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CONNECTING BIODIVERSITY AND HUMAN WELLBEING

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Introduction

Approximately 55% of the world's human population live in urban areas (UN 2018). By 2050, that figure will be nearly 70% (UN 2018). People migrate to cities for better housing, health care, and education opportunities (UN 2018). Yet poor urban planning and ineffectively managed expansion can lead to overcrowding, pollution, and inadequate sanitation (UN-Habitat 2016). For urban populations, the multiple and synergistic impacts of these stressors can lead to physical (e.g. respiratory illnesses, cardiovascular disease) and mental ill health (e.g. anxiety, depression) (Peen et al. 2010; Abbot 2012; WHO 2016). Indeed, the prevalence and costs allied with treating mental ill health and associated non-communicable diseases (e.g. diabetes, cardiovascular disease, depression) are rising worldwide (WHO 2014). Given the projected expansion of urban populations, maintaining good health and wellbeing for people living in cities is a global priority, reflected in international policy agreements such as the Sustainable Development Goals (SDGs; Griggs et al. 2013).

Urban green (e.g. parks, gardens, roadside verges) and blue (e.g. rivers, waterways, lakes) space is a critical centrepiece of urban design due to the contribution it makes to improving human health and wellbeing (WHO 2017). Highlighting how urban biodiversity can benefit people living in cities is important, particularly where low budget and competing land-uses are prioritised over high-quality green and blue space provision in planning and management decision-making (Abbot 2012; van den Bosch and Nieuwenhuijsen 2016). Compared to high-income countries, very little is known about the health-promoting ('salutogenic') qualities of urban green and blue space in low- and middle-income countries (Nawrath et al. 2021), yet almost all of the projected growth in urban populations will take place in these nations (Angel et al. 2011). This is particularly concerning, given that they are also in the world's most biodiverse regions (Barlow et al. 2018; Simkin et al. 2022).

Ecosystem services and disservices

Biodiversity underpins the functioning of Earth's natural systems and the support they provide to humanity, conceptualised as 'ecosystem services' (Reid et al. 2005). Urban green and blue space deliver a wide range of ecosystem services in cities (TEEB 2011), such as agriculture (provisioning services), reducing pollution and improving air quality (regulating services), and promoting tourism (cultural services). Vegetation in these spaces can play roles such as acting as a flood

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defence, or absorbing rainfall that is deflected off impervious surfaces (e.g. buildings, roads; Silvennoinen et al. 2017). Likewise, shade-giving trees can contribute to temperature cooling at local scales, helping mitigate the effects of heatwaves and local heat-island effects (Ward et al. 2016).

Urban biodiversity can also lead to ecosystem disservices, negatively impacting human health and wellbeing. For instance, in Europe, the likelihood of allergic and respiratory disorders can be greatly increased by living near green space (Parmes et al. 2020). Green space can provide habitat for vectors of disease (e.g. mosquitoes; Zhao et al. 2020), especially in equatorial regions (Allen et al. 2017), which can lead to people worrying about disease risks (e.g. Kathmandu, Nepal; Nawrath et al. 2022). Similarly, dense vegetation can be perceived as a hotspot for criminal activity in both low/middle-income (Fisher et al. 2021c) and high-income nations (Kondo et al. 2017), as well as potentially harbouring species thought to be dangerous or unappealing (Bixler and Floyd 1997). In Mumbai, India, leopards enter residential areas and pose a potential health risk (Nulkar 2017). From a wider perspective, the spatial distribution of urban green and blue space can enhance social inequities through gentrification and the displacement of low-income residents (Wolch et al. 2014). As such, understanding both the benefits and disservices underpinned by urban biodiversity is fundamental to the sustainable design and management of cities.

Ecosystem service assessments are now one of the prominent lenses through which nature is valued and incorporated into decision-making. Nonetheless, our knowledge of how biodiversity underpins cultural ecosystem services and disservices is still relatively limited for human health and wellbeing (Bratman et al. 2019).

Theories and mechanisms underpinning biodiversity-wellbeing relationships

Defining human wellbeing

Wellbeing is a multidimensional concept, encompassing different contributions to human quality of life (Stiglitz et al. 2010). The World Health Organisation (WHO) conceptualises wellbeing as 'a state of complete, physical, mental and social well-being and not merely the absence of disease or infirmity' (WHO and CBD 2015). Multiple domains of wellbeing are encompassed in this definition – bio, which is physical; psycho, which is mental, consisting of both cognitive and emotional (Andrews and McKennell 1980); and social – comprise the 'biopsychosocial' model of wellbeing that originates from medicine (Engel 1977). An expanded version of this model, called the biopsychosocial-spiritual model of human wellbeing (Linton et al. 2016; Irvine et al. 2019), also includes a spiritual domain, conceived as including a connection to something greater than oneself.

