# Greener and quieter: a Swiss participatory mapping study on the choice of places for everyday restoration

Natalia Kolecka1, Lukas Graz2, María García-Martín1, Christian Ginzler1, Silvia Tobias1

**Affiliations:**

1 WSL, Swiss Federal Research Institute, Land Change Science Research Unit, Birmensdorf, Switzerland

2 ETH Zürich, Seminar for Statistics, Switzerland

**ORCIDs:** Please check your ORCIDs!

Natalia Kolecka: 0000-0001-6143-0870

Lukas Graz: [0009-0003-5147-8370](https://orcid.org/0009-0003-5147-8370)

María García-Martín: [0000-0003-4616-3844](javascript:popup_orcidDetail('https://orcid.org'%20,'0000-0003-4616-3844');)

Christian Ginzler: [0000-0001-6365-2151](https://orcid.org/0000-0001-6365-2151)

Silvia Tobias: 0000-0002-7865-005X

\*Corresponding author:

**Silvia Tobias**, Swiss Federal Research Institute WSL, Zürcherstrasse 111, CH-8903 Birmensdorf, [silvia.tobias@wls.ch](mailto:silvia.tobias@wls.ch), +41-44-739 23 49

Highlights

* Places chosen for everyday outdoor recreation are usually greener and quieter than home locations.
* People living at noisy places have limited availability of quiet restorative places.
* Higher traffic noise levels impair perceived soundscape quality and restorativeness.
* We recommend a limit of Lday < 55dB for anthropogenic noise in recreational green spaces.

# Greener and quieter: a Swiss participatory mapping study on the choice of places for everyday restoration

## Abstract

Continuous urban growth with increased noise exposure of the residents makes public green spaces becoming increasingly important for everyday restoration. This study assessed how perceived restorativeness of green spaces is influenced by its physical characteristics, such as greenness and traffic noise, and subjective perceptual qualities. We conducted a participatory mapping survey among the Swiss population in which the respondents mapped the place of their most recent outdoor recreational activity and described the perceived restorativeness, feeling of being in nature, soundscape quality and other sensory perceptions. These responses were linked to geospatial data on greenness (NDVI), land cover, and road traffic noise level (Lday) at the respondents’ restorative places and home locations. Our results show that people tend to choose greener and quieter places than their home environments for restoration, but those living in noisy areas have limited access to such spaces. Road traffic noise impaired self-reported soundscape quality and perceived restorativeness of the mapped places, particularly above 55 dB (Lday). Machine learning models explained up to 25% of the variance in perceived restorativeness. While geodata alone had limited predictive power for perceived restorativeness, adding perceptual variables (soundscape quality, feeling of being in nature, and sensory perceptions such as sounds, scents, and visual impressions) substantially improved model performance. Our findings support the European Environment Agency’s recommendation of maintaining traffic noise levels below 55 dB (Lday) in quiet areas. They further show that restorativeness of a place strongly depends on how the environment is perceived by the individuals.

**Keywords**

restorative environments; quiet areas; road traffic noise; noise limits; soundscape; GIS-based analysis; sensory perception

## 1. Introduction

In today’s increasingly urbanised world, stress and mental fatigue are pervasive challenges to public health and well-being. Urban environments—marked by limited natural elements, air and noise pollution—can worsen stress, reduce quality of life, and impair cognitive function (EEA, 2010; Schlittmeier, Feil, Liebl, & Hellbrück, 2015; Hegewald et al., 2020; Arregi et al., 2024). Traffic and industrial noise increase stress levels, lead to noise annoyance or sleep disturbance (Basner & McGuire, 2018), and thus promote risk factors such as high blood pressure and cardiovascular diseases, or even mortality (Babisch, 2002). In contrast, the presence of green spaces and natural environments such as parks, urban forests, and vegetated areas, can mitigate the negative effects of traffic noise through physical (Schäffer, Brink, Schlatter, Vienneau, & Wunderli, 2020; Van Renterghem, 2019) and psychological (Hartig, 2004; Hartig, Evans, Jamner, Davis, & Gärling, 2003; Markevych et al., 2017) effects. Vegetation, especially dense shrubs and trees, provide physical separation from traffic and can absorb and scatter sound waves, leading to a reduction in noise levels by up to 10 dB (Ow & Ghosh, 2017). Moreover, even in areas with high traffic noise, exposure to green spaces reduces annoyance caused by traffic noise and is associated with lower levels of perceived stress, better mental health and well-being, enhanced restoration experience, and improved residents' overall satisfaction with their living environment (Dzhambov et al., 2018; Aletta et al., 2018; van Renterghem et al., 2023). Given that noise-induced health problems are likely to increase with ongoing urbanisation, the question arises whether people find sufficient restorative places in their neighbourhoods to recover from noise and stress.

There is scientific evidence that restorative perceptions vary due to the physical characteristics of a place (Hartig, Mitchell, De Vries, & Frumkin, 2014; Holland et al., 2021). Studies consistently report that green spaces, such as extensively managed nature areas, forests, urban parks, waterside environments, and exercise and hobby areas, are perceived as particularly restorative (Huang, Qi, Li, Dong, & van den Bosch, 2021; Korpela, Ylén, Tyrväinen, & Silvennoinen, 2010; Ojala, Korpela, Tyrväinen, Tiittanen, & Lanki, 2019; Song et al., 2022; Tyrväinen et al., 2014). Key attributes include abundance of vegetation, varied topography, proximity to water, and absence of roadways (De Valck et al., 2017).

High levels of environmental noise, particularly in urban areas, can impair cognitive functioning and hinder stress recovery, resulting in lower perceived restorativeness of a place (Alvarsson, Wiens, & Nilsson, 2010; Yin, Bratman, Browning, Spengler, & Olvera-Alvarez, 2022). Conversely, quieter settings are more likely to be perceived as tranquil, and conducive to relaxation (Watts & Pheasant, 2015). Today, more than 20% of the European population (112 million people) are exposed to high levels of environmental noise (EEA, 2025). Therefore, researchers and policy makers have increasingly focused on the preservation of quiet places. In its “good practice guide on quiet areas” (EEA, 2014) the European Environment Agency (EEA) defines a quietness suitability index (QSI) for specific places inside and outside urban areas and suggests thresholds for acoustic parameters of quiet areas in both urban and rural settings. However, noise pressure level alone does not determine perceived restorativeness. The type and quality of sound also play a critical role. Experimental studies using virtual reality (VR) and qualitative interviews have consistently shown that natural sounds foster psychological restoration and anthropogenic sounds tend to impede it (e.g. Ratcliff et al., 2013; Uebel et al., 2021; Li, Yuan, Sun, & Sun, 2022; Kawai et al., 2024).

To assess perceived restorativeness of a place, we relied on the Attention Restoration Theory (ART) formulated by (R. Kaplan & Kaplan, 1989). This concept of psychological restoration specifies four main factors to identify restorative environments: fascination, being-away, extent, and compatibility. Fascination, defined as an effortless attention towards the environment, is considered central to restorative experience, while the other components reflect spatial richness, escape from routine, and alignment between environmental qualities and personal needs (S. Kaplan, 1995, 2001). The four ART dimensions are captured with the Perceived Restorativeness Scale (PRS), developed to evaluate how individuals perceive the restorative potential of environments (Hartig et al., 1997).

Building on the ART, Pheasant et al. (R. Pheasant, Horoshenkov, Watts, & Barrett, 2008; R. J. Pheasant, Watts, & Horoshenkov, 2009) included soundscape in the framework of psychological restoration with their concept of “tranquil places”, that is settings where natural sounds dominate over anthropogenic noise, and visual elements are calming and unspoiled. Their studies highlight the importance of harmony between soundscapes and visual aesthetics, suggesting that tranquillity arises from the interplay of sensory harmony and the absence of disruptive, human-made elements. This underpins the relevance of assessing perceived soundscape quality beyond annoyance by certain noise sources. In a Swedish study on urban and suburban green spaces, Nilsson and Berglund (2006) assessed perceived acoustic quality with a single item of “overall soundscape quality”, on a 5-point scale (1 = very bad to 5 = very good). In the following, several models have been developed to better characterize the auditory environments of urban settings using psychoacoustic characteristics, such as roughness, sharpness, fluctuation, and tonality (Axelsson et al., 2010; Farina and Pieretti, 2012; Torija et al., 2013; Farina, 2014; Aletta and Kang, 2018). In parallel, soundscape experts have worked toward standardising assessment methods for practical applications in urban planning (Fiebig and Schulte-Fortkamp, 2019). This effort resulted in the technical standard ISO TS 12913 published in 2014 (part 1), 2018 (part 2) and 2019 (part 3), which provides a structured framework and validated scales for evaluating perceived soundscape quality through interviews or questionnaires.

This study examined everyday restoration patterns of inhabitants of Switzerland, focusing on the relationships between perceived restorativeness, road traffic noise as a wide-spread environmental noise, and other environmental attributes. To evaluate how individuals perceive the restorative potential of environments, we used the Perceived Restorativeness Scale (PRS), which captures the four ART dimensions. Landscape experience is, however, not only a result of its physical characteristics but also influenced by individual perceptions (Hunziker et al., 2007). A previous study by the authors (Garcia-Martin et al., 2025) found that the relationship between greenness and restoration was mediated by the feeling of being in nature, a subjective perception that reflects how immersed individuals feel in natural surroundings. Building on this, we included this variable to explore how it helps to explain variation in perceived restorativeness beyond what is captured by geospatial indicators alone. In addition, we included a set of items related to sensorial perceptions (e.g., noticing sounds, scents, or visual elements). The inclusion of sensorial aspects is grounded in the idea that the senses provide a direct pathway for immersion in the environment, enabling active engagement with nature’s smells, sights, sounds, and textures (McEwan et al., 2020; Richardson, Hallam & Lumber, 2015). We assume that noticing such sensorial aspects of the environment may enhance the perception of qualities considered restorative, such as fascination. Sensory experiences, such as pleasant natural scents or birdsongs, also contribute to tranquillity and psychological restoration, in ways not easily replicated by artificial environments (Kjellgren & Buhrkall, 2010; Ratcliffe, Gatersleben & Sowden, 2013). Moreover, the experience of beauty in nature, particularly through visual elements like colour and natural forms, has been shown to mediate the relationship between nature-connectedness and wellbeing (Zhang, Howell & Iyer, 2014) and deepen the restorative experience (Kjellgren & Buhrkall, 2010). Finally, to assess the perceived soundscape, we used overall soundscape quality from Nilsson and Berglund (2006) and compared the results with stated noise annoyance and the detailed soundscape assessments according to ISO TS 12913-2.

