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Developing a Multi-sensory Public Participation GIS (MSPPGIS) method for integrating landscape values and soundscapes of urban green infrastructure

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HIGHLIGHTS

- Presents a multi-sensory PPGIS method integrating landscape values and soundscapes.
- PPGIS data (N = 507) from 2 suburbs in Helsinki is used to operationalize the method.
- Low spatial overlap between hotspots of different values and pleasant/unpleasant sounds was found.
- Generally pleasant and unpleasant sounds were located closer to home than values.
- Landscape values do not necessarily reflect sonic perceptions of UGI.

ABSTRACT

This paper develops, tests and validates a Multi-sensory Public Participation GIS (MSPPGIS) method combining the qualities of soundscapes and landscape values mapping. The development of the method involved: a) Public Participation GIS survey design; b) three-phase evaluation of survey addressing analytical, applicability and usability criteria; c) survey refinement; d) sampling and data collection, and; e) spatial data analysis. The analysis consisted of hotspot mapping involving Kernel Density Estimation, spatial overlap assessment using Jaccard coefficients and value compatibility analysis showing the level of spatial compatibility between positive landscape values and positive and negative soundscapes. Results indicated very low to low spatial overlap between the different landscape values and pleasant/unpleasant sound hotspots, suggesting that landscape values do not necessarily reflect sonic perception of urban green and blue spaces. Pleasant and unpleasant sounds were located closer to home than landscape values (except for urban life values), indicating that respondents' soundscape 'cognitive map' is smaller in spatial range. The MSPPGIS method enables the elicitation of a more dynamic and diverse set of sounds compared to previous soundscape mapping which tend to focus on 'noise' instead of multiple experiences of different sounds. Also, the combination of landscape values and soundscapes in MSPPGIS provides for a more integrated assessment of 'where' and 'how' to design urban green infrastructure.

1. Introduction

Urban green infrastructure (UGI), including green roofs, private gardens, public parks, wetlands or forests provide multiple benefits, such as human well-being, biodiversity conservation and social cohesion (see European Commission, 2021 for overview). UGI is often embedded within multi-functional landscapes that are perceived and experienced by humans in specific spatio-temporal contexts and also affected by multi-sensory perception, thoughts, physical condition, cultural cues and the opportunities and constraints posed by the physical setting (Aletta et al., 2016).

Public Participation Geographic Information Systems (PPGIS) provide a way of assessing the multiple benefits of UGI (e.g., Korpilo et al., 2021). This method involves the marking of spatial attributes on maps using stickers, markers or digital annotations *ex situ*, such as at home or as part of focus groups (Brown et al., 2017). Studies have often mapped

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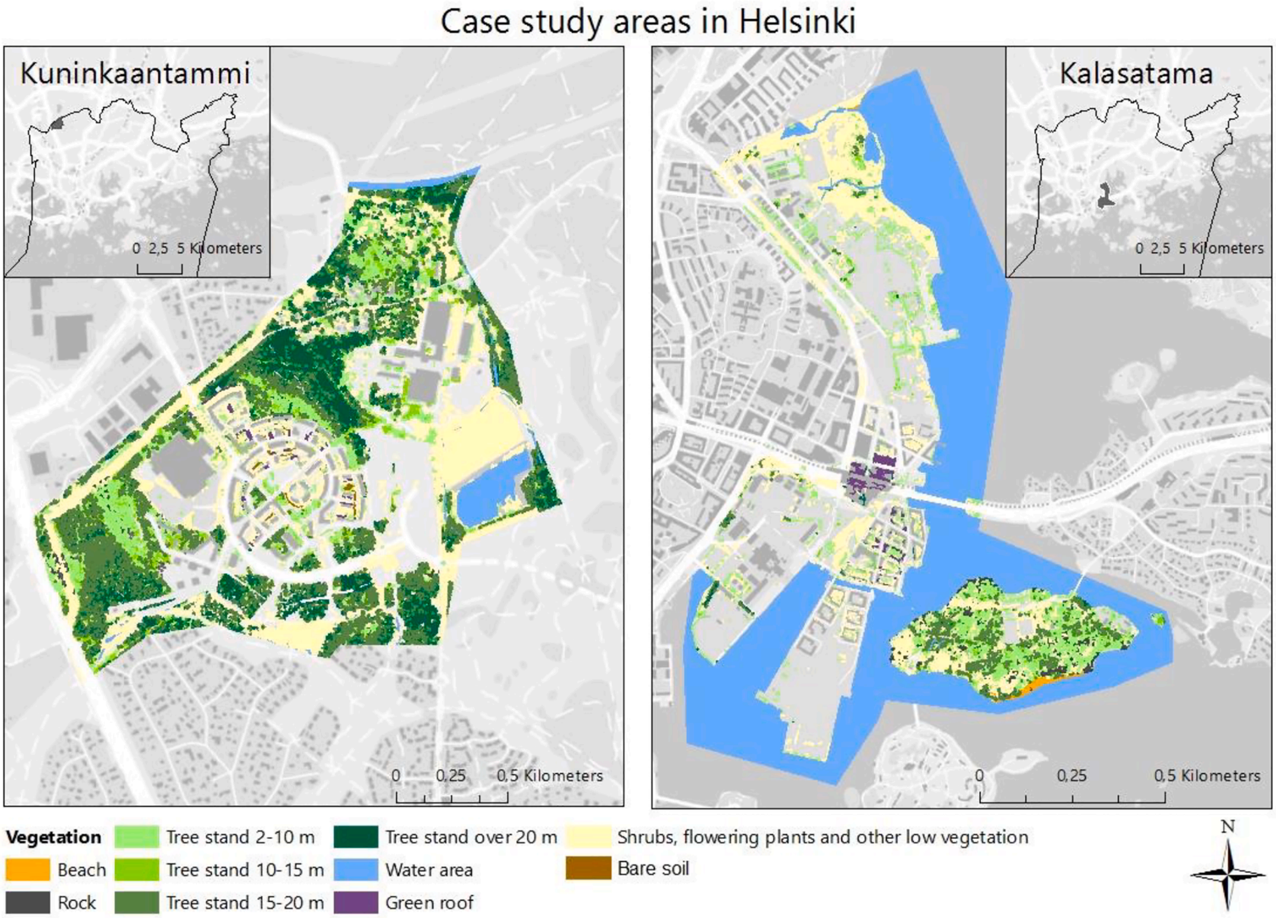

Fig. 1. Study sites in Helsinki, Finland and their green infrastructure. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

residents' landscape values in UGI, which reflects individual's direct use of or interaction with places (Brown et al., 2020), in some cases providing for material benefits (e.g., economic, recreation values) while in other cases providing for non-material benefits (e.g., spiritual and intrinsic values) (e.g. Brown et al., 2014; Heikinheimo et al., 2020). Across all applications, PPGIS *connects* what is generally important to the individual to what is important to the individual in the physical landscape. Emphasis is placed on how individuals think, feel and act in the landscape (Brown et al., 2020). Less attention is paid to the role of other sensory systems in the construction of embodied experience and value of place (Bates et al., 2020; Franco et al., 2017), including auditory systems.