Many traditional measures of quality of life (e.g. life expectancy, social support) correlate with self-reported evaluations of life satisfaction (Helliwell et al. 2016). However, evidence shows that life satisfaction does not improve with increases in GDP (gross domestic product), beyond a threshold of meeting a person's basic needs (Diener et al. 2018). As such, self-reported, subjective measures of human wellbeing such as life satisfaction are now being used by some policymakers as important indicators of economic and social progress (Costanza et al. 2014). They have been shown to be comparable across continents (Dolan and Metcalfe 2012), a determinant of mortality (Steptoe et al. 2015) and interlinked with life expectancy (Diener and Chan 2011).

Theoretical underpinnings

Several prominent theories underpin the widely accepted fact that human wellbeing improves in natural environments. Attention restoration theory (ART) postulates that nature restores people's

ability to concentrate, focus their attention, process information, and problem-solve (Kaplan and Kaplan 1989; Kaplan 1995). The 'perceived restorativeness' of nature is thought to be based on four qualities (Kaplan and Kaplan 1989; Kaplan 1995): (1) 'fascination' (interesting stimuli that effortlessly attract attention); (2) 'coherence' (arrangement of stimuli); (3) 'compatibility' (the ability to carry out purposes freely); and (4) 'being away' (distance from everyday tasks or those that demand directed attention). Additionally, natural environments facilitate recovery from stress. The psychoevolutionary theory (Ulrich et al. 1991) posits that initial emotive reactions to natural environments (e.g. positive emotion – also known as 'affect'), can stimulate reduce physiological activity (e.g. cardiovascular, skeletomuscular; Ulrich 1983).

Kellert and Wilson (1993) popularised the term 'biophilia' (Fromm 1964), whereby people are presumed to have evolved to be inherently emotionally affiliated and drawn to natural environments. Nonetheless, genetic adaptations predispose people to exhibit negative responses to certain stimuli ('biophobia'), such as snakes. There remains contention as to whether biophilia is too broad a concept to be considered a valid explanation, and whether biophobia is in fact a contradiction of the concept itself (Joye and de Block 2011; Clayton et al. 2017). Biophilia theory extends to 'topophilia', which posits that people's emotional affiliation with and attachment to their local environment occurs via both biological selection and cultural learning (Tuan 1974; Beery et al. 2015).

Human perceptions of the environment can also be influenced by memories, ideas, and conceptions (sense of place; i.e. place attachment, place identity, meanings; Proshansky et al. 1983). However, the contribution that biodiversity makes to a sense of place remains not well understood (Hausmann et al. 2016).

People's preferences for specific attributes in nature determine the benefits they obtain. Theory proposes that moderately complex environments are most preferred (Ulrich 1983; Kaplan and Kaplan 1989). Ecologists have demonstrated that geometric fractals (a shape comprised of similar copies of the whole, determined by a D score) are indicative of biodiversity in an environment (e.g. habitat complexity or species richness; Dibble and Thomaz 2009; Stevens 2018). A mid-range fractal D score is most prevalent in nature and species-rich habitats (Hägerhäll et al. 2015; Stevens 2018). Concurrently, studies have shown that mid-range D scores are aesthetically preferred by people (Spehar et al. 2003; Bies et al. 2016) as they simplify the ease with which the human brain can process its surroundings (Joye et al. 2016).

Frameworks, mechanisms, and pathways

Several frameworks have sought to structure our understanding of how nature/biodiversity relates to different aspects of human wellbeing (Hartig et al. 2014; Markevych et al. 2017; Bratman et al. 2019; Marselle et al. 2021). Within the pathways and mechanisms, these frameworks incorporate the biopsychosocial (but not biopsychosocial-spiritual) model of health, as well as many of the prominent theories (e.g. ART, psychoevolutionary theory). Recent work suggests that biodiversity (actual or perceived, measured as the organism or trait, abundance, or richness) influences health and wellbeing (e.g. improved self-reported health, greater risk of allergic rhinitis) via four pathways (Marselle et al. 2021): (1) reducing harm (e.g. reducing heat exposure); (2) restoring capacities (e.g. stress recovery); (3) building capacities (e.g. encouraging physical activity); and (4) causing harm (e.g. harmful microbiota). Much of the empirical research substantiating these frameworks originates from high-income countries and may therefore mis- or under-represent the diverse ways in which people across the world experience or relate to urban biodiversity. As our knowledge of biodiversity-wellbeing relationships develop, these frameworks will likely undergo revision.