We addressed three research questions: (1) What are the geospatial characteristics of places selected for everyday restoration? (2) How does road traffic noise influence perceived soundscape and restorativeness of these places? and (3) To what extent can the perceived restorativeness of a place be predicted with its physical characteristics, and how do perceptual variables (feeling of being in nature, soundscape quality, sensory perceptions) mediate this relationship? For simplicity, we use the expression “green space” throughout the manuscript, to refer to any (semi)natural area visited for recreation, including urban parks, forests, agricultural land, and shores of water bodies.

## 2. Methods and materials

This study was based on a country-wide participatory mapping survey conducted among Swiss residents. In the survey, participants were asked about the perceived restorativeness of the place of their last outdoor activity and its geographical location. The responses were integrated with the quantitative spatial information (biophysical landscape characteristics, referred to as metrics) on the visited locations, obtained from spatial and remote sensing data (referred to as geodata), and subsequently analysed to investigate the relations between the objective (geodata-based) features of a place and their perceived (subjective) restorativeness.

### 2.1 Study area

Switzerland is an Alpine country with almost 9 million inhabitants, yet 75% live in the lowlands in urban and periurban areas with a population density of 440 inhabitants per km2. There are three official languages which represent geographical regions: German (northern and eastern Switzerland), French (western Switzerland) and Italian (southern Switzerland). The Federal Office for the Environment (BAFU, 2018b) counts about 1.1 million inhabitants exposed to day-time traffic noise levels above the tolerable limits according to the Federal Ordinance of Noise Abatement, which is 60 dB (Lday) for pure residential areas. At the same time, outdoor physical activity is deeply embedded in Swiss culture, with many residents regularly engaging in nature-based recreation for both physical and mental well-being (Bundesamt für Sport BASPO, 2020).

### 2.2 Data collection and preparation

Data was collected via an online participatory mapping survey targeting residents of urban, peri-urban, and rural areas across Switzerland. Respondents were selected using a stratified random sampling method, considering the greenness and noise exposure of their home locations, as well as demographic factors such as age, gender, and language region. To ensure a focused analysis on road traffic noise, individuals living in areas with high exposure to aircraft and railway noise were excluded from the survey. The survey was conducted using Maptionnaire software (<https://maptionnaire.com>). Participants were asked to map the location of their most recent outdoor activity (referred to as restorative location, RL) and provide information on the type and duration of the activity. In addition, they were asked to evaluate the perceived restorativeness of the location, rate their feeling of being in nature, sensory perceptions and overall soundscape quality, specify the reasons for choosing the location, and indicate how frequently they visit it (García-Martín and Tobias, 2025).In order to prevent bias towards "high-quality" environments, we inquired about the most recent outdoor restorative location, instead of the favourite or the most frequently visited place as other authors have done, e.g., (Hartig et al., 1997; Korpela et al., 2008; Tyrväinen et al., 2014). Two survey campaigns were conducted in spring and summer 2022, each targeting 10,000 residents of Switzerland. Records were excluded if they contained missing data for mandatory questions, or if respondents (1) reported wearing headphones during the outdoor activity, (2) indicated an activity duration exceeding 2 hours, or (3) identified a restorative location more than 33 km from their home, considered beyond the scope of everyday recreation. The thresholds for criteria (2) and (3) corresponded to the 90th percentile of the respective distributions. To examine differences based on noise exposure, respondents were categorized into three groups (referred to as noise groups) based on home noise exposure levels (HM) (as explained in Section 2.4.1). The classification followed the sound-pressure level (Lday) thresholds associated with perceived acoustic quality from the EEA Technical report ”Good practice guide on quiet areas” (EEA, 2014: p. 9): N1 (low exposure): Lday < 45 dB, where >90 % of visitors perceive acoustic quality as good, N2 (moderate exposure): 45 dB < Lday < 55 dB, where 50 to 90 % of visitors perceive acoustic quality as good, and N3 (high exposure): Lday > 55 dB, where the percentage of visitors perceiving acoustic quality as good is falling rapidly with rising sound-pressure levels. We applied this classification to RLs as well for the interpretation of perceived restorativeness and overall soundscape quality.

### 2.3 Perceived environmental qualities

To assess the subjective experience of the restorative locations (RLs), we included several self-reported measures in the survey: (1) perceived restorativeness, (2) feeling of being in nature, (3) sensory perceptions and (4) overall soundscape quality. Perceived restorativeness was the key outcome variable in this study. It was measured using the PRS-11 (Pasini, Berto, Brondino, Hall, & Ortner, 2014), a validated short form of the original PRS (Hartig et al., 1997). The scale includes 11 items grouped into four dimensions: fascination, being away, extent-coherence, and extent-scope. Respondents rated each item on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree).

We developed perceptual variables to capture complementary aspects of the subjective experience during the restorative visit. The variable ‘feeling of being in nature’ (FEELNAT) was adopted from Garcia-Martin et al. (2025) and stresses the emotional experience at the restorative locations in contrast to a cognitive evaluation of a setting which can also be gained without interaction with the environment, e.g. with photo interpretation. Respondents were asked to rate their feeling of being in nature on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree).

Given our interest in how environmental qualities are perceived and contribute, or not, to restoration, we also included a set of self-developed items capturing sensorial perception of the natural environment. These items were informed by themes identified in prior research by Richardson, Hallam & Lumber (2015) on noticing "three good things in nature," including sensations (e.g. wind, sunshine), sounds (e.g. birdsong, rustling leaves), scents (e.g. flowers, soil), visual elements (e.g. colours, forms, patterns of light and shadow), vegetation and its seasonal change, and wildlife (Richardson, Hallam & Lumber, 2015).

Perceived overall soundscape quality (LNOISE) was adopted from Nilsson and Berglund (2006) and captures the subjective general evaluation of the acoustic environment at the restorative location. It was assessed using a 5-point scale (1 = very bad, 5 = very good). For better interpretation of perceived overall soundscape quality we added three questions about the soundscape at the restorative places. We asked how strongly different types of sound dominated at RLs (natural, human, traffic, other technical sounds) on a 5-point scale. We further assessed noise annoyance by these sound sources with the 11-point scale ISO/TS15666 (ISO, 2003). Finally, the respondents were asked to assess the soundscape properties at RLs on the 5-point scale according to ISO/TS12913-2 (ISO, 2019). A complete list of the variables and corresponding survey items is provided in Table 1.

*Table 1 Survey questions capturing perceived restorativeness, feeling of being in nature, sensory perceptions and perceived soundscape*

|  |  |  |
| --- | --- | --- |
| Perceived restorativeness of the place (PRS-11 scale, (Pasini et al., 2014)) | This place is fascinating (FA) | 1 = strongly disagree  7 = strongly agree |
| In this place my attention is drawn to many interesting things (FA) |
| In this place It's hard to get bored (FA) |
| This place is a refuge from annoyance (BA) |
| In this place I can get away from things that normally occupy my attention (BA) |
| In this place I can stop thinking about the things I still have to do (BA) |
| There is a clear order of things in this place (EC) |
| In this place it is easy to see how things are organized (EC) |
| In this place everything seems to have its right place (EC) |
| This place is big enough to allow exploration in many directions (ES) |
| In this place there are few boundaries that restrict my movements (ES) |
| Feeling of being in nature (FEELNAT) | How true is the following statement for the place you indicated on the map? I had the feeling of being in nature at this place | 1 = strongly disagree  7 = strongly agree |
| Sensory perceptions:  What did you notice at this place? | Sensations, such as wind in my hair, sunshine on my face (LOC\_SENS) | 1 = strongly disagree  5 = strongly agree |
| Sounds, such as twittering of birds, rustling of leaves (LOC\_SOUND) |
| Scents and odours, e.g. from flowers or earth (LOC\_SCENT) |
| Visual elements: colours, forms, structures, patterns of light and shadows (LOC\_VISE) |
| Vegetation and its changes, e.g. blooming flowers, colourful leaves of trees (LOC\_VEGE) |
| Wild animals in their habitat (LOC\_FAUN) |
| Overall soundscape quality (LNOISE)  (Nilsson and Berglund, 2006) | How would you describe the noise environment at the site in the map in general? | 1 = very bad  5 = very good |
| Dominating types of sound at the restorative places (LDOMAUD) | Nature sounds (birds, wind, leaves and water noise) | 0 = not occurring  1 = not dominating  5 = strongly dominating |
| Human sounds (voices, children playing) |
| Traffic sounds (cars, trains, airplanes) |
| Other technical noises (construction sites, forestry work, drones, music) |
| Noise annoyance:  How disturbed or bothered you felt at this place by the noise from the following sources?  ISO/TS15666 (ISO, 2003) | Road traffic (cars, trucks)  Public transport only (trams, buses)  Rail traffic  Air traffic  Restaurants, bars, nightlife and leisure  Music / noises from other people  Construction sites | 0 = not at all  10 = extremely |
| When you think about the sounds at this place, which terms best describe the acoustic impression?  ISO/TS12913-2 (ISO, 2019) | Pleasant  Chaotic  Lively  Uneventful  Quiet  Disturbing  Eventful  Monotonous  Loud | 1 = not agree at all  3 = neither nor  5 = fully agree |

### **2.4 Geodata and** Landscape metrics / Modelling variables

#### 2.4.1 Geodata

To account for greenness of a place, we used the Normalized Difference Vegetation Index (NDVI) map of Switzerland with 10 m spatial resolution derived from the Sentinel-2 (S2) Level-1C (orthoimage, Top-Of-Atmosphere) satellite imagery (<https://sentinel.esa.int/web/sentinel/sentinel-data-access/sentinel-products>) accessed in Google Earth Engine (GEE, <https://earthengine.google.com>) platform. The NDVI indicates whether the investigated places contain green healthy vegetation. We limited the input images to those collected between 1 April and 31 October in the years 2019-2021 (leaf-on season and no-snow conditions) with cloud coverage not exceeding 30% and applied additional cloud masking algorithms to ensure high quality.

