Biodiverse urban forests, happy people: experimental evidence linking perceived biodiversity, restoration, and emotional wellbeing

Abstract

Here we investigate whether perceived biodiversity is linked to emotional wellbeing, taking into account the individual level of connection to nature, and whether such relationship is mediated by perceived restorativeness. We exposed participants to urban trails of different biodiversity levels and analysed the data using linear mixed-effects and structural equation models. Our results show that animal diversity and nature relatedness are positively linked to perceived restorativeness that, in turn, increases positive affect and decreases negative affect; thus suggesting that restoration mediates the effect of biodiversity on emotional wellbeing. We also found walk duration is linked to increased positive affect and reduced negative affect while crowdedness level in the trail has the opposite effect. Our results show an important link between urban biodiversity conservation and public mental health.

Keywords: ecosystem services; urban parks; subjective wellbeing; environmental psychology; Stress Reduction Theory**;** Attention Restoration Theory

1. Introduction

Exposure to natural environments has been shown to promote wellbeing, amongst other benefits (Hartig et al., 2003; Lee et al., 2011; Marselle et al., 2015; Park et al., 2007). For instance, a study in Japan demonstrated that positive psychological wellbeing is significantly higher after walking in the forest than in the urban environments (Takayama et al., 2014) and exposure to natural environments as compared to urban/built environments associates with an increased positive emotion, cognition ability, and physical health (Bowler et al., 2010). In the long run, residential exposure to nature is known to associate with better psychological (Nutsford et al., 2016; Reklaitiene et al., 2014), mental (van den Berg et al., 2010), and physical health (Wang et al., 2017).

Several theories have been proposed to explain the mechanisms by which nature exposure contributes to mental wellbeing. The Stress Reduction Theory (SRT) proposes that exposure to natural environments aids stress recovery and evokes positive emotional responses (Ulrich, 1981). Lower stress levels are manifested as enhanced levels of positive affect, reduced levels of negative affect, and thus improves emotional, physiological, and cognitive functioning. Ulrich, (1983) further contended that perceiving particular environmental features and qualities, such as vegetation and water and richness complexity (e.g. biodiversity level), can benefit the psychophysiological stress recovery and, elicit an increase in positive affect and a decrease in negative affect. .

Another of such mechanisms is through perceived restorativeness, based on the Attention Restoration Theory (ART, Kaplan and Kaplan, 1989). The ART puts forth that being in nature help restore one's capacity to concentrate by engaging one's involuntary attention, resulting in improved cognitive functioning. The ART also posits that natural environments have higher restorative qualities than built environments (Kaplan, 1995), which can be measured using reliable self-report scales, such as the Perceived Restorativeness Scale (PRS) (Hartig et al., 1997).

1.1. Biodiversity and wellbeing

While research has found that actual biodiversity (measured as species richness in an environment as determined by experts) is positively associated with wellbeing, other studies unveiled inconsistencies in such relationships. Fuller et al., (2007) found that psychological wellbeing (measured by self-reported reflection, distinct identity, continuity with past and attachment) benefits gained by individuals exposed to green spaces increased with higher actual plant and bird diversity separately. Similarly, Wolf et al., (2017) discovered that exposure to higher levels of actual tree and bird diversity individually led to an increase in mental wellbeing (as measured by self-reported positive and negative affect and vitality) and lower anxiety. However, Dallimer et al., (2012) found that psychological wellbeing (measured by self-reported reflection, contemplation, emotional attachment and personal identity) increased with higher actual bird diversity, decreased with higher actual plant/tree diversity, and was unrelated to actual butterfly diversity.

In contrast, perceived biodiversity (the number of species each participant notices or encounters) has been more consistently shown to be positively associated with wellbeing. Again Dallimer et al., (2012) demonstrated that higher perceived bird, butterfly, plant/tree diversity led to greater psychological wellbeing. As compared to the inconsistent results reported using actual biodiveristy, the potential reason lies in individuals varying in their ability to distinguish species of animals or plants. In other words, some participants could not detect (or perceive) the actual level of species richness in a greenspace. To substantiate such an argument, Dallimer et al., (2012) discovered no consistent positive associations between actual and perceived levels of biodiversity for their participants. Similarly, White et al., (2017) found that greater perceived biodiversity was associated with an increase in mood and recovery while Dallimer et al., (2012) demonstrated that higher perceived bird, butterfly, plant/tree biodiversity led to greater psychological wellbeing. Similarly, Cameron et al., (2020) reported that more positive mental health outcomes were reported when participants perceived greater avian diversity. In addition, perceived biodiversity was also found to improve wellbeing of greenspace visitors, including their stress, mood, concentration, and self-esteem levels (Schebella et al., 2019).

1.2. Emotional wellbeing

The emotional aspect of wellbeing, or mood, has been shown to improve with nature exposure (i.e. Bratman et al., 2015; Mayer et al., 2009; Schebella et al., 2019). Many studies have assessed mood as a uni-dimensional measure such that it ranges from worst to best, or poor to good (Clark and Watson, 1988). However, more recent research assess mood as comprising of separate affectivities: positive and negative. Although the terms *positive* and *negative* might suggest opposing affectivities, they are not necessarily a function of each other or binary. For example, negative affect is related to stress and coping strategies (Goh et al., 2012, 2010), while positive affect – but not negative affect – is related to social interactions (Clark and Watson, 1988). The self-reported Positive and Negative Affect Schedule (PANAS) (Watson et al., 1988b) has been shown to be stable and consistent measure that can reliably assess both constituents of mood.

1.3. Biodiversity, emotional wellbeing, and the role of restorativeness

While restorativeness is a plausible mechanism by which nature exposure improves wellbeing based on ART, only a few studies have investigated the relationship between biodiversity and perceived restorativeness. Carrus et al., (2015) and Wood et al., (2018) found that greater actual biodiversity led to increased ratings of the perceived restorative properties of the environment. Similarly, Scopelliti et al., (2012) found positive associations between actual biodiversity and the level of perceived restorativeness measured by PRS. Contrarily, Peschardt and Stigsdotter, (2013) concluded that actual plant and animal diversity were only positively related to the restorative quality of coherence component in the PRS. To our knowledge, only one study examined the relationship between perceived biodiversity and perceived restorativeness. Marselle et al., (2016) found greater bird diversity led to an increase in perceived restorativeness, which in turn was correlated with greater positive affect and lower negative affect.

While the link between perceived biodiversity and perceived restorativeness is poorly resolved, the effect of perceived restorativeness on emotional wellbeing is well-established. Studies suggest that perceived restorativeness could serve as mediator of the relationship between perceived biodiversity and emotional wellbeing (Carrus et al., 2017; Hartig et al., 1997; Korpela et al., 2014; Marselle et al., 2016, 2015). Despite the appeal of this hypothesis, there is a paucity of research in this area. A few studies have explored the relationship of nature and emotional wellbeing through perceived restorativeness using the general construct of ‘nature’ (Martínez-Soto et al., 2014), while other studies examined different specific features of nature rather than perceived biodiversity (e.g. actual biodiversity, perceived greenness) (Carrus et al., 2015; Hipp et al., 2016).

