Review

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

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HIGHLIGHTS

• Green space quality determines multifunctionality but is often neglected.
• 114 indicators of green space quality affected mental health and wildlife support.
• Synergies between the two dimensions overcame trade-offs.
• Framework uncovers environment-human-animal interlinkages in urban green spaces.
• One Health is a useful approach for aiming effective multifunctional green spaces.

ABSTRACT

Green infrastructure improves environmental health in cities, benefits human health, and provides habitat for wildlife. Increasing urbanization has demanded the expansion of urban areas and transformation of existing cities. The adoption of compact design in urban planning is a recommended strategy to minimize environmental impacts; however, it may undermine green infrastructure networks within cities as it sets a battleground for urban space. Under this scenario, multifunctionality of green spaces is highly desirable but reconciling human needs and biodiversity conservation in a limited space is still a challenge. Through a systematic review, we first compiled urban green space’s characteristics that affect mental health and urban wildlife support, and then identified potential synergies and trade-offs between these dimensions. A framework based on the One Health approach is proposed, synthesizing the interlinkages between green space quality, mental health, and wildlife support; providing a new holistic perspective on the topic. Looking at the human-wildlife-environment relationships simultaneously may contribute to practical guidance on more effective green space design and management that benefit all dimensions.

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1. Introduction

Ensuring sustainable urban development is one of the greatest challenges of the coming decades. By 2030, around 5 billion people will be living in cities, demanding a threefold expansion of urban areas compared to the beginning of this century (Seto et al., 2012). It is essential to carry out this expansion involving a change of the urban forms (i.e. land use patterns, urban design, and transportation system, see Jhajharia, 2006) that have created environments that pose several risks to human health (Gruebner et al., 2017) and threat biodiversity (McDonald et al., 2018). As a potential solution to this challenge, the integration of green infrastructure into urban planning has emerged as a multifold strategy to build and transform urban environments in order to provide more livable, healthy, and biodiversity-friendly cities (World Health Organization, 2016).

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 (Oikkels et al., 2018). In comparison to rural areas, urban dwellers are exposed to health risks originating from social (e.g. social segregation) and physical (e.g. specific urban designs) environments that contribute to increased stress levels and thus higher risks for mental illnesses (Gruebner et al., 2017; Peen et al., 2010). Good practices in urban planning may counteract part of these risks 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, urban green spaces are essential for providing habitat, shelter, and food to non-domestic animal species that can adapt to urban environments (Nielsen et al., 2014), hereafter referred to as urban wildlife (Magle et al., 2012; Parker and Nilon, 2012). However, in green infrastructure projects in the European context, biodiversity conservation in general is mostly mentioned only as a desirable side effect or co-benefit and, without minimal requirements, green spaces are often reduced to lawn areas free of buildings (Garmendia et al., 2016). This perspective may result in a collection of “green deserts” and jeopardize biodiversity conservation since green space’s quality is determinant for providing the balance of characteristics that are necessary for wildlife support (Hodgson et al., 2009).

The New Urban Agenda promotes sustainable urban development in line with the principles of compact design, i.e. minimal conversion of land and higher population densities, to minimize environmental impacts (United Nations, 2017). An unwanted effect of this form of development is the loss of green spaces’ quantity and quality that has already happened worldwide (Haaland and van den Bosch, 2015) due to their direct competition with housing and grey infrastructure developments. Therefore, considering that space for nature is becoming more limited and placed under increasing pressure within cities, there is a need for quality and multifunctional green spaces, which strategically combine different functions in order to maximize benefits for social and ecological dimensions (Hansen and Pauketat, 2014).

The One Health approach advocates that complex health and ecological challenges should be addressed through holistic systems-thinking that recognizes the interconnections between the health of humans, animals, and the environment, and fosters multidisciplinary and cross-sectoral collaborations (Queenan et al., 2017). Looking at multiple dimensions of a problem simultaneously may result in more efficient interventions (Lebov et al., 2017). Applying this holistic view to the
context of urban green spaces may help to identify several and often competing or incompatible ecosystem services (Aronson et al., 2017) through the understanding of interactions at the humans-animals-urban spaces interface.

