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Perceived biodiversity, sound, naturalness and safety enhance the restorative quality and wellbeing benefits of green and blue space in a neotropical city

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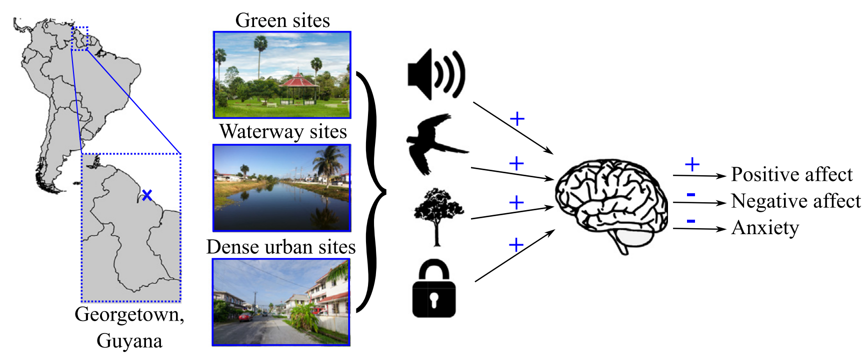
HIGHLIGHTS

- Specific characteristics of urban green and blue spaces influence human wellbeing.
- We examined perceived and objective sound, species richness, naturalness and safety.
- Bird surveys, acoustic recordings, and questionnaires were conducted in Georgetown.
- Perceived restorativeness influenced how perceptions related to human wellbeing.
- City planners can augment these specific characteristics for multiple co-benefits.

GRAPHICAL ABSTRACT



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ABSTRACT

Urban land cover expansion and human population growth are accelerating worldwide. This is resulting in the loss and degradation of green and blue spaces (e.g. parks, waterways, lakes) in cities, which provide resources to sustain biodiversity and improve human wellbeing. The specific characteristics of these spaces (e.g. sounds, species, safety) that enhance or detract from wellbeing are underexplored, yet this knowledge is needed to inform urban planning, management and policies that will ultimately benefit both people and biodiversity. Research of this kind is rarely conducted in the Global South, where rapid urbanisation threatens biodiversity-rich ecosystems of worldwide significance. Here, we examine how perceptions of green, waterway, and dense urban spaces relate to wellbeing in Georgetown, Guyana. Specifically, we use mediation models to test how perceptions of sound, bird species richness, naturalness, and safety concerns contribute to sites being perceived as restorative which, subsequently, influences wellbeing. We assess the accuracy of these site perceptions with objective measures of sound (using a bioacoustic sound index), bird species richness, and percent coverage of vegetation, water, and impervious surfaces. Results showed that if sites were perceived as species rich, containing natural sounds like birdsong, natural rather than artificial, and safe, they were perceived as more restorative, resulting in improved wellbeing. In general, people's perceptions were consistent with objective measures. Green, compared with waterway and dense urban sites, contained more biophonic sounds, higher species richness, greater vegetation and water coverage. Although waterways were biodiverse, they were dominated by anthrophonic sounds, so were perceived as artificial and non-restorative. We shed light on how city planners

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might augment specific characteristics to improve the wellbeing of urban dwellers, with implications for biodiversity conservation. Our findings provide a scientific evidence base for urban design and management plans that could deliver multiple co-benefits, particularly in biodiversity-rich cities in neotropical regions.

1. Introduction

Globally accelerating rates of urbanisation pose challenges for human health and wellbeing (Giles-Corti et al., 2016), with exposure to noise, environmental pollution and crime contributing to physical illnesses and psychological disorders for city dwellers (Abbot, 2012; Peen et al., 2010). Within the urban landscape of the Global North, fragments of green space (e.g. parks, meadows, gardens) have been shown to benefit self-reported general health (Wheeler et al., 2015), reduce the risk of cardiovascular and respiratory disease (Lee et al., 2014; Liddicoat et al., 2018), and improve psychological wellbeing (White et al., 2017). More recently, the wellbeing benefits of blue spaces (e.g. inland waterways, lakes, rivers) have been related to improvements in anxiety, stress and emotional wellbeing (Maund et al., 2019), better self-reported general and mental health (Pasanen et al., 2019), improved subjective wellbeing and lower risk of depression (Garrett et al., 2019). Through carefully targeted interventions, such as incorporating new and/or enhancing existing green and blue spaces in cities, relatively small health and wellbeing gains at an individual level could scale-up to substantial benefits across entire populations.

Several dominant theories underpin the associations between improved human health and wellbeing and green/blue space. Attention Restoration Theory (ART) postulates that spending time in natural environments restores an individual's ability to concentrate and focus attention, thereby improving memory, the ability to process information, and to solve problems (Kaplan and Kaplan, 1989; Kaplan, 1995). Four experiential qualities are thought improve depleted attentional fatigue: fascination (interesting stimuli that effortlessly attract attention), coherence (arrangement of stimuli), compatibility (conceived ability to carry out purposes freely), and being away (distance from everyday tasks or those that demand directed attention). Together these constitute 'perceived restorativeness' (the potential for an environment to be restorative) (Hartig et al., 1997). Natural environments, such as green and blue space, are also thought to facilitate recovery from stress (i.e. physiological, psychological, negative affect) via Stress Reduction Theory (SRT) (Ulrich et al., 1991). SRT posits that the emotive reaction induced by the surrounding environment influences behavioural responses and cognitive appraisals, leading to emotional and physiological reactions (Ulrich, 1983). Other scholars hypothesise that people are inherently 'biophilic', meaning they are emotionally affiliated and drawn toward 'nature' throughout evolution, leading to genetic adaptations to natural environments which predispose people to exhibit certain responses to specific stimuli (e.g. running water) (Kellert and Wilson, 1993). These theories are thought to operate via myriad and synergistic biopsychosocial pathways, through which exposure to or experience of an environment can reduce harm (exposure to environmental stressors), restore capacities (ART and SRT), and build capacities (encourage physical activity and social cohesion), thereby enhancing or detracting from health and wellbeing (Hartig et al., 2014; Markevych et al., 2017).

Empirical studies show support for these multiple theories, and providing important evidence to inform land-use planning and management decision-making. Specifically, researchers are identifying the characteristics of green and blue spaces that benefit or diminish human wellbeing. For example, seeing trees relates to higher momentary mental well-being (Bakolis et al., 2018), and feeling safe in blue space relates to greater subjective wellbeing (Garrett et al., 2019). Similarly, unmanaged vegetation is perceived as more 'natural', and this perceived degree of naturalness is associated with increased perceived restorativeness (Hoyle et al., 2019). However, evidence for the role that biodiversity plays in underpinning human wellbeing in urban green spaces is equivocal (Carrus et al., 2015; Cox et al., 2017; Dallimer et al., 2012; Fuller et al., 2007; Wolf et al., 2017). Species richness or abundance of taxa, such as birds and butterflies, have been found to improve wellbeing, although trends are inconsistent and complicated by the use of different metrics of wellbeing and biodiversity. The variation in results may also be explained by a mismatch in the levels of biodiversity people perceive to be present, compared with what objectively exists (Dallimer et al., 2012). These differences could be informed by personal preferences that influence whether the experience is positive or negative (Bell et al., 2019; Clayton et al., 2017; Pett et al., 2016). As such, characteristics that positively influence people's wellbeing may not be the same as those that conservationists seek to support. Pett et al. (2016) argue that it is crucial that researchers consider this paradox if we are to effectively align public health and conservation objectives and outcomes within urban green (and blue) spaces.

