, J., Paris, J.M.G., Patel, K., Savi, M.K., Schmiege, D., Falkenberg, T., 2023. One Health as an Integrated Approach: Perspectives from Public Services for Mitigation of Future Epidemics. In: Rezaei, N. (eds) Integrated Science of Global Epidemics. Integrated Science, vol 14. Springer, Cham. https://doi.org/10.1007/978-3-031-17778-1_3

Felappi, J.F., Fischer, S., Isidorio, W., Paris, J., 2020. Urban green in São Paulo city. Promoting health and wellbeing. Center for Development Research (ZEF) One Health and Urban Transformation Policy Brief 5/2020. https://www.zef.de/project-homepages/one-health/template-following/policy-briefs.html

c. Conference contributions

Oral presentations

Felappi, J.F., Sommer, J.H., Falkenberg, T., Terlau, W., Kötter, T., 2023. Urban parks through the One Health lens: Balancing people and wildlife needs. International Urban Wildlife Conference, Washington DC, United States.

Felappi, J.F., Sommer, J.H., Terlau, W., Kötter, T., 2020. Reconciling mental health promotion and biodiversity conservation in a megacity: the role of urban parks' quality. World Biodiversity Forum, Davos, Switzerland.

Felappi, J.F., Sommer, J.H., Terlau, W., Kötter, T., 2019. Are all greens the same? Investigating the effect of urban park quality on visitors' mental well-being outcomes. Ecocity World Summit, Vancouver, Canada.

Felappi, J.F., Sommer, J.H., Terlau, W., Kötter, T., 2019. Tales of the Global South: people-related factors influencing restoration in urban parks of a megacity. International Conference on Environmental Psychology, Plymouth, England.

Poster presentations

Mansur, A.V., Koffler, S., Sena, P. H. A., Picharillo, C., Cronemberger, C., Lembi, R. C., **Felappi, J.F.**, Moraes, A. R. de ., Santos, J. P. dos ., Arshad, A., 2020. Applying the Nature Futures Framework for Urban Areas in the Brazilian Atlantic Forest. World Biodiversity Forum, Davos, Switzerland.

Felappi, J.F., Sommer, J.H., Terlau, W., Kötter, T., 2019. The urban nature gradient: do some parks provide better restorative experiences than others? 16th International Conference on Urban Health, Xiamen, China.

Declaration of the candidate

I hereby declare, to the best of my knowledge and belief, that this thesis does not contain any material previously published or written by another person, except where due reference has been made in the text. This thesis contains no material, which has been previously accepted or definitely rejected for the award of any other doctoral degree at any university or equivalent institution.

Hiermit erkläre ich, dass ich die vorliegende Promotionsarbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

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