1.4. Nature relatedness

Though the impacts of nature exposure on wellbeing is well-documented, the magnitude of impact might depend on individual differences in their nature relatedness. For example people who are more perceptive to natural beauty scored higher in pro-sociality tasks after viewing pictures of natural landscapes (Zhang et al., 2014). In another example, connectedness to nature mediates the positive effects of nature exposure on mood (Mayer et al., 2009). Connection to nature could therefore be important in explaining the variation in individual response to nature exposure. The inclusion of connection to nature in linking nature exposure with wellbeing in an experimental study has however been limited.

1.5. Study aims

These research gaps lead to the objectives and research questions of this study. Firstly, we aim to investigate the effect of the level of perceived animal and plant diversity of an environment on emotional wellbeing after an outdoor individual walk. Secondly, we examined whether perceived restorativeness of an environment mediates the relationship between perceived animal and plant diversity levels and positive and negative affects following an outdoor individual walk. In all analyses, we included the subjective level of nature connection to account for the individual differences in perceptiveness to the impact of nature exposure. The Stress Reduction Theory (SRT) and the Attention Restoration Theory (ART) are used to form the basis of our study's predictions. To our knowledge, these research gaps have only been addressed in Marselle et al., (2015) but using a group walk experimental design. In this study, we conducted individual walks to eliminate the impact of socialization on changes in emotional wellbeing.

2. Materials and methods

2.1. Ethics Statement. This study was approved by the Institutional Review Board of the University.

2.2. Participants

We recruited undergraduate students at the University via online research recruitment platforms. We also advertised the research at lectures and posted posters at the hallway of the Department of Biological Sciences. Students were asked to pass the invitation to participate only to their fellow students to control for age and educational level in the study design. A total of 182 students participated in our research including seven students that failed to follow the stipulated path and one student that failed to finish the pre-walk survey. In both cases these observations were excluded, resulting in 174 students in the final dataset. All students were rewarded financially or with research points for 33 students from the Department of Psychology. As part of ethical clearance, participants were informed that this research was "to understand public preference for urban green spaces as well as the psychological impacts of nature exposure" and no further information about the research questions was provided before and during the experiment.

2.3. Study locations and instructions for walks

A total of nine trips were conducted on weekday mornings between September 2019 and February 2020. On each trip, each participant was randomly assigned to one of eight trails in either the Windsor Nature Park site or the Singapore Botanic Gardens site. These trails consisted of one trail that cut through a primary forest, three trails that cut through secondary forest, two trails within manicured urban parks, and two trails in urban areas nearby the greenspace sites (Fig. 1). Two-way transportation was provided between the University campus and the study sites. Due to logistical constraints, each trip was conducted at either the Windsor Nature Park site (n = 121) or the Singapore Botanic Gardens site (n = 61).

On arriving at the site, participants completed the online pre-survey using their smartphones. Participants were then led by a researcher to the start of their respective trails, all of which were loops and between 600 m-1 km. They were instructed to complete the walk individually in at least 20 minutes. Participants were not given an upper limit of time to complete the walk but knew that the bus was to return to campus 1.5-2 hours from the start of the walk. Participants assigned to the same trail started at one-minute intervals to eliminate the influence of socialization amongst participants on their wellbeing. Participants were told to take the walk at their own pace and observe their surroundings, but no specific instructions were given to minimize a priming effect. As such, biodiversity sightings were based on what they recalled of the walk. After the walk, participants were then instructed to complete the online post-survey using their smartphones at the starting point of their respective trails.

To prevent participants from straying from their instructed trail, we marked the trail with colored ribbons at intersections and provided each participant with a map (Supporting information B4 and B5). Participants were asked to take a picture of a landmark on the trail as evidence that they walked the correct trail.

2.4. Measures

The Positive and Negative Affect Schedule (PANAS) (Watson et al., 1988b) was administered to measure participants' positive and negative affect with *moment* (how they felt in the present moment) as time instruction. The scale was administered before and after the walk to capture changes in participants' positive and negative affect as a result of the walk. The scale comprises of 10 statements each for positive (e.g. interested, excited) and negative (e.g. upset, nervous) affects. Participants rated the extent they felt each emotion on a 5-point Likert scale (1 = very slightly or not at all, 5 = extremely). Separate analyses were conducted for positive and negative affect (see statistical analysis section) on the changes in the average score of each affect between post- and pre-walk.

The Perceived Restorativeness Scale (PRS) (Hartig et al., 1997) was administered only after the walk to assess the perceived restorativeness of the environment during the walk. Participants were asked to rate how much each of the 26 positively- and negatively-worded statements applied to them on a 7-point Likert scale (1 = not at all, 7 = completely). Analyses were conducted using the average score of the 26 items.

A one-way analysis of variance was calculated to detect differences between groups at the beginning of the experiment, i.e. whether the pre-walk positive and negative affect were statistically different between the trails. The reliabilities of these measures (affects and PRS) were assessed using the Cronbach's α using package *psych* (Revelle, 2014) in R.

2.5. Statistical analyses

2.5.1. Nature exposure impact on wellbeing

To investigate which characteristics of the walk experience impacted emotional wellbeing, we conducted linear mixed-effect modelling following the gain-score approach which has been proposed to prevent a regression artifact (Eriksson and Häggström, 2014; Farmus et al., 2019). In each analysis, the outcome variable was the difference between the average score of the positive and negative affect reported after and before the walk.

Explanatory variables included perceived animal diversity and abundance, perceived plant diversity and abundance with statements adapted from Fuller et al., (2007), nature relatedness score (Nisbet et al., 2009) and PRS score. For animals, the participants recalled and estimated the number of species and number of individuals they saw during the walk separately for mammals, birds, lizards/snakes/frogs, butterflies/moths, dragonflies/damselflies, and other animals by selecting from one of the nine options (0, 1, 2, 3, between 4-6, 7-10, 11-20, 21-30, more than 30). Similarly, they recalled and estimated the number of plant species separately for each group: trees, plants that grow on others, and shrubs/herbs by selecting from one of the five options (0, 1-10, 11-20, 21-30, more than 30). For plant abundance, the options were: fewer than 20, 21-50, 51-100, 101-500, and >500 plant individuals. These options were converted into numeric values (e.g. for plant abundance, fewer than 20 individuals was coded as 1, 21-50 individuals as 2, 51-100 individuals as 3, 101-500 individuals as 4, and >500 individuals as 5) and the average of these numeric values were used in the analysis. For nature relatedness, the averaged score from participants' answers to the six statements of the brief nature relatedness (NR) scale (Nisbet and Zelenski, 2013) was used in the analysis.

As confounding variables, we measured walk duration (in minutes, recorded by researchers) and crowdedness level. For crowdedness level, participants recalled how many people they saw during the walk from seven options (<3, 3-5, 6-10, 11-25, 26-40, 41-60, >60). This variable was included as crowding can increase stress and cognitive fatigue (Arnberger and Eder, 2015), thereby may impact restorativeness according to the ART. In addition, participants also provided demographic data before the walk (e.g. gender, ethnicity) to ensure the balanced distribution of such variables across the trails. Saw et al., (2015) found that extraversion is related to subjective wellbeing in Singapore students; therefore we also collected data on the extraversion personality using statements from Gosling et al., (2003) before the walk. Possible differences between the groups to different trails on demographics and extraversion personality were examined using chi-square and one-way ANOVA.