Soundscape research provides a complementary way of investigating the values of UGI. The term 'soundscape' has evolved differently across disciplines with diverse definitions aiming to describe the relationship between the landscape and its sonic dimension, as well as the perception of sounds in a place by animals and people (see Pijanowski et al. 2011a, 2011b; Brown, 2011). Southworth (1969) defined soundscape as human perception of sounds in the urban built environment. Later Schafer (1977, 1994) identified soundscape as any defined acoustic environment that reflects ecological processes and properties of places. Pijanowski et al. (2011a) suggested a more detailed definition focusing on the sound sources (biophony, geophony and anthrophony) and the spatio-temporal dimension of soundscapes, while the definition provided by ISO 12913-1 series on soundscape uses a more human-centred inquiry i.e. soundscape is an "acoustic environment as perceived or experienced and/or understood by a person or people, in context" (Axelsson, 2012). In this study, we draw largely on the latter ISO 12913-1 definition emphasising human perception of sounds in the urban environment.

Soundscape research identifies sound as a resource which can be modified and used to enhance the quality of human place-based experiences (Dumyahn & Pijanowski, 2011; Preis et al., 2015). For example, natural sounds may improve the acoustic quality of built-up environments to a certain extent e.g. by masking noise (Coensel et al., 2011; Kang et al., 2016) or increasing crowd tolerance (Kim & Shelby, 2011). Natural sounds such as wind, water, and birdsongs are also perceived to be pleasant, relaxing and restorative (e.g., replenish cognitive resources, reduce stress levels) (e.g. Björk et al., 2008; Buxton et al., 2021), are shown to contribute to greater stress recovery than sounds from the built environment (Alvarsson et al., 2010; Benfield et al., 2014), and can mitigate negative emotions such as confusion and unpleasantness (Jo & Jeon, 2020). Human sounds on the other hand, can increase perception of vibrancy and liveliness in urban public spaces and parks (Aletta & Kang, 2018; Jo & Jeon, 2020).

Soundscape studies in urban environments have experienced slow but steady progress in recent years using a diversity of participatory tools and methodologies (Aletta et al., 2016), from which soundwalks have been the most widely used (e.g. Aletta & Kang, 2015; Herranz-Pascual et al., 2017). Other methods include interviews and questionnaires (e.g. Axelsson et al., 2014; Payne & Guastavino, 2018), mixed field methods (e.g. Bild et al., 2018; Liu et al., 2014), laboratory experiments (e.g. Preis et al., 2015, Margaritis et al., 2020) and more recently VR technologies (e.g., Jo & Jeon, 2020, Sun et al., 2019) and social media data (e.g. Aiello et al., 2016).

While scholars have developed participatory soundscape sensing using mobile phones to gather data *in situ* (e.g. Li et al., 2018; Brambilla

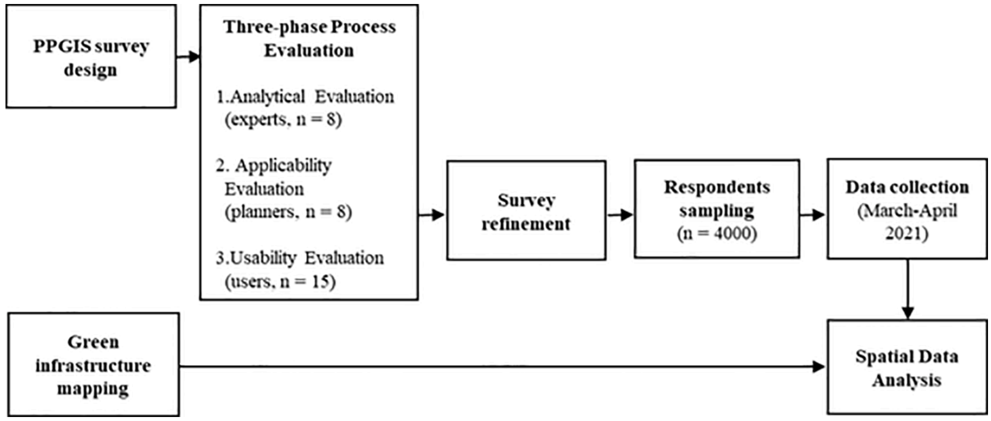

Fig. 2. Study methodological framework.

& Pedrielli 2020), the PPGIS and soundscape scholarships have remained largely disconnected. There is some theoretical support for an integrated approach. Different soundscapes (especially of natural and musical sources) (Southworth, 1969; Schafer, 1977; Li et al., 2018) can significantly influence landscape evaluations and preference (Brambilla & Pedriellie, 2020), and vice versa, the landscape's physical characteristic and spatial patterns have been shown to affect soundscape perception (Liu et al., 2014); however, empirical testing of integrated approaches to landscape value and soundscape mapping remain limited.

The overall goal of this article is to test and validate a new methodology called multi-sensory PPGIS (MSPPGIS) that integrates landscape values and soundscapes of urban green infrastructure (UGI). Results are compared across two study sites to aid method validation. The goal is addressed through the two objectives of: 1) to map the spatial distribution of residents' positive landscape values and pleasant/unpleasant sounds, and explore their relationship with distance from respondents' home; and 2) to identify hotspot areas (i.e. high density of mapped points) of the different landscape values and sounds, and analyse their level of spatial overlap. We hypothesise that spatial distribution and density of mapped landscape values and sounds across both study areas will show low spatial coincidence, indicating complementary importance. Finally, we discuss implications for PPGIS methodology and UGI planning based on our results. In a global context, the MSPPGIS methods can help operationalise the concept of senses of place in terms of helping researchers and practitioners more holistically assess the multiple layers of people–place relationships across space and time (building on Raymond et al. 2021).

2. Methods

2.1. Study areas

This study focuses on two neighbourhoods – Kalasatama and Kuninkaantammi, in Helsinki, Finland. Fig. 1 shows locations of these two areas and their respective urban green infrastructure in 2020 (see Section 2.2). The study sites were selected to be able to test and validate the MSPPGIS methods in two different rapidly developing neighbourhoods. Both areas are partly developed and are already providing homes for many residents but continuing to grow, meaning that residents need to adapt to changes and construction activities (including a lot of temporary noises) in their everyday living environment. However, these two neighbourhoods also differ in planning volume (e.g. planned floor area and inhabitants), location (Kuninkaantammi – suburb vs Kalasatama – inner city neighbourhood), types and extent of nature-based solutions, and planning visions, providing necessary contrast for analysis.

Kuninkaantammi planning has been guided by the Green City concept emphasizing climate smart solutions such as nature-based solutions in stormwater management, energy efficient housing, and the use of a green factor tool during the planning process (City of Helsinki, 2019a). Also, reuse of excavated soil and rock materials received special attention in the development of green areas and private courtyards. First residents moved to the area in 2016 and the planned number of new residents is 5500 with an additional 1000 workplaces by 2027 (City of Helsinki, 2019a). In the past, Kuninkaantammi was partly industrial brownfield and partly woodland with scattered detached housing. Kuninkaantammi is surrounded by the large forest areas of Helsinki Central Park and the recreational routes of the river Vantaanjoki are relatively nearby.

In Kalasatama, on the other hand, the focus has been on Smart City agenda using technological solutions and services e.g. digital applications for car sharing, smart locks, and smart waste management (City of Helsinki, 2021). The area is a former harbour and industrial area owned by the city and located in the urban core. Kalasatama is one of the largest ongoing development projects in Helsinki – First residents moved to the area in 2012 and by 2040 the area will be inhabited by 25 000 residents, providing over 10 000 workplaces. For outdoor recreation, the residents of Kalasatama are heavily dependent on the island of Mustikkamaa, which can be accessed along a new bridge used only by pedestrians and bikers.

