

# **Can biodiverse streetscapes mitigate the effects of noise and air pollution on human wellbeing?**

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## **Abstract**

Changes to the behaviours and priorities of the human population have led to an unprecedented number of urban inhabitants worldwide. Urban dwellers are exposed to high levels of air and noise pollution that negatively impact both human well-being and species diversity. However, research has shown that biodiversity present within urban areas can positively contribute toward human well-being. Despite this, no literature to date has examined the potential for urban biodiversity to mitigate or lessen the negative associations between air and noise pollution and mental well-being. This study used parallel mediation models to examine the complex interplay between these factors, testing whether species richness (actual and perceived) can mediate the relationship between air (PM<sub>2.5</sub>) and noise (dB) pollution and well-being (mental well-being and happiness) across 30 streetscapes in the city of Leeds, UK. The results revealed that greater actual flowering plant richness reduced the negative impact of noise pollution on resident's self-reported well-being across streetscapes. Additionally, there was a direct negative association between noise pollution and flowering plant and pollinator richness. This could be because residents are deterred from gardening in streetscapes where noise pollution is high. However, noise pollution can also have a direct negative impact on pollinator species. No direct or mediated negative associations between air pollution and well-being measures were identified in this study. This thesis provides a valuable insight into the complex interplay between streetscape pollution, biodiversity and human mental well-being, which until now remained largely unexamined. Increasing plant diversity should be considered a priority within any future plans to reduce urban noise. In turn, critical gains in pollinator conservation can also be made. Trends in population growth, increased pollution and declines in mental health that characterise cities worldwide, mean that the findings presented here are applicable to a multitude of urban settings.

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## Contents

|  |    |
|--|----|
| Chapter 1. Introduction .....  | 5  |
| 1.1 The rise of urbanisation .....   | 5  |
| 1.2 Implications of urbanisation for biodiversity .....                              | 5  |
| 1.3 Urban greenspace and ecosystem services/disservices .....                        | 9  |
| 1.5 Nature and human well-being .....  | 11 |
| 1.6 Theories and concepts describing nature and human well-being relationships ..... | 11 |
| 1.7 Public health and conservation policy .....                                      | 14 |
| 1.8 Biodiversity and well-being .....  | 15 |
| 1.9 Pollution and people .....   | 16 |
| 1.10 Urban gardens and streetscapes .....  | 17 |
| 1.11 Thesis scope, aims and outline .....  | 18 |
| Chapter 2. Methods .....   | 20 |
| 2.1 Study system .....   | 20 |
| 2.2 Noise and air pollution .....  | 21 |
| 2.3 Greenness (NDVI) .....   | 22 |
| 2.4 Actual measures of biodiversity .....  | 22 |
| 2.5 Questionnaire .....  | 23 |
| 2.6 Statistical analysis .....   | 25 |
| Chapter 3. Results .....   | 29 |
| 3.1 Descriptive and bivariate statistics .....                                       | 29 |
| 3.2 Parallel mediation models .....  | 35 |
| Chapter 4. Discussion .....  | 43 |
| 4.1 The Covid-19 pandemic .....  | 46 |
| 4.2 Limitations .....  | 47 |
| 5. Conclusion .....  | 48 |
| References .....   | 50 |
| Supplementary Information .....  | 69 |

# 1 Chapter 1. Introduction

## 2 1.1 The rise of urbanisation

3

4 The planet is undergoing the most radical and fast-paced transformation in humanity's history. Changes  
5 to the behaviours and priorities of the human population have led to an unprecedented number of urban  
6 inhabitants worldwide. Urban areas account for ~3% of global landcover yet harbour 56% of the human  
7 population (Liu et al., 2014). This latter percentage is projected to reach 68% by 2050, which would  
8 increase the number of urban dwellers by 2.5 billion (United Nations, 2018). Despite covering a  
9 relatively small proportion of Earth's surface, urban land is expanding more rapidly than any other land-  
10 use type (Marzluff and Ewing, 2001). The degree of urbanisation within the developed world,  
11 particularly across temperate regions, is already substantial (~80% throughout most of North America  
12 and Europe) (United Nations, 2018).

13

14 Urban settings can provide considerable benefit to society, such as improved healthcare, education,  
15 social equality, and increased housing and economic growth (United Nations 2018). However, where  
16 there is a lack of thorough and strategic planning, urban expansion can result in overcrowding, increased  
17 pollution and poor sanitation (United Nations, 2016). These characteristics also increase an area's  
18 susceptibility to severe damage following stochastic events, particularly those associated with climate  
19 change (e.g., extreme weather, epidemics). Furthermore, the World Health Organisation has described  
20 urbanisation as one of the foremost health challenges facing the 21<sup>st</sup> century (WHO, 2015), as cities  
21 continue to act as epicentres for chronic, non-communicable diseases (e.g., obesity, stress, poor mental  
22 health, declines in physical activity) and mental health conditions (e.g., depression, anxiety) (Dye, 2008;  
23 Peen et al., 2010).

24

## 25 1.2 Implications of urbanisation for biodiversity

26

27 Biodiversity is rapidly declining on a global scale. Since 1900, the average abundance of native species  
28 across most terrestrial habitats has fallen by at least one-fifth (IPBES, 2019). One million species of  
29 fauna and flora are now threatened by extinction, many of which have a trajectory of just a few decades  
30 (IPBES, 2019). Observations suggest that we are now undergoing the sixth mass extinction, which is,  
31 for the first time in history, propelled by anthropogenic behaviours (Barnosky et al., 2011). The threats  
32 to biodiversity are multi-faceted and often inextricably linked, typically involving one or more of the  
33 following: direct exploitation (Rosser and Mainka, 2002), climate change (Walther et al., 2002),  
34 invasive non-native species (Sala et al., 2000), land conversion/fragmentation (Brooks et al., 2002) and  
35 pollution (Hernández et al., 2016).

36 Urban expansion has profound implications for the natural world. The rapid development of urban land,  
37 particularly since the 1950s, has coincided with significant change to the world's ecosystems leading  
38 to environmental degradation, habitat loss and the depletion of natural resources (Liu et al., 2014;  
39 McNeill, 2000). Modelled future scenarios suggest that global urban growth could threaten an  
40 additional 290,000 km<sup>2</sup> of natural habitat by 2030 (McDonald et al. 2018). Urbanisation is now  
41 considered a leading cause of species extinction (Czech et al., 2000). Biological communities are unable  
42 to persist in urban landscapes where there is a lack of suitable habitat and where urban infrastructure,  
43 such as roads and buildings, isolate remaining patches of habitat (Beninde et al., 2015). Furthermore,  
44 the ecological footprint of urban settlements far exceeds the physical perimeters of towns and cities, as  
45 the demand for energy and agricultural production required to sustain them increase in tandem  
46 (Newman, 2006). Indeed, species which urbanisation pose the most threat of extinction to tend also to  
47 be highly threatened by agricultural activity (Czech et al., 2000). Moreover, due to the nature of  
48 urbanisation, the impacts are long lasting and intensify over time, rarely allowing opportunities for  
49 ecological succession (Marzluff and Ewing, 2001).

50

### 51 *1.2.1 Urban greenspace*

52

53 Urban greenspace can be defined as an area comprised of vegetation, which can encompass planned  
54 and managed natural and semi-natural landscapes (e.g., domestic gardens, urban parks/forests, street  
55 verges, allotments), in addition to unmanaged space (e.g., brownfields found in cities) (European  
56 Environment Agency, 2014; Taylor and Hochuli, 2017). Urban greenspaces can support endemic,  
57 threatened and specialist species and thus are deserving of conservation attention (Aronson et al., 2014;  
58 Ives et al., 2016; Soannes and Lentini, 2019). This counters evidence that biodiversity losses are  
59 inevitable along rural to urban gradients. For example, Buchholz et al., (2016) recorded a total of 600  
60 species in the Berlin Weißensee Jewish cemetery, which included 25 plant, five bat and nine bird species  
61 of conservation concern, as well as one lichen species rarely found across the region. However, research  
62 has shown that size and composition of natural features remain fundamental to the viability of urban  
63 greenspace habitat (Beninde et al., 2015; Braaker et al., 2017; Lowry et al., 2013). Small patches of  
64 urban greenspaces (e.g., domestic gardens) can also facilitate the movement of species between larger  
65 public greenspace (e.g., urban forests) and the wider countryside, thereby improving habitat  
66 connectivity (Fernández-Juricic and Jokimäki, 2001; Rudd et al., 2002). Furthermore, the accumulation  
67 of residential gardens (typically heterogeneous in nature) across a single geographical area can be of  
68 more benefit to species that require larger swathes of habitat to fulfil niche requirements, than individual  
69 garden plots (Cannon et al., 2005; Knight et al., 2005). The contribution of domestic gardens to overall  
70 urban greenspace cover makes their existence and management critical for the preservation of many  
71 urban species (Baldock et al., 2019; Davies et al., 2009). For example, in the UK, an estimated 28.7

72 million trees, 4.7 million nest boxes and 3.5 million ponds are supported by domestic gardens (Davies  
73 et al., 2009).

74

### 75 ***1.2.2 Biotic homogenisation***

76

77 Urbanisation not only extirpates many native species, but also results in the homogenisation of biotic  
78 communities, typically favoring fewer generalist non-native species (McKinney, 2006). Such patterns  
79 ensue when non-urban specialist species, reliant on narrow ranges of habitat and which generally occur  
80 in semi-natural environments, are replaced by species capable of adapting and exploiting the habitats  
81 which urban settings support. For instance, patterns of biotic homogenisation in European avifauna  
82 were found to correlate with increased urbanisation, leading to a decrease in species richness and the  
83 overall dominance of fewer species within city-dwelling avian communities (Clergeau et al., 2006).  
84 Urban pollinator assemblages were more homogenous compared to those observed in agricultural land  
85 and nature reserves in the UK (Baldock et al., 2015). In New York City, USA, 578 (approximately  
86 43%) native plant species have been lost, while the city has gained 411 non-native species (DeCandido  
87 et al., 2004). While the shift from native to non-native species at local scales might appear to enrich  
88 some urban ecosystems, the overall implication for conservation is concerning as the native taxa are  
89 reduced and sometimes lost from the global species pool (Sax and Gaines, 2003).

90

### 91 ***1.2.3 Impacts of pollution on biodiversity***

92

93 At fine spatial scales increased temperatures, artificial light, radiation and the accumulation of  
94 pollutants reduce the favorability of urban habitats for biodiversity (Grimm et al., 2008; Iserhard et al.,  
95 2019; New, 2015). For example, vehicle exhaust emissions (CO, NO, NO<sub>2</sub>) disrupt the volatile  
96 recognition process in honeybees, thereby reducing their ability to recognise and retain memory of floral  
97 food resources (Leonard et al., 2019). Nitrogen oxides, typical roadside pollutants, accelerate  
98 senescence in herbaceous plants, in addition to other phenological changes such as delayed flower  
99 development (Honour et al., 2009). They have also been shown to disturb height growth in conifers and  
100 lead to the defoliation of trees (Ots and Rauk, 2001; Ots et al., 2009;).

101

102 When a sound exceeds the sensitivity threshold of a species it becomes “noise” (referred to as “noise  
103 pollution”) and can lead to disruptions in a species’ behaviours and abilities (Sordello et al., 2020). The  
104 primary source of noise pollution is, in many cases, a byproduct of transportation (e.g., cars, motorbikes,  
105 airplanes), although other anthropogenic sources, such as windfarms, fireworks and large group  
106 gatherings (e.g., festivals, sporting events) are also known to impact biodiversity (Rast et al., 2019;  
107 Shamoun-Baranes et al., 2011; Zwart et al., 2016). For example, noise pollution reduced sexual  
108 signaling in insects (Lampe et al., 2012) and anurans (Sun and Narins, 2005). In avian species, nest

109 construction, territory defence and predator defence were impaired due to the energy trade-off between  
110 those behaviours and increased vigilance due to noise pollution (Gil and Brumm, 2013; Quinn et al.,  
111 2006; Zwart et al., 2016). The same trade-off has been observed in bats, leading to reduced foraging  
112 success (Luo et al., 2015). Direct noise pollution can also cause elevated stress, leading to physiological  
113 changes to birds such as decreased production of eggs and stunted chick growth (Kleist et al., 2018).

114

115 Urban heat islands occur when the temperature of a given built-up area is noticeably greater than that  
116 of the countryside directly surrounding it (Nakayama and Fujita, 2010; Santamouris, 2015). This  
117 phenomenon is caused by reduced vegetation and evotranspiration, increased volume of dark surfaces  
118 with low albedo that absorb and reradiate solar radiation, and the overall increase in human heat/energy  
119 output (Stone et al., 2010). Current studies suggest that heat island effects can increase temperatures by  
120 between 5 and 15 degrees Celsius (Santamouris, 2013). Urban heat islands can alter species richness  
121 and abundance, as well as cause changes to community composition (Yuan and Bauer, 2007). For  
122 example, many bee species are particularly intolerant to warming, as demonstrated by contractions  
123 northward in response to climatic warming (Kerr et al., 2015). Indeed, Hamblin et al. (2018) found that  
124 bee abundance declined by 41% for every degree Celsius increase in average site temperature. Urban  
125 trees display reduced photosynthesis and subsequent growth owing to urban stressors such as  
126 insufficient water. In the context of urban areas, water stress is an interactive factor which is exacerbated  
127 by the effects of urban heating (Meineke and Frank, 2018).

128

#### 129 ***1.2.4 Pollinators***

130

131 Pollinators are vital for many of the key ecosystem services (see sub-section 1.3 for definition)  
132 responsible for sustaining human health and well-being globally, including ecosystem regulation (e.g.  
133 hydrology), the reproduction of wild plants, crop production and food security (Klein et al., 2007; Potts  
134 et al., 2016). Subsequently, they bare substantial economic weight, worth ~€153 billion per annum  
135 (2005) (Gallai et al., 2009). Despite their importance, declines in the abundance of all key insect  
136 pollinator groups have been reported, including honeybees, bumblebees, solitary bees and hoverflies  
137 (Baldock et al., 2019). Habitat loss and fragmentation are key drivers of pollinator declines (Potts et al.,  
138 2010; Banaszak-Cibicka, 2012). Despite the general trend of pollinator declines alongside increased  
139 urbanisation (e.g., Bates et al., 2011; Hernandez et al., 2009), research has also demonstrated the ability  
140 of urban greenspaces to support remarkably high levels of pollinator richness and abundance. For  
141 example, 50% of the German bee fauna was recorded within the highly urbanised city of Berlin (Owen,  
142 2010). Some studies have demonstrated positive effects of urbanisation on the richness of particular bee  
143 taxa, including bumblebees and cavity-nesting bees (Cane et al., 2006; Carre et al., 2009). Bumblebee  
144 (*Bombus terrestris*) nests across the gardens of suburban homes in the UK (~36 nests ha<sup>-1</sup>) were  
145 comparable to the quantity recorded in rural habitats such as hedgerows (20 – 37 ha<sup>-1</sup>) (Osborne et al.,

146 2008). The enhancement of agricultural and peri-urban landscapes for pollinators has been a favourable  
147 conservation strategy in recent decades (Goddard, et al., 2010). However, due to the rapid expansion of  
148 urban areas, the improvement of urban greenspace for pollinators is also becoming increasingly  
149 recognised as an important component of conservation and restoration efforts (Goddard et al., 2010).

150

### 151 **1.3 Urban greenspace and ecosystem services/disservices**

152

153 Ecosystem services are the benefits that people derive, directly and indirectly, from ecological systems  
154 (Millennium Assessment, 2005). Within urbanised areas, urban greenspaces support many ecosystem  
155 services pivotal to society (Pauleit et al., 2010; Gómez-Baggethun and Barton, 2013). For example,  
156 urban greenspaces help to mitigate against urban heat island effects by regulating temperatures (Bowler  
157 et al., 2010). Vegetation, particularly trees, can provide shade during the summer, reflect solar radiation  
158 and absorb heat through evapotranspiration (Nowak et al., 2008). Indeed, the role of alleviating the heat  
159 load of urban areas is one of the most beneficial regulatory ecosystem services provided to cities by  
160 trees (McPhearson, 2011). Increased impervious surface cover (e.g., concrete, tarmac), which is  
161 characteristic of urban areas, exacerbates water runoff following precipitation and increases the risk of  
162 flooding. Vegetation limits this runoff by acting as a sponge and storing water in pore spaces (Pataki et  
163 al., 2011). The interception of precipitation by canopies further reduces flooding by slowing down  
164 rainfall and alleviating pressures placed on urban drainage systems (Pataki et al., 2011). Vegetation also  
165 improves surrounding air quality via the deposition of pollutants through photosynthesis (e.g., sulfur  
166 dioxide (SO<sub>2</sub>), nitrogen dioxide (CO<sub>2</sub>), carbon monoxide (CO) and particulate matter (PM<sub>2.5</sub>) (Beckett  
167 et al., 2000; Lovett, 1994;). It also acts as a barrier to noise through diffraction and absorption, which  
168 lessens the burden of acoustic disturbance caused by roads (van Renterghem et al., 2012) (see sub-  
169 section 1.9).

170

171 The crucial role in which biodiversity plays in supporting provision of ecosystem services is well  
172 established within the literature (Mace et al., 2012; Norris, 2012). For example, large proportions of  
173 soil nutrient cycles are determined by the biological composition within the soil, and resilience to pests  
174 and environmental change is stronger in biological communities where diversity is greater (Hector et  
175 al., 2000; Cardinale et al., 2003). Indeed, the quality of ecosystem functioning has been found to be  
176 associated with increased species richness in several studies (Worm and Duffy, 2003; Balvanera et al.,  
177 2006). As such, biodiversity plays an important role in the delivery of ecosystem services.

178

179 On the other hand, there are also several ecosystem disservices associated with urban greenspaces. For  
180 instance, densely vegetated urban greenspaces can provide cover for criminal activity (Kondo et al.,  
181 2017), or lead to residents feeling unsafe walking at night (Tandogan and Ilhan, 2016). Urban  
182 greenspaces can support species which are vectors for disease, or which might be considered a nuisance

183 (e.g., flies, ticks, mosquitos) (Dunn, 2010). Urban flora (e.g., some trees, grasses, flowering plants) can  
184 cause and aggravate allergies such as hayfever. One study conducted in New York identified significant  
185 associations between the extent of tree canopy and asthma and allergic sensitisation in African  
186 American and Dominican children (Lovasi et al., 2013). Furthermore, urban greenspaces are not  
187 equitably distributed, with their availability often disproportionately stratified by socioeconomic  
188 background (e.g., income, ethnicity) (Wolch et al., 2014). Housing price premiums associated with  
189 homes close to greenspaces can therefore lead to the gentrification and the displacement of low-income  
190 earners (Wolch et al. 2014).

191

## 192 **1.4 Human well-being**

193

194 Well-being is a multidimensional concept made difficult to define by the varied and complex  
195 determinants that underpin it, including genetic pre-dispositions, environmental factors, life conditions  
196 and opportunities, lifestyle and patterns of thoughts (Stiglitz et al. 2010). Indeed, there is a growing  
197 recognition that there is more to mental health and well-being than simply the absence of psychological  
198 disorders such as depression and anxiety, for example, the promotion of positive subjective well-being  
199 (i.e., how people view and feel about their own lives) (Diener et al., 2018). The assessment of people's  
200 well-being can be split up into objective and subjective measures.

201

### 202 ***1.4.1 Objective well-being***

203

204 Objective well-being indicators are calibrated against an index of what is considered necessary for a  
205 quality standard of living, including variables such as material resources (e.g., income, housing) and  
206 social attributes (e.g., education, political voice, social networks) (Diener and Suh, 1997).

207

### 208 ***1.4.2 Subjective well-being***

209

210 Subjective well-being measures require an individual to evaluate their own lives. Results are subjective  
211 not simply because they are self-reported, but because the individual is asked to rate how they feel,  
212 typically done using Likert-style scales (Hicks et al., 2013). Questions can be evaluative (e.g., life  
213 satisfaction), experiential (e.g., positive and negative affect or emotion) or eudaimonic (e.g., a sense of  
214 purpose and meaning in life) (Dolan and Metcalfe, 2012). It has been demonstrated that subjective well-  
215 being is comparable transnationally, regardless of societal variation (Dolan and Metcalf 2012). Indeed,  
216 recognition of the importance of standardised and comparable subjective well-being measures has  
217 increased (Samman, 2007). More recently, the United Nations Development Programme (UNDP)  
218 sought to utilise subjective assessments of people's own lives to identify indices of inequality that are  
219 in harmony with objective measures collected on national scales. Doing so recognises that inequalities

220 are often a symptom of an unfair system rather than a cause (United Nations Development Programme,  
221 2019). Increased subjective well-being is positively correlated with longevity (Diener and Chan, 2011).

222

## 223 **1.5 Nature and human well-being**

224

225 Research suggests that humans now spend less time outdoors than their predecessors, leading to a  
226 certain degree of “disconnection” from nature (Miller, 2005; Wilson, 1984;). This trend has been  
227 contextualised as an adaptation to contemporary urban lifestyles, such as office working and increased  
228 usage of digital media platforms (Kellert, 2018; Larson et al., 2019). For example, screen time has now  
229 reached nine hours per day in youth ages 13 to 18 across the USA (Rideout, 2015), a pattern reflected  
230 across the globe (Taylor and Silver, 2019). The “extinction of experience” phenomenon is a term used  
231 to describe this growing disconnect between humans and nature and posits that people are less exposed  
232 to nature due to a lack of time spent in greenspaces and, indeed, a lack of greenspaces (Pyle, 1993; Soga  
233 and Gaston, 2016). Examples of this widening gap are well documented. For instance, in the UK, youths  
234 were more competent at identifying cartoon characters than locally found biodiversity (Balmford,  
235 2002).

236

237 The extinction of experience phenomenon is concerning for two overarching reasons. Firstly, it is not  
238 conducive to biodiversity conservation as “collective ignorance ultimately leads to collective  
239 indifference” (Prévot et al., 2018; Pyle, 2002), which is considered one of the fundamental obstacles to  
240 reversing environmental degradation (Miller, 2005; Prévot et al., 2018). Increased detachment of people  
241 from nature leads to a cycle of reduced support and interest in conservation initiatives, resulting in  
242 greater losses to biodiversity and a further worsening of the extinction of experience phenomena (Soga  
243 and Gaston, 2016). Secondly, lack of nature contact diminishes associated positive health and well-  
244 being outcomes. For example, time spent in greenspace has shown to reduce blood pressure (Hartig et  
245 al. 2003), lower mortality rates from cardio-vascular disease (Mitchell and Popham, 2008) and improve  
246 self-perceived general health (Kardan et al., 2015). Improvements to mental health following exposure  
247 to greenspace is also a widely studied outcome within the literature (Barton and Rogerson, 2017;  
248 Gascon et al., 2015; Martin et al., 2020). Even relatively short-term exposure to parks, urban forests,  
249 domestic gardens and other semi-natural environments can reduce symptoms brought on by stress and  
250 depression, restore attentional fatigue and improve self-esteem and perceived mental state (Barton and  
251 Pretty, 2010; Marselle et al., 2014, 2016; van den Bosch and Ode Sang, 2017).

252

## 253 **1.6 Theories and concepts describing nature and human well-being relationships**

254

### 255 ***1.6.1 Psychological restoration***

256

257 One of the first attempts made to understand the relationship between well-being and nature was through  
258 the biophilia (or “love of life or living systems”) hypothesis. This theory postulates the relationship  
259 between humans and nature as being innate by virtue of humans’ coevolution alongside the natural  
260 environment (Kellert and Wilson, 1993), described as “the connections that human beings  
261 subconsciously seek with the rest of life”. Critics of biophilia contend that the theory is biologically  
262 determinist (Bone, 2009) and thus neglects to account for influential environmental factors (Newton,  
263 2007), for example those outlined in behaviorism and its encompassing theories of conditioning  
264 (Bandura, 1965). Determinism seeks to precede and limit cultural and social effects on the psyche,  
265 which research has shown to be greatly influential (Van der Veer, 1996). Therefore, it can be argued  
266 that many aspects of biophilia, and indeed the converse of biophobia, are in part learned ways of  
267 thinking (Bandura, 1965). For instance, a fear of spiders may be passed down to children as they learn  
268 to imitate observed behaviours and subsequently acquire the fear of spiders for themselves. The notion  
269 of learned behaviours extends into a cultural argument. For example, Noe and Snow (1990) observed  
270 significant differences in sensitivity levels for environmental concerns and natural environments  
271 between Hispanic and Non-Hispanic populations in the USA. Thus, a cultural effect was determined  
272 responsible. Moreover, some researchers argue that there is limited empirical evidence to support the  
273 biophilia theory (Joye and De Block, 2011; Joye and Van den Berg, 2011). However, amidst the  
274 contention, widespread interest in the evolutionary origin of nature-human well-being relationships has  
275 continued. More specific hypotheses grounded in the works of biophilia were proposed in the 1980s,  
276 including Attention Restoration Theory (ART, Kaplan and Kaplan, 1989) and Stress Reduction Theory  
277 (SRT, Ulrich, 1983). They are complimentary psycho-evolutionary theories that infer that nature  
278 provides more restorative qualities than urban/artificial environments. However, they differ  
279 fundamentally in terms of what drives one to a restorative state.

280

281 SRT posits that humans have a positive pre-cognitive response to natural scenes comparable to the  
282 fight-or-flight response found in non-human primates (Ulrich, 1983; Ulrich et al., 1991). Landscapes  
283 that contain vegetation, water and that are of modest depth or complexity are evolutionarily associated  
284 with general feelings of safety (from predators) and availability of resources, thus reducing the arousal  
285 of negative thought. As such, it is theorised that humans have not had sufficient time to evolve  
286 analogous responses to urban settings and are therefore hindered in their capacity to recover from  
287 stressful experiences. Indeed, evidence suggests that, on average, city dwelling residents suffer from  
288 greater levels of psychological stress compared to those who reside in rural areas (Dhingra et al., 2009;  
289 Lambert et al., 2015; Verheij et al., 2008).

290

291 On the other hand, ART refers more specifically to the struggles of recovering from mental fatigue in  
292 urban environments (Kaplan and Kaplan, 1989; Kaplan, 1995, 2001). For humans to focus on a

293 particular task at hand (referred to as “directed attention”), the brain is required to exclude surrounding  
294 stimuli (e.g., noise, visual cues) and other cognitive activity which may manifest into conscious thought  
295 (e.g., remembering to purchase food from the supermarket). The mechanism responsible for this  
296 inhibitory response fatigues with use over a relatively short period of time, making it increasingly  
297 difficult to concentrate. This theory therefore hypothesises that being in view of, or immersed in natural  
298 environments, provides an opportunity to rest and restore cognitive function that allows for the re-focus  
299 of attention (referred to as “fascination” or “effortless involuntary attention”). By extension, attentional  
300 fatigue is considered a condition that elevates an individual’s predisposition to stress. There is now a  
301 substantial body of SRT and ART literature demonstrating that natural environments have significantly  
302 greater restorative ability than entirely built-up settings (e.g., Chawla et al., 2014; Mennis et al., 2018).

303

### 304 *1.6.2 Social cohesion*

305

306 As highly sociable species, it is argued that humans possess an innate need to interact with conspecifics  
307 and to feel a sense of being part of a particular social group (Baumeister and Leary, 1995). An individual  
308 can thus gain psychological benefits from social support, including an improved sense of meaning,  
309 belonging, self-esteem and general companionship, all of which have been correlated positively with  
310 increased well-being and negatively with mental health disorders (Matthews et al., 2016; Nieminen et  
311 al., 2010; Shankar et al., 2015; Thoits, 2011). Indeed, both actual (e.g., social networks, social  
312 participation) and subjective social connectedness have shown to play an important role in facilitating  
313 positive mental health and well-being outcomes (Cornwell and Waite, 2009; Yu et al., 2015). As such,  
314 there is an increasing breadth of research which suggests that social connectedness (or “social  
315 cohesion”) may mediate the relationship between well-being and nature by providing a setting through  
316 which to connect (Cartwright et al., 2018; de Vries et al., 2013; Maas et al., 2009).

317

318 Cartwright et al. (2018) showed that greater nature exposure and social connectedness over seven days  
319 both were associated with increased subjective well-being over the same time period. Interestingly,  
320 nearby nature, although not visitation frequency, acted as a moderator between social connectedness  
321 and subjective well-being. However, individuals with low social connectedness still presented with  
322 elevated levels of well-being and a decreased likelihood of depression if nature was reported close-by.  
323 It is therefore possible that, due to the similar processes and mechanisms which underlie the outcomes  
324 of both nature contact and social interaction (e.g., stress reduction, Ozbay et al., 2007; attention  
325 restoration, Baumeister et al., 2005; rumination, Nolen-Hoeksema et al., 1994; self-esteem, Leary,  
326 2005); sense of belonging, Walton et al., 2012; mood and affect, Krach et al., 2010), that nature contact  
327 can buffer against negative well-being outcomes associated with low social connectedness.

328

### 329 *1.6.3 Promotion of physical activity*

330

331 Physical inactivity is one of four leading risk factors for global mortality (WHO, 2010). Environmental  
332 factors, such as high traffic volumes, lack of greenspace and footpaths, are known to exacerbate physical  
333 inactivity (An et al., 2018; Coombs et al., 2010). Increased and regular physical activity has been shown  
334 to improve neurocognitive development and mental well-being, in addition to other physical outcomes  
335 including improved cardiovascular health, reduced obesity, cancer and osteoporosis, the occurrence of  
336 which can also negatively impact on an individual's mental well-being (Owen et al., 2010). Numerous  
337 publications from a variety of countries have linked improved physical activity, recreational walking  
338 and reductions in sedentary time to the access and use of urban greenspaces in children, adults and  
339 geriatrics (e.g., Coombes et al., 2012; Ellaway et al., 2005; Lachowycz and Jones, 2013; Schipperijn et  
340 al., 2013), although this is not consistent throughout the literature (King et al., 2005).

341

342 The quality of greenspace may also impact people's levels of physical activity and therefore well-being  
343 outcomes. For example, attractiveness of greenspace related positively to walking behaviours for both  
344 exercise and leisure (De Vries et al. 2013). De Vries et al. (2013) also found that while total physical  
345 activity was not a mediator between well-being and greenspace, physical activities which could  
346 specifically take place within greenspace were (although such relationships were not as strong as with  
347 stress and social cohesion). This may be due to the concept of 'green exercise', which can be defined  
348 as a physical activity undertaken in natural/semi-natural environments (Barton and Pretty, 2010).  
349 Empirical evidence suggests that green exercise (e.g., running in the park) is more beneficial to  
350 psychological restorative processes than exercise carried out in other settings (e.g., running in urban  
351 areas or inside a gym) (Bodin and Hartig, 2003; Marselle et al., 2014).

352

### 353 **1.7 Public health and conservation policy**

354

355 Since 2010, approximately US\$ 2.5 trillion has been lost per annum from the global economy due to  
356 the two most common mental health disorders, depression and anxiety (Bloom et al., 2012). This is  
357 projected to reach US\$ 6 trillion by 2030 (Bloom et al., 2012). The opportunity to utilise urban  
358 greenspaces to address rising mental ill-health as an 'upstream' preventative method, considered more  
359 efficient and economical than treating issues 'downstream', is now increasingly recognised by policy  
360 makers. The implementation and management of urban greenspaces for this purpose may  
361 simultaneously help to achieve conservation goals and provide a strong argument for conservation itself  
362 (Dean et al., 2011). For example, in the UK, it was said that: "*safe, green spaces may be as effective as*  
363 *prescription drugs in treating some forms of mental illness*" (Faculty of Public Health 2010; p. 2). A  
364 total of 34 English conservation NGO's have since actively participated in lobbying for 1% of health  
365 spending to be directed toward nature-based solutions (Response for Nature Partnership, 2015).  
366 However, policy makers and urban planners cannot effectively implement urban greenspaces for the

367 promotion of mental well-being without a clear understanding of what natural elements/characteristics  
368 are responsible for such outcomes (Marselle et al. 2015; Wheeler et al. 2015; Wood et al. 2018). For  
369 example, Southon et al. (2017) identified that people had a strong preference for urban meadows rather  
370 than manicured plant beds and herbaceous borders.

371

## 372 **1.8 Biodiversity and well-being**

373

374 Much of the existing nature-human well-being research has focused on how factors such as presence,  
375 size, accessibility and proximity of greenspace promote well-being (Bokalis et al., 2018). However, this  
376 viewpoint neglects to account for the overall ecological ‘quality’ of the greenspace available,  
377 accounting for factors such as diversity of landcover and species richness. Indeed, there is an  
378 accumulating body of research that demonstrates the positive mental well-being outcomes associated  
379 with increased species richness, some of which illustrate the superior effects of richness over just  
380 abundance. For example, Methorst et al., (2021) identified a significant positive relationship between  
381 bird and plant species and mental health. However, no such relationship was observed when accounting  
382 for abundance. Likewise, Fuller et al., (2007) found that increased measures of psychological well-  
383 being strongly correlated with higher plant and bird richness across urban greenspaces. While the  
384 researchers identified a positive correlation between well-being and the size of the greenspace, it was  
385 not as strong as with plant or bird species richness. In Italy, higher measures of biodiversity across  
386 urban and peri-urban habitats lead to increased perceived restorativeness and subjective well-being  
387 (Carrus et al., 2015). Wood et al. (2018) found that biodiversity enhanced the restorative benefit of  
388 urban parks and with minor influence from other variables. The notion that quality may be of equal, if  
389 not of greater, importance than the presence, size, accessibility and proximity of greenspace means that  
390 a shift in focus is vital for informing both effective public health and conservation policy (Taylor and  
391 Hochuli, 2015; Wood et al., 2018).

392

393 Despite the increase in literature demonstrating the positive benefits of increased biodiversity on mental  
394 well-being, the evidence is equivocal. Trends are inconsistent, which could be caused by  
395 methodological discrepancies in both well-being and biodiversity metrics (Markevych et al., 2017).  
396 Furthermore, there has been an observed disparity between perceived levels of biodiversity and those  
397 which objectively exist, determined by the often-limited biodiversity knowledge skills of the general  
398 public (Dallimer et al., 2012). Dallimer et al. (2012) found that while there was a lack of consistent  
399 relationship between actual species richness and well-being benefit, a correlation between perceived  
400 species richness and well-being was observed.

401

402 It may also be necessary to consider the role of people’s own biodiversity preferences when accounting  
403 for observed discrepancies in reported subjective well-being, as suggested by Pett et al. (2016). People

404 are a product of their lives, shaped by individual and unique experiences, concepts and spiritual/cultural  
405 beliefs (Proshansky et al., 1983). Components of each can influence a person's momentary emotional  
406 state when immersed in greenspace (Gopal et al., 2019). For example, people have been found to be  
407 happier in environments which they perceive to be scenic, regardless of whether those locations are  
408 urban instead of natural (Seresinhe et al., 2019). As a result, there may discord between factors that are  
409 beneficial to people's well-being and characteristics that conservations seek to change.

410

## 411 **1.9 Pollution and people**

412

413 Air pollution is the largest environmental cause of non-communicable disease (WHO, 2016). Annually,  
414 an estimated 10.2 million premature deaths are attributed to air pollution; a figure three times that caused  
415 by AIDs, malaria and tuberculosis combined (Vohra et al., 2021). Air pollution is of particular concern  
416 for urban dwellers as approximately 75% of globally produced CO<sub>2</sub> emissions originate in urban areas  
417 (Seto et al., 2012). Moreover, urban inhabitants are exposed to increased levels of noise pollution which,  
418 as stated by the WHO, is the third most hazardous environmental pollutant found in cities (WHO, 2016).  
419 Several studies have highlighted the potential health and well-being benefits gained by those residing  
420 in quieter areas, concluding that the former possess a better quality of life compared to those living in  
421 noisier areas (Shepherd et al., 2013).

422

423 From a physiological perspective, systemic and direct nose-to-brain routes trigger neuroinflammation  
424 and oxidative stress when airborne pollutants enter the bloodstream. Research has shown that exposure  
425 to environmental pollution may therefore play a role in triggering and exacerbating psychiatric disorders  
426 due to neuroinflammatory and excitotoxic processes (Khan et al., 2019). Exposure to nitrogen dioxide  
427 (NO<sub>2</sub>) and particulate matter may disturb sleep quality (Billings et al., 2019). Sleep disturbances are  
428 known to increase a person's susceptibility to developing psychiatric disorders, such as depression,  
429 anxiety and schizophrenia, when experienced over a prolonged period.

430

431 Self-reported annoyance caused by high levels of noise diminished the restorative effects of  
432 neighbourhoods in Bulgaria and reduced physical activity, thus leading to poorer mental health  
433 (Dzhambov et al., 2018). These findings reflect conclusions drawn up from other studies (Foraster et  
434 al., 2016; von Lindern et al., 2016). Foraster et al. (2016) found that reduced physical activity triggered  
435 by noise related annoyance was a possible outcome of both night-time sleep disturbance and subsequent  
436 day-time sleepiness. On the other hand, Zijlema et al., (2017) did not find evidence that natural  
437 environments mediated the relationship between self-reported noise annoyance and particulate matter  
438 and cognitive function.

439

440 There is compelling evidence to suggest that anthropogenic noise can be buffered to a substantial degree  
441 by purposefully designed greenspace areas and green infrastructure, providing relief to urban residents  
442 (González-Oreja et al., 2010; Irvine et al., 2009). Roadside vegetation can be especially useful for  
443 abating surface transport noise (Han et al., 2018; Pathak et al., 2018) and is superior to synthetic barriers  
444 both psychologically and in absolute values of noise (Gallagher et al., 2015; Ow and Ghosh, 2017).  
445 Furthermore, synthetic barriers are often considered to be less economical than vegetation barriers as  
446 the costs associated with construction are high (Ohiduzzaman et al., 2016). Ow and Ghosh (2017) found  
447 that reductions in transport noise of up to 50% were observed when vegetation barrier densities  
448 increased from minimal to moderate, with only marginal improvements recorded beyond that density.  
449 Similarly, vegetation barriers for improving surrounding air quality via the deposition of pollutants have  
450 been evaluated in numerous numerical, field and wind tunnel studies and have provided extremely  
451 promising results (Al-Dabbous and Kumar, 2014; Hagler et al., 2012). While research can support the  
452 effective implementation of vegetation barriers, it is important to remember that the optimum physical  
453 structure of such barriers is typically context-dependent and must account for environmental variables  
454 (e.g., topography, air flow) as well as vegetation characteristics (Abhijith et al., 2017; Barwise and  
455 Kumar, 2020; Hewitt et al., 2020).

456

#### 457 **1.10 Urban gardens and streetscapes**

458

459 Domestic gardens make up a substantial proportion of greenspace coverage within urbanised  
460 landscapes. Estimates vary from 16% in Sweden (Colding et al., 2006), to 36% in New Zealand  
461 (Mathieu et al., 2007), and between 25 – 50% in the United Kingdom (Loram et al., 2007). Figures can  
462 also be high in developing nations. For example, in the city of León, Nicaragua, estimations stretch as  
463 far as 86% (González-García and Sal 2008). In addition to supporting biodiversity conservation,  
464 gardens can also benefit the well-being of urban dwellers by acting as a primary source of nature  
465 contact. This is of particular importance for those who are less physically mobile (Finlay et al., 2015),  
466 and, indeed, anyone who lacks garden space as people do not typically compensate with more frequent  
467 visits to public greenspaces (Grahn and Stigsdotter, 2003). In the UK, one in eight households (12%)  
468 do not have access to a private or shared garden space, affecting more than 3.3 million families. This  
469 statistics rises to more than one in five (12%) across large cities such as London (ONS, 2020).

470

471 The vast majority of geospatial analyses exclude greenspaces less than one hectare in size, usually due  
472 to the spatial resolution of landcover datasets used for the analyses (Cox et al., 2017; van den Bosch  
473 and Ode Sang, 2017). Only a small amount of research has considered these overlooked small-scale  
474 greenspaces when measuring what “dose” of nature is needed to bring about positive outcomes.  
475 However, the few studies that have been conducted show that spending five hours in a garden per week  
476 could prevent 27% of depression cases (Cox et al., 2017), and garden owners consider positive well-

477 being outcomes as a main benefit provided by gardens (Calvet-Mir et al., 2012). Results also scale  
478 proportionately to improved public health and well-being (Cox et al., 2017; Shanahan et al., 2015).  
479 More research into small-scale greenspaces specifically could potentially yield some important policy  
480 and practice outcomes.

481  
482 There is a very limited understanding as to the social and ecological contribution or importance of front  
483 gardens and streetscapes (i.e., people's own front gardens, neighbouring gardens, street trees and public  
484 greenspace/green infrastructure such as road verges) (Chalmin-Pui et al., 2021). In a review by  
485 Wendelboe-Nelson et al. (2019) it was revealed that only 1% of the literature surrounding greenspace  
486 and well-being involved residential gardens. Likewise, while evidence suggests that residents who live  
487 in greener neighbourhoods are happier and healthier than those who do not (Wang et al., 2020; Wood  
488 et al., 2018b), very few studies have considered streetscapes specifically. Streetscapes are an important  
489 spatial scale to consider as they are akin to a viewshed from people's households and are the first point  
490 of contact before entering the home.

491  
492 In the UK, approximately five million front gardens are absent of flora (~33%) and four and a half  
493 million (~25%) are completely paved over (Royal Horticultural Society, 2015). Front gardens are now  
494 comprised of three times less flora coverage than just one decade ago (Royal Horticultural Society,  
495 2015). In part, this is due to the fees and regulations associated with roadside parking and the desire for  
496 low maintenance gardens, as well as the lack of skill required to manage greenspaces (London  
497 Assembly, 2005). Moreover, in the UK, planning law does not cover the protection of domestic gardens  
498 as they are not categorised as a stand-alone land-use type (Sayce et al., 2012).

499

## 500 **1.11 Thesis scope, aims and outline**

501

502 This thesis aims to explore the knowledge gaps surrounding biodiversity and human mental well-being  
503 associations at the streetscape level, using the city of Leeds, UK, as a study system. Urban biodiversity  
504 may help to lessen the negative impacts of pollution on human mental well-being across streetscapes,  
505 especially as air and noise pollution are heightened by road traffic. Therefore, this thesis specifically  
506 seeks to understand how species richness might mediate the often negative association between air and  
507 noise pollution and mental well-being. Given the likely complex interplay between these interactions,  
508 parallel mediation models are used to examine simultaneous effects. To my knowledge, this is the first  
509 time in the literature that a study has accounted for potential disparity between public estimations of  
510 species richness and actual measures of species richness by including both actual and perceived  
511 biodiversity measures (flowering plants, pollinators and trees) within this kind of modelling framework.  
512 Understanding how these variables (perceived and actual levels of air and noise pollution and  
513 biodiversity, and their impacts on subjective mental well-being) interact means taking steps towards

514 creating cities which can benefit biodiversity conservation while also addressing rising trends in  
515 declining mental health (Patel et al., 2018). This is particularly pertinent as urban population growth is  
516 set to continue (United Nations, 2018).

517

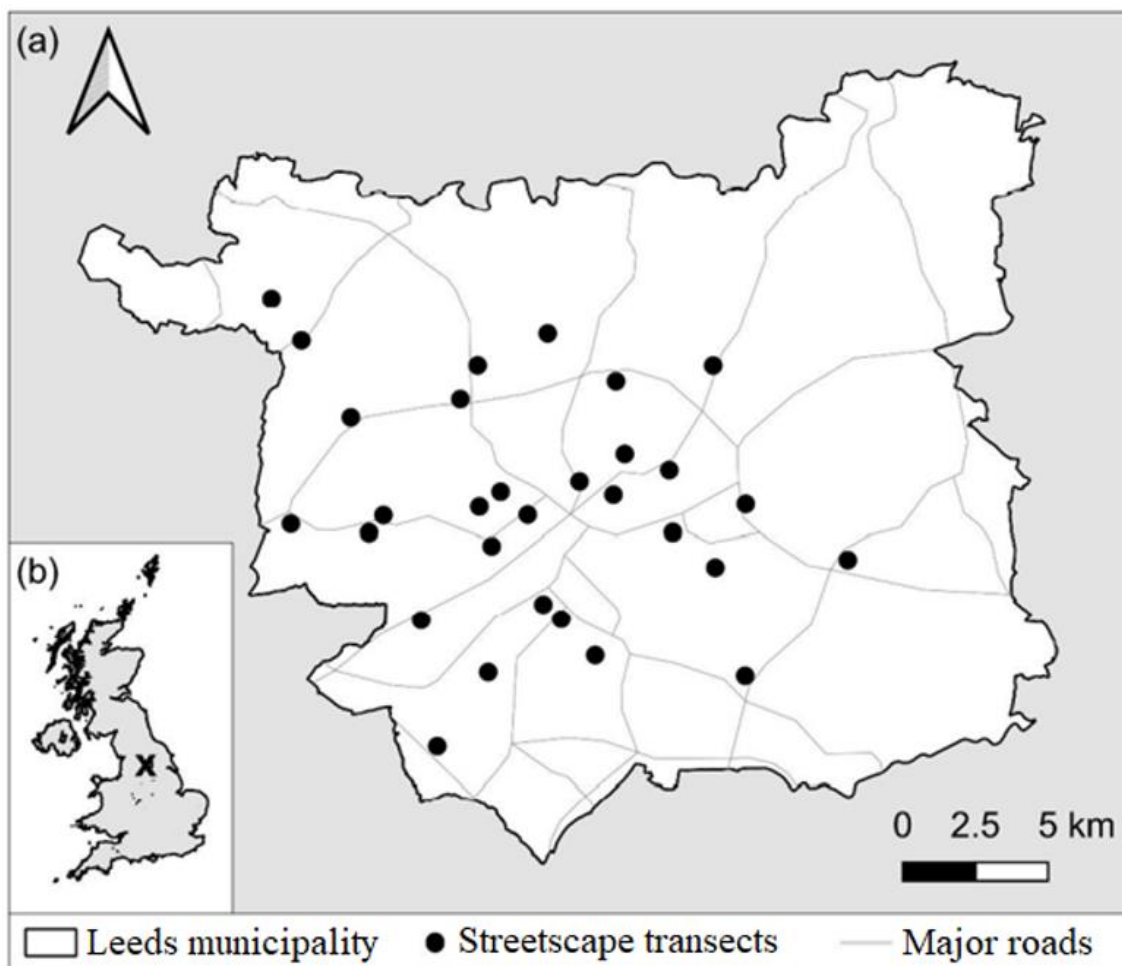
518

519 **Chapter 2. Methods**

520 **2.1 Study system**

521

522 This research was conducted across a sample of urban streets in the city of Leeds, UK (53° 47' 59" N,  
523 1° 32' 57" W; Fig. 1). The city is the fourth largest in England (~552 km<sup>2</sup>) with a human population of  
524 ~790,000, which is highly ethnically and culturally diverse (Office for National Statistics, 2018). Leeds  
525 is typical of cities found in developed, temperate nations, as it includes a wide range of residential areas  
526 and housing types (Goddard et al., 2013). Urban greenspaces cover more than half of the city (~55%),  
527 while gardens alone account for 28% of the area (Baldock et al., 2019). However, over a 33-year period,  
528 impervious surfaces have increased by 13% across Leeds (Perry and Nawaz, 2008).



529

530 **Figure 1.** Study area showing (a) the municipality of Leeds, its major roads (grey lines) and the location  
531 of each of the 30 streetscape transects (black circles). (b) The location of Leeds (cross) in the UK.

532

533 In the UK, most air and noise pollution is caused by road transport (United Kingdom Department for  
534 Business, Energy and Industrial Strategy, 2018, p14) but, at the time of research, no systematic and

535 accessible data had been collected on either for Leeds. This study therefore used a hierarchical sample  
536 design to capture air and noise pollution variation, using road size and traffic capacity as a proxy. Three  
537 pollution categories were identified based on road type. ‘High’ pollution roads included major roads  
538 designated to provide large-scale transport links within or between major urban centres, including dual  
539 carriageways (i.e., classified formally as “A roads”). ‘Medium’ pollution roads comprised roads  
540 intended to connect different areas and to feed traffic between major and smaller roads on the network,  
541 including any roads greater than 4 metres in width (i.e., “B roads”). ‘Low’ pollution roads were all other  
542 roads less than 4 metres in width.

543  
544 Ten roads from each pollution category (30 in total) were selected (Fig. 1), with a 200 m long streetscape  
545 transect established down each one. Each streetscape was located in a different ward of Leeds to  
546 maximise spatial variation. Streetscapes encompassed all green infrastructure (GI) within the transect,  
547 which included GI within front gardens and GI situated outside of front gardens (e.g., street trees).  
548 Transects were at least 0.6 km apart, although the majority were over 1 km in distance, to maximise  
549 sample independence. Most urban pollinator species do not forage beyond distances of 1 km (Garbuzov  
550 et al., 2015; Langelotto et al., 2018). Streetscapes were selected to ensure that variation in housing type  
551 was represented (e.g., detached, semi-detached, terrace) as this is a good proxy for garden size and  
552 socio-economic status (Loram et al., 2007).

553

## 554 **2.2 Noise and air pollution**

555

556 Ambient nitrogen dioxide (NO<sub>2</sub>) and particulate matter (PM<sub>2.5</sub>) concentrations (µg/m<sup>3</sup>) were measured  
557 at each streetscape transect. The data collection methods used are suitable for relative spatial  
558 comparisons across a study system (e.g., Bush et al., 2001), but are not suitable for carrying out  
559 internationally recognised monitoring of pollution levels (e.g., Ngo et al., 2019). Therefore, the findings  
560 cannot be compared to other air pollution data that has been gathered in Leeds collected by other studies,  
561 or to that collected from other cities.

562

563 Diffusion tube samples were used to measure NO<sub>2</sub> concentrations. Three diffusion tubes were situated  
564 on separate lampposts approximately 2.5 m high, within at least 10 m of the start/end of the transect  
565 and on alternating sides of the street (where possible) to maximise the distance between tubes. The  
566 diffusion tubes were left in place for four weeks in May/June and three weeks in July/August. An  
567 average concentration was calculated across all tubes and sampling periods.

568

569 PM<sub>2.5</sub> concentrations were recorded using the IQAir AirVisual Pro. While the AirVisual Pro is a low-  
570 cost monitor, the data derived from it allow discrepancies in concentrations between study streets to be  
571 evaluated (e.g., Ngo et al. 2019). Noise pollution was collected at breast height using a Reed ST-8850

572 sound level metre and was measured in decibels (dB). PM<sub>2.5</sub> and noise levels were obtained by walking  
573 at a slow pace along both sides of the 200 m transect across two independent visits between May and  
574 August 2019. To minimise potential bias that may have arisen due to variation in meteorological  
575 conditions (which is known to affect air quality; Yoshikado and Tsuchida, 1996), all streets from each  
576 of the respective pollution categories were sampled on the same or adjacent days. PM<sub>2.5</sub> concentration  
577 measurements were only taken on days with comparable and suitable weather conditions (Mues et al.,  
578 2012).

579

### 580 **2.3 Greenness (NDVI)**

581

582 The greenness of a neighbourhood is known to impact the psychological well-being of its residents  
583 (Sarkar et al., 2018; Wang et al., 2020). To quantify the overall ‘greenness’ of each transect, NDVI data  
584 were obtained based on MODIS (MOD13Q1 Collection 6 satellite data 16-day 185 composite at a 250  
585 m spatial resolution; ORNL DAAC, 2018) satellite imagery at two spatial scales (0.25 km<sup>2</sup> and 2.25  
586 km<sup>2</sup> centred on the transect midpoint) and used as a covariate within the parallel mediation models. The  
587 spatial scale of 0.25 km<sup>2</sup> was included as this is the finest spatial scale made available from the Modis  
588 vegetation indices data (MOD12Q1) and corresponds to the vegetation along the street as well as within  
589 the immediate vicinity. The 2.25 km<sup>2</sup> scale represents the vegetation cover in the local landscape more  
590 broadly as a crude measure of habitat availability for biodiversity. NDVI is a widely used method for  
591 quantifying green vegetation and does so by normalising green leaf scattering in Near Infra-red  
592 wavelength with chlorophyll absorption in red wavelengths (Myneni et al., 1995).

593

### 594 **2.4 Actual measures of biodiversity**

595

596 Actual species richness was recorded for pollinators, flowering plants and trees across each of the 30  
597 streetscapes. Pollinators were included as they form a large component of urban biodiversity that is  
598 visible throughout the day, such as bees and butterflies. This study used an adapted sampling approach  
599 from Baldock et al. (2015). Pollinator transects were conducted by walking at a steady pace down each  
600 200 m streetscape transect. Pollinators were observed and recorded if seen foraging on flowers or flying  
601 within the transect, within a 2 m height and 4 m width boundary. Transects ran between the pavement  
602 and residential gardens (including road verges if present) on the side of the streetscape where most GI  
603 was present. Pollinators were recorded as one of 20 morpho-functional groups (Supplementary  
604 Information S2). Data collection was conducted during May and July 2019 when weather conditions  
605 were suitable. Flowering plant richness was measured by noting down each observed plant within the  
606 200 m transect, which was in flower at the time the transect was conducted. Grasses, sedges and wind-

607 pollinated forbs were not included. Flowering plant data was collected over two separate visits. All tree  
608 species  $\geq 2$  m in height were recorded within each streetscape transect.

609

## 610 **2.5 Questionnaire**

611

612 Questionnaires (Supplementary Information S2) were administered *in-situ* face-to-face from June to  
613 August 2019. A total of 1033 households from all 30 streetscapes were eligible to complete one  
614 questionnaire per household. Each street was visited on three separate occasions, on different days (both  
615 weekends and weekdays) and at different times of the day (e.g., during the day and evening) to  
616 maximise response rates. Participants were required to be over the age of 18 to complete a questionnaire  
617 and informed consent was obtained prior to completion. Questionnaires were available to complete in  
618 English and Urdu (the most commonly spoken language in Leeds, second to English). Ethics approval  
619 was granted by the University of Leeds Social Sciences, Environment and LUBS (AREA) Faculty  
620 Research Ethics Committee, reference AREA 19-165 (University of Leeds was the institution leading  
621 the overarching project, rather than University of Kent). The questionnaire was piloted with a total of  
622 21 Leeds residents who were not residing in any of the 30 streetscapes included within the study.  
623 Following the pilot, some wordings were changed to improve flow and clarity of the questionnaire.

624

### 625 **2.5.1 Perceptions of biodiversity and pollution**

626

627 Human perceptions of biodiversity were obtained by asking each participant to estimate the number of  
628 flowering plant, pollinator and tree species in their streetscape, which was termed 'street environment'  
629 in the questionnaire. It was explained in the questionnaire (Supplementary Information S1) that 'street  
630 environment' referred to all GI included within front gardens and the street itself (e.g., road verges).  
631 Participants were asked to estimate the number of species using a five-point scale for flowering plants  
632 ('fewer than 10', '10 to 30', '31 to 50', '51 to 99', '100 or more'), pollinators ('fewer than 5', '5 to 9',  
633 '10 to 13', '14 to 19', '20 or more') and trees ('fewer than 5', '5 to 10', '11 to 15', '16 to 20', '21 or  
634 more'). Categories were informed by previous research conducted on urban biodiversity in Leeds  
635 (Goddard et al., 2013).

636

637 Human perceptions of air pollution were obtained by asking each participant (Supplementary  
638 Information S1) how polluted they believed their streetscape to be, using a five-point scale as a response  
639 ('very polluted', 'polluted', 'neutral', 'clean', 'very clean'). Noise pollution perceptions were obtained  
640 by asking participants to respond to four items (Supplementary Information S1). Each of these were  
641 answered using five-point scales, which were added together to form a composite score: (i) 'completely  
642 unacceptable', 'unacceptable', 'neutral', 'acceptable', 'completely acceptable'; (ii) 'very quiet', 'quiet',  
643 'Neutral', 'noisy', 'very noisy'; (iii) 'not at all annoying', 'not annoying', 'neutral', 'annoying', 'very

644 annoying’; (iv) ‘very relaxing’, ‘relaxing’, ‘neutral’, ‘stressful’, ‘very stressful’). Item (i) was reverse  
645 coded as the scale was inverted. Participants were also asked to list: “*What three main sounds do you*  
646 *hear in your street environment?*” to gain further insight into their streetscape soundscape.

647

### 648 **2.5.2 Well-being outcomes**

649

650 The questionnaire (Supplementary Information S1) used two different self-reported well-being  
651 outcomes: the Short Warwick-Edinburgh Mental Well-being Scale (SWEMWBS) and happiness. Both  
652 are validated scales commonly used in nature-health related research (Houlden et al., 2017; van Herzele  
653 and de Vries, 2012). SWEMWBS consists of seven affect items relating to the primary components of  
654 psychological well-being, including those of a hedonic (feeling of positive emotions, satisfaction) and  
655 eudaimonic (functioning, relationships, sense of purpose) nature (Stewart-Brown et al., 2009).  
656 Participants were asked to: “*Tick the box that best describes your experience of each over the last two*  
657 *weeks*” and responded using a five-point scale (‘none of the time’, ‘rarely’, ‘some of the time’, ‘often’,  
658 ‘all of the time’). Scores for each item were summed to produce an initial raw score that was then  
659 transformed using the SWEMWBS conversion table to give a final score, which could have ranged  
660 from 7 to 35. The happiness scale used was adapted from Fordyce (1988) and asked participants: “*In*  
661 *your life in general, how happy would you say you are?*” on a scale of one to ten.

662

### 663 **2.5.3 Covariates**

664

665 An individual’s sensitivity to noise is likely to influence how noisy and acceptable they believe their  
666 streetscape to be, and therefore may influence the restorativeness of streetscape biodiversity. To  
667 measure self-reported sensitivity to noise we used four items from Weinstein’s (1978) noise sensitivity  
668 scale in the questionnaire (Supplementary Information S1). The four items have shown relative context  
669 independence while, in particular, the last item (“*I am sensitive to noise*”) correlates with results from  
670 Weinstein’s scale in its entirety in the adult Finnish population (Heinonen-Guzejev et al., 2004).  
671 Participants were asked to respond on a five-point scale. One item was adapted to represent the  
672 streetscape scale from: “*I get annoyed when my neighbours are noisy*” to: “*I get irritated when there is*  
673 *noise in my street*”.

674

675 Given the influence that social cohesion has on well-being in the literature and, by extension influences  
676 people’s perception of the world around them, we included a self-reported social cohesion scale  
677 (Sampson et al., 1997) in the questionnaire (Supplementary Information S1). Social cohesion was  
678 measured using five items, three of which were positive affect and two negative affect. The scores were  
679 then added together to create an overall social cohesion score.

680

681 Sociodemographic characteristics collected from the participants in the questionnaire (Supplementary  
682 Information S1) included: age, gender, ethnicity and employment status. Information pertaining to the  
683 household was also gathered, such as the number of years lived at the property, tenure status and number  
684 of permanent residents. Gross household income data was not requested due to the sensitive nature of  
685 the question. Instead, this was obtained from the most recent national census in 2011 (Office for  
686 National Statistics, 2018), using the most spatially resolved data ('Lower Layer Super Output Area') to  
687 cover each streetscape.

688

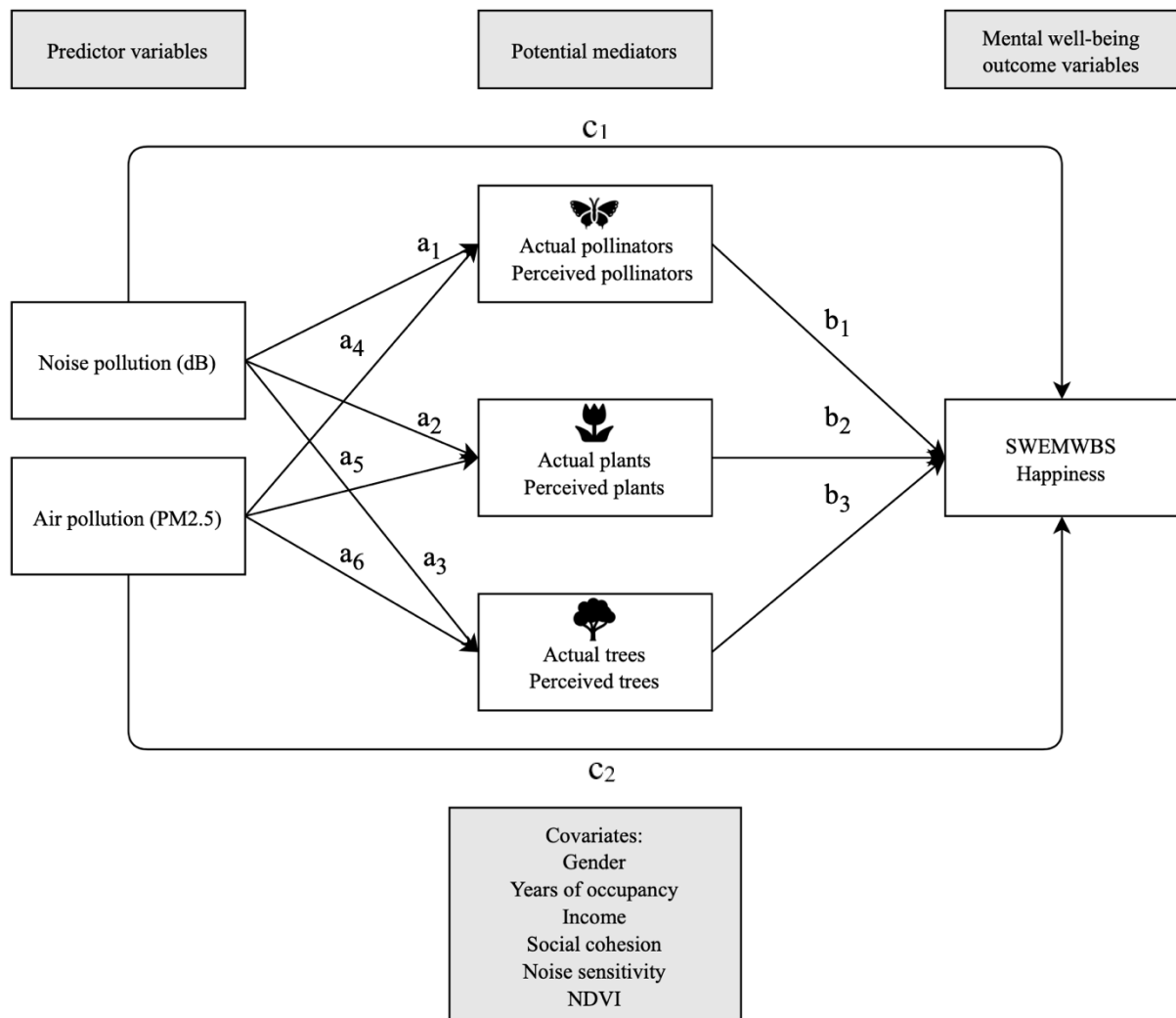
## 689 **2.6 Statistical analysis**

690

### 691 ***2.6.1 Parallel mediation models***

692

693 Four parallel mediation models (Fig. 2) were constructed to test the mediating effect of species richness  
694 (actual and perceived) on the relationship between noise (dB) and air (PM<sub>2.5</sub>) pollution on human well-  
695 being (SWEMWBS and happiness). The models were adjusted for covariates (NDVI, noise sensitivity,  
696 social cohesion, gender, years of household occupancy, gross household income). They simultaneously  
697 calculate regression analyses between predictors (dB, PM<sub>2.5</sub>) and mediators (biodiversity actual,  
698 perceived) (paths a1 – a6), predictors and outcome variables (SWEMWBS, happiness) (direct effect,  
699 paths c1 and c2), and mediators and outcome variables (b1 – b3). The indirect effect (a\*b) measures  
700 how predictors influence the wellbeing outcomes as a result of the influence of the predictors on the  
701 mediators, that, in turn, also affect the wellbeing outcomes.



703

704 **Figure 2.** Conceptual diagram of the model framework. Parallel mediation models tests the effects of  
 705 predictors (noise and air pollution) on well-being outcomes (SWEMWBS and happiness), via potential  
 706 mediators (actual and perceived flowering plant, pollinator and tree richness). Actual pollinator richness  
 707 was recorded at morpho-functional group richness level, rather than species richness. a paths = tested  
 708 direct associations between predictor and wellbeing outcomes. b paths = tested direct associations  
 709 between mediators and wellbeing outcomes. c paths = tested direct associations between predictors and  
 710 wellbeing outcomes. The indirect effect is the product of the a and b paths ( $a*b$ ).

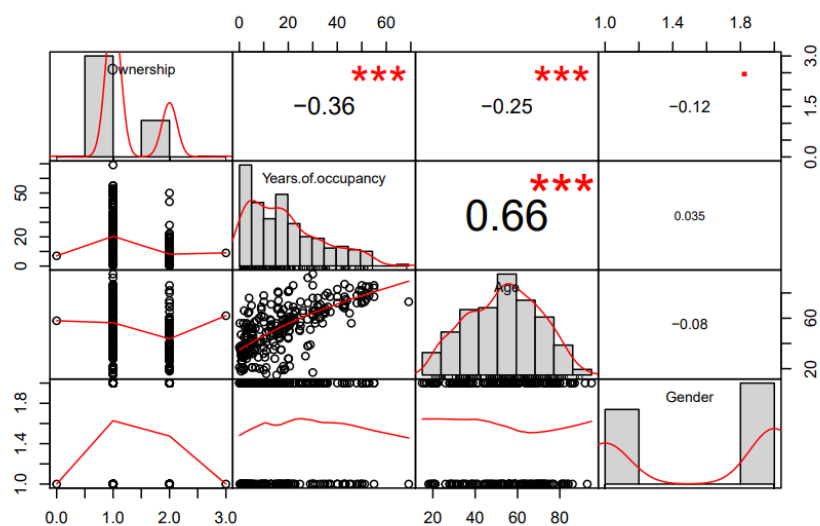
711

712 Parallel mediation models were performed using R statistical software version 3.6.0 (R Core  
 713 Development Team, 2020), using the ‘Lavaan survey’ package designed for structural equation  
 714 modelling (Oberski, 2014). ‘Lavaan survey’ allows for the analysis of clustered samples using cluster-  
 715 robust standard errors (SE) (i.e., households from the same streetscape). Analyses accounted for ‘street  
 716 code’ clustering of data by including it as a random effect. Three streetscapes with fewer than five

717 completed questionnaires were removed from analyses to strengthen statistical reliability. Two were  
 718 from the low pollution streetscapes and one from the medium pollution streetscapes.

719

720 Spearman’s pairwise correlations (Fig. 3) and Kruskal Wallace tests were used to test for associations  
 721 between categorical and continuous demographic variables. Due to a large proportion of the sample  
 722 choosing not to disclose their age ( $n = 31$ ), which strongly correlated with years of household occupancy  
 723 ( $r = 0.67$ ,  $p < 0.001$ ), the latter was used to maximise sample size. A strong association was identified  
 724 between employment status and gross household income ( $X^2 = 6.46$ ,  $df = 2$ ,  $p < 0.05$ ) using the ‘het.cor’  
 725 function on R, specifically designed for categorical and ordinal data. Gross household income was  
 726 therefore included as a covariate to account for the possible influence it may have on regular garden  
 727 maintenance (Kendal et al., 2012). Gender was treated as binary, and both years of household occupancy  
 728 and income were scaled and centred to stabilise variances. Due to a strong correlation between dB and  
 729  $\text{NO}_2$  ( $r = 0.77$ ,  $p = < 0.001$ ),  $\text{NO}_2$  was not included in the models.



730

731 **Figure 3.** Spearman’s rank correlation analyses used to identify associations between categorical  
 732 covariates: ownership, years of occupancy, age and gender.

733

734 Four models were run in total, interchanging between perceived/actual biodiversity measures as  
 735 mediators and SWEMWSB/happiness as outcome variables. The data showed no evidence of  
 736 multicollinearity via Variance Inflation Factors, all of which were  $< 1.9$ . Models were estimated using  
 737 a maximum likelihood estimator and a Satorra-Bentler scaled test statistic that is robust to non-  
 738 normality in the model variables. The error variances between the three mediators were free to covary  
 739 due to the plausible biological associations between them (e.g., more pollinators are likely to be found  
 740 where flowering plant richness is greater). To check for model fit, a Chi-square p value adjusted for the  
 741 random effect/clustered data was used (‘pval.pFsum’ function; Obserski, 2014) alongside other fit

742 measure statistics including RMSEA (and its 95% CI), SRMR and comparative fit index (CFI). Good  
743 model fit was identified ( $p > 0.05$ , CFI  $> 0.95$ , 313 RMSEA  $< 0.06$ , RMSEA 95% confidence intervals  
744  $< 0.06$ , SRMR  $< 0.08$ ) (Hu and Bentler, 1999; MacCallum et al., 1996; Oberski, 2014; Barrett, 1997).

745

#### 746 ***2.6.2 Bivariate analyses***

747

748 Bivariate analyses were performed using R statistical software version 3.6.0 (R Core Development  
749 Team 2020). Spearman's rank correlations were used to test the associations between perceptions of  
750 flowering plant, pollinator and tree species richness/morpho-functional group richness and actual  
751 richness for each taxon. A spearman's rank correlation was also performed on perceptions and actual  
752 measurements of air (PM<sub>2.5</sub>, NO<sub>2</sub>) and noise pollution (dB). Pearson's correlations were used to test the  
753 associations between actual measures of flowering plant, pollinator and tree species richness/morpho-  
754 functional group richness and actual pollution readings (PM<sub>2.5</sub>, NO<sub>2</sub>, dB). Kruskal Wallis tests for non-  
755 normally distributed data were used to check for statistical differences in SWEMWBS, happiness, social  
756 cohesion and noise sensitivity scores between the three pollution categories. A Kruskal-Wallis test and  
757 Dunn's test were used to identify statistical differences between NO<sub>2</sub> and dB levels across the three  
758 pollution categories.

759 Chapter 3. Results

760 **3.1 Descriptive and bivariate statistics**

761

762 A total of 282 participants (27.3% response rate) from across all 30 streetscapes completed the  
 763 questionnaire. Participant’s ages ranged from 18 to 91 and 55.3% (n = 156) were female. At the time  
 764 of data collection most participants (92%, n = 260) had been living at their property for at least one  
 765 year. The demographic profile of the sample was representative of the overall population of Leeds,  
 766 based on sex, age and ethnicity (Table 1).

767

768 **Table 1.** Demographic characteristics of the study sample (sex, age, ethnicity) taken from 282  
 769 questionnaires across 30 streets in Leeds and the 2011 national census population for Leeds (Office for  
 770 National Statistics, 2018). G-tests (indicated in italics) used to measure data goodness of fit show that  
 771 the study sample was representative of the overall population of Leeds.

772

| Demographic Characteristic                      | N   | %    | Census % |
|---|-----|------|----------|
| <b>Gender</b>                                   |     |      |          |
| Male  | 116 | 41.1 | 49.1     |
| Female  | 156 | 55.3 | 50.9     |
| Prefer not to say                               | 10  | 3.5  | -        |
| <i>G = -2500.7, X<sup>2</sup> df = 1, p = 1</i> |     |      |          |
| <b>Age</b>                                      |     |      |          |
| 16 – 24   | 19  | 6.7  | 18.8     |
| 25 – 29   | 10  | 3.5  | 9.7      |
| 30 – 44   | 50  | 17.7 | 25.3     |
| 45 – 59   | 76  | 26.9 | 21.6     |
| 60 – 64   | 17  | 6    | 6.5      |
| 65 – 84   | 66  | 23.4 | 15.4     |
| 85+   | 10  | 3.5  | 2.3      |
| Prefer not to say                               | 34  | 12   | -        |
| <i>G = -2222.3, X<sup>2</sup> df = 6, p = 1</i> |     |      |          |
| <b>Ethnicity</b>                                |     |      |          |
| White   | 205 | 72.7 | 81.1     |
| White other                                     | 20  | 7.1  | 3.9      |
| Asian   | 27  | 9.6  | 7.8      |
| Black   | 7   | 2.5  | 3.4      |
| Other   | 14  | 5    | 4.3      |
| Prefer not to say                               | 9   | 3.2  | -        |
| <i>G = -2507.0, X<sup>2</sup> df = 4, p = 1</i> |     |      |          |

773

774 NO<sub>2</sub> and dB pollution measures (Table 2) both increased across the three pollution categories (low,  
 775 medium, high) (NO<sub>2</sub>: X<sup>2</sup> = 112.93, df = 2, p < 0.001; dB: X<sup>2</sup> = 229.46, df = 2, p < 0.001) (Table 3),  
 776 demonstrating that the sampling approach was representative of how polluted each streetscape was (Fig.  
 777 4). However, PM<sub>2.5</sub> measures were highly variable across pollution categories (X<sup>2</sup> = 0.92, df = 2. p =  
 778 0.62).

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**Table 2.** Summary statistics detailing the median, interquartile range (IQR), mean, standard error (SE), minimum and maximum recorded values for the predictors, well-being outcomes, mediators and covariates examined in the study. Noise pollution, air pollution, actual biodiversity (pollinators, flowering plants, trees) and greenness (NDVI) were measured across all 30 streetscapes. Actual pollinator richness was recorded at morpho-functional group level, whereas flowering plants and trees were recorded as species richness. Well-being outcomes, perceived biodiversity (pollinators, flowering plants, trees) and remaining covariates were assessed via the questionnaire (n = 282).

|  | <b>Median</b> | <b>IQR</b> | <b>Mean</b> | <b>SE</b> | <b>Min</b> | <b>Max</b> |
|--|---------------|------------|-------------|-----------|------------|------------|
| <b>Predictors</b>                                    |               |            |             |           |            |            |
| Noise pollution (dB)                                 | 82.40         | 13.65      | 59.56       | 0.50      | 67.5       | 93.6       |
| Air pollution (PM <sub>2.5</sub> µg/m <sup>3</sup> ) | 4.69          | 3.17       | 5.15        | 0.11      | 2.26       | 8.83       |
| <b>Well-being outcomes</b>                           |               |            |             |           |            |            |
| SWEMWBS  | 22.33         | 4.67       | 22.87       | 0.22      | 13.33      | 35         |
| Happiness  | 8.00          | 2          | 7.90        | 0.10      | 1          | 10         |
| <b>Mediators</b>                                     |               |            |             |           |            |            |
| Actual pollinator richness                           | 7.00          | 4          | 6.91        | 0.17      | 0          | 14         |
| Actual flowering plant richness                      | 63.00         | 19         | 63.01       | 1.09      | 31         | 101        |
| Actual tree richness                                 | 17.00         | 8.75       | 19.02       | 0.43      | 2          | 33         |
| Perceived pollinator richness                        | 3.00          | 2          | 2.90        | 0.07      | 1          | 5          |
| Perceived flowering plant richness                   | 2.00          | 1          | 2.51        | 0.07      | 1          | 5          |
| Perceived tree richness                              | 2.00          | 1          | 2.24        | 0.05      | 1          | 5          |
| <b>Covariates</b>                                    |               |            |             |           |            |            |
| Greenness (NDVI)                                     | 0.50          | 0.28       | 0.48        | 0.01      | 0.15       | 0.79       |
| Social cohesion                                      | 2.88          | 0.75       | 2.85        | 0.03      | 1          | 4.62       |
| Noise sensitivity                                    | 13.00         | 3          | 12.74       | 0.14      | 4          | 20         |
| Gender   | -             | -          | -           | -         | -          | -          |
| Years of household occupancy                         | 16            | 22.34      | 18.90       | 0.91      | 0.08       | 69.16      |
| Gross household income                               | 31334         | 16256      | 32062       | 602.32    | 11553      | 51598      |

788 **Table 3.** Results of Kruskal-Wallis test (indicated in italics) and the post hoc Dunn's multiple  
 789 comparisons test, showing significant differences in NO<sub>2</sub> and dB readings across the three pollution  
 790 categories (low, medium, high).