Model selection was conducted following the Information Theoretic approach (Burnham and Anderson, 2002). Model subsets were automated using the *dredge* function in R package *MuMIn* (Barton and Barton, 2015) with NR score present in the fixed component in all subsets. Fixed effects that were correlated (Pearson correlation $r > 0.2$) were not included in the same model to prevent multicollinearity. As a result, variables in the following pairs were not present in the same model subset: animal diversity and animal abundance, plant diversity and plant abundance, animal abundance and plant abundance. Random effects included NR score as the random slope and trail as the random intercept. The random intercept was meant to account for non-independence due to individuals walking the same trail. The random slope was meant to allow individuals assigned to the different trail to have difference in the relationship between their NR level and response variable. We fit random slope and intercept as this practice is recommended when employing the information theoretic approach on hierarchical study designs (Grueber et al., 2011). Model selection was based on the Akaike information criterion. All mixed-effects models were fitted using R with the package *lme4* with *lmerControl* function to enable fitting models with both random slope and intercept (Bates et al., 2012). Following the recommended procedure in Grueber et al., (2011), we estimated the regression coefficients from the top 2AICc of models using the zero method (or full averaging, Barton and Barton, (2015)). To assess whether the analysis achieved adequate statistical power, we performed the post-hoc power analysis using the R package SIMR (Green and MacLeod, 2016) on the best fitting model (lowest AIC).

2.5.2. Nature exposure impact on restoration

We also conducted linear mixed-effect modelling to investigate which characteristics of the walk experience impacted the restorativeness level in walkers. The outcome variable was the average perceived restorativeness score. Explanatory variables included characteristics of the trail (animal diversity, animal abundance, plant diversity, plant abundance, crowdedness level), level of walkers' connection to nature (NR score), and walk duration. Similar to the analysis on wellbeing (positive and negative affect), we conducted model selection following the Information Theoretic approach and the post-hoc power analysis using the R package SIMR (Green and MacLeod, 2016) on the best fitting model.

Since this analysis showed that animal diversity positively correlated with restorativeness (see results section), we further conducted additional post-hoc analyses in which the composite index of animal diversity and abundance was replaced with their components. These components are the respectively reported diversity and abundance of (1) mammals, (2) birds, (3) butterflies, (4) reptiles and amphibians, (5) dragonflies and damselflies, and (6) other animals (such as other insects and fishes) (see supporting information 2 for details).

2.5.3. Mediation effect of restorativeness on subjective wellbeing

We hypothesized that restorativeness had a mediating effect on the relationship between trail characteristics, walk experience, and walkers' characteristics (e.g. NR) and positive and negative affect. To do so, we performed confirmatory path analysis using piecewise SEM using the R package *piecewiseSEM* (Lefcheck, 2016) which allows fitting of hierarchical (mixed-effects) models. The overall model was based on the global models from the positive/negative affect and restorativeness analyses above. Non-significant pathways were removed based on AIC following a backwards stepwise elimination process. SEM models with random intercept and slope could not converge and we simplified the models to only a random intercept. Goodness-of-fit of models were assessed using Fisher's C statistic (Shipley, 2009).

3. Results

An exploratory analysis to check for potential biases in the allocation of participants to trails did not show any pattern. The participants in different trails did not differ by gender (X^2 (7, N = 174) = 8.09, p = 0.32) and ethnic composition (X^2 (7, N = 174) = 4.19, p = 0.76) with in general more (58.05%) female and the majority (85.63%) being Chinese ethnicity. Participants in different trails did not differ significantly in terms of self-reported extraversion (F(7,166) = 0.65, p = 0.72). One-way analyses of variance showed that the pre-walk positive (F(7,166) = 0.95, p = 0.47) and negative affect (F(7,166) = 1.24, p = 0.28) also did not differ across trails. The study measures showed internal consistency reliabilities with Cronbach's α for positive affect were 0.88 and 0.9 respectively for pre- and post-walk, Cronbach's α for negative affect were 0.82 and 0.81 respectively for pre- and post-walk (as compared to values reported in Watson et al., (1988), and Cronbach's α for PRS was 0.92 (as compared to values reported in Korpela et al., (2001).

A power analysis on the best fitting model in the linear mixed-effect modelling on restorativeness suggested that our sample size is sufficient to detect the effect size of animal diversity and nature relatedness (statistical power>0.8 based on 1000 simulations) (Green and MacLeod, 2016). For the remaining analyses, the responses were the within-subject differences between post-treatment and pre-treatment, which gives better control for individual differences as compared to between-subject design, and thus increases statistical power to detect the effects of treatments (Kim, 2010)(Staats and Hartig, 2004). The power analysis on the best fitting model in the linear mixed-effect modelling on wellbeing also indicated that the sample size was sufficient to detect the effect size of PRS score on positive affect (statistical power>0.8 based on 1000 simulations) while the statistical power for time on positive and negative affect were 0.64 and 0.63 respectively.

Participants spent between 15 to 35 minutes on the trail, with a mean of 21.8 minutes (SE = 0.3). On average, participants saw more mammals and butterflies in the manicured trail at Singapore Botanic Gardens site, more birds and other animals in the primary trail at Singapore Botanic Gardens site, and relatively few (between 0 and 1-3 individuals) reptiles, amphibians, dragonflies and damselflies in all the trails. In terms of animal diversity, participants reported seeing more mammal, bird, butterfly species in the manicured trail at Singapore Botanic Gardens site and more of other animal species in both the secondary forest trails at Windsor Nature Park site (Fig. A. a). Participants recalled more individual of plants of all categories (tree, climber, shrub) in the secondary forest trail at Windsor Nature Park site, and fewer plant individuals in the urban trail at Windsor Nature Park site (Fig. A. b).

3.1. Nature exposure impact on wellbeing and restoration

We found that walk duration significantly improved positive affect and reduced negative affect, while PRS significantly improved positive affect (Table 1). There were marginal effects of PRS in reducing negative affect and crowdedness in influencing positive and negative affect when using the natural average method (Grueber et al., 2011) in estimating coefficients from the top 2AICc models (Table 1).

We found that the NR score of the walker strongly improved restorativeness. Perceived animal diversity also improved restorativeness, and this effect was only found when using the composite index of animal diversity (Table 1). The diversity and abundance indices of each animal groups (mammal, bird, butterfly, reptile and amphibian, dragonfly and damselfly, and other animals) individually were not detected to significantly impact restorativeness level (Fig. B.2).

We extracted the random effects from the best models and found that, for the random intercept, manicured and forest trails generally had higher values than urban trails in the models for positive affect and PRS (Figs. B.3 and B.3c). These results suggested that the urban trails had lower contribution to the increase in positive affect and PRS. However, NR score had a dampening effect on the strength of the random effect contribution of the trail; i.e. those with higher NR had less of an increase in positive affect (Fig. B.3a). For negative affect, there was no clear pattern among the random effects estimates which could be due to the high correlation between random slope and intercept (Fig. B.3b).