To determine the noise exposure in the restorative locations (RLs), data from the most recent edition (2015) of the Swiss noise database sonBASE were used (BAFU, 2018a). This 10 m spatial resolution raster represents the daytime road traffic noise level Leq(6–22h) (in dBA, referred to as Lday), i.e., the yearly averaged A-weighted equivalent continuous sound pressure level over 16 hours, from 6 a.m. to 10 p.m. For home locations (HMs), we used the daytime road traffic noise level at the loudest point of the façades (maximum Leq(6–22h), i.e. maximum Lday, (dBA)) in the height of the dwellings’ floors. Both noise datasets were provided by the Federal Office for the Environment (BAFU; 2018).

To calculate the proportions of different land cover types and land cover heterogeneity around the RLs, we used the Land Cover Map of Europe 2017 (Malinowski et al., 2020). The 10 m spatial resolution raster was produced based on multi-temporal Sentinel-2 with accuracy of 86% and is composed of 13 land cover classes, such as artificial surfaces, broadleaf and coniferous tree cover, herbaceous vegetation, cultivated areas, and natural material surfaces. The dataset is freely available online (<https://s2glc.cbk.waw.pl/>).

To assess the length of roads with various traffic intensity, and the distance to public transport, we used the vector Topographic Landscape Model (swissTLM3D) (Swisstopo, 2022). This is the most comprehensive and accurate large-scale 3D vector dataset for Switzerland, describing the position, shape and attributes of nearly 20 million natural and artificial landscape features. It includes eight main categories: roads and tracks, public transport, buildings, areas with special use, land cover, hydrography, single point objects, and names.

To account for visual openness and depth of view at RLs, we incorporated the visibility map of Switzerland (Lienhard & Binna, 2013), which indicates the percentage of the area visible within a 5 km radius from each location.

#### 2.4.2 Geodata-based metrics / Modelling variables

To describe environmental characteristics of RLs, we calculated landscape metrics based on 2D geodata within 250 m buffer zones, which allowed to account for respondents’ mapping uncertainty. These metrics were: mean NDVI, mean Lday, proportion of artificial surfaces and forest cover, and land cover heterogeneity (expressed as the Shannon Diversity Index H' = -Σ (Pi \* ln(Pi)), where Pi is the proportion of area covered by the i-th land cover type, (Shannon & Weaver, 1964)). The percentage of visible area within a radius of 5 km was extracted from the visibility map of Switzerland for the exact (not buffered) RLs.

For home locations, which were precisely known, we applied a 50 m buffer to calculate NDVI and included the exact values of the daytime road traffic noise level (Lday) at the loudest point of the façades in the height of the dwellings’ floors. Proximity between RL and HM was captured using Euclidean distances calculated based on spatial coordinates, and self-reported travel time from the survey. All variables used in the modelling are listed in Table 2.

*Table 2 Landscape metrics used in this study; mean values within 250 m buffer were used for RL variables and exact or 50 m buffer for HM variables. ‘\*' indicates if the square-root transformation was applied for a given variable for the statistical analyses in Section 2.5*

|  |  |  |
| --- | --- | --- |
| **Acronym** | **Explanation** | **Source** |
| RL\_NOISE | mean road traffic noise in 250 m buffer around RL | sonBASE (BAFU, 2018a) |
| HM\_NOISE | person’s noise exposure at home (facade) | sonBASE (BAFU, 2018a) |
| RL\_NDVI | mean NDVI in 250 m buffer around RL | Sentinel-2 / GEE |
| HM\_NDVI | mean NDVI in 50 m buffer around HM | Sentinel-2 / GEE |
| DISTKM\* | Euclidean distance between home and RL | Calculation |
| JNYTIME\* | travel time from home to RL (as indicated in the survey) | Survey |
| LCARTIF\* | proportion of artificial surfaces within 250 m buffer | Land Cover Map of Europe 2017 |
| LCFOREST\* | proportion of forest within 250 m buffer | Land Cover Map of Europe 2017 |
| OVDIST\* | distance to the nearest public transport stop | swissTLM3D (Swisstopo, 2022) |
| STRIMP123 | length of roads with high traffic intensity | swissTLM3D (Swisstopo, 2022) |
| STRIMP999\* | length of other roads (low traffic intensity) | swissTLM3D (Swisstopo, 2022) |
| HETER | land cover heterogeneity in 250 m buffer | Land Cover Map of Europe 2017 |
| VIS5K\* | percentage of visible area within a radius of 5 km | Visibility map (Lienhard & Binna, 2013) |
| LANG | Language region according to respondent’s address | Survey |

### **2.5 Statistical analyses**

Data preparationincluded transforming right-skewed spatial variables (c.f. Table 2). Missing values were imputed using MissForest (Stekhofen and Bühlmann, 2012), for each variable set (c.f. Figure 1) separately to avoid introducing spurious correlations. This method leverages conditional dependencies between variables to predict missing values through an iterative random forest approach.

#### 2.5.1 Exploring environmental characteristics of restorative locations

Descriptive analyses of the geodata-based metrics of the restorative locations (RLs) included an overview of the RLs, the respondents’ living conditions and restoration patterns. To explore differences between respondents exposed to varying levels of traffic noise at home, we stratified the sample into three noise exposure groups (low, moderate, and high sound levels: Lday < 55 dB (N1), 45 dB < Lday < 55 dB (N2), Lday >= 55 dB (N3); cf. section 2.2).

We further analysed the relations between home and restorative locations in terms of greenness and noise level. We performed the procedure below for both response variables separately greenness at RL (RL\_NDVI) and noise level at RL (RL\_NOISE). We used the following variables as predictors: NDVI at HM, noise level at HM, language region of the respondents (as they represent geographical regions of Switzerland), travel speed (logarithmic), journey time (square root). As we considered all two-way interactions of the predictors, we first performed a forward stepwise feature selection using Bayesian Information Criterion on the training data (50%) to mitigate the multiple testing problem and reduce the variance inflation factor. Selected features were subsequently used to fit the models on the test set (50%) to obtain valid p-values.

#### 2.5.2 Modelling perceived restorativeness

As illustrated in Figure 1, we predicted a) the PRS outcomes with geodata only, b) the feeling of being in nature, overall soundscape quality and sensory perceptions with geodata, c) the PRS outcomes with meditators only, and d) the PRS outcomes with geodata and mediators combined. Here, we briefly describe the procedure. For details about the procedure see supplementary material XXX.



*Fig. 1 Principle of our mediation analysis to predict the PRS outcomes.*

Our dependent variables were the four dimensions of the PRS, i.e., ‘fascination’ (FA), ‘being away’ (BA), ‘extent-coherence’ (EC), ‘extent-scope’ (ES), and the aggregated mean of all dimensions (PRS\_Mean). Verification with principal component analysis (PCA) showed that the data could well be approximated with three to four dimensions, whereas the first dimension was close to the weighted average of all variables (correlation >0.99). Extent-coherence (EC) showed the most divergence (PC2). Fascination (FA) and being away (BA) showed similarities (PC1, PC3). The PCA results justified the use of the aggregated mean of the PRS variables.

The machine learning methods to quantify the predictive power of different variable sets were: i) ordinary least squares (OLS) as a baseline; ii) XGBoost (gradient boosting with tree-based models and hyperparameter tuning for learning rate and tree depth) (Cheng & Guestrin, 2016); iii) Random Forests (with default parameters) (Breiman, 2001). Computations were performed using the mlr3 framework (Lang et al., 2019). Performance was measured as percentage of explained variance on hold-out data via 5-fold cross-validation, calculated as (1 - MSE/Variance(y)), where MSE represents mean squared error. In a first version of the model, we included all mediator variables given in Figure 1. We then tried to simplify the model by reducing the number of mediators and ran it with only the feeling of being in nature (FEELNAT) and overall soundscape quality (LNOISE), leaving out the sensory perceptions (sensations, sounds, scents etc.).

With multiple linear regression using OLS, we investigated i) which geodata and mediator variables influenced perceived restorativeness, and ii) which geodata variables influenced the mediators. Since in both cases we had a set of dependent variables, we performed the following steps for each variable separately. To obtain valid p-values, we performed the same procedure as in section 2.5.1, with train/test data splitting (50%) and forward stepwise feature selecion. Missing values were imputed as described above, but for the training and test sets separately to avoid contamination of the test set. Computations were carried out using the basic utilities of the stats package of the R programming language (Cite R XXX).

## 3. Results

### 3.1 Sample description

The overall response rate was 14%, resulting in 2850 data sets. After cleaning, the final database contained 1494 valid responses. The gender distribution was balanced (50% women and 50% men) and participants represented all major language regions of Switzerland: German (73.5%), French (20.4%) and Italian (6.1%). Ages ranged from 18 to 99 years, with a mean of 52±15 years. Regarding employment status, 37% of respondents worked full time, 30% part time, and 26% were retired. The remaining participants were unemployed, training or looking for a job. Considering traffic noise exposure at home, the majority of respondents lived at rather quiet places with Lday < 55 dB (76%, N1 and N2), whereas 24% of the respondents were exposed to higher noise levels at home (Lday > 55 dB, N3) (Table 3). Housing characteristics varied across noise exposure groups. Overall, nearly 80% lived in single or double-family houses, while the others lived in apartments. Most participants (87.5%) had access to a private balcony or terrace, and 86.5% had a garden. However, respondents in the highest noise exposure group (N3) were more likely to live in apartments and less likely to have access to a balcony, terrace or garden, reflecting the urban nature of these environments.

*Table 3 Distribution of respondents across noise exposure groups based on Lday at home. Values indicate the percentage of respondents within each group, unless stated otherwise. The table also summarizes housing characteristics, including dwelling type and access to private outdoor spaces (balcony/terrace and garden).*

|  |  |  |  |
| --- | --- | --- | --- |
| **Group of noise exposure at home (Lday)** | **N1: <45 dB** | **N2: 45–55 dB** | **N3: >55 dB** |
| Number of respondents (% of entire sample) | 642 (44%) | 468 (32%) | 354 (24%) |
| Residents in single/double family houses | 86.1% | 77.0% | 70.1% |
| Residents in apartments | 13.9% | 23.0% | 29.9% |
| Respondents with balcony/terrace at home | 90.8% | 88.9% | 79.1% |
| Respondents with garden at home | 92.8% | 85.3% | 79.4% |

### 3.2 Geospatial characteristics of restorative locations (RQ1)

As the Swiss settlements mostly consist of (suburban) villages or small towns, most restorative locations (RLs) were mapped in nearby natural settings, such as forests, agricultural landscapes, or along water bodies, rather than in urban parks in city centres (Figure 2). They were typically situated close to the respondents’ homes, with an average distance of 1.38 km and an average travel time of 12 minutes. Locations in closer vicinity of home were visited more frequently even when they were noisier and less green. However, longer travel distances were associated with quieter and greener RLs (P < 0.001).

Ein Bild, das Karte, Text, Atlas enthält.

KI-generierte Inhalte können fehlerhaft sein.

*Figure 2 Two examples of the geographic distribution of restorative locations (dots) overlaid on the day-time road traffic noise levels (heat map) according to SonBASE data. Dot colours indicate the respondents’ noise exposure at their home location: green for N1 (Lday < 45 dB), yellow for N2 (45 dB < Lday < 55 dB), and red for N3 (Lday > 55 dB).*

We found significant negative correlations between greenness (NDVI) and noise levels at both HM (r = -0.247, p < 0.001) and RL (r = -0.285, p < 0.001), indicating that greener places tended to be quieter. Figure 3 illustrates that people generally choose places for restoration that are greener and quieter than their home locations. Particularly people exposed to higher noise levels at home visit restorative places where they can escape from traffic noise. While 31% of respondents visited RLs noisier than their HMs, this was more common among those living in quieter areas (N1: 48.9%, N2: 26.1%, N3: 5.9%).

|  |  |
| --- | --- |
| Ein Bild, das Diagramm, Karte, Reihe enthält.  KI-generierte Inhalte können fehlerhaft sein. | Ein Bild, das Diagramm, Reihe, Karte enthält.  KI-generierte Inhalte können fehlerhaft sein. |
| 1. Greenness (NDVI) | 1. Noise level (Lday) |

*Figure 3 Distribution of greenness (a) and noise level (b) at home (HM) and at the restorative locations (RL): Dashed black lines indicate the identity line where x- and y-values are identical; Blue lines are (penalized cubic regression) smoothing splines estimating conditional expectations (E[Y|X=x]) with 95% confidence intervals (grey areas) (Wood, 2017). The vertical dashed grey lines in (b) indicate the noise limits according to which we assigned the respondents to noise groups N1, N2, N3.*

Noise levels and NDVI at HM revealed to be strong predictors of these variables at RL (P <0.001), suggesting that individuals living in greener and quieter areas also had access to similarly green and quiet places for restoration. With the prediction of greenness (R2 = 0.08), we found that higher NDVI values at HM correspond to slightly higher NDVI at RL (P < 0.001), and longer journey time corresponds to slightly higher NDVI at RL (P < 0.01). In addition, NDVI and travel speed had a negative interaction effect, which means that the faster (or further) people travelled to RL, the more NDVI at RL differed from NDVI at HM (for details see Tables S34 and S36 in supplementary material).

Noise level at HM revealed to be a positive predictor of noise level at RL (P < 0.001; R2 = 0.184), saying that noise level at RL increases with higher noise level at HM. Journey time had a negative effect on the noise level at RL; i.e. the longer people are travelling, the quieter their RLs. Surprisingly the language region Italian had a strong positive effect on the noise level at RL. The Italian speaking part is a mountainous region in southern Switzerland with a motorway and railway at the bottom of the main valley, whereas many RLs were mapped on the slopes above these traffic corridors. Hence, the higher noise levels at RLs in the Italian part of Switzerland might be an amphitheatre effect due to the topography.

Land cover analysis revealed that RLs included a variety of environments, such as broadleaf and coniferous forests, herbaceous vegetation, cultivated land, artificial surfaces, open water, and vineyards. RLs dominated by open water were typically the farthest from home (in terms of distance and travel time), while those dominated by vineyards, artificial surfaces and agricultural land were the closest. Artificial surfaces were more common in RLs visited daily and less frequent in those visited occasionally. The quietest RLs were associated with coniferous forests, whereas the noisiest were dominated by artificial surfaces and vineyards. Consequently, respondents living in noisier home environments (N3), more frequently selected RLs with a higher proportion of artificial surfaces (Figure 4).

![Ein Bild, das Diagramm, Screenshot, Kreis, Farbigkeit enthält.

KI-generierte Inhalte können fehlerhaft sein.]()

*Figure 4 Pie charts of land cover types at the restorative places for each noise exposure at the home location (Lday) group (left: N1 <45 dB; middle: N2 45–55 dB; N3 >55 dB at home)*

### 3.3 The influence of road traffic noise on perceived soundscape and restorativeness (RQ2)

#### 3.3.1 Soundscape perception

Respondents generally rated the soundscapes in their RLs positively (Figure 5). Natural sounds such as birdsong, wind, leaves, and water were most frequently reported as dominant, while anthropogenic sounds (e.g. traffic, music) were less prevalent. Most participants described the soundscape at RL as “pleasant” and “tranquil”, with low levels of annoyance, while the most annoying were road traffic, aircraft noise and music of others. However, differences emerged with exposure to road traffic noise (RL-Noise). At higher noise levels, particularly above 55 dB (Lday), respondents reported lower scores for positive soundscape attributes (e.g. nature sounds, pleasantness) and higher scores to negative attributes (e.g. road traffic noise, loud).

Equally, respondents reported low scores for noise annoyance, saying that they found places without disturbing noise (Figure 5c). However, annoyance from road traffic noise clearly increased at noise levels of 50 dB (Lday) and higher.

|  |
| --- |
| Ein Bild, das Reihe, Diagramm, Screenshot, Text enthält.  KI-generierte Inhalte können fehlerhaft sein. |
| a. Sound type |
| Ein Bild, das Screenshot, Reihe, Text, Diagramm enthält.  KI-generierte Inhalte können fehlerhaft sein. |
| b. Soundscape assessment |
| Ein Bild, das Text, Screenshot, Reihe, Diagramm enthält.  KI-generierte Inhalte können fehlerhaft sein. |
| c. Noise annoyance |

*Figure5 Soundscapes of the restorative locations (RL) reported by the respondents in relation to road traffic noise level at RLs. Sources of the scales: a. own representation; b. ISO/TS12913-2 (ISO, 2019); c. ISO/TS15666 (ISO, 2003).*

The influence of actual road traffic noise levels (Lday) on perceived overall soundscape quality was notable (Figure 6). For RLs with Lday > 55 dB (12% of all RLs), only 73% of respondents rated the perceived overall soundscape quality as “rather good” or “very good”, compared to 82% for RLs with 45 dB < Lday < 55 dB, and 92% for RLs with Lday < 45 dB. This pattern was consistent across noise groups according to road traffic noise exposure at home, with N3 respondents reporting the lowest overall soundscape quality. Only 79% of them rated the overall soundscape as good, while in less noisy areas (N2, N1), that was the case for 88% and 91%, respectively.

Ein Bild, das Text, Schrift, Reihe, Screenshot enthält.

KI-generierte Inhalte können fehlerhaft sein.

*Figure 6 Perceived overall soundscape quality at RL on a 5-point scale (1 = very bad; 5 = very good) according to Nilsson and Berglund (2006). The vertical dashed grey lines indicate the noise exposure thresholds associated with perceived acoustic quality according to EEA (2014); low exposure < 45 dB (Lday); high exposure > 55 dB (Lday).*

#### 3.3.2 Perceived restorativeness

Respondents rated the restorativeness of their visited outdoor locations (RLs) as generally high, with an average score of 5 out of 7 across most dimensions of the Perceived Restorativeness Scale (PRS) across all noise levels at RL (Figure 7). However, with increasing noise levels the scores for fascination and being away declined by 0.25 points, and for extent-scope by almost 0.75 points.

Ein Bild, das Reihe, Diagramm, Screenshot, parallel enthält.

KI-generierte Inhalte können fehlerhaft sein.

*Figure 7 Scores of the Perceived Restorativeness Scale (PRS) reported by the respondents for the restorative locations (RL) in relation to road traffic noise exposure at RL, on a 7-point scale (1 = very bad; 7 = very good). PRS-dimensions: BA = being away; EC = extent-coherence; ES = extent-scope; FA = fascination. The vertical dashed grey lines indicate the noise exposure thresholds associated with perceived acoustic quality according to EEA (2014); low exposure < 45 dB (Lday); high exposure > 55 dB (Lday).*

### 3.4 Predicting perceived restorativeness of RL (RQ3)

We focused on the Perceived Restorativeness Scale (PRS) as the primary outcome variable. The prediction of the PRS dimensions and the aggregated PRS revealed that the three models used performed rather similarly, with XGBoost being slightly superior, OLS in the middle, and Random Forest slightly inferior on average. The best out-of-sample performance was achieved with the combination of geodata and all mediators (Table 4). While geospatial data such as greenness (NDVI), land cover, and noise levels provide important contextual information, they alone explained a very small portion of the variance in PRS. In contrast, the inclusion of the perceptual variables (mediators), overall soundscape quality, feeling of being in nature and sensory perceptions, substantially improved model performance. Particularly, the items of sensory perceptions increased the predictive power of the models considerably. For details about the statistics see supplementary material.

*Table 4* *Out-of-sample proportion of explained variance of the PRS dimensions when using different sets of predictors; in each case maximum value out of the three models: OLS, XGBoost, Random Forest*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Predictors** | **PRS Mean** | **FA** | **BA** | **EC** | **ES** |
| All variables | 0.234 | 0.260 | 0.131 | 0.042 | 0.168 |
| Mediator variables only (all mediators) | 0.235 | 0.254 | 0.145 | 0.036 | 0.137 |
| Mediators without sensory perceptions | 0.155 | 0.170 | 0.086 | 0.011 | 0.116 |
| All variables except sensory perceptions | 0.143 | 0.164 | 0.072 | 0.019 | 0.144 |
| Geodata only | 0.005 | 0.013 | 0.000 | 0.001 | 0.048 |

@ Lukas: only negative values for BA -- Lukas: I think truncating it at 0 is fine as it prevents confusion and and is still correct with the figure caption

As ordinary least squares (OLS) performed competitively to the other models, further modelling and inferring linear effects were justified (as described in Section 2.5.2). Tables 5 and 6 present the linear regression coefficients for i) which geodata and mediator variables influenced perceived restorativeness, and ii) which geodata variables influenced the mediators. To keep the coefficients interpretable in the presence of interactions, each variable was scaled to mean 0 and standard deviation 1. In this way, if A increases by one standard deviation, Y increases by β times its standard deviation (assuming everything else stays constant).

#### Table 5 Regression coefficients of regressing geodata and mediators (rows) on the PRS (columns) after variable selection on a training set. Variables were z-standardized for interpretability. Acronyms are explained in Tables 1 and 2. \*\*\*p<0.001, \*\*p<0.01, \*p<0.05

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Covariate** | **PRS MEAN** | **FA** | **BA** | **EC** | **ES** |
| (Intercept) | -0.008 | -0.003 | -0.008 | -0.009 | 0.031 |
| DISTKM\_sqrt |  |  |  |  | 0.081\* |
| FEELNAT | 0.202\*\*\* | 0.169\*\*\* | 0.188\*\*\* |  | 0.258\*\*\* |
| FEELNAT:LOC\_SCEN |  | -0.002 |  |  |  |
| FEELNAT:LOC\_SENS | 0.054 |  |  |  |  |
| LCFOREST\_sqrt |  |  |  | -0.090\* |  |
| LNOISE | 0.177\*\*\* | 0.133\*\*\* |  |  | 0.133\*\* |
| LNOISE:FEELNAT |  |  |  |  | -0.006 |
| LOC\_FAUN |  | 0.176\*\*\* |  |  |  |
| LOC\_SCENT |  | 0.164\*\*\* |  | 0.004 |  |
| LOC\_SENS | 0.104\* |  | 0.147\*\*\* | 0.142\*\*\* | 0.096\* |
| LOC\_VISE | 0.173\*\*\* | 0.128\*\* | 0.122\*\* |  |  |
| RL\_NDVI |  | -0.133\*\*\* |  |  |  |
| RL\_NDVI:LOC\_SCENT |  | 0.024 |  |  |  |

#### Table 6 Regression coefficients of regressing geodata (rows) on the mediators (columns) after variable selection on a training set. Variables were z-standardized for interpretability. Acronyms are explained in Tables 1 and 2. \*\*\*p<0.001, \*\*p<0.01, \*p<0.05

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Covariate** | **FEELNAT** | **LNOISE** | **LOC\_**  **SENS** | **LOC\_**  **SOUND** | **LOC\_**  **SCENT** | **LOC\_**  **VISE** | **LOC\_**  **VEGE** | **LOC\_**  **FAUNA** |
| (Intercept) | 0.062 | -0.001 | -0.000 | 0.000 | -0.001 | -0.000 | -0.019 | -0.001 |
| HETER |  |  | 0.130\*\*\* | 0.109\*\* |  |  |  |  |
| JNYTIME\_sqrt |  |  |  |  |  |  | -0.114\*\* |  |
| LCARTIF\_sqrt | -0.152\*\* | -0.124\* |  | -0.175\*\*\* |  | -0.071 |  | -0.214\*\*\* |
| LCARTIF\_sqrt:RL\_NDVI | 0.115\*\* |  |  |  |  |  |  |  |
| OVDIST\_sqrt | 0.027 |  |  |  |  |  |  |  |
| RL\_NDVI | 0.150\*\*\* |  |  |  | 0.217\*\*\* |  | 0.219\*\*\* |  |
| RL\_NOISE |  | -0.242\*\*\* |  |  |  |  |  |  |
| STRIMP999\_sqrt |  |  | -0.073 |  |  |  |  |  |

Table 5 confirms the information of Table 4 that the perceptual variables (mediators) outperform the geodata in predicting the PRS dimensions. Greenness (NDVI) was the only geodata with some influence on fascination (FA). However, the geodata had more influence on the mediators (Table 6). The various perceptions of the place partly depend on different geophysical characteristics. NDVI and the land-cover type ‘artificial surfaces’ showed strong influence on several perception variables suggesting that participants reported stronger perceptual engagement and higher perceived naturalness in environments with more vegetation and fewer artificial surfaces. For the ‘feeling of being in nature’ (FEELNAT) the interaction between these variables had a significant influence, too. This means that at places with a high share of artificial surfaces, higher NDVI values enhance the feeling of being in nature disproportionally and can compensate for the negative effect of artificial surfaces. Reversely, a high share of artificial surfaces combined with low NDVI values aggravates the negative effect of the artificial surfaces on the feeling of being in nature. For overall soundscape quality (LNOISE), the noise level at the RL (RL\_NOISE) had a strong negative influence, which was already suggested in Figure 6. Finally, landscape heterogeneity had a significant positive influence on perceived sensations and sounds at RLs, indicating that diverse landscapes promote sensory experiences (Table 6).

## 4. Discussion

In this study, we explored the places selected for everyday restoration by combining participatory mapping data with geodata indicators on a representative Swiss sample. We focused on the role of road traffic noise and greenness in shaping perceived restorativeness. To interpret our findings, we structure the discussion around the three research questions.

### 4.1 Sample characteristics and representativeness

The sample was broadly representative of the Swiss population in terms of age, gender, language region, and the standard of residential buildings. Slight underrepresentation of full-time workers and overrepresentation of retirees should be noted. Importantly, 24% of respondents lived at places (HMs) with higher road traffic noise (Lday >55 dB, referred to as noise exposure group N3).

### 4.2 RQ1: Geospatial characteristics of restorative places

Proximity, addressed as distance and time needed to reach the restorative place, emerged as a key factor in the selection of restorative locations. This finding aligns with previous studies from other countries. For example, in Sweden the median travel distance to the recreational area was 2 km (Lehto et al., 2022), while proximity increased the frequency of recreational visits in Finland (Neuvonen, Sievänen, Tönnes, & Koskela, 2007) and in urban green spaces in Zurich, Switzerland (Dopico Magadan et al., 2025). In addition, respondents usually chose places for restoration that were greener and quieter than their home locations. This pattern was particularly evident among individuals living in noisier areas. They actively sought out quieter settings for restoration, especially in forests, around water bodies, in agricultural landscapes and vineyards, alike participants of a Swedish PP-GIS study (Lehto et al., 2024).

Yet, the ability to access such “high-quality” environments was not equally distributed. We found that people living at noisy places, where Lday > 55 dB (N3), had fewer options of quiet and green RLs in their immediate surroundings. Their restorative locations were, on average, noisier and contained a higher proportion of artificial surfaces, compared to those of people living at quieter places, where Lday <= 55 dB (N1 and N2). People living in noisier urban environments are clearly disadvantaged in terms of access to green spaces with high acoustic quality. This disadvantage is further compounded by limited private outdoor space: every fifth respondent in the N3 group lacked access to a private garden or balcony (Table 3), what makes public green spaces especially vital for their everyday restoration. These findings suggest that people living in more urbanised or noise-exposed environments face structural limitations in accessing restorative green spaces, although they might benefit most from access to quiet green spaces.

Topography revealed to play a role in the traffic noise level at the restorative location, as RLs in the Italian part of Switzerland (an Alpine valley) were noisier than in the other language regions. It should be considered that the slopes of large Alpine valleys with transit routes at their bottoms may suffer from noise pollution which might impair their restorative and touristic qualities.

### 4.3 RQ2: The influence of road traffic noise on perceived restorativeness and soundscape

Our results show that despite the differences in the physical properties of the restorative locations people assess their RLs very positive across all dimensions of the Perceived Restorativeness Scale (PRS), independently of how noisy the restorative and home environments are. The rather small differences between PRS ratings might be due to the fact that the restorative locations in our case did not show fundamental differences in their geospatial characteristics, whereas other studies focused on broad land use categories: natural, urban, and urban green settings (Hartig, Korpela, Evans, & Gärling, 1997; Korpela et al., 2008, 2010; Tyrväinen et al., 2014; Weber & Trojan, 2018). The high PRS ratings suggest that individuals can experience restoration even in more urbanised or noisier settings, possibly due to the intentional nature of the visit or to performing a physical activity, which fosters mental restoration (Ryan et al., 2010; Fuegen and Breitenbecher, 2018). However, a slight decline in these ratings (particularly in the dimensions of fascination, being away and extent-scope) observed with increasing noise levels indicates that road traffic noise may subtly impair the restorative experience, which is consistent with findings from surveys and soundwalks in an urban park in Norway (Evensen et al., 2016). This is noteworthy, as soundscape quality has been shown to affect physiological restoration, including heart rate and skin conductance (Medvedev et al., 2015).