The detailed green infrastructure mapping (see Section 2.2) showed that nearly a third (29 %) of the Kalasatama study site (excluding sea areas) consists of green space such as human-constructed parks, green roofs and residential yards. Most of the green space land cover is situated in Mustikkamaa and the brownfield site in the northern part of the study area. Kuninkaantammi on the other hand is greener as 57 % of its area is composed of green spaces. Most of the green infrastructure in Kuninkaantammi is forests and especially older and higher tree stands (over 20 m). In Kalasatama, lower tree stands (2–10 m) are more common and the share of forest overall is lower and the share of low vegetation higher than in Kuninkaantammi.

2.2. Survey development and sampling

In this study, a methodological framework with several refining steps for data collection and analysis was developed (Fig. 2). First, the web based MSPPGIS survey was developed. This survey follows the ethical principles of research in the humanities and social and behavioural sciences issued by the Finnish Advisory Board on Research Integrity as well as according to European General Data Protection Regulation (Art. 12–14). The study was conducted with principles of informed consent i.e. participants were provided with Privacy Policy Notice with clear terms and conditions of voluntary participation, and were asked to digitally give consent. All information was anonymised and aggregated before analysis.

The survey was designed using the Maptionnaire Software in three languages - Finnish, Swedish and English. The software enables

Table 1
List of value and sound categories used in the survey. Source types based on the survey qualitative data (i.e. as identified by respondents in the survey by writing in a free-form) and categories by Axelsson et al., 2010.

Value category	Description
Aesthetic	I value this place because I enjoy the scenery, sounds, smells etc. in there
Biodiversity	I value this place because there are a variety of plants, animals and nature there
Outdoor activities	I value this place because it offers opportunities for recreation and various active and passive outdoor activities (e.g. being with friends and family, exercise or doing different hobbies)
Restorative sounds	I value this place because the sounds there help me to relax or forget about everyday worries
Restorative views	I value this place because the views there help me to relax or forget about everyday worries
Urban life	I value this place because I can enjoy city life and variety of services there

Sound category	Source types
Natural	Nature, forest, trees, waves, water, sea, birds and bird songs, wind, animals
Human	Human activity & recreation, human speech and laughter, dogs, children & children playing, music, events
Technological	Metro, boats, cars, planes, traffic, construction, buildings
Mixed	Human & natural sounds/ natural & technological sounds / natural & quietness
Quietness	Quiet, absence of noise

Table 2
Mapped landscape values in the two study areas.

	Kalasatama		Kuninkaantammi	
Value category	N points	% all	N points	% all
Aesthetic	510	21.5	270	19.8
Biodiversity	249	10.5	242	17.8
Outdoor activities	508	21.4	436	32.0
Restorative sounds	219	9.2	155	11.4
Restorative views	450	19.0	208	15.3
Urban life	437	18.4	51	3.7
Total	2373	100	1362	100

respondents to digitally assign place-based information (here landscape values, sounds and home location) on a map using a mobile device or a desktop computer. Respondents were asked to choose and map an unrestricted number of positive landscape values from a predefined list including: *"Aesthetic", "Biodiversity", "Outdoor activities", "Restorative sounds", "Restorative views"* and *"Urban Life"* (see Table 1). The list of landscape values was adapted from previous studies (Brown, et al., 2015; Korpilo et al., 2018; Tyrväinen et al., 2007) aiming to incorporate different senses, while the restorative values specifically were derived from psychological restoration theory related to being away from everyday life (Kaplan & Kaplan, 1989; Korpela et al., 2008). Restorative sounds and views were then presented in the mapping interface in order to acknowledge their equal role in perception of 'tranquil space' (Pheasant et al., 2010) and to test respondents' ability to locate these spatially. Participants were also asked to map places where they have experienced pleasant and unpleasant sounds, after which a pop-up window asked them to write in a free-form the source of each mapped sound: "What is the source of this sound (e.g. cars, people, bids, etc.)? ". Then participants needed to identify when the sounds can be heard choosing from four options: "Constantly/almost all the time", "Only sometimes or at certain time of the day (e.g. mornings or evenings)", "Just once", "At other times (please specify)". In addition, the survey included several questions on socio-demographics including gender, age group, number of persons in a household, education level, mother tongue and annual income level. Respondents were also asked to map their home location (i.e. a street intersection nearest to home) and how long they have lived in their neighbourhood.

After the survey was developed, it was evaluated in a rigorous three-step process in order to assess its social and ecological validity before data collection. The first step included an Analytical Evaluation with eight experts in the field i.e. international interdisciplinary researchers that were part of the research project with expertise in urban ecology, sociology, PPGIS and green space planning and governance. In an online workshop, experts were asked to rate the survey using a six-level Likert-scale (from "strongly disagree" to "strongly agree") according to nine pre-defined criteria on different types of validity (based on Brown et al., 2017) including ecological, social, technological, content, construct, criteria, internal, external and ethical validity (for detailed description, see Appendix A, Table 1). This was followed by an Applicability Evaluation online workshop with eight local planners from the City of Helsinki and the City of Helsinki innovation company "ForumVirium". The planners assessed another set of criteria related to the timing, inclusiveness, privacy and data protection, relevance, integrating knowledge, external validity and transparency of the survey (see Appendix A, Table 2). The final step of the evaluation processes was focused on the usability and functionality of the survey. A volunteer sample of 15 students from the University of Helsinki tested and assessed the survey using several criteria based on the Quality in Use Integrated Management (QUIM) model (Seffah et al., 2006) related to the benefits, mapping instructions, orientation, simplicity and clarity, adaptability, descriptiveness, length, engagement, access to information, privacy and security of the survey (see Appendix A, Table 3).

After the three-phase process evaluation was completed, the survey was refined according to the experts', planners' and users' feedback and then launched in March 2021 for a period of two months. To recruit participants, we used a combination of random and volunteered sampling. First, we sent 4000 postal invitations (2000 in Kalasatama and 2000 in Kuninkaantammi) to randomly selected residents in each area (addresses provided by the Finnish Population Registry). In addition, we used social (e.g. Facebook and Twitter) and traditional media (e.g. local newspapers, national coverage by Yle Radio) to advertise the survey widely to interested groups and individuals.

Parallel to the PPGIS survey development, in 2020, we conducted detailed green infrastructure mapping from the two study areas in July 2020 (see Fig. 1) by combining several available GIS datasets on land cover in the Helsinki Metropolitan Area including regional datasets (HSY and the municipalities in the region (2018)) and the register of public areas in the city of Helsinki (City of Helsinki, 2020). The Helsinki Metropolitan area land cover dataset classifies the land cover into water areas, bare ground, green surfaces, impermeable surfaces and open rock areas. The green surfaces are interpreted from orthophotos (resolution 0,2 m) from the year 2017 using NDVI (Normalized Difference Vegetation Index). The register of public areas in the city of Helsinki includes the location and attribute data on green infrastructure and streets in the City of Helsinki. The data is updated to the register from traffic, park, and detailed plans, other GIS-data and field work and the used data had been updated in May 2020. To account for recent changes in green infrastructure in these rapidly developing and continuously built neighbourhoods, missing data of newly built yards, green roofs and other green spaces were manually digitized based on the most recent satellite images (City of Helsinki, 2019b), which were then validated by field visits to the study sites.