3.2. Mediation effect of restorativeness on subjective wellbeing

Using Fisher'C statistic (Shipley, 2009), the best-fitting piecewise SEM models met the Shipley's test of directed separation:$C_6 = 2.73$, $p = 0.84$, AIC = 22.73 for negative affect, and $C_6 = 2.75$, $p = 0.84$, AIC = 26.75 for positive affect (Fig. 2).

The best-fitting SEM models showed that higher perceived animal diversity on the trail together with higher nature relatedness of the walker improved PRS, which subsequently impact both positive and negative affect. Significant paths confirm our hypothesis that PRS has a mediator effect on changes in emotional wellbeing (higher PRS is linked to both higher positive affect and lower negative affect), and the direction of effect is consistent with the result of the mixed-effects models. Walk duration significantly improved positive and reduced negative affect. Crowdedness significantly reduced positive affect, though this variable did not have a significant impact on the restorativeness level.

4. Discussion

We find that perceived animal diversity contributes to perceived restorativeness and this, in turn, increases positive affect and decreases negative affect. The finding that higher perceived animal diversity of the trails improves affect is in line with field studies that show higher bird (Cameron et al., 2020) as well as plant and butterfly diversity (Dallimer et al., 2012; Fuller et al., 2007) leads to more positive emotions and studies in which viewing videos of higher number of tree or bird species promotes positive affect and reduces anxiety (Wolf et al., 2017). This result is further corroborated by the random effects in the model whereby forested and manicured park trails, on average, led to higher positive affect and PRS than urban trails. Different to previous studies, we find that the changes in emotional wellbeing due to biodiversity are explained by an indirect pathway with the mediation role of perceived restorativeness, while previous studies report a direct correlation [except for Carrus et al., (2015)]. One possible explanation is that these studies did not investigate both direct and indirect pathways. In addition, our research employs a pre- and post-walk design to measure the changes in mood as a result of nature walk, while research that collect cross-sectional emotional wellbeing data (i.e. approach park users) does not have a baseline for calculating changes.

These results agree with Marselle et al., (2016) that investigated the effects of perceived bird/butterfly/plant diversity on emotional wellbeing through perceived restorativeness. They found positive indirect effects for perceived bird diversity, but no significant indirect effects for plant and butterfly diversity. On the other hand, we found the effects to be significant only when using a composite index of animal diversity, not when using diversity index of individual animal group. This different results may be due to Marselle et al. (2016)

conducting group walks, while this study used solitary walks to minimise the possible social effects, such as discussing about certain animal group among walkers. In addition, Staats and Hartig, (2004) found that participants reported higher restorative effects when walking alone, rather than in the company of a friend, in a natural environment. Similarly, Johansson et al., (2011) found that the affective state of revitalisation increased during park walks when alone than when with a friend. Therefore, results from Marselle et al.'s (2016) study may have been influenced by its design of having a group walk. A second difference is that, while Marselle et al. (2016) conducted their study on a sample of participants who were 55 years or older, we studied a sample of undergraduate students. Another possible reason why we found a relationship between animal diversity in general with perceived restorativeness and affect but not when we considered more disaggregated individual diversity groups is the a limited sample size and walk duration, making the number of animal encounters for specific groups low. The low number of encounters with specific animal groups might thus be subjected to stochasticity preventing us from observing reliable patterns.

That perceived animal diversity contributes to an increase in positive affect and a reduction in negative affect has implications for public health, linking ecosystem health to human health. The broaden-and-build theory of positive emotions posits that positive emotions may enhance resilience against stress through the mediating role of coping strategies, and can subsequently attenuate the impact of stress on anxiety and depressive symptoms (Gloria and Steinhardt, 2016; Ong, 2010). Increased positive emotions have also been demonstrated to account for individuals' ability to recover effectively from stress and ward off depression (Fredrickson et al., 2003; Ong et al., 2006; Tugade and Fredrickson, 2004). Furthermore, negative affect has been consistently found to be correlated with symptoms and diagnoses of depression and anxiety (Watson et al., 1988a). As such, greater positive affect provided by animal diversity would have large beneficial impacts on one's psychological health.

We found that nature relatedness significantly improved the experience of restorativeness; and our SEM results supported its indirect and positive connection to improve positive and negative affects via the mediation role of restorativeness. Taken together, this study suggests that people's psychological response to nature exposure also depends on their subjective connection to nature. As a trait-like between-person difference (Capaldi A. et al., 2014), nature connectedness has been shown to correlate with various measurements of happiness such as positive affect (Mayer et al., 2009; Zelenski and Nisbet, 2014), life satisfaction (Mayer and Frantz, 2004; Zelenski and Nisbet, 2014), eudaimonic wellbeing (Pritchard et al., 2020; Zelenski and Nisbet, 2014) and with lower level of anxiety (Martyn and Brymer, 2016). The link between nature relatedness and psychological wellbeing has been relatively well-studied in Western populations (see review by (Capaldi A. et al., 2014; Pritchard et al., 2020), and our study supports this link in a predominantly Asian population.

The finding (from our SEM result) that walking duration significantly improves the positive affect and reduces the negative affect of walkers agrees with the concept of nature dose. Recent literature has likened the impact of nature exposure to health therapies that deliver different levels of physical and psychological benefits depending on the dose of nature (Cox et al., 2017). Overall, existing evidence points to a positive association between nature visit duration and subjective wellbeing, such as an increase in feelings of restoration (White et al., 2013), positive affect (Marselle et al., 2013), life-satisfaction (Yuen and Jenkins, 2020), and a decrease in perceived stress (Marselle et al., 2013). Positive response to nature dose has been reported to arise at a threshold, and reach a peak from which health increment becomes marginal. For example, improvement of wellbeing following nature walks can be obviously detectable at the dose of 20.5 min (Yuen & Jenkins, 2020). Studies in UK population report that spending at least 10 minutes a week in a garden could prevent depression (Cox et al., 2017), while health and wellbeing start to improve at 120 minutes a week of contact with nature, and this positive association peaks at 200-300 minutes in a week (White et al., 2019). Our result thus corroborates the nature dose-response framework.

Our study reports a direct impact of crowding in reducing the increase in positive affect in the walk experience. Previous research have reached similar conclusion of human's preference for less crowdedness level when visiting outdoor greenspaces (Arnberger et al., 2010), especially when seeking stress relief (Arnberger and Eder, 2015). For example, respondents in a study in Denmark were willing to travel 4 km more to reach less crowded locations when engaging in recreational activities (Bakhtiari et al., 2014).

Overall, our study shows that the emotional wellbeing response following a nature walk depends on multiple elements: the quality of nature to which humans are exposed (high animal diversity, low level of crowdedness), the orientation of the walkers themselves (high nature relatedness), and the dose of the nature exposure (longer duration of the walk). For the public to fully reap the benefits of the visits of outdoor green spaces, park managers and urban planners could focus on improving the animal diversity of the green space, such as by diversifying the habitat types within a landscape and introducing biodiversity enhancing measures to maximize the diversity of animals in the green space. These interventions could be coupled with environmental education. Our results show that nature relatedness plays an important role in perceived restorativeness and subsequently the affect. Though nature relatedness can be considered a consistent between-individual trait across time and situations (Nisbet et al., 2009), it is not fixed and can be enhanced. For example, environmental education programmes such as engagement with nature campaigns increase both connection to nature and pro-nature behaviours in adults (Richardson et al., 2016). Similarly, such education programmes have been effective in increasing different measures of connection to nature in children (Ernst and Theimer, 2011) and emotional affinity toward nature (Collado et al., 2013). The enhancing on connectedness to nature can be impactful, such as people whose family nurture a love for nature and grow up in the vicinity of natural places also score higher in NR scale (Windhorst and Williams, 2015).