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 linkages on the mental health-wildlife-environment interface in the context of urban green spaces.

2. Material and methods

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.

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).

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 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.

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 < .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.

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 adopt 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 (Kleem 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; Kleem 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. Results

A total of 1,428 articles were screened through the steps depicted in Fig. 1, 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 Fig. 1. Flow diagram illustrating the selection process of studies included in the systematic review.
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.

3.1. Overview of selected studies

As a general pattern, studies were mainly conducted in Europe and North America (67% of studies, Supplementary material S.2.). 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.

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 measured 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. 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) and 81 indicators for wildlife support (Supplementary material S.5 and S.6.). We separated indicators into two domains - site-level and landscape-level factors - and further classified them according to Table 1. Overall, indicators related to vegetation structure of green spaces were the majority but with a huge influence of the wildlife dimension (Fig. 2). 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).

3.3.1. 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

Table 1

<table>
<thead>
<tr>
<th>Category</th>
<th>Explanation</th>
<th>Example of indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site-level factors</td>
<td>Green space as the unit of analysis. Capture conditions at the microhabitat scale.</td>
<td>Patch area; tree cover; grass cover; water cover; sealed area; shape</td>
</tr>
<tr>
<td>Spatial configuration</td>
<td>Factors related to different types of land cover, size, and shape. A green space view from above.</td>
<td>Spatial arrangement; tree density; tree diversity; understory coverage</td>
</tr>
<tr>
<td>Vegetation structure</td>
<td>Aspects describing composition, complexity and spatial arrangement of different vegetation types.</td>
<td>Accessibility to water; topography; habitat diversity; artificial structures</td>
</tr>
<tr>
<td>Design</td>
<td>Refer to explicit decisions in the planning and implementation process in order to modify the original area for multiple purposes.</td>
<td>Vegetation maintenance; flowers; mowing height</td>
</tr>
<tr>
<td>Management</td>
<td>Regarding maintenance of vegetation and facilities, and operation rules.</td>
<td>Noise level; bird songs; natural sounds</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>Present only in the human health dimension. Comprises measures of plant and animal diversity.</td>
<td>Biodiversity level; bird richness; Bird density</td>
</tr>
<tr>
<td>Landscape-level factors</td>
<td>Buffer surrounding the green space in a specified radius as the unit of analysis. Capture conditions of the adjacent matrix.</td>
<td>Impervious surface; green coverage; adjoining land use; water cover</td>
</tr>
<tr>
<td>Urban matrix</td>
<td>Land use cover reflecting permeability to animal dispersion and qualities of the neighborhood.</td>
<td>Connectivity/distance to other green spaces, wetlands, natural habitats</td>
</tr>
<tr>
<td>Connectivity</td>
<td>Present only in the animal health dimension. Factors reflecting proximity to other areas of interest.</td>
<td>Connectivity/distance to other green spaces, wetlands, natural habitats</td>
</tr>
</tbody>
</table>

* The complete list of green space indicators is provided as Supplementary material S.3 to S.6.
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 (C.S. Fontana et al., 2011; Hamer and Parris, 2011).

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 (S. Fontana et al., 2011; 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. 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-Espinell et al., 2019; Burghardt et al., 2009; Dures and Cumming, 2010).

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 (Nielson 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.

3.3.5. 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 understorey 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).

3.3.6. 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 was not present with high levels of ambient noise (González-Oreja, 2017).

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.

3.4. 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 2) 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. 3). 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. 4).

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.

We identified several characteristics of green spaces that might influence the user’s perception and restoration outcomes and thus the

![Fig. 3](image-url)
restorative potentials may differ from place to place. Most 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.

4. Discussion

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.

4.2. Mental restoration in urban green spaces

Restoration is one pathway linking exposure to nature and human health and well-being outcomes (Markeyvych 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 (Markeyvych 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.

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 (C.S. Fontana et al., 2011). 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.

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.

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 such as biodiversity and natural urban green elements.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.141589.

References


