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Where the wild things are! Do urban green spaces with greater avian biodiversity promote more positive emotions in humans?

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Abstract

Urban green space can help mitigate the negative impacts of urban living and provide positive effects on citizens' mood, health and well-being. Questions remain, however, as to whether all types of green space are equally beneficial, and if not, what landscape forms or key features optimise the desired benefits. For example, it has been cited that urban landscapes rich in wildlife (high biodiversity) may promote more positive emotions and enhance well-being. This research utilised a mobile phone App, employed to assess people's emotions when they entered any one of 945 green spaces within the city of Sheffield, UK. Emotional responses were correlated to key traits of the individual green spaces, including levels of biodiversity the participant perceived around them. For a subsample of these green spaces, actual levels of biodiversity were assessed through avian and habitat surveys. Results demonstrated strong correlations between levels of avian biodiversity within a green space and human emotional response to that space. Respondents reported being happier in sites with greater avian biodiversity ($p < 0.01$, $r = 0.78$) and a greater variety of habitats ($p < 0.02$, $r = 0.72$). Relationships were strengthened when emotions were linked to perceptions of overall biodiversity ($p < 0.001$, $r = 0.89$). So, when participants thought the site was wildlife rich, they reported more positive emotions, even when actual avian biodiversity levels were not necessarily enhanced. The data strengthens the arguments that nature enhances well-being through positive affect, and that increased 'engagement with nature' may help support human health within urban environments. The results have strong implications for city planning with respect to the design, management and use of city green spaces.

Keywords Biodiversity · Birds · Green space · Health · Nature · Quality · Well-being

Introduction

The natural world is increasingly viewed as being salutogenic, with good numbers of studies linking aspects of nature (Fuller et al. 2007; McMahan and Estes 2015; Wood et al. 2018) and green spaces (Wheeler et al. 2015; Markevych et al. 2017; Brindley et al. 2018; Tost et al. 2019) to human health and

well-being. In a world that is rapidly urbanising, however, access to nature and green spaces can be restricted owing to densification or urban sprawl (Haaland and van den Bosch 2015), and provision of green space not being prioritised within city planning (Moseley et al. 2013; Sanesi et al. 2017; Douglas et al. 2019). More generally, urbanisation is associated with habitat loss, reduction in native biodiversity, greater disturbance to wildlife, and problems aligned to pollution and ecosystem degradation (Seto et al. 2012). Yet, providing urban green space is important given its influence on physical and psychological human health, helping shape behaviour that can promote health and social capital, as well as the health of the environment and the wider ecosystem services it provides (Cameron and Hitchmough 2016; Jennings and Bamkole 2019). Policy makers and city planners are increasingly aware of the health and well-being benefits of urban green space, however, if green space is needed then will *any type* of green space do? If the aim for policy makers is to optimise human health benefits (Gómez-Baggethun and Barton 2013), then what extent, type, variation within (heterogeneity) and quality

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of green space is required, and how should people be encouraged to use these spaces (Marselle et al. 2015)?

Moreover, studies suggest that health benefits may be increased if people experience/perceive greater levels of biodiversity within these green spaces. The study outlined here used the city of Sheffield to determine whether human emotions varied with the types of green space people encountered and whether these emotions were influenced by the amount of biodiversity in different locations. It tested the prediction that human emotion was more positive in urban green spaces (UGS) with greater biodiversity.

Theories relating health/well-being to nature

A number of concepts explain why green space may be beneficial to human health and well-being, these include:

1. ‘Soft’ fascination and preference: These are key components of the attention restoration theory (Kaplan and Kaplan 1989) and indicate that natural environments promote interest but avoid overstimulation (Grassini et al. 2019). Natural environments are ‘preferred’ as the brain interprets them as more coherent than artificial ones (Abkar et al. 2011; Van den Berg et al. 2016), promoting relaxation and positive emotions (affect) (Sato et al. 2018; Ballew and Omoto 2018). If soft fascination is a key component, then this raises the question whether landscapes that have more opportunities for soft fascination provide greater restorative potential? For example, is the restorative potential of a spatially-simple landscape such as a grass lawn, improved by the addition of artefacts (e.g. abiotic - rocks, water, meandering pathways or biotic - flowering plants, insects, grazing mammals), due to the capacity of these features to create more interest? Preference, coherence and response to aesthetics (i.e. the concept of beauty, Kellert 1993) may play a part here too; it may be preferable to view an out-crop of limestone or granite within the grass than something less ‘natural’ or ‘coherent’ such as a pile of bricks. Components that encompass movement, sound or strong colour may induce greater fascination, and thus certain elements within the landscape (e.g. birds) are perhaps, especially restorative (Hedblom et al. 2017).
2. Security and Opportunity: ‘Prospect – refuge’ or ‘Savannah’ theories suggest we favour landscape features that were once important for survival or linked to our evolution. This includes attractions to water, protected vantage points and even vegetation forms that mimic those of the African savannah (Hagerhall 2000; McGranahan 2008). Thus, we may be attracted to more heterogeneous landscapes because they provide greater opportunities for refuge, or a wider range of species to hunt or forage for.
3. The influence of physical and biotic aspects of the natural environment on human physiology: This includes processes, compounds or organisms that elicit positive responses in humans, including those that ultimately affect mood. These include exposure to sunlight (vitamin D; Webb 2006), negatively charged ions (Liang et al. 2014), phytoncides (Hansen et al. 2017); aromatic volatiles (Herz 2009) and deactivation of aerial pollutants by plant/microbial populations (Janhäll 2015). It is also thought that exposure to microbial species found in natural environments positively influences human immune responses and can affect mental well-being (Schmidt 2015). Environments that promote diverse microbial communities, often correlate with those with greater diversity of macro-flora and fauna (Flies et al. 2017; Aerts et al. 2018; Robinson et al. 2018), and humans may associate these higher animals and plants (and their typical habitats) with enhanced health, even though the beneficial mechanisms actually relate to the complementary microbial communities.

Each theory highlights intrinsic human dependence on the natural world. In consequence, the ‘biopsychophysic’ of biological, psychological and natural unity (Richardson et al. 2017) is now seen in some models of health, for example the one health perspective (Rabinowitz et al. 2018). Such accounts indicate nature as a positive force and Jordan (2009) cites that perception and exposure to nature is central to positive emotional states. It’s clear that engagement with nature can induce positive emotions and this goes beyond restoration and counteracting negative affect (Kaplan and Kaplan 1989; Ulrich 1984). Nature also brings benefits when human ‘self-control’ resources are not depleted (Beute and De Kort 2014), helping manage emotions (Richardson 2019); a role that is often overlooked (Korpela et al. 2018). McMahan and Estes (2015) argue that the beneficial effects of nature on emotional well-being are driven primarily by increases in positive affect. Positive emotions, for example through savouring nature, broaden thoughts and actions which in turn help build resilience, leading to sustained well-being benefits (Tugade and Fredrickson 2007). Experimental evidence demonstrates that increasing positivity broadens attention, improves thoughts, behaviour and mental health (Fredrickson and Branigan 2005). Finally, there is a relationship between positive affect and immune function through up-regulation of immune components (Marsland et al. 2007). Therefore, in this study we use ‘in the moment’ emotional responses to nature in urban environments as a measure of positive emotion.