Our findings on perceived animal diversity linked to emotional wellbeing are a step forward among research employing pre- and post-walk designs to study the psychological benefits of nature exposure. These studies traditionally treat nature without differentiated typologies, with the typical setting of treatment vs control sites (Martens et al., 2011; South et al., 2015) with small number of trails (e.g. Takayama et al., (2014)) and simple categorizations [such as "high" and "low" biodiversity levels (Carrus et al., 2015). Our study comes to also contribute to a dearth of studies on the psychological impacts of nature walks in tropical landscapes and Asian populations.

Our study has several limitations. The walks were conducted for a relatively short duration of time, although this duration has been suggested as sufficient for the accurate estimation of changes to subjective wellbeing following a park visit (Yuen and Jenkins, 2020). In addition, there could also be a link between walk duration and nature relatedness as participants who enjoy nature more chose to spend more time in the walk, resulting in an increase in emotional wellbeing. Finally, the sampling population consists of students of similar age, educational level, and probably health conditions which limits the generalizability of the findings. Therefore, future research could consider a longitudinal design to explore how walk duration impacts wellbeing and the duration of such impact while controlling for the level of nature relatedness of the participants.

5. Conclusion

Our results show that perceived animal diversity of the environment and nature relatedness of the individual contribute to perceived restorativeness. Perceived restorativeness, in turn, increases positive affect and reduces negative affect. Taken together, these results suggest that perceived restorativeness mediates in the relationship between perceived animal diversity and affects. This result is important given that high positive affect and low negative affect attenuate the risk of anxiety and depression. These results create a bridge between the seemingly unrelated disciplines of biodiversity conservation and public health, highlighting the importance of maintaining biodiverse urban ecosystems to contribute to the mental health of urban dwellers.

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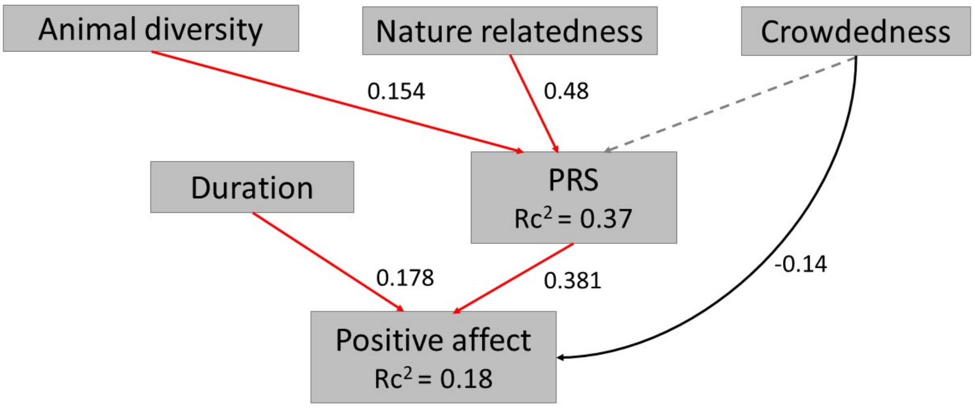
Figures and Tables

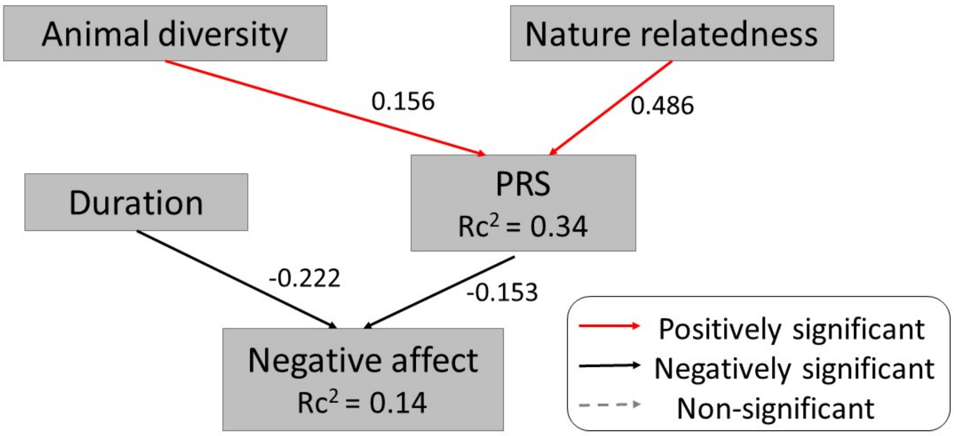
Figure 1. Map of Singapore with scenes from study locations. Site 1 (Windsor Nature Park): secondary forest trails (SF_S1.1, top left, n=23 and SF_S1.2, top right, n=30), manicured trail (M_S1, bottom left, n=34), and urban trail (U_S1, bottom right, n=27). Site 2 (the Singapore Botanic Gardens): primary forest trail (PF_S2, top left, n=15), secondary forest trail (SF_S2, top right, n=14), manicured trail (M_S2, bottom left, n=16), and urban trail (U_S2, bottom right, n=15).

Table 1. Model averaging of the top 2AICc linear mixed-effect models. The table shows averaged coefficient values and standard errors (SE) of the fixed effects. Variables significant at $p<0.05$ are in bold.

Variables	**Negative affect**		**Positive affect**		**PRS**	
	Coefficient (SE)	p-value	Coefficient (SE)	p-value	Coefficient (SE)	p-value
PRS	-0.315 (0.35)	0.37	**2.274 (0.527)**	**<0.0001**	-	-
Crowdedness	0.099 (0.178)	0.58	-0.449 (0.407)	0.27	0.024 (0.043)	0.57
Duration	**-0.158 (0.061)**	**0.01**	**0.254 (0.108)**	**0.02**	-0.005 (0.011)	0.65
Nature relatedness (NR)	-0.161 (0.333)	0.63	0.299 (0.591)	0.62	**0.58 (0.08)**	**<0.0001**
Plant abundance	0.081 (0.194)	0.68	0.1 (0.294)	0.73		
Plant diversity			-0.381 (0.745)	0.61	0.012 (0.047)	0.8
Animal abundance			0.072 (0.376)	0.85		
Animal diversity					**0.237 (0.09)**	**<0.01**



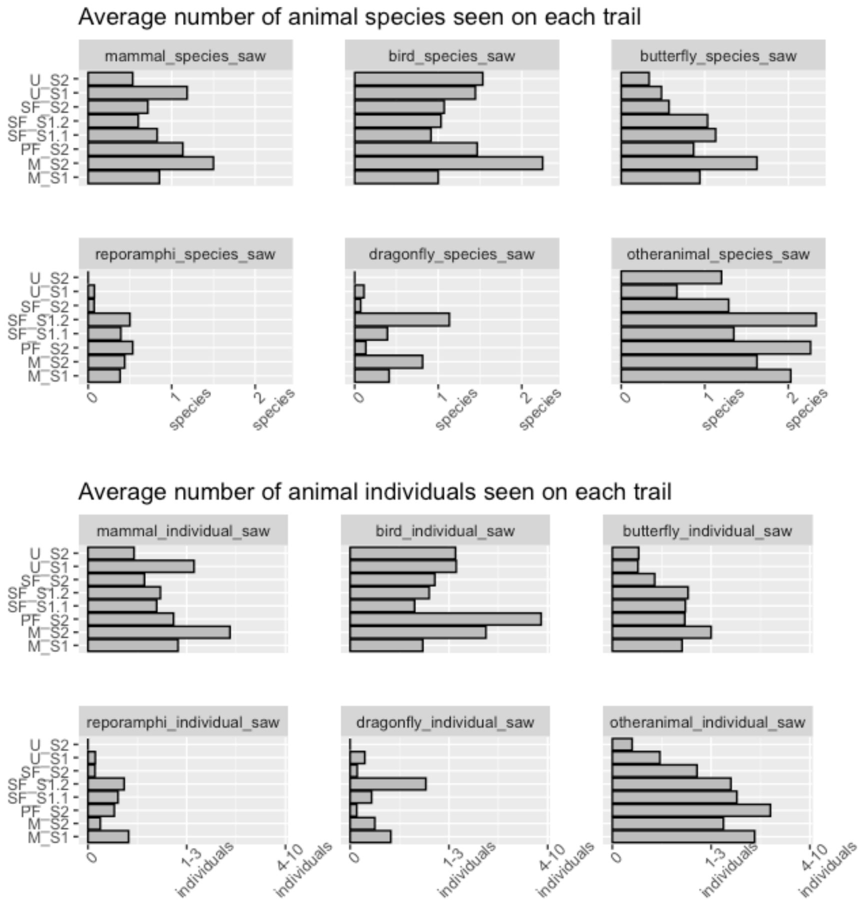
(a)



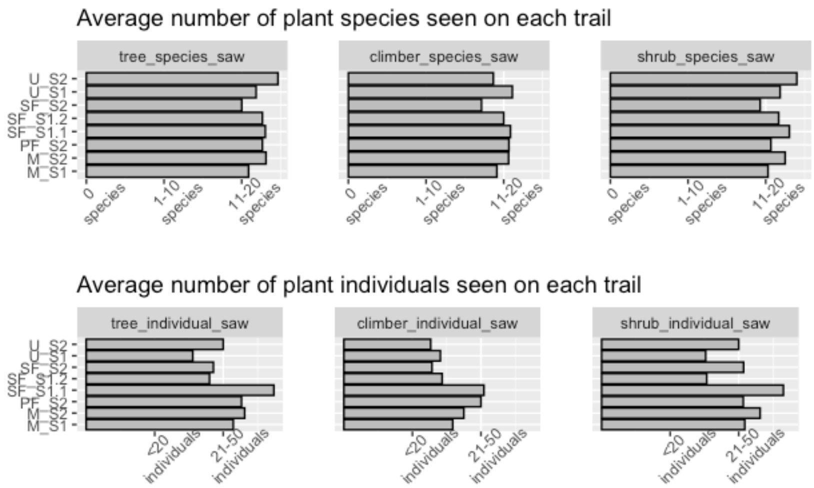
(b)

Figure 2. Results of the best piecewise SEMs based on AIC values analysing the relationship between walk characteristics and (a) change in positive affect and (b) change in negative affect with the mediation role of restorativeness. Numbers next to arrows show regression coefficients of the significant variables. Conditional R^2 values (Rc^2) for response variables are presented.

Supporting Information



(a)



(b)

Figure A. Average number of (a) animal species and animal individuals and (b) plant species and individuals seen by subjects on each trail, divided by animal groups where M_S1: manicured trail at Windsor Nature Park (WNP) site, U_S1: urban trail at WNP site, SF_S1.1 and SF_S1.2: secondary forest trails at WNP site, M_S2: manicured trail at the Singapore

Botanic Gardens (SBG) site, U_S2: urban trail at the SBG site, SF_S2: secondary forest trail at the SBG site, PF_S2: primary forest trail at the SBG site.

Table B.1: Model average of the top 2AICc linear mixed-effect models using the natural average approach (Grueber et al., 2011) (or conditional averaging, Barton and Barton (2019)). The table shows averaged coefficient values and standard errors (SE) of the fixed effects. Variables significant at $p<0.05$ are in bold.

Variable	**PANAS negative**		**PANAS positive**		**PRS**	
	Coefficient (SE)	p-value	Coefficient (SE)	p-value	Coefficient (SE)	p-value
PRS	-0.53 (0.03)	0.08	**2.274 (0.527)**	**<0.0001**		
Crowdedness	0.271 (0.2)	0.18	-0.632 (0.342)	0.07	0.065 (0.048)	0.18
Duration	**-0.158 (0.061)**	**0.01**	**0.254 (0.108)**	**0.02**	-0.016 (0.015)	0.28
Nature relatedness (NR)	-0.161 (0.333)	0.63	0.299 (0.591)	0.62	**0.58 (0.08)**	**<0.0001**
Plant abundance	0.247 (0.27)	0.37	0.576 (0.468)	0.22		
Plant diversity			-1.189 (0.878)	0.18	0.082 (0.097)	0.4
Animal abundance			0.674 (0.958)	0.49		
Animal diversity					**0.238 (0.09)**	**<0.01**

