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Urban green space soundscapes and their perceived restorativeness

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Abstract

1. The positive influence of urban green spaces on human health and well-being is well known while the pathways are little understood. Past research has largely focused on visual stimuli, yet the auditory pathway is also an important means for contact with nature.

2. The sonic environments of urban green spaces, however, are rarely entirely natural and many differ in their composition of natural sounds and anthropogenic noise. Few studies have investigated how these differences may impact the restorative potential of these soundscapes and, in particular, how the presence of traffic noise may constrain the benefits of natural sounds.

3. To address this gap, we examined differences in the perceived restorativeness and perceived restorative outcomes across a gradient of eight park soundscapes that differed in bird and traffic sounds. In a laboratory setting, 162 participants listened to sound samples and reported on perceptions of the soundscapes and restorative potential and outcomes.

4. The results strongly indicate that park soundscapes with a rich array of perceived bird sounds and minimal perceived traffic noise offer the greatest perceived restoration. Traffic noise was found to moderate the positive effect of bird sounds. The duration of time lived in the city and noise sensitivity were also positively associated with greater perceived restorative benefits while noise-sensitive people were also more negatively affected by traffic noise.

5. The promotion of highly natural soundscapes in urban green spaces and the reduction of traffic noise can provide nature-based solutions to human health and well-being in urban areas.

KEYWORDS

bird sounds, perceived restorativeness, soundscapes, traffic noise, urban parks

1 | INTRODUCTION

With more than half of the world's population now residing in cities (United Nations, 2012), urban green spaces have become a principal means of contact with the natural environment for many people. The importance of such nature interactions has become well documented with a multitude of evidence demonstrating benefits to human health and well-being (Marselle et al., 2019), including improved cognitive function, recovery from stress and attention restoration (Berman et al., 2008; Bowler et al., 2010; Dean et al., 2019; Fuller et al., 2007; Hartig et al., 2014; Hartig & Staats, 2004; Kaplan & Berman, 2010; Marselle et al., 2019; Scopelliti & Vittoria Giuliani, 2004; Shin et al., 2010).

While much of this research on nature-health effects has often used visual stimuli as a focus (e.g. Carrus et al., 2013; Conniff & Craig, 2016; Staats & Hartig, 2004), sound is also an important pathway through which the environment is perceived by humans and can have direct influence over quality of life and physical well-being (Chuengsatiansup, 1999; Frumkin et al., 2017; Öhrström et al., 2006; Yang & Kang, 2005). In recent years, research has explored the restorative potential of natural sounds, commonly employing a soundscape approach which describes the sonic environment of a given area from a human perspective (Schafer, 1994). Such studies have typically used bird calls as a focus of natural sounds (Ratcliffe et al., 2013). In addition to being perceived as pleasant and relaxing (Payne, 2013), bird sounds have been shown to offer potential for stress recovery (Alvarsson et al., 2010) and attention restoration (Krzywicka & Byrka, 2017; Payne, 2013; Ratcliffe et al., 2013).

While urban parks are a source of natural sounds, their soundscapes also commonly include anthropogenic noise, such as vehicle and air traffic, which often dominates surrounding urban areas (Liu et al., 2013; Raimbault et al., 2003). Indeed, studies have shown birdsongs and vehicle traffic are the two principal sounds within parks recognised by park visitors (Szeremeta & Zannin, 2009). Evaluations of traffic noise within Brazilian and Italian city parks have indicated levels exceed city guidelines in a majority of parks (Brambilla et al., 2013; Szeremeta & Zannin, 2009). This is important as the negative effects of traffic and other anthropogenic noise are well established. Prolonged exposure to unwanted sounds is associated with a wide variety of health disorders, including annoyance, sleep disruption, fatigue, hypertension, heart disease and mental health disorders (Berglund et al., 2000; WHO, 2011).

Although studies have compared distinct natural and urban soundscapes, showing greater psychological restoration for natural soundscapes (Abbott et al., 2016; Krzywicka & Byrka, 2017; Payne, 2013), few studies have considered how varying degrees of both bird and traffic sounds *within* parks may influence restorative qualities and outcomes. In particular, we are interested in the interaction of positive and negative effects of soundscapes, that is, the extent to which vehicle traffic noise may diminish the restorative benefits of bird sounds. Currently, research in this area is somewhat unclear, with Suko et al. (2019) finding faint traffic noise mixed with bird songs, had a physiological impact but no effect on psychological

restoration. As urbanisation continues to place pressure on existing urban and peri-urban green spaces (Fuller & Gaston, 2009), maintaining or creating diverse ecosystems within urban or peri-urban parks can constitute a critical investment in improving the quality of life of citizens (Dean et al., 2011). It is therefore important to develop insights into the therapeutic value of urban and peri-urban green space soundscapes and to identify how anthropogenic noise might confound this benefit.

1.1 | Theoretical frameworks

Much of the theoretical understanding for the mechanisms behind the restorative and stress recovery potential of green spaces are grounded in two frameworks: Attention Restoration Theory (Kaplan & Kaplan, 1989) and the Stress Reduction Theory (Ulrich, 1983). Attention Restoration Theory (ART) contends that cognitively demanding tasks result in directed attention fatigue but natural environments can facilitate the restoration of directed attention (Kaplan, 1995). Restoration of directed attention fatigue requires person–environment transactions in which a person experiences the following four qualities: *Fascination*, *Being Away*, *Compatibility* and *Extent* (Kaplan & Kaplan, 1989). *Fascination* refers to an environment's ability to capture attention effortlessly, such as, 'strange things, wild animals, bright things, pretty things, etc.' (James, 1985). *Being-Away* refers to the experience of physical or psychological distance to one's everyday routine. *Compatibility* describes the extent to which the environment's features align with the individual's intended activity in that space. *Extent* refers to the scope of the environment and its ability to provide explorative potential. The greater these four qualities are experienced by an individual, the greater the potential of the environment to facilitate attention restoration (Kaplan, 1995). Natural environments are theorised to have a high level of these four restorative qualities (Kaplan & Kaplan, 1989; Kaplan, 1995) and studies have demonstrated that bird sounds are associated with attention restoration (Ratcliffe et al., 2013).

