Title: Variation in experiences of nature across gradients of tree cover in compact and sprawling cities

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Abstract

Urban environments are expanding globally, and by 2050 nearly 70% of the world's population will live in towns and cities, where opportunities to experience nature are more limited than in rural areas. This transition could have important implications for health and wellbeing given the diversity of benefits that nature delivers. Despite these issues, there is a lack of information on whether or how the experience of nature changes as green space becomes less available. We explore this question for residents of two case study cities of varying urban designs, sprawling (Brisbane, Australia) and compact (three English towns, U.K). Second, we examine how people's feelings of connection to nature (measured using the Nature Relatedness scale) vary across this same gradient of nature availability. Despite climatic and cultural differences we found substantial similarities between the two locations. Lower levels of neighbourhood tree cover were associated with a reduced frequency of visits to private and public green spaces, and a similar pattern was found for the duration of time spent in private and public green spaces for Brisbane. Residents of both urban areas showed similar levels of nature relatedness, and there was a weak but positive association between tree cover and Nature Relatedness. These results suggest that regardless of the style of urban design, maintaining the availability of nature close to home is a critical step to protect people's experiences of nature and their desire to seek out those experiences.

1. Introduction

With nearly 70% of the global population predicted to live in cities by 2050 (United Nations, 2014), there is growing concern that urbanisation is driving a broad-scale 'extinction of experience' with the natural world, ultimately resulting in a disconnection between people and nature (Miller, 2005; Pyle, 1978; Soga and Gaston, 2016). This trend is particularly important given the growing body of evidence demonstrating the link between interactions with nature and positive physical, psychological and social wellbeing outcomes (Hartig et al., 2014; Keniger et al., 2013; Shanahan et al., 2015b). The extinction of experience has two fundamental components; a physical decline in the quantity or quality of nature in cities (i.e. the 'intensity' of nature experiences; Shanahan et al., 2015a), and changes in human behaviour associated with urban life-styles (including reduced frequency and duration of nature experiences; Lin et al., 2014; Miller, 2005; Shanahan et al. 2015a).

The physical impact of urbanisation on biodiversity has received considerable attention from urban ecologists, with studies documenting significant variation in species richness and abundance across different urban forms, but with a general decrease relative to natural habitat (e.g. Catterall, 2009; McKinney, 2002). Furthermore, whether a city has a sprawling or compact design is also known to influence the availability of nature around people's homes (Soga et al., 2014), as sprawling designs generally ensure ready access to relatively large private gardens, while in contrast compact city designs can reduce wider biodiversity loss and deliver greater accessibility to public green spaces (Sushinsky et al., 2013). However, few studies have explored the behavioural component of the extinction of experience of nature; specifically, how does the frequency or duration of experiences with nature vary with variation in availability of nature? Does this differ for cities with sprawling and compact designs?

The behavioural component of the extinction of experience of nature is likely to be driven by many complex and interacting factors. For example, urban residents spend greater periods of time indoors or engaged in recreational activities that are not nature-based (Juster et al., 2004; Sigman, 2012). Furthermore, variation in the availability of nature within cities could conceivably affect people's ability and inclination to engage with it. For example, people may more actively seek out nature (both within public and private spaces) as it becomes less available in their day-to-day living environment, perhaps motivated by the potential wellbeing benefits (Home et al., 2012). However, other research suggests that patterns of green space use simply reflect its availability (Gong et al., 2014; Kaczynski et al., 2014), with some influence of interacting factors such as gender, age or socio-economic advantage (Jones et al., 2009; McCormack et al., 2010). As such, characteristics of urban form, such as whether a city is sprawling or compact could influence nature interactions (Gaston et al., 2005; Lin et al., In review). Exploration of these potential patterns warrants considerable attention. Whether or not people alter their behaviour to compensate for a lower availability of nature in their living environment will have important implications for how cities are designed to accommodate the rapidly growing urban population.

Ultimately, variation in exposure to nature may not only affect urban residents' wellbeing, but also their attitudes and behaviours towards nature itself (Miller, 2005; Pyle, 1978; Soga and Gaston, 2016). There is some evidence, for example, that experiences with nature as a child correlate with environmental activism or environmental career pathways in adult life (e.g. Wells and Lekies, 2006), and wilderness experiences appear to influence a person's world-view (Kaplan and Kaplan, 1989). This has potential implications for the support of nature conservation by urban residents (Miller, 2005; Pyle, 1978); how can people value what they do not experience or understand?

However, a key unresolved issue is whether the availability of nature in the local environment is associated with people's orientation towards nature.

This study explores whether the availability of nature is related to nature experience and orientation towards nature for urban residents. Specifically, we first examine the association between urban residents' frequency and duration of nature interactions across a gradient of percentage neighbourhood tree cover. Second, we scrutinise whether people's levels of connection to nature (measured using the Nature Relatedness scale) vary across that same gradient. We address these questions for two case-study locations of contrasting urban design; specifically Brisbane, Australia, with sprawling urban development around a central business district, and the 'Cranfield Triangle', U.K., which is a cluster of three compact urban centres.

2. MATERIALS AND METHODS

2.1 Study locations

This study was undertaken in Brisbane, Australia (27°27'S 153°01'E, population 1.1 million people), and the Cranfield Triangle, United Kingdom (52°07'N, 0°61'W, Milton Keynes, Luton and Bedford, population c.524 000 people; Fig. 1). Brisbane is a subtropical sprawling city with considerable amounts of public green space distributed rather evenly both spatially and socio-economically (Shanahan et al., 2014), and a population density of approximately 1200 people per km^2. The urban centres of the Cranfield Triangle are located in a temperate region with compact urban form and a denser population (around 3100 people per km^2), surrounded by open countryside. There are climatic differences between the locations; in the survey period the Cranfield Triangle had a maximum temperature of 18.7°c and minimum 9.0°c with 39.6mm rainfall, and the Brisbane maximum was 34.4°c, minimum 14.1°c, with 116.8mm rainfall (Bureau of Meteorology, 2015).

Properties in the Cranfield Triangle have a lower average residential plot size (278 m^2 vs 769 m^2 in Brisbane). Both locations are primarily English speaking, but there are likely to be a range of cultural differences between the sites.

2.2 Population surveys

We conducted an urban lifestyle survey during late spring on 1538 respondents in Brisbane and 519 respondents in the Cranfield Triangle (Brisbane, November 2012; Cranfield Triangle, May 2014), approximately 0.1% of the population for both locations. The survey was delivered online over a two-week period through market research companies (Brisbane, Q&A Market Research Ltd; UK, Shape the Future Ltd) to a subset of adults (18 years +) enrolled in their survey databases. We collected several socio-demographic and personal circumstance variables that could influence exposure to nature including age, gender, the primary language spoken at home (an indicator of ethnicity), personal annual income and highest formal qualification (Table S1 shows the classifications within these groups for analysis purposes, and Appendix C includes the full survey). The demographic and socio-economic survey group was comparable for the two locations (Table S2). Participants were requested to provide their address, or their approximate address if they preferred for privacy reasons.

Survey respondents provided a measure of their orientation to nature using the Nature Relatedness scale (Nisbet et al., 2009). The scale has been shown to correlate with environmental attitudes, and also differentiates between groups of nature enthusiasts and those who do not engage in nature experiences (Nisbet et al., 2009). Respondents rated a set of 21 statements using a five-point Likert scale ranging from one (disagree strongly) to five (agree strongly), and these responses were aggregated according to Nisbet et al. (2009). Collectively the components of the scale measure the affective, cognitive, and experiential relationship with the natural world, with a higher score indicating a stronger orientation towards nature. We also separated the nature relatedness scale into three established components (Nisbet et al., 2009): NR-Self, which can be thought of as the ecological self, or how strongly people identify with the natural environment; NR-Perspective, which is an indication of how a person's personal relationship with the environment is manifested through attitude and behaviour; and NR-Experience, which reflects the physical familiarity and attraction people have to nature.

2.3 Nature dose frequency and duration

For each respondent we generated two measures of nature dose (frequency and duration) for both private gardens and public green spaces, two settings in which experiences with nature are common. Frequency was estimated based on the respondent's self-reported usual frequency of use of their private garden or of visits to public green spaces, and duration was estimated based on self-reported total time spent within each location during the week of the survey. Given the more frequent use of private gardens indicated from preliminary survey outcomes, more categories were used at the finer time scale (Table S3 provides details on the categories that could be selected for both public and private spaces). For all duration measures, the mid-points of the selected categories for all public green space visits were summed (where 4 or more hours was treated as '4'). All four measures of nature dose were treated as ordinal.

2.4 Nature dose intensity

We used tree cover equal to or that exceeding 2 m in height as a measure of the availability of nature (or nature intensity) around the home. We measured neighbourhood tree cover within a 250 m buffer around each respondent's address location, approximately reflecting the viewscape from, and the area immediately adjacent to, people's homes. Trees are a highly visible component of nature, and are found throughout the urban matrix at both locations. The presence of trees also provides a reasonable indicator of many other aspects of biodiversity (e.g. birds, Sandström et al., 2006), and as tree cover increases several studies have recorded increases in well-being as shown by a reduction of stress and asthma, and increased feelings of psychological restoration (Dallimer et al., 2012; Fuller et al., 2007; Jiang et al., 2014; Lovasi et al., 2008). The tree cover maps used here were derived from airborne Light Detection and Ranging (LiDAR) data for both regions, alongside Normalized Difference Vegetation Index (NDVI) for the U.K.; full details of their development are provided in the Appendix (Appendix A; Armston et al., 2009). We restricted the analysis to the core populated areas of the Brisbane City Council area (i.e. excluding outlying islands and large nature reserves), and for the Cranfield Triangle the extent of the towns was estimated using the Ordnance Survey MasterMap Topography Layer (Updated Jan 2015) to develop a polygon for each town that surrounded all the residential and commercial land plots. We finally generated an estimate of mean size of residential plots (i.e. area encompassing the main house, any out buildings, and garden if present) for Brisbane and the Cranfield Triangle. In Brisbane these areas were manually delineated for respondents who provided their exact address using Google Maps, and in the Cranfield Triangle we used the Ordnance Survey MasterMap™ Topography Layer to digitise polygons around the boundaries of two residential properties within each respondent's postcode, before calculating the area (m^2) within each polygon. Data extraction was performed in ArcGIS v10.3 (ESRI, 2015) and QGIS v2.6 (Quantum GIS Development Team, 2015).

2.5 Analysis

All statistical analyses were carried out in R (version 3.1.2; R Development Core Team, 2014). We examined the relationship between and neighbourhood tree cover and first the frequency and then the duration of nature dose within private gardens and within public green spaces (response variables), using ordinal logistic regression (Ordinal package version 2015.6-28; Christensen, 2015). We incorporated age, gender, ethnicity, income and formal education level (highest qualification) as covariates. We then applied an Information Theoretic approach that simultaneously evaluates hypotheses by balance between model complexity and goodness of fit (Burnham and Anderson, 2002). We used the MuMIn package (Bartoń, 2015) to model all possible combinations of variables in turn against each response variable, with the models fitted and ranked on the basis of the weights w_i of the Akaike's Information Criterion (AIC) corrected for small sample sizes (AICc). Following Richards (2005) and to be 95% sure that the most parsimonious models were maintained within the best supported model set, we retained all models where the AICc < 6. We then used model averaging to produce the average parameter estimates and associated standard errors (Burnham and Anderson, 2002). Second, we examined how respondents' Nature Relatedness scores (both overall and the three components) varied with neighbourhood tree cover using model averaged linear regression, and again accounted for the additional covariates in the model including age, gender, ethnicity, income and formal education level.

3. RESULTS

A similar proportion of survey respondents had access to their own garden (91.6% in Brisbane, 93% in Cranfield Triangle). A greater percentage of respondents living in Brisbane used private gardens, but more Cranfield Triangle residents used public green spaces (Fig. 2). For both cities we found a positive relationship between the level of tree cover surrounding a person's home and the frequency of garden use during the week the respondent completed the survey, and in Brisbane only there was a significant relationship with the total duration of that use (Table 1; Fig. 3). We found a similar positive relationship between tree cover and the duration of visits to public green spaces, but the frequency of visits was significant for the Cranfield Triangle but not Brisbane. A range of other factors clearly correlated with the exposure of people to nature in both locations. Specifically, a person's level of formal education and age were significant across many models, with those in the second salary quartile in Brisbane less likely to visit public green spaces; ethnicity was also an significant predictor of garden use in Brisbane (Table 1).

Overall, Nature Relatedness scores were significantly higher in the sprawling city of Brisbane, with an average of 3.47 (standard error = 0.02) in comparison with 3.37 (standard error = 0.02) in the more compact Cranfield Triangle ($t = 3.45$, $df = 1002$, $p < 0.001$). In both cases we found a significant, but weak positive relationship between Nature Relatedness scores and tree cover that held even after adjusting for socio-demographic covariates (Table 2 & Fig. 4, Brisbane $R^2 = 0.07$, $p < 0.001$; Cranfield Triangle $R^2 = 0.07$; $p < 0.001$). We found that the results varied for the three factors within the Nature Relatedness scale. Specifically, NR-perspective had a significant relationship with tree cover in Brisbane, whereas NR-self and NR-experience factors were significant for the Cranfield Triangle.

4. DISCUSSION

4.1 Experiences of nature

Here we have mapped how experiences of nature vary across a gradient of neighbourhood vegetation cover. We show that people's propensity to engage with nature is lower in neighbourhoods with poorer physical availability of tree cover. Given the range of health and wellbeing benefits that people can gain from nature via both passive pathways (e.g. temperature regulation or pollution reduction; Donovan et al., 2013) and those that require nature interactions (e.g. relief from mental fatigue, reduced stress and improved cognitive function; e.g. Berman et al., 2008; Kaplan and Kaplan, 1989), these differences could lead to long-term health inequalities.

People who live in nature-poor neighbourhoods visited both private and public green spaces less frequently, and for a shorter duration than those living in more vegetated neighbourhoods. This effect could have arisen for a range of non-mutually exclusive reasons. First, people who enjoy spending time outdoors may ‘self-select’ by electing to move into neighbourhoods that are greener, or by actively working to create a greener living environment. Indeed, there is some support for this in our study as Nature Relatedness scores of respondents showed a positive correlation with tree cover. Moreover, people who have a higher Nature Relatedness score are also more likely to visit more natural public green spaces (Shanahan et al., 2015c). Thus, it remains unclear whether a person’s connection to nature is shaped by the environment they live in, whether they move to a neighbourhood that reflects this trait, or whether it is some combination of these factors. Population-level studies that explore how attitudes to nature change as people move between neighbourhoods, or as neighbourhoods themselves change over time, would provide valuable insight into this issue on causality. A second explanation is that the nature present within neighbourhoods creates an environment that is more conducive to spending time outdoors (Shanahan et al., 2015b). This is particularly likely to be a contributing factor in sub-tropical locations such as Brisbane, where vegetation provides important climate regulation services including shade and temperature regulation. However, several studies have now shown that simply having green space available within a neighbourhood is insufficient to guarantee its use by local residents (Cohen et al., 2010; Lin et al., 2014). This study supports these results, suggesting that interventions that aim to improve people’s nature dose might be best focused on enhancing their connection with nature, perhaps in concert with enhancing the availability and quality of green spaces spaces in cities.

4.2 Differences between sprawling and compact cities

We observed surprising similar relationships between engagement with nature and the availability of tree cover for both the sprawling (Brisbane) and compact (Cranfield Triangle) urban case studies examined here. This is despite the considerable climatic and cultural differences between these two locations. These results suggest that there may be a consistent trend towards a reduction in nature experiences as it becomes less available; however, further studies in additional cities would be required to further tease out the various factors that could contribute to patterns in nature experiences. These results also suggest that neither approach to city growth is immune from the extinction of experience with nature. Urban sprawl is a major facet of urbanization in countries such as the US and Australia, and there is a range of arguments as to the benefits and costs of this development for both people's way of life and biodiversity. For example, in some instances urban sprawl has been shown to have a negative impact on biodiversity as it can extend into higher quality habitats both within and on the outskirts of cities (Sushinsky et al., 2013), and it can also have a negative impact on people's way of life as commute times grow (Rydin et al., 2012). Yet there are also instances where urban sprawl could lead to biodiversity gains, for example in the UK countryside where the agricultural landscape is already highly disturbed (e.g. Robinson and Sutherland, 2002).

An additional interesting pattern observed in this study was that despite the much higher population density in the Cranfield Triangle, a similar proportion of households had private gardens to the Brisbane sample. Though these gardens were much smaller, they had similar levels of use in both locations. Likewise, Syme et al. (2001) found that residents with small lot developments in Perth, Australia, did not visit local green spaces any more than did residents with larger lots. This suggests that compact development can be achieved in a way that maintains ready access to nature in the form of a private garden or backyard, albeit a relatively small one, and these spaces can be as important for enabling interactions with nature.

Ultimately the variation in nature dose observed here has the potential to lead to a decline in attitudes towards nature (Miller, 2005; Pyle, 1978). Indeed, though the relationship was weak, we did show that city residents Nature Relatedness scores were lower where there were lower levels of nature in the surrounding neighbourhood. This overall pattern was markedly similar for both sprawling and compact urban designs, but the components of Nature Relatedness showed different patterns. Specifically, in the Cranfield Triangle only the perspective factor showed a correlation with tree cover, whereas both the self and experience factors were significant for Brisbane. There could be a range of reasons for these trends, for example, differences in education of the surveyed population could cause differences in the attitudes and values associated with nature (i.e. Nature Relatedness Perspective), whereas cultural differences might drive the observed variation in Nature Relatedness self or experience. Exploring these differences in full was not the focus of this study (rather, we examined patterns across the gradient of tree cover); as such, future research might fruitfully focus on comparing individuals with similar characteristics in multiple locations. In any case, the consequences of the association between Nature Relatedness and tree cover have potential implications beyond the influence on conservation support; Nature Relatedness itself (not just exposure to nature) has been found to correlate with wellbeing, specifically, increased happiness (Zelenski and Nisbet, 2012) and reduced anxiety (Martyn and Brymer, 2014). This again suggests that interventions that aim to enhance a city resident's connection to nature could provide an important avenue to better health and wellbeing.

Our results highlight that the provision of tree cover should continue to be a key objective in city planning to ensure people continue to access nature and so the health benefits it provides. This could include encouraging (or even legislating for) natural features that can be integrated into space-poor urban environments. Furthermore, given the variation in Nature Relatedness seen here, social programs should be considered a key approach that encourage people to engage with the local green spaces that are already available to enhance their levels of connection to nature (e.g. Cohen et al., 2013; Shanahan et al., 2015c).

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Table 1: Results from ordinal regression models exploring the relationship between predictor variables and the frequency and duration of visits to private gardens and public green spaces. We show parameter estimates and associated standard errors. Given the ordinal nature of predictor variables, the results show the outcome as compared to a base factor level (i.e. for age the base factor is <40 years age, thus a positive coefficient suggests those > 40 tend to have a higher level of frequency or duration of green space visits; the base factors for the other variables are: gender, female; ethnicity, English not the primary language spoken at home; income, 1st quartile income group; education, year 10 completed or lower).

Table 2: Results from linear regression between the Nature Relatedness scores of Brisbane and Cranfield Triangle residents, with neighbourhood tree cover, and other potential covariates. We show the model averaged coefficients and standard errors of variables relative to a comparative base factor level (i.e. for age the base factor is <40 years age, thus a coefficient suggests those > 40 tend to have a higher Nature Relatedness score; the base factors for the other variables are: gender, female; Ethnicity, English not primary language spoken at home; income, 1st quartile income group; education, secondary school not completed).