People's perceptions of green and blue space characteristics can be informed by a variety of sensory cues (Franco et al., 2017). Evidence shows, for instance, that more colourful planting regimes in green spaces provide greater aesthetic enjoyment (Hoyle et al., 2018). The role of sound is increasingly being examined by researchers. For example, birdsong increases perceived restorativeness (Ratcliffe et al., 2018), while other natural sounds (e.g. breeze in the trees) are found to be more calming (Hedblom et al., 2017) and more pleasant (Irvine et al., 2009; Jahncke et al., 2015) than anthropogenic sounds (e.g. mechanical, people), relating to more positive emotions and higher mental wellbeing (Bakolis et al., 2018; Moscoso et al., 2018). This might subsequently lead to specific features, such as trees and birds, being proactively managed for in green spaces and throughout the urban landscape more broadly (Hedblom et al., 2017; Ratcliffe, 2019). Nonetheless, understanding how people's perceptions of sound relate to objective measurements is needed. This is a substantial knowledge gap that needs to be filled to inform the design of urban green and blue spaces that maximise benefits to human wellbeing (Erfanian et al., 2019). To date, objective sound measures used within nature-health research have focussed on sound pressure, to inform policies aimed at reducing noise pollution and preserving 'urban quietness' (Evensen et al., 2016; Irvine et al., 2009; Payne and Bruce, 2019). Ecologists have developed a suite of bioacoustic indices for biodiversity monitoring, where recordings capture noise from specific features like animals, machinery or rain (Bradfer-Lawrence et al., 2019). Thus far, few studies have sought to relate bioacoustic indices to human perceptions, but Carruthers-Jones et al. (2019) found strong correlative associations between acoustic indices and people's perceptions of wildness across an urban-wild gradient.

To aid our understanding of how objective and perceived green and blue space characteristics influence health and wellbeing, there have been calls for studies to be structured around testing the pathways within existing conceptual frameworks (Hartig et al., 2014; Markevych et al., 2017). Additionally, to enable comparisons to be drawn between studies, there are calls for consistency in the choice of measures used to assess these pathways as well as outcome variables. For example, perceived restorativeness acts as a 'mediator' (a variable, 'M' that intervenes in the relationship between 'X' and 'Y'; Hayes, 2009) when explaining how perceived bird diversity and perceived naturalness influence positive and negative wellbeing ('affect') and happiness after an outdoor walk (Marselle et al., 2016). In the same way, outcome measures, including positive/negative affect (Hartig et al., 1997; Marselle et al., 2016) and 'state' anxiety (Lee et al., 2014; Wang et al., 2016; Wolf et al., 2017), have been identified as important short-term outcomes resulting from interactions with nature, although state anxiety has yet to be tested with perceived restorativeness as a mediator.

The majority of nature-wellbeing studies originate from the Global North (Hossain et al., 2020). However, findings from this body of work may not be directly transferable to the Global South, where the green and blue characteristics that are important for human wellbeing may vary as a result of differing climates, cultures, and socio-economic challenges (Rigolon et al., 2018; Saw et al., 2015). Global South cities are also subject to faster rates of urban land cover expansion (Angel et al., 2011) and population growth (United Nations, 2018), which concomitantly put pressure on existing urban green and blue spaces, and the incorporation of new ones into development plans (Richards et al., 2017). In South America, the rate of urbanisation into biodiversity-rich areas is predicted to be faster than elsewhere in the world (Güneralp and Seto, 2013). Here, we investigate how perceptions of urban green and blue spaces' characteristics are related to human wellbeing in Guyana, northern South America. Georgetown, Guyana's capital city, was historically referred to as the 'Garden City of the Caribbean' (Edwards et al., 2005) and contains a wealth of urban green and blue spaces that host a rich diversity of birds, given its proximity to the Guiana Shield Amazonian forest (Hayes et al., 2019).

Here, we investigate how people's perceptions of certain green and blue space characteristics within Georgetown relate to their momentary wellbeing (positive and negative affect, and anxiety), compared with dense urban spaces in the city centre that are predominately built infrastructure. Specifically, we explore how perceptions of sound, perceptions of bird species richness, perceived naturalness and concerns for personal safety all contribute to the perceived restorativeness of the green/blue spaces, and whether perceived restorativeness acts as a mediator of people's wellbeing. Finally, we assess people's perceptions of sound, bird species richness, and perceived naturalness in relation to objective measures. Taken together, these findings are valuable to decision-makers tasked with designing, restoring, maintaining and enhancing urban green and blue spaces in Global South cities like Georgetown.

2. Methods

2.1. Study area

Georgetown, capital of Guyana (Fig. 1a), contains many green and blue spaces, including a large botanical garden, several public parks, and abundant vegetation alongside the roads and inland waterways. The neotropical city covers approximately 30 km^2 and contains 16% (~119,000 people) of Guyana's population, characterised by a high diversity of ethnicities and socioeconomic backgrounds (Bureau of Statistics, 2012).

We undertook point count surveys for birds, made sound recordings, and conducted questionnaires across Georgetown. First, survey sites were randomly selected with a minimum distance of 250 m between them to ensure independence (Silva et al., 2015). We examined sites across three landcover types: public parks (National Park and Botanical Gardens) (green, $n = 19$); artificial freshwater waterways (waterways, $n = 19$); and built-up residential or commercial areas that predominately comprise buildings and roads (dense urban, $n = 19$) (Fig. 2). Landcover types were defined and ground-truthed by the ground coverage (%) of nine environmental variables within a 50 m radius of the central point of the site, matching the search area of the point count bird surveys and the area participants were asked to consider around them during the questionnaire (see below for details).

2.2. Objective measures

We grouped percent coverage of the nine environmental variables into three objective measures of landcover: vegetation (tree, shrub, grass); water (ponds, canals, drains); and impervious surfaces (buildings, roads, pavements) (Fig. 1b). We conducted point count surveys for birds at each of the 57 sites (Fig. 1c) as part of an associated study on bird diversity across Georgetown (Hayes et al., 2019). Point counts were carried out on clear days between 05:30 and 08:30, using a fixed radius of 50 m, and recording all birds seen or heard in 15 min (Huff et al., 2000) to species level. All birds were considered part of the survey if flying within 25 m of the highest structure, whereas birds above this threshold were deemed to be flyovers. We additionally quantified the soundscape by taking sound recordings as the questionnaires were delivered ($n = 5$ per landcover type), averaging 6 min 46 s (see Section 2.3 for the procedure). We took sound recordings using a digital recorder (Zoom H4N Pro), that has two built-in unidirectional stereo microphones positioned perpendicular to one another. The device was placed at the centre of the point count survey site which participants were also asked to consider during the questionnaire. This specification efficiently records binaural digital audio (sampling rate 48 kHz). We also set the microphones at maximum sensitivity (+100, at a sensitivity rating of −45 dB/1 Pa at 1 kHz) to capture the wide range of sounds that exist in an urban soundscape, and used a microphone windshield to reduce distortion.

2.3. Questionnaire

We delivered questionnaires at 15 of the 57 sites ($n = 5$ per landcover type), where a sufficient number of people passed by, so people's momentary wellbeing, as well as objective and perceived measures, could be compared. We first asked about people's visit patterns, including: visit frequency '*How frequently do you come to this spot?*' (daily, weekly, monthly, less than monthly, yearly); visit company '*Who are you with today?*' (kids, friends, partner, parents, alone, other); and visit motivations with an open question '*What is the main reason you are here today?*'. We asked these questions at the beginning to reduce response bias (Robson and McCartan, 2016).

To measure perceived restorativeness, we asked participants to rate the extent to which 16 statements reflected their experience '*in this spot where we are standing*' (Perceived Restorativeness Scale, Hartig et al., 1997). Participants responded on a five-point scale (1 = not at all, 2 = a little, 3 = moderately, 4 = quite a bit, 5 = extremely), modified from the original seven-point one to be consistent with the other scales used in the questionnaire and reduce potential participant confusion (Table S1). We created a single perceived restorativeness index by reversing negatively-worded statements then summing all 16 (index ranging from 16 to 80), resulting in good internal consistency (Cronbach's $\alpha = 0.85$) (Cronbach, 1951).