Stress Reduction Theory (SRT) asserts that positive appraisals and interactions with nature can provide physiological benefits resulting in a reduction of stress and a shift towards relaxation and positive mood change (Ulrich, 1983; Ulrich et al., 1991). These positive changes are referred to as restorative outcomes (Ulrich et al., 1991). Evidence has shown that visiting green spaces, such as parks and forests, can provide these restorative benefits (Hartig et al., 2003). Within a soundscape context, we hypothesise that natural soundscapes containing a high degree of bird sounds may facilitate these restorative outcomes (Alvarsson et al., 2010).

The concept of constrained restoration (Hartig et al., 2007; von Lindern et al., 2016) contends that restoration may sometimes be impaired by certain environmental conditions. Hartig et al. (2007) explored this concept in a study in which cool summer weather served as an environmental condition which caused people to stay indoors more often, which, in turn, limited their exposure to restorative outdoor environments, thus constraining restoration. Anthropogenic

sounds such as traffic noise may constrain restoration benefits associated with bird sounds. Although Suko et al. (2019) found that bird songs with and without low traffic noise displayed no significant difference between perceived restorativeness scores, they did not examine the effect of varying levels of traffic noise. We hypothesise that as traffic noise is more strongly perceived among bird sounds, the beneficial effects of these soundscapes will be increasingly constrained.

Several environmental characteristics, such as the perceived naturalness of the soundscape and perceptions of bird species richness may also influence the restorative potential of soundscapes. For example, Carrus et al. (2013) found that as photos of parks were perceived to be more natural, perceived restorativeness increased, and a similar effect may occur in soundscapes. Additionally, personal factors such as noise sensitivity, environmental knowledge and familiarity with local birds may also be important. Noise sensitivity refers to people who react more strongly and negatively to elevated levels of noise than a typical person (Stansfeld, 1992). Such people may be more negatively impacted by traffic noise or, conversely, derive more benefit from a natural soundscape (Okokon et al., 2015). Knowledge of local birds may influence the ability to perceive bird sounds and species richness, a factor found to be important by Dallimer et al. (2012) in gauging levels of biodiversity. The amount of time lived in the city may also be a consideration, potentially influencing a greater sense of place attachment or familiarity of local birds which may lead to more positive perceptions of birds (Terzano & Gross, 2020). As such, we include these personal factors as confounders in our analyses.

1.2 | The current study

In the current study, our goal was to assess the influence of perceptions of bird and traffic sounds and overall naturalness on perceived restorativeness and perceived restorative outcomes. For this, we examined differences between eight different park soundscapes in a controlled laboratory setting along with moderating variables, such as noise sensitivity, environmental knowledge and the amount of time lived in the city.

Specifically, we addressed the following questions: (a) Do perceived restorativeness and perceived restorative outcomes vary in park soundscapes differing in perceived bird and traffic sounds? (b) How do perceived restorativeness and perceived restorative outcomes vary with perceived awareness, volume and pleasantness of bird calls and traffic sounds? (c) Do perceived traffic sounds constrain restoration by moderating the effect of perceived bird pleasantness on perceived restorativeness and perceived restorative outcomes? (d) How do perceptions of environmental characteristics of the soundscapes influence perceived restorativeness and perceived restorative outcomes? (e) Do noise sensitivity, environmental knowledge and the amount of time lived in the city moderate the effect of bird calls on perceived restorativeness and perceived restorative outcomes?

2 | METHODS

2.1 | Study area

Soundscape recordings were made in parks within the Brisbane Local Government Area (LGA) in southeast Queensland, Australia. With just over 1 million residents, Brisbane (27°28′S, 153°07′E) covers an area of 1,378 km^2 and Brisbane City Council maintains over 2,000 parks (ABS, 2016, BCC, 2020). These range in size from small suburban parks to urban and peri-urban forest bushland reserves (BCC, 2020).

2.2 | Site selection and park recordings

We aimed to capture a range of soundscapes commonly experienced by park users. Consequently, we recorded at sample sites along a gradient of low to high bird species richness and activity within the recordings and varying degrees of traffic noise. A single recording sample point was used 150 m along from the start of a main walking path or trail for each park which provided a location commonly used by park users and removed from the park boundary. Recordings were taken for 5 min between 6.30 and 7.30 a.m. on week days, an hour with bird activity, morning traffic and when parks are frequented by pre-work walkers/exercisers and commuters. All recordings were conducted during May to July 2019 in clear weather conditions using a Song Meter 4 acoustic recorder held at shoulder height (approximating the height of human ears).

From each 5-min recording, a 70-s sample was derived and for each 70-s sound sample a measure of bird and traffic sounds were obtained. Bird sounds were measured with species richness and a 'bird activity' score (Table S1). Bird species were identified manually by bird calls within the recordings with the process randomised and repeated to improve accuracy. Bird activity was obtained by ascribing a 'bird activity' score (using a five point scale of 1 = *Very low* to 5 = *Very high*) for every 5-s interval of each recordings. The mean score was taken as the bird activity score (A. Truskinger, personal communication, May 5, 2019). An indicator of traffic sound was derived by measuring the maximum A-weighted volume (dB) in the low level frequency of 25–500 Hz (similarly used by Suko et al., 2019) (Table S1). In the decibel scale, a 3db increase represents twice the sound pressure energy (sound intensity level), while in psychoacoustic terms, an approximately 10 db increase equates to twice the perceived loudness of a sound (Vic Roads, 2013).

To satisfy the repeated measures research design (see Section 2.3 below), eight sites were selected, using measures of bird species richness, bird activity and traffic noise volume (Figure 1). The eight sites were selected to provide a gradient of park soundscape samples that ranged from Sample 1: high traffic noise and very low bird activity/species richness, to, Sample 8: very low traffic noise and high bird activity/species richness. As such, the soundscape of Sample 1 was dominated by a high level of traffic noise with few bird sounds and contained only two species within the recording while Sample 8 had no traffic noise and comprised almost entirely bird sounds with seven

species identified. Samples 2–7 provide a broad gradient between Sample 1 and Sample 8, with decreasing traffic noise and increasing bird activity and species richness within their soundscape samples. An inverse relationship between biophony (e.g. bird sounds) and anthrophony (e.g. traffic noise) is often found in soundscapes, whereby as one increases the other tends to decrease (Joo et al., 2011); this trend was observed in these soundscape samples.

2.3 | Experimental design and procedure

A repeated measures within subjects design was employed in which each participant listened to all eight sound samples, consistent with similar studies (e.g. Benfield et al., 2018; Krzywicka & Byrka, 2017). A laboratory setting was favoured over an in-situ approach for its ability to remove the influence of visual surrounding, isolate the audio pathway and control for potentially moderating factors, such as reason and duration of use of green spaces by visitors (Benfield et al., 2018; Payne, 2008).