Overall, soundscapes were rated positively, with natural sounds such as birdsong, wind, and water dominating the acoustic environment. However, our results indicate that road traffic noise at places of restoration has a direct and measurable impact on perceived soundscape quality. Respondents exposed to higher noise levels reported lower scores for positive soundscape attributes and higher scores for negative ones, including loudness and traffic noise. Notably, at restorative locations with Lday > 55 dB the percentage of visitors rating the soundscape as “rather good” or “very good” dropped to 73%. This is below the Swedish Environment Agency’s (2005) target that at least 80% of visitors to nearby recreational areas in urban settings should assess soundscape quality as good. Furthermore, our results align with the recommendation by Nilsson and Berglund (2006) that traffic noise level (Lday) in urban parks should not exceed 50 dB to preserve soundscape quality. Similarly, they corroborate the European Environment Agency’s (EEA, 2014) “Good practice guide on quiet areas” that recommends maintaining noise levels (Lday) below 55 dB in such environments. Collectively, these findings underscore the importance of managing traffic noise in restorative spaces to safeguard their acoustic and experiential quality.

### 4.4 RQ3: Predicting perceived restorativeness from geodata and perceptual variables

Our models predicted perceived restorativeness (PRS) with up to 25% of explained variance; a level that is consistent with similar studies predicting restoration outcomes or landscape preferences (Hegetschweiler et al., 2020; Sella et al., 2023). However, it also highlights the complexity of restorative experiences, which are likely influenced by personal, situational, and contextual factors that are difficult to capture through geodata and standardised questionnaires. Our findings align with the concept of “tranquil places” proposed by Pheasant et al. (2009; 2010), where harmony between sensory inputs and the occurrence of natural and cultural landscape features fosters restoration.

Notably, perceptual variables (mediators) were the strongest predictors of PRS, supporting the concept that subjective environmental experiences mediate the relationship between physical characteristics and perceived restorativeness (Hunziker et al., 2007). In addition to the more general perceptions of feeling of being in nature and overall soundscape quality, the sensory experiences had a strong influence on perceived restorativeness, as other authors also found for perceived restorativeness of forests (Chiang, 2023; Wei and Hou, 2023).

In contrast, geodata alone had limited predictive power, except for a small contribution of NDVI (greenness) to fascination and extent-scope dimensions. Interestingly, the relationship between NDVI and fascination was negative, which may seem counterintuitive. This could be explained by a bias toward forested areas with high NDVI values, which, while ecologically rich, may be perceived as dense or less visually open conditions that are less preferred according to evolutionary landscape preference theories (Kaplan & Kaplan, 1989; Bourassa, 1991; Hunziker & Kienast, 1999). These theories suggest that humans are more drawn to semi-open, savannah-like environments that offer both refuge and prospect.

While geodata had limited direct influence on PRS, they significantly affected the mediator variables. NDVI and the proportion of artificial surfaces were particularly influential on the feeling of being in nature and sensory perceptions. For example, NDVI had a strong positive effect on the feeling of being in nature, and this effect was even more pronounced in areas with a high share of artificial surfaces. This interaction suggests that greenness can compensate for sealed surfaces, enhancing the perceived naturalness of a place even in built-up environments. Similarly, road traffic noise at the RL was a strong negative predictor of overall soundscape quality, reinforcing the importance of managing noise levels in public green spaces. The significant influence of NDVI on many perceptual variables supports the studies relying on NDVI to investigate human–nature relationships (Holland et al., 2021; Reyes-Riveros et al., 2021). On the other hand, including additional physical and spatial variables (such as land cover, heterogeneity, noise exposure) provides more detailed information about perceived characteristics of a place, and researchers make increasingly use of the advances in remote sensing and topographic data (e.g. Komossa, van der Zanden, Schulp, & Verburg, 2018; Lehto, Hedblom, Öckinger, & Ranius, 2022). Collectively, these findings underscore that perceptual engagement acts as a critical bridge linking objective landscape features with subjective restoration.

### 4.5 Limitations

As we asked the respondents to map their restorative locations with participatory GIS, the spatial accuracy of these points might be limited according to the scale used for mapping. On the other hand, people perceive a specific location in a larger spatial context with fuzzy boundaries which cannot be represented by a precise point on the map (McCall, 2006; Hasanzandeh, 2022). We overcame these uncertainties by drawing a buffer of 250 m around the mapped points for assessing the RLs’ geospatial characteristics.

Another limitation considers the sample of our survey. The response rate of 14% might seem modest, however, it aligns with expectations for online-only surveys (Daikeler et al., 2020). The participatory GIS approach might have caused additional challenges, as many incomplete questionnaires stopped at the question about mapping the restorative location. Such mapping approaches require skills in the use of digital devices which are more common among younger and well-educated people leading to a potential bias in the sample (Stern et al., 2009). In our case, this might have even turned into an advantage, as retirees are often strongly overrepresented in surveys.

## 5. Conclusions

With ongoing urban development and, particularly, densification, public green spaces play an increasingly vital role in supporting everyday restoration. Our study shows that people tend to seek out restorative environments that are not only greener but also quieter than their home surroundings. This highlights the importance of preserving quiet areas near settlements and minimizing anthropogenic noise, especially traffic noise, in public green spaces. Our findings suggest that road traffic noise should ideally remain below Lday < 55 dB to maintain the restorative quality of these areas. Urban planners are therefore encouraged to design green spaces as refuges from traffic noise (Spano et al., 2023), using strategies such as noise barriers (e.g., buildings or earth banks) or thoughtful placement of by-pass roads around residential areas. Although the perceived restorativeness of a location is difficult to predict using geodata alone, indicators like greenness (NDVI) and noise levels can serve as useful proxies, as they influence the feeling of being in nature, sensory perceptions and the perceived quality of the soundscape. By introducing sensory perception items, we demonstrate their substantial contribution to predicting perceived restorativeness and advocate including such measures in future urban wellbeing studies.

## References

Aletta, F., van Renterghem, T., Botteldooren, D., 2018. Influence of personal factors on sound perception and overall experience in urban green areas. A case study of a cycling path highly exposed to road traffic noise. *Int. J. Environ. Res. Public Health* **15:** 1118. <https://doi.org/10.3390/ijerph15061118>

Aletta, F., Kang, J. 2018. Towards an urban vibrancy model: a soundscape approach. Int. J. Environ. Res. Public Health 15, 1712. <https://doi.org/10.3390/ijerph15081712>

Alvarsson, J. J., Wiens, S., & Nilsson, M. E., 2010. Stress recovery during exposure to nature sound and environmental noise. *International Journal of Environmental Research and Public Health*, *7*(3), 1036–1046. <https://doi.org/10.3390/ijerph7031036>

Arregi, A., Vegas, O., Lertxundi, A., Silva, A., Ferreira, I., Bereziartua, A., … Lertxundi, N., 2024. Road traffic noise exposure and its impact on health: evidence from animal and human studies—chronic stress, inflammation, and oxidative stress as key components of the complex downstream pathway underlying noise-induced non-auditory health effects. *Environmental Science and Pollution Research*, *31*(34), 46820–46839. <https://doi.org/10.1007/s11356-024-33973-9>

Axelsson, Ö., Nilsson, M.E., Berglund, B. 2010. A principal components model for soundscape perception. Journal of Acoustical Society of America 128: 2836–2846. <https://doi.org/10.1121/1.3493436>

Babisch, W., 2002. The noise/stress concept, risk assessment and research needs. *Noise and Health*, *4*(16), 1–11.

BAFU, 2018a. Lärmbelastung der Schweiz. Ergebnisse des nationalen Lärmmonitorings sonBASE, Stand 2015. In *Umwelt-Zustand*. Retrieved from [www.bafu.admin.ch/uv-1820-d](http://www.bafu.admin.ch/uv-1820-d)

BAFU, 2018b. Stand der Lärmbelastung in der Schweiz. Retrieved September 25, 2024, from <https://www.bafu.admin.ch/bafu/de/home/themen/laerm/fachinformationen/laermbelastung/stand-der-laermbelastung-in-der-schweiz.html>

Basner, M., & McGuire, S. (2018). WHO environmental noise guidelines for the european region: A systematic review on environmental noise and effects on sleep. *International Journal of Environmental Research and Public Health*, *15*(3). <https://doi.org/10.3390/ijerph15030519>

Bourassa, S.C. 1991. The Aesthetics of Landscape. Belhaven, London

Breiman, L. 2001. Random Forests*. Machine Learning* **45**(1): 5–32. <https://doi.org/10.1023/A:1010933404324>

Bundesamt für Sport BASPO, 2020. Sport Schweiz 2020. *Observatorium Sport Und Bewegung Schweiz*, 64. <https://www.baspo.admin.ch/>

Cheng, T., Guestrin, C. 2016. XGBoost: a scalable tree boosting system. [KDD '16: Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining](https://dl.acm.org/doi/proceedings/10.1145/2939672): 785–794. <https://doi.org/10.1145/2939672.2939785>

Chiang Y. J. 2023. Multisensory Stimuli, Restorative Effect, and Satisfaction of Visits to Forest Recreation Destinations: A Case Study of the Jhihben National Forest Recreation Area in Taiwan. *International journal of environmental research and public health*, *20*(18), 6768. https://doi.org/10.3390/ijerph20186768

Daikeler, J., Bošnjak, M., Manfreda, K.L. 2020. Web versus other survey modes: an updated and extended meta-analysis comparing response rates. *Journal of Survey Statistics and Methodology* **8**: 513–539. <https://doi.org/10.1093/jssam/smz008>

de la Iglesia Martinez, A., Labib, S.M. 2023. Demystifying normalized vegetation index (NDVI) for greenness exposure assessments and policy interventions in urban greening. Environmental Research 220: 115155. <https://doi.org/10.1016/j.envres.2022.115155>

De Valck, J., Landuyt, D., Broekx, S., Liekens, I., De Nocker, L., Vranken, L. 2017. Outdoor recreation in various landscapes: which site characteristics really matter? *Land Use Policy* **65**: 186–197. <https://doi.org/10.1016/j.landusepol.2017.04.009>

Dopico Magadan, J., Wunderli, J.M., Kawai, C., Röösli, M., Vienneau, D., Brink, M., Tobias, S., Schäffer, B. 2025. Determinants of green space visits in urban areas: the role of personal, situational and physical characteristics. A cross-sectional study in Zurich, Switzerland. *Urban Forestry and Urban Greening* **111**: 128872. <https://doi.org/10.1016/j.ufug.2025.128872>