2.3. Analysis

All spatial analyses were conducted using ArcGIS Pro version 2.8. In total 305 respondents mapped 3600 landscape values and sound points in the Kalasatama survey, and 202 respondents mapped 2370 points in the Kuninkaantammi survey. Our objective was to focus on the daily living environment within walking distance of the study sites and understanding the soundscapes in the residential areas in question. As some of the mapped points were located too far from the study sites

Table 3
Mapped pleasant and unpleasant sounds in the two study areas. NB: The table includes only sound points for which respondents have identified the relevant sound source.

	Kalasatama						Kuninkaantammi					
Soundscape category	Pleasant sounds (PS)	% all PS	% C/T*	Unpleasant sounds (US)	% all US	% C/T	PS	% all PS	% C/T	US	% all US	% C/T
Natural	292	53.5	71.1/ 28.9	1	0.2	100.0/ 0.0	268	81.2	68.3/ 31.7	0	–	–
Human	147	26.9	25.8/ 74.2	45	10.3	7.3/92.7	25	7.6	29.2/ 70.8	8	3.8	12.5/ 87.5
Technological	5	0.9	25.0/ 75.0	384	88.1	75.4/ 24.6	1	0.3	–	199	93.9	59.3/ 40.7
Mixed	92	16.8	72.3/ 27.7	6	1.4	100.0/ 0.0	32	9.7	76.9/ 23.1	5	2.4	75.0/ 25.0
Quietness	10	1.8	37.5/ 62.5	0	–	–	4	1.2	50.0/ 50.0	0	–	–
Total	546	100		436	100		330	100		212	100	

* % C/T = % constant/temporary sounds.

crossing over different neighbourhoods, we performed initial data cleaning by intersecting all points with a 1 km buffer around the study boundary of each area. The size of the buffer was chosen based on the mean distance of all outside points to the study boundary (Kalasatama = 588 m and Kuninkaantammi = 687 m) and a heuristic approach by testing different size buffers for maximum data inclusion. Points located outside the buffer were excluded from the analysis (in total 16 % of points in Kuninkaantammi and 3 % of points in Kalasatama). The greater number of excluded points in Kuninkaantammi was largely influenced by the relatively small size of the initially planned study area (1.090 km^2 compared to 3.429 km^2 in Kalasatama).

First, we explored the overall spatial distribution of the different landscape values and pleasant/unpleasant sound types. We coded all sound sources identified by respondents in the survey into several main categories which included a combination of an inductive and deductive approach i.e. three categories ("*natural*", "*human*", "*technological*") were identified based on established soundscape literature (Axelsson et al., 2010), while the "*mixed*" and "*quietness*" categories were derived based on the qualitative data. Table 1 shows a list of sound sources.

Sounds were further analysed based on their temporal dimension including "constant" (i.e. identified as respondents to be heard "Constantly/almost all the time") and "temporal" categories (i.e. heard "Only sometimes or at certain time of the day (e.g. morning or evenings)" and "Just once"). Overall, 5.2 % (Kalasatama) and 15.6 % (Kuninkaantammi) of the pleasant sound dataset, and 10.8 % (Kalasatama) and 12.0 % (Kuninkaantammi) of the unpleasant sound dataset was missing data. i.e. data that did not include an identified source and temporal dimension, and therefore was excluded from the categorical analysis. Maps and descriptive statistics of the spatial distribution of the landscape values and sounds types were then presented. In addition, we calculated mean distances (Euclidean distance in meters) of all mapped landscape values and sounds to respondents' homes in each study area, building on previous studies on PPGIS and home range assessments (Brown et al., 2002; Brown et al,. 2015). Then, Welch's ANOVA was used to calculate statistical differences between landscape values and sounds per area in SPSS (version 25). Welch's ANOVA was selected since our data had unequal variances and unequal sample size.

Finally, we used Kernel Density Estimation (KDE) as an established method for identifying socio-ecological hotspots (e.g., Korpilo et al., 2018). The Kernel density analysis, which uses a Kernel function to calculate the density of points in a neighbourhood around those points, was performed for all landscape value types and pleasant and unpleasant sound datasets using Nearest Neighbour Distance as a search radius and a 10-m cell size. Then, after testing several cut-off thresholds, a 20 % quantile delineation method was used to determine the hotspots (Schröter & Remme, 2016). To map the level of spatial overlap between the hotspots of landscape values and sounds raster layers, we used an arithmetic pixel-to-pixel analysis to determine overlapping cells and non-overlapping cells. The areas for both overlapping and non-overlapping cells were measured as the product of the respective cell count and the raster resolution. These count values constitute the input for calculating the Jaccard coefficient of spatial overlap between the different layers (van Jaarsveld et al., 1998). The Jaccard coefficient is a spatial statistic used for measuring similarity of two raster maps and is obtained as the intersection (overlapping cells) divided by the union (overlapping and non-overlapping cells) of the two rasters. It produces values from 0 to 100, where a larger Jaccard coefficient indicates greater spatial overlap (i.e. 0–20 % = very low overlap, 20–40 % = low, 40–60 % = moderate, 60–80 % = high, and 80–100 % = very high overlap) (Korpilo et al., 2018). Finally, drawing on the methodology presented by Brown & Raymond (2014), we used the produced value and sound hotspots to create a compatibility map showing level of overlap between positive and negative raster values. To assess spatial compatibility, we developed hypothetical landscape value/sound hotspot scores assigning numeric positive and negative values with equal weight as follows: landscape values (+1), positive sounds (+1) and negative sounds (-1). Based on these hypothetical weighting scores, areas of high compatibility are identified as areas of overlap between landscape values hotspots and pleasant sounds hotspots (+2). Areas of medium compatibility refer to areas of overlap between landscape values hotspots, pleasant sounds hotspots and unpleasant sounds hotspots (+1). And low compatibility refers to areas of overlap between landscape values hotspots and negative sounds hotspots (0). The resulting map indicates geographic location and level of spatial compatibility based on these scores.

3. Results

3.1. Respondents' profile and mapping behaviour

In total, 507 residents provided complete responses to the survey in Kalasatama (n = 305) and in Kuninkaantammi (n = 202). The respondents had typically lived in the neighbourhood for less than three years. The majority (65 %) of respondents were between 30 and 64-years old (see Appendix B, Table 1) and most common types of households were couples (39 %) and families with at least one child (28 %). Majority of the respondents had a bachelor or higher education degree (71 %). Finnish speaking citizens dominated (82 %), and two out of three were employed (64 %). Compared to the overall socio-demographic profile of the population in both areas (Digital and Population Data Services Agency, 2020), the survey was slightly biased toward female respondents (Kuninkaantammi 55 %, Kalasatama 52 % in the study areas). Adults aged 30–44 most frequently answered the survey. The percentage of young adults (ages 18–29) in Kuninkaantammi