Participants were University of Queensland students enrolled in first year psychology courses, recruited from the School of Psychology research participation programme. Participants received 1 credit point for taking part in the study; no monetary reimbursement was provided. At the start of the study, participants were provided with a brief written description of the procedure which outlined they were about to listen to eight different sound recordings from different Brisbane parks. Participants were instructed to close their eyes prior to listening to each sound recording. No accompanying visual stimuli of parks were provided, such that we could exclusively assess perceptions of sounds without confounding analyses.

All eight 70-s sound samples were played to participants in a randomised order. After listening to each sound sample, participants completed an identical block of questions relating to perceptions of the soundscape, perceived restorativeness and perceived restorative outcomes (Figure 2, see Supplementary Material for survey). To alleviate participant fatigue, two 1-min breaks were built in, after the third sample and again after the sixth sample. After listening to the eighth sound sample, the survey concluded with several items

assessing participant characteristics, including age, gender, the amount of time (years) lived in Brisbane and whether the participant was born in Australia.

The survey was completed online using identical Microsoft Surface Pro tablets and Audio-Technica headphones set at a consistent volume. A quiet partitioned room was used with a maximum of four participants per survey session. The survey was conducted in accordance with approved guidelines and following Institutional Human Research Ethics Approval by the University of Queensland (Approval #2019001046). Participants provided informed written consent.

2.4 | Sample characteristics

In total, 162 participants took part in the study with almost three-quarters (74.1%) female and an average age of 20 years ($M = 19.86$, $SD = 2.17$). Just over half of participants were born in Australia (54.9%). Almost half of participants (49.4%) had lived in Brisbane for less than 3 years, and, of that group, almost a third (30.1%) for a year or less. Less than half (39.0%) of participants reported living in Brisbane for more than 10 years.

2.5 | Measures

2.5.1 | Outcome variables

Perceived Restorativeness was evaluated using a short-form of the 14-item Perceived Restorative Soundscape Scale (PRSS; Payne, 2013). For this study, we developed an abridged 5-item version of the Perceived Restorative Soundscape Scale—Short Form (called the PRSS-SF) by selecting the five items of the Perceived Restorative Scale by Berto (2005) but using the language and phrasing of the PRSS. These five items assessed the four restorative qualities of ART and were rated on a 7-point Likert scale (1 = Not at all, 7 = Completely). The mean of the following five items was used to create a Perceived Restorative score (range: 1–7, Cronbach's $\alpha = 0.91$):
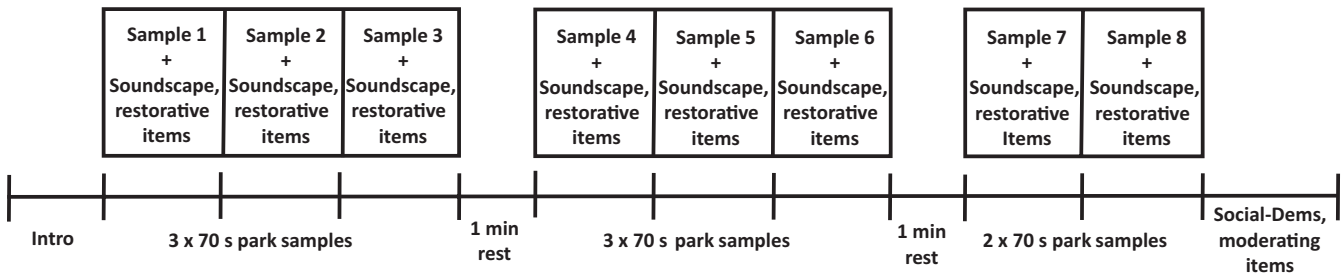
FIGURE 2 Overview of experimental procedure. After a short explanatory introduction, each participant listened to all eight sound samples in random order. After listening to each sample, participants answered questions relating to soundscape, perceived restorativeness and perceived restorative outcomes. Sound samples were presented in two blocks of three, and one block of two. Two 1-min rest periods occurred after the completion of the third and sixth sound samples. Covariate and moderating items were completed after the listening to the final sound sample

- *Fascination*—1 item ('*The sounds in the recording have fascinating qualities*')
- *Being-Away*—1 item ('*The sounds in the recording give me a good break from my day-to-day routine*')
- *Compatibility*—2 items ('*The sounds in the recording seem to fit together quite well*',
- '*The sounds in the recording relate to activities I like to do*')
- *Extent*—1 item ('*The sounds in the recording suggest there is much to explore and discover*')

Perceived Restorative Outcomes from listening to the soundscapes were measured with the 6-item Restorative Outcomes Scale (ROS; Korpela et al., 2008). The outcomes assessed are related to both ART and SRT: attention restoration, clearing one's thoughts, and relaxation and calmness. The wording of items on the ROS was adapted in this study to focus on perceived sounds rather than experience of a physical place (e.g. 'I feel calmer after being here' became 'I feel calmer after listening to this recording') The mean of the following six items was used to create a Perceived Restorative Outcomes score (range: 1–7, Cronbach's $\alpha = 0.94$):

- *Attention Restoration*—1 item ('*My concentration and alertness clearly increases after listening to these sounds*')
- *Clearing One's Thoughts*—2 items ('*I can forget everyday worries listening to these sounds*' and '*Listening to these sounds is a way of clearing and clarifying my thoughts*')
- *Relaxation and Calmness*—3 items ('*I feel calmer after listening to these sounds*', '*After listening to these sounds I feel restored and relaxed*' and '*I get new enthusiasm and energy for my everyday routines after listening to these sounds*')

2.5.2 | Predictor variables

After listening to each sound sample, participants rated their perceptions of each of the following categories of sound: (1) Vehicle traffic, (2) Bird songs/calls, (3) Other natural sounds, (4) Voices/people talking and (5) Other (open-ended).

For each type of sound, participants rated perceived awareness, volume and pleasantness:

Perceived Awareness of each sound category in each sound sample was assessed with a single item ('*I was aware of the following sounds in the recording*') using a 7-point Likert scale (1 = *Not at all*; 7 = *Completely*) (Payne, 2008).

Perceived Volume of each sound category in each sound sample was assessed with a single item assessed ('*Please rate how quiet or loud the following sounds seem to you in the recording*') on a 7-point semantic differential scale (1 = *Very quiet*, 7 = *Very loud*), with an additional option ('*I didn't hear this sound*') (Payne, 2008).