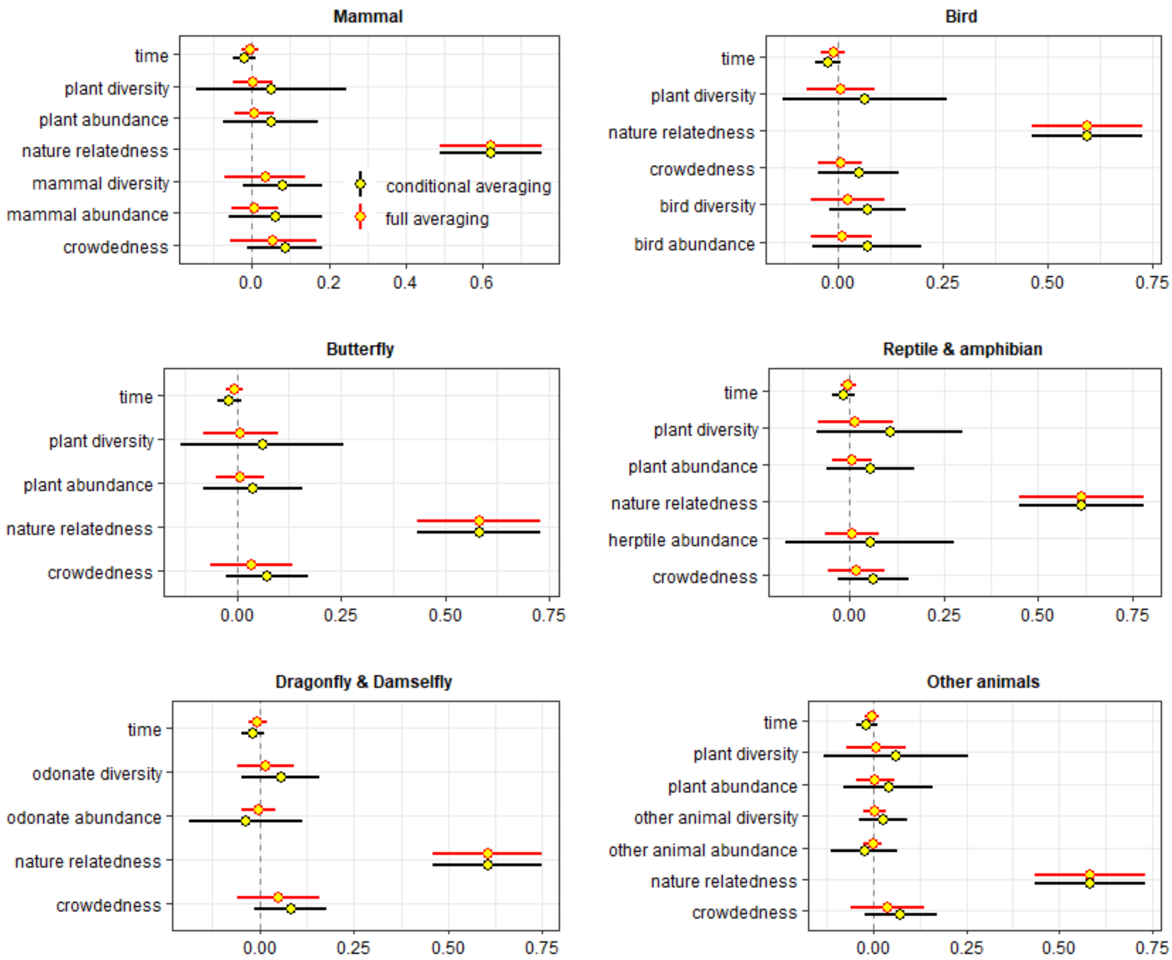
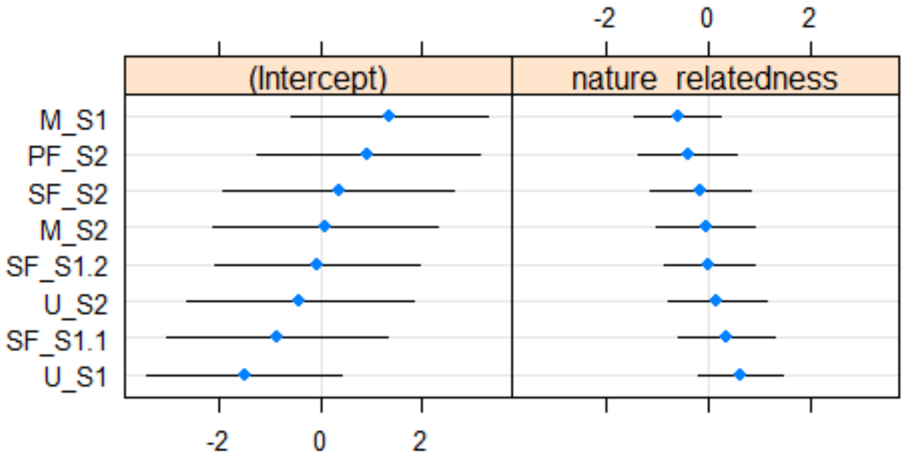
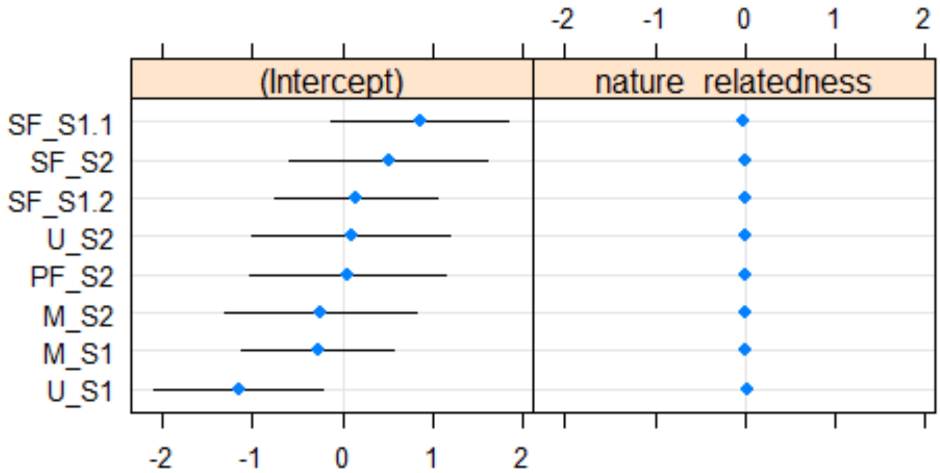


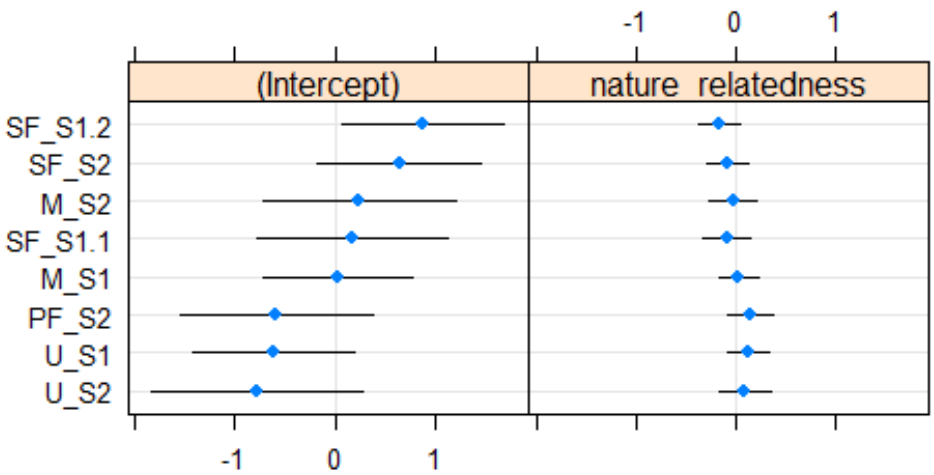
Figure B.2: Model results when the composite index of animal richness and abundance indices was replaced with its components (mammal, bird, butterfly, reptile & amphibian, dragonfly & damselfly and other animals richness and abundance).



(a)



(b)



(c)

Figure B.3: Coefficients with 95% confidence interval of the random intercept (trail) and slope (nature relatedness) from the lowest AIC models, of which the outcome variables are (a) positive affect, (b) negative affect, (c) PRS.