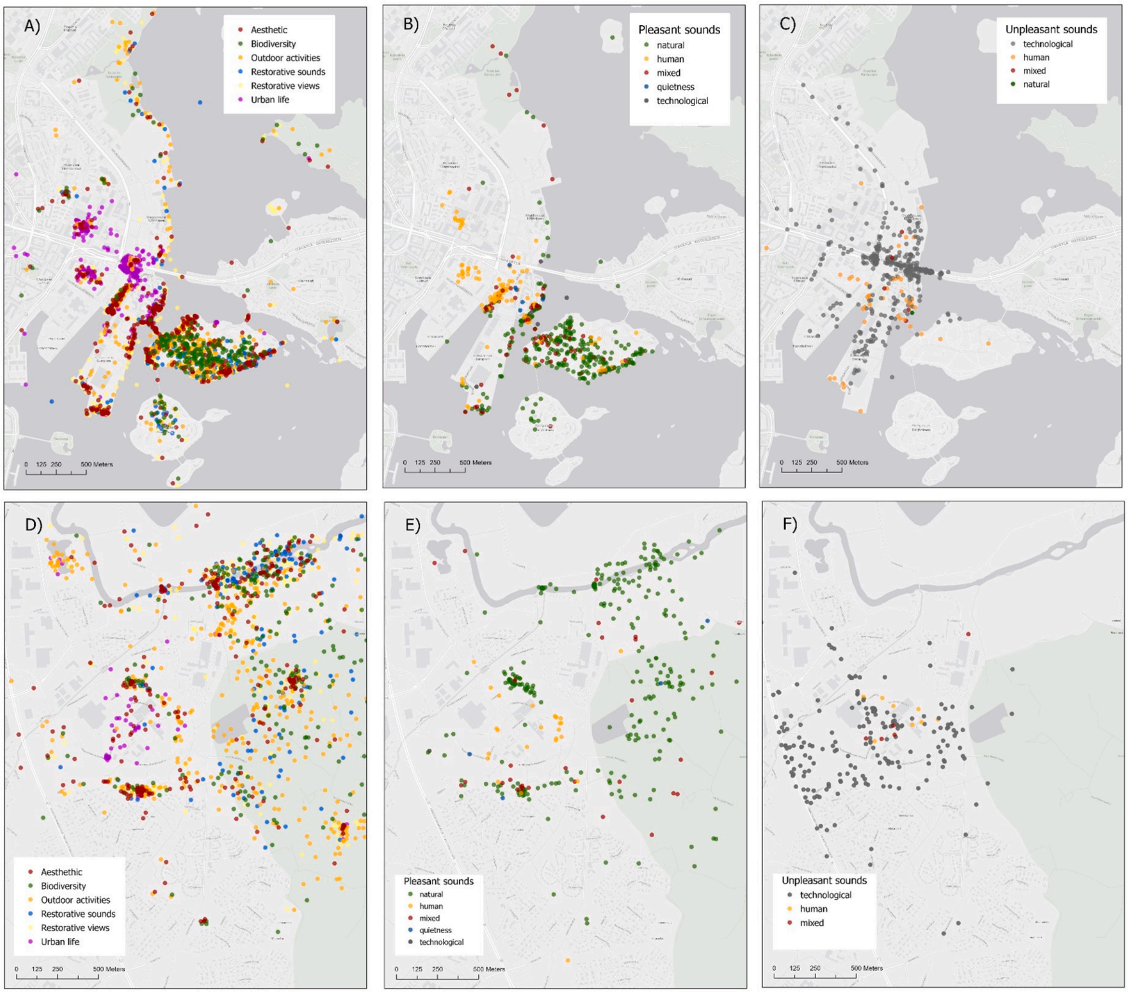

Fig. 3. Spatial distribution of all mapped points for A) landscape value categories; B) pleasant sound categories; C) unpleasant sound categories in Kalasatama; and D) landscape value categories; E) pleasant sound categories; F) unpleasant sound categories in Kuninkaantammi.

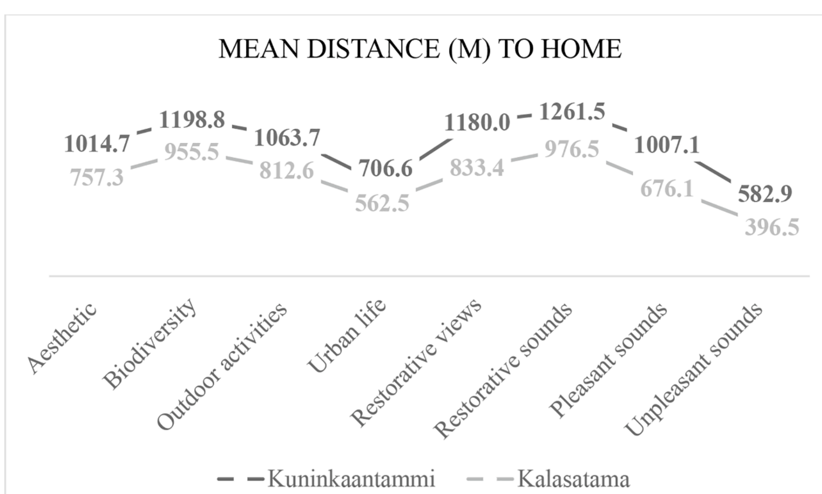

Fig. 4. Mean distance in meters of mapped landscape values and pleasant/unpleasant sounds to respondent's home.

was low as this age group contributes to 26 % of the adult population in the area but only 10 % of respondents in the survey. By contrast, the oldest age group was overrepresented (65+ contributing to 11 % in the area vs 21 % in the survey). In Kalasatama, the proportional distribution of the age groups was generally more representative of that in the area.

3.2. Spatial distribution of mapped landscape values and sounds

In total, 2373 and 1362 points (after data cleaning) were mapped in Kalasatama and Kuninkaantammi respectively. The spatial distributional patterns of value and sound points were more concentrated in