Dzhambov, A. M., Markevych, I., Hartig, T., Tilov, B., Arabadzhiev, Z., Stoyanov, D., … Dimitrova, D. D., 2018. Multiple pathways link urban green- and bluespace to mental health in young adults. *Environmental Research*, *166*(June), 223–233. <https://doi.org/10.1016/j.envres.2018.06.004>

EEA European Environment Agency, 2010. *Good practice guide on noise exposure and potential health effects*. Retrieved from <https://www.eea.europa.eu/publications/good-practice-guide-on-noise>

EEA European Environment Agency, 2014. Good practice guide on quiet areas. EEA Technical Report 4/2014. 58 pp. <https://www.eea.europa.eu/publications/good-practice-guide-on-quiet-areas>

EEA European Environment Agency, 2025. Environmental noise in Europe 2025. *EEA Report 5/2025*. 151 pp. Download: <https://www.eea.europa.eu/en/analysis/publications/environmental-noise-in-europe-2025>

Evensen, K.H., Raanaas, R.H., Fyhri, A. 2016. Soundscape and perceived suitability for recreation in an urban designated quiet zone. *Urban Forestry and Urban Greening* **20**: 243–248. <http://dx.doi.org/10.1016/j.ufug.2016.09.003>

Farina, A. 2014. Soundscape ecology: principles, patterns, methods and applications. Springer Science+Business Media Dordrecht. DOI: 10.1007/978-94-007-7374-5\_5

Farina, A., Pieretti, N. 2012. The soundscape ecology: a new frontier of landscape research and its application to islands and coastal systems. J. Marine and Island Cultures 1, 21–26. <https://doi.org/10.1016/j.imic.2012.04.002>

Fiebig, A., Schulte-Fortkamp, B. 2019. Soundscape – Fortschritte in der Standardisierung auf internationaler Ebene. Akustik Journal 1/2019: 36–43. <https://www.dega-akustik.de/fileadmin/dega-akustik.de/publikationen/akustik-journal/19-01/akustik_journal_2019_01_online_artikel3.pdf>

Fuegen, K., Breitenbecher, K.H. 2018. Walking and being outdoors in nature increase positive affect and energy. Ecopsychology 10:14–22. [https://doi.org/10.1089/eco.2017.003](https://doi.org/10.1089/eco.2017.0036)

García-Martín, M.; Kolecka, N.; Hunziker, M.; Graz, L.; Dopico, J.; Schäffer, B.; Wunderli, J.M.; Tobias, S. 2025. The role of greenness and road traffic noise for psychological restoration in everyday environments. A participatory mapping approach. *Landscape and Urban Planning* **259**: 105339. <https://doi.org/10.1016/j.landurbplan.2025.105339>

García-Martín, M.; Tobias, S., 2025. Swiss-wide survey on restorative places and road traffic noise. EnviDat. [doi:10.16904/envidat.629](https://doi.org/10.16904/envidat.629).

Hartig, T., 2004. Restorative Environments. *Encyclopedia of Applied Psychology, Three-Volume Set*, 273–279. <https://doi.org/10.1016/B0-12-657410-3/00821-7>

Hartig, T., Evans, G. W., Jamner, L. D., Davis, D. S., & Gärling, T., 2003. Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology*, *23*(2), 109–123. <https://doi.org/10.1016/S0272-4944(02)00109-3>

Hartig, T., Korpela, K., Evans, G. W., & Gärling, T., 1997. A measure of restorative quality in environments. *Scandinavian Housing and Planning Research*, *14*(4), 175–194. <https://doi.org/10.1080/02815739708730435>

Hartig, T., Mitchell, R., De Vries, S., & Frumkin, H., 2014. Nature and health. *Annual Review of Public Health*, *35*, 207–228. <https://doi.org/10.1146/annurev-publhealth-032013-182443>

Hasanzadeh, K. 2022. Use of participatory mapping approaches for activity space studies: a brief overview of pros and cons. *GeoJournal* **87** (Suppl 4): 723–738. <https://doi.org/10.1007/s10708-021-10489-0>

Hegetschweiler, T., Fischer, C., Moretti, M., & Hunziker, M. 2020. Integrating data from National Forest Inventories into socio-cultural forest monitoring – a new approach. *Scand. J. For. Res.*, *35*(5-6), 274–285. <https://doi.org/10.1080/02827581.2020.1799066>

Hegetschweiler, T., Salak, B., Wunderlich, A. C., Bauer, N., & Hunziker, M. 2022. *Das Verhältnis der Schweizer Bevölkerung zum Wald. Waldmonitoring soziokulturell WaMos3. Ergebnisse der nationalen Umfrage* (Vol. 120). Swiss Federal Institute for Forest, Snow and Landscape Research, WSL. <https://doi.org/10.55419/wsl:30512>

Hegewald, J., Schubert, M., Freiberg, A., Starke, K. R., Augustin, F., Riedel-Heller, S. G., … Seidler, A., 2020. Traffic noise and mental health: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health*, *17*(17), 1–26. <https://doi.org/10.3390/ijerph17176175>

Holland, I., Deville, N. V., Browning, M. H. E. M., Buehler, R. M., Hart, J. E., Aaron Hipp, J., … James, P., 2021. Measuring nature contact: A narrative review. *International Journal of Environmental Research and Public Health*, *18*(8), 1–15. <https://doi.org/10.3390/ijerph18084092>

Huang, S., Qi, J., Li, W., Dong, J., & van den Bosch, C. K., 2021. The contribution to stress recovery and attention restoration potential of exposure to urban green spaces in low-density residential areas. *International Journal of Environmental Research and Public Health*, *18*(16). <https://doi.org/10.3390/ijerph18168713>

Hunziker, M., Kienast, F., 1999. Potential impacts of changing agricultural activities on scenic beauty – a prototypical technique for automated rapid assessment. *Landscape Ecology* **14:** 161–176. <https://doi.org/10.1023/A:1008079715913>

Hunziker, M., Buchecker, M., Hartig, T. 2007. Space and Place – Two Aspects of the Human-Landscape Relationship. In: Kienast, F., Wildi, O., Ghosh, S. (eds) A Changing World. Landscape Series, vol 8. Springer, Dordrecht. Doi: 10.1007/978-1-4020-4436-6\_5.

ISO, 2003. ISO/TS 15666. Technical Specification: Acoustics – Assessment of Noise Annoyance by Means of Social and Socio-Acoustic Surveys. International Organisation for Standardization (ISO), Geneva, Switzerland.

ISO, 2019. ISO/TS 12913-2. Acoustics — Soundscape — Part 2: Data collection and reporting requirements. Geneva, Switzerland: International Organisation for Standardization (ISO).

Kadmon, R., & Harari-Kremer, R., 1992. † Present address: Department of Ecology and Evolution, Univer-1996. *Remote Sens. Environ*, *68*(98), 164–176.

Kajosaari, A., & Pasanen, T. P., 2021. Restorative benefits of everyday green exercise: A spatial approach. *Landscape and Urban Planning*, *206* (November 2020), 103978. <https://doi.org/10.1016/j.landurbplan.2020.103978>

Kaplan, R., & Kaplan, S., 1989. *The experience of nature: A psychological perspective.* New York: Cambridge University Press. Retrieved from <https://psycnet.apa.org/record/1989-98477-000>

Kaplan, S., 1995. The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, *15*(3), 169–182. <https://doi.org/10.1016/0272-4944(95)90001-2>

Kaplan, S., 2001. Meditation, Restoration, and the Management of Mental Fatigue. *Environment and Behavior*, *33*(4), 480–506. <https://doi.org/https://doi.org/10.1177/00139160121973106>

Kawai, C., Georgiou, F., Pieren, R., Tobias, S., Mavros, P., & Schäffer, B. 2024. Investigating effect chains from cognitive and noise-induced short-term stress build-up to restoration in an urban or nature setting using 360° VR. *J. Environ. Psychol.* **100**: 102466. <https://doi.org/10.1016/j.jenvp.2024.102466>

Kjellgren, A., Buhrkall, H. 2010. A comparison of the restorative effect of a natural environment with that of a simulated natural environment’. *Journal of Environmental Psychology* **30**: 464–472. <https://doi.org/10.1016/j.jenvp.2010.01.011>

Komossa, F., van der Zanden, E. H., Schulp, C. J. E., & Verburg, P. H., 2018. Mapping landscape potential for outdoor recreation using different archetypical recreation user groups in the European Union. *Ecological Indicators*, *85*(October 2017), 105–116. <https://doi.org/10.1016/j.ecolind.2017.10.015>

Korpela, K. M., Ylén, M., Tyrväinen, L., & Silvennoinen, H., 2010. Favorite green, waterside and urban environments, restorative experiences and perceived health in Finland. *Health Promotion International*, *25*(2), 200–209. <https://doi.org/10.1093/heapro/daq007>

Lang,M., Binder, M., Richter, J., Schratz, P., Pfisterer, F. Coors, S., Au, Q., Casalicchio, G., Kotthoff, L., Bischi, B. 2019. mlr3: A modern object-oriented machine learning framework in R. *Journal of Open Source Software* **4**(44): 1903. <https://doi.org/10.21105/joss.01903>

Lehto, C., Hedblom, M., Filyushkina, A., Ranius, T. 2024. Seeing through their eyes: revealing recreationists’ landscape preferences through viewshed analysis and machine learning. *Landscape and Urban Planning* **248**: 105097. <https://doi.org/10.1016/j.landurbplan.2024.105097>

Li, C., Yuan, Y., Sun, C., & Sun, M., 2022. The Perceived Restorative Quality of Viewing Various Types of Urban and Rural Scenes: Based on Psychological and Physiological Responses. *Sustainability (Switzerland)*, *14*(7). <https://doi.org/10.3390/su14073799>

Malinowski, R., Lewiński, S., Rybicki, M., Gromny, E., Jenerowicz, M., Krupiński, M., … Schauer, P., 2020. Automated production of a land cover/use map of europe based on sentinel‐2 imagery. *Remote Sensing*, *12*(21), 1–27. <https://doi.org/10.3390/rs12213523>

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., … Fuertes, E., 2017. Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environmental Research*, *158*(June), 301–317. <https://doi.org/10.1016/j.envres.2017.06.028>

McCall, M.K. 2006. Precision for whom? Mapping ambiguity and certainty in (participatory) GIS. *Participatory Learning and Action* **54**: 114–119. Available at <https://www.iied.org/g02958>

McEwan, K., Ferguson, F.J., Richardson, M., Cameron, R. 2020. The good things in urban nature: A thematic framework for optimising urban planning for nature connectedness. *Landscape and Urban Planning* **194:** 103687. <https://doi.org/10.1016/j.landurbplan.2019.103687>

Medvedev, O., Shepherd, D., Hautus, M.J. 2015. The restorative potential of soundscapes: a physiological investigation. *Applied Acoustics* **96**: 20–26. <http://dx.doi.org/10.1016/j.apacoust.2015.03.004>

Neuvonen, M., Sievänen, T., Tönnes, S., & Koskela, T., 2007. Access to green areas and the frequency of visits - A case study in Helsinki. *Urban Forestry and Urban Greening*, *6*(4), 235–247. <https://doi.org/10.1016/j.ufug.2007.05.003>

Nilsson, M.E., Berglund, B. 2006. Soundscape quality in suburban green areas and city parks. *Acta Acustica united with Acustica* **92**: 903–911. Download: <https://www.researchgate.net/publication/233638356_Soundscape_Quality_in_Suburban_Green_Areas_and_City_Parks> (accessed February 9, 2025).