To measure momentary wellbeing, we then asked participants to '*Rate how you feel at the present moment in this spot*' for each of 10 positive (positive affect) and 10 negative (negative affect) emotions (Positive and Negative Affect Schedule, PANAS) (Watson et al., 1988), using the same five-point scale as for perceived restorativeness. Scores for each set of 10 emotions are summed to create a continuous measure (ranging from 10 to 50) of positive and negative affect (Table S2). To assess anxiety, we used the State-Trait Anxiety Inventory (STAI), which has the same stem question as PANAS (Marteau and Bekker, 1992) (Table S2). Once again, we used a five-point rather than the original four-point response scale. Negatively-worded items were reverse-scored, then all scores were summed and multiplied by 3.33 to generate a range of 20 to 100. All scales were internally consistent: positive affect (Cronbach's $\alpha = 0.0.85$), negative affect (Cronbach's $\alpha = 0.68$), and anxiety (Cronbach's $\alpha = 0.70$).

Enjoyment of nearby sounds was quantified on a continuous scale (1 = strongly disagree, 5 = strongly agree) in response to the

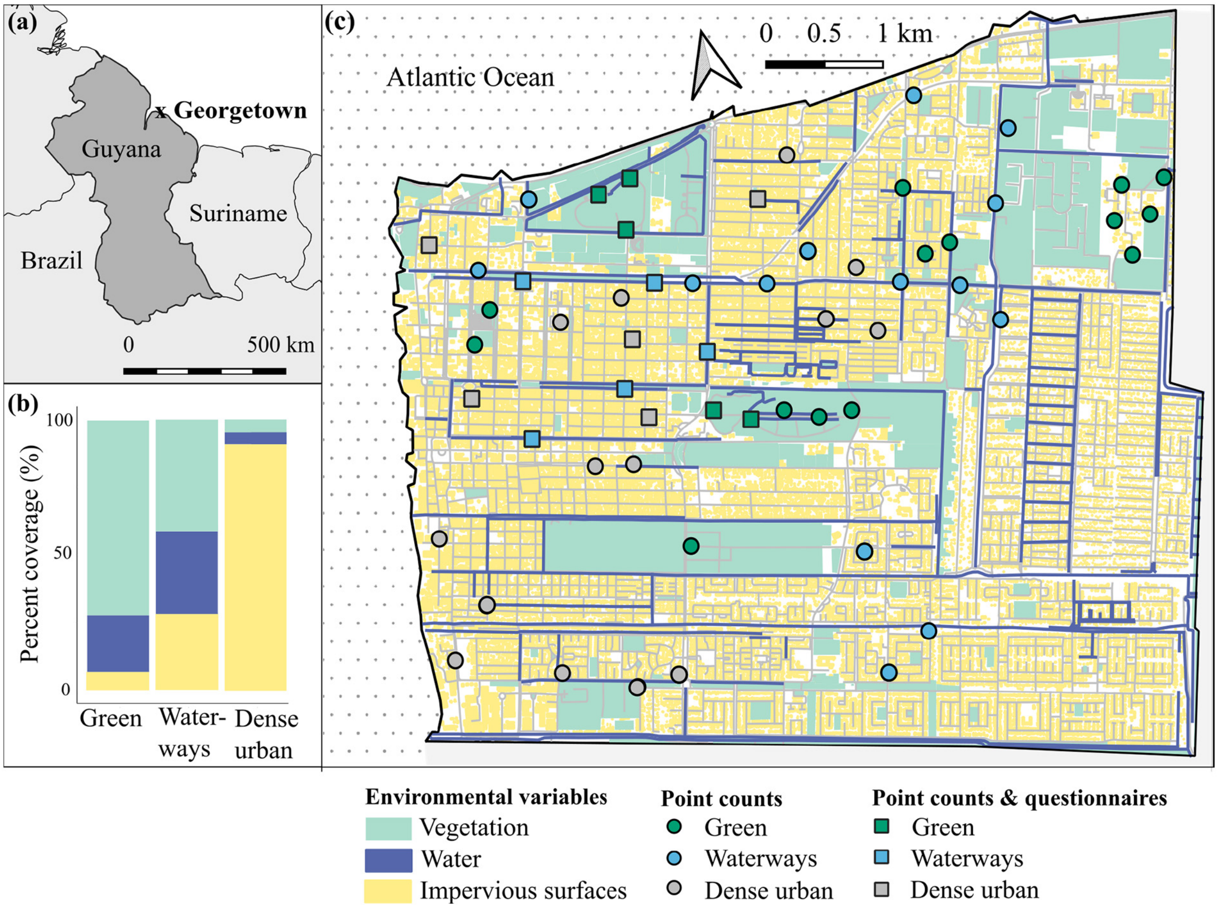

Fig. 1. Map of the study area in Georgetown Guyana**.** (a) Location of Georgetown in Guyana, South America, (b) percent cover of environmental variables (vegetation = light green, water = dark blue, impervious surfaces = yellow), within each of three landcover types (green, blue, dense urban), (c) map of the landcovers and sites (n = 19 green sites, n = 19 waterway sites, n = 19 dense urban sites) used for bird point counts (circles), and for both bird point counts and questionnaires (squares) (green, n = 5 green sites, n = 5 waterway sites, n = 5 dense urban sites). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

statement *'I like the sounds I hear in this spot we are standing*'. We then asked participants '*What three sounds can you hear in this spot?*'. Perceived biodiversity was measured by asking '*How many different types of birds would you say could normally be found in this spot?*', with a seven-point scale offering options (<5, 5 to 15, 16 to 25, 26 to 35, 36 to 50, 51 to 75, 75+) that related directly to the bird point count data. The scale was based on the quartiles of average site-level diversity, with the lower tail offering an option for fewer species than could actually be found, and the upper half of the scale lengthened to incorporate the highest measure found at the most species-rich site. We assessed perceived naturalness with the question '*How natural would you say this area was?*' on a continuous scale (1 = very natural, 5 = very artificial). Participants also rated the extent to which '*I feel unsafe in this place*', using the same five-point scale used for perceived restorativeness.

To account for covariation amongst sociodemographic groups, we recorded gender, age, ethnicity, religion, and education using questions from Guyana's most recent census (Bureau of Statistics, 2012), and a household income question generated through conversation with experts working within the Protected Areas Commission Guyana. A measure of residential history (experience of living in an urban or rural environment) was created by asking participants where, if anywhere, they had lived prior to Georgetown, given evidence that it could influence perceptions (Colléony et al., 2017; Moscoso et al., 2018). We did this through two dichotomous questions: '*Do you live in Georgetown?*' and '*Have you ever lived outside of Georgetown?*'. Two categories were drawn out: (1) urban (entire life spent in Georgetown), (2) rural/abroad (some time spent living in the interior of Guyana, or time spent living outside the country).

We piloted the questionnaire with 20 members of the public from varying sociodemographic backgrounds. Within PANAS, the emotion 'jittery' was subsequently replaced with 'uneasy'. Show cards displaying response options for participants to pick from were used to reduce the number of skipped questions and act as a literacy aid (OECD, 2013). We conducted the questionnaires face-to-face with every third passer-by aged over 18 years old during the daytime (07:30 to 18:30) and across all days of the week. Ethics approval was granted from the University of Kent's Faculty of Social Sciences Research Ethics Advisory Group for Human Participants (Ref. No. 0511617). The questionnaire is available from the corresponding author upon reasonable request.

2.4. Data analyses

Qualitative answers to visit motivations were iteratively analysed by two authors (JCF, KNI), clustered into codes (n = 24), themes (n = 9), and domains (n = 5), using an adapted typology from Irvine et al. (2013). Clustering was based on language used by participants (e.g. '*take some breeze*' and '*fresh air*' were both coded as 'fresh air'). Visit motivation was analysed at the domain level (physical, space qualities, unstructured time, social, cognitive) due to sample size limitations.

The reported sounds were coded (JCF, KNI) as 'mechanical', 'people', 'natural' and 'bird-related' (Irvine et al., 2009; Schafer, 1977). For example, 'mechanical' sounds included '*traffic*', '*horns*', and '*machinery*'; 'people' sounds included '*gym*', '*footsteps*', and '*chattering*'; 'natural' sounds were coded as '*wind*', '*water*', and '*trees*'; and 'bird-related' included

Fig. 2. Photographs taken from Georgetown, Guyana, giving examples of the landcover types (a) green, (b) waterway, (c) dense urban. Photos (a) and (c) were taken by Meshach Pierre, (b) by Ralph Blackburn. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

'*birds*', '*peaceful birds*', and '*birds chirping*'. Coding was done independently but resulted in high inter-rater reliability (kappa = 0.91). Only the first mentioned sound for each participant was used in subsequent analysis, as these were deemed the most salient to people's perceptions.

Analyses were performed using R version 3.5.0 (R Core Development Team, 2020). There was no evidence of spatial autocorrelation between sites (see supplementary text). To generate an objective measure of sound, we calculated the Normalised Difference Soundscape Index (NDSI), which is the ratio of biological (biophony) to anthropological sound (anthrophony) ('soundecology' package, (Villanueva-Rivera and Pijanowski, 2018). We used NDSI because previous research has suggested that natural sounds, particularly birdsong, are related positively to psychological wellbeing (Irvine et al., 2009; Ratcliffe et al., 2018). The spectral profile of each sound recording was split into two ranges of frequency bands: biophonic (2 to 8 kHz) or anthrophonic (0.2 to 2 kHz) (Kasten et al., 2012), with NDSI calculated as a ratio from −1 to +1, respectively. We averaged NDSI across the two recordings made by each of the two built-in microphones.

From the questionnaire, we first conducted G-tests to ascertain whether our sample represented Georgetown's population. To compare perceived and objective measurements, and to compare them between landcover types, we used Kruskal Wallis rank sum tests for numerical variables (with Dunn's test for post-hoc comparisons) and chi-squared tests for categorical variables. We used a significance threshold of $p < 0.05$ throughout our statistical analyses.

Prior to building models to investigate the mediating role of perceived restorativeness between site perceptions and wellbeing, we ran a series of exploratory analyses. We tested for associations between covariates using chi-squared goodness-of-fit tests for categorical data, subsequently removing income, education, and religion, leaving age and ethnicity. We also removed visit motivation, as the majority of answers fell into the 'physical activity' domain (92% green, 79% waterway, 78% dense urban), and visit company, as the most participants were visiting 'alone' (43% green, 87% waterway, 86% dense urban). We tested for an association between participant safety concerns and perceived naturalness to gauge whether to use an interaction term following Weimann et al. (2017), but found no significant result. Visit frequency was collapsed into 'daily', 'weekly', and 'monthly or less' (monthly, less than monthly, yearly) to improve power. We used Variance Inflation Factors to check for multicollinearity (Zuur et al., 2016), and all scores were below 1.7, indicating no issues.

We used linear mixed-effect models ('lme4' package, Bates et al., 2015) to examine the relationships between perceptions (perceived sound enjoyment, perceived bird species richness, perceived naturalness, safety concerns) and momentary wellbeing (positive affect, negative affect, anxiety), while adjusting for sociodemographics and visit patterns (age, residential history, ethnicity, gender, visit frequency) within single mediation models (Fig. 3a). Site was treated as a random effect to control for independence, and landcover type (green, waterways or dense urban) was included as a fixed effect. We ran separate models for each wellbeing measure, including all perceived measures to account for their combined effects on perceived restorativeness, the mediator. To compare landcover type, we also built linear mixed-effect models using site as a random effect, following the same structure used for the full dataset. To improve power, we trichotomised perceived bird species richness into 'low' (<5), 'medium' (5 to 25), and 'high' (>26), and safety concerns into 'low' (not at all), 'medium' (a little, moderately), and 'high' (quite a bit, extremely). As perceived bird species richness and safety concerns were multi-categorical, we used indicator coding to specify 'low' as the reference category for both. The pathways between these predictors and the wellbeing outcome variables are therefore estimated by multiplying the *a* pathways between each category with *b* to estimate the indirect effects separately, relative to the reference category (Fig. 3b) (Hayes and Preacher, 2014).

All models were checked for model fit adequacy statistics (Burnham et al., 2011; Harrison et al., 2018), including overdispersion and homoscedasticity (Feld et al., 2016; Zuur and Ieno, 2016). Using the 'mediation' package (Tingley et al., 2014), we ran 5000 simulations for each model (Hayes, 2009), using the bias-corrected and accelerated bootstrapping method for estimating mediation effects to correct for non-normality and address power limitations (Preacher and Hayes, 2008). We report the indirect effects to infer results (Hayes, 2009), recommended where some predictors are multi-categorical (Hayes and Preacher, 2014), drawing statistical significance where confidence intervals do not include zero.

3. Results

3.1. Summary statistics

The composition of sites differed significantly between each landcover (Table 1; Table S3). The highest bird species richness was

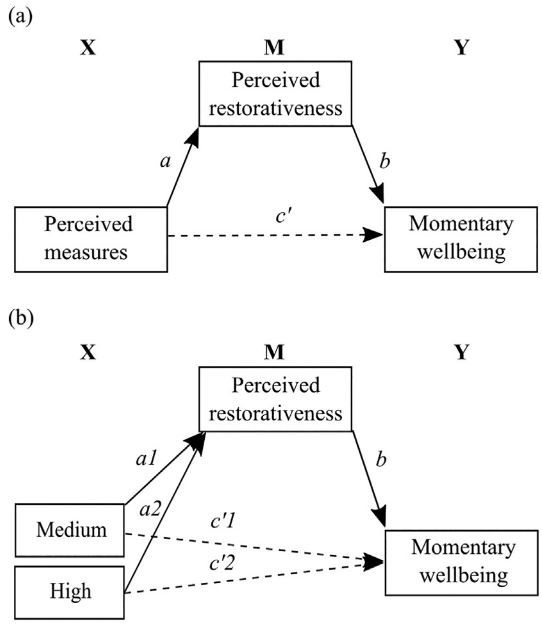

Fig. 3. Single mediation models to investigate how perceptions relate to wellbeing via perceived restorativeness. (a) Single mediation model with perceived restorativeness mediating the relationship between X, people's perceptions and Y, their momentary wellbeing (positive affect, negative affect, anxiety). This model simultaneously calculates regressions between X on M (the mediator) (path *a*, solid arrow), X on Y while holding M constant (direct effect, *c*′, dashed arrow), and between M and Y (*b*, solid arrow). The indirect effect (*a***b*) measures how X affects Y as a result of the effect of X on M which, in turn, also affects Y. (b) Amendment to the single mediation model when X is a multicategorical variable with >2 categories (e.g. perceived bird species richness at low, medium or high level). As there is no single *a* pathway that represents the effect of X on M, or on Y, indicator coding of X is used to reflect quantifications of the effect size of each category relative to a reference category (in this case, 'low'). We therefore interpret the indirect effect *ab* to represent the difference in one sequentially higher step relative to the reference.

found in green sites, compared to waterways and dense urban sites. The sounds recorded in green sites were, on average, biophonic (NSDI>0), while sounds at waterways and dense urban sites were anthrophonic (NSDI<0).

A total of 449 participants completed the questionnaire (70% response rate, green = 148, waterways = 134, dense urban = 121), 55% of whom were male ($n = 247$) and 72% under the age of 45 years old ($n = 322$). The sample was representative of Georgetown's population (Table 2). Participants were generally alone (70%, $n = 313$), and mostly visited sites daily (49%, $n = 219$) rather than weekly (22%, $n = 100$) or 'monthly or less' (29%, $n = 130$) (Table S4). The majority of participants were either passing through or on route to/from work (76%, $n = 284$) (Table S5), within the 'Physical' (84%, $n = 376$) motivation domain.

Momentary wellbeing varied between landcover types (Table 1). Positive affect at green sites was significantly greater than at dense urban sites. Negative affect at green and waterways did not differ, but both were significantly lower than at dense urban sites. Anxiety levels were significantly lower at green sites than both waterways and dense urban sites. Participants perceived green sites to be more restorative than both waterways and dense urban sites, with there being no difference between the latter two.

Participants reported liking the sounds they could hear significantly more in green sites compared with waterways and dense urban sites (Table 1). Perceptions of bird species richness differed between sites, with more high answers for green and waterways than dense urban sites. Green sites were perceived to be significantly more natural than waterways which, in turn, were perceived as more natural than dense urban sites. Participants felt 'low' levels of safety concern in all landcover types equally, responding with 'low' most often. Participants mentioned hearing more bird-related sounds in green than waterways or dense urban sites, and more mechanical sounds in the latter two landcover types.

3.2. Mediation

Single mediation models indicated that, for all sites combined, participants who enjoyed the sounds they could hear reported higher levels of positive affect, as a result of the positive relationship between enjoying the sounds and increased restorativeness (Fig. 4a; Fig. 5a; Table S6). There was a significant direct effect of disliking sounds on negative affect, independent of perceived restorativeness (Fig. 4b). Participants who disliked sounds were more anxious, but only when they perceived the site as not restorative (Fig. 4c). Within green sites, there was a direct effect of sound enjoyment on positive affect (Table S7). Perceiving waterways as restorative resulted in higher levels of positive affect when participants enjoyed sounds (Table S8).

Overall, participants who perceived species richness at 'medium" and 'high' relative to 'low' levels, reported higher positive affect as a result of the positive influence of species richness on perceived restorativeness which, in turn, increased positive affect (Fig. 4a; Fig. 5b; Fig. 5c). There was no relationship between perceived species richness and negative affect but, for anxiety, individuals who perceived 'medium' or 'high' species richness reported less anxiety than people who perceived 'low' species richness, inversely mediated by perceived restorativeness (Fig. 4c). At green sites, 'medium' and 'high' perceived species richness positively influenced positive affect, and negatively influenced negative affect and anxiety due to mediation by perceived restorativeness (Fig. 5b; Fig. 5c; Table S7). At waterway sites, perceiving 'medium' species richness was directly associated more positive affect, while perceiving 'high' species richness resulted in more positive affect mediated by perceived restorativeness (Fig. 5b; Fig. 5c; Table S8). Conversely, at dense urban sites, perceiving 'high' species richness was directly related to more negative affect (Fig. 5c; Table S9).

Participants who perceived sites as artificial, as opposed to natural, reported lower levels of positive affect and more anxiety, as the sites were also perceived as less restorative (Fig. 5d). When the different landcover types were examined individually, perceived naturalness showed no significant relationships with any wellbeing measure other than at green sites (Fig. 5d; Table S7), where sites perceived as more artificial negatively influenced positive affect via the mediator, although this finding could be spurious as the confidence interval almost crosses zero.

If participants had safety concerns (i.e. 'medium' or 'high' levels), they reported lower positive affect, than those who felt safer (i.e. 'low' levels), as feeling more unsafe was inversely related to perceived restorativeness (Fig. 5e; Fig. 5f). There was a direct effect between participants with safety concerns ('medium' or 'high') reporting significantly more negative affect and more anxiety than those individuals who felt safer. Anxiety was also mediated by perceived restorativeness (partial mediation, where the outcome variable is influenced by the independent variable both directly and indirectly via the mediator). Negative affect and anxiety were both positively and directly influenced by safety concerns ('high') for all landcover types (Tables S7; S8; S9).

3.3. Perceived and objective measures

Perceptions of sound enjoyment were related to NDSI. Participants mentioned they enjoyed the sounds at sites where more biophonic sounds were recorded ($X^2 = 35.249$, $df = 4$, $p < 0.001$), most often in green sites (Fig. 6a). When we asked what sounds participants were hearing, biophonic sounds were generally mentioned first and tended to be 'bird-related' ($X^2 = 83.78$, $df = 3$, $p < 0.001$), particularly at green sites (Fig. 6b). Perceptions of bird species richness were significantly associated with objective measurements of species richness ($X^2 = 16.801$, $df = 2$, $p < 0.001$) (Fig. 6c). Participants also perceived sites to be more natural, as opposed to artificial, when they contained

Table 1
Variable summary statistics. Objective measures for environmental variables, bird species richness and NDSI ($n = 19$ sites per site type), wellbeing measures and perceived characteristics (green sites = 148 participants, waterway sites = 134 participants, dense urban sites = 121 participants). Median and range provided unless noted.

Variable	Green	Waterway	Dense urban
Objective measures			
Vegetation (%)	70 (60–85)[*,§]	40 (30–60)[*,†]	5 (0–10)[†,§]
Water (%)	25 (5–30)[*,§]	30 (20–40)[*,†]	0 (0–10)[†,§]
Impervious surfaces (%)	10 (0–10)[*,§]	20 (10–45)[*,†]	90 (80–100)[†,§]
Bird species richness	14 (11−21)[*,§]	7 (5–18)[*,†]	7 (3−10)
NDSI	0.08 (−0.52–0.84)[*,§]	−0.30 (−0.75–0.47)[*]	−0.30 (−0.93–0.39)[§]
Outcome: wellbeing			
Positive affect	41 (18–50)[§]	38 (10–50)	35 (13–50)[§]
Negative affect	10 (10–40)[§]	10.5 (10–42)[†]	12 (10–43)[†,§]
Anxiety	26.67 (20–70)[*]	33.3 (20–86.67)[*,§]	36.67 (20–90)[§]
Mediator			
Perceived restorativeness	64 (24–80)[*]	48.5 (18–80)[*,§]	46 (23–70)[§]
Predictors: perceived measures			
Perceived sound enjoyment	5 (1–5)[*,§]	3 (1–5)[*,†]	3 (1–5)[†,§]
Perceived bird richness[‡]			
Low	$n = 21$ (12.5%)	$n = 44$ (31.2%)	$n = 58$ (42.3%)
Medium	$n = 125$ (74.4%)	$n = 79$ (56.0%)	$n = 70$ (51.1%)
High	$n = 22$ (13.1%)	$n = 18$ (12.8%)	$n = 9$ (6.6%)
Perceived naturalness	1 (1–5)[*,§]	2 (1–5)[*,†]	3 (1–5)[†,§]
Safety concerns			
Low	$n = 104$ (57.4%)	$n = 77$ (53.9%)	$n = 76$ (55.5%)
Medium	$n = 48$ (28.0%)	$n = 41$ (29.1%)	$n = 37$ (27.0%)
High	$n = 17$ (14.6%)	$n = 24$ (17.0%)	$n = 25$ (17.5%)
Sounds heard[‡]			
Bird-related	$n = 97$ (57%)	$n = 9$ (6%)	$n = 7$ (5%)
Natural	$n = 12$ (7%)	$n = 3$ (2%)	$n = 3$ (2%)
People	$n = 22$ (13%)	$n = 3$ (2%)	$n = 11$ (8%)
Mechanical	$n = 37$ (22.0%)	$n = 126$ (89%)	$n = 116$ (85%)

[*] Indicates significant differences ($p < 0.05$) between green and waterways (Dunn's test)
[†] Indicates significant differences ($p < 0.05$) between waterways and dense urban (Dunn's test).
[§] Indicates significant differences ($p < 0.05$) between Green and dense urban (Dunn's test).
[‡] Indicates significant differences ($p < 0.05$) between all site types using chi-squared test for categorical variables (details in Table S3).

Table 2
Sample sociodemographics in comparison to Guyana's most recent census (Bureau of Statistics, 2012). G-tests for goodness of fit comparing sample data (n; %) with census (where available) (%C) showed that the sample was representative of the city's population (presented in italics). Non-respondents ($n = 196$) were 54% male, 46% female, aged 53% under 40, and 47% over 40.

Characteristic	n	%	%C
Gender			
Female	202	45	47.5
Male	247	55	52.5
Other/Prefer Not To Say	0	0	0
G test: $G = -4134.3$, X^2 df = 1, p = 1			
Age			
18–24	120	27	26.8
25–34	121	27	24.3
35–44	81	18	18.9
45–54	51	11	13.5
55–64	47	10	6.9
65+	29	1	6.9
Other/Prefer Not To Say	0	0	2.6
G test: $G = -4100.9$, X^2 df = 5, p = 1			
Ethnicity			
African	187	42	52.8
Amerinidian	13	3	1.0
East Indian	97	22	19.6
Mixed	128	29	23.8
Other/Prefer Not To Say	24	5	2.7
G test: $G = -4098.7$, X^2 df = 4, p = 1			
Religion/denomination			
Anglican	23	5.1	9.1
Muslim	33	7.8	2.3
Pentecostal	26	5.8	21.2
Roman Catholic	32	7.1	11.8
Hindu	34	7.6	12.0
Other Christian	219	48.8	23.6
7th Day Adventist	20	4.5	4.3
Non/no religion	42	9.4	7.2
Other/Prefer Not To Say	20	4.5	4.3
G test: $G = -3873.5$, X^2 df = 8, p = 1			

Characteristic	n	%	%C
Education			
Primary/None	27	6	29
Secondary	174	39	53
Post-Secondary	28	6	6
Technical/Advanced	58	13	NA
University	159	35	8
Other/Prefer Not To Say	3	<1	4
G test: $G = -3222.5$, X^2 df = 4, p = 1			
Household income			NA
Less than GY$40,000	39	9	
GY$40,001 to $100,000	83	18	
GY$100,001 to $160,000	54	12	
GY$160,001 to $220,000	37	8	
GY$220,001 to $280,000	21	5	
> GY$280,001	55	12	
Other / Prefer Not To Say	160	36	
Residential History			NA
Georgetown	115	26	
+ Interior	221	49	
+ Outside of Guyana	113	25	
Other/Prefer Not To Say	0	0	

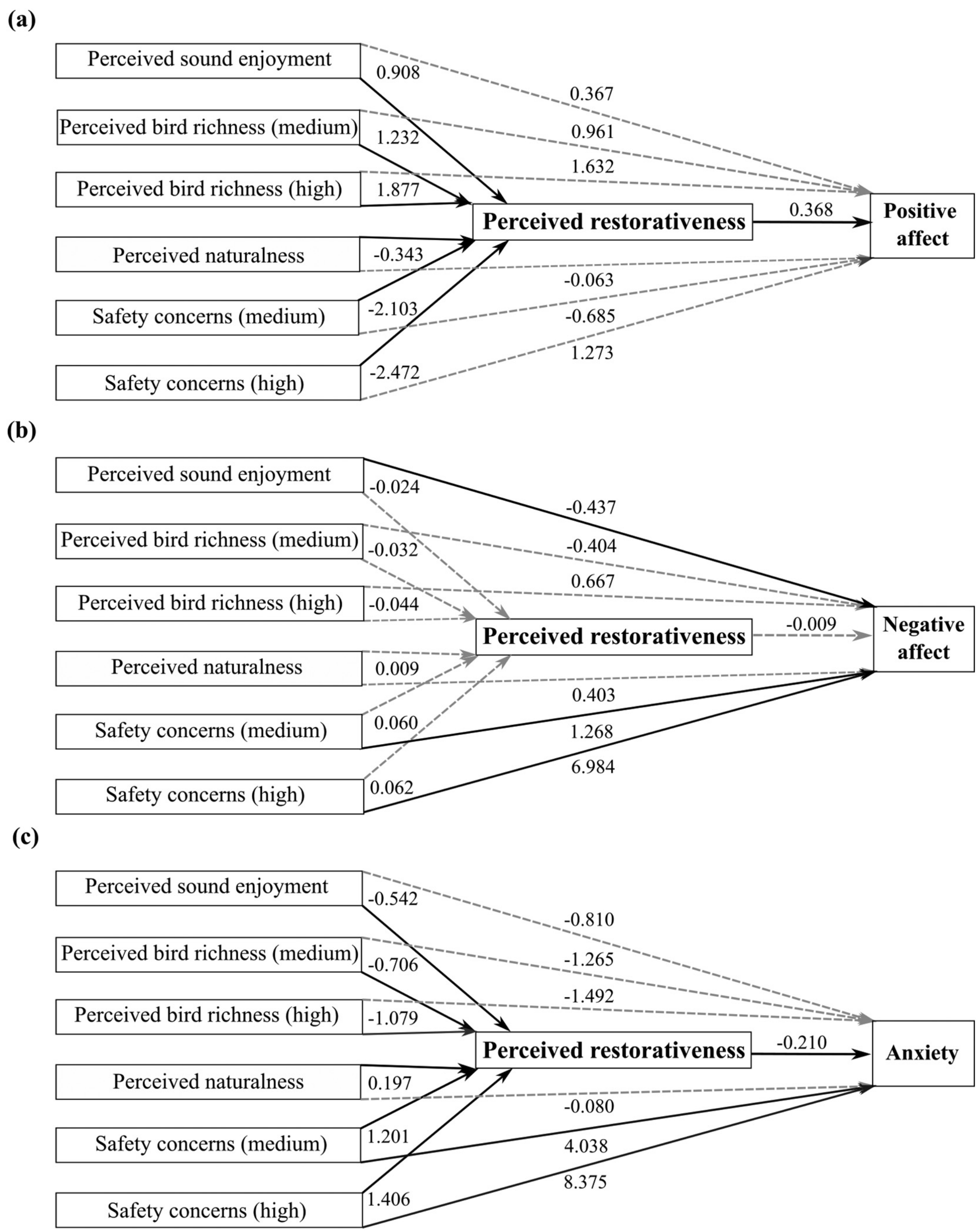

Fig. 4. Diagrammatic representation of single mediation models. Perceptions (perceived sound enjoyment, perceived bird species richness, perceived naturalness, safety concerns) influencing momentary wellbeing (a) positive affect, (b) negative affect, (c) anxiety, adjusted for covariates (age, residential history, ethnicity, gender, visit frequency, landcover type) at all sites combined across landcover types. Plots display direct effect (c'), and the mediating effect of perceived restorativeness (indirect effect = *ab*), with significant paths ($p < 0.05$) in bold. Reference category for both perceived bird richness and safety concerns is 'low'.

more vegetation (trees, shrubs, grass) ($X^2 = 60.354$, $df = 4$, $p < 0.001$), more water (ponds, canals, drains) ($X^2 = 109.45$, $df = 4$, $p < 0.001$), and less impervious surfaces (buildings, roads, pavements) ($X^2 = 113.26$, $df = 4$, $p < 0.001$) (Fig. 6d).

4. Discussion

Decision-making authorities that manage human-dominated landscapes have to deliver, and trade-off between, multiple biodiversity, individual and societal benefits (Dearborn and Kark, 2010). Urban green and blue spaces can simultaneously support biodiversity and enhance human wellbeing, but understanding exactly how people perceive and respond to specific characteristics of these spaces is key to maximising their effectiveness for both humans and conservation (Pett et al., 2016). Here, we show that the restorativeness of green and blue spaces is considered greater if an individual perceives a site as safe, species-rich, natural (as opposed to artificial) and a place where they can enjoy biophonic sounds that are principally bird-related. This increased perceived restorativeness then results in improved wellbeing (increased positive affect, and decreased negative affect and anxiety). To date, a paucity of such research has been conducted in the tropics. Comparing perceptions with objective measures gave insight into how

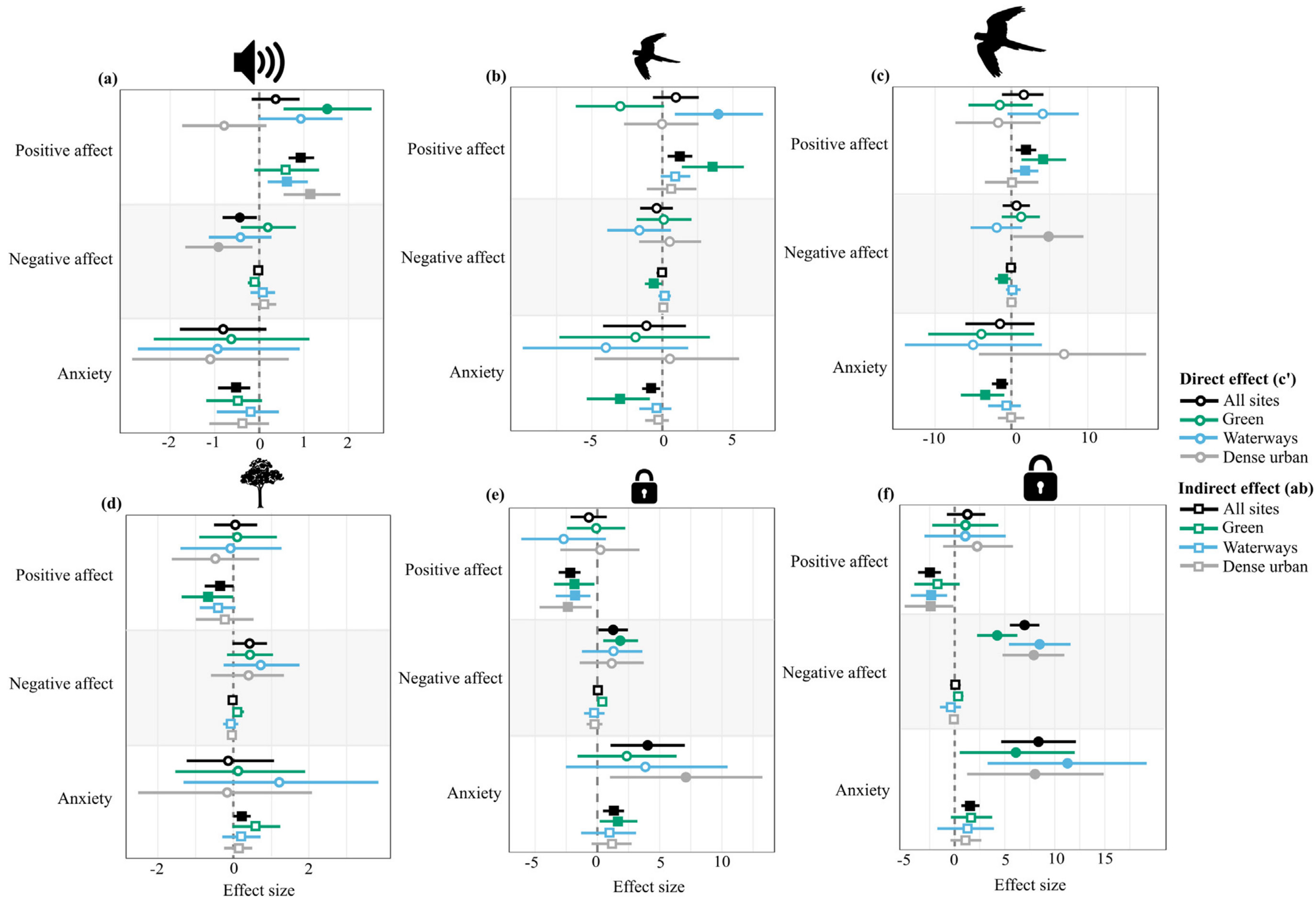

Fig. 5. Direct and indirect effect of single mediation models at each site type for each perception. Single mediation models showing direct effect (circles) and indirect effect via perceived restorativeness (squares) of (a) perceived sound enjoyment (b) perceived bird species richness ('medium'), (c) perceived bird species richness ('high'), (d) perceived naturalness, (c) safety concerns ('medium'), and (f) safety concerns ('high'), influencing momentary wellbeing (positive affect, negative affect, anxiety). Models (all sites combined = black, green sites = green, waterway sites = blue, dense urban = grey) are adjusted for covariates (age, residential history, ethnicity, gender, visit frequency). The reference category for both perceived bird richness and safety concerns is 'low'. Plotted unstandardised regression coefficients (β) and their bias-corrected and accelerated bootstrap confidence intervals (coloured lines) are from 5000 simulations. Statistically significant ($p < 0.05$) variables (filled symbols) do not cross zero (grey dotted line), with those above zero positively related, and those below zero negatively related, to wellbeing. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

people respond to local environmental characteristics. Participants accurately estimated bird species richness around them, perceived sites that contained greater proportions of vegetation and water as more natural, and enjoyed and recognised sounds that were objectively measured as biophonic. In Georgetown, these features could be enhanced across the city to support biodiversity and the subsequent benefits this brings to human wellbeing.

For the first time, we tested how people's perceptions of sound matched with a bioacoustic index (NDSI) traditionally used in ecological monitoring research and connect it to human wellbeing. By classifying sound recordings taken while participants were completing the questionnaire, we demonstrate the importance of biophonic sounds, perceived as bird-related, in contributing positively to perceived restorativeness and, subsequently, improving wellbeing for people in species-rich green spaces. This aligns with findings from the UK that show birdsong influences perceived restorativeness and stress recovery (Ratcliffe et al., 2013), that people report higher momentary wellbeing when they can hear birdsong (Bakolis et al., 2018), and that a diverse birdsong provides greater benefits than single species singing (Hedblom et al., 2014). Higher NDSI values in the biophonic range have been associated with higher species richness (Bradfer-Lawrence et al., 2020), and characterise sites that contain more biodiversity, including in South America (Machado et al., 2017). While the use of NDSI to monitor biodiversity in urban environments has been contested (Fairbrass et al., 2017), we discovered that it accurately reflected the types of sounds participants reported hearing and enjoying. Using bioacoustic indices as a tool to explore the role that ecological sounds play in supporting human wellbeing in cities therefore shows promise. Moreover, while participants may have expected greener sites to be more restorative, and reported hearing sounds they expected from these types of areas, wellbeing was also enhanced in densely urban sites where sounds were as enjoyable and the space was perceived as restorative. This contributes to a growing line of enquiry into the positive perception of urban sounds (e.g. people, mechanical), that can be thought of as vibrant, exciting, and contributing to a sense of place (Aletta and Kang, 2018; Ratcliffe, 2019).

Our results demonstrated that higher perceived bird species richness positively enhanced the perceived restorativeness of sites, resulting in improved wellbeing. This finding is consistent with research from the Global North (Marselle et al., 2016), thus advancing our understanding of how this relationship might persist cross-culturally. Future work needs to uncover what factors shape perceptions of species richness. For instance, Dallimer et al. (2012) show that individuals with better identification skills are more likely to accurately perceive species richness. In Georgetown, there was a positive trend between perceived and objective species richness across all three landcover types. This

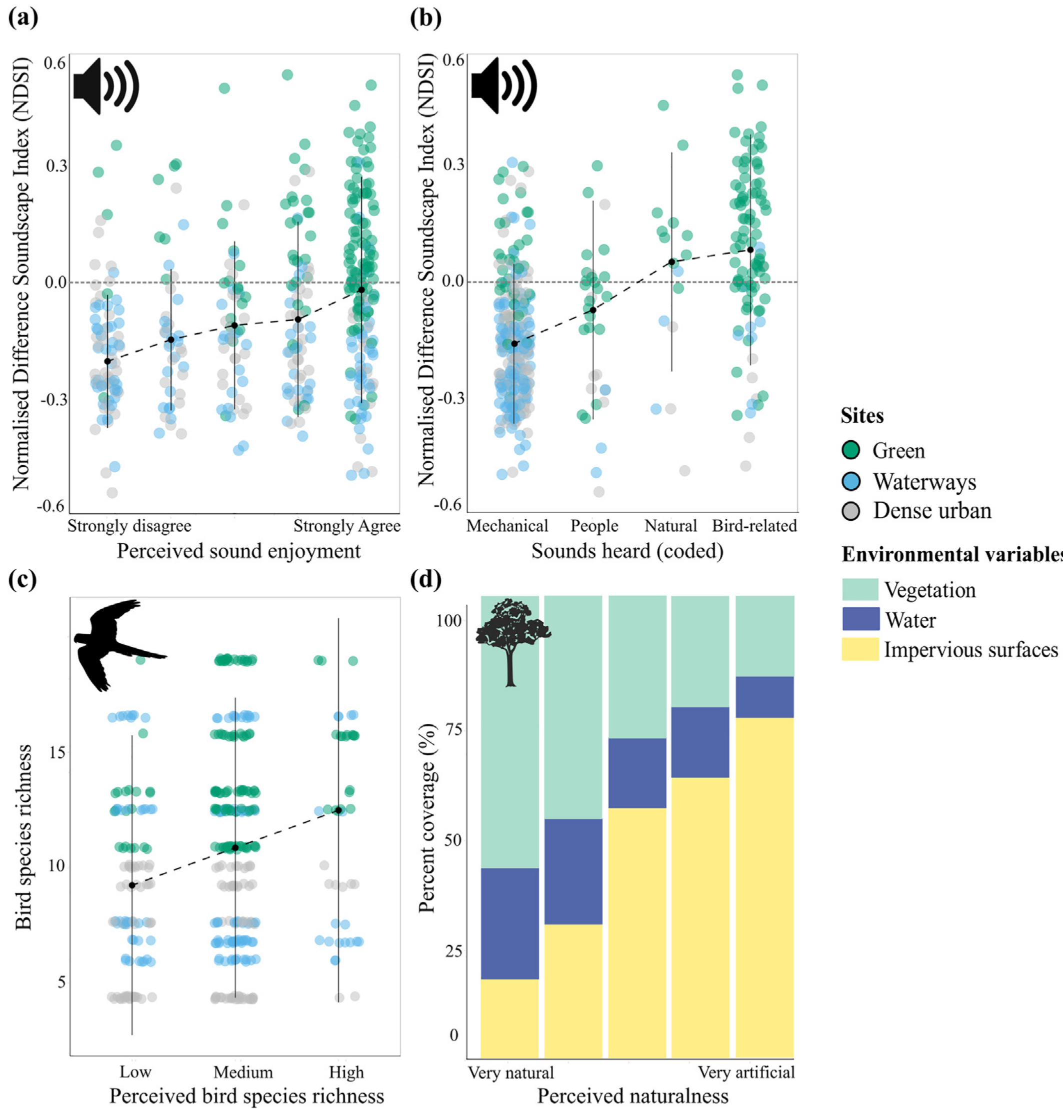

Fig. 6. Perceived characteristics against objective measures. Relationships between (a) perceived sound enjoyment and NDSI, (b) sounds heard and NDSI, (c) perceived bird species richness and measured species richness, where coloured circles (green sites = green, waterway sites = blue, dense urban sites = grey) represent participants at each site (green sites = 148 participants, waterway sites = 134 participants, dense urban sites = 121 participants), median and range are indicated by black points and vertical lines, respectively, while the dashed line shows the trend, (d) the percent coverage of environmental variables for each point on the five-point scale of perceived naturalness (1 = very natural), where vegetation = teal, water = dark blue, impervious surfaces = yellow. Central vertical line in (a) and (b) show divide between biophonic (>00) and anthrophonic (<0) sounds. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

could be driven by the individuals visiting green and waterway sites having better identification skills, amongst other pro-environmental attitudes and behaviours (Alcock et al., 2020). However, it could also be that anywhere people perceive as biodiverse could aid wellbeing, regardless of whether the site is biodiverse or not. This has implications for decision-makers raising people's awareness of urban biodiversity through environmental education campaigns, with the ultimate goal to influence their wellbeing positively.

The mechanistic role of perceived restorativeness influencing how perceptions relate to wellbeing was shown through the use of mediation models, building on work from the Global North (Hartig et al., 1997; Marselle et al., 2016, 2015; Wang et al., 2016). Perceived restorativeness was highest in green sites; it did not differ between waterway and dense urban sites, despite significant differences in the composition of vegetation, water, and impervious surfaces. Georgetown's waterways are often heavily vegetated, supporting high species richness of birds relative to dense urban sites (Hayes et al., 2019). While participants did perceive the waterway sites as more natural than dense urban sites, likely due to these ecological features, participants reported an abundance of mechanical sounds, objectively classed as anthrophonic. This abundance of anthrophony is likely explained by the location of many waterways alongside roads. As such, despite the presence of ecological features which might enhance perceived restorativeness, the presence of anthrophonic sounds that are typically loud and overwhelming of biophonic sounds (Pijanowski et al., 2011), may have led to waterway sites being perceived as less restorative. Similarly, at dense urban sites, participants only reported more positive affect if they found the sounds enjoyable which led to higher perceived restorativeness. Certainly, instances of inconsistent mediation (where the coefficient switched from negative to positive once perceived restorativeness was considered as a mediator) have helped elucidate the mechanism through which perceived restorativeness can influence how people perceive and, consequently, react to their surroundings in terms of wellbeing. From an urban planning perspective, if pathways were installed and/or improved alongside waterways for pedestrians and cyclists, vehicle-use and anthrophonic sounds may be reduced, thereby improving the restorative quality of waterways and the wellbeing of Georgetown's public.

Participants with safety concerns reported lower positive affect, higher negative affect and anxiety, either directly or mediated by perceived restorativeness, across all landcover types combined and separately. The relatively high effect size implies that feeling unsafe has a comparatively stronger influence on wellbeing than other site characteristics. Participants who feel unsafe will be alert to the threat of danger and, as such, will not recover from mental fatigue or feel reduced levels of stress, and will not perceive the sites as restorative (Kaplan, 1995). It was beyond the scope of our study to ask participants why they felt unsafe. However, green space visitors in the Global North have reported that criminal activity, poor visibility, and pest species contribute to safety concerns (Sonti et al., 2020). Similarly, in blue spaces, characteristics including cleanliness, lighting, and surveillance can increase people's sense of safety (Pitt, 2019).

Overall, sites perceived as more natural were perceived as more restorative, which related to increased positive affect, whereas sites perceived as more artificial were thought less restorative, which related to increased anxiety. Sites containing more vegetation and water were perceived as more natural. When green sites were examined alone, sites perceived as more artificial resulted in less positive affect via the mediator, despite all sites being typically dominated by vegetation. Specific green sites may have been perceived as more artificial when vegetation was more manicured or 'tidy'. This conflicts with evidence from the Global North that wilder vegetation can evoke fear (Bixler and Floyd, 1997; Jansson et al., 2013; Jorgensen et al., 2007), and manipulating the arrangement of vegetation can influence the perception of safety (Jorgensen et al., 2002; Tabrizian et al., 2018). We did not ask participants to specify what characteristics contributed to the feeling of a site being 'natural' or 'artificial', which would require additional qualitative work in the future.

5. Conclusion

Within cities, urban green and blue spaces provide a wealth of human health and wellbeing benefits, as well as resources for biodiversity. Specifically, we show how certain perceived green and blue space characteristics (birdsong, perceived bird species richness, perceived naturalness, and safety concerns) contribute positively to the perceived restorativeness of a site through multi-sensory pathways. By comparing these perceptions with objective measurements (species richness of birds, biophonic and anthrophonic sounds, and vegetation and water coverage), we shed light on how city planners might augment these specific characteristics to improve the wellbeing of urban dwellers. Given the high levels of biodiversity that can be found throughout Georgetown, such efforts could have positive implications for conservation. Interdisciplinary studies such as this are important as they highlight where careful urban design and management could deliver multiple co-benefits in the face of increasing urbanisation and biodiversity loss across the Global South, particularly in biodiversity-rich neotropical regions.

CRediT authorship contribution statement

Jessica Claris Fisher: Conceptualization, Methodology, Formal analysis, Visualization, Writing - original draft. **Katherine Nesbitt Irvine:** Conceptualization, Methodology, Validation, Writing - review & editing. **Jake Emmerson Bicknell:** Methodology, Supervision. **William Michael Hayes:** Investigation, Writing - review & editing. **Damian Fernandes:** Resources, Methodology, Supervision. **Jayalaxshmi Mistry:** Methodology, Supervision, Writing - review & editing. **Zoe Georgina Davies:** Conceptualisation, Methodology, Supervision, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.143095.

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