Biodiversity is a multisensory experience (Franco et al. 2017; Marselle et al. 2021). Each species may comprise a variety of morphologies (e.g. body size, eye position, flower structure), colours (e.g. red plumage, pink flowers, yellow leaves), sounds (e.g. wind blowing through trees, insects buzzing, bird song), smells (e.g. pine sap, mammal faeces, wild garlic), textures (e.g. dead/living leaves, stinging plants, furry animals), behaviours (e.g. parental care of young, elusive, predatory), and cultural meanings (e.g. emblematic, historical, spiritual). Research into how the multisensory aspects of biodiversity affect human wellbeing is only just emerging (e.g. Ferraro et al. 2020; Austen et al. 2021).

Empirical research examining biodiversity-wellbeing relationships

Much of the available evidence linking urban natural environments to human wellbeing focusses on the concepts of nature, green/blue space, or remotely sensed greenness from satellite imagery (e.g. normalised difference vegetation index [NDVI]). For instance, exposure to green space has been linked to improved quality of life (Stigsdotter et al. 2010), life satisfaction (White et al. 2013), and happiness (MacKerron and Mourato 2013). Higher residential greenness has been associated with reduced use of depression and anxiety-related medication in Spain (Gascón et al. 2018) and Scotland (Roberts et al. 2021), as well as higher subjective wellbeing in Australia (Mavoa et al. 2019). However, these approaches assume that urban green space is homogeneous (Eigenbrod et al. 2010) and do not elucidate which specific features are needed to promote health/wellbeing, despite this information being crucial to improving the quality of such environments for people. Certainly, specific characteristics like cleanliness, maintenance, and adequate facilities are important in urban green spaces (Giles-Corti et al. 2005; McCormack et al. 2010; Madureira et al. 2018). In low- to middle-income countries, this list includes crime, pollution, and sanitation more prominently (Amano et al. 2018). In urban blue space, features like the linearity of canals and motion and fluidity of the water can also influence people's wellbeing (Fisher et al. 2021a; Völker and Kistemann 2011).

Dissecting nature, green/blue space, and greenness into their constituent parts (i.e. biodiversity) provides a better assessment of quality from an ecological perspective and enables researchers to ask whether more biodiverse natural environments lead to enhanced benefits to human wellbeing (Wheeler et al. 2015; Wood et al. 2018). However, comparisons between existing biodiversity-wellbeing studies are complicated by the use of a diverse range of human wellbeing measures (e.g. anxiety or psychological wellbeing), biodiversity metrics (e.g. species richness or abundance), focal taxonomic groups (e.g. birds or plants), geographic locations (e.g. high-, middle-, or low-income countries), and sampling methodologies (e.g. proxy-measures or point counts for biodiversity; cross-sectional or momentary assessments of people). Disparities can also exist between people's perceptions of biodiversity and objective reality (Pett et al. 2016). In a seminal study in England by Dallimer et al. (2012), perceived butterfly, bird, and plant species richness all had a positive effect on wellbeing, whereas actual species richness had a variable impact, differing for each of the three taxa (Dallimer et al. 2012). In an experimental manipulation of green space in France, Shwartz et al. (2014) showed that although people preferred sites that were species-rich, they were unable to detect changes in richness of plants, birds, and pollinators after manipulation, and species richness was largely underestimated.

Nonetheless, the evidence-base exploring links between biodiversity and wellbeing is diverse and growing. In three English towns, vegetation cover and bird abundances were positively associated with lower depression prevalence (Cox et al. 2017). In perennial urban meadows in southern England, high perceived plant, bird, and butterfly species richness was linked to higher

psychological wellbeing (Southon et al. 2017). Elsewhere in England, the introduction of potted plants to front gardens was linked to reduced stress (Chalmin-Pui et al. 2021). In Italy, Carrus et al. (2015) showed that a more biodiverse urban woodland stimulates greater perceived restorativeness, while Marselle et al. (2020) found that street tree density in residential urban areas in Leipzig in Germany was inversely associated with antidepressant prescription rates. At a countrywide scale across Germany, Methorst et al. (2021) demonstrated that bird and plant species richness of plants and birds was positively associated with mental health, and across 26 countries in Europe, bird species richness was associated with higher life satisfaction (Methorst et al. 2020).

Although, much of the empirical evidence investigating biodiversity and wellbeing in urban green space originates from Europe, a nascent body of biodiversity-wellbeing literature is emerging from Asia and South America. In Hong Kong, people were more likely to visit urban blue space and have good mental wellbeing if there were wildlife to see (Garrett et al. 2019b). Across urban trails in Singapore, higher perceived animal diversity (mammals, amphibians, birds, insects) was positively linked to perceived restorativeness and, subsequently, greater positive and lower negative emotion (Nghiem et al. 2021). Contrary to this, Chang et al. (2016) showed that urban green space with higher insect species richness, abundance, and Simpson diversity in Taiwan was not correlated with any physiological responses. Similarly, in Guyana, there was no relationship between actual measures of bird diversity and anxiety, positive or negative emotion (Fisher et al. 2021b). However, perceived biodiversity was mediated by perceived restorativeness, which then improved measures of anxiety and positive emotion (Fisher et al. 2021c). Across low-, middle-, and high-income countries, consistent patterns are yet to emerge.

People perceive biodiversity in rich and complex ways, responding to specific attributes (e.g. colours, textures) and relating them to past experiences (e.g. culture, media; Austen et al. 2021; Bell et al. 2019). In a mobile phone app-based study in the UK, Bakolis et al. (2018) showed people who saw trees and heard birds reported higher momentary wellbeing. Elsewhere in the UK, birdsong improved attention restoration and reduced stress (Ratcliffe et al. 2013). These findings are corroborated by similar studies in Guyana (Fisher et al. 2021c) and Ecuador (Moscoso et al. 2018). Other work in England also shows more colourful planting regimes provide greater aesthetic enjoyment (Hoyle et al. 2018). People also tend to recognise species that they are familiar with in other situations, such as domestic gardens (Austen et al. 2021), or misidentify species due to what they see represented in the media (Celis-Diez et al. 2017). Perceptions can be both positive and negative (Austen et al. 2021). For instance, people have positive associations with culturally important songbirds (Clucas et al. 2015; Brock et al. 2017) and negative associations with local wildlife thought to be dangerous (Schuttler et al. 2019).

Implications for policy and practice

Practitioners and policy-makers tasked with managing urban landscapes must deliver, and trade-off among, multiple biodiversity, individual, and societal benefits and disservices. Interventions that produce mutually reinforcing positive outcomes for both humans and conservation are highly desirable. Nonetheless, we cannot optimise these crucial trade-offs until we understand how biodiversity underpins health and wellbeing, which requires transcending terminology, methods, and paradigms championed by different disciplines (Sandifer et al. 2015). This evidence can then be incorporated into urban design, landscape planning, and architecture to create new, and retrofit old, spaces to maximise the occurrence of positive human-biodiversity interactions (Davies et al. 2019).

Biodiversity conservation

Understanding biodiversity-wellbeing linkages could lead to positive outcomes for conservation through two main pathways (Davies et al. 2019). The first is through win-win scenarios, whereby green/blue space that contain high levels of biodiversity (e.g. including threatened or specialist species) are also beneficial for people (e.g. gardens designed for recreation or aesthetic value). These include space primarily managed for people, such as botanical gardens, which are popular recreational spaces and simultaneously support high levels of species richness (Westwood et al. 2021), and allotments, which are known to be particularly beneficial for pollinating insects (Baldock 2020), as well as for human health and food sustainability (Soga et al. 2016). Win-wins are also seen in green space managed for biodiversity, such as urban protected areas, which protect habitat for species while also attracting tourists, bringing employment opportunities and other benefits (ten Brink et al. 2016).

The second pathway through which biodiversity-wellbeing research could benefit conservation is through altering people's perceptions of biodiversity so that their interest and concern for it may stimulate conservation gains. Urban biodiversity has been associated with '(re)connecting people with nature' at a time when urban populations are increasingly devoid of nature experiences (Soga and Gaston 2016). The literature is expanding rapidly on the associations between nature connection, pro-environmental behaviours, and human wellbeing (Rogerson et al. 2017; Alcock et al. 2020; Martin et al. 2020). Yet these concepts are still muddled by terminological plurality (i.e. what exactly constitutes 'nature', an 'experience', or a 'connection'), thereby limiting the scientific rigour and policy-impact of the research (Clayton et al. 2017; Ives et al. 2017). Moreover, the imagining and visualisation of nature ('*thereness*') is important for people's wellbeing but is independent of any actual interaction with it (Kaplan and Kaplan 1989). Fundamentally, acknowledging that people's experiences of biodiversity differ between individuals is essential to delivering win-wins for both humans and non-human sssspecies.

Public health

Through carefully targeted interventions, such as strategically optimising the quality of green/blue space (e.g. urban parks, woodlands, wetlands, rivers) within heavily populated landscapes, relatively small health and wellbeing gains at an individual level could scale-up to substantial benefits across entire populations, generating substantial healthcare cost-savings (DEFRA 2011). Indeed, government policies searching for low-cost, non-medical health interventions have fuelled the growth of social-prescribing (pathways linking individuals to activities that improve health and wellbeing) in countries such as the UK (e.g. Garside et al. 2020) and Canada (e.g. www.parkprescriptions.ca/). 'Green' or 'nature-based' social prescribing encompasses interventions that harness the natural environment. These may constitute changes to spaces where people visit (e.g. provision of hospital gardens) or changes to people's behaviour (e.g. enrolling people in programmes; Shanahan et al. 2019). Evidence is still needed about what qualities of these spaces might be the most beneficial, and for whom, during interventions (Shanahan et al. 2019).

Likewise, the benefits of biodiversity are not equal across different sectors of society. For instance, urban populations from deprived households have been shown to benefit most from interactions with biodiversity (Garrett et al. 2019a; Roberts et al. 2021). We also know relatively little about the physical and mental barriers that facilitate the (in)accessibility of urban biodiversity (Cronin-de-chavez et al. 2019; Ibes et al. 2021). Indeed, our growing knowledge about the rich and

varied ways in which different people relate to biodiversity (Austen et al. 2021) could be seen to complicate the emerging literature about what 'doses' are needed to optimise health and wellbeing gains (e.g. 120 minutes, White et al. 2019; 25 minutes, Fisher et al. 2021d; 10 minutes, Meredith et al. 2020) Nonetheless, it is clear that biodiversity could become a powerful tool through which significant public health benefits could become available for all.

Aligning global challenges

International, national, and local government support is required for the effective implementation of policies that support both biodiversity conservation and human wellbeing. The linkage between biodiversity and human wellbeing has been endorsed by the WHO and the Convention on Biological Diversity (CBD), stating that human health and wellbeing are basic human rights and essential to securing longer-term insurance and resilience for future generations (WHO and CBD 2015). The International Union for the Conservation of Nature (IUCN) have promoted urban-protected areas, arguing that alongside contributing toward urban ecosystem service delivery, climate change resilience, and protection of vulnerable species, they also serve to change attitudes towards nature for vast numbers of visitors (Trzyna et al. 2014).

There will be instances where biodiversity is detrimental to human wellbeing. As such, a mismatch can exist between the biodiversity that conservationists seek to support and those that actually have beneficial influence (Pett et al. 2016). While some trade-offs will be necessary to avoid disservices, these will be lessened by uncovering instances where win-wins can be achieved (e.g. botanical gardens; Gobster et al. 2007; Adams 2014). Ultimately, decisions about which biodiversity attributes of the urban environment are to be conserved for what purpose will be influenced by people's individual values and motivations, but a balance must be struck between prioritising people or biodiversity (Dearborn and Kark 2010).

Conclusions

Recognising the benefits and disservices that biodiversity can bring to human wellbeing is crucial in a world of fast-changing urban landscapes. As the building block that underpins ecosystem service delivery and the promotion of human wellbeing, biodiversity must be an essential part of the toolkit in the design and management of cities (Giles-Corti et al. 2016; Hartig and Kahn 2016). However, while current evidence exploring biodiversity-wellbeing linkages is promising, more is needed. This is particularly true because of the complexity of people-biodiversity relationships (Austen et al. 2021) and geographical skew in the current evidence-base (Nawrath et al. 2021). Given that improving the quality of urban green/blue space is likely to be synergistically advantageous to both people and biodiversity, human experiences of nature need to be explored empirically, systematically, and with more nuance in relation to biodiversity specifically.

Key companion papers

Austen, G.E., et al. 2021. Exploring shared public perspectives on biodiversity attributes. *People and Nature* 3(4):901–913.

Dallimer, M., et al. 2012. Biodiversity and the feel-good factor: Understanding associations between self-reported human well-being and species richness. *BioScience* 62:47–55.

Marselle, M.R., et al. 2021. Pathways linking biodiversity to human health: A conceptual framework. *Environment International* 150:106420.

Nawrath, M., S. Guenat, H. Elsey, M. Dallimer. 2021. Exploring uncharted territory: Do urban greenspaces support mental health in low- and middle-income countries? *Environmental Research* 194:110625.

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