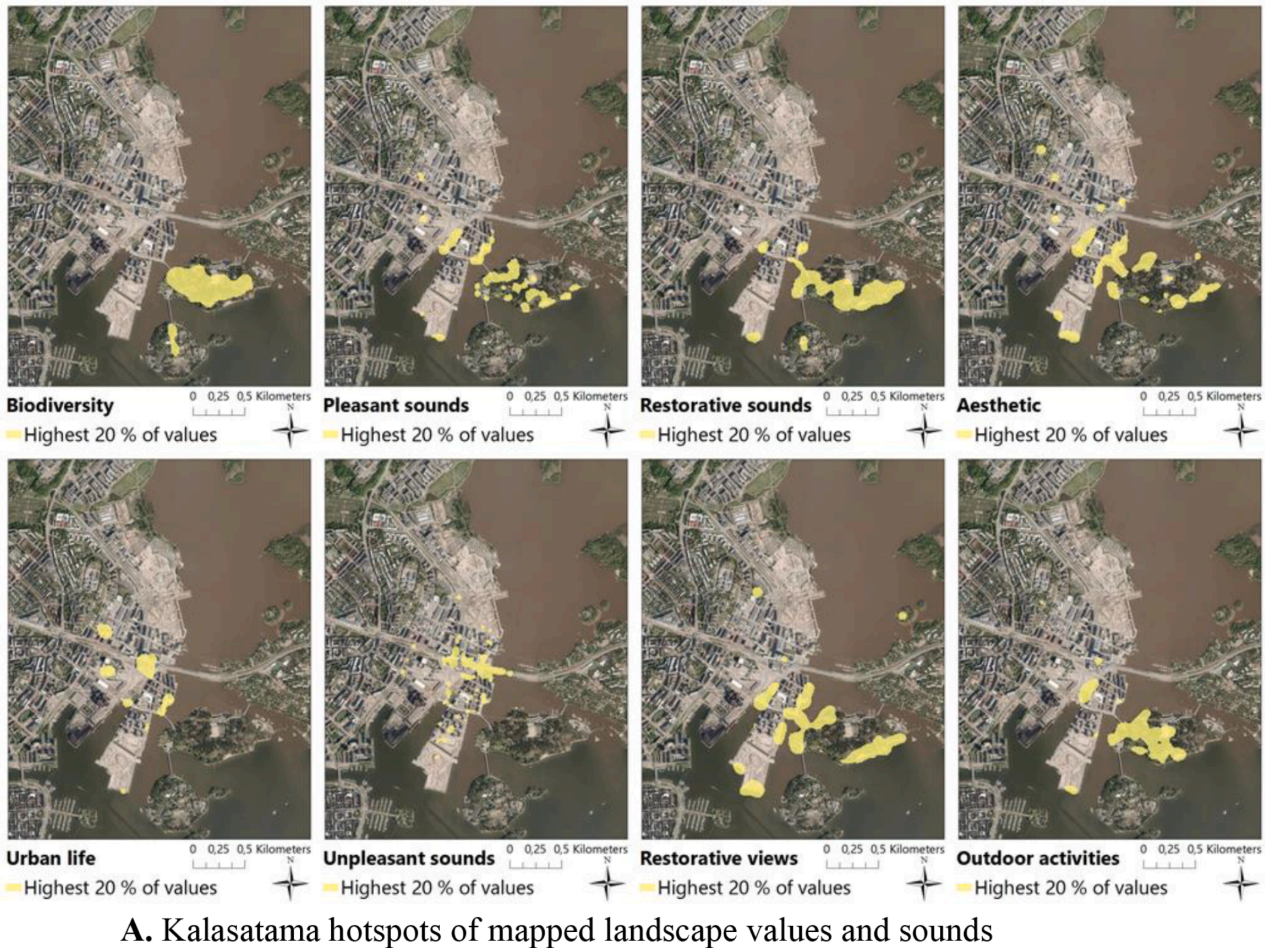

Fig. 5A. Kalasatama hotspots of mapped landscape values and sounds. Orthophotograph by City of Helsinki (2019b).

Kalasatama, but more spatially dispersed in Kuninkaantammi (Fig. 3). In the two study areas, respondents mapped a large number of places for aesthetics (21.5 % of all points in Kalasatama, 19.8 % in Kuninkaantammi) (Table 2). However, Kalasatama respondents assigned proportionally more values for restorative views (19.0 %) and urban life (18.4 %) compared to Kuninkaantammi respondents (15.3 % and 3.7 % respectively), who on the other hand, mapped a higher number of outdoor activities (32.0 %) and biodiversity (17.8 %) points. In both areas, fewer places were assigned for restorative sounds than restorative views. Diverse landscape values were mostly situated in forested areas like Mustikkamaa in Kalasatama and Central Park in Kuninkaantammi, and near water (e.g. the seaside in Kalasatama and Vantaajoki river in Kuninkaantammi). Out of all landscape values, only urban values showed distinct locations in urban centres, housing, and commercial areas (Fig. 3 A and D).

In terms of the soundscape, pleasant sounds were mapped mostly in parks, forests and nearby water (Fig. 3). Mainly *natural* sounds (e.g. bird songs, water, forest) were perceived and mapped as pleasant and constant (Table 3). Pleasant *human* sounds were identified as primarily temporary, while *mixed* sounds were perceived as constant, reflecting the complex and hybrid nature of the urban acoustic environment. Natural sounds contributed to only half (53.5 %) of all pleasant sounds in Kalasatama, while they counted for 81.2 % in Kuninkaantammi (Table 3). There was also a higher number of mapped *human* (e.g. human activity and speech, children) and *mixed* sounds (e.g. a mix of human and natural sounds) in Kalasatama (26.9 % and 16.9 % respectively) indicating more diversity in the pleasant soundscape. Unpleasant sounds on the other hand were mainly *technological* (e.g. traffic, construction, planes) (Table 3) and were concentrated along roads and urban centres (Fig. 3). Noise associated with *technological* sounds was perceived more often as constant by respondents in Kalasatama (76.9 %) compared to Kuninkaantammi (59.3 %). Some *human* sounds such as children playing or music were also considered and mapped as unpleasant (10.3 % in Kalasatama and 3.8 % in Kuninkaantammi).

3.2.1. *Distances of mapped landscape values and sounds to home locations*

In both study areas, there was a similar distributional pattern of mean distances (in metres) of mapped landscape values and sounds to respondents' homes (Fig. 4). Overall, Kalasatama residents mapped all landscape values and sounds closer to home (mean total distance = 719.2 m) compared to Kuninkaantammi residents (mean total distance = 1020 m). In the two study areas, places valued for biodiversity, restorative sounds and views were located furthest away from respondents' homes, while places valued for urban life and unpleasant sounds were mapped nearest to home (Fig. 4). The furthest mean distance was found for restorative sounds (Kuninkaantammi = 1261.5 m; Kalasatama = 976.5 m), while the shortest mean was observed for unpleasant sounds (Kuninkaantammi = 582.9 m; Kalasatama = 396.5 m).

Results from Welch's ANOVA revealed significant differences between mapped landscape values and the mean distances of sounds from homes both for Kalasatama ($F = 41.461$, $p < 0.001$) and