Perceived Pleasantness of each sound category in each sound sample was assessed with a single item ('*Please rate how unpleasant/pleasant you found the following sounds in the recording*') on a 7-point semantic differential scale (1 = *Very unpleasant*, 7 = *Very pleasant*), with an additional option ('*I didn't hear this sound*') (Payne, 2008).

Perceived Bird Species Richness was assessed with a single item ('*About how many different types of birds would you say you can hear in these recordings?*') using a 4-point scale (0 = *None at all*, 1 = *1–3 types*, 2 = *4–6 types* and 3 = *7–10 types*). Items and response options were drawn from Fuller et al. (2007).

Perceived Tree Cover was assessed with a single item ('*Based on the sound recording, about how many trees would you say are in the park?*'), utilising a 4-point scale (0 = *None at all*, 1 = *Some*, 2 = *Quite a lot* and 3 = *Lots*). Items and response options were adapted from Fuller et al. (2007).

Overall Naturalness was assessed with a single item ('*Overall, how would you rate the naturalness of the sounds in the recording you just listened to?*') on a 10-point semantic differential scale (1 = *Not natural at all*; 10 = *Completely natural*), adapted to focus on sounds from Carrus et al. (2013).

2.5.3 | Moderators and covariates

Several moderating variables were also assessed:

Noise Sensitivity was assessed with three items ('*Noises get on my nerves and get me irritated*', '*I'm good at concentrating no matter what is*

going on around me' (reverse scored) and 'I am sensitive to noise' on a 7-point Likert scale (1 = Not at all; 7 = Completely) (Weinstein, 1978). A mean of these three items was used to create a 'Noise Sensitivity' score (Cronbach's α = 0.84).

Bird wildlife knowledge was assessed using a methodology based on Dallimer et al. (2012) in which participants were asked to identify (by common name) 10 photos of common birds in the South East Queensland area. These were coded 0 = Incorrect, 1 = Correct and a summed count was used to create a 'Bird wildlife knowledge' score.

Time Lived in Brisbane was assessed by asking participants to enter (rounding to the nearest whole year) the number of years of they had lived in Brisbane city.

The survey concluded with covariate socio-demographic items, including gender, age and whether the participant was born in Australia.

2.6 | Statistical analysis

All data analyses were carried out with R Studio V1.2. To answer research question (a) and test for significant differences across the eight park sound samples on perceived restorativeness and perceived restorative outcomes, nonparametric one-way (Kruskal–Wallis H test) ANOVA tests were performed. This was selected instead of a parametric one-way ANOVA because the distribution of both outcome variables, perceived restorativeness and perceived restorative outcomes, failed Shapiro–Wilk tests for normality ($p < 0.001$ for both outcome variables). The sample size in the study was also sufficiently large to justify a nonparametric one-way ANOVA test, given that there were $N = 162$ responses for each of the eight groups (Fan et al., 2011). Subsequent post-hoc tests (Tukey HSD) were used to assess significant pairwise differences among park samples.

Pearson's correlation coefficient scores were calculated for all variables of interest to determine inclusion/exclusion for models. Perceived bird awareness and perceived bird volume were found to be strongly correlated ($r > 0.7$; Dancey & Reidy, 2007). Similarly, perceived traffic awareness and perceived traffic volume were also strongly correlated ($r > 0.8$; Dancey & Reidy, 2007). Perceived bird awareness and perceived traffic awareness were both excluded. Perceived volume variables (bird and traffic) were further explored and selected over perceived awareness variables as perceived volume had been consistently used in similar past studies as a predictor variable of perceived restorativeness of soundscapes (Payne et al., 2008). Perceived naturalness and perceived tree cover also displayed a moderate correlation ($r > 0.6$; Dancey & Reidy, 2007), with only perceived naturalness used in later analyses. Perceived naturalness was selected as it was considered a more important predictor variable, previously positively associated with perceived restorativeness in a visual context of parks by Carrus et al. (2013).

To assess the effect of predictor variables of interest on perceived restorativeness and perceived restorative outcome, mixed models were constructed, which allow the inclusion of both fixed and random effects (Fischer et al., 2011). Fixed effects included all predictor variables while random effects accounted for variation among participants and sound samples.

Mixed models were fitted using either perceived restorativeness or perceived restorative outcomes as dependent variables, with perceptions of the soundscape (perceived bird volume, perceived bird pleasantness, perceived traffic volume and perceived traffic pleasantness) and perceptions of environmental characteristics (perceived bird species richness and perceived naturalness) as fixed effects (predictor variables). Moderating effects were examined using the variables noise sensitivity, environmental knowledge and years lived in Brisbane. Random effects accounted for differences in the intercepts of participant responses and sound samples. Covariates included age, gender and whether the participant was born in Brisbane.

For each dependent variable (perceived restorativeness and perceived restorative outcomes), five models were conducted:

1. Model 1 addressed research question (b) and examined the effect of perceived bird volume, perceived bird pleasantness, perceived traffic volume and perceived traffic pleasantness.
2. Model 2 addressed research question (c) and examined the effect of the same predictor variables in Model 1 while also testing for an interaction between perceived traffic volume and perceived bird pleasantness to investigate constraint to restoration.
3. Model 3 addressed research question (d) and examined the effect of perceived bird species richness and perceived naturalness.
4. Model 4 further assessed research questions (b) and (d) and examined the effect of all soundscape perception variables from Model 1 with the perceived environmental characteristic variables (perceived bird species richness and perceived naturalness).
5. Model 5 addressed research question (e) with a complete model that included the same predictor variables in Model 4, along with all moderating variables (noise sensitivity, time lived in Brisbane and bird wildlife knowledge). For this model, iterative model reduction was performed using the lowest Akaike information criterion (AIC) (Akaike, 1974) to identify the optimal structure of the final model.

All five models were assessed for and met normality of residuals. No multicollinearity among independent variables was detected (variance inflation factor (VIF) < 2.5). All models were run with and without covariate variables which were not found to be significant factors in any models.