Typology and quality of urban landscapes

Increasingly, quality of green landscape is seen as a factor determining health and well-being outcomes (Jorgensen and

Gobster 2010; Nieuwenhuijsen et al. 2017; Brindley et al. 2019; Ayala-Azcárraga et al. 2019), but this aspect is still under-researched. Previous studies often fail to define or quantify the green space being studied, yet ‘urban green space’ can comprise anything from flat expanses of turfgrass to highly heterogeneous land forms full of wildlife (Botzat et al. 2016). Certain typologies have been linked with greater restorative effects, such as those including water, open-treed landscapes or informal gardens (Ivarsson and Hagerhall 2008; Barton and Pretty 2010). Reid et al. (2017) found proximity to trees a better indicator of health than proximity to grassland. More natural landscape styles have been cited as providing greater restoration from stress (Ivarsson and Hagerhall 2008), but some studies indicate that when levels of naturalness reach a certain point, the beneficial effects start to diminish or even cause negative responses (Koole and Van den Berg 2005). For example, dense woodland can be seen as threatening (Jorgensen and Tylecote 2007) with medium-density forests being preferred (Chang et al. 2016). Little information exists on how heterogeneity of land form/typology within a given UGS influences well-being, although Fuller et al. (2007) suggest that the number of habitats within a given park influences responses to that park.

The importance of biological diversity and abundance (real and perceived)

Higher biodiversity levels have been linked to more positive psychological responses (Dallimer et al. 2012; Cracknell et al. 2016; Wood et al. 2018). For example, Fuller et al. (2007) reported positive relationships between perceived self-reflection and self-identity and species richness. Biologically rich landscapes too, have been linked to better appreciation by citizens (Schipperijn et al. 2010). Botzat et al. (2016) in a review of urban biodiversity and people’s valuations, indicated that 52% of studies showed a positive effect of biodiversity on green space evaluation, whereas 22% showed a negative impact and 27% no effect. Negative responses though were often part of mixed results – for example plants, but not insects, being appreciated in some locations. Shwartz et al. (2014) enhanced biodiversity in small parks by increasing the diversity of flowers present and adding bird boxes, and found visitors thought their well-being improved as biodiversity increased (excluding insects). These visitors, however were not adept at noting actual changes in biodiversity over time i.e. biodiversity and perceptions of biodiversity were not well correlated. Video studies have shown that increasing the numbers of tree or bird species present, promoted more positive responses (vitality, positive affect) and decreased anxiety levels (Wolf et al. 2017). In contrast, Chang et al. (2016) found no correlations between insect abundance or biodiversity and physiological measures of well-being, although exposure times in this case were quite short (1 min).

Studies evaluating responses to plant diversity in urban meadows (Southon et al. 2017, 2018) found mixed results, in that the creation of florally and species-rich meadows did not increase psychological well-being in local residents. They did find, however, that perceived floral richness was associated with greater satisfaction with the site and connectivity to nature; factors that themselves can mediate well-being outcomes (Capaldi et al. 2014, 2015; Zhang et al. 2014). As well as structural aspects, species composition (and knowledge levels of participants, Cox and Gaston 2015; McGinlay et al. 2018) may affect well-being. A mixed shrubbery within a park of a temperate climate may be viewed differently from equivalent vegetation in the tropics, due to the risk of encountering a venomous snake or spider (Karjalainen et al. 2010). Although a number of papers cite health links to relative levels of biodiversity Marselle et al. (2019) suggest the evidence is not yet of the extent necessary to characterise the role of biodiversity in relation to mental well-being.

As alluded to above, taxa or species may influence human response. Colourful flowers usually lead to positive responses in viewers (Kendal et al. 2012). Even within taxa, certain species may have more ‘charisma’ than others. Thus, respondents have reported ‘fewer benefits’ from species deemed less charismatic e.g. *Lamium album* (white dead nettle) and *Canthophorus impressus* (down shieldbug) than those with more ‘charisma’ e.g. *Dactylorhiza fuchsia* (common spotted orchid) and *Polyommatus icarus* (common blue butterfly) (McGinlay et al. 2017).

Care is required when defining biodiversity within this context. Urbanisation is linked with losses to *native* biodiversity, but actual overall biodiversity can rise in green spaces, such as parks and gardens, largely due to the wide use of non-native and cultivated plants (including hybrids and selected mutations – varieties). Indeed, biodiversity in its true sense embraces genetic variation within a species, again this aspect is often overlooked; a single genus such as *Rosa* could be represented by many hundreds of genotypes, with a wide range of morphological forms and flower colours (Cameron and Hitchmough 2016). Frequently too, the term biodiversity is linked only with species who are visually observed, thus for example, rarely account for soil macro- or micro-biological communities. In this study we restrict ourselves to bird taxa and defined habitat types to avoid such complications.

Despite recent research on the value of green space and interactions with nature on human well-being, it is still not clear which type(s) of urban green space should be promoted to optimise positive affect (and potentially aid longer-term well-being). This information is critical, however, if design and management of green space is expected to help alleviate key stress factors associated with urban living. Moreover, it is still not evident, to what extent such green spaces need to be biologically-rich to elicit the positive affect. Thus the aims of this research were to determine how typology of urban green

space affected human emotion (how happy they felt) and whether more positive emotion was associated with higher biodiversity (as determined by bird species richness and habitat number) and participants' perceptions of biodiversity or bird abundance. A mobile phone App was used to prompt participants when within an urban green space to record their feelings, and their perceptions of the surrounding levels of biodiversity. Locations with high response rates (≥ 10) were later assessed for their bird biodiversity and abundance and the number of ecologically-defined habitats present on site.

Birds were chosen as an indicator of overall biodiversity for a variety of reasons. These being used in previous studies to act as a reasonable proxy for wider biodiversity indicators (Williams and Gaston 1994; Butler et al. 2010; Farinha-Marques et al. 2011), their capacity to draw attention/fascination due to colour, movement or song (Woods 1998), their general popularity and likelihood of participants recognising different species compared to other taxonomic groups (Cox and Gaston 2015) and their potential to provide positive affect (Ratcliffe et al. 2013; Cox and Gaston 2016).

Materials and methods

Participant engagement

A mobile phone App (Shmapped) was developed to determine levels of engagement with the natural environment and health/well-being changes over a 7-day period. The App was promoted using social media, posters, leaflets, newsletters, and events (including guided walks). Potential participants were targeted through community groups, local employers, doctors' surgeries and charities within the social and environmental sectors. As the use of Smartphone Apps tends to be skewed towards more affluent adults (MacKerron and Mourato 2013), target sampling was employed to ensure sufficient representation from neighbourhoods associated with low socio-economic status (as determined by the UK's Index of Multiple Deprivation). For full details of the App and recruitment efforts see McEwan et al. (2019). Participants were 'prompted' via a push notification by the App to notice the 'good things in nature' when present within one of 945 digitally geo-fenced green spaces within Sheffield city. These green spaces were identified by a Sheffield City Council audit as having recreation or leisure value (Strategic Leisure Limited 2008). Of these, 161 were visited by participants during the experimental period. These areas varied in the amount of vegetation present, ranging from city squares with a few planted containers, up to extensive peri-urban parks covering 86 ha. The App used GPS to collect information on the user's location but only recorded data when the user was within the greenspace. It also requested user input related to their activity, who they were with (data not reported here), their perception of biodiversity ('How many types of

plant/tree/animal would you guess there were?') with a sliding response scale from 'None' to 'Lots') and how the location made them feel ('How did you feel about this place?' expressed as happy to sad emoji faces with responses converted to a 5 point Likert scale).

The App also directed participants to an additional short questionnaire on three separate occasions, (to provide baseline, post-intervention [7 days] and follow-up [1 month] data) that helped determine further information about well-being and engagement with nature. Primary outcome measures included: the 10-item Recovering Quality of Life scale (ReQoL; $\alpha = 0.92$; a measure of mental health) (Keetharuth et al. 2018) and the single item Inclusion of Nature with Self scale (INS; $\alpha = 0.90$; a measure of the implicit connection that individuals make between self and nature) (Schultz et al. 2004). Secondary outcome measures included the 6-item short form Nature Relatedness scale (NR6; $\alpha = 0.86$) (Nisbet et al. 2008) and the 4-item Engagement with Natural Beauty scale (EWNB; $\alpha = 0.87$) (Diessner et al. 2008). Two items measured previous exposure to the natural world – time spent outdoors as a child and time spent outdoors within the last year. A 5 point Likert scale being used again for these last two points (0 = almost none; 4 = lots of time). The questionnaire also provided home post-code data, allowing geographical distributions to be checked.