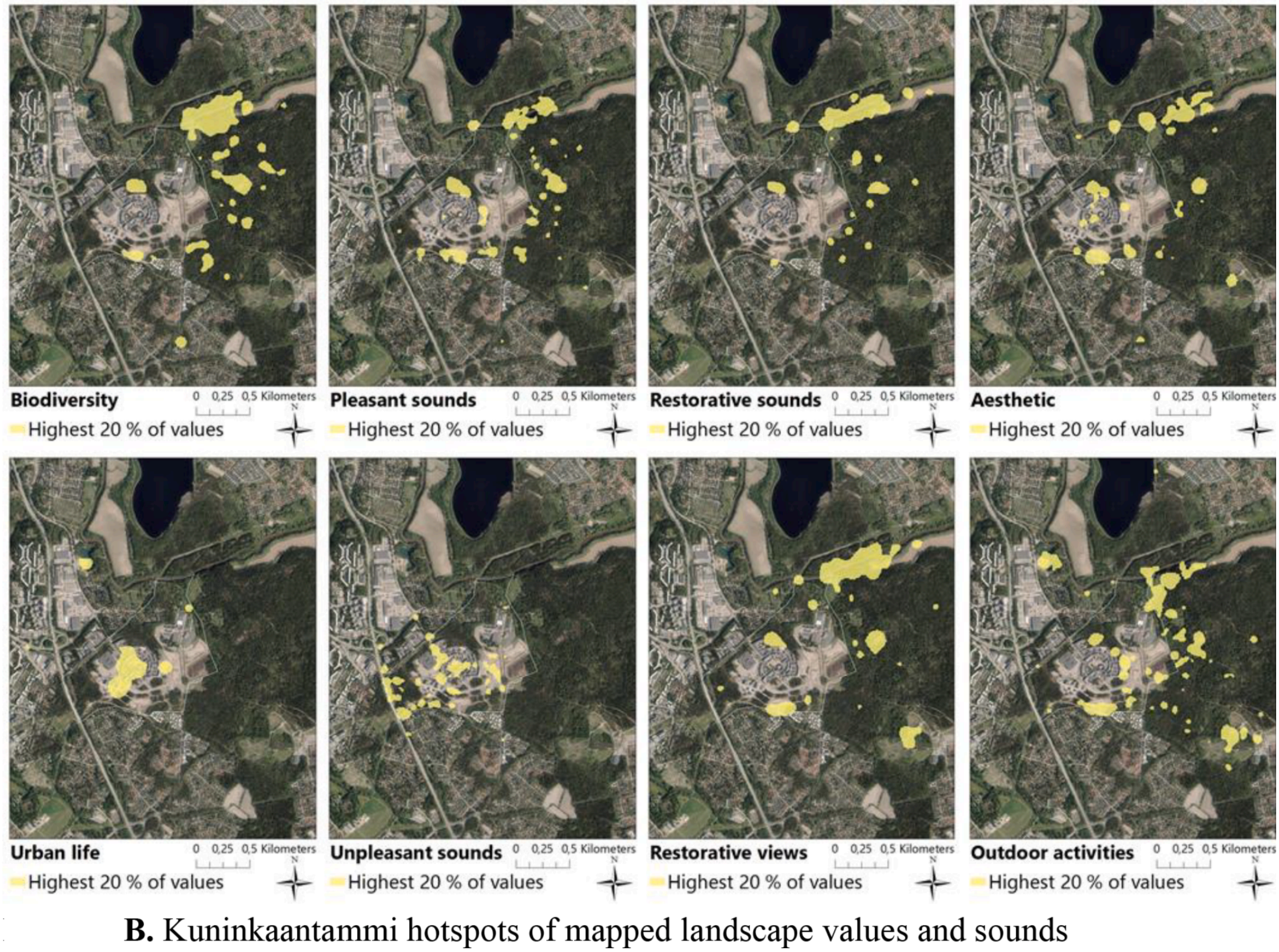

Fig. 5B. Kuninkaantammi hotspots of mapped landscape values and sounds. Orthophotograph by City of Helsinki (2019b).

Kuninkaantammi ($F = 15.321$, $p < 0.001$). However, pairwise comparisons (analysed using Games-Howell post-hoc tests) indicated that these statistical differences are more strongly evident in Kalasatama compared with Kuninkaantammi. In the latter area, results were mostly influenced by distance differences between urban life values and the pleasant and unpleasant sounds. In both study areas, unpleasant sounds was the only variable that showed statistically significant differences in distances compared with all other variables, except with urban life in Kuninkaantammi ($p = 0.968$).

3.3. Hotspots of landscape values and pleasant/unpleasant sounds

The hotspot analysis further identified areas of highest density (top 20 %) of mapped landscape values and pleasant/unpleasant sounds. Pleasant sounds and landscape values hotspots were often situated in recreational and green areas, whereas urban life and unpleasant sounds hotspots were more common in built areas (Figs. 5A and 5B). In both study areas, biodiversity hotspots were primarily situated in recreational and forested areas, however some differences could be observed. In Kalasatama, this included two large hotspots - the whole forested area and island of Mustikkamaa and parts of the Korkeasaari zoo island (Fig. 5A), whereas in Kuninkaantammi, there was a higher number of biodiversity hotspots with the largest one situated along the shores of Vantaanjoki River and several smaller hotpots in the forests of Helsinki Central Park (Fig. 5B). Biodiversity hotspots were often located in the same water or forest areas where hotspots for aesthetics, outdoor activities, restorative sounds and restorative views were also found. However, in Kalasatama, the aesthetic hotspots were mainly situated along the seashore and in some urban places such as Suvilahti or Teurastamo, which are former industrial and currently cultural centres.

Restorative views hotspots were situated in very similar places as the aesthetic value hotspots in both study sites. Water elements and shores were important for restoration (both in terms of views and sounds) and aesthetics, for example in Kuninkaantammi – Vantaanjoki River, Pitkäkoski rapids, Silvolankangas park bridge, and in Kalasatama – the seashore and beaches along Mustikkamaa. Other than water elements, elevated places with views, such as cliffs in the Helsinki Central Park, Fanny Churnberg’s cliffs, the Paloheinä outdoor centre hilltop or the green rooftop in Kalasatama REDI shopping centre were marked as important hotspots for restorative views. New recently constructed public parks such as the Helene Schjerfbeck park in Kuninkaantammi and Kalasatama Park were also identified as hotspots for restorative views. There were however some interesting differences between the spatial distribution of pleasant sounds and areas valued for restorative sounds. For example, public parks were hotspots for pleasant sounds (mostly of human and mixed source) but not for restorative sounds.

Urban life hotspots were clearly located in urban areas with restaurants, shops or places for organizing events. In Kalasatama, this included REDI shopping centre, Suvilahti and Teurastamo cultural centres, the south-eastern shores of Kalasatama (where many restaurants are situated) and the south of Kalasatama Park where a cafe and small events have been organized. In Kuninkaantammi, which offers less cultural facilities, the heart of the suburb/residential area, Pitkäkoski shelter and Kaivoksela beach were marked as important places for urban life. In

Table 4
Jaccard coefficient of spatial overlap between the different landscape values and sounds.

	Kalasatama		Kuninkaantammi	
	Pleasant sounds	**Unpleasant sounds**	**Pleasant sounds**	**Unpleasant sounds**
Aesthetic	0.396	0.087	0.334	0.062
Biodiversity	0.259	0.001	0.293	0.009
Outdoor activities	0.443	0.052	0.216	0.046
Restorative sounds	0.391	0.045	0.302	0.001
Restorative views	0.313	0.074	0.298	0.019
Urban life	0.141	0.173	0.031	0.209
All values	0.321	0.090	0.227	0.117
Pleasant vs Unpleasant sounds	0.054		0.045	

(dark orange)	Moderate level of hotspot overlap
(light orange)	Low level of hotspot overlap
(yellow)	Very low level of hotspot overlap

both study areas, unpleasant sound hotspots were situated in built areas, around major roads such as Hämeenlinnanväylä and Itäväylä, and possible construction sites in the middle of the study areas.

3.3.1. Spatial overlap of the landscape values/sounds hotspots

The results from the Jaccard coefficient calculations showed an overall very low to low level of overlap between the different landscape values and pleasant/unpleasant sound hotspots (Table 4), except for the moderate overlap between pleasant sounds and outdoor activities hotspots in Kalasatama (=0.443). Spatial coincidence was higher between all landscape values and pleasant sounds, and especially low for unpleasant sounds compared to all other categories in both areas. Among all value types, urban life hotspots showed relatively low levels of overlap with pleasant sounds, but this value type overlaid more strongly with unpleasant sounds in both study areas. In addition, overlap between hotspots of biodiversity values and pleasant and unpleasant sounds in both areas was rather low (Table 4).

The compatibility maps further illustrate the spatial relations between landscape values and the pleasant and unpleasant sounds (Fig. 6). In both study areas, the patterns were quite similar. The highest compatibility (i.e. areas of hotspot overlap between landscape values and pleasant sounds) was found primarily in natural areas such as remnant forests and along water infrastructure. On the other hand, the lowest compatibility (i.e. areas of overlap between landscape values and unpleasant sounds) was situated in built areas and newly built green infrastructure such as the northern part of Kalasatama Park and residential yards in Kuninkaantammi. A high density of landscape values, and overlap of pleasant and unpleasant sounds, were found in public parks and areas specifically developed and managed for recreation (e.g. Helene Schjerfbeck park in Kuninkaantammi and a seashore recreational open green space in Kalasatama).