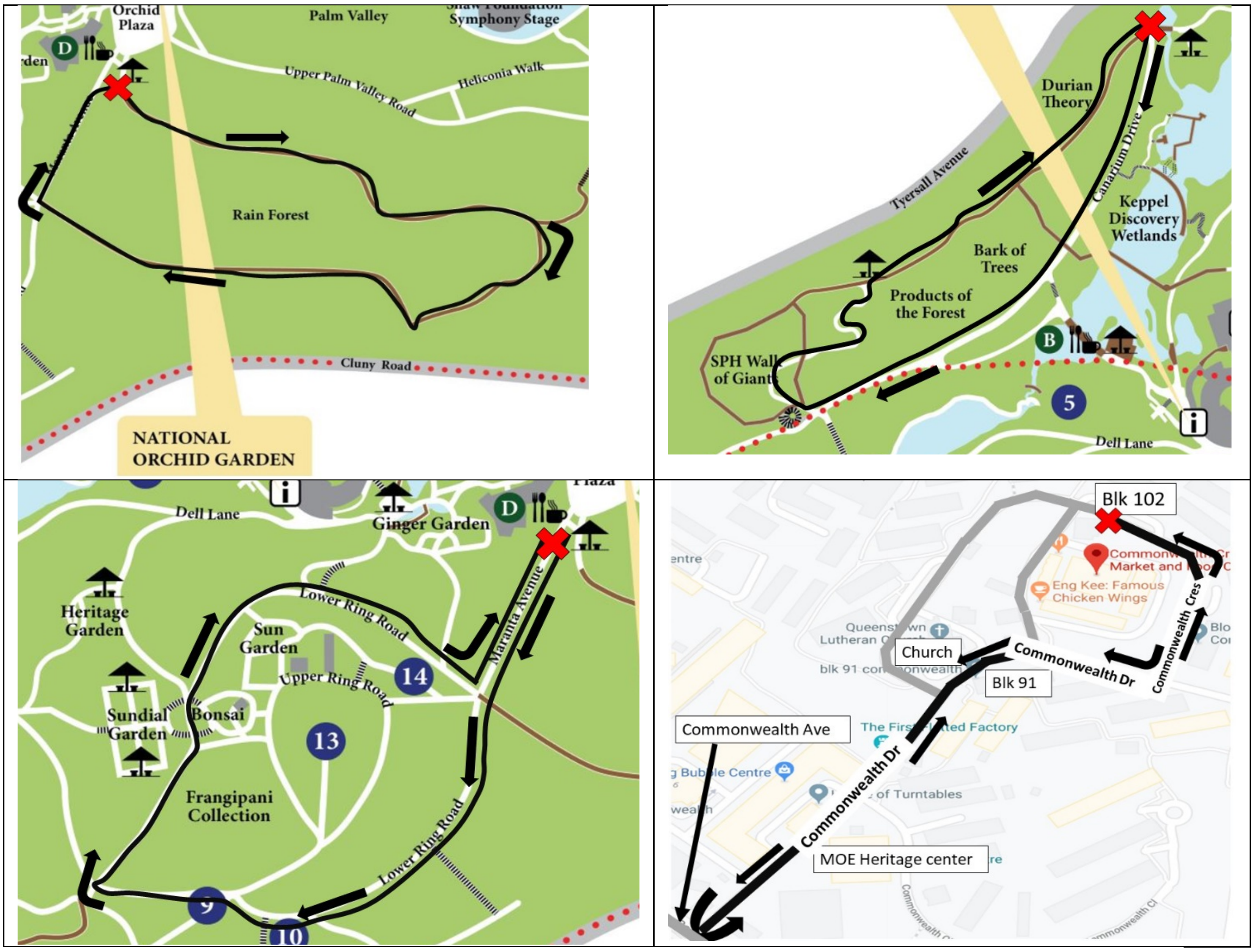


Figure B.4. Trail maps provided to the participants in the Singapore Botanic Gardens site: primary forest trail (PF_S2, top left), secondary forest trail (SF_S2, top right), manicured trail (M_S2, bottom left), and urban trail (U_S2, bottom right)

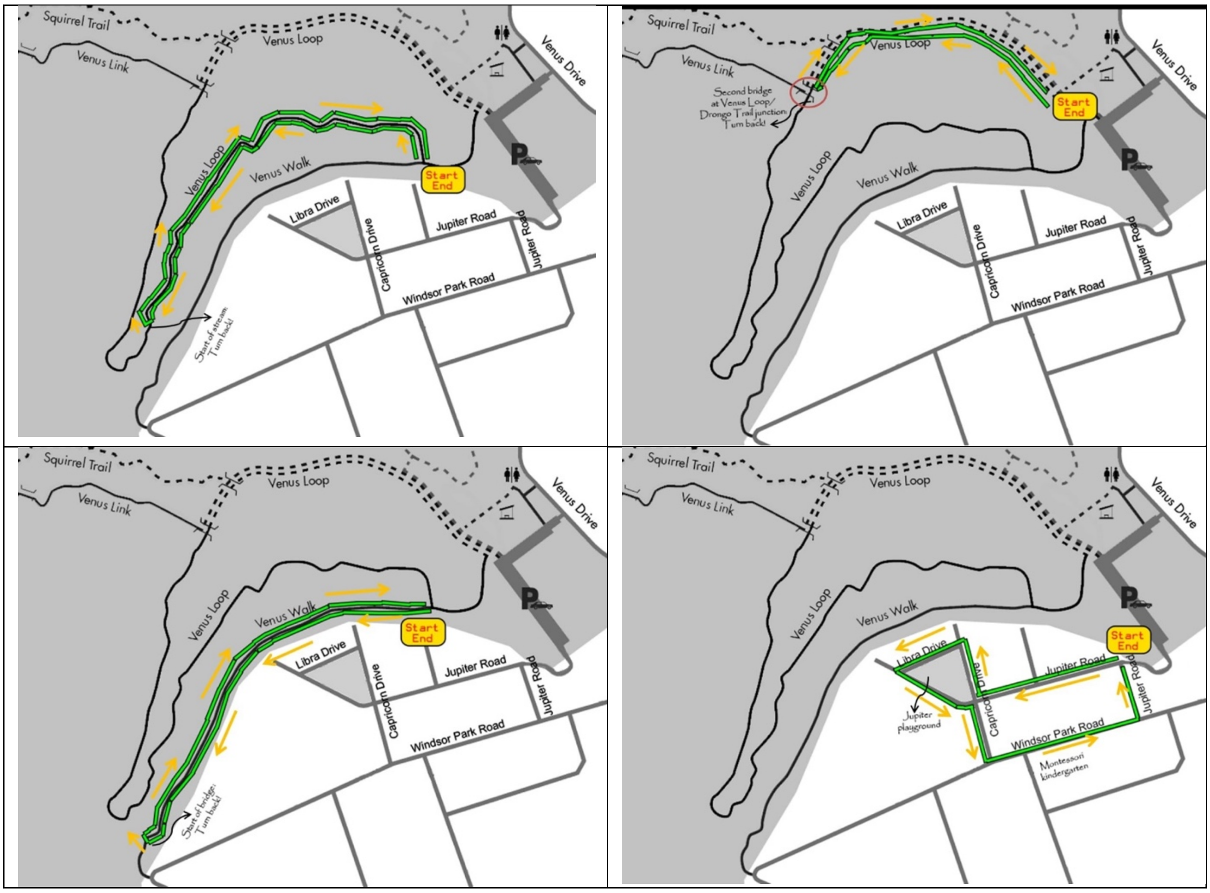


Figure B.5. Trail maps provided to the participants in the Windsor Nature Park site: secondary forest trails (SF_S1.1, top left, and SF_S1.2, top right), manicured trail (M_S1, bottom left), and urban trail (U_S1, bottom right)