Between November 2017 and May 2018, 414 participants provided baseline data through the App with 228 participants completing the 7-day study with demographics of 53% female, 47% male, 22% black, Asian or minority ethnicity, and a mean age of 29 yrs. Some participants continued to interact with the App for several days after this and provided data for ≥ 8 days (equating to 259 responses in total). Participants completing the study (114 completed a 1-month follow-up when prompted) were rewarded with £20 vouchers.

Green space and biodiversity metrics

The most frequently visited green spaces in Sheffield were identified based on interaction with the App, i.e. where there were ≥ 10 participants. Ten UGS (details provided in Supplementary, Table S1, Fig. S1) were then selected from these to provide contrasts based on area of vegetation ($>50 \text{ m}^2$), landscape typology (variety of plant communities, including natural or designed) and location within the city. These were then surveyed for avian biodiversity and abundance, the number of ecologically defined habitats present and proximity to rural areas at the city boundary. Bird data was generated by a modified version of the BTO breeding bird survey technique (Risely et al. 2011). Each of these UGS was assessed via Google Earth Pro and 6 (80 m long) transects per site identified. A stratified randomised process was used to ensure part of all the main habitats within each UGS were within the survey area. An ornithologist walked each transect

(over 15 min. period) recording avian species and number within a 25 m range on either side of the transect. Each UGS was surveyed on 3 separate occasions (between 12 and 22 June; 26 June–10 July and 11–18 July, 2018), with all surveys conducted in the morning (05.45–10.15). Birds that were considered to have been counted from one transect, were excluded from data for another transect (to avoid double counting). For each UGS the total and mean number of individual birds (abundance), the total and mean number of bird species (avian biodiversity), and the total and mean number of individual birds within a species were recorded. Three bird species (*Columba livia domestica* – feral pigeon; *Larus ridibundus* – black-headed gull and *Anas platyrhynchos* – mallard i.e. gregarious species) had relatively high numbers of individual birds within one or more of the sites and abundance data was calculated both with these either included or restricted (minus gregarious species) for subsequent analysis. This was due to common species being linked with negative, as well as positive, perceptions (Jerolmack 2008). In addition to avian species, the number of habitat types in each UGS were recorded (using Phase 1 survey method, habitat classifications) and the distance between the centre of each UGS and the city boundary calculated.

Differences in avian abundance and the number of species present in the different UGS were assessed via one-way ANOVA. After testing residuals for normal distribution, significance levels due to treatment were attained (probability p values) and significant differences between means ascertained by Tukey post-hoc tests (denoted by different letters in Table 1). The effect of time on reported emotions and perceptions of biodiversity were assessed using a predictive ANOVA model with estimated means (due to an unbalanced design) with significant levels between times being determined by Bonferroni post-hoc tests. Data on avian biodiversity, avian abundance, avian abundance minus gregarious species, number of habitats present and proximity to rural boundary were correlated against emotional scores from the App, using the Pearson product-moment correlation (r) with values for degrees of freedom (df), probability for the significance of the correlation (p) and coefficient of determination (r^2) quoted in each case. Data from the App on perceived biodiversity was correlated with actual avian biodiversity for the 10 surveyed UGS. As perceived and actual biodiversity matched closely, perceived data was then used as a proxy for biodiversity in a further correlation against emotion. This relationship was tested using correlation for the 10 surveyed UGS and secondly, for sensitivity analysis, the number of sites were expanded to include all those with greater than 5 responses from the App.

To test whether the relationship between perceived biodiversity and emotion is influenced by any of the App outcome measures (previously discussed, such as ReQoL), linear mixed models were undertaken at the individual respondent rather than park level. Due to clustering of responses to the measures

at the medians (Supplementary Table S2) we split the users into ‘low’, ‘median’ and ‘high’ groups. Linear mixed models were fitted (estimated using REML) to predict emotion with perceived biodiversity, low/median/high group (coded using treatment contrasts), and the interaction between these two terms. User identity was included as a random effect. Users with fewer than 5 responses were excluded. Sensitivity analysis was also undertaken excluding users with fewer than 10 responses and the results were similar (supplementary Table S3). Degrees of freedom for fixed effects were estimated using Satterthwaite’s method, and 95% confidence intervals were computed using Wald approximation. The dataset was standardised prior to model fitting in order to obtain standardised parameters. To test the overall significance of the categorical variable, an ANOVA using type III sums of square was performed. We attempted to include greenspace identity as a second random effect in these analyses, but the within-group sample size was insufficient for adequate replication.

Results

Avian biodiversity and abundance

The number of avian species recorded varied significantly with UGS ($p < 0.001$, F ratio 22.5, df 20) with the greatest number of species associated with Graves, Endcliffe, Crookes Valley and Weston parks (Table 1). These values were significantly greater than those for UGS nearer the city centre i.e. Peace Gardens, Devonshire Green and South Street. The number of individual birds present also varied significantly with UGS ($p < 0.001$, F ratio 16.6, df 20). Weston Park had the greatest number of individual birds, but this dropped by more than 50% when more gregarious species were excluded (Table 1). Graves, Ponderosa and Botanic Gardens reported high numbers of birds (>100 even without the gregarious species being counted in).

Emotional responses and perceptions

People using the App showed even distribution across low, middle and high deprivation classes, suggesting participants were not skewed to any particular socio-economic group. Data showed there was a strong relationship between mean avian biodiversity and positive emotion ($r = 0.78$, Fig. 1). Similarly, positive emotions correlated strongly with UGS with a greater number of defined habitats present ($r = 0.72$, Fig. 2). Emotions tended to be more positive in UGS that were further away from the city centre ($r = 0.86$, Fig. 3). Size of site had a moderate effect on emotion ($r = 0.60$), with larger sites showing more positive responses (data not shown).

Actual avian biodiversity was closely correlated with participants’ perceptions of biodiversity in the different UGS ($r =$

Table 1 Summary of urban green spaces where $n > 5$ including their area, percentage cover (Grass, woody vegetation-‘Wdy’ or water-‘Wat’) and perceived biodiversity mean score based on number of visits (n). For the 10 sites ecologically surveyed, additional information provided on

mean avian biodiversity (Av. Bio), abundance (Av. Abu.) and abundance-gregarious species (Av. Abu.-Gr.) with standard deviation values (in parenthesis) and letters to note significant differences between sites (Tukey test)

