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12

13 **Life satisfaction linked to the diversity of nature experiences and nature views from the**
14 **window**

15

16 **Abstract**

17 The effects of interacting with nature on multiple aspects of human subjective wellbeing are
18 increasingly well understood. Although nature experience has been shown to be positively
19 associated with life satisfaction, it remains unknown whether the diversity of nature experiences
20 contributes to increased life satisfaction and whether the relationship is mediated by a person's
21 strength of connection with nature. We conducted a national survey in Singapore through online
22 questionnaires ($n = 1, 262$), where we measured frequency, duration, diversity of nature
23 experiences, and presence or absence of nature views from windows at home and at the
24 workplace. We also measured participants' strength of connection with nature (how strongly a
25 person identifies with nature). We found that people who visited more diverse types of natural
26 spaces (ranging from wild nature, managed parks, and beaches) had higher life satisfaction. The
27 presence of nature views from windows at the home and/or at the workplace was also linked with
28 higher life satisfaction. We also found that people with a stronger connection with nature had
29 higher life satisfaction when they spent more than one hour in natural spaces per week, while this
30 relationship was weak for people without a strong connection with nature. Our results suggest
31 that urban planning should aim to provide a diversity of natural spaces to increase life
32 satisfaction.

33 **Keywords:** *life satisfaction, human-nature interaction, nature relatedness, environmental*
34 *psychology, tropical Asia, happiness*

35

36 **Introduction**

37 Evidence is accumulating that experiences of nature benefits wellbeing, including subjective
38 wellbeing (comprising emotions and cognitive judgments of life satisfaction; Bratman, Hamilton,
39 & Daily, 2012; Diener, Suh, Lucas, & Smith, 1999; Keniger, Gaston, Irvine, & Fuller, 2013;
40 Shanahan, Fuller, Bush, Lin, & Gaston, 2015a; Hunter, Gillespie, & Chen, 2019; MacKerron, &
41 Mourato, 2013; McMahan, & Estes, 2015). As a result, increasing the nature experience of urban
42 residents is often considered as an intervention that would improve wellbeing as well as
43 generating economic benefits (Buckley, & Brough, 2017; Shanahan, Astell–Burt, Barber,
44 Brymer, Cox, Dean, Depledge, Fuller, Hartig, & Irvine, 2019; Shanahan, Bush, Gaston, Lin,
45 Dean, Barber, & Fuller, 2016; Shanahan, Lin, Bush, Gaston, Dean, Barber, & Fuller, 2015b).
46 However, little is known about how different types of nature experience are associated with
47 subjective wellbeing, and whether individual differences in connection to nature influence the
48 benefits that are delivered from these nature experiences.

49 Nature experiences are diverse and consist of multiple elements and types (Keniger et al.,
50 2013; Russell, Guerry, Balvanera, Gould, Basurto, Chan, Klain, Levine, & Tam, 2013; Soga &
51 Gaston, 2020; Shanahan et al., 2015a; Zhang et al., 2017). For example, nature experiences
52 include intentional (e.g., spending time in natural environments) and indirect (e.g., nature viewed
53 from home) experiences (Keniger et al., 2013; Soga & Gaston, 2020). Elements of nature
54 experience include its frequency, its duration, and the quality or quantity of nature that is
55 experienced (Shanahan et al., 2015a). Different elements of nature experience may influence
56 subjective wellbeing in different ways (Cleary et al., 2017; White, Pahl, Wheeler, Depledge, &
57 Fleming, 2017). For example, it has been shown that people who visited nature frequently in a
58 year were more likely to feel that their lives were worthwhile, but a recent specific visit (e.g.,

59 yesterday) was not associated with life worthiness (White et al., 2017). Other considerations are
60 that the effects of different nature experiences are not independent from each other.

61 Although there is increasing evidence of a relationship between nature experience and
62 subjective wellbeing, the mechanisms underlying this association are poorly understood (Cleary,
63 Fielding, Bell, Murray, & Roiko, 2017; Zhang, Tan & Diehl, 2017). For example, visiting parks
64 regularly influences subjective wellbeing potentially through outdoor social activities
65 (Biedenweg, Scott, & Scott, 2017), something that nature viewed from windows is unable to
66 provide. On the other hand, nature viewed from windows can improve subjective wellbeing
67 through brief and repeated breaks to reduce stress (Bratman et al., 2012; Kaplan, 2001).
68 Knowing how different types of nature experience are linked with improved subjective wellbeing
69 might allow us to design better urban environments and nature engagement programs in cities.

70 Life satisfaction is a cognitive evaluation of a person's life based on their personal
71 standard, which varies among individuals (Diener, Emmons, Larsen, & Griffin, 1985; Helliwell
72 & Putnam, 2004; Ryan & Deci, 2001). Individuals vary in the level of inclusion of nature in their
73 sense of self (hereafter, "connection with nature", Nisbet, Zelenski, & Murphy, 2009; Schultz,
74 2002). Some people perceive nature as part of their identities, with the level of connection with
75 nature being stable and consistent across time and situation, but others do not (Nisbet et al.,
76 2009). When people are evaluating their lives, whether the individual includes nature as part of
77 themselves may influence the relationship between nature experience and life satisfaction. In
78 addition, the level of connection with nature itself has been shown to be positively associated
79 with life satisfaction, but there is a large variation in the relationship among studies (Capaldi et
80 al., 2014; Cervinka, Röderer, & Hefler, 2012; Nisbet, Zelenski, & Murphy, 2011). The
81 relationship between connection with nature and life satisfaction is likely to be influenced by

82 whether the needs of experiencing nature are met. People with a stronger connection with nature
83 may be more sensitive to a change in nature experience and more likely to enjoy nature since
84 they are more attentive to nature and give nature more meaning to their lives (Bang, Medin, &
85 Atran, 2007; Cleary et al., 2017; Howell, Dopko, Passmore, & Buro, 2011; Howell, Passmore, &
86 Buro, 2013; Soga & Gaston, 2020; Zhang, Howell, & Iyer, 2014). Thus, it is important to
87 examine whether life satisfaction is associated with the types of nature that a person engages in,
88 as well as the person's level of connection with nature.

89 People from different cultural backgrounds consider different aspects of life when they
90 evaluate their life satisfaction. However, most studies examining the relationship between nature
91 experience and life satisfaction have been carried out in temperate regions (Capaldi et al., 2014).
92 Studies from tropical areas are very limited, and this lack of knowledge may limit the planning
93 and development of urban natural spaces as the results from other regions are unlikely to be
94 transferable (Saw, Lim, & Carrasco, 2015). For example, a comparative study showed that Swiss
95 participants preferred forest with high biodiversity, but Chinese participants did not show such a
96 preference (Lindemann-Matthies, Keller, Li, & Schmid, 2013). While many temperate studies
97 report a positive relationship between nature experience and life satisfaction (Ambrey, &
98 Fleming, 2014; Biedenweg et al., 2017; White, Alcock, Grellier, Wheeler, Hartig, Warber, Bone,
99 Depledge, & Fleming, 2019), a tropical study has had inconclusive results (Saw et al., 2015). It is
100 thus necessary to have a greater focus on tropical countries which are not only currently
101 undergoing rapid urban development but also contain high biodiversity (Song, Richards,
102 Edwards, & Tan, 2017). The tropical city-state of Singapore offers an excellent study population
103 as a global city with a high density and growing human population (Friess, 2017). In addition to
104 cultural and climatic differences from most studies, Singapore also has an unusually high density

105 of public natural spaces and high biodiversity in the context of a fully urbanized human
106 population (Friess, 2017).

107 Using Singapore as a case study, we: (i) quantify the relationship between various types
108 of nature experience and life satisfaction; and (ii) evaluate whether this relationship is influenced
109 by a person's level of connection with nature.

110

111 **Methods**

112 *Data collection*

113 A national survey was delivered by a market research company in January and February 2019 to
114 1,519 Singapore residents aged between 18 and 75 years old. The respondents were recruited
115 based on five stratification criteria, including age (similar numbers above and below 45), gender
116 (similar numbers of males and females), income (four quartiles), and racial composition
117 (Chinese; Malay; Indian; Eurasian; Other). Respondents' addresses were spread across four
118 quartiles of greenspace coverage across residential areas in Singapore. Socio-demographic
119 variables were collected in the survey, including age, gender, ethnicity, personal monthly income
120 (collected in 16 income bands from no income to \$10,000 and above), highest formal education
121 qualification, and house type. The total number of hours spent at home in a week was also
122 collected (the descriptive statistics of the sociodemographic variables are shown in
123 Supplementary Data 1). Respondents were also asked to provide postal codes of their current
124 residence and/or workplace, or an approximate address (i.e., sub-region and road name) if they
125 preferred for privacy reasons. A postal code in Singapore is made up of the sector code and the
126 delivery point (i.e., building or house).

127 Life satisfaction measurement

128 We measured life satisfaction using the Satisfaction-with-Life Scale (Diener et al., 1985). We
129 asked participants to respond to five statements on a 5-point Likert scale (1 = strongly disagree,
130 disagree, neutral, agree, 5 = strongly agree). The life satisfaction score for each person was
131 calculated as the average of these responses.

132 Nature experience measurement

133 We measured various dimensions of nature experience as 9 different independent variables. We
134 measured both intentional and indirect nature experience. For intentional nature experience
135 (Shanahan et al., 2016; Soga & Gaston, 2020), we used 5 independent variables: 1) reported
136 frequency of natural space visits, 2) reported duration of public natural space visits over the last
137 week, 3) reported duration of domestic garden visits over the last week, 4) number of different
138 types of public natural space visits over the last week (“weekly diversity”), and 5) number of
139 different types of public natural space visits over the last year (“annual diversity”). For indirect
140 nature experience (Keniger et al., 2013; Soga & Gaston, 2020), we used 4 independent variables:
141 the reported presence/absence of nature views 1) from home within 500m, 2) from home beyond
142 500m, 3) from workplace within 500m, and 4) from workplace beyond 500m (the descriptive
143 statistics are shown in Supplementary Data 2).

144 Intentional nature experience comprised the following variables:

145 *Frequency of natural space visits:* Participants were asked how often they usually visit or
146 pass through natural spaces for any reason, including beach, park and nature reserve, rooftop
147 garden, golf course, and garden. “Garden” in this question was not explicitly stated as publicly
148 accessible gardens or private domestic gardens. The frequency was selected from the following

149 categories: 6-7 days a week, 3-5 days a week, 2-3 days a week, once a week, 2-3 times a month,
150 once a month, once every three months, once a year, and never.

151 *Duration of public natural space visits and domestic garden visits over the last week:*

152 Participants were asked the duration of time spent in public natural spaces and in domestic
153 gardens in the past week. Participants were asked which public natural spaces they visited or
154 passed through over the last week with five different types of public natural spaces: 1) beach, 2)
155 park and nature reserve, 3) rooftop garden, 4) golf course, and 5) garden. In the category of
156 “garden”, we provided examples of publicly accessible gardens (e.g., Gardens by the Bay and
157 Singapore Botanic Gardens). Participants were also asked to estimate the total time spent in each
158 type of natural space in the last week (hours, open-ended question). The total number of hours
159 spent in public natural spaces were summed to yield the duration of public natural space visits.
160 For time spent in domestic gardens, participants were asked how much time in total they spent in
161 their domestic gardens at home in the last week (hours, open-ended question), including their
162 own gardens, community gardens, and with potted plants along the corridor. The number of
163 hours spent in the domestic garden in the last week was used.

164 *Diversity of public natural space visits over the last week (weekly) and last year (annual):*

165 Participants were asked which types of public natural spaces they visited or passed through in the
166 last week (i.e., weekly) and that they visited most often in the last year (i.e., annual), with five
167 different types of public natural spaces: 1) beach, 2) park and nature reserve, 3) rooftop garden,
168 4) golf course, and 5) garden. The “garden” category was also given examples of publicly
169 accessible gardens (e.g., Gardens by the Bay and Singapore Botanic Gardens). The number of
170 types of public natural spaces visited was used as a measure of the diversity of natural space

171 visits. The diversity of natural space visits was further categorized into weekly diversity of
172 natural space visits and the annual diversity of natural space visits.

173 Indirect nature experience comprised the following variables:

174 *Nature view through windows from home and from workplace:* Participants were asked
175 whether they had a nature view from the room in which they spend most of their time at home
176 (home) and from where they work most often (workplace) for two different distances (within
177 500m and beyond 500m). Nature views included trees, parks, rooftop gardens, nature reserves,
178 sea, reservoir, river, and canals. The presence or absence of a nature view was used in the
179 analysis.

180 Connection with nature

181 To quantify how strongly a person identifies with nature, we used the component of the Nature
182 Relatedness (NR) Scale, NR-self (Nisbet et al., 2009). NR-self comprises 8 statements on a
183 Likert scale (1 = strongly disagree, disagree, neutral, agree, 5 = strongly agree). NR-Self
184 measures the internalized identification of a person with nature and the connection between the
185 person and nature in feelings and thoughts (e.g., “*My connection to nature and the environment*
186 *is a part of my spirituality*” and “*My relationship to nature is an important part of who I*
187 *am*”). The average score was calculated as the NR-self score of each person (the level of
188 connection with nature). The full statements are included in Supplementary information.

189 Natural space coverage around house and workplace location

190 The natural space coverage around the house and workplace location was used as a proxy
191 of the natural space availability of participants. A geographic information systems layer with
192 land use classifications was obtained from Gaw, Yee and Richards (2019). Natural spaces

193 included both greenspaces and bluespaces. The natural space coverage was estimated by the
194 proportion of land classified as vegetation with limited human management (with and without
195 tree canopy), vegetation with structure dominated by human management (with and without tree
196 canopy), freshwater swamp forest, freshwater marsh, mangrove forest, water courses, water
197 bodies, and marine areas. We excluded the land classified as buildings, artificial impervious
198 surfaces, and non-vegetated pervious surfaces. The natural space coverage was quantified within
199 a radius of 500m around the house and workplace addresses as one single variable (converted to
200 GPS coordinates using the *ggmap* package; Kahle, & Wickham, 2013). For participants who did
201 not provide postal codes, the middle point of the road was used as the location to calculate the
202 natural space coverage. For home location, only six respondents provided road names instead of
203 postal codes. All respondents provided road names for workplace location. Additional analyses
204 were run without the six observations who did not provide postal codes for home location and
205 excluding the natural space coverage around the workplace location variable for comparison
206 (final models are shown in Supplementary Table 1, 2).

207 *Statistical analyses*

208 All statistical analyses were carried out in R v3.5.3 (R Core Team, 2019). A total of 1,262
209 observations were used in the statistical analyses after we removed observations with inaccurate
210 data. To investigate the relationship between life satisfaction and various dimensions of nature
211 experience, we ran linear regression models. First, we ran an initial model with life satisfaction
212 score as the response variable and as the explanatory variables we included all 9 nature
213 experience variables: intentional nature experience (continuous variables) and indirect nature
214 experience (categorical variables: presence or absence of nature view). The NR-self score (as
215 continuous variable) was also included as an explanatory variable. Total time spent at home in a

216 week (hours), rank in highest education qualification, rank in house type (as a proxy of
217 household socio-economic status), age, personal monthly income rank, ethnicity (as factor,
218 Chinese as reference), and gender (as factor, males as reference), natural space coverage within
219 500m around the home location and workplace location were also included in the model. Multi-
220 collinearity of explanatory variables was checked (using the *vif* function in the *car* package with
221 3 as a cutoff), and the presence or absence of a nature view in far distance (beyond 500m) at
222 workplace was excluded on this basis. The other 8 nature experience variables were included in
223 the initial model.

224 To understand whether the association of nature experience and life satisfaction was
225 influenced by NR-self, a two-way interaction between NR-self and each nature experience
226 variable was added to form eight models (the presence/absence of a nature view in far distance at
227 workplace was excluded due to multi-collinearity). Each contained a different interaction term
228 that was compared with the initial model without the interaction term using likelihood ratio tests
229 (Supplementary Table 3). Only models with a significant interaction term were employed for
230 further stepwise model simplification until all variables were significant (the final model), and
231 the full model for the stepwise model simplification is shown in Supplementary Table 4. Model
232 heteroscedasticity and normality were checked, and the models fulfilled the assumptions.

233 In addition to the first analysis, we conducted a second analysis following the
234 abovementioned procedure. The variables included in the initial models of both analyses were
235 identical. The only difference was that, instead of using reported number of hours in nature
236 experiences, the duration of public natural space visits and in domestic gardens were coded as
237 categorical variables with two categories: 0-1 hour and more than 1 hour. This was motivated by
238 previous literature that found a threshold effect of nature dose and wellbeing (e.g., Shanahan et

239 al., 2016; White et al., 2019) and after visual inspection of the results suggested a “threshold”
240 effect at one hour of nature experience rather than a linear relationship (see Results). The
241 continuous natural experience of duration is shown in Supplementary Figure 1. This second set
242 of models was considered post-hoc analyses. Stepwise model simplification was also performed.
243 The likelihood ratio tests to compare between models with and without an interaction term are
244 shown in Supplementary Table 5. The full model for the stepwise model simplification is shown
245 in Supplementary Table 6. Model heteroscedasticity and normality were also checked. The final
246 models from these two analyses were compared using the Akaike information criterion (AIC),
247 and the model with a smaller AIC value, meaning better in predicting the variation in life
248 satisfaction, was selected.

249

250 **Results**

251 The final model from the first analysis showed that weekly diversity of natural space visits was
252 positively correlated with life satisfaction, and the interaction between annual diversity of natural
253 space visits and the person's strength of connection with nature were positively correlated with
254 life satisfaction (Figure 1a, Table 1). We failed to find, however, a significant relationship
255 between life satisfaction and the frequency or duration of nature experience both with and
256 without the interaction with connection with nature (Figure 1b-d, Supplementary Table 3 and
257 Supplementary Table 4).

258 Since a closer inspection of Figure 1c and Figure 1d suggested a "threshold" effect at one
259 hour of nature experience rather than a linear relationship, we ran a post-hoc second analysis
260 with duration of nature experience as two categories (0 – 1 hour vs > 1 hour). The final model
261 from the second analysis better predicted life satisfaction (AIC = 2237.78, df = 9) than that from
262 the first analysis (AIC = 2248.14, df = 9). This final model from the second analysis showed that
263 the annual diversity of natural space visits was positively correlated with life satisfaction (Figure
264 2a, Table 2). The model also showed that, when the duration of public natural space visits was
265 divided into more or less than 1 hour, the relationship between duration of public natural space
266 visits and life satisfaction was modulated by individual variation in connection with nature
267 through an interaction term (Table 2, Figure 2b). Specifically, spending more than one hour in
268 public natural spaces was positively correlated with life satisfaction of the individuals with a
269 stronger connection with nature, while this association was not evident for individuals with a
270 weaker connection with nature (Figure 2b, Table 2).

271 Both final models showed that life satisfaction was positively correlated with the
272 presence of a nature view through windows from home and from the workplace (Figure 3, Table

273 1, Table 2). The presence of nature views from home within short distances (< 500m) was
274 positively correlated with life satisfaction. We failed to identify a significant relationship
275 between the presence of nature views at longer distances (> 500m) and life satisfaction
276 (Supplementary Table 4, Supplementary Table 6). As expected, personal income was positively
277 correlated with life satisfaction (Table 1, Table 2).

278 **Discussion**

279 We found that diversity in natural space visits was positively correlated with life satisfaction.
280 The relationship between duration of nature experience and life satisfaction was modulated by
281 the individual's connection with nature. People with a stronger sense of connection with nature
282 were more likely to have higher life satisfaction when they spent more than one hour in public
283 natural spaces in a week. A nature view from windows at home and at the workplace was
284 positively correlated with life satisfaction, confirming results from previous studies (Gilchrist,
285 Brown, & Montarzino, 2015; Kaplan, 2001; Russell et al., 2013).

286 Our results showed the diversity of nature experience is positively correlated with life
287 satisfaction as people who visited more different types of natural spaces tend to have higher life
288 satisfaction. Life satisfaction may be determined by extrinsic aspirations (i.e., externally valued
289 materials, e.g. income) and intrinsic aspirations (i.e., satisfying psychological needs, e.g.
290 connection with people, Kahneman, & Deaton, 2010; Ryan, & Deci, 2000). It has been shown
291 that human psychological wellbeing increases with higher species richness (Fuller, Irvine,
292 Devine-Wright, Warren, & Gaston, 2007). By visiting different types of natural spaces, people
293 are more likely to experience higher species richness as different natural spaces may house

294 different animal and plant taxa. The diversity of nature that a person experiences might also
295 prevent habituation to a single type of natural space in providing the benefits. Our data showed a
296 linear relationship between the diversity of nature experience and life satisfaction, suggesting
297 that given the five general types of natural spaces in this study, the more different types of
298 natural space visited, the higher the life satisfaction. Our better model showed that for every
299 extra type of natural space visited in a year, life satisfaction scores, ranging from 1 to 5, increase
300 by 0.049 ± 0.024 . This implies that the threshold for the number of types of natural space visits
301 to reach a plateau may be high. These results thus suggest that the variety of natural spaces
302 should be considered when planning cities to increase life satisfaction.

303 We also found that views of nature from home and workplace had a significant positive
304 correlation with life satisfaction. We found that when the nature view from home is close by (i.e.
305 less than 500 m), there is a positive relationship between nature view and life satisfaction. The
306 results thus suggest that nearby nature is important. This could be because people experience
307 nature through multiple sensory pathways, such as visual, auditory, and olfactory signals
308 (Franco, Shanahan, & Fuller, 2017). It has been found that nature sounds, such as bird songs and
309 river sounds, improve wellbeing (Benfield, Taff, Newman, & Smyth, 2014; Ratcliffe,
310 Gatersleben, & Sowden, 2013). Conversely, we failed to find a significant relationship when the
311 nature view is more than 500m away from home. Further research with larger sample sizes could
312 further examine this relationship at greater distances. Our results could have urban planning
313 implications by suggesting that nearby nature is related to higher life satisfaction. Further
314 research could also focus on the multiple sensory signals of nature to dissect the effect of nature
315 stimuli on life satisfaction (Franco et al., 2017).

316 In the evaluation of life satisfaction, every person varies in their criteria (Diener et al.,
317 1985). Our results show that for people with a strong connection with nature, the duration of
318 public natural space visits is positively correlated with their life satisfaction, suggesting that a
319 person's connection with nature moderates the relationship between nature experience and
320 subjective wellbeing. People with a strong connection with nature may feel relaxed after
321 spending time in nature, while those people with a weak connection with nature may feel
322 discomfort (e.g., due to hot and humid climate in tropics; Soga & Gaston, 2020; Saw et al.,
323 2015). This result could potentially explain the lack of significant association between the
324 duration of nature experience and life satisfaction reported in a previous study in Singapore as
325 the individual variation in connection with nature was not considered (Saw et al., 2015). In our
326 post-hoc analysis after visual inspection of the initial analysis, we also found a threshold effect
327 between duration of public natural space visits and life satisfaction. Previous studies have shown
328 that a threshold occurs between nature experience and its psychological benefits. Once the nature
329 experience exceeded the threshold, the benefit plateaued, such as 30 minutes/week threshold for
330 the odds of depression in an Australian population and 120 minutes/week threshold for life
331 satisfaction in an UK population (Shanahan et al., 2016; White et al., 2019). Our results might
332 suggest that given a positive relationship between the strength of connection with nature and life
333 satisfaction, the 60 minutes/week may be a threshold for higher life satisfaction for people with a
334 stronger connection with nature in a Singaporean population. Although this result provides
335 important insights into the minimal duration of nature experience and the influence of individual
336 variation in the connection with nature, we note that this threshold was identified through a post-
337 hoc analysis. It may thus be too early to make specific recommendations and further studies
338 are required to investigate the causal relationship and actual mechanisms behind this threshold.

339 In our correlative analyses, we could not eliminate the possibility that wealthier people
340 may have higher life satisfaction and choose to live in neighborhoods with better accessibility to
341 natural spaces, such as higher mobilities or more opportunities. In Singapore, the housing is
342 highly regulated by government and about 80% of household living in apartments owned by the
343 government (Department of Statistics Singapore 2019). The Singapore government has
344 developed the residential areas to ensure natural space availability across income levels and
345 aiming to reach 90% of the houses to be within 10-minute walking distance to a natural space by
346 2030 (Ministry of the Environment and Water Resources and Ministry of National Development
347 2014). This urban development could potentially minimize covarying in the income levels and in
348 the natural space accessibility.

349 The correlational nature of our analyses is certainly a key limitation of our study. As
350 such, it is not possible to identify the causal directionality between nature exposure and life
351 satisfaction. Experimental studies have found that people immersed in natural environments tend
352 to value the relationship with others more, make less selfish decisions, become more prosocial,
353 and have better mood (Guéguen, & Stefan, 2016; Piff et al., 2015; Weinstein et al., 2009). As
354 mentioned earlier, the shift to intrinsic value may lead to higher life satisfaction (Benita, Bansal,
355 & Tunçer, 2019; Ryan, & Deci, 2001). Other experimental studies have also shown that nature
356 experience benefits the recovery from cognitive fatigue and reduces stress (Bratman et al., 2012;
357 Hunter et al., 2019). However, we could not exclude the possibility that people with higher life
358 satisfaction may be more active in visiting various public natural spaces and choose houses with
359 nature views. Future work should perform experiments to examine whether individuals with
360 better (or worse) subjective wellbeing may choose (or not) to interact with nature. It is also
361 possible that there is a circular feedback loop between nature exposure and life satisfaction. For

362 example, people could experience an initial variation in their nature exposure by chance, which
363 could itself lead to individual variation in life satisfaction. If people with higher life satisfaction
364 prefer to experience nature more than people with lower life satisfaction, this would lead to
365 cycles of increasing nature exposure and higher life satisfaction (and vice-versa). Yet another
366 possibility is that nature exposure and life satisfaction are correlated among individuals through
367 other factors not accounted for in this study, such as childhood experiences, personality, or
368 genetic factors.

369

370 **Conclusions**

371 We showed that diversity of nature experience is positively correlated with life satisfaction. We
372 recommend that, in tropical areas, the number of different types of natural environments should
373 be considered in urban natural space planning – and this could include nature reserves, public
374 parks, rivers, and coastal areas. Interestingly, we found that the relationship between nature dose
375 and life satisfaction was modulated by the strength of connection with nature of the individual.
376 This result suggests that increasing the strength of connection with nature could potentially later
377 help people to reap the benefits of nature exposure. Furthermore, the nearby nature view through
378 windows from home and the workplace was found to correlate positively with life satisfaction,
379 suggesting the importance of promoting opportunity of nature views in residential and work
380 areas. Policy interventions should consider the need to increase nature elements, such as trees
381 and parks, near buildings as window viewpoints of such elements can provide many benefits to
382 the local community.

383

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List of tables

Table 1. The final model of the first analysis. The positive relationship between nature experiences and life satisfaction includes weekly diversity of natural space visits, the presence of a nature view from home and from workplace within 500m, and the interaction between NR-self (connection with nature) and annual diversity of natural space visits. Significant variables are in bold font. Income rank was included as a covariate to account for the relation between income and life satisfaction.

Table 2. The final model of the second analysis. The positive relationship between nature experiences and life satisfaction includes annual diversity of natural space visits, the presence of a nature view from home and from workplace within 500m, and the interaction between NR-self (connection with nature) and duration of public natural space visits in two categories (0-1 hour vs > 1 hour). Significant variables are in bold font. Income rank was included as a covariate to account for the relation between income and life satisfaction.

Table 1. The final model of the first analysis. The positive relationship between nature experiences and life satisfaction includes weekly diversity of natural space visits, the presence of a nature view from home and from workplace within 500m, and the interaction between NR-self (connection with nature) and annual diversity of natural space visits. Significant variables are in bold font. Income rank was included as a covariate to account for the relation between income and life satisfaction.

Explanatory variable	Estimate	SE	t	<i>p</i>
(Intercept)	2.113	0.284	7.451	<0.0001
Annual diversity of natural space visits	-0.241	0.140	-1.718	0.086
Weekly diversity of natural space visits	0.086	0.031	2.745	0.006
Nature view from home (< 500m)	0.231	0.057	4.070	<0.0001
Nature view from workplace (< 500m)	0.106	0.051	2.080	0.038
NR-Self	0.109	0.078	1.404	0.161
NR-self × annual diversity of natural space visits	0.079	0.038	2.100	0.036
Income rank	0.019	0.007	2.603	0.009

Table 2. The final model of the second analysis. The positive relationship between nature experiences and life satisfaction includes annual diversity of natural space visits, the presence of a nature view from home and from workplace within 500m, and the interaction between NR-self (connection with nature) and duration of public natural space visits in two categories (0-1 hour vs > 1 hour). Significant variables are in bold font. Income rank was included as a covariate to account for the relation between income and life satisfaction.

Explanatory variable	Estimate	SE	t	<i>p</i>
(Intercept)	1.961	0.201	9.734	< 0.0001
Annual diversity of natural space visits	0.049	0.024	2.077	0.038
Duration of public natural space visits (> 1hr)	-0.594	0.303	-1.963	0.050
Nature view from home (< 500m)	0.224	0.057	3.962	< 0.0001
Nature view from workplace (< 500m)	0.103	0.051	2.030	0.043
NR-Self	0.147	0.055	2.693	0.007
NR-Self × duration of public natural space visits (> 1hr)	0.218	0.083	2.621	0.009
Income rank	0.018	0.007	2.573	0.010

List of figures

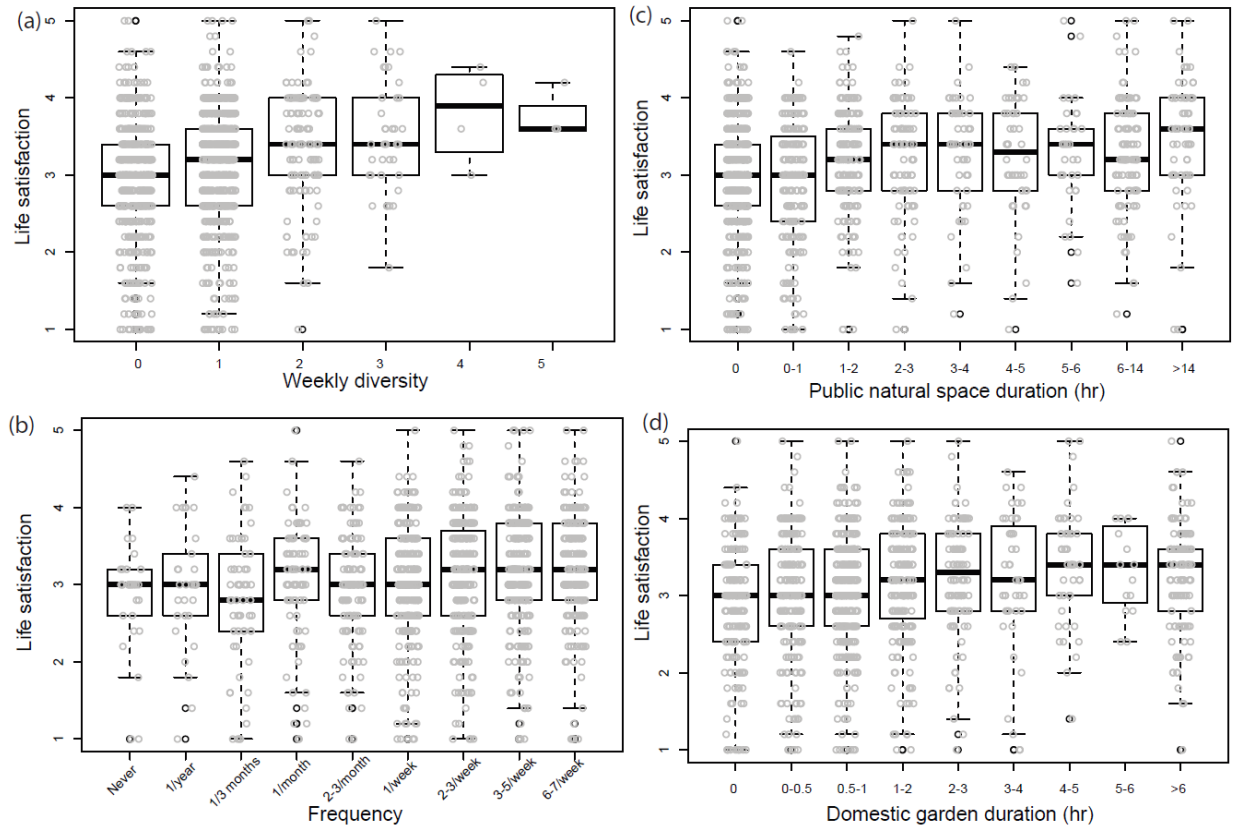


Figure 1. The relationship between nature experience and life satisfaction from the first analysis with scatted plots and box plots. (a) The number of different types of natural space visits in the last week (weekly diversity of natural space visits) was positively associated with life satisfaction. (b) The frequency of natural space visits was not significantly associated with life satisfaction. (c, d) The duration of public natural space visits and in domestic gardens last week were not associated with life satisfaction. The reported number of hours from each participant was used in the statistical analysis.

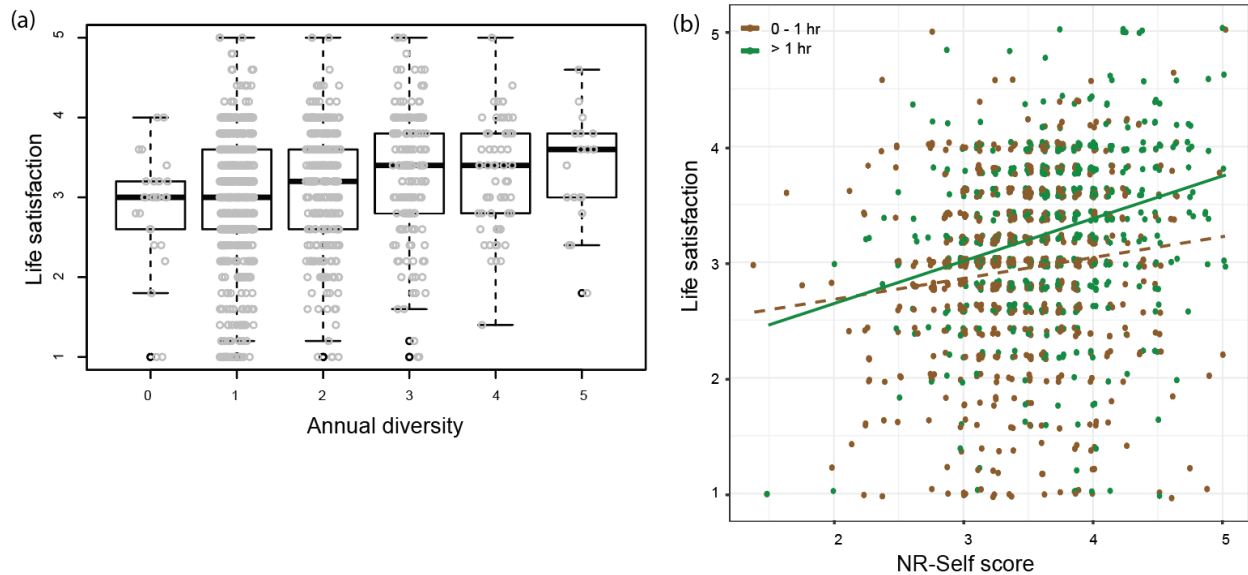


Figure 2. The relationship between nature experience and life satisfaction from the second analysis. (a) Using the scatted plot and box plot, the number of different types of natural space visits in the last year (annual diversity of natural space visits) was positively associated with life satisfaction. (b) The interaction between the duration of public natural space visits in the last week and the individual variation in the strength of connection with nature (NR-self) was positively associated with life satisfaction. Spending more than one hour in public natural spaces in a week (green; brown represents spending less than one hour in a week) was positively associated with higher life satisfaction for people with higher NR-self as compared to people with lower NR-self.

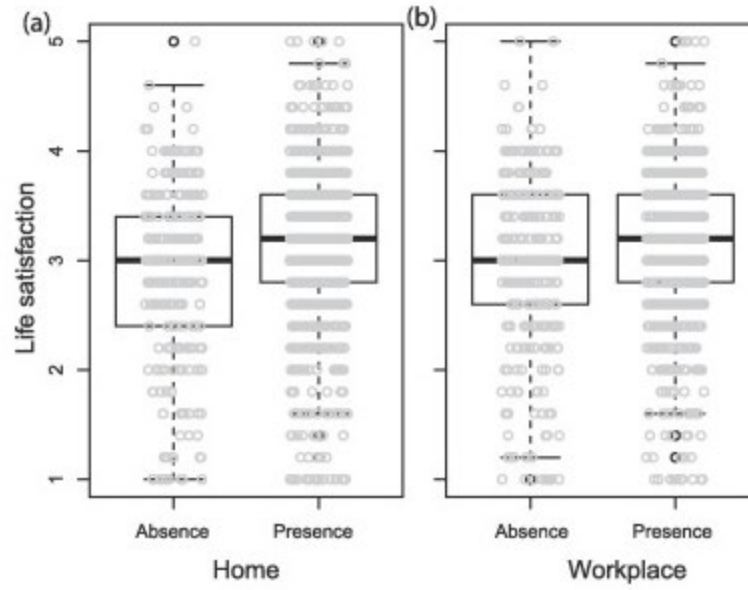


Figure 3. The relationship between life satisfaction and the presence/absence of a nature view within 500 m with scatted plots and box plots. Final models of two analyses showed the presence of a nature view from home (a) and from workplace (b) were positively associated with life satisfaction.

List of appendices

Supplementary Table 1. The final model of the first analysis (without the variable of workplace nature space coverage and observations with imprecise home location removed). Significant variables are in bold font.

Explanatory variable	Estimate	SE	t	<i>p</i>
(Intercept)	2.125	0.285	7.462	0.0000
Annual diversity of natural space visits	-0.252	0.141	-1.785	0.075
Weekly diversity of natural space visits	0.087	0.032	2.749	0.006
Nature view from home (< 500m)	0.227	0.057	3.971	0.0001
Nature view from workplace (< 500m)	0.107	0.051	2.093	0.037
NR-Self	0.107	0.078	1.366	0.172
NR-self × annual diversity of natural space visits	0.082	0.038	2.162	0.031
Income rank	0.019	0.007	2.611	0.009

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387

388 Supplementary Table 2. The final model of the second analysis (without the variable of
 389 workplace nature space coverage and samples with imprecise home location removed).
 390 Significant variables are in bold font.

Explanatory variable	Estimate	SE	t	<i>p</i>
(Intercept)	1.962	0.202	9.701	< 0.0001
Annual diversity of natural space visits	0.049	0.024	2.057	0.040
Duration of public natural space visits (> 1hr)	-0.614	0.304	-2.019	0.044
Nature view from home (< 500m)	0.219	0.057	3.862	0.0001
Nature view from workplace (< 500m)	0.104	0.051	2.048	0.041
NR-Self	0.147	0.055	2.690	0.007
NR-Self × duration of public natural space visits (> 1hr)	0.223	0.084	2.671	0.008
Income rank	0.019	0.007	2.581	0.010

391

392

393 Supplementary Table 3. Likelihood ratio tests to compare between the full model with different
 394 interaction terms (NR-self interacting with different nature experience variables) and the full
 395 model without interaction terms. The full model includes frequency of natural space visits
 396 (frequency), duration of public natural space visits last week (public natural space duration),
 397 duration in domestic gardens last week (domestic garden duration), number of different types of
 398 public natural space visits last year (annual diversity of natural space visits), number of different
 399 types of public natural space visits last week (weekly diversity of natural space visits), presence
 400 of a nature view from home within 500 m (nature view from home < 500m), presence of a nature
 401 view from home more than 500m (nature view from home > 500m), and presence of a nature
 402 view from workplace within 500m (nature view from workplace < 500m). We also included
 403 other covariates: natural space coverage around home within 500m, natural space coverage
 404 around workplace within 500m, total time spent at home in a week, highest education
 405 quantification, house type, age, income rank, gender, and ethnicity.

Interaction term with NR-self	F	<i>p</i>
NR-self × frequency	1.518	0.218
NR-self × annual diversity of natural space visits	6.277	0.012
NR-self × public natural space duration	0.038	0.845
NR-self × weekly diversity of natural space visits	3.401	0.065
NR-self × nature view from home (<500m)	3.389	0.066
NR-self × nature view from home (>500m)	0.416	0.519
NR-self × nature view from workplace (<500m)	1.526	0.217
NR-self × domestic garden duration	0.422	0.516

406 Supplementary Table 4. The relationship between nature experience and life satisfaction
 407 including the interaction between NR-self and annual diversity of natural space visits. Significant
 408 variables are in bold font.

	Explanatory variable	Estimate	SE	t	p
Nature experience	(Intercept)	2.307	0.329	7.013	<0.0001
	Annual diversity of natural space visits	-0.309	0.147	-2.099	0.036
	Weekly diversity of natural space visits	0.052	0.038	1.382	0.167
	Frequency	0.000	0.014	-0.021	0.983
	Public natural space duration	0.003	0.002	1.311	0.190
	Domestic garden duration	0.001	0.005	0.188	0.851
	Nature view from home (<500m)	0.176	0.076	2.325	0.020
	Nature view from home (>500m)	0.062	0.074	0.839	0.402
	Nature view from workplace (<500m)	0.108	0.054	1.993	0.047
	NR-Self	0.050	0.082	0.606	0.544
	NR-self × annual diversity of natural space visits	0.098	0.039	2.505	0.012
Covariates	Income rank	0.016	0.009	1.853	0.064
	Age	0.001	0.002	0.303	0.762
	Education	0.001	0.015	0.045	0.965
	Rank in house type	0.004	0.014	0.270	0.787
	Natural space coverage around house location	-0.188	0.220	-0.857	0.392
	Natural space coverage around workplace location	0.096	0.153	0.626	0.531
	Time spent at home in a week	0.000	0.001	-0.335	0.738
	Gender (Female)	0.056	0.048	1.185	0.236
	Ethnicity (Malay)	0.045	0.076	0.598	0.550
	Ethnicity (Indian)	0.138	0.087	1.596	0.111
	Ethnicity (Eurasian)	-0.083	0.212	-0.393	0.694
Ethnicity (Other)	0.159	0.147	1.080	0.280	

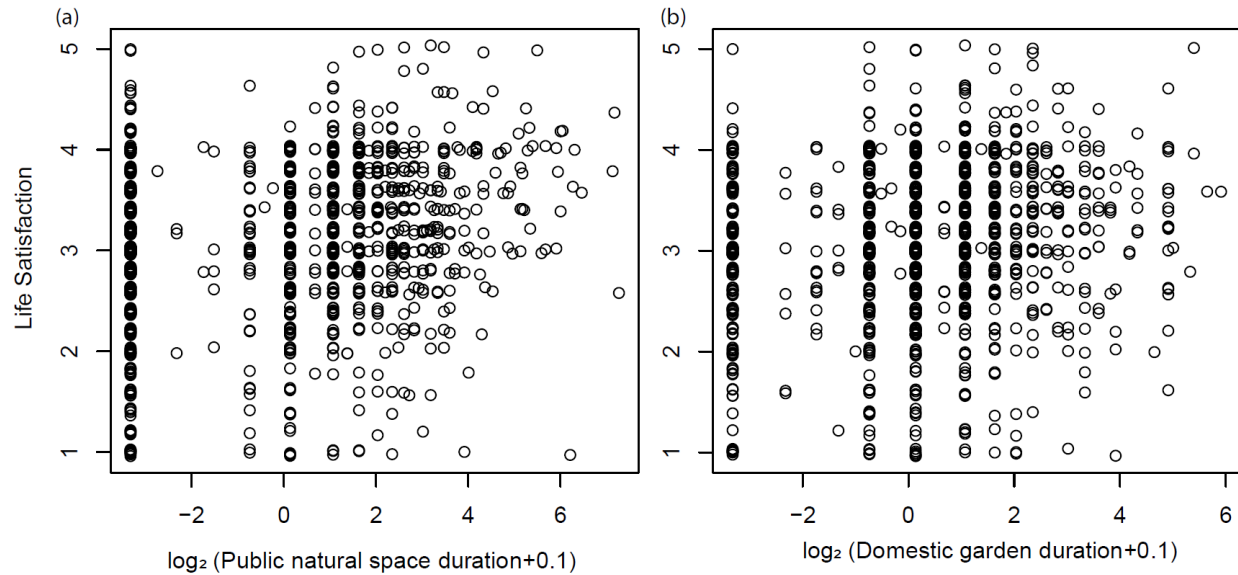
410 Supplementary Table 5. Likelihood ratio tests to compare between the full model with different
 411 interaction terms (NR-self interacting with different nature experience variables) and the full
 412 model without interaction term. The full model includes frequency of natural space visits
 413 (frequency), duration of public natural space visits last week (public natural space duration in
 414 two categories: 0-1 hour vs > 1 hour), duration in domestic gardens last week (domestic garden
 415 duration in two categories: 0-1 hour vs > 1 hour), number of different types of public natural
 416 space visits last year (annual diversity of natural space visits), number of different types of public
 417 natural space visits last week (weekly diversity of natural space visits), presence of a nature view
 418 from home within 500 m (nature view from home < 500m), presence of a nature view from home
 419 more than 500m (nature view from home > 500m), and presence of a nature view from
 420 workplace within 500m (nature view from workplace < 500m). We also included other
 421 covariates: natural space coverage around home within 500m, natural space coverage around
 422 workplace within 500m, total time spent at home in a week, highest education quantification,
 423 house type, age, income rank, gender, and ethnicity.

Interaction term with NR-self	F	<i>p</i>
NR-self × frequency	1.395	0.238
NR-self × annual diversity of natural space visits	6.152	0.013
NR-self × public natural space duration (> 1hr)	6.796	0.009
NR-self × weekly diversity of natural space visits	4.636	0.032
NR-self × nature view from home (<500m)	3.679	0.055
NR-self × nature view from home (>500m)	0.734	0.392
NR-self × nature view from workplace (<500m)	1.806	0.179
NR-self × domestic garden duration (> 1hr)	0.656	0.418

424 Supplementary Table 6. The relationship between nature experience and life satisfaction
 425 including the interaction between NR-self and annual diversity of natural space visits, interaction
 426 between NR-self and weekly diversity of natural space visits, and interaction between NR-self
 427 and public natural space duration in two categories (0-1 hour vs > 1 hour). Significant variables
 428 are in bold font.

	Explanatory variable	Estimate	SE	t	p
	(Intercept)	2.441	0.332	7.36	< 0.0001
Nature experience	Annual diversity of natural space visits	-0.218	0.159	-1.376	0.169
	Weekly diversity of natural space visits	-0.004	0.275	-0.014	0.989
	Frequency	-0.007	0.014	-0.517	0.606
	Public natural space duration (> 1hr)	-0.453	0.435	-1.041	0.298
	Domestic garden duration (> 1hr)	0.063	0.050	1.253	0.210
	Nature view from home (<500m)	0.166	0.075	2.205	0.028
	Nature view from home (>500m)	0.064	0.073	0.876	0.381
	Nature view from workplace (<500m)	0.106	0.054	1.972	0.049
	NR-Self	0.005	0.084	0.054	0.957
	NR-Self × public natural space duration (> 1hr)	0.176	0.118	1.499	0.134
	NR-self × annual diversity of natural space visits	0.073	0.043	1.715	0.087
	NR-self × weekly diversity of natural space visits	0.000	0.074	0.005	0.996
Covariates	Income rank	0.015	0.009	1.768	0.078
	Age	0.001	0.002	0.33	0.742
	Education	0.002	0.015	0.13	0.897
	Rank in house type	0.006	0.014	0.458	0.647
	Natural space coverage around house location	-0.208	0.219	-0.952	0.341
	Natural space coverage around workplace location	0.108	0.151	0.714	0.475
	Time spent at home in a week	0.000	0.001	-0.186	0.853
	Gender (Female)	0.061	0.047	1.285	0.199
	Ethnicity (Malay)	0.039	0.076	0.513	0.608
	Ethnicity (Indian)	0.132	0.086	1.532	0.126
	Ethnicity (Eurasian)	-0.086	0.211	-0.406	0.685
	Ethnicity (Other)	0.146	0.146	0.995	0.320

429



430

Supplementary Figure 1. The relationship between duration of public natural space visits (a) and in domestic gardens (b) last week and life satisfaction. The reported number of hours from each participant was used in the statistical analysis.

431

432 Supplementary information:

The statements used to measure the connection with nature include: “*My connection to nature and the environment is a part of my spirituality*”, “*My relationship to nature is an important part of who I am*”, “*I feel very connected to all living things and the earth*”, “*I am not separate from nature, but a part of nature*”, “*I always think about how my actions affect the environment*”, “*I am very aware of environmental issues*”, “*Even in the middle of the city, I notice nature around me*”, “*My feelings about nature do not affect how I live my life*”.

Supplementary Data 1. Descriptive statistics of the sociodemographic variables used in this study

Variable		n
Gender	Male	634
	Female	628
Ethnicity	Chinese	953
	Malay	158
	Indian	101
	Eurasian	15
	Other	35
Age (years)	18-25	180
	26-35	316
	36-45	274
	46-55	268
	56-65	164
	66-75	60
Monthly personal Income (SGD)	No income	104
	< 400	45
	400 – 599	37
	600 - 799	20
	800 - 999	30
	1,000 - 1,499	67
	1,500-1,999	52
	2,000-2,999	156
	3,000-3,999	186
	4,000-4,999	136
	5,000-5,999	118
	6,000-6,999	95
	7,000-7,999	51
8,000-8,999	64	
9,000-9,999	33	
>10,000	68	
House type HDB flats are public housing	HDB 1 room flat	20
	HDB / SAF / PSA / PUB 2-room flat	32
	HDB / SAF / PSA / PUB 3-room flat	208
	HDB / SAF / PSA / PUB 4-room flat	425
	HDB / SAF / PSA / PUB 5-room flat	285
	HDB / Government Executive flat	72
	HUDC flat	160
	Condominium/ Private flat/ Apartment	58
Terrace/ Semi-detached house/ Bungalow	2	
Education	No formal education	3
	Primary school	5
	Secondary school	136
	Institute of Technical Education/Vocational Certification	71
	Post-secondary school	110
	Polytechnic diploma	271
	Arts institute	4
	Bachelor degree	528
	Post-graduate degree	130
Other	4	
Total time spent at home in a week (hr)	0-20	77
	21-40	318
	41-60	377
	61-80	141
	81-100	80
	101-120	22
	>120	13
	NA	234

Supplementary Data 2. Descriptive statistics of the nature experience variables used in this study

Variable		n	
Annual diversity of natural space visits (Number of different types of natural space visits over the last year)	0	29	
	1	676	
	2	302	
	3	174	
	4	62	
	5	19	
Weekly diversity of natural space visits (Number of different types of natural space visits over the last week)	0	490	
	1	613	
	2	115	
	3	37	
	4	4	
	5	3	
Frequency of natural space visits	Never	29	
	Once a year	29	
	Once every three months	62	
	Once a month	79	
	2-3 times a month	115	
	Once a week	260	
	2-3 days a week	260	
	3-5 days a week	234	
6-7 days a week	194		
Public natural space duration (hr, over the last week)	0	490	
	0-1	208	
	>1-2	173	
	>2-3	95	
	>3-4	49	
	>4-5	48	
	>5-6	33	
	>6-14	101	
	>14	65	
	Domestic gardens duration (hr, over the last week)	0	183
0-0.5		206	
>0.5-1		339	
>1-2		208	
>2-3		106	
>3-4		44	
>4-5		47	
>5-6		15	
>6		113	
NA		1	
Nature view from home	< 500m	Presence	992
		Absence	270
	> 500m	Presence	967
		Absence	295
Nature view from workplace	< 500m	Presence	717
		Absence	311
		NA	234
	> 500m	Presence	709
		Absence	319
		NA	234