3 | RESULTS

3.1 | Perceived restorativeness (PRSS-SF) and perceived restorative outcome (ROS) scores across sound samples

Mean perceived restorativeness scores differed significantly between park samples ($p < 0.001$). Post-hoc tests revealed significant pairwise differences between the majority of sample scores, with only samples 6 and 7 and samples 3, 4 and 5 displaying no significant
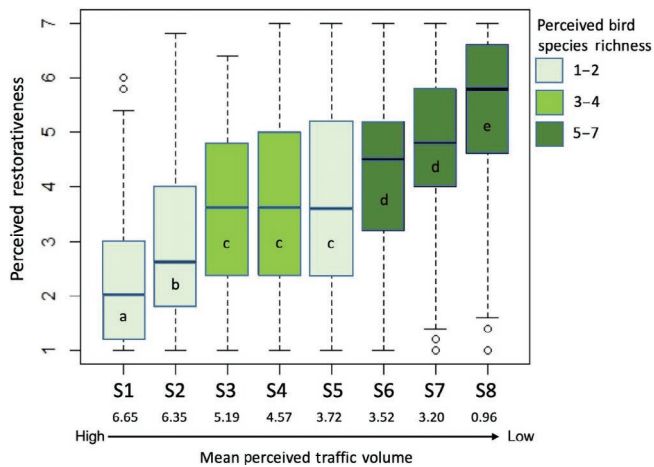
FIGURE 3 Boxplots of perceived restorativeness (PRSS-SF) for each sound sample, ordered by mean perceived traffic volume scores (highest to lowest) and colour-coded by perceived bird species richness. Letters denote significant ($p < 0.05$) differences between sound samples. Greater PRSS-SF scores indicate higher perceived restorative qualities in soundscapes. Sound sample S1 = highest objective traffic noise + low objective bird sounds, S8 = highest objective bird activity and species richness + no traffic noise, S2–S7 = decreasing objective traffic noise + increasing bird activity and species richness

FIGURE 4 Boxplots of perceived restorative outcomes scores (ROS) for each sound sample (S), ordered by mean perceived traffic volume scores (highest to lowest) and colour-coded by perceived bird species richness. Letters denote significant ($p < 0.05$) differences between sound samples. Greater ROS scores indicate higher perceived restorative outcomes in soundscapes. Sound sample S1 = highest objective traffic noise + low objective bird sounds, S8 = highest objective bird activity and species richness + no traffic noise, S2–S7 = decreasing objective traffic noise + increasing bird activity and species richness

pairwise differences (Figure 3). Results demonstrate a clear gradient of increasing perceived restorativeness scores as perceived traffic volume decreases and perceived bird species richness increases (Figure 3). Perceived bird species richness was also moderately correlated with actual bird species richness within park sample recordings ($r = 0.59$; Table S2).

Perceived restorative outcomes scores were highly correlated with perceived restorativeness scores ($r = 0.89$) and showed similar significant differences across samples ($p < 0.001$). Post-hoc tests revealed significant pairwise differences between most samples (Figure 4). Results show increasing perceived restorative outcomes scores with decreasing perceived traffic volume and increasing perceived bird species richness (Figure 4).

3.2 | Mixed models analyses

The first model examined the influence of perceived soundscape factors on perceived restorativeness and perceived restorative outcomes. Overall, the four fixed effect perceived soundscape variables explained 35% of the variance in perceived restorativeness (Table 1). Perceived bird pleasantness ($p < 0.001$), perceived bird volume ($p < 0.001$) and perceived traffic pleasantness ($p < 0.001$) were all positively associated with perceived restorativeness scores. Perceived traffic volume ($p < 0.001$) had a negative impact on perceived restorativeness scores. For perceived restorative outcomes, the four fixed effect perceived soundscape variables explained 35% of the variance (Table 1). Similarly, perceived bird pleasantness, perceived bird volume and perceived traffic pleasantness were associated with higher
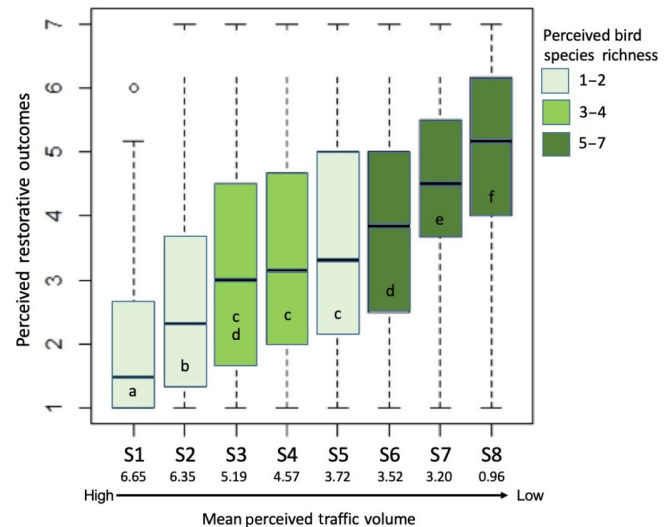
perceived restorative outcomes scores while perceived traffic volume had a negative influence on perceived restorative outcomes (Table 2).

The second model tested the constraint to restoration hypothesis by examining the moderating role of perceived traffic volume on the relationship between bird sounds and restoration scores. This revealed that perceived traffic volume negatively moderates the positive effect of perceived bird pleasantness on perceived restorativeness ($p = 0.002$). Differences in the intercepts of each sound sample illustrate lower perceived restorativeness scores as perceived traffic volume increases (Figure 5; Table 1). When perceived traffic volume is high, the influence of perceived bird pleasantness on perceived restorativeness is reduced (Figure 5). The same effect was found when the model was repeated with perceived restorative outcomes as the dependent variable (Table 2).

The third model explored the effect of perceived bird species richness and perceived naturalness on perceived restorativeness and perceived restorative outcomes and explained 44% of the variance in perceived restorativeness scores. Perceived bird species richness and perceived naturalness were significantly associated with higher perceived restorativeness scores (Table 1) and higher perceived restorative outcomes scores (Table 2).

The fourth model combined soundscape perception variables (model one) and perceived environmental variables (model three). For perceived restorativeness, all four soundscape perception variables, as well as perceived naturalness ($p < 0.001$) and perceived bird species richness ($p = 0.044$) were significant (Table 1). For perceived restorative outcomes, all four soundscape perception variables and perceived

TABLE 1 Summary of multiple regression models (regression coefficients, standard errors and p values) for the outcome variable perceived restorativeness of soundscape (PRSS-SF)

Dependent variable: Perceived restorativeness of Soundscape (PRSS-SF)

	Perception of soundscapes (Model 1)			Perception of soundscapes + Moderators (Model 2)			Perception of env. characteristics (Model 3)			Perception of soundscapes + env. characteristics (Model 4)			Perception of soundscapes + env. characteristics + moderators (Model 5)		
	B ± SE	95% CI	p	B ± SE	95% CI	p	B ± SE	95% CI	p	B ± SE	95% CI	p	B ± SE	95% CI	p
Perceived bird volume	0.24 ± 0.02	0.19, 0.29	<0.001***	0.24 ± 0.03	0.19, 0.29	<0.001***				0.11 ± 0.02	0.07, 0.16	<0.001***	0.13 ± 0.02	0.08, 0.17	<0.001***
Perceived traffic volume	−0.23 ± 0.02	−0.27, −0.19	<0.001***	0.006 ± 0.07	−0.20, −0.01	0.93				−0.11 ± 0.02	−0.15, −0.08	<0.001***	0.10 ± 0.06	−0.03, 0.22	0.11
Perceived bird pleasantness	0.25 ± 0.02	0.20, 0.29	<0.001***	0.40 ± 0.05	0.26, 0.42	<0.001***				0.17 ± 0.02	0.12, 0.21	<0.001***	0.26 ± 0.04	0.19, 0.33	<0.001***
Perceived traffic pleasantness	0.17 ± 0.02	0.13, 0.21	<0.001***	0.17 ± 0.02	0.13, 0.21	<0.001***				0.12 ± 0.02	0.09, 0.16	<0.001***	0.13 ± 0.02	0.09, 0.16	<0.001***
Perceived bird pleasantness × Perceived traffic volume				−0.02 ± 0.008	−0.04, 0.007	0.002**							−0.02 ± 0.007	−0.04, −0.008	0.002**
Perceived bird species							0.22 ± 0.05	0.11, 0.32	<0.001***	0.10 ± 0.05	0.003, 0.20	0.044*			
Perceived naturalness							0.40 ± 0.05	0.38, 0.44	<0.001***	0.31 ± 0.02	0.27, 0.34	<0.001***	0.31 ± 0.02	0.28, 0.35	<0.001***
Noise sensitivity													0.21 ± 0.07	0.06, 0.35	0.006**
Noise sensitivity × perceived traffic volume													−0.02 ± 0.01	−0.04, −0.003	0.025*
	$R^2_m = 0.35$; $R^2_c = 0.63$			$R^2_m = 0.35$; $R^2_c = 0.63$			$R^2_m = 0.44$; $R^2_c = 0.67$			$R^2_m = 0.54$; $R^2_c = 0.73$			$R^2_m = 0.54$; $R^2_c = 0.73$; AIC = 3,749.68		

*p < 0.05; **p < 0.01; ***p < 0.001.

TABLE 2 Summary of multiple regression models (regression coefficients, standard errors and *p* values) for the outcome variable perceived restorative outcomes scale (ROS)

Dependent variable: Perceived restorative outcomes scale (ROS)

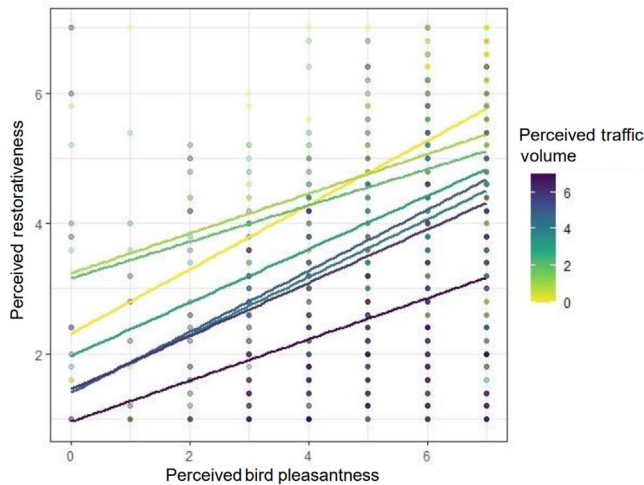|	Perception of soundscapes (Model 1)			Perception of soundscapes + moderators (Model 2)			Perception of env. characteristics (Model 3)			Perception of soundscapes (Model 4)			Perception of soundscapes + env. characteristics + moderators (Model 5)		
	B ± SE	95% CI	p	B ± SE	95% CI	p	B ± SE	95% CI	p	B ± SE	95% CI	p	B ± SE	95% CI	p
Perceived bird volume	0.22 ± 0.02	0.16, 0.26	**<0.001***	0.22 ± 0.02	0.19, 0.29	**<0.001***				0.12 ± 0.02	0.07, 0.16	**<0.001***	0.12 ± 0.02	0.08, 0.17	**<0.001***
Perceived traffic volume	-0.10 ± 0.05	-0.29, -0.21	**<0.001***	-0.10 ± 0.05	-0.20, -0.01	0.93				-0.15 ± 0.02	-0.19, -0.11	**<0.001***	0.17 ± 0.06	0.05, 0.30	**0.006****
Perceived bird pleasantness	0.37 ± 0.04	0.22, 0.31	**<0.001***	0.37 ± 0.04	0.26, 0.42	**<0.001***				0.20 ± 0.02	0.16, 0.24	**<0.001***	0.36 ± 0.04	0.27, 0.44	**<0.001***
Perceived traffic pleasantness	0.15 ± 0.02	0.11, 0.19	**<0.001***	0.15 ± 0.02	0.13, 0.21	**<0.001***				0.12 ± 0.02	0.08, 0.15	**<0.001***	0.13 ± 0.02	0.08, 0.15	**<0.001***
Perceived bird pleasantness × perceived traffic volume				-0.03 ± 0.00	-0.04, 0.007	**0.002****							-0.03 ± 0.007	-0.04, -0.01	**<0.001***
Perceived bird species							0.13 ± 0.05	0.02, 0.24	**0.018***	0.005 ± 0.05	-0.10, 0.10	0.92			
Perceived naturalness							0.38 ± 0.02	0.34, 0.41	**<0.001***	0.26 ± 0.02	0.22, 0.30	**<0.001***	0.25 ± 0.02	0.22, 0.29	**<0.001***
Time lived in Brisbane													0.04 ± 0.02	0.002, 0.07	**0.038**
Time lived in Brisbane × Bird pleasantness													-0.006 ± 0.002	-0.04, -0.01	**0.018***
Noise sensitivity													0.36 ± 0.08	0.20, 0.51	**<0.001***
Noise sensitivity × traffic volume													-0.04 ± 0.01	-0.06, -0.02	**0.025***
	$R^2_m = 0.35$; $R^2_c = 0.63$			$R^2_m = 0.35$; $R^2_c = 0.63$			$R^2_m = 0.35$; $R^2_c = 0.64$			$R^2_m = 0.54$; $R^2_c = 0.73$			$R^2_m = 0.54$; $R^2_c = 0.73$; AIC = 3,885.20		

*p < 0.05; **p < 0.01; ***p < 0.001.

FIGURE 5 The association of perceived restorativeness of soundscapes (PRSS-SF) and perceived bird pleasantness as a function of perceived traffic volume for eight sound samples. All scores rated on a 7-point scale

naturalness ($p < 0.001$) were positively associated with higher perceived restorative outcomes scores but perceived bird species was not (Table 2).

The final model included all variables (perceptions of soundscapes, environmental characteristics and moderating items). With perceived restorativeness as the dependent variable, perceived bird pleasantness, perceived bird volume, perceived traffic pleasantness and perceived naturalness were significantly associated with higher perceived restorativeness scores. Perceived traffic volume remained as a significant moderator of the relationship between bird pleasantness and perceived restorativeness. Additionally, noise sensitivity ($p = 0.006$) displayed a negative interaction with perceived traffic volume ($p = 0.025$; Table 1), where people with stronger noise sensitivity exhibited stronger negative impacts of traffic volume on perceived restorativeness.

The same associations were found when the final model was repeated for perceived restorative outcomes, with several notable additions. Perceived traffic volume and the amount of time lived in Brisbane were also significantly associated with higher perceived restorative outcomes scores (Table 2). The amount of years lived in Brisbane, however, marginally reduced the effect of bird pleasantness on perceived restorative outcomes scores (Table 2).

4 | DISCUSSION

This study assessed the restorative potential of urban green space soundscapes with respect to perceptions of bird calls and the moderating impact of perceived traffic noise. Our results showed greater perceived restorative potential and outcomes for park soundscapes when birds were perceived as both louder and more pleasant; however, perceived traffic noise was found to diminish the potential restorative effects of perceived birds sounds. A number of other perceptions and participant characteristics were also found to be important influences

on perceived restorativeness, including perceived naturalness, perceived bird species richness and personal attributes such as noise sensitivity. These results highlight the importance of considering the sonic environment when assessing the potential restorative benefits of an urban green space and managing the composition of natural and anthropogenic sounds within these green spaces.

Previous studies have demonstrated that urban park soundscapes can be restorative and that natural soundscapes are rated as more restorative than urban sonic environments (Krzywicka & Byrka, 2017; Payne, 2008, 2013). These results build on this previous research to demonstrate potential restorative gradients as park soundscapes are perceived as more natural, highlighting the importance of these subjective perceptions. This also supports the findings of Levenhagen et al. (2020), who found park visitors reported greater pleasantness of natural sounds when other human-made sounds were mitigated. Importantly, by assessing the combined effect of beneficial and non-beneficial sounds, we could demonstrate that increasing perceptions of traffic volume undermined the beneficial effects of bird pleasantness. Recently, Suko et al. (2019) found that faint levels of traffic noise among birdsongs resulted in significantly less physiological restoration than birdsongs without traffic noise. However, with respect to perceived restorativeness, the same study did not find any significant differences with or without the traffic noise amongst bird songs. Our results here demonstrate more strongly that increasing traffic noise impacts the perceived restorativeness of natural soundscapes. This is a notion supported by the constrained restoration concept (Hartig et al., 2007) which contends that restoration may become impaired by certain environmental conditions. In this context, the restorative experience of a soundscape consisting of bird sounds is diminished when traffic volume becomes an increasing feature of the overall soundscape. It is also important, however, to acknowledge the interplay between visual and auditory pathways. Studies have shown, for example, that bird songs are rated more positively when accompanied with congruent visual stimuli (Hedblom et al., 2014). Given this, the environmental conditions experienced in an urban park in situ involve several sensory pathways, including visual, potentially resulting in different results seen here.

Both pleasantness and volume of both bird and traffic sounds were important factors in restorative qualities and outcomes of the park soundscapes. Previous studies have demonstrated bird songs are largely rated positively (Hedblom et al., 2014; Krzywicka & Byrka, 2017) and, correspondingly, associated with greater restoration (Krzywicka & Byrka, 2017). While Ratcliffe et al. (2013, 2020) reported that loud bird sounds can be perceived as more threatening and less restorative, in our study the perceptions of bird call volume were associated with greater restoration. This may indicate that perceived bird volume was related to perceptions of more birds being present in the recording, that is, a higher abundance, rather than the loudness of birds per se, a notion supported by the high correlation of perceived bird awareness with perceived bird volume. Although limited research has focussed on perceptions of traffic volume, this aligns with previous findings highlighting the negative impact of unwanted sounds above certain objective levels (Berglund et al., 2000; WHO, 2011).

The perceived naturalness of the soundscape was also an important factor and strongly associated with perceived restorative qualities

and outcomes. This was similarly found by Carrus et al. (2013) in a visual context in which photos of parks that were rated more natural were associated with greater perceived restorativeness. Notably, parks samples rated the most natural also had the greatest objective and perceived bird species richness and the lowest objective and perceived traffic noise scores. While perceived bird species richness was associated with greater restorative potential and outcomes in some scenarios, it was not an important factor in complete model analyses, indicating that, overall, perceived naturalness was the more important variable. This may be a result of traffic sounds in recordings which may not unduly affect perceptions of bird species within the soundscape but, almost by definition, may impact perceptions of naturalness. Nevertheless, given that the natural sounds in recordings were almost exclusively bird calls, there is a strong implication that actual bird species richness is driving greater perceptions of naturalness within the recordings.

Participants who had lived in the city for longer and those sensitive to noise were also associated with increased perceived restorative outcomes while noise-sensitive people were also more negatively affected perceived traffic volume. Noise sensitivity appears to be partially genetic and is associated with a higher prevalence of hypertension and pronounced stress and anxiety (Heinonen-Guzejev et al., 2005; Ojala et al., 2019; Stansfeld, 1992). Natural soundscapes appear to be particularly important for this segment of the population, providing benefit from a quiet soundscape and an absence of annoyances such as traffic noise. Conversely, a soundscape containing high levels of traffic noise appears to be particularly problematic for noise-sensitive people. This aligns with a framing of noise-sensitive people as being sensitive to poor environmental quality (Ryu & Jeon, 2011). Although it is difficult to make robust generalisations, participants who had lived in the city for longer may exhibit a stronger sense of place attachment and connection to urban green spaces and common bird calls experienced from these nature interactions. Previous studies indicate that greater place identity is positively associated with well-being (Knez et al., 2018) while place attachment has been linked to a greater sensitivity of the environmental conditions of a place (Eder & Arnberger, 2012).