Location	Total Area (ha)	% Cover			Av. Bio.	Av. Abu.	Av. Abu. -Gr.	Perc. Bio. Sc.	n
		Grass	Wdy	Wat					
Graves	86.1	62	33	≤5	27.0* (3.6) a	213 (42.1) ab	161 (30.5) a	4.6	19
Ecclesall Woods	82.6	5	93	≤5				5	5
Richmond	26.6	95	≤5	≤5				4.3	8
Norfolk	25.6	55	32	0				3.8	5
Whiteley Woods	20.0	27	65	≤5				4.8	10
Hillsborough	19.8	67	11	≤5				4.1	14
Bolehills	17.4	52	39	0	20.3 (2.1) b	138 (9.7) cd	107 (13.6) a	3.9	10
Meersbrook	16.3	73	20	0				4.4	9
Endcliffe	14.6	32	51	7	21.7 (0.6) ab	157 (7.8) bcd	103 (7.4) b	4.1	48
Ponderosa	12.3	70	23	0	19 (1.0) bc	164 (27.9) bc	118 (21.8) ab	3.7	22
Millhouses	10.6	57	23	11				4.0	6
Botanical Gardens	7.2	19	62	≤5	17.7 (0.6) bc	142 (7.0) cd	116 (4.0) ab	4.3	23
Crookes Valley	5.8	35	17	28	20.7 (0.6) ab	132 (12.8) cd	76 (15.1) bc	4.0	43
General Cemetery	5.6	≤5	87	≤5				4.7	6
Weston	4.6	59	21	≤5	20.7 (1.5) ab	259 (17.9) a	95 (17.7) b	3.9	76
South Street	3.4	43	49	0	13 (2.6) cd	108 (17.7) cd	76 (15.1) bc	3.4	11
Mount Pleasant	2.7	74	≤5	0				3.2	6
Northumd. Rd.	2.2	42	≤5	0				3.3	11
Devon. Gn.	1.2	64	6	0	13.3 (3.5) cd	114 (27.1) cd	70 (16.2) bc	3.2	16
St. Georg. Ch.	0.7	95	≤5	0				2.9	14
Peace Gardens	0.5	29	≤5	≤5	7 (1.0) d	96 (15.6) cd	24 (8.6) c	2.3	12
Tudor Square	0.4	12	≤5	0				2.6	9
Cathedral	0.4	28	≤5	0				2.6	9
Upper Allen	0.2	63	≤5	0				1.8	6
Barkers Pool	0.2	0	0	≤5				1.7	6

NB * Although Graves is the UGS with highest recorded avian biodiversity in this survey, this would be considered ‘intermediate’ compared to richer, non-urban habitats. In systematic surveys carried out between 2003 and 2008, Wood and Hill, (2013) estimated 45 breeding bird species within the tetrad corresponding to Graves Park. This compares to 65–70 species typically found in tetrads with a range of habitat types found in rural locations, outside the Sheffield City boundary

0.92, Fig. 4). This data gave confidence that the ‘perceived biodiversity’ metric could be used as a proxy for genuine biodiversity levels. Thus when perceived biodiversity data was utilised, a very strong relationship with emotion level for the 10 UGS resulted ($r = 0.81$, Fig. 5). Sensitivity analysis using a greater number of sites (25 in total) also supported a very strong relationship ($r = 0.89$, Fig. 5).

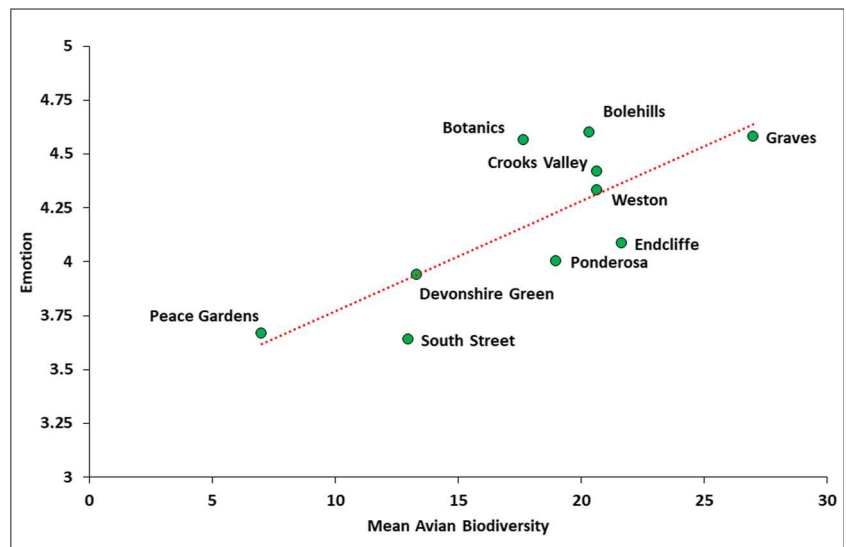
Avian abundance (number of individual birds across all species) demonstrated a positive and moderate relationship with emotion ($r = 0.51$, Fig. 6). Removing the gregarious species from this data set, however, strengthened the relationship ($r = 0.69$, Fig. 7), suggesting that qualitative decisions were being made about the type of birds that may have been observed. In essence, seeing more of the very common species was not strengthening the relationship.

It was noted that perceptions of biodiversity mean scores increased as the period of interaction with the App increased (effect due to time being significant, $p < 0.01$, $df = 2154$, Fig. 8). Although time also had a significant effect on emotional response ($p = 0.007$, $df = 2146$), a consistent pattern was less clear (Fig. 8), although the response was highest for those people who voluntarily continued to use the App for ≥ 8 days (259 responses); data here being significantly greater than day 1 and days 6–7, but not days 2–3 or 4–5.

Respondents relationship/engagement with nature and self-reported well-being

Finally, mixed effects modelling at the individual rather than park level supported the relationship between perceived

Fig. 1 The relationship between mean avian biodiversity and human emotion ('How did you feel about this place?') in 10 UGS. $r(df 8) = 0.776$, $p = 0.008$, $r^2 = 0.602$



biodiversity and positive emotions. Using the additional outcome measures from the App, a statistically significant interaction effect was found for Engagement with Natural Beauty (Table 2; see Supplementary Table S3 for full model results). This interaction indicates that the relationship between perceived biodiversity and emotion scores varied depending on an individual's general attitude or response to natural beauty. There was also a marginally significant interaction term for ReQoL ($p = 0.07$). For the other outcome measures (time spent outside as a child and in the last year, INS and Nature Relatedness), neither the main effect for the outcome measure term nor the interaction term were significant.

Closer examination of the interaction effects illustrate how the levels of ReQoL and Engagement with Natural Beauty

appear to influence emotions at different levels of perceived biodiversity (Fig. 9). At high levels of perceived biodiversity, participants across all ReQoL levels give similarly high emotion scores (Fig. 9a). In contrast, at low levels of perceived biodiversity, participants with a low ReQoL score have higher emotion scores than those with median or high ReQoL scores. For Engagement with Natural Beauty, at intermediate levels of perceived biodiversity, emotion scores are similar across all levels of engagement (Fig. 9b). There is a steeper slope, however (i.e. a stronger response to perceived biodiversity), for participants with a high Engagement level, and a flatter slope (weaker response) for participants with a low Engagement level. Whilst the differences in emotional response are relatively modest (as shown in Fig. 9b) they are statistically significant (Table 2).

Fig. 2 The relationship between number of ecological habitats present and human emotion ('How did you feel about this place?') in 10 UGS. $r(df 8) = 0.722$, $p = 0.018$, $r^2 = 0.521$