791

| Comparison  | Z     | P       |
|---|-------|---------|
| <b>NO<sub>2</sub></b>                             |       |         |
| High – Med  | 7.53  | < 0.001 |
| High – Low  | 15.13 | < 0.001 |
| Low – Med   | -7.35 | < 0.001 |
| <i>X<sup>2</sup> = 112.93, df=2, p &lt; 0.001</i> |       |         |
| <b>dB</b>   |       |         |
| High – Med  | 10.52 | <0.001  |
| High – Low  | 3.57  | < 0.001 |
| Low – Med   | -6.71 | < 0.001 |
| <i>X<sup>2</sup> = 229.46, df=2, p &lt; 0.001</i> |       |         |

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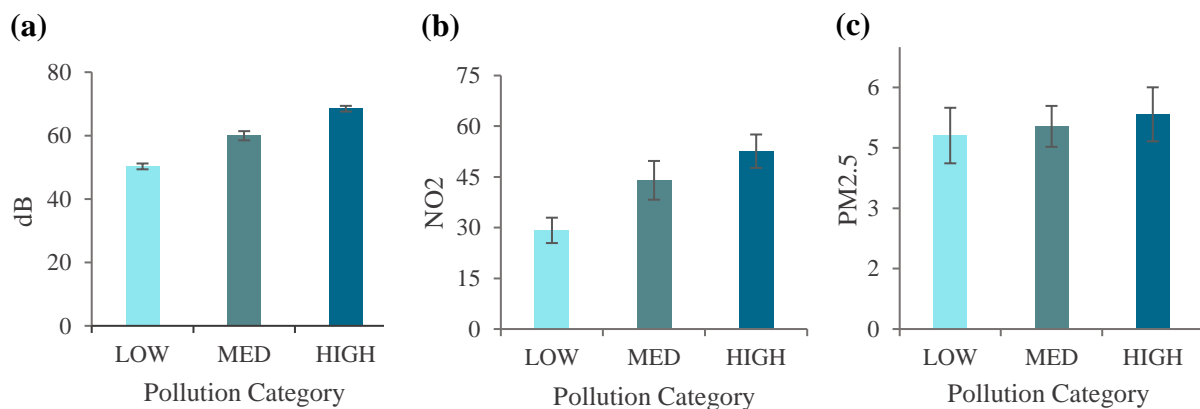
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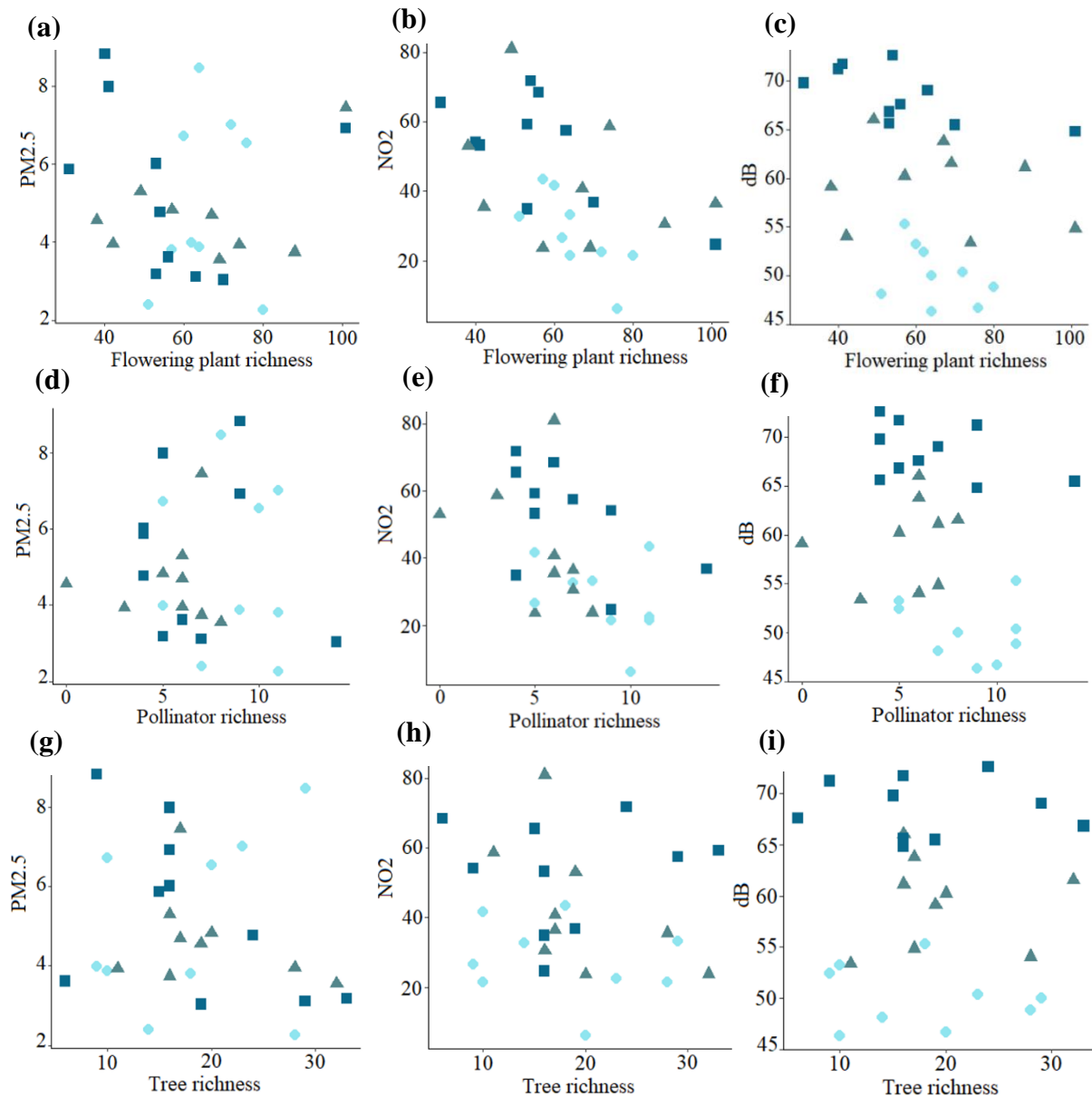
802



803 **Figure 4.** Median pollution levels and associated IQR in the low, medium and high pollution category  
 804 streetscapes for: (a) noise (dB); (b) nitrogen dioxide (NO<sub>2</sub>); and (c) particulate matter (PM<sub>2.5</sub>).

805

806 Actual biodiversity richness (pollinators, flowering plants, trees) was variable across streetscapes  
 807 (Table 1). Flowering plant richness had a significant negative association with NO<sub>2</sub> ( $r = -0.54$ ,  $p <$   
 808  $0.001$ ) and dB ( $r = -0.35$ ,  $p < 0.001$ ), but not with PM<sub>2.5</sub> ( $r = 0.08$ ,  $p = 0.178$ ). Pollinator richness also  
 809 had a significant negative association with NO<sub>2</sub> ( $r = -0.54$ ,  $p < 0.001$ ) and dB ( $r = -0.35$ ,  $p < 0.001$ ), but  
 810 not with PM<sub>2.5</sub> ( $r = -0.03$ ,  $p = 0.543$ ) (Fig. 5). No associations were observed between tree richness and  
 811 any of the pollution measures.



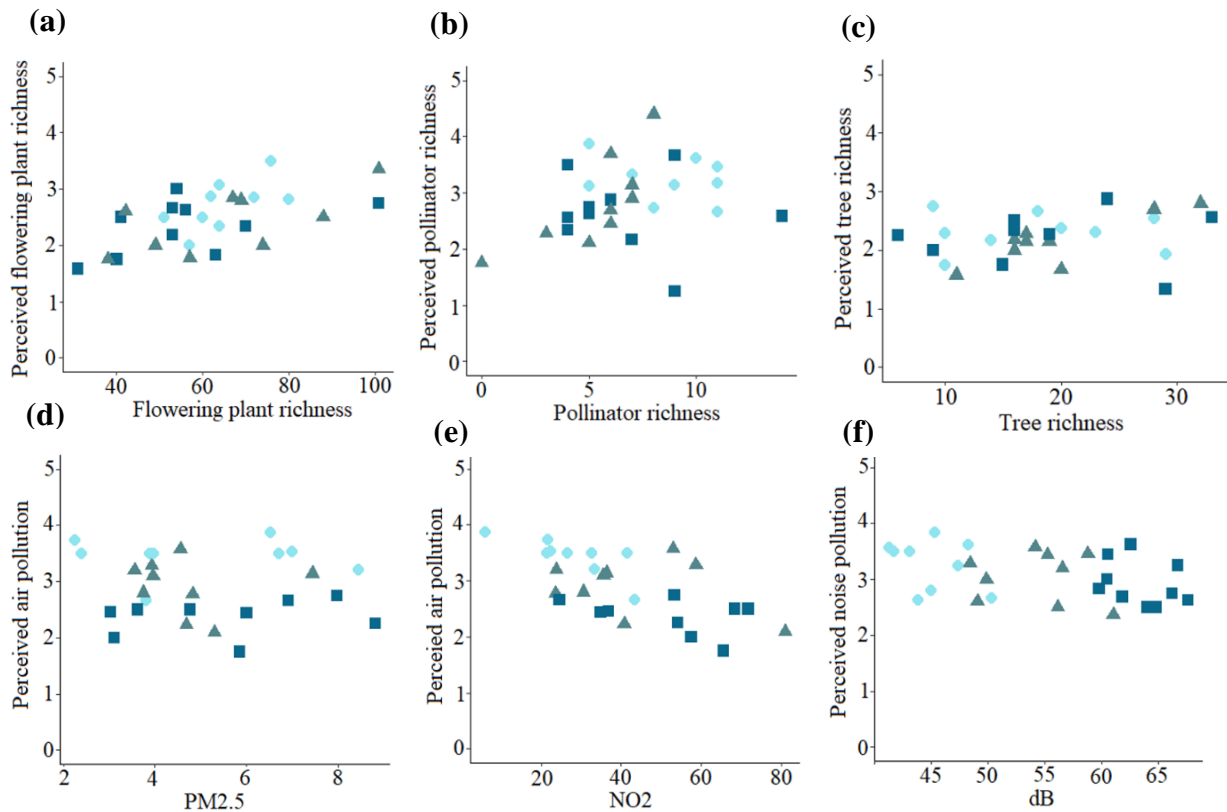
812

813 **Figure 5.** Associations between actual flowering plant richness and (a) particulate matter ( $PM_{2.5}$ ); (b)  
 814 nitrogen dioxide ( $NO_2$ ); and (c) noise (dB) pollution. Associations between actual pollinator richness  
 815 and (d) particulate matter ( $PM_{2.5}$ ); (e) nitrogen dioxide ( $NO_2$ ); and (f) dB. Actual pollinator richness was  
 816 assessed by morpho-functional group richness. Associations between actual tree richness and (g)  
 817 particulate matter ( $PM_{2.5}$ ); (h) nitrogen dioxide ( $NO_2$ ); and (i) noise pollution (dB). Each symbol is a  
 818 mean value for each streetscape, with the shape indicating the pollution category of the streetscape:  
 819 circle = low; triangle = medium; and square = high.

820

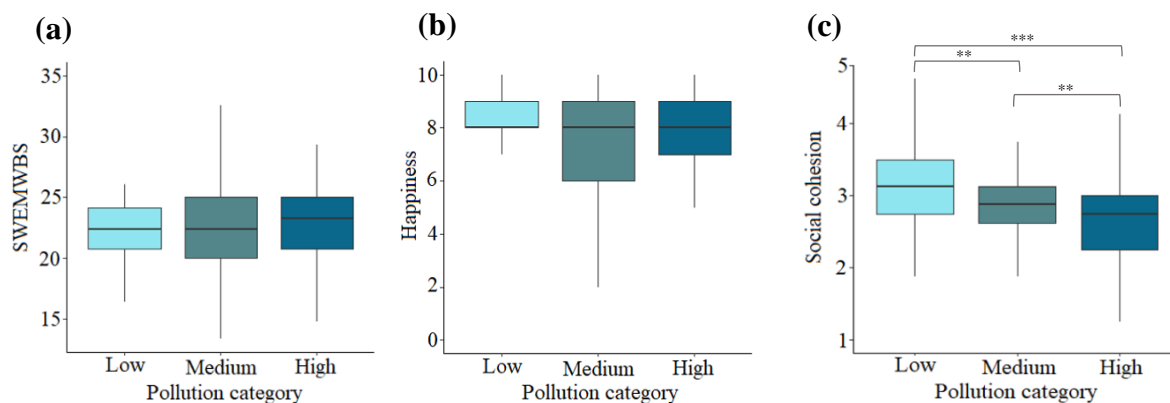
821 No association between participant perceptions of pollinator richness and actual pollinator richness ( $r$   
 822 = 0.29,  $p = 0.126$ ) was recorded (Fig. 6). However, significant positive associations were observed  
 823 between perceived and actual flowering plant ( $r = 0.54$ ,  $p < 0.05$ ) and tree ( $r = 0.37$ ,  $p < 0.05$ ) richness.

824 A significant negative association was observed between perceived air pollution and NO<sub>2</sub> ( $r = -0.41$ ,  $p$   
 825  $< 0.001$ ), although no association was found with PM<sub>2.5</sub> ( $r = -0.002$ ,  $p = 0.970$ ). A significant negative  
 826 association was also observed between perceived noise pollution and dB ( $r = -0.20$ ,  $p < 0.001$ ).  
 827



828  
 829 **Figure 6.** Associations between actual and perceived richness of: (a) flowering plants; (b) pollinators;  
 830 and (c) trees. Actual pollinator richness was assessed by morpho-functional group richness, whereas  
 831 flowering plants and trees were measured by species richness. Associations between perceived  
 832 streetscape air pollution and (d) particulate matter (PM<sub>2.5</sub>) and (e) nitrogen dioxide (NO<sub>2</sub>). Associations  
 833 between perceived streetscape noise pollution and (f) noise pollution (dB). Each symbol is a mean value  
 834 for each streetscape, with the shape representing pollution category of the streetscape: circle = low;  
 835 triangle = medium; and square = high.

836  
 837 Across the 282 participants, SWEMWBS and social cohesion scores had a central tendency, whereas  
 838 happiness scores were right-skewed (Table 1). There were no significant differences in SWEMWBS  
 839 ( $X^2 = 1.49$ ,  $df = 2$ ,  $p = 0.481$ ) and happiness ( $X^2 = 2.26$ ,  $df = 2$ ,  $p = 0.322$ ) scores between the three  
 840 pollution categories (Fig. 7). Social cohesion demonstrated significance between pollution categories  
 841 ( $X^2 = 27.27$ ,  $df = 2$ ,  $p < 0.001$ ), whereby social cohesion scores decreased as the pollution category  
 842 increased.



844

845 **Figure 7.** Box plots showing participant responses ( $n = 268$ ), grouped by the low, medium and high  
 846 pollution categories, to: (a) SWEMWBS; (b) happiness; and (c) social cohesion. No significant  
 847 relationship was identified between SWEMWBS or happiness scores across pollution categories.  
 848 Significant differences between pollution categories for social cohesion scores are indicated using  
 849 symbols: \*\* =  $< 0.05$ ; \*\*\* =  $< 0.001$ .

850

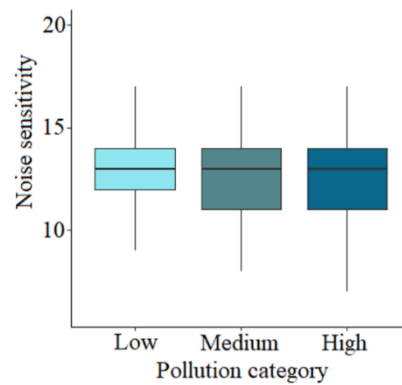
851 Participants most commonly reported hearing sounds that were anthropogenic in nature, such as cars  
 852 and traffic (Table 4), across all pollution categories. However, ‘traffic’ was mentioned much less in low  
 853 pollution streetscapes ( $n = 6$ ) compared to medium ( $n = 34$ ) and high ( $n = 41$ ) ones. ‘Birds’ were  
 854 reported most by participants living in low pollution streetscapes and least in high ones ( $n = 17$  and 2  
 855 respectively). No significant differences were apparent in noise sensitivity scores across the three  
 856 pollution categories ( $X^2 = 2.09$ ,  $df = 2$ ,  $p = 0.35$ ) (Fig. 8).

857

858 **Table 4.** Types of sounds listed by participants when asked: “*What three main sounds do you hear in*  
 859 *your street environment?*”, grouped by pollution categories.

| 860 | <b>Sound Types</b> | <b>Low</b> | <b>Medium</b> | <b>High</b> |
|-----|--------------------|------------|---------------|-------------|
| 861 | Road vehicles      | 50         | 71            | 86          |
| 862 | Aeroplanes         | 2          | 2             | 0           |
| 863 | Birds              | 17         | 5             | 2           |
| 864 | People             | 9          | 3             | 2           |
| 865 | Music              | 1          | 0             | 1           |
| 866 | Construction       | 0          | 0             | 2           |
|     | Weather            | 0          | 1             | 0           |
|     | Dogs               | 0          | 1             | 0           |

867



868

869 **Figure 8.** Box plot showing participant self-reported sensitivity to noise scores (n = 269), grouped by  
870 the low, medium and high pollution categories.

871

### 872 **3.2 Parallel mediation models**

873

874 The variance explained for the SWEMWBS and happiness well-being outcomes was 8% in each of the  
875 four models (Fig. 9). Noise pollution significantly and negatively influenced both actual pollinator and  
876 flowering plant richness, although this was not observed for tree richness. No such relationship was  
877 observed between air pollution and actual pollinator, flowering plant, or tree richness. Actual flowering  
878 plant richness had a positive effect on SWEMWBS outcomes, but not happiness (Table 5). Indirect  
879 pathways revealed that when noise pollution is increased, SWEMWBS decreases, mediated by  
880 decreasing actual flowering plant richness (Table 5). Air and noise pollution showed no direct effect on  
881 either SWEMWBS or happiness well-being outcomes.

882

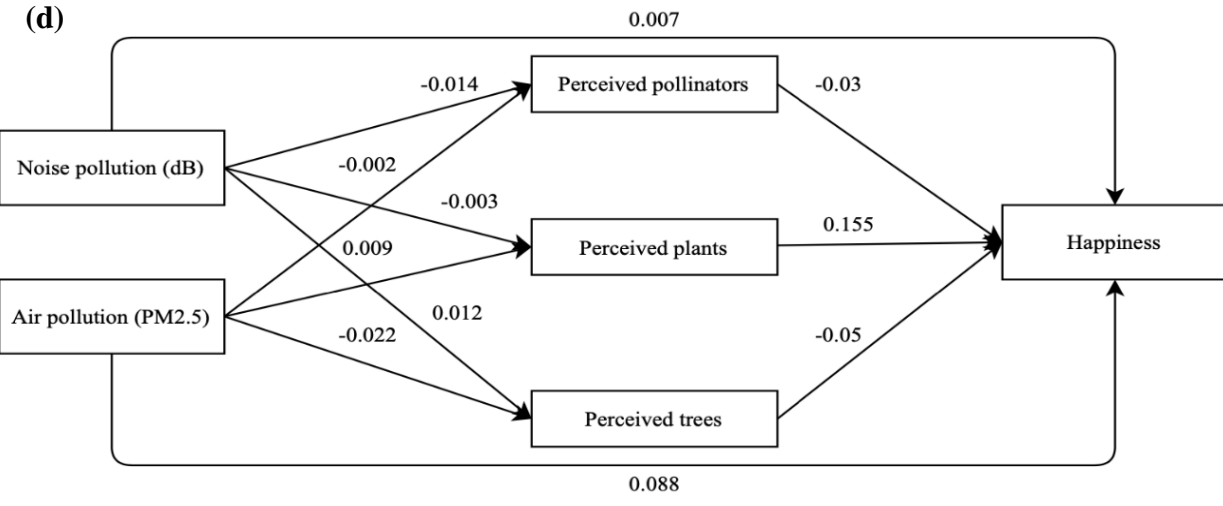
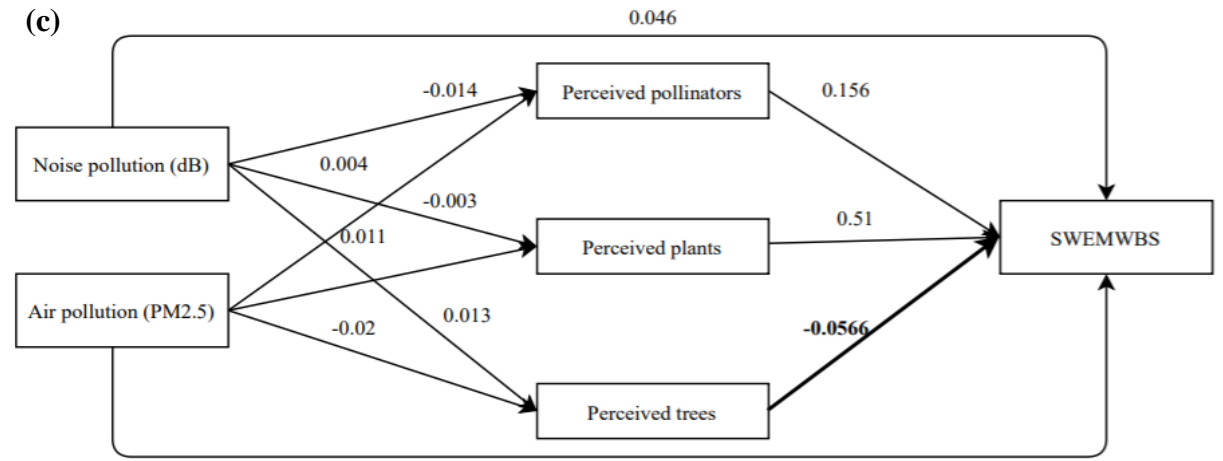
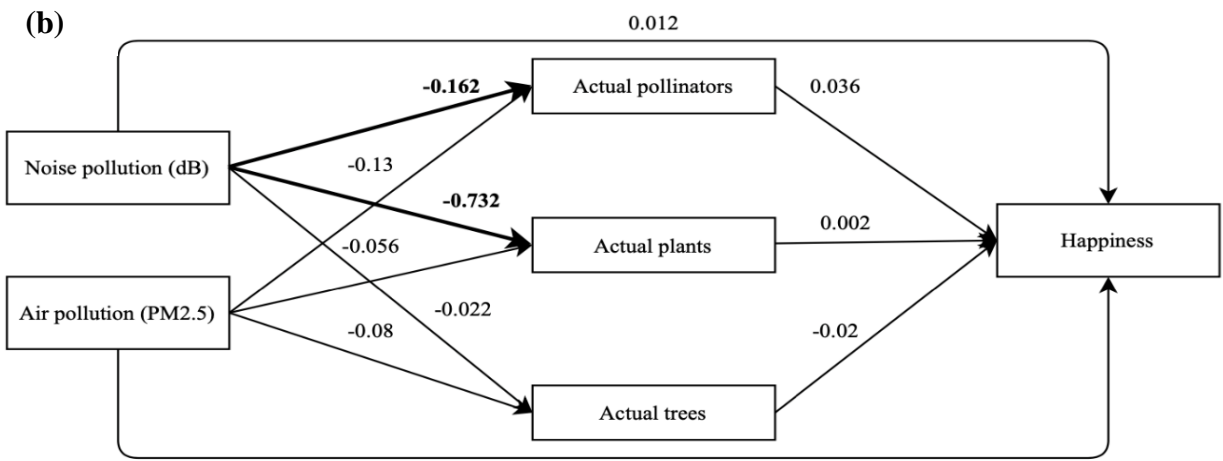
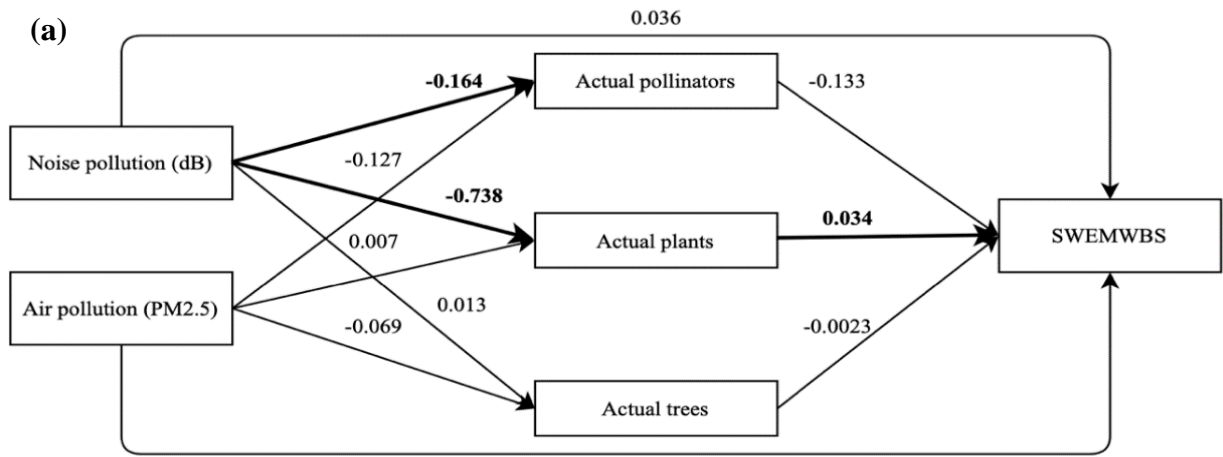
883 People's perceptions of flowering plant, pollinator or tree richness was not influenced by the noise or  
884 pollution in their streetscape. Perceived flowering plant and pollinator richness had no direct effect on  
885 SWEMWBS or happiness scores either (Tables 7 and 8). However, perceived tree richness did have a  
886 significant and negative direct association with SWEMWBS score (Table 7).

887

888 Amongst covariates, gross household income had a significant positive effect on actual tree richness ( $\beta$   
889 = 4.805,  $p = 0.004$ ) and was positively associated with perceived pollinator and tree richness when  
890 happiness was used as a well-being outcome variable (Table 8). Social cohesion, across all models, was  
891 a significant positive predictor for perceived flowering plant, pollinator and tree richness.

892

893



895 **Figure 9.** Parallel mediation models showing the effects of air pollution (PM<sub>2.5</sub>) and noise pollution  
896 (dB) on (a) SWEMWBS mediated by actual pollinator (recorded as morpho-functional groups),  
897 flowering plant and trees richness, (b) happiness mediated by actual pollinator, flowering plant and trees  
898 richness, (c) SWEMWBS mediated by perceived pollinator, flowering plant and trees richness and (d)  
899 happiness mediated by perceived pollinator, flowering plant and trees richness. All models are adjusted  
900 for covariates (NDVI, social cohesion, noise sensitivity, gender, years of household occupancy and  
901 gross household income). Plots display the unstandardised estimates (n = 241) after rows containing  
902 missing values were removed, with statistically significant paths highlighted in bold (p < 0.05).  
903

904 **Table 5.** Parallel mediation model testing the effect of noise and air pollution on SWEMWBS, mediated  
905 by actual richness of pollinators (assessed as morpho-functional group richness), flowering plants, and  
906 trees. Estimate values are standardised  $\beta$  values. Standard error = SE. Bold values indicate statistical  
907 significance (p < 0.05).

| <b>Model 1</b>                 |                |                 |           |          |              |
|--------------------------------|----------------|-----------------|-----------|----------|--------------|
| <b>OUTCOME = SWEMWBS</b>       |                |                 |           |          |              |
| <b>NOISE = ACTUAL</b>          |                |                 |           |          |              |
| <b>BIODIVERSITY = ACTUAL</b>   |                |                 |           |          |              |
| <b>Fit statistics – Rubust</b> |                |                 |           |          |              |
| Observations used              |                | 244             |           |          |              |
| Model fit test statistic       |                | 3.626           |           |          |              |
| Degrees of freedom             |                | 3               |           |          |              |
| P value from F test            |                | 0.306           |           |          |              |
| CFI (robust)                   |                | 0.984           |           |          |              |
| SRMR                           |                | 0.014           |           |          |              |
| RMSEA                          |                | 0.041           |           |          |              |
| Lower CI                       |                | 0.000           |           |          |              |
| Upper CI                       |                | 0.164           |           |          |              |
|                                |                | <b>Estimate</b> | <b>SE</b> | <b>Z</b> |              |
|                                |                |                 |           | <b>P</b> |              |
| <b>Actual pollinators</b>      |                |                 |           |          |              |
| Noise pollution                | a <sub>1</sub> | <b>-0.164</b>   | 0.059     | -2.786   | <b>0.005</b> |
| PM <sub>2.5</sub>              | a <sub>4</sub> | -0.127          | 0.343     | -0.37    | 0.711        |
| Years occupancy                |                | -0.139          | 0.246     | -0.564   | 0.573        |
| NDVI                           |                | -1.188          | 2.82      | -0.421   | 0.673        |
| Noise sensitivity              |                | -0.013          | 0.066     | -0.192   | 0.848        |
| Social cohesion                |                | -0.154          | 0.525     | -0.293   | 0.769        |
| Income                         |                | 0.583           | 0.529     | 1.101    | 0.271        |
| <b>Actual plants</b>           |                |                 |           |          |              |
| Noise pollution                | a <sub>2</sub> | <b>-0.738</b>   | 0.312     | -2.367   | <b>0.018</b> |
| PM <sub>2.5</sub>              | a <sub>5</sub> | 0.007           | 2.249     | 0.003    | 0.998        |
| Years occupancy                |                | 0.922           | 1.178     | 0.783    | 0.434        |
| NDVI                           |                | 12.938          | 19.63     | 0.659    | 0.51         |
| Noise sensitivity              |                | 0.381           | 0.351     | 1.084    | 0.278        |
| Social cohesion                |                | 2.953           | 2.666     | 1.107    | 0.268        |
| Income                         |                | 2.409           | 3.145     | 0.766    | 0.444        |
| <b>Actual trees</b>            |                |                 |           |          |              |
| Noise pollution                | a <sub>3</sub> | -0.013          | 0.223     | -0.059   | 0.953        |
| PM <sub>2.5</sub>              | a <sub>6</sub> | -0.069          | 0.88      | -0.079   | 0.937        |

|                                |                |              |       |        |              |
|--------------------------------|----------------|--------------|-------|--------|--------------|
| Years occupancy                |                | -1.033       | 0.453 | -2.278 | 0.023        |
| NDVI                           |                | -7.229       | 8.487 | -0.852 | 0.394        |
| Noise sensitivity              |                | 0.176        | 0.154 | 1.143  | 0.253        |
| Social cohesion                |                | -1.027       | 1.045 | -0.983 | 0.326        |
| Income                         |                | 4.912        | 1.681 | 2.922  | 0.003        |
| <b>SWEMWBS</b>                 |                |              |       |        |              |
| Actual pollinators             | b <sub>1</sub> | -0.133       | 0.092 | -1.439 | 0.15         |
| Actual plants                  | b <sub>2</sub> | <b>0.034</b> | 0.013 | 2.663  | <b>0.008</b> |
| Actual trees                   | b <sub>3</sub> | -0.023       | 0.039 | -0.595 | 0.552        |
| Noise pollution                | c <sub>1</sub> | 0.036        | 0.039 | 0.933  | 0.351        |
| PM <sub>2.5</sub>              | c <sub>2</sub> | 0.12         | 0.163 | 0.739  | 0.46         |
| Years occupancy                |                | 0.352        | 0.199 | 1.773  | 0.076        |
| NDVI                           |                | -3.093       | 1.629 | -1.898 | 0.058        |
| Noise sensitivity              |                | 0.006        | 0.097 | 0.063  | 0.95         |
| Social cohesion                |                | 0.592        | 0.342 | 1.729  | 0.084        |
| Income                         |                | 0.446        | 0.448 | 0.995  | 0.32         |
| Gender                         |                | 0.097        | 0.439 | 0.222  | 0.824        |
| <b>Mediation</b>               |                |              |       |        |              |
| Noise_pollinators              |                | 0.022        | 0.015 | 1.428  | 0.153        |
| PM <sub>2.5</sub> _pollinators |                | 0.017        | 0.039 | 0.43   | 0.667        |
| Noise_plants                   |                | -0.025       | 0.008 | -2.993 | 0.003        |
| PM <sub>2.5</sub> _plants      |                | 0            | 0.077 | 0.003  | 0.998        |
| Noise_trees                    |                | 0            | 0.005 | 0.058  | 0.954        |
| PM <sub>2.5</sub> _trees       |                | 0.002        | 0.02  | 0.08   | 0.936        |

908

909 **Table 6.** Parallel mediation model testing the effect of noise and air pollution on happiness,  
910 mediated by actual richness of pollinators (assessed as morpho-functional group richness),  
911 flowering plants, and trees. Estimate values are standardised  $\beta$  values. Standard error = SE.  
912 Bold values indicate statistical significance ( $p < 0.05$ ).

| <b>Model 2</b>                 |                |                 |           |          |              |
|--------------------------------|----------------|-----------------|-----------|----------|--------------|
| <b>OUTCOME = HAPPINESS</b>     |                |                 |           |          |              |
| <b>NOISE = ACTUAL</b>          |                |                 |           |          |              |
| <b>BIODIVERSITY = ACTUAL</b>   |                |                 |           |          |              |
| <b>Fit statistics – Rubust</b> |                |                 |           |          |              |
| Observations used              |                | 251             |           |          |              |
| Model fit test statistic       |                | 4.931           |           |          |              |
| Degrees of freedom             |                | 3               |           |          |              |
| P value from F test            |                | 0.197           |           |          |              |
| CFI (robust)                   |                | 0.977           |           |          |              |
| SRMR                           |                | 0.015           |           |          |              |
| RMSEA                          |                | 0.051           |           |          |              |
| Lower CI                       |                | 0.000           |           |          |              |
| Upper CI                       |                | 0.107           |           |          |              |
|                                |                | <b>Estimate</b> | <b>SE</b> | <b>Z</b> | <b>P</b>     |
| <b>Actual pollinators</b>      |                |                 |           |          |              |
| Noise pollution                | a <sub>1</sub> | <b>-0.162</b>   | 0.059     | -2.788   | <b>0.005</b> |
| PM <sub>2.5</sub>              | a <sub>4</sub> | -0.13           | 0.334     | -0.389   | 0.697        |
| Years occupancy                |                | -0.14           | 0.237     | -0.593   | 0.553        |
| NDVI                           |                | -1.088          | 2.785     | -0.391   | 0.696        |
| Noise sensitivity              |                | -0.008          | 0.064     | -0.129   | 0.898        |
| Social cohesion                |                | -0.148          | 0.513     | -0.288   | 0.773        |

|                                |                |               |        |        |             |
|--------------------------------|----------------|---------------|--------|--------|-------------|
| Income                         |                | 0.557         | 0.519  | 1.074  | 0.283       |
| <b>Actual plants</b>           |                |               |        |        |             |
| Noise pollution                | a <sub>2</sub> | <b>-0.732</b> | 0.314  | -2.329 | <b>0.02</b> |
| PM <sub>2.5</sub>              | a <sub>5</sub> | -0.056        | 2.212  | -0.026 | 0.98        |
| Years occupancy                |                | 0.636         | 1.134  | 0.561  | 0.575       |
| NDVI                           |                | 13.164        | 19.402 | 0.678  | 0.497       |
| Noise sensitivity              |                | 0.385         | 0.345  | 1.114  | 0.265       |
| Social cohesion                |                | 2.814         | 2.559  | 1.1    | 0.271       |
| Income                         |                | 2.227         | 3.182  | 0.7    | 0.484       |
| <b>Actual trees</b>            |                |               |        |        |             |
| Noise pollution                | a <sub>3</sub> | -0.022        | 0.221  | -0.098 | 0.922       |
| PM <sub>2.5</sub>              | a <sub>6</sub> | -0.08         | 0.871  | -0.092 | 0.927       |
| Years occupancy                |                | -1.048        | 0.412  | -2.546 | 0.011       |
| NDVI                           |                | -7.327        | 8.526  | -0.859 | 0.39        |
| Noise sensitivity              |                | 0.186         | 0.157  | 1.185  | 0.236       |
| Social cohesion                |                | -1.042        | 1.005  | -1.037 | 0.3         |
| Income                         |                | 4.805         | 1.672  | 2.873  | 0.004       |
| <b>Happiness</b>               |                |               |        |        |             |
| Bees perceived                 | b <sub>1</sub> | 0.036         | 0.031  | 1.134  | 0.257       |
| Plants perceived               | b <sub>2</sub> | 0.002         | 0.006  | 0.279  | 0.78        |
| Trees perceived                | b <sub>3</sub> | -0.02         | 0.021  | -0.95  | 0.342       |
| Noise pollution                | c <sub>1</sub> | 0.012         | 0.019  | 0.672  | 0.501       |
| PM <sub>2.5</sub>              | c <sub>2</sub> | 0.087         | 0.07   | 1.252  | 0.21        |
| Years occupancy                |                | 0.095         | 0.091  | 1.038  | 0.299       |
| NDVI                           |                | -1.121        | 0.969  | -1.157 | 0.247       |
| Noise sensitivity              |                | -0.052        | 0.036  | -1.44  | 0.15        |
| Social cohesion                |                | 0.336         | 0.173  | 1.942  | 0.052       |
| Income                         |                | 0.372         | 0.214  | 1.735  | 0.083       |
| Gender                         |                | 0.054         | 0.192  | 0.28   | 0.779       |
| <b>Mediation</b>               |                |               |        |        |             |
| Noise_pollinators              |                | -0.006        | 0.005  | -1.111 | 0.266       |
| PM <sub>2.5</sub> _pollinators |                | -0.005        | 0.012  | -0.374 | 0.709       |
| Noise_plants                   |                | -0.001        | 0.005  | -0.277 | 0.782       |
| PM <sub>2.5</sub> _plants      |                | 0             | 0.004  | -0.026 | 0.979       |
| Noise_trees                    |                | 0             | 0.004  | 0.097  | 0.922       |
| PM <sub>2.5</sub> _trees       |                | 0.002         | 0.017  | 0.093  | 0.926       |

913

914 **Table 7.** Parallel mediation model testing the effect of noise and air pollution on SWEMWBS,  
915 mediated by perceived richness of pollinators, flowering plants, and trees. Estimate values are  
916 standardised  $\beta$  values. Standard error = SE. Bold values indicate statistical significance ( $p <$   
917 0.05).

---

### Model 3

**OUTCOME = SWEMWBS**

**NOISE = ACTUAL**

**BIODIVERSITY = PERCEIVED**

---

#### Fit statistics – Rubust

|                          |        |
|--------------------------|--------|
| Observations used        | 241    |
| Model fit test statistic | 266.55 |
| Degrees of freedom       | 3      |

---

|                                |                |                 |           |          |             |
|--------------------------------|----------------|-----------------|-----------|----------|-------------|
| P value from F test            |                | 0.908           |           |          |             |
| CFI (robust)                   |                | 1               |           |          |             |
| SRMR                           |                | 0.004           |           |          |             |
| RMSEA                          |                | 0.000           |           |          |             |
| Lower CI                       |                | 0.000           |           |          |             |
| Upper CI                       |                | 0.019           |           |          |             |
|                                |                | <b>Estimate</b> | <b>SE</b> | <b>Z</b> | <b>P</b>    |
| <b>Perceived pollinators</b>   |                |                 |           |          |             |
| Noise pollution                | a <sub>1</sub> | -0.014          | 0.015     | -0.924   | 0.356       |
| PM <sub>2.5</sub>              | a <sub>4</sub> | 0.004           | 0.05      | 0.084    | 0.933       |
| Years occupancy                |                | -0.045          | 0.08      | -0.565   | 0.572       |
| NDVI                           |                | -0.483          | 0.607     | -0.797   | 0.425       |
| Noise sensitivity              |                | 0.049           | 0.038     | 1.286    | 0.199       |
| Social cohesion                |                | 0.556           | 0.169     | 3.296    | 0.001       |
| Income                         |                | 0.265           | 0.119     | 2.226    | 0.026       |
| <b>Perceived plants</b>        |                |                 |           |          |             |
| Noise pollution                | a <sub>2</sub> | -0.003          | 0.014     | -0.225   | 0.822       |
| PM <sub>2.5</sub>              | a <sub>5</sub> | 0.011           | 0.048     | 0.224    | 0.823       |
| Years occupancy                |                | -0.065          | 0.095     | -0.681   | 0.496       |
| NDVI                           |                | 0.163           | 0.587     | 0.277    | 0.781       |
| Noise sensitivity              |                | 0.03            | 0.035     | 0.873    | 0.383       |
| Social cohesion                |                | 0.995           | 0.169     | 5.883    | 0           |
| Income                         |                | 0.124           | 0.08      | 1.549    | 0.121       |
| <b>Perceived trees</b>         |                |                 |           |          |             |
| Noise pollution                | a <sub>3</sub> | 0.013           | 0.011     | 1.133    | 0.257       |
| PM <sub>2.5</sub>              | a <sub>6</sub> | -0.02           | 0.036     | -0.565   | 0.572       |
| Years occupancy                |                | -0.067          | 0.067     | -1.007   | 0.314       |
| NDVI                           |                | -0.077          | 0.342     | -0.225   | 0.822       |
| Noise sensitivity              |                | -0.005          | 0.021     | -0.254   | 0.8         |
| Social cohesion                |                | 0.629           | 0.112     | 5.625    | 0           |
| Income                         |                | 0.153           | 0.063     | 2.449    | 0.014       |
| <b>SWEMWBS</b>                 |                |                 |           |          |             |
| Bees perceived                 | b <sub>1</sub> | 0.156           | 0.257     | 0.608    | 0.543       |
| Plants perceived               | b <sub>2</sub> | 0.51            | 0.293     | 1.743    | 0.081       |
| Trees perceived                | b <sub>3</sub> | <b>-0.566</b>   | 0.289     | -1.96    | <b>0.05</b> |
| Noise pollution                | c <sub>1</sub> | 0.046           | 0.032     | 1.426    | 0.154       |
| PM <sub>2.5</sub>              | c <sub>2</sub> | 0.155           | 0.158     | 0.979    | 0.328       |
| Years occupancy                |                | 0.381           | 0.199     | 1.917    | 0.055       |
| NDVI                           |                | -2.35           | 1.692     | -1.389   | 0.165       |
| Noise sensitivity              |                | 0.021           | 0.091     | 0.231    | 0.817       |
| Social cohesion                |                | 0.448           | 0.418     | 1.073    | 0.283       |
| Income                         |                | 0.282           | 0.347     | 0.813    | 0.416       |
| Gender                         |                | 0.136           | 0.411     | 0.331    | 0.741       |
| <b>Mediation</b>               |                |                 |           |          |             |
| Noise_pollinators              |                | -0.002          | 0.005     | -0.471   | 0.638       |
| PM <sub>2.5</sub> _pollinators |                | 0.001           | 0.008     | 0.083    | 0.934       |
| Noise_plants                   |                | -0.002          | 0.007     | -0.233   | 0.816       |

|                           |        |       |        |       |
|---------------------------|--------|-------|--------|-------|
| PM <sub>2.5</sub> _plants | 0.005  | 0.025 | 0.222  | 0.825 |
| Noise_trees               | -0.007 | 0.007 | -1.108 | 0.268 |
| PM <sub>2.5</sub> _trees  | 0.011  | 0.023 | 0.508  | 0.611 |

918

919 **Table 8.** Parallel mediation model testing the effect of noise and air pollution on happiness,  
920 mediated by perceived richness of pollinators, flowering plants, and trees. Estimate values are  
921 standardised  $\beta$  values. Standard error = SE. Bold values indicate statistical significance ( $p <$   
922 0.05).

| <b>Model 4</b>                  |                |                 |           |          |          |
|---------------------------------|----------------|-----------------|-----------|----------|----------|
| <b>OUTCOME = HAPPINESS</b>      |                |                 |           |          |          |
| <b>NOISE = ACTUAL</b>           |                |                 |           |          |          |
| <b>BIODIVERSITY = PERCEIVED</b> |                |                 |           |          |          |
| <b>Fit statistics – Rubust</b>  |                |                 |           |          |          |
| Observations used               |                | 248             |           |          |          |
| Model fit test statistic        |                | 0.421           |           |          |          |
| Degrees of freedom              |                | 3               |           |          |          |
| P value from F test             |                | 0.931           |           |          |          |
| CFI (robust)                    |                | 1               |           |          |          |
| SRMR                            |                | 0.004           |           |          |          |
| RMSEA                           |                | 0.000           |           |          |          |
| Lower CI                        |                | 0.000           |           |          |          |
| Upper CI                        |                | 0.000           |           |          |          |
|                                 |                | <b>Estimate</b> | <b>SE</b> | <b>Z</b> | <b>P</b> |
| <b>Perceived pollinators</b>    |                |                 |           |          |          |
| Noise pollution                 | a <sub>1</sub> | -0.014          | 0.015     | -0.958   | 0.338    |
| PM <sub>2.5</sub>               | a <sub>4</sub> | -0.002          | 0.05      | -0.035   | 0.972    |
| Years occupancy                 |                | -0.017          | 0.083     | -0.202   | 0.84     |
| NDVI                            |                | -0.466          | 0.573     | -0.814   | 0.416    |
| Noise sensitivity               |                | 0.041           | 0.038     | 1.091    | 0.275    |
| Social cohesion                 |                | 0.564           | 0.172     | 3.274    | 0.001    |
| Income                          |                | 0.231           | 0.118     | 1.967    | 0.049    |
| <b>Perceived plants</b>         |                |                 |           |          |          |
| Noise pollution                 | a <sub>2</sub> | -0.003          | 0.014     | -0.235   | 0.814    |
| PM <sub>2.5</sub>               | a <sub>5</sub> | 0.009           | 0.046     | 0.192    | 0.847    |
| Years occupancy                 |                | -0.064          | 0.092     | -0.698   | 0.485    |
| NDVI                            |                | 0.184           | 0.587     | 0.314    | 0.754    |
| Noise sensitivity               |                | 0.027           | 0.035     | 0.764    | 0.445    |
| Social cohesion                 |                | 0.994           | 0.159     | 6.264    | 0        |
| Income                          |                | 0.112           | 0.082     | 1.361    | 0.174    |
| <b>Perceived trees</b>          |                |                 |           |          |          |
| Noise pollution                 | a <sub>3</sub> | 0.012           | 0.011     | 1.114    | 0.265    |
| PM <sub>2.5</sub>               | a <sub>6</sub> | -0.022          | 0.031     | -0.725   | 0.469    |
| Years occupancy                 |                | -0.063          | 0.064     | -0.986   | 0.324    |
| NDVI                            |                | -0.069          | 0.354     | -0.196   | 0.845    |

|                                |                |        |       |        |       |
|--------------------------------|----------------|--------|-------|--------|-------|
| Noise sensitivity              |                | -0.009 | 0.021 | -0.433 | 0.665 |
| Social cohesion                |                | 0.631  | 0.109 | 5.798  | 0     |
| Income                         |                | 0.142  | 0.062 | 2.284  | 0.022 |
| <b>SWEMWBS</b>                 |                |        |       |        |       |
| Bees perceived                 | b <sub>1</sub> | -0.03  | 0.124 | -0.242 | 0.809 |
| Plants perceived               | b <sub>2</sub> | 0.155  | 0.103 | 1.507  | 0.132 |
| Trees perceived                | b <sub>3</sub> | -0.05  | 0.145 | -0.348 | 0.728 |
| Noise pollution                | c <sub>1</sub> | 0.007  | 0.017 | 0.408  | 0.683 |
| PM <sub>2.5</sub>              | c <sub>2</sub> | 0.088  | 0.07  | 1.259  | 0.208 |
| Years occupancy                |                | 0.113  | 0.087 | 1.292  | 0.196 |
| NDVI                           |                | -1.036 | 0.873 | -1.186 | 0.236 |
| Noise sensitivity              |                | -0.055 | 0.037 | -1.496 | 0.135 |
| Social cohesion                |                | 0.251  | 0.196 | 1.285  | 0.199 |
| Income                         |                | 0.293  | 0.152 | 1.927  | 0.054 |
| Gender                         |                | 0.052  | 0.197 | 0.262  | 0.793 |
| <b>Mediation</b>               |                |        |       |        |       |
| Noise_pollinators              |                | 0      | 0.002 | 0.246  | 0.806 |
| PM <sub>2.5</sub> _pollinators |                | 0      | 0.002 | 0.034  | 0.973 |
| Noise_plants                   |                | 0      | 0.002 | -0.249 | 0.804 |
| PM <sub>2.5</sub> _plants      |                | 0.001  | 0.007 | 0.199  | 0.842 |
| Noise_trees                    |                | -0.001 | 0.002 | -0.353 | 0.724 |
| PM <sub>2.5</sub> _trees       |                | 0.001  | 0.003 | 0.326  | 0.745 |

## 924 **Chapter 4. Discussion**

925 Both air and noise pollution above a certain threshold can be detrimental to the health and psychological  
926 well-being of urban residents (WHO, 2006, 2018). On the other hand, biodiversity-rich greenspaces  
927 have shown to promote positive well-being outcomes (Nghiem et al., 2021; Young et al., 2020).  
928 Furthermore, the presence of greenspaces and green infrastructure can play an important role in  
929 reducing pollution and thereby protect urban residents (Barwise and Kumar, 2020; Ow and Ghosh,  
930 2017). This thesis extends previous research on the associations between urban biodiversity, pollution  
931 and subjective well-being. Specifically, it enhances our knowledge regarding the role biodiversity might  
932 play in mitigating the increasingly recognised negative well-being outcomes associated with air and  
933 noise pollution exposure, with implications for urban policy and planning. For the first time to my  
934 knowledge, this research integrates both actual and perceived measures of taxa richness (flowering  
935 plants, pollinators, trees) into sophisticated parallel mediation models capable of examining potential  
936 simultaneous effects. The results revealed that greater actual flowering plant richness reduced the  
937 negative impact of noise pollution on resident's self-reported well-being across streetscapes.  
938 Interestingly, people's perceptions of the richness of different taxa did not mediate the relationship.

939  
940 Increased actual flowering plant species richness had a significant and direct positive effect on  
941 resident's self-reported well-being across streetscapes. This is consistent with Chalmin-Pui et al. (2021),  
942 who found that adding ornamental plants to bare front gardens positively influenced the biochemical  
943 regulation of cortisol (stress hormone), reduced perceived stress levels improved motivation and a sense  
944 of place in residents. However, SWEMWBS scores did not improve, which is in discord to findings  
945 presented here. A greater presence of plant diversity has also been shown to enhance the restorativeness  
946 of allotments for gardeners (Young et al., 2020), and increased happiness and well-being levels of public  
947 greenspace visitors (Adjei and Agyei, 2015; Fuller et al., 2007).

948  
949 In this study, social cohesion was a significant predictor of perceived species richness for all three taxa.  
950 This might be because a greater familiarity of streetscape biodiversity comes with spending more time  
951 within the streetscape itself, while socialising with neighbours. Indeed, existing research has found that  
952 species richness perception accuracy can increase alongside measured levels of eco-centricity (i.e.,  
953 those who were more accurate were more connected to nature), as observed in urban meadows (Hoyle  
954 et al., 2018). Importantly, increased social cohesion requires long-term social interaction compared to  
955 a simple nodding acquaintance (Kawachi and Berkman, 2001). It is therefore possible that an individual  
956 who perceives greater levels of species richness within their streetscape is more inclined to spend more  
957 time socialising within that environment, as was found to be the case in the Netherlands (de Vries et al.,  
958 2013). Wang et al. (2021) also found that streetscape greenspace quality, rather than quantity, positively  
959 influenced mental well-being through building capacities, such as better levels of activity and social

960 cohesion. These findings imply that more biodiverse streetscapes could contribute to the improved  
961 mental wellbeing of people via multiple biopsychosocial pathways (Hartig et al., 2014).

962

963 The results showed that the well-being measures used (happiness and SWEMWBS) were not directly  
964 influenced by actual tree and pollinator richness. There is a growing recognition of the role in which  
965 eye-level greenspace perspectives play on well-being (Wang et al., 2021). Eye-level greenspace has  
966 received far less attention than that of the over-head perspective (e.g., NDVI, LiDAR), mostly due to  
967 methodological limitations (Lachowycz and Jones, 2013; Markevych et al., 2017). Tree canopy is not  
968 necessarily always at eye-level, particularly through windows when inside the home and on the ground  
969 level. Contrary to this, Wolf et al. (2017) found that increased tree richness had a positive effect on  
970 various self-reported well-being measures. However, the study was an ex-situ video-based exercise that  
971 depicted trees in their entirety.

972

973 Participant estimates of pollinator richness did not correlate with actual richness in streetscapes,  
974 although perceived estimates of trees and flowering plants were a better reflection of actual richness.  
975 Dallimer et al. (2012) found that people could not correctly identify plant or butterfly richness within  
976 public urban greenspaces. This disparity between our study and Dallimer et al. (2012) may be due to  
977 the familiarity people have with their own streetscapes. Nonetheless, findings here support existing  
978 evidence of the public's limited ability to estimate pollinator richness, regardless of setting. The  
979 popularisation of the 'save the bees' campaign has helped to garner support and educate the public about  
980 the importance of bees at a macro-scale, highlighting their importance in food security (Dicks, 2019).  
981 However, this rarely translates to an understanding of diversity in bee species or other kinds of  
982 pollinators (Wilson et al., 2017).

983

984 When asked about the noises people hear in their streetscapes, answers pertaining to road  
985 vehicles/traffic were most common across all three of the pollution categories. This reflects the fact  
986 that, within the UK, noise pollution is primarily derived from road surface transport and is a core  
987 component of people's immediate soundscapes (United Kingdom Department for Business, Energy and  
988 Industrial Strategy, 2018, p14). Birds were the second most common noise heard, and this decreased in  
989 frequency as the pollution category of the streetscape increased. Birds were not a taxonomic focus of  
990 this study. However, given their noticeable presence, it is possible that they could exert some mediating  
991 effect on the relationship between pollution and well-being. Indeed, unsurprisingly, the public consider  
992 natural sounds like bird song to be favourable compared to road traffic (Viollon et al., 2002). Bird song  
993 has also been found to be better at reducing human stress than other natural sounds, such as running  
994 water or non-avian animals (Ratcliffe et al., 2013), and contributes to positive values associated with  
995 urban green space (Hedblom et al., 2014). However, when Fuller et al. (2007) examined the associations

996 between psychological benefits and plant, bird and butterfly species richness, they found stronger  
997 support for an effect of the number of plant species than for birds.

998

999 The ability of vegetation to buffer against noise is improved when planting patterns include species  
1000 with thick stems, or dense and complex leaf structure, better able to refract sound (Fang and Ling, 2005;  
1001 Ow and Ghosh, 2017). Reductions in noise levels of up to 15 dB can be achieved (Tyagi et al., 2006).  
1002 However, much of the existing literature has concentrated on the attenuation of noise via wide swathes  
1003 of vegetation (e.g., 30 m), which are unrealistic and impractical in many urban settings. Nonetheless,  
1004 some studies have found that far narrower vegetation belts can still produce significant reductions in  
1005 noise. For example, vegetation heights of 3 and 5 m comprised of coniferous species have shown to  
1006 attenuate noise from between 5 and 11 dB (Kragh, 1981; Ow and Ghosh, 2017). To sufficiently reduce  
1007 noise pollution in urban settings, narrow vegetation belts can be complemented by a setback (the  
1008 distance between a building/structure and a road) comprised of sparse to medium planting regimes (Ow  
1009 and Ghosh, 2017). The most recorded plant species across the streetscapes in this study were those with  
1010 highly dense, evergreen foliage, such as holly (*Ilex aquifolium*), garden privet (*Ligustrum ovalifolium*)  
1011 and Leyland cypress (*Cupressus × leylandii*). Our results showed that greater flowering plant richness  
1012 reduced the negative impact of noise pollution on resident's self-reported well-being across  
1013 streetscapes, therefore highlighting the need to incorporate diverse planting regimes into future urban  
1014 planning. This maps onto existing WHO guidelines that strongly advise that noise pollution derived  
1015 from road transport be reduced to a maximum of 53 dB in the daytime and 45 dB in the evening, as  
1016 traffic noise beyond this has proven to reduce health (WHO, 2018). Nevertheless, levels recorded in  
1017 this study averaged 82.4 dB, with the maximum reaching 93.6 dB. Therefore, even the lowest recorded  
1018 noise level (67.5 dB) within this study far exceeded WHO recommendations. Tee species richness did  
1019 not impact noise levels. Several studies suggest that while noise is absorbed by tree trunks, other parts  
1020 of the tree such as foliage, small stems and branches (i.e., the canopy) can be equally as important for  
1021 noise attenuation (Fang and Ling, 2005). Noise recordings in this study were taken at breast height and  
1022 therefore did not capture the noise attenuation ability of tree canopy, which may explain why tree  
1023 richness did not have the same mediating effects on noise pollution as flowering plants. However, this  
1024 is speculation as vegetation structure was not explored specifically in this study, but could be a  
1025 potentially fruitful avenue for future research. Moreover, the residents are unlikely to plant more than  
1026 a single row of trees in their garden due to space constraints and the desire to maintain natural light in  
1027 the home, thereby limiting their noise reduction potential at a streetscape scale.

1028

1029 Actual flowering plant and pollinator richness decreased as noise pollution increased in this study. This  
1030 could be because residents are deterred from gardening in streetscapes where noise pollution is high.  
1031 Plant diversity may therefore be less in these areas and, by extension, the pollinators which rely on them  
1032 (Baldock et al., 2019). Noise pollution can also have a direct negative impact on pollinator species. In

1033 comparison to light and air pollution, there is much less research into the effects of noise pollution on  
1034 pollinators (Morley et al., 2013). However, the vastly diverse mix of auditory structures found across  
1035 invertebrate species mean that hearing sensitivities can sit anywhere between 10 Hz to more than 100  
1036 kHz. Many invertebrates specifically communicate at frequencies below 10 kHz, which is well within  
1037 the frequency spectrum of most anthropogenic noise (Morley et al., 2013). The vulnerability of  
1038 pollinators to this pollutant is therefore clear and is supported by the small amount of literature available,  
1039 which demonstrates impairments from noise to survival mechanisms and behaviours (e.g., Davis et al.,  
1040 2018; Lampe et al., 2012). Improving urban habitat to intensify insect conservation is an urgent  
1041 challenge in the face of global mass invertebrate decline (Cardoso et al., 2020; Hallmann et al.,  
1042 2017). Diversely planted streetscape vegetation has the potential to buffer against noise pollution while  
1043 also providing pollinators with higher quality and better-connected habitat.

1044

1045 Air pollution did not have a direct effect on well-being measures (SWEMWBS and happiness) across  
1046 the streetscapes. Unlike noise pollution, air pollution ranges did not exceed those recommended by the  
1047 WHO ( $>10 \mu\text{g}/\text{m}^3$  annual mean;  $> 25 \mu\text{g}/\text{m}^3$  24 hour mean) (WHO, 2006). However, localised  
1048 pollution events were recorded on a small number of occasions, where  $\text{PM}_{2.5}$  concentrations did exceed  
1049  $10 \mu\text{g}/\text{m}^3$ . This may have been due to traffic associated with the time of day in which recordings were  
1050 taken, or other *ad hoc* occurrences such as temporary traffic lights/road works.

1051

#### 1052 **4.1 The Covid-19 pandemic**

1053

1054 Governments around the world were forced to enact policy measures to curtail transmission of the novel  
1055 coronavirus SARS-CoV-2 following the World Health Organisation's declaration of a global pandemic  
1056 on 11<sup>th</sup> March 2020 (WHO, 2020). Restrictions were placed on transport and public mobility, resulting  
1057 in over half the global population living under stay-at-home orders (with varying degrees of stringency)  
1058 for one or more time-periods. These stay-at-home measures were typically coupled with social  
1059 distancing orders. Although data collection for this study took place prior to the pandemic, several key  
1060 points are worth raising that are pertinent to the research topic.

1061

1062 Firstly, a considerable proportion of workers swapped their office-based working environment for  
1063 homeworking during the pandemic to comply with lockdown/social distancing measures (Bartik et al.,  
1064 2020). Even as government restrictions begin to lift, many companies believe that working from home  
1065 is set to become the long-term norm, as the upfront costs associated with remote systems have already  
1066 been paid for and there are financial benefits associated with cutting back on office space (Bartik et al.,  
1067 2020). As society adapts, understanding how the home as a working environment can be modified to  
1068 enhance well-being, such as reducing noise pollution, is set to become a priority (Bouziri et al., 2020;  
1069 Xiao et al., 2021). Secondly, when outdoor interaction with greenspace is impeded, viewing greenery

1070 through the window can be an important act of engagement to promote mental health. Being in view of  
1071 greenspace through the window has shown to trigger micro-restorative episodes that promote healing  
1072 (Jo et al., 2019), mental restoration (Lee et al., 2015) and stress recovery (Li and Sullivan, 2016) after  
1073 a matter of hours or days. Over longer time periods, green window views have shown to elevate an  
1074 individual's capacity to complete cognitive tasks and improve self-reported life and job satisfaction  
1075 (Benfield et al., 2015; Chang et al., 2020; Shin, 2007). Indeed, during the pandemic, Wang et al. (2021)  
1076 observed reduced depression and anxiety in home-schooled students who had window views with  
1077 greater plant abundances.

1078

1079 Working from home may negatively impact an individual's sense of social cohesion as it can limit the  
1080 opportunity to socialise with colleagues, which can be particularly detrimental to those who live alone  
1081 (Tavares, 2017). Moreover, blurred boundaries between work and home life can make it difficult to  
1082 recover from mental fatigue (Evanoff et al., 2020; Vander Elst et al., 2017). Several papers have  
1083 highlighted the negative implications of prolonged stay-at-home measures on mental well-being  
1084 outcomes (e.g., generalised anxiety disorder, major depressive disorder, loneliness) across countries  
1085 including Canada, Greece and China (Dozois, 2021; Fountoulakis et al., 2021; Huang and Zhao, 2020).  
1086 Socialising with those close to the home (e.g., neighbours) could be an increasingly crucial point of  
1087 contact for many home-workers. This adds weight to concerns over the inequalities surrounding front  
1088 garden access (ONS, 2018). Overall, the context of the pandemic adds weight to the importance of  
1089 considering streetscapes as a spatial scale and biodiversity within future urban planning regimes.

1090

## 1091 **4.2 Limitations**

1092

1093 There are several limitations to this study that may have introduced bias into the results. For example,  
1094 compared to some other research of this nature, the overall sample size is relatively small. Streetscapes  
1095 with fewer than five completed questionnaires were removed from analyses, which included two low  
1096 and one medium pollution category streetscapes. The number of streetscapes across categories was  
1097 therefore disproportionate, with the greatest amount of representation falling within the high pollution  
1098 category. All possible efforts were made to remain impartial while the questionnaires were being  
1099 delivered, so to avoid influencing questionnaire responses. However, given that questionnaires were  
1100 administered face-to-face, it cannot be ruled out that some individuals may have tried to respond in a  
1101 manner that they thought the researcher might expect or prefer them to, regardless of how speculative  
1102 this would have been on the respondent's part (Bowling, 2005).

1103

1104 There may also be some limitation to the study design itself. The categorisation of pollution levels based  
1105 on road type may have introduced some bias due to the diffuse nature of particulate matter. It is possible  
1106 that roads close-by to an A road, despite being classed as low pollution due to road width, might

1107 experience much higher pollution levels than you would expect as a by-product of the nearby A road.  
1108 Indeed, some of the low pollution streetscapes experienced PM<sub>2.5</sub> levels higher than those recorded in  
1109 high pollution streetscapes. As previously mentioned above, pollution readings were collected at breast  
1110 height and therefore would have failed to capture the full extent of pollution reduction by trees.

1111  
1112 People's perceptions of species richness have already been successfully utilised within the nature-health  
1113 literature (e.g., Fuller et al., 2007; Dallimer et al., 2012; Fisher et al., 2021). However, it is worth bearing  
1114 in mind that there are several factors that may influence people's perceptions. For example, an  
1115 individual's eco-centricity (including ecological knowledge and pro-environmental behaviour) can  
1116 positively influence identification skills (Southon et al., 2018) which, in turn, can affect an individual's  
1117 ability to estimate the species richness of a given area (Dallimer et al., 2012). Research has also shown  
1118 that amongst the general public, even those who value nature are unable to detect changes in species  
1119 richness across parks and gardens (Schwartz et al., 2014). The accuracy of people's perceptions might  
1120 also vary depending on the taxonomic group. For instance, Dallimer et al. (2012) found that participants  
1121 were better able to identify bird species than either butterflies or plants. The amount of time an  
1122 individual has spent living in an urban area may also impact people's perceptions of species richness  
1123 and pollution. For example, an individual who has only ever resided in an area of high pollution may  
1124 not perceive it to be highly polluted as they are accustomed to such levels. On the other hand, an  
1125 individual who might have spent some time living rurally would presumably hold a different baseline  
1126 for what they consider to be of high or low pollution, and this was not controlled for within the model.  
1127 Perceptions may also be influenced by an individual's sensory system. Quantitative alterations in  
1128 olfactory and auditory function, including impaired and enhanced performance, may distort the level of  
1129 air and noise pollution experienced. In addition, anosmia (the loss or erosion of the ability to smell) can  
1130 be caused by air pollution (Hudson et al., 2006; Guarneros et al., 2009; Zhang et al., 2021). Therefore,  
1131 people living in highly pollution areas may over time experience decreased olfactory sensitivity, thus  
1132 potentially distorting their perception of pollution.

## 1133 **5. Conclusion**

1134  
1135 This thesis provides a valuable insight into the complex interplay between streetscape pollution,  
1136 biodiversity and human mental well-being, which until now remained largely unexamined. Given the  
1137 findings presented here, governments, city planners and urban residents themselves ought to take action  
1138 to reduce noise pollution across streetscapes to improve mental well-being. Increasing plant diversity  
1139 should be considered a priority within any future plans to reduce urban noise. In turn, critical gains in  
1140 pollinator conservation can also be made. Although recent years have seen the public take a greater  
1141 interest in biodiversity and, specifically, the vital role played by pollinators, this does not necessarily

1142 always translate into conservation action (Wilson et al., 2017). In part, this could be attributed to a lack  
1143 of detailed ecological knowledge, or failure to see what real-time benefits could be gained. As such,  
1144 governments and local councils could offer fiscal incentives, coupled with educational ecological and  
1145 pollution-wellbeing related guidance, as one way to increase planting. Additionally, more should be  
1146 done to reduce noise pollution at the source. For example, by re-routing busy traffic which passes  
1147 through residential areas, or by encouraging and improving public transport to minimise the quantity of  
1148 vehicles on the road. Trends in population growth, increased pollution and declines in mental health  
1149 that characterise cities worldwide, mean that the findings presented here are applicable to a multitude  
1150 of urban settings. Additionally, this study offers particularly timely insights given that people are  
1151 projected to spend more time at home within the coming years.

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- 1816


1817 **Supplementary Information**

1818 **Supplementary Information S1.** The 20-morpho-functional groups of pollinators recorded across the  
 1819 30 streetscape transects in Leeds, UK. Bumblebees (*Bombus* spp.) and butterflies constitute six and five  
 1820 morpho functional groups, respectively.

| Morpho-functional group                     | Notes  |
|---|--|
| Bumblebees ( <i>Bombus</i> spp.):           |  |
| 2 yellow bands, white/buff tail:            |  |
| <i>B.terrestris/B.lucorum</i>               |  |
| 2 yellow bands, red tail: <i>B.pratorum</i> |  |
| 3 yellow bands, white tail:                 |  |
| <i>B.hortorum/B.ruderatus</i>               | Group including all individuals belonging to the genus <i>Bombus</i>   |
| ( <i>B.ruderatus</i> maybe melanic)         |  |
| Brown/Ginger:                               |  |
| <i>B.pascuorum/B.humulis/B.muscorum</i>     |  |
| Black, red tail:                            |  |
| <i>B.lapidarius/B.ruderarius</i>            |  |
| Tree bumblebee ( <i>B. hypnorum</i> )       |  |
| Honeybee                                    | <i>Apis mellifera</i>  |
| Solitary bee                                | Group including bees from the Apoidea super-family except those from genus <i>Bombus</i> and <i>Apis mellifera</i> |
| Social wasp                                 | Social wasps in the sub-family Vespinae  |
| Other hymenoptera                           | All other hymenoptera, including solitary wasps (e.g. ichneumonids) and sawflies                                   |
| Hoverfly                                    | Group including all individuals from the Syrphidae family (Diptera)  |
| Other fly                                   | Group including all non-Syrphidae Diptera  |
| Butterflies:                                |  |
| White                                       | Group including all white species from the family Pieridae   |
| Red   | Group including the red species from the family Nymphalidae; <i>Lycaena</i> spp.                                   |
| Brown                                       | Group including the brown/orange species from the family Nymphalidae   |
| Blue  | Group including the blue species from the family Lycaenidae  |
| Yellow                                      | Group including the yellow species from the family Pieridae  |
| Moth  | Day-flying moth species ( <i>Tyria jacobaeae</i> ; <i>Zygaena</i> spp.)  |
| Beetle                                      | All insects in the order Coleoptera  |
| Bug   | All insects in the order Hemiptera   |

1821 **Supplementary Information S2.** Research questionnaire used to collect participant data, administered  
 1822 in 30 streetscapes across the city of Leeds, UK.

1823



**UNIVERSITY OF LEEDS**

Q code \_\_\_\_\_

### Your street environment and quality of life questionnaire

This questionnaire explores your views about your street environment and your quality of life.

Please think about the street that your home is on. This includes everything you can see from your home to the opposite side of the street, such as gardens (including if they are paved over), parking spaces, yards, pavements, the road, trees, bushes or shrubs in the street, and verges and the plants and flowers that are on them, including any insects, birds or animals that might be there.

There are no right or wrong answers as we are interested in what you think

**1. How would you best describe the area outside your home that faces the street environment that is still part of your property?**  
*Tick all that apply*

There is no area outside my home that faces the street that is part of my property  
 Somewhere to park a car  
 An area of garden with lawn, flowers, shrubs, trees (or some of these)  
 A gravel area  
 A yard covered by concrete, paving or decking  
 Other (Please state): \_\_\_\_\_

**2. In general when thinking about the sounds in your street environment, how would you describe them?**  
*Circle one option per row*

|                         |              |         |            |                       |
|-------------------------|--------------|---------|------------|-----------------------|
| Completely unacceptable | Unacceptable | Neutral | Acceptable | Completely acceptable |
| Very quiet              | Quiet        | Neutral | Noisy      | Very noisy            |
| Not at all annoying     | Not annoying | Neutral | Annoying   | Very annoying         |
| Very relaxing           | Relaxing     | Neutral | Stressful  | Very stressful        |

**3. What three main sounds do you hear in your street environment?**  
*Please write in up to three sounds and tick one box per sound*

| Sounds I hear | Very unpleasant | Unpleasant | Neutral | Pleasant | Very pleasant |
|---------------|-----------------|------------|---------|----------|---------------|
| 1             |                 |            |         |          |               |
| 2             |                 |            |         |          |               |
| 3             |                 |            |         |          |               |

1



**4. In general how would you describe the level of air pollution in your street environment?**

*Circle one option*

Very polluted      Polluted      Neutral      Clean      Very clean

**5. In general, how would you describe the acceptability of air pollution in your street environment?**

*Circle one option*

Completely unacceptable      Unacceptable      Neutral      Acceptable      Completely acceptable

**6. About how many different species of tree would you say are in your street environment?**

*Circle one option*

Fewer than 5      5 to 10      11 to 15      16 to 20      21 or more

**7. About how many different species of flowering plants would you say are in your street environment?**

*Circle one option*

Fewer than 10      10 to 30      31 to 50      51 to 99      100 or more

**8. About how many different species of bees, butterflies and other insects that visit flowers would you say are in your street environment?**

*Circle one option*

Fewer than 5      5 to 9      10 to 13      14 to 19      20 or more

**9. To what extent do you notice nature out the windows of your home that face your street environment?**

*Circle one option*

Not at all      Rarely      Sometimes      Often      Very Often

**10. How much of the view out of the windows that face your street environment is of nature, such as plants, trees, bushes, flowers, grass?**

*Circle one option*

None      Less than a quarter      Between a quarter and a half      Between a half and three quarters      More than three quarters      All



**11. Please indicate how much you agree with each statement about your street environment.**

*Tick one box per row*

|  | Strongly disagree | Disagree | Neutral | Agree | Strongly agree |
|--|-------------------|----------|---------|-------|----------------|
| I look forward to coming to my street                          |                   |          |         |       |                |
| My street reflects the type of person I am                     |                   |          |         |       |                |
| Lots of things in my street remind me of past experiences      |                   |          |         |       |                |
| My street is a desirable place to be                           |                   |          |         |       |                |
| My street feels almost like a part of me                       |                   |          |         |       |                |
| I have had a lot of memorable experiences in my street         |                   |          |         |       |                |
| When I am in my street I feel that I belong there              |                   |          |         |       |                |
| I am proud of my street  |                   |          |         |       |                |
| I really miss my street when I am away from it for a long time |                   |          |         |       |                |
| I feel happy when I am in my street                            |                   |          |         |       |                |
| I gain pleasure from using my street                           |                   |          |         |       |                |
| I like my street   |                   |          |         |       |                |
| My street has many advantages compared to other streets        |                   |          |         |       |                |
| I am not satisfied with my street                              |                   |          |         |       |                |



**12. Please indicate how much you agree with each statement about your street environment.**  
Tick one box per row

**(a) When I am out of doors in my street environment...**

|   | Strongly disagree | Disagree | Neutral | Agree | Strongly agree |
|---|-------------------|----------|---------|-------|----------------|
| I can easily think about personal matters   |                   |          |         |       |                |
| I gain perspective on life                  |                   |          |         |       |                |
| I have time to listen to what is on my mind |                   |          |         |       |                |

**(b) When I look at my street environment out of a window...**

|   | Strongly disagree | Disagree | Neutral | Agree | Strongly agree |
|---|-------------------|----------|---------|-------|----------------|
| I can easily think about personal matters   |                   |          |         |       |                |
| I gain perspective on life                  |                   |          |         |       |                |
| I have time to listen to what is on my mind |                   |          |         |       |                |

**13. On how many of the last 14 days did you do each of the following in your street environment?** *Your street environment includes your garden/yard, pavements, trees, any plants, grass verges and road*  
Tick one box per row

|  | None | 1 or 2 | 2 or 3 | 3 or 4 | 5 or 6 | 7 or 8 | 9 or 10 | 11 or 12 | 13 or 14 |
|--|------|--------|--------|--------|--------|--------|---------|----------|----------|
| Relax  |      |        |        |        |        |        |         |          |          |
| Observe nature   |      |        |        |        |        |        |         |          |          |
| Play games / sports  |      |        |        |        |        |        |         |          |          |
| Think about things   |      |        |        |        |        |        |         |          |          |
| Park a car/vehicle   |      |        |        |        |        |        |         |          |          |
| Walk or cycle to work, school, the shops, or another destination |      |        |        |        |        |        |         |          |          |
| Walk, cycle or run/jog for exercise or enjoyment                 |      |        |        |        |        |        |         |          |          |
| Tend plants, trees, shrubs or lawn/grass                         |      |        |        |        |        |        |         |          |          |
| Talk to other people   |      |        |        |        |        |        |         |          |          |
| Other (please state):<br>_____                                   |      |        |        |        |        |        |         |          |          |
| Other (please state):<br>_____                                   |      |        |        |        |        |        |         |          |          |



**14. Please indicate how much you agree or disagree with the following statements.**  
*Tick one box per row.*

|   | Strongly disagree | Disagree | Neutral | Agree | Strongly agree |
|---|-------------------|----------|---------|-------|----------------|
| People on this street are willing to help their neighbours      |                   |          |         |       |                |
| This is a close-knit street                                     |                   |          |         |       |                |
| People on this street can be trusted                            |                   |          |         |       |                |
| People on this street generally don't get along with each other |                   |          |         |       |                |
| People on this street do not share the same values              |                   |          |         |       |                |

### **The next questions are about you**

**15. In general, would you agree or disagree with the statement: Spending time out of doors is an important part of my life.**

*By 'out of doors' we mean open spaces in and around towns and cities, including parks, canals and nature areas; the coast and beaches; and the countryside including farmland, woodland, hills and rivers. It includes time spent close to your home, workplace, further afield or while on holiday in Britain.*

*Circle one option*

Strongly agree      Agree      Neutral      Disagree      Strongly disagree

**16. In your life in general, how happy would you say you are?**

*Circle one number*

Extremely unhappy \_\_\_\_\_ Extremely happy

1      2      3      4      5      6      7      8      9      10

**17. Over the past 14 days to what extent have you felt:**

*Tick one box per row*

|                    | Not at all | A little | Somewhat | Quite | Very much |
|--------------------|------------|----------|----------|-------|-----------|
| Irritated          |            |          |          |       |           |
| Tired              |            |          |          |       |           |
| Worn out           |            |          |          |       |           |
| Mentally exhausted |            |          |          |       |           |



**18. Below are some statements about feelings and thoughts. Please tick the box that best describes your experience of each over the last two weeks.**

*Tick one box per row*

|  | None of the time | Rarely | Some of the time | Often | All of the time |
|--|------------------|--------|------------------|-------|-----------------|
| I've been feeling optimistic about the future      |                  |        |                  |       |                 |
| I've been feeling useful                           |                  |        |                  |       |                 |
| I've been feeling relaxed                          |                  |        |                  |       |                 |
| I've been dealing with problems well               |                  |        |                  |       |                 |
| I've been thinking clearly                         |                  |        |                  |       |                 |
| I've been feeling close to other people            |                  |        |                  |       |                 |
| I've been able to make up my own mind about things |                  |        |                  |       |                 |

**19. Please indicate how much you agree with the following statements.**

*Tick one box per row*

|   | Strongly disagree | Disagree | Neutral | Agree | Strongly agree |
|---|-------------------|----------|---------|-------|----------------|
| I get irritated when there is noise in my street            |                   |          |         |       |                |
| I am good at concentrating no matter what happens around me |                   |          |         |       |                |
| It is difficult for me to relax in a noisy place            |                   |          |         |       |                |
| I am sensitive to noise                                     |                   |          |         |       |                |

**20. On how many of the last 14 days did you do the following?**

*Tick one box per row*

|  | None | 1 or 2 | 2 or 3 | 3 or 4 | 4 or 5 | 6 or 7 | 8 or 9 | 10 or 11 | 13 or 14 |
|--|------|--------|--------|--------|--------|--------|--------|----------|----------|
| Visit local parks or the countryside   |      |        |        |        |        |        |        |          |          |
| Spend time in your back garden (e.g. gardening, sitting, socialising, playing) |      |        |        |        |        |        |        |          |          |

**21. About your home:**

a. Do you:  Own  Rent

b. How long have you lived in your current home? \_\_\_\_\_ Years \_\_\_\_\_ Months

c. How many bedrooms does your home have? \_\_\_\_\_

d. How many people living at this home are:

Under 16 years \_\_\_\_\_ Over 16 years \_\_\_\_\_

22. What year were you born in? \_\_\_\_\_  Prefer not to say

**23. What gender do you identify with?**

*Tick one option*

Male  Female  Prefer not to say

**24. How would you describe your ethnic group or background?**

*Tick one option*

- White English/British/Scottish/Welsh  
 White (other background)  
 Any Asian background  
 Any black background  
 Any other ethnic background: \_\_\_\_\_  
 Prefer not to say

**25. Which of the following best describes your employment status over the last 12 months?**

*Tick one option*

- |  |  |
|--|--|
| <input type="checkbox"/> Employed          | <input type="checkbox"/> Long-term sick/disabled   |
| <input type="checkbox"/> Self-employed     | <input type="checkbox"/> Looking after home/family |
| <input type="checkbox"/> Unemployed        | <input type="checkbox"/> Student                   |
| <input type="checkbox"/> Retired           | <input type="checkbox"/> Other: _____              |
| <input type="checkbox"/> Prefer not to say |  |

**26. Do you have a disability?** Under the Equality Act 2010, a person has a disability if they have a physical or mental impairment, and the impairment has a substantial and long-term adverse effect on his or her ability to carry out normal day-to-day activities.

*Tick one option*

Yes  No  Prefer not to say

☺ ☺ Thank you for taking the time to complete this questionnaire ☺ ☺