4.1 | Implications for practice

These results provide evidence that urban green space soundscapes with a greater array of perceived bird sounds and minimal perceived traffic noise can provide greater potential for restorative benefits to human health and well-being. In contrast, excessive perceptions of traffic noise can dampen these positive effects.

Urban planners and policymakers may maximise the restorative potential of urban green spaces by promoting greater diversity and abundance of birds within parks. Depending on the subset of bird species prevalent in the region, this may include strategic planting of vegetation, such as flowering and fruiting plants or trees, the inclusion of waterways, such as lakes or ponds, or providing an appropriate mix of open grassland with forested areas.

For existing parks in areas of dense traffic, noise mitigation and traffic reduction strategies should be a key focus. Factors known to influence traffic noise levels include the amount, type and speed of vehicles, along with the distance and type of surface between the source of noise and the receiver (i.e. the park; Rochat & Reiter, 2016). Accordingly, policies might consider traffic speed limits along streets adjacent to parks and restrict large trucks, which can be up to 10 times as loud as a regular vehicle (Rochat & Reiter, 2016). Where possible, acoustically soft surfaces in between parks and main roads, such as grass or loose dirt would attenuate more noise than smooth surfaces, such as concrete and asphalt. Natural features such as trees and bushes or man-made barriers that block sound can also be effective in impeding noise propagation (Rochat & Reiter, 2016). Policies that contribute towards traffic reduction, such as promoting greater use of bicycle lanes and public transport could also be effective. A long-term transition towards electric cars could also assist in traffic noise reduction.

Urban planners might also consider areas spatially within parks likely to contain the most natural soundscapes and promote use of these areas, particularly for people visiting to experience nature or tranquillity. This may, for example, involve increased provision of seating in areas of higher vegetation that are removed from park boundaries. Organised group nature walks could also explicitly consider green spaces with highly natural soundscapes in addition to the visual features of the park to increase perceptions of restorative qualities and maximise psychological and emotional well-being (Marselle et al., 2016).

Notably, the parks soundscapes included in our assessment resembled everyday encounters, such as those experienced by a morning park visit or during a commute to work. To gain from the beneficial effects of biodiversity in daily life and enhance the opportunity of achieving a substantial weekly nature dose through effortless contact, urban planners should seek to consider the design of green spaces in easily accessible places or known routes of commuters.

4.2 | Limitations and future directions

The park soundscape samples assessed were recorded at a single location on a path between 6.30 and 7.30 a.m. on week days in parks around Brisbane, Australia. Although this provided an example of a real-world soundscape sample commonly experienced by park visitors, soundscapes can vary significantly over space and time (Pijanowski et al., 2011). A useful future focus would be to further investigate temporal and spatial variability, particularly differences between morning and late afternoon soundscapes, as the psychological benefits of bird sounds may differ during the day (Cox et al., 2017). There may also be differences spatially within parks, particularly between park boundaries, which may be subject to higher levels of traffic noise compared to areas more towards the centre of parks. At a broader scale, there may also be differences depending on the geographical region and local avian community which could be further explored. Participants in this study were also a homogeneous group

who were all young University students between the ages of 18 and 30 years, potentially limiting our ability to make generalisations about the wider population. Future studies could seek to assess a more representative sample of the population that encompasses a broader socio-demographic spectrum, including older adults and people with hearing loss (Van Kamp & Davies, 2013).

Future research could further examine how perceived restorativeness might differ between particular bird species. Previous studies have indicated that not all bird calls are perceived favourably, with some bird calls viewed as threatening or aggressive associated with negative appraisals and higher arousal (Ratcliffe et al., 2013). Another line of research might explore the potential of priming a park visitor to sounds of nature through information signs at park entrances or by other means (Colléony et al., 2020; Duvall, 2011). This may assist in generating greater awareness of bird sounds, a factor associated with greater perceived restorativeness and perceived restorative outcomes in this study. In particular, strategies could focus on highlighting bird species known for their melodic, pleasant calls, such as songbirds (Cox & Gaston, 2015). The amount of time lived in Brisbane, while potentially indicative of greater familiarity or place attachment with local parks and birds, does not allow for robust generalisations about these two factors. Direct assessments about familiarity and place attachment would also be useful inclusions in future research.

This study also had a specific focus on the auditory pathway and, as such, we deliberately provided no accompanying visual stimuli of parks, so as not to confound analyses. Although there have been relatively few studies with a focus exclusively on the restorative effects of soundscapes (Ratcliffe, 2021), studies also show an important interplay between visual and auditory perceptions of nature (Hedblom et al., 2014, 2019; Zhao et al., 2018) and this constitutes an important area of future focus.

4.3 | Conclusions

There is growing recognition that the provision of urban green spaces allows for benefits to human health as well as the conservation of biodiversity. Soundscapes are an important means through which humans perceive nature and warrant careful consideration in the management of green spaces. In conjunction with visual features, the sonic environment can further enhance perceptions of nature and highly natural soundscapes can help facilitate synergistic human–nature outcomes. Importantly, results also indicated that park soundscapes associated with the highest potential for perceived restorativeness were from parks with the highest actual bird species richness, further highlighting the potential ecological, as well as psychological, benefits of promoting higher biodiversity in parks. Conversely, when offset by heavy traffic noise the benefits of soundscapes in green spaces can be confounded and limited. Therefore, urban nature-based solutions should seek to (a) include opportunities to experience urban greenspaces and natural soundscapes into everyday life, for example, when commuting to work on foot or bicycle through parks or green cycle lanes and to (b) minimise traffic and other anthropogenic noise in otherwise natural soundscapes.

CONFLICT OF INTEREST

Aletta Bonn and Melissa Marselle are Associate-Editors of *People and Nature*, but took no part in the peer review and decision-making processes for this paper.

AUTHORS' CONTRIBUTIONS

K.U., M.M., A.J.D., J.R.R. and A.B. conceived the ideas and designed the methods; K.U. collected the data; K.U. analysed the data and led the writing of the manuscript. All the authors contributed critically to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

The survey data used for this study are available at UQ eSpace https://doi.org/10.14264/b1a04ed (Uebel, 2021).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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