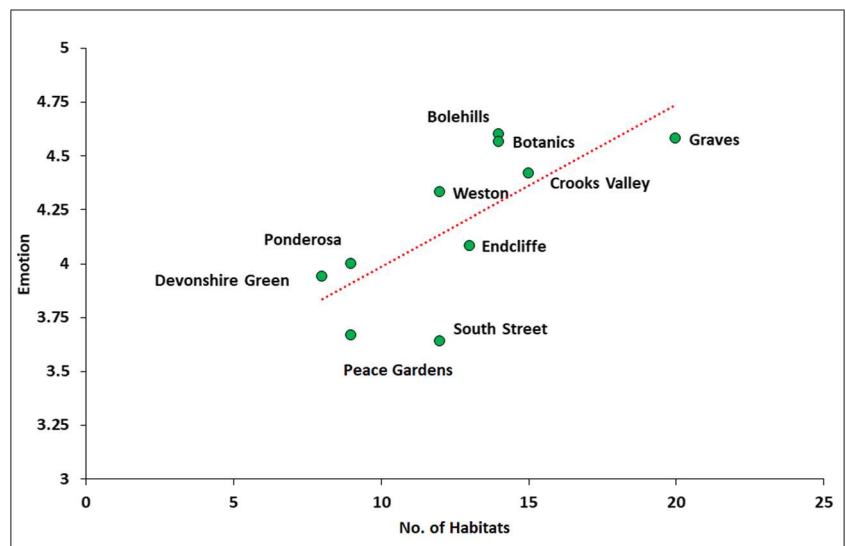
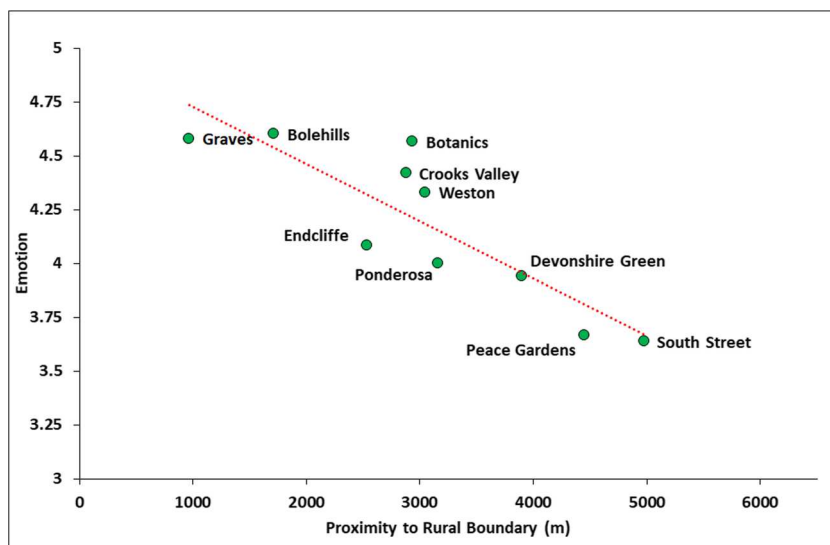


Fig. 3 The relationship between the distance (m) from the centre of UGS to the rural boundary and human emotion ('How did you feel about this place?'). $r(df 8) = 0.863$, $p = 0.001$, $r^2 = 0.745$



Discussion

Biodiversity and emotion

This study focussed on the associations between biodiversity and emotions in different UGS and whether more positive emotions were associated with higher perceived and measured biodiversity. Results demonstrated strong correlations between the levels of biodiversity within a site and human emotional responses to that site. Respondents reported being happier in sites with greater avian biodiversity (Fig. 1) or with a wider variety of habitats (Fig. 2). An even stronger relationship is reported when the emotions are linked to the respondent's *perceptions* of overall biodiversity (Fig. 5). Sites that were considered rich in wildlife, including those dominated by dissimilar landscape typologies (plant communities/habitats) e.g. ancient but continuous woodland (Eccleshall Woods),

diverse grassland with patches of woodland (Graves), scrub (Bolehills) and even aesthetic vegetation dominated by large numbers of non-native plant species (Botanic Gardens), all scored high on the emotional ratings. There was also a strong relationship between sites close to the rural edge and positive emotion (Fig. 3 and discussed in more detail subsequently).

In sum, this data strongly indicates the participants were responding much more positively to those UGS that support greater diversity of wildlife, and thus supports our hypothesis. This is in line with previous studies where increases in biodiversity have correlated with increases in health/well-being (Lovell et al. 2014; Aerts et al. 2018) or have caused positive changes in mood (Cracknell et al. 2016; Wolf et al. 2017). This is the case even when such places may not necessarily be regarded as 'top quality' in terms of infrastructure and management, nor even those representing iconic 'high-quality' wildlife habitat. Bolehills for example, is dominated by

Fig. 4 The relationship between perceived biodiversity (data from App) and mean avian biodiversity. $r(df 8) = 0.923$, $p < 0.001$, $r^2 = 0.852$

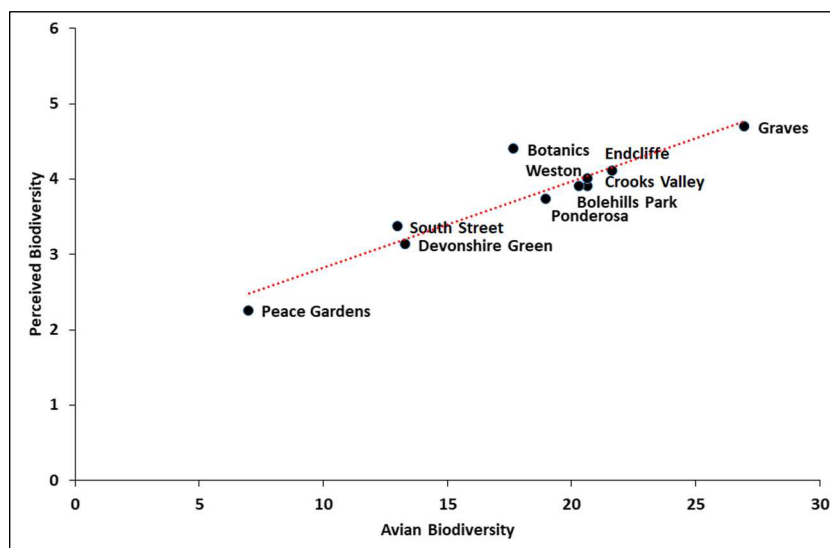
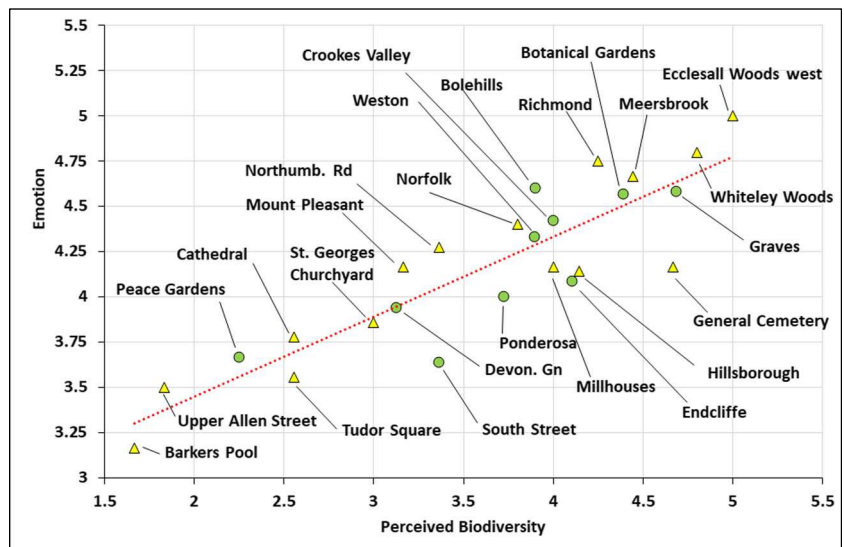


Fig. 5 The relationship between perceived biodiversity and human emotion ('How did you feel about this place?') in different UGS within Sheffield. Circles are those UGS where biodiversity surveys were carried out in addition to perceived values from the App. Relationship for the main 10 sites represented by circles ($n \geq 10$) $r(df 9) = 0.813$, $p < 0.001$, $r^2 = 0.661$. Relationship for 25 sites represented by circles and triangles ($n \geq 5$) $r(df 23) = 0.886$, $p < 0.001$, $r^2 = 0.785$



low scrub, rough grass, with clear indications of dog fouling and derelict equipment. Graves Park with the highest avian biodiversity and habitat number, does not warrant a 'Green Flag' award; a standard based on public accessibility, environmental standards, maintenance levels and facilities available (Anon 2018). Nevertheless, such UGS, although not award winning, are promoting strong positive feelings. Although not conclusive – we have no evidence of 'a cause and effect' - the data does suggest that those UGS that are promoting greater biodiversity are indeed associated with enhanced positive emotional responses in humans. The data is also encouraging in that perceived biodiversity closely aligned with actual avian biodiversity (Fig. 4). This agrees with Fuller et al. (2007) and Qiu et al. (2013) but not Dallimer et al. (2012). This may be due to the App requesting a simplified definition of perceived biodiversity – a simple ranking of 1–5 rather than

estimates of numbers of species in different taxa, as in the final study cited.

The Botanic Gardens in Sheffield elicited strong positive emotions and relatively high perceived biodiversity, but only middle ranking avian diversity. This site is also intermediate in terms of distance from the city centre to the rural fringe. The site is designed, however, to host a high floral diversity and has strong reliance on non-native plant species. Thus, the high level of 'attractive', 'colourful' plants in this UGS corresponding to positive emotions resonates with other findings (Cameron et al. 2012; Southon et al. 2018). Indeed, Adjei and Agyei (2015) indicated that non-native plants (i.e. those often present solely due to their aesthetics and colour) correlated more positively to happiness than native species. Other UGS though, dominated by non-native colourful flowering plants (e.g. Peace Gardens) did not elicit such positive

Fig. 6 The relationship between mean avian abundance (total number of birds) and human emotion ('How did you feel about this place?') in 10 UGS. $r(df 8) = 0.511$, $p = 0.131$, $r^2 = 0.262$

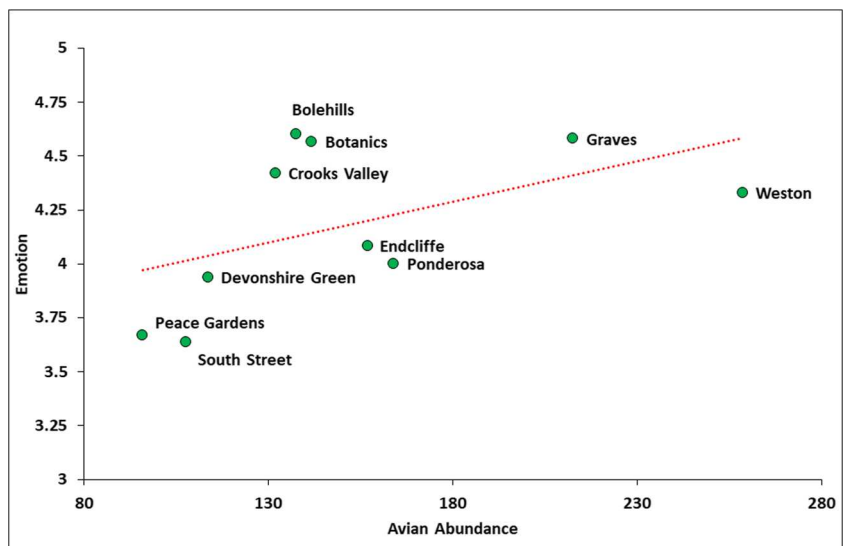
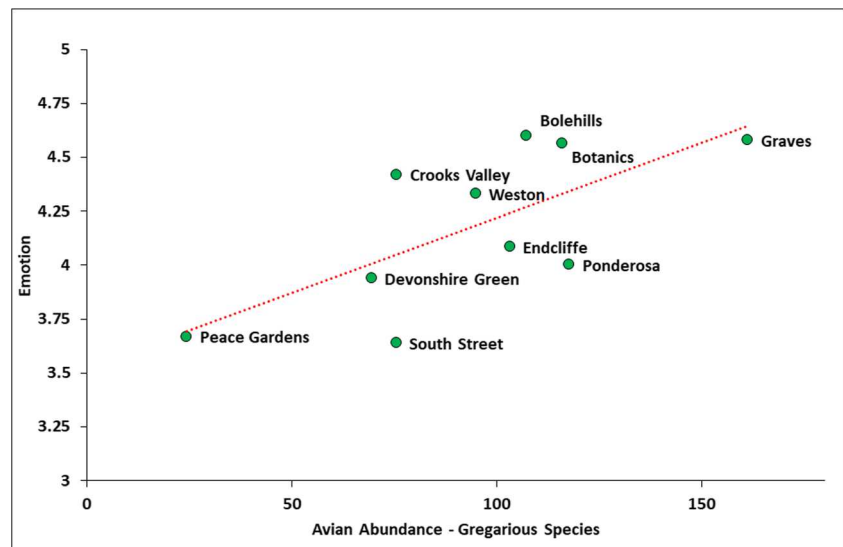


Fig. 7 The relationship between mean avian abundance minus gregarious species (total number of birds with gregarious species removed – *Columba livia domestica*, *Larus ridibundus*, *Anas platyrhynchos*) and human emotion ('How did you feel about this place?') in 10 UGS. $r(df 8) = 0.688$, $p = 0.028$, $r^2 = 0.473$



emotions, but this may be due to their smaller scale, fewer trees, less naturalistic planting style, potentially greater noise (Ivarsson and Hagerhall 2008; Adjei and Agyei 2015) and busier, city centre location (see points below).

Although the data shows good correlation between biodiversity and emotion, we cannot entirely rule out other factors from influencing the response. Heterogeneity in land form (irrespective of the diversity or abundance of wildlife present) may be promoting positive psychological responses. Using refuge theory, humans may have preference for certain landscapes associated with our evolution, open grass plains, with small copses of woodland and clear vantage points (McGranahan 2008). Bolehills with its low scrub vegetation, scattered sections of woodland and clear vistas overlooking river valleys may partially fit this 'model', but the denser forest of Ecclesall perhaps less so. Arguably, South Street Park has some aspects in common with Bolehills (grass,

groups of trees and fascinating vistas over the city centre), but it scored lower in the emotional ratings. Again, other factors may explain variation in responses here, for example South Street Park having less green space extent, but also more people, noise and obvious urban infrastructure within the vicinity (Adjei and Agyei 2015). Many of the sites associated with lower emotion scores in Fig. 7 were located nearer the city centre, again despite some of them having a high aesthetic architectural or heritage appeal, e.g. Tudor Square, Barkers Pool and Peace Gardens. Perhaps these locations were not providing the same degree of 'serenity' as UGS located in the suburbs. So, peace, quietness, tranquillity, less 'direct' stimulations/intrusions from human influences, greater 'coherence' and more 'soft' fascination (indirect attention) may also help explain the advantages of UGS in peri-urban locations (Kaplan and Kaplan 1989; Berman et al. 2008; Cruzet et al. 2012). More broadly, the strong relationship between

Fig. 8 Change in perceptions of biodiversity scores, emotion scores ('How did you feel about this place?') and number of responses to the App over time (numbers along top). Lines on points = \pm S.E. Points on each line with entirely different letters are significantly different from one another (Bonferroni, post-hoc test)

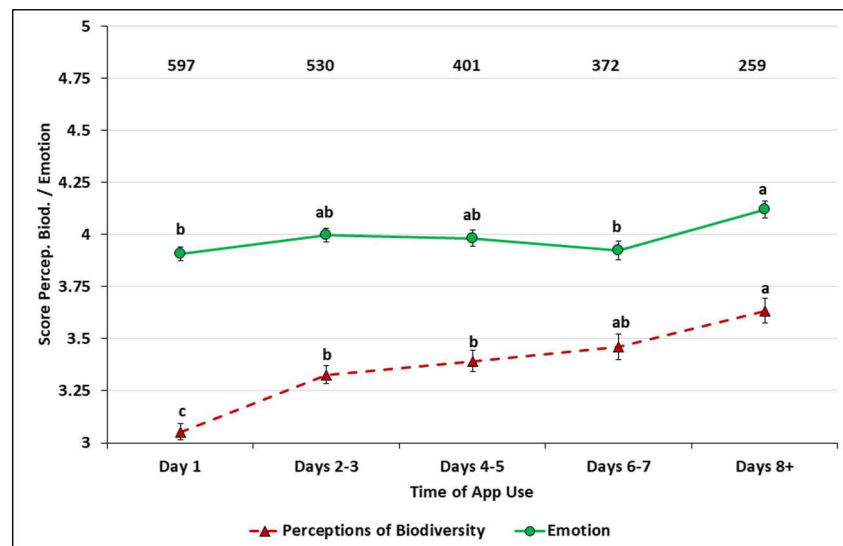


Table 2 ANOVA of mixed effects analysis of the relationship between emotion, perceived levels of biodiversity and the App outcome measures. Den df = denominated degrees of freedom, estimated using Satterthwaite's method

	Sum of Squares	Mean Square	df	Den df	F value	p value	
Time spent outside as a child							
Perceived biodiversity	339.55	339.55	1	4717	579.498	<0.001	***
Outcome measure	0.00	0.00	1	3152	0.000	0.993	
Interaction	0.01	0.01	1	4717	0.017	0.895	
Time spent outside in the last year							
Perceived biodiversity	277.75	277.75	1	4694	474.348	<0.001	***
Outcome measure	1.81	0.91	2	3161	1.547	0.213	
Interaction	1.61	0.80	2	4693	1.373	0.253	
Inclusion of Nature with Self							
Perceived biodiversity	292.61	292.61	1	4692	499.430	<0.001	***
Outcome measure	0.06	0.03	2	3136	0.048	0.953	
Interaction	0.45	0.23	2	4690	0.384	0.682	
Recovering Quality of Life							
Perceived biodiversity	63.38	63.38	1	4770	108.198	<0.001	***
Outcome measure	4.18	2.09	2	3334	3.570	0.028	*
Interaction	3.16	1.58	2	4745	2.698	0.067	.
Nature Relatedness							
Perceived biodiversity	283.57	283.57	1	4686	484.029	<0.001	***
Outcome measure	1.03	0.52	2	3097	0.880	0.415	
Interaction	0.51	0.25	2	4685	0.432	0.649	
Engagement with Natural Beauty							
Perceived biodiversity	267.15	267.15	1	4732	456.903	<0.001	***
Outcome measure	4.14	2.07	2	3116	3.540	0.029	*
Interaction	5.82	2.91	2	4724	4.979	0.007	**

sites close to the rural edge and positive emotion (Fig. 3) may relate to these alternative factors, but equally such locations are often associated with more likelihood of encountering a wider range of species (Faeth et al. 2011). Such peri-urban environments have a greater abundance of 'suburban-adapted' species e.g. *Dendrocopos major* (great spotted woodpecker) and potentially even some typically 'urban-avoiding' species e.g. *Tyto alba* (barn owl) (Wood and Hill 2013).

Avian richness and abundance

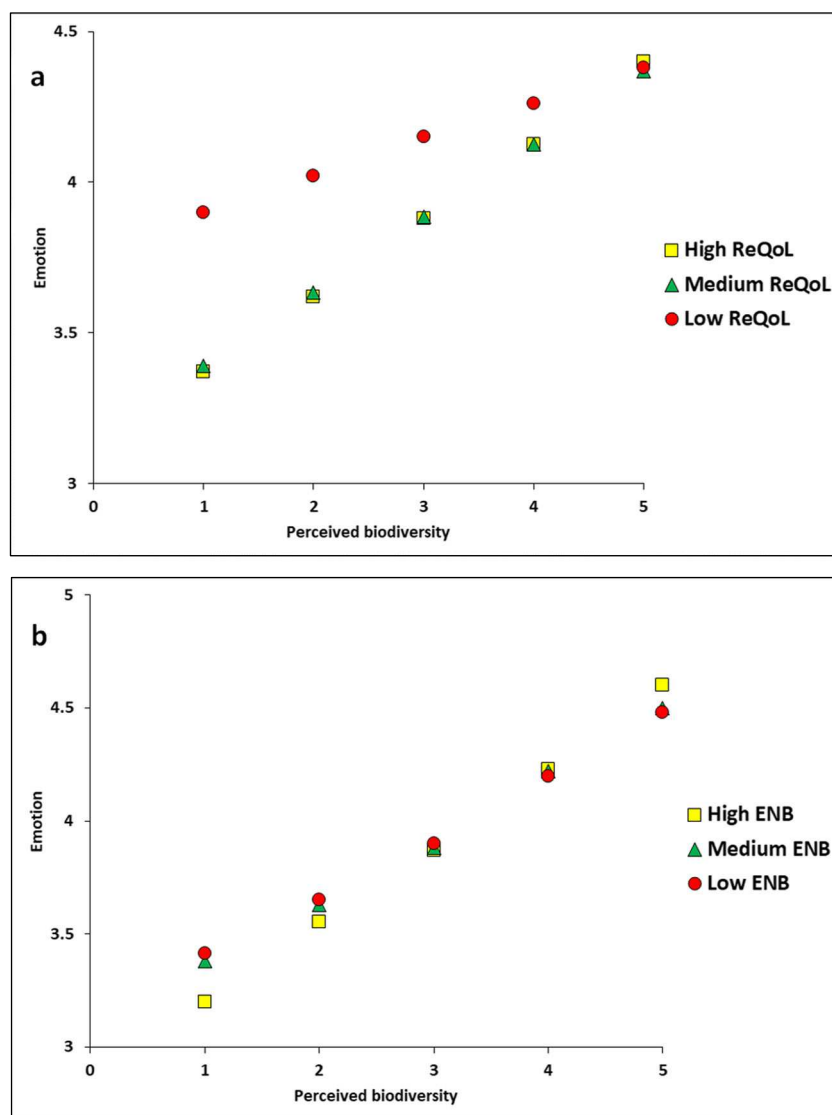
We found stronger correlations with avian biodiversity compared to avian abundance. This contrasts with Cox and Gaston (2016) where they found stronger correlation with avian abundance than biodiversity in lowering anxiety levels in participants. This could relate to the circumstances of the individual, for example avian abundance could be important for restorative effects for those with anxiety, whereas bird variety may be intrinsically important to positive affect, with some species being better than others in promoting positive emotions (McGinlay et al. 2017). Our correlations with avian abundance and emotion, improved markedly when we excluded gregarious species. This may be due to some of these species being dismissed as 'common' or unclean (Jerolmack 2008).

Studies on home-based bird feeders suggested that visitation from small passerine species (e.g. *Erethacus rubecula* - robin, *Cyanistes caeruleus* - blue tit) were preferred to that of larger (e.g. *Columba palumbus* - woodpigeon, *Sturnus vulgaris* - starling) or predatory species (e.g. *Pica pica* - magpie, *Accipiter nisus* - sparrowhawk) (Cox and Gaston 2015). Moreover, some people are averse to the flocking/instant flight habit such species have and that they fear being in close proximity to large numbers of birds at any one time (Lyytimäki et al. 2008). This demonstrates that cultural relationships affect perceptions of wildlife and these may impact on the potential restorative effects of different animal and plant species (Cox and Gaston 2015).

Nature engagement

There was some evidence that engagement with nature increased with use of the App (Fig. 8). Perceptions of biodiversity increased over time ($p < 0.001$, df 2154), and emotional levels tended to be higher at the end compared to the start of App use ($p = 0.007$, df 2154). This suggests that using the App is stimulating participants to become more aware of nature; a process in itself with salutogenic potential (Seligman et al. 2005; Richardson et al. 2015, 2016).

Fig. 9 Significant interaction effects between perceived biodiversity emotion scores within the ANOVA mixed effects modelling for (a) ReQoL and (b) Engagement with Natural Beauty



The results can also be considered in relation to well-being mechanisms. The data provide a link between perceived biodiversity and positive emotions, which in-turn can be linked to well-being. The beneficial effects of nature on well-being being driven by positive affect (Tugade and Fredrickson 2007; McMahan and Estes 2015). However, emotional responses to perceived biodiversity are complex. Our analysis indicates that responses are influenced by a person's level of engagement with natural beauty and perhaps also by mental health (as measured by ReQoL; $p = 0.07$) (Table 2, Fig. 9). Participants with a high level of engagement with natural beauty (i.e. appreciate the aesthetics and have strong emotional connections to the natural world), actually responded less positively when they perceived low biodiversity than those with less engagement. Conversely, engaged participants responded more positively when they thought the UGS was biologically rich. This suggests that for those people who have

a strong appreciation of nature and its aesthetic elements, then viewing biological variety is important for them to elicit their positive emotions. Extending this thinking further, they may also have the greatest to lose emotionally if UGS become less diverse and depauperate in wildlife. A similar effect has been found in other contexts. Marshall et al. (2019) studied emotional responses to the degradation of Australia's Great Barrier Reef, and found that individuals with greater place identity, appreciation and place attachment showed the strongest grief response to the reef's plight.

It is interesting to note that of all the outcome measures tested, many of which link to a connection to nature, only the Engagement with Natural Beauty gave a significant interaction effect (Table 2). Previous research has indicated that engagement with nature's beauty has impact on affect regulation (Song et al. 2017) and well-being (Capaldi et al. 2017; Zhang et al. 2014). Richardson and McEwan (2018)

concluded that well-being in nature is more than visits and exposure, there is a need to notice nature's beauty to access the wider benefits of well-being that nature offers.

Although the relationship with ReQoL in this study does not meet a statistical significance level of 0.05, the pattern is interesting, and warrants further research. Our data tentatively suggests that participants with low ReQoL scores (i.e. potentially possessing or prone to mental health problems) do not have a strong requirement for high levels of biodiversity to be present in order to benefit emotionally from being prompted to notice their surroundings. This may reflect the benefits of 'grounding' techniques that bring attention to the present moment for individuals with mental health conditions (Burrows 2013).

Results within a theoretical framework

The data demonstrates that people were responding more positively to UGS they perceived to be biologically rich. In many cases these places corresponded to higher avian biodiversity, but we do not know if participants themselves were consciously noting more bird species in these locations. Nevertheless, positive emotions were more likely to be reported in larger UGS that were diverse in terms of habitats and species present and were located nearer the city edge. This supports a number of theories outlined in the introduction. More diverse landscapes may promote greater opportunities for soft-fascination (Kaplan and Kaplan 1989; Grassini et al. 2019), and particularly those larger UGS at the city boundary are less likely to cause over-stimulation through noise and man-made artefacts. We may relate larger, more diverse landscapes with abundant wildlife to better 'evolutionary survival' (Hagerhall 2000) – essentially more opportunity to hunt, forage and find water. Landscapes rich in birds, for example, would have been useful for trapping birds per se, but also an indicator of other nutritional resources in terms of fruit, seeds, invertebrate food as well as suggesting the presence of water. Likewise, diverse habitats may promote stronger immune responses or 'healthier' human microbiomes, due to greater exposure to a wide range of microbial organisms or beneficial natural compounds (Flies et al. 2017; Hansen et al. 2017). Through our evolution, we may have been drawn to such locations due to one or more of these factors, and our preference today is a legacy of this. Conversely, it is possible that these landscapes are becoming increasingly important to us, and they and the species within elicit positive affect due to the fact that they have increasingly become 'the other' rather than 'the norm' for many urban citizens. Indeed, perhaps they are valued simply because they help distract from 'the normal/everyday' aspects of modern urban life? The fact that some species are becoming increasingly rare, just amplifies the fascination and positive emotion associated with them (Farber and Hall 2007; McGinlay et al. 2017). This may explain why the more abundant, common urban bird species were

not necessarily provoking a positive response from some respondents. More research is required however, to understand how individuals background and health history influence their emotional responses to biodiversity and green space. There was a suggestion that our appreciation of the aesthetics of nature (Engagement with Natural Beauty) and mental health status (ReQoL) could influence in some ways our 'requirement' for biodiversity.

Limitations of research

Although attempts were made to ensure App users represented a cross section of society, we cannot guarantee that socio-demographic factors were not affecting responses in the different green spaces. For example, the relative positive emotions associated with UGS on the peri-urban edge may relate to a greater proportion of users in these localities having higher income levels, being better educated and thus having higher life satisfaction in general (Boyce et al. 2010). Conversely though, a number of UGS identified with the most positive emotions were not in the most affluent areas of Sheffield, e.g. Meersbrook, Richmond and Bolehills. Our data sets for emotion and biodiversity did not coincide chronologically and this potentially may have caused some mismatches in the correlations, e.g. migratory birds would have been absent for *some* of the time the App was active, but these represented a relatively small proportion of the total species number (10%). Despite us carrying out pilot studies, it is possible that questions in the App were also mis-interpreted and this affected responses. We used lay language and emojis rather than technical terms to encourage participation and continued engagement. This could have led to misunderstandings in interpreting the questions. Also we can't guarantee that emotional responses were not influenced by factors other than the location and the amount of biodiversity people noticed. This could include App users' previous mood when entering the UGS, or be influenced by other aspects of the UGS. Finally, all data was collected from the one city, and needs to be viewed in that context, although results broadly agree with similar studies in the UK (Wood et al. 2018) and elsewhere (Gunnarsson et al. 2017).

Conclusions

This data shows some of the strongest correlations between urban biodiversity and human positive emotions published to date. The relationship between perceived biodiversity and positive emotion being particularly strong ($r = 0.87$). Policy makers need to consider more carefully the value that wildlife has (or landscapes with diverse habitats have) for urban residents. This strengthens the arguments that happiness can be strongly influenced by a connection to nature and the capacity to explore the natural/semi-natural world and appreciate its

beauty (Douglas et al. 2017). Worryingly, the data suggests that smaller scale green space interventions placed near the city centre do not provide the same level of emotional engagement as the larger scale green spaces that contain more habitats (and in this study a more diverse range of bird species). The implications for this on longer term human health per se requires further evaluation (Taylor and Hochuli 2015), but results from this study imply that city planners do indeed need to give space for quite extensive, diverse, green landscapes within the city precincts. Although further work is required to determine the precise role for biodiversity/ wildlife encounters, the data does confirm that these green spaces should at least vary in typology and the number of potential habitats present.

Similarly, planners need to consider whether the smaller, city centre UGS could be better connected through green corridors/networks (Douglas and Sadler 2010), linking these locations more effectively via avenues of street trees, adjacent gardens, green roofs/walls and brown field sites. This in turn allowing species migration through, and potentially residency within, the city centre. Joining spaces together may also promote feelings of greater green space extent amongst users. Habitat extension and improvement is also required, and innovative approaches to re-greening city centres are warranted, e.g. cladding entire buildings in vegetation such as the Bosco Verticale, in Milan, Italy (Flannery and Smith 2015). Such approaches need further evaluation, but with careful design they could provide appropriate habitat and feeding/nesting opportunities. Moreover, they would facilitate the regular interaction between people and a diverse range of wildlife species, this paper and others advocate.

Where wildlife is to be encouraged from a salutogenic perspective, it is also clear that not any type of wildlife will do. Our relationships between positive emotions and bird biodiversity were stronger than those with bird species abundance, though the relationships with abundance improved when the more common species were removed from the analysis. Thus, it is again imperative that policy makers and conservation bodies maximise the opportunities to enhance biodiversity within the urban matrix – it is encounters with a *variety* of wildlife that appears important to many city residents. Again, city planners need to give consideration to diversifying the range of habitats available, increasing their complexity and scale, and thereby promoting new niches for wildlife within UGS. Such actions are likely to increase the diversity of species present, rather than ‘simpler’ landscapes that may only suit a limited number of species.

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