Ojala, A., Korpela, K., Tyrväinen, L., Tiittanen, P., & Lanki, T., 2019. Restorative effects of urban green environments and the role of urban-nature orientedness and noise sensitivity: A field experiment. *Health and Place*, *55*(November 2018), 59–70. <https://doi.org/10.1016/j.healthplace.2018.11.004>

Ow, L. F., & Ghosh, S., 2017. Urban cities and road traffic noise: Reduction through vegetation. *Applied Acoustics*, *120*, 15–20. <https://doi.org/10.1016/j.apacoust.2017.01.007>

Pasini, M., Berto, R., Brondino, M., Hall, R., & Ortner, C., 2014. How to Measure the Restorative Quality of Environments: The PRS-11. *Procedia - Social and Behavioral Sciences*, *159*, 293–297. <https://doi.org/10.1016/j.sbspro.2014.12.375>

Pheasant, R., Horoshenkov, K., Watts, G., & Barrett, B., 2008. The acoustic and visual factors influencing the construction of tranquil space in urban and rural environments tranquil spaces-quiet places? *The Journal of the Acoustical Society of America*, *123*(3), 1446–1457. <https://doi.org/10.1121/1.2831735>

Pheasant, R.J., Watts, G.R., Horoshenkov, K.V. 2009. Validation of a tranquillity rating prediction tool. *Acta Acustica united with Acustica* **95:** 1024–1031. DOI: <https://doi.org/10.3813/AAA.918234>

Pheasant, R.J., Fisher, M.N., Watss, G.R., Whitaker, D.J., Horoshenkov, K.V. 2010. The importance of auditory-visual interaction in the construction of ‘tranquil space’. *J. Environmental Psychology* **30:** 501–509. DOI: <https://doi.org/10.1016/j.jenvp.2010.03.006>

Ratcliffe, E., Gatersleben, B., Sowden, P.T., 2013. Bird sounds and their contributions to perceived attention restoration and stress recovery. *Journal of Environmental Psychology* 36, 221–228. <https://doi.org/10.1016/j.jenvp.2013.08.004>

Reyes-Riveros, R., Altamirano, A., De La Barrera, F., Rozas-Vásquez, D., Vieli, L., & Meli, P., 2021. Linking public urban green spaces and human well-being: A systematic review. *Urban Forestry and Urban Greening*, *61*(September 2020). <https://doi.org/10.1016/j.ufug.2021.127105>

Richardson, M., Hallam, J., & Lumber, R. 2015. One Thousand Good Things in Nature: Aspects of Nearby Nature Associated with Improved Connection to Nature. *Environmental Values* **24**(5): 603–619. <https://doi.org/10.3197/096327115X14384223590131>

Ryan, R.M., Weinstein, N., Bernstein, J., Warren Brown, K., Mistretta, L., Gagné, M. 2010. Vitalizing effects of being outdoors and in nature. *Journal of Environmental Psychology* **30**:159–168. DOI: 10.1016/j.jenvp.2009.10.009

Schäffer, B., Brink, M., Schlatter, F., Vienneau, D., & Wunderli, J. M., 2020. Residential green is associated with reduced annoyance to road traffic and railway noise but increased annoyance to aircraft noise exposure. *Environment International*, *143*(March), 105885. <https://doi.org/10.1016/j.envint.2020.105885>

Schlittmeier, S. J., Feil, A., Liebl, A., & Hellbrück, J., 2015. The impact of road traffic noise on cognitive performance in attention-based tasks depends on noise level even within moderate-level ranges. *Noise and Health*, *17*(76), 148–157. <https://doi.org/10.4103/1463-1741.155845>

Sella, E., Meneghetti, C., Muffato, V., Borella, E., Carbone, E., Cavalli, R., Pazzaglia, F. 2023. The influence of individual characteristics on perceived restorativeness and benefits associated with exposure to nature in a garden. *Frontiers in Psychology* **14**: 1130915. DOI: 10.3389/fpsyg.2023.1130915

Song, S., Tu, R., Lu, Y., Yin, S., Lin, H., & Xiao, Y., 2022. Restorative Effects from Green Exposure: A Systematic Review and Meta-Analysis of Randomized Control Trials. *International Journal of Environmental Research and Public Health*, *19*(21). <https://doi.org/10.3390/ijerph192114506>

Spano, G., Ricciardi, E., Theodorou, A., Giannico, V., Caffò, A. O., Bosco, A., … Panno, A., 2023. Objective greenness, connectedness to nature and sunlight levels towards perceived restorativeness in urban nature. *Scientific Reports*, *13*(1), 1–13. <https://doi.org/10.1038/s41598-023-45604-3>

Stekhoven, D.J., Bühlmann, P. 2012. MissForest—non-parametric missing value imputation for mixed-type data, *Bioinformatics* **28**(1): 112–118, <https://doi.org/10.1093/bioinformatics/btr597>

tern, E., Gudes, O., Svoray, T. 2009. Web-Based and Traditional Public Participation in Comprehensive Planning: A Comparative Study. *Environment and Planning B: Planning and Design*, *36*(6), 1067-1085. <https://doi.org/10.1068/b34113>

Swedish Environmental Protection Agency. 2005. Sound quality in natural and cultural environments. Swedish EPA report 5440. Stockholm, Naturvådsverket. 24 pp. Download: <https://www.naturvardsverket.se/4ac336/globalassets/media/publikationer-pdf/5700/978-91-620-5709-x.pdf> (accessed May 15, 2025)

Torija, A.J., Ruiz, D.P., Ramos-Ridao, A.F. 2013. Application of a methodology for categorizing and differentiating urban soundscapes using acoustical descriptors and semantic-differential attributes. Journal of the Acoustical Society of America 134(1), 791–802. <https://doi.org/10.1121/1.4807804>

Tyrväinen, L., Ojala, A., Korpela, K., Lanki, T., Tsunetsugu, Y., & Kagawa, T., 2014. The influence of urban green environments on stress relief measures: A field experiment. *Journal of Environmental Psychology*, *38*, 1–9. <https://doi.org/10.1016/j.jenvp.2013.12.005>

Uebel, K., Marselle, M., Dean, A.J., Rhodes, J.R., Bonn, A. 2021. Urban green space soundscapes and their perceived restorativeness. *People and Nature* **2021/3**: 756–769. <https://doi.org/10.1002/pan3.10215>

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M., 1991. Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology*, *11*(3), 201–230. <https://doi.org/10.1016/S0272-4944(05)80184-7>

Van Renterghem, T., 2019. Towards explaining the positive effect of vegetation on the perception of environmental noise. *Urban Forestry and Urban Greening*, *40*(November 2017), 133–144. <https://doi.org/10.1016/j.ufug.2018.03.007>

Van Renterghem, T., Vermandere, E., Lauwereys, M. 2023. Road traffic noise annoyance mitigation by green window view: Optimizing green quantity and quality. *Urban Forestry and Urban Greening* **88**: 128072. https://doi.org/10.1016/j.ufug.2023.128072

Watts, G. R., & Pheasant, R. J., 2015. Identifying tranquil environments and quantifying impacts. *Applied Acoustics*, *89*, 122–127. <https://doi.org/10.1016/j.apacoust.2014.09.015>

Weber, A. M., Trojan, J., 2018. The Restorative Value of the Urban Environment: A Systematic Review of the Existing Literature. *Environmental Health Insights*, *12*. <https://doi.org/10.1177/1178630218812805>

Wei, Y., Hou, Y. 2023. Forest Visitors’ Multisensory Perception and Restoration Effects: A Study of China’s National Forest Parks by Introducing Generative Large Language Model. Forests **2023**, 14*:* 2412. https://doi.org/10.3390/f14122412

Wood S.N. 2017. Generalized Additive Models: An Introduction with R (2nd edition). Chapman and Hall/CRC Press; 496 pp. <https://doi.org/10.1201/9781315370279>

Yin, J., Bratman, G. N., Browning, M. H. E. M., Spengler, J. D., & Olvera-Alvarez, H. A., 2022. Stress recovery from virtual exposure to a brown (desert) environment versus a green environment. *Journal of Environmental Psychology*, *81*(February 2021), 101775. <https://doi.org/10.1016/j.jenvp.2022.101775>

Zhang, J.W., Howell, R.T. Iyer, R. 2014. Engagement with natural beauty mod­erates the positive relation between connectedness with nature and psychological well-being. *Journal of Environmental Psychology* **38:** 55–63. [https://doi.org/10.1016/j.jenvp.2013.12.013](https://psycnet.apa.org/doi/10.1016/j.jenvp.2013.12.013)