4. Discussion

4.1. The added value of MSPPGIS

This study tested a Multi-sensory Public Participation GIS (MSPPGIS) methodology for integrating landscape values and soundscape perception. The method is multi-sensory because it invites participants to identify and map a diversity of landscape values resulting from feeling, using and experiencing specific places through various senses (e.g. “I value this place because I enjoy the scenery, sounds, smells etc. in there”, “I value this place because the views there help me to relax or forget about everyday worries”) together with positive and negative sound mapping – perception responses to auditory stimuli that are spatially assigned to places. In line with our hypothesis, the results indicated an overall low spatial overlap between the positive landscape values and pleasant and unpleasant sound hotspots (see Table 3). In both of our study areas, there was a similar distributional pattern and statistically significant differences between the mean distance of mapped landscape values and sounds to respondents’ homes. In general, pleasant and unpleasant sounds were located closer to home than landscape values (except for urban life values), supporting the research of Granö (1997) who found that proximate landscapes are perceived with all the senses, including sound, but physically remote landscapes mainly with visual or other cognitive cues.

The spatial differences between landscape values and soundscape perception can in part be explained by issues of scale. Previous PPGIS studies have found that communities with high senses of place tend to have more landscape values found closer to their location of domicile than further away (Brown et al., 2002). However, some landscape values, like biodiversity values or specialised forms of recreation, are often identified and mapped by participants at very large scales or at a large distance from one’s location of domicile (Brown et al., 2015; Raymond et al., 2016). Our results tend to confirm these trends. Biodiversity values were mapped furthest from respondents’ home and were

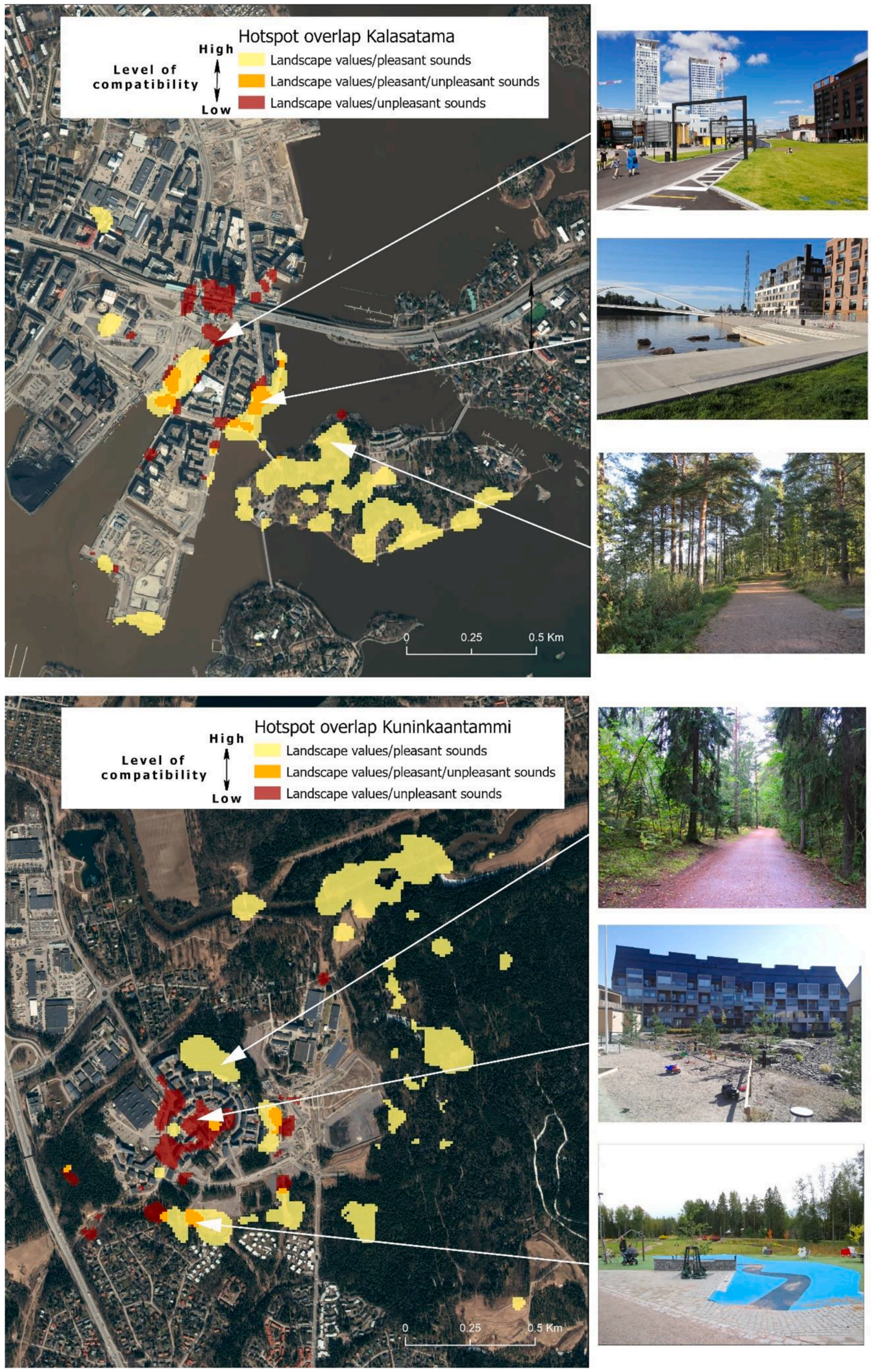

Fig. 6. Hotspot compatibility map of mapped landscape values and pleasant/unpleasant sounds for Kalasatama (top) and Kuninkaantammi (bottom) study areas based on the hotspot overlap of landscape values (+1), pleasant sounds (+1) and unpleasant sounds (-1). Orthophotograph by City of Helsinki (2019b).

primarily situated in remnant forested or water areas, where also hotspots of values for outdoor activities, restorative views and restorative sounds could be found. However, there was low spatial overlap between these biodiversity values and soundscapes, suggesting two separate cognitive systems of value attribution are at play in MSPPGIS. Raymond et al. (2017) offered a framework for describing these different cognitive systems relevant to senses of place. It is plausible that soundscapes are activating 'place as a perception–action process' where perception starts at the stimulus and where the physical aspects of place provide sufficient contextual information for the attribution of value. In contrast, PPGIS research is activating 'place as a locus of attachment' whereby contextual information in the form of attitudes or beliefs are used as a basis for creating meaningful mental perceptions (i.e., landscape values). Therefore, by combining landscape values and soundscape mapping in MSPPGIS, it is possible to elicit not only a more diverse mix of values for places, and at different spatial scales, but also to tap into different cognitive starting points on value. MSPPGIS is more likely to be more useful compared to PPGIS when seeking to assess multiple layers of people–place relationships *ex-situ* when a detailed understanding of values linked to *both* direct perception and place attachment are important for ecosystem management. Such a multi-sensory approach is critical to operationalising a plurality of 'senses of place' