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Abstract: By 2050, 70% of the worlds population will live in urban areas. In many cases urbanization reduces the richness and abundance of native species. Living in highly modified environments with fewer opportunities to interact directly with a diversity of native species may adversely affect residents' personal well-being and emotional connection to nature. We assessed the personal well-being, neighborhood well-being (a measure of a persons satisfaction with their neighborhood), and level of connection to nature of over 1000 residents in 36 residential neighborhoods in southeastern Australia. We modeled these response variables as a function of natural features of each neighborhood (e.g., species richness and abundance of birds, density of plants, and amount of vegetation cover) and demographic characteristics of surveyed residents. Vegetation cover had the strongest positive relations with personal well-being, whereas residents' level of connection to nature was weakly related to variation in species richness and abundance of birds and density of plants. Demographic characteristics such as age and level of activity explained the greatest proportion of variance in well-being and connection to nature. Nevertheless, when controlling for variation in demographic characteristics (examples were provided above), neighborhood well-being was positively related to a range of natural features, including species richness and abundance of birds, and vegetation cover. Demographic characteristics and how well-being was quantified strongly influenced our results, and we suggest demography and metrics of well-being must be considered when attempting to determine relations between the urban environment and human well-being.

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Relations between urban bird and plant communities, human well-being and connection to nature

Running head: Urbanization and well-being

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ABSTRACT

By 2050, 70% of the world's population will live in urban areas. In many cases, urbanization reduces the richness and abundance of native species. This means that an increasing number of people are living in highly modified environments. Fewer direct interactions with diverse, less modified ecosystems may adversely affect residents' personal well-being and emotional connection to nature, and ultimately their understanding of the need for biodiversity conservation. However, there is limited knowledge of how variation in the urban environment influences these factors. We measured the personal well-being, neighborhood well-being (a measure of a person's satisfaction with their neighborhood) and level of connection to nature of over 1000 residents in 36 residential neighborhoods in south-eastern Australia. We modeled these response variables as a function of various natural features of each neighborhood including the richness and abundance of bird and plant species, vegetation cover, and demographic characteristics of surveyed residents. Measures of vegetation cover had the strongest positive relationships with personal well-being, whereas resident's feelings of connection to nature were weakly related to variation in urban bird and plant communities. Demographic characteristics such as age and level of activity were always the best predictors of well-being and connection to nature. However, when controlling for variation in demographic characteristics (e.g., age, gender, marital status and activity level), neighborhood well-being was positively related to a range of environment measures including bird species richness and abundance, and vegetation cover. Demographic characteristics and the approach used to measure well-being had a strong influence on our results and we suggest demography and methods for assessing well-being must be considered when attempting to determine relationships between the urban environment and human well-being.

INTRODUCTION

In 2008, for the first time, greater than 50% of the global population lived in urban areas (United Nations 2008). This is predicted to increase to 70% by 2050. Urbanization can reduce the species richness of many taxonomic groups relative to areas that are not urbanized, although this may not be true for some groups (e.g., plants) or in particular contexts (e.g., at low levels of urbanization; McKinney 2002, 2008). Some researchers have suggested that the loss of species in human settlements will increase the physical and emotional separation between people and nature (e.g., Turner et al. 2004; Miller 2005; Dunn et al. 2006). Owing to rapid urbanization, human-nature experience is increasingly characterized by the interactions between people and the biota of their yards, streets and neighborhoods (Kinzig et al. 2005). The importance of nature in areas where people live is emphasized by recent shifts away from nature-based recreation (Pergams & Zaradic 2008).

Frequent interaction with highly modified ecosystems may affect perceptions of what constitutes biological diversity (which includes taxonomic, functional and genetic diversity and the diversity of ecosystems) and reduce public support for conservation of biodiversity and empathy for nature (Chawla 1999; Schultz 2001; Dunn et al. 2006; Saunders et al. 2006). Moreover, the loss and alteration of natural features in urban areas may adversely affect residents' health and well-being. Many studies demonstrate that nature in urban areas improves aspects of human health and personal well-being (see review papers by Tzoulas et al. 2007; Matsuoka & Kaplan 2008), but it is less well known whether variation in the natural features of residential neighborhoods affects well-being or feelings of connectedness to nature (defined as an individual's emotional connection to the natural world; Mayer & Frantz 2004).

A fundamentally important question for conservation is whether a decrease in the richness and abundance of species, particularly natives, adversely affects people's well-being or connection to nature. Fuller et al. (2007) demonstrated that certain aspects of psychological well-being of urban greenspace users increased as the species richness of plants and birds in the greenspace increased.

However, no study has examined this issue where people live, and where, arguably, the majority of human-nature interactions occur. Here, we determined whether variation in urban bird and plant communities in residential neighborhoods was related to the personal and neighborhood well-being of residents and their feelings of connection to nature.

METHODS

Study area

Our study was conducted in nine towns and cities (population size ranged from 16,845 to 78,221) across Victoria and New South Wales in south-eastern Australia. We surveyed four neighborhoods in each town (total 36 neighborhoods) with neighborhood boundaries defined by census collection districts, the smallest sampling unit (≈ 200 houses) used by the Australian Bureau of Statistics (ABS) in its 5-yearly census of the Australian population. Neighborhoods were selected with stratified random sampling to capture the full range of variation in housing density, income levels and vegetation cover. The boundaries of neighborhoods in the same town were separated by at least 1 km, the center of each neighborhood was within 10 km of a town center, dominant land use was residential and housing density ranged from 0.5 to 10 houses/ha (see Luck et al. 2009).

The definition of urban varies from study to study and may be context dependent (Pickett & Cadenasso 2006). Owing to the relatively low housing density, most of the neighborhoods in our study could reasonably be described as suburban or peri-urban, although neighborhood location varied from the fringes of towns to town centers.

Neighborhood environment measures

We aimed to determine if residents' personal well-being, neighborhood well-being or connection to nature varied as a function of the following five aspects of the urban environment: species richness, species abundance, vegetation cover, vegetation density, and level of urban development. We measured a range of variables in each neighborhood that represented the five aspects, but narrowed these to five variables (one for each aspect) that had the strongest and most consistent relationships with the response variables (Appendix S1) as follows: species richness = the species richness of native and non-native birds (measured in the field by L. S. over four seasons from summer 2007 to spring 2008); species abundance = the abundance of native birds (all species, measured in the field as above); vegetation cover = neighborhood vegetation cover (the proportional cover of woody and non-woody vegetation, measured during the peak growing season (late spring 2007) via Advanced Land Observation Satellite (ALOS) imagery at a 10 m resolution); vegetation density = the proportional cover of understory, midstory and overstory vegetation in each neighborhood (measured in the field in spring and summer 2007–08 by L. S.); and urban development = the proportional cover of impervious surfaces in each neighborhood measured via ALOS as above. See Table 1 and Appendix S1 for further details.

Neighborhood demographic measures

Demographic factors (e.g., age, gender and activity levels) may influence well-being and connection to nature (Driver et al. 1991; Moro et al. 2008; Smyth et al. 2008). Following the approach for neighborhood environment measures, we narrowed a range of demographic measures to the following six variables representing different aspects of the demography of neighborhoods: age; gender; residency (the number of years a respondent (i.e., a resident who responded to the survey) had lived in the neighborhood); neighborhood activity level (the respondent's level of social and physical activity *within* their neighborhood); general activity level (the respondent's level of social/physical activity both within and outside their neighborhood); and socio-economic status (a composite of the positively correlated variables of income, home ownership, and education level; see Table 1 and Appendix S1).

Survey instrument

We developed a questionnaire with the following sections: personal well-being; neighborhood well-being; connectedness to nature; level of interaction with the outdoor environment and social interaction; and demography (Fig. S1). To evaluate personal well-being, we used a cross-cultural index that is widely used to measure self-reported, subjective well-being (International Wellbeing Group 2006). The index includes eight items that represent different aspects of overall life satisfaction (Appendix S1). Each item was measured using a 0–10 scale, with 0 – completely dissatisfied, 5 – neutral and 10 – completely satisfied. We determined the personal well-being index value for each household by averaging the responses to the eight items. The personal well-being index was included in our study so our results could be compared with other surveys.

We developed a new neighborhood well-being index that represented residents' level of satisfaction with life in their neighborhood. This index also comprised eight items; each measured on the same 0–10 scale as for the personal well-being index. Examination of the capacity of each item to explain variation in overall neighborhood satisfaction found that four items contributed significantly to the latter (Cronbach's alpha = 0.89), while the remaining items had a weaker association (Appendix S1). The neighborhood well-being index value for each household was an average of these four items. Our measures of neighborhood well-being were similar to those used by Fuller et al. (2007).

We used the connectedness to nature scale (Mayer & Frantz 2004) to measure residents' self-reported levels of connection to the natural environment. The scale consisted of 14 items measured from 0–10 as above, and the value for the index was an average of the values of these 14 items (Appendix S1). The connectedness to nature scale, similar to the new ecological paradigm scale (Dunlap et al. 2000), explores humans' psychological relationship to the natural world. In a critique of the scale, Perrin and Benassi (2009) suggested that it measures cognitive beliefs about an individual's connection with nature rather than an emotional connection *per se*. Nevertheless, they concluded that the scale '…taps a connectedness to nature dimension' (Perrin & Benassi 2009; p. 439).

The mean values of the two well-being indices were positively correlated across households (*rho* = 0.61, *n* = 967), but because the correlation was not 1.0 they likely captured different aspects of well-being. Moreover, both indices were weakly correlated with the connectedness to nature scale (personal well-being index, *rho* = 0.25; neighborhood well-being index, *rho* = 0.28, *n* = 967).

Data collation and analysis

We followed the survey design and implementation guidelines of Dillman et al. (2009). Surveys were delivered in July 2009 to the mail boxes of 100 randomly selected households in each of 35 neighborhoods, and to all 45 households in one neighborhood. A total of 3545 surveys were delivered and 1078 (30%) were returned. While the response rate was not 100%, we did not identify strong systematic biases in responses across neighborhoods that undermine our conclusions (Appendix S1).

Returned questionnaires were reviewed to filter out incomplete responses. This resulted in revised sample sizes for personal well-being (1044), neighborhood well-being (993) and connection to nature (1043), which were the three response variables for the analysis. A median value for each index in each questionnaire was calculated from the individual items in the index. To examine variation in responses both within and among neighborhoods, we employed a multinomial regression model with an ordinal scale response variable. Median values for each index across households within a neighborhood were assigned to one of the following three categories: low (median value ≤ 5); medium ($> 5 \leq 7.5$); and high (> 7.5). This represented, for example, low, medium and high levels of well-being. These breakpoints ensured that the sample size in each category was adequate for modeling, and accurately reflected relative well-being or connectedness to nature. Median values were preferred to means in this analysis because the distribution of numerical values across items in each index was skewed towards larger values and the median was a more accurate measure of central tendency and yielded clearer breakpoints.

We modeled the probability that a resident's response would occur in one of the three categories of personal well-being, neighborhood well-being or connection to nature using a hierarchical generalized linear model with a multinomial response and an ordinal complementary log-log link (Norušis 2008). We used a hierarchical model to reflect the spatial structure of the data whereby households were nested within neighborhoods that were nested within towns ('neighborhood' and 'town' were included as random factors in each model). All modeling was conducted using the software program LISREL 8.8 (Jöreskog & Sörbom 2001).

Following an Information Theoretic Approach (Burnham & Anderson 2002), we compared the explanatory capacity of 13 alternative models [hypotheses] for explaining variation in the response variables. Covariates in these were either neighborhood environment or demographic measures (Table 2). Models were ranked using Akaike's Information Criterion (AIC; Burnham & Anderson 2002). We compared the difference in the criterion values of the best ranked model to model i (Δ_i) and calculated the Akaike weight for each model (Appendix S1). Model fit was assessed by comparing the AIC value of the more complex models with the constant only model and the model including only the constant and the random effects. We did not include highly correlated variables in the same model ($r > 0.6$ or variance inflation factors > 4; see Neter et al. 1996).

Given the apparent strength of association between neighborhood demography and well-being and connectedness (see Results), we also determined if any environment measures were related to personal well-being, neighborhood well-being or connection to nature while controlling for variation in demographic characteristics. We modeled each environment measure separately (as above) against each response variable within designated categories of, for example, age, gender and activity level (see Appendix S1 for details).

RESULTS

Personal well-being

Personal well-being was positively associated with species richness, species abundance, vegetation cover and vegetation density, and negatively associated with urban development. The strength of the association was strongest for vegetation cover and density, and urban development. For example, based on the regression coefficients and their standard errors (Tables 3 and S2), the odds of recording a higher level of personal well-being increased by 55% (26 – 90% confidence limits based on ± 1 SE) with change in vegetation cover across the range of the data, and by 48% (22 – 79%) with change in vegetation density (i.e., the cover of understory–overstory plants; percentage values calculated by converting log-odds to odds). Conversely, the odds increased by 20% (1 – 45%) with change in species richness across the range of the data. Certain demographic variables were also strongly related to personal well-being. For example, there was a 114% (101 – 127%) increase in the odds of recording a higher level of personal well-being if residents were married rather than single (Table S3).

The highest ranked model explaining variation in personal well-being included age, general activity level, residency and socio-economic status (Table 3). This was the only model among the 13 considered that had substantial support ($w_i = 1.0$) with a reduction in the AIC value of 61.3 compared to the constant + random effects model. The four highest ranked models included only demographic variables. Urban development and vegetation cover were the only variables in the two highest ranked models that included environment measures, but the difference in the AIC value between these two models and the constant + random effects model was < 2.

Within particular demographic categories (i.e., examining relationships within, for example, a particular age category (< 55 years or ≥ 55 years old) or gender category (male or female)), only urban development improved model fit (reduced the AIC value by > 2 compared to the constant + random effects model) and had a variable coefficient that was significantly ($p < 0.05$) related to personal well-being (Table 4). The odds of recording a higher level of personal well-being for females decreased by 124% (64 – 206%) with change in urban development across the range of the data. Variable coefficients for vegetation density and urban development were significant in a number of demographic categories, although inclusion of these variables mostly did not improve model fit (Table S4).

Neighborhood well-being

Neighborhood well-being was related in the same way to environment measures as personal well-being, but these relationships were stronger for the former. For example, the odds of recording a higher level of neighborhood well-being increased by 246% (178 – 330%) with change in vegetation cover across the range of the data (Tables 3 and S2). The general relationships between the demographic measures and neighborhood well-being mirrored those with personal well-being (Table S3).

Only one model explaining variation in neighborhood well-being had substantial support (w_i = 0.97). This model included age, neighborhood activity level, residency and socio-economic status (Table 3). Again, the four highest ranked models included only demographic variables, whereas the two highest ranked models with environment variables included only urban development or vegetation density, with the former reducing the AIC value by 3 compared to the constant + random effects model.

Within particular demographic categories a number of environment variables were significantly related to neighborhood well-being and improved model fit (Table 4). For example, species abundance reduced the AIC value by 6.2 compared to the constant + random effects model, and the odds of recording a higher level of neighborhood well-being increased by 34% (25 – 45%) with change in species abundance across the range of the data for residents < 55 years old. Moreover, although not always improving model fit, variable coefficients for each of the environment variables were significantly related to neighborhood well-being in many demographic categories (Table S5). These results suggest a stronger association between the neighborhood environment and neighborhood well-being than between the former and personal well-being.

Connection to nature

Although connection to nature was related in the same way to environment measures as personal well-being and neighborhood well-being, the relationships were much weaker with a greater level of uncertainty. For example, the odds of recording a higher level of connectedness to nature increased by 19% (1 – 40%) with change in vegetation cover (Tables 3 and S2).

Again, only one model explaining variation in connection to nature had strong support (w_i = 0.87) and this included the variable general activity level (Table 3). The two highest ranked models with environment variables included only urban development or vegetation density, but these reduced the AIC value by < 2 compared to the constant + random effects model.

Within particular demographic categories, only one variable was significantly related to connectedness to nature and improved model fit. The odds of recording a higher level of connectedness for tertiary educated residents *decreased* by 19% (10 – 28%) with change in species abundance across the range of the data (Table 4). Moreover, only a few variable coefficients were significantly related to connectedness to nature regardless of the improvement in model fit (Table S6).

DISCUSSION

Most neighborhood environment measures were weakly related to residents' personal well-being or their feelings of connection to nature. There was some evidence that increased vegetation density may improve personal well-being for certain types of residents, but this variable did not improve model fit. Conversely, a number of environment measures were more strongly related to variation in neighborhood well-being across a range of demographic categories, and it appeared that residents' satisfaction with their local neighborhood increased when neighborhoods had, for example, more bird species, more vegetation cover, and a lower level of urban development. Nevertheless, demographic variables were always the strongest predictors of well-being or connection to nature.

Our results are not consistent with the general consensus that natural features in urban landscapes are important for personal well-being (e.g., Matsuoka & Kaplan 2008) or the possibility that urbanization will reduce people's feelings of connectedness to nature. However, our findings highlight two key issues. First, when attempting to determine the relationship between nature and well-being, researchers must account for the substantial influence of demographic factors. Second, how well-being is measured is likely to have a major impact on the results.

Also, our analysis was restricted to low to medium density neighborhoods (typical of many residential suburbs) in regional towns and cities with populations of < 100,000 people, and surveying in these areas may yield different results to major metropolitan centers. This raises an extremely important question – if housing density is constrained along with the total size of urban settlements will this alleviate the potential negative impacts of urbanization on residents' well-being and connection to nature?

Personal well-being

There was substantial uncertainty surrounding the association of most measures of personal well-being and environment measures. Personal well-being was most strongly associated with vegetation cover and density and urbanization level suggesting that the relative proportion of greenspace and urban development may have a greater influence on well-being than more specific environment measures or species richness *per se*. Our results are qualitatively different to Fuller et al. (2007) who identified a much stronger positive relationship between psychological well-being of urban park users and species richness of birds and plants. However, they used a different measure of well-being that represented aspects of reflection, attachment and identity. These items are very similar to the ones we used in our neighborhood well-being index, which may explain why we detected a much stronger relationship between environment measures and neighborhood well-being than between the former and personal well-being.

The relationships between human well-being and the natural features of urban landscapes undoubtedly reflect dynamic interactions among nature, settlement type, aesthetics, demographics, and other environmental factors (e.g., noise and pollution levels; Tzoulas et al. 2007). Our study found a strong assocation between demographic factors and personal well-being, especially age, residency and general activity levels. When controlling for these factors, we found that only urbanization level was significantly related to personal well-being and improved model fit. Across neighborhoods, females reported lower levels of personal well-being than males as urban development increased, possibly indicating a gender bias in the number of hours spent at home. Those residents less active in their neighborhood (i.e., engaging in less physical or social activity) reported lower well-being, possibly reflecting an interaction between urban density and the likelihood of being active within the neighborhood (see below).

Previous research has demonstrated a strong positive link between natural features and human well-being in urban landscapes (reviewed in Matsuoka & Kaplan 2008) or reported lower levels of personal well-being for residents living in more urbanized settlements compared to less urbanized ones (e.g., Moro et al. 2008; Smyth et al. 2008). In Australia, recent research using the same personal well-being index we used found that of the nine federal electoral divisions where people reported the highest level of personal well-being, eight were located outside of major metropolitan centers and had relatively low population densities. Conversely, the nine electorates with the lowest reported well-being were mostly in metropolitan areas with high population density (Australian Unity 2008).

It is possible that by not sampling neighborhoods in major metropolitan cities we did not record sufficient variation in personal well-being or levels of urbanization to identify a stronger link between well-being and the urban environment. If this is true, we would expect the mean well-being scores of our residents to show little variation across sites and, given the results above, to be closer to that recorded by residents of other non-metropolitan centers than those of major metropolitan locations. However, this was not the case. Across the nine towns we surveyed, the mean personal well-being index ranged from 65.7 to 75.9, and the mean score among towns (72.3) was much closer to that recorded by the metropolitan regions mentioned above (71.2) than the high-ranking non-metropolitan locations (77.6; Australian Unity 2008). Therefore, our results suggest that well-being can vary substantially across smaller urban settlements and is not necessarily higher, on average, than that recorded in major cities.

Neighborhood well-being

In general, there was a stronger relationship between the neighborhood environment and the neighborhood well-being index compared to the personal well-being index. This was highlighted by the range of environment measures that were positively related to neighborhood well-being after controlling for variation in demographic characteristics. For example, bird species richness was positively related to the well-being of tertiary educated residents (i.e., those with at least a bachelor degree) or those < 55 years old and improved model fit. This tentatively supports the idea that species richness *per se* may improve residents' satisfaction with where they live, although vegetation cover and level of urbanization were most strongly associated with well-being among different types of residents (Tables 4 and S5).

As for personal well-being, models including demographic variables were the best explanation for variation in neighborhood well-being. The positive relationship between well-being and age and residency likely reflects the interaction between these variables (longer-term residents are generally older) and the fact that age and residency are often strongly associated with place attachment (Lewicka 2010). Neighborhood activity level was also strongly associated with neighborhood well-being. Neighborhood vegetation cover has been shown to relate positively to neighborhood satisfaction and place attachment (e.g., Bonaiuto et al. 2003; Crow et al. 2006; Lee et al. 2008), and to the likelihood of residents engaging in neighborhood activities (e.g., walking) and informal social interaction (Kuo & Sullivan 1998; Naderia & Raman 2005). Hence, urban nature may impact on neighborhood well-being directly and indirectly through encouraging other activities that in turn improve well-being. However, we found little evidence for the latter in our study, as there was no relationship between neighborhood environment measures and the likelihood of residents engaging in neighborhood activities (unpublished data).

Connection to nature

Variation in the urban environment had little association with residents' feelings of connection to nature. Demographic measures were much more important, particularly neighborhood and general activity levels (Tables 1 and 3). This emphasizes that physical and social activities, particularly those occurring outdoors, may increase humans' sense of connection with the natural world (Ewert et al. 2005). Also, it is well recognized that experiences during childhood may influence environmental attitudes and actions (e.g., Chawla 1999; Ewert et al. 2005; Thompson et al. 2008). Residents' feelings of connection to nature may reflect past rather than current circumstances.

Our research also assumes that daily interactions with nature within a resident's neighborhood affect feelings about the natural environment. However, for residents living in smaller urban settlements it may be easier to access natural areas outside settlement boundaries than for those living in major cities. Hence, people living in smaller urban centers may be less separated from nature than residents of major cities regardless of the natural features of their neighborhood.

Conversely, residents' yards and gardens, rather than their neighborhood *per se*, may influence well-being and connection to nature. Substantial variation among households within neighborhoods may reduce the strength of inference from neighborhood-level analyses (e.g., Kirkpatrick et al. 2009). We attempted to account for this by stratifying neighborhood selection to maximize consistency across households within a neighborhood. Moreover, a number of studies show that there is considerable similarity in garden types among adjacent houses owing to the influence of social and cultural norms on individual actions (e.g., Zmyslony & Gagnon 1998; Warren et al. 2008; Nassauer et al. 2009).

As human settlements are often preferentially located in regions of high species richness (Luck 2007), effective management and protection of urban biodiversity is important for meeting broader conservation goals in addition to the potential benefits bestowed on humans (Dearborn & Kark 2010). We found that across small to medium-sized human settlements in neighborhoods of relatively low housing density, the relationships between urban nature and resident's well-being were complex and strongly influenced by demographic factors and the approach used to measure well-being. There was little evidence that variation in the urban environment influenced resident's feelings of connection to nature.

Our findings should not be extrapolated to larger cities. It is possible that results will differ between residents living in similar neighborhoods in major metropolitan areas versus those living in smaller towns. In major cities there is likely much greater variation in urban development and urban nature, and analyses in this context may identify a stronger effect of urbanization on well-being or connectedness. From a conservation perspective, more attention should be given also to the role of native versus exotic species in influencing well-being. There was little evidence in our study of different relationships when considering only native species, although natives were a large proportion of the species we recorded.

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SUPPORTING INFORMATION

Supporting methods and results (Appendix S1 including Tables S1–S6 and Fig. S1) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

LITERATURE CITED

Australian Unity. 2008. Australian Unity wellbeing index report April 2008. Australian Unity Ltd., South Melbourne. Available from http://australianunity.republicast.com/wbr2008/ (accessed March 2010).

Bonaiuto, M., F. Fornara, and M. Bonnes. 2003. Indexes of perceived residential environment quality and neighborhood attachment in urban environments: a confirmation study on the city of Rome. Landscape and Urban Planning **65:** 41–52.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd edition. Springer-Verlag, New York, N.Y.

Chawla, L. 1999. Life paths into environmental action. Journal of Environmental Education **31:** 15–26.

Crow, T., T. Brown, and R. De Young. 2006. The Riverside and Berwyn experience: contrasts in landscape structure, perceptions of the urban landscape, and their effects on people. Landscape and Urban Planning **75:** 282–299.

Dearborn, D. C. and Kark, S. 2010. Motivations for conserving urban biodiversity. Conservation Biology **24:** 432–440.

Dillman, D. A., J. D. Smyth, and L. M. Christian. 2009. Internet, mail and mixed-mode surveys: the tailored design method. 3rd edition. Wiley, Hoboken, N. J.

Driver, B. L., P. J. Brown, and G. L. Peterson. 1991. Benefits of leisure. Venture Publishing, State College, Pa.

Dunlap, R. E., K. D. Van Liere, A. G. Mertig, and R. E. Jones. 2000. Measuring endorsement of the New Ecological Paradigm: a revised NEP scale. Journal of Social Issues **56:** 425–442.

Dunn, R. R., M. C. Gavin, M. C. Sanchez, and J. N. Solomon. 2006. The pigeon paradox: dependence of global conservation on urban nature. Conservation Biology **20:** 1814–1816.

Ewert, A., G. Place, and J. Sibthorp. 2005. Early-life outdoor experiences and an individual's environmental attitudes. Leisure Sciences **27:** 225–239.

Fuller, R. A., K. N. Irvine, P. Devine-Wright, P. H. Warren, and K. J. Gaston. 2007. Psychological benefits of greenspace increase with biodiversity. Biology Letters **3:** 390–394.

International Wellbeing Group. 2006. Personal wellbeing index. 4th Edition. Australian Centre on Quality of Life, Deakin University, Melbourne.

Jöreskog, K., and D. Sörbom. 2001. LISREL 8: user's reference guide. Scientific Software International, Lincolnwood, IL.

Kinzig, A. P., P. Warren, C. Martin, D. Hope, and M. Katti. 2005. The effects of human socioeconomic status and cultural characteristics on urban patterns of biodiversity. Ecology and Society **10:** http://www.ecologyandsociety.org/vol10/iss1/art23/.

Kirkpatrick, J. B., G. Daniels, and A. G. Davison. 2009. An antipodean test of spatial contagion in front garden character. Landscape and Urban Planning **93:** 103–110.

Kuo, F. E., and W. C. Sullivan. 1998. Fertile ground for community: inner-city neighborhood common spaces. American Journal of Community Psychology **26:** 823–851.

Lee, S-W., C. D. Ellis, B-S. Kweon, and S-K Hong. 2008. Relationship between landscape structure and neighborhood satisfaction in urbanized areas. Landscape and Urban Planning **85:** 60–70.

Lewicka, M. 2010. What makes neighborhood different from home and city? Effects of place scale on place attachment. Journal of Environmental Psychology **30:** 35–51.

Luck, G. W. 2007. A review of the relationships between human population density and biodiversity. Biological Reviews **82:** 607–645.

Luck, G. W., L. T. Smallbone, and R. O'Brien. 2009. Socio-economics and vegetation change in urban ecosystems: patterns in space and time. Ecosystems **12:** 604–620.

Matsuoka, R. H., and R. Kaplan. 2008. People needs in the urban landscape: analysis of *Landscape and Urban Planning* contributions. Landscape and Urban Planning **84:** 7–19.

Mayer, S. F., and C. M. Frantz. 2004. The connectedness to nature scale: a measure of individuals' feeling in community with nature. Journal of Environmental Psychology **24:** 505–515.

McKinney, M. L. 2002. Urbanization, biodiversity, and conservation. BioScience **52:** 883–890.

McKinney, M. L. 2008. Effects of urbanization on species richness: a review of plants and animals. Urban Ecosystems **11:** 161–176.

Miller, J. R. 2005. Biodiversity conservation and the extinction of experience. Trends in Ecology and Evolution **20:** 430–434.

Moro, M., F. Brereton, S. Ferreira, and J. P. Clinch. 2008. Ranking quality of life using subjective well-being data. Ecological Economics **65:** 448–460.

Naderi, J. R., and B. Raman. 2005. Capturing impressions of pedestrian landscapes used for healing purposes with decision tree learning. Landscape and Urban Planning **73:** 155–166.

Nassauer, J. I., Z. Wang, and E. Dayrell. 2009. What will the neighbors think? Cultural norms and ecological design. Landscape and Urban Planning **92:** 282–292.

Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. 1996. Applied linear statistical models. 4th edition. Irwin, Homewood, IL.

Norušis, M. J. 2008. SPSS 17.0: statistical procedures companion. Prentice Hall, Upper Saddle River, N. J.

Pergrams, O. R. W., and P. A. Zaradic. 2008. Evidence for a fundamental and pervasive shift away from nature-based recreation. Proceedings of the National Academy of Sciences (U.S.A.) **105:** 2295–2300.

Perrin, J. L., and V. A. Benassi. 2009. The connectedness to nature scale: a measure of emotional connection to nature? Journal of Environmental Psychology **29:** 434–440.

Pickett, S. T. A., and M. L. Cadenasso. 2006. Advancing urban ecological studies: frameworks, concepts, and results from the Baltimore Ecosystem Study. Austral Ecology **31:** 114–125.

Saunders, C. D., A. T. Brook, and O. E. Myers Jr. 2006. Using psychology to save biodiversity and human well-being. Conservation Biology **20:** 702–705.

Schultz, P. W. 2001. Empathizing with nature: the effects of perspective taking on concern for environmental issues. Journal of Social Issues **56:** 302–304.

Smyth, R., V. Mishra, and X. Qian. 2008. The environment and well-being in urban China. Ecological Economics **68:** 547–555.

Thompson, C. W., P. Aspinall, and A. Montarzino. 2008. The childhood factor. Adult visits to green places and the significance of childhood experience. Environment and Behavior **40:** 111–143.

Turner, W. R., T. Nakamura, and M. Dinetti. 2004. Global urbanization and the separation of humans from nature. BioScience **54:** 585–590.

Tzoulas, K., K. Korpela, S. Venn, V. Yli-Pelkonen, A. Kaźmierczak, J. Niemela, and P. James. 2007. Promoting ecosystem and human health in urban areas using green infrastructure: a literature review. Landscape and Urban Planning **81:** 167–178.

United Nations. 2008. World urbanization prospects: the 2007 revision. Department of Economic and Social Affairs, United Nations, New York, N.Y.

Warren, P. S., S. B. Lerman and N. D. Charney. 2008. Plants of a feather: spatial autocorrelation of gardening practices in suburban neighborhoods. Biological Conservation **141:** 3–4.

Zmyslony, J. and D. Gagnon. 1998. Residential management of urban front-yard landscape: a random process? Landscape and Urban Planning **40:** 295–307.

Table 1. The explanatory variables used to examine the relationships between the neighborhood environment and demographic measures, and personal well-being, neighborhood well-being and connection to nature.

Variable (type/range)[a]	Short name	Description	Source[b]
Neighborhood environment measures			
Species richness of birds (11 – 48)	Species richness	The number of bird species in each neighborhood	Field survey
Abundance of native birds (2 – 15/ha)	Species abundance	The abundance of all species of native birds corrected for detection probability (square-root)	Field survey
Neighborhood vegetation cover (8% – 77%)	Vegetation cover	The proportion of the neighborhood covered in woody and non-woody vegetation (arcsine-square-root)	Satellite imagery
Understory, midstory and overstory cover (6% – 45%)	Vegetation density	The proportional cover of understory, midstory and overstory vegetation in each neighborhood (arcsine-square-root)	Field survey
Impervious surface cover (1% – 88%)	Urban development	The proportion of the neighborhood covered in impervious surfaces (arcsine-square-root)	Satellite imagery
Demographic measures			
Age (categorical)		< 55 years or ≥ 55 years old	Questionnaire[c]
Gender (categorical)		Male or female	As above
Neighborhood activity level (categorical)	Neighborhood activity	High (engaging in activities ≥ once per week) or low (engaging in activities ≤ once or twice per month)	As above
General activity level (categorical)	General activity	High (engaging in activities ≥ once per week) or low (engaging in activities ≤ once or twice per month)	As above
Residency (categorical)		Number of years lived in the	As above

	neighborhood (≤ 10 years or > 10 years)	
Socio-economic status	A composite variable combining the positively correlated measures of income, home ownership and education level (Appendix S1)	ABS[d]

[a]The name and type of variable (categorical variables noted; all other variables are continuous). The range of values across neighborhoods is included in brackets for each continuous variable except socio-economic status.

[b]The data source for each variable (see Appendix S1 for further details of data collection methods).

[c]The questionnaire delivered to residents to measure personal and neighborhood well-being and connection to nature.

[d]Australian Bureau of Statistics.

Table 2. Alternative models of personal well-being, neighborhood well-being and connection to nature.

#	Alternative models
	Personal well-being
1	Species richness
2	Species abundance
3	Vegetation cover
4	Vegetation density
5	Species richness + vegetation cover
6	Species richness + vegetation density
7	Vegetation cover + vegetation density
8	Urban development
9	Age
10	Residency
11	Socio-economic status
12	General activity
13	Age + general activity + residency + socio-economic status
	Neighborhood well-being
	Models 1 – 11 (above)
	Neighborhood activity
	Age + neighborhood activity + residency + socio-economic status
	Connectedness to nature
	Models 1 - 8, 10 - 12 (above)
	Gender
	Gender + general activity + residency + socio-economic status

Table 3. The ranking of alternative models examining relationships between the neighborhood environment and demographic measures, and personal well-being, neighborhood well-being and connection to nature.

	AIC[a]	Δ_i[b]	w_i[c]
Personal well-being[d]			
Age (0.34 ± 0.11) + general activity (0.67 ± 0.11) + residency (0.35 ± 0.11) + socio-economic status (1.42 ± 0.25)	1672.4	0	0.999
Residency (0.65 ± 0.10)	1697.1	24.7	<0.001
General activity (0.66 ± < 0.01)	1699.9	27.5	<0.001
Age (0.70 ±< 0.01)	1701.4	29.0	<0.001
Urban development (-0.80 ± 0.22)	1732.5	60.1	<0.001
Vegetation cover (0.56 ± 0.26)	1733.5	61.1	<0.001
Species abundance (0.01 ± 0.02)	1734.2	61.8	<0.001
Species richness (0.005 ± 0.005)	1734.6	62.2	<0.001
Species richness (-0.002 ± 0.006) + vegetation cover (0.61 ± 0.29)	1735.0	62.6	<0.001
Vegetation density (0.80 ± 0.39)	1735.4	63.0	<0.001
Vegetation cover (0.41 ± 0.27) + vegetation density (0.55 ± 0.42)	1736.8	64.4	<0.001
Species richness (-0.001 ± 0.006) + vegetation density (0.84 ± 0.46)	1737.3	64.9	<0.001
Socio-economic status (1.19 ± 0.25)	1741.0	68.6	<0.001
Saturated model[e]	1680.6		
Constant only[f]	1810.9		
Constant + random effects	1733.7		
Neighborhood well-being			
Age (0.33 ± <0.01) + neighborhood activity (0.35 ± 0.11) + residency (0.29 ± <0.01) + socio-economic status (1.76 ± 0.28)	1572.3	0	0.967
Age (1.02 ± 0.11)	1579.6	7.3	0.025

Residency (0.98 ± 0.11)	1581.7	9.4	0.009
Neighborhood activity (0.86 ± < 0.01)	1598.6	26.3	<0.001
Urban development (-1.66 ± 0.24)	1603.8	31.5	<0.001
Vegetation density (1.80 ± 0.41)	1605.6	33.3	<0.001
Species abundance (0.07 ± 0.02)	1605.7	33.4	<0.001
Vegetation cover (1.59 ± 0.28)	1606.4	34.1	<0.001
Species richness (0.02 ± 0.006)	1607.0	34.7	<0.001
Socio-economic status (1.60 ± 0.27)	1608.5	36.2	<0.001
Vegetation cover (1.29 ± 0.29) + vegetation density (1.12 ± 0.44)	1608.8	36.5	<0.001
Species richness (0.009 ± 0.007) + vegetation cover (1.36 ± 0.32)	1609.0	36.7	<0.001
Species richness (0.02 ± 0.007) + vegetation density (1.48 ± 0.48)	1610.1	37.8	<0.001
Saturated model	1593.6		
Constant only	1741.3		
Constant + random effects	1606.8		
Connectedness to nature			
General activity (0.73 ± 0.08)	1941.1	0	0.869
Gender (0.20 ± <0.01) + general activity (0.60 ± 0.10) + residency (-0.02 ± 0.09) + socio-economic status (0.30 ± 0.21)	1944.9	3.8	0.131
Gender (0.07 ± 0.05)	1978.4	37.3	<0.001
Urban development (-0.28 ± 0.18)	1981.3	40.2	<0.001
Vegetation density (0.28 ± 0.33)	1982.0	40.9	<0.001
Species richness (0.009 ± 0.005)	1982.5	41.4	<0.001
Vegetation cover (0.22 ± 0.21)	1982.6	41.5	<0.001
Socio-economic status (0.22 ± 0.20)	1982.6	41.5	<0.001
Species abundance (0.009 ± 0.02)	1983.3	42.2	<0.001
Vegetation cover (0.19 ± 0.23) + vegetation density (0.13 ± 0.35)	1984.2	43.1	<0.001

Species richness (0.009 ± 0.005) + vegetation cover (-0.008 ± 0.24)	1984.5	43.4	<0.001
Residency (≤ 10 years -0.03 ± 0.08; > 10 years 0.03 ± 0.08)	1985.2	44.1	<0.001
Species richness (0.01 ± 0.005) + vegetation density (-0.27 ± 0.38)	1987.3	46.2	<0.001
Saturated model	1952.8		
Constant only	1998.2		
Constant + random effects	1982.1		

[a]Akaike's Information Criterion.

[b]The difference in the criterion values of the best ranked model to model *i*.

[c]Akaike weights.

[d]Parameter estimates (variable coefficients) and their standard error are provided in brackets. See Appendix S1 for further details.

[e]The saturated model includes all of the explanatory variables.

[f]The constant and constant + random effects models have been included for comparison and to help assess model fit.

Table 4. The neighborhood environment measures that improved model fit (reduced the AIC value by > 2) and were significantly related ($p < 0.05$; variable coefficients and standard errors in brackets) to personal well-being, neighborhood well-being or connection to nature for particular demographic categories.

	Personal well-being	Neighborhood well-being					Connectedness to nature
	Urban development	Species richness	Species abundance	Vegetation cover	Vegetation density	Urban development	Species abundance
Age							
< 55 years		4.2[a] (0.03; 0.01)	6.2 (0.12; 0.03)	3.7 (2.05; 0.35)	5.2 (2.63; 0.52)	2.8 (-1.76; 0.31)	
Gender							
Male				2.1 (1.88; 0.49)		2.9 (-1.85; 0.41)	
Female	3.6 (-0.72; 0.28)					3.6 (-1.47; 0.29)	
Marital status							
Married						2.6 (-1.38; 0.27)	
Single			9.5 (0.18; 0.05)	6.5 (1.25; 0.49)	2.5 (2.85; 0.72)	5.9 (-1.63; 0.46)	
Education level							
Tertiary		2.9 (0.03; 0.01)		4.9 (2.17; 0.47)	3.3 (1.97; 0.71)	2.4 (-1.49; 0.39)	8.0 (-0.07; 0.03)
NH activity level							
Low	2.6 (-0.77; 0.30)						
High						3.0 (-1.65; 0.34)	
General activity level							
Low					2.6		

			(1.90; 0.49)	
High				2.3
				(-2.11; 0.45)
Residency				
≤ 10 years	4.0	4.3	3.5	2.5
	(-0.87; 0.28)	(0.09; 0.03)	(2.34; 0.55)	(-1.48; 0.30)

[a]Each numerical value is the amount the AIC value was reduced compared to a model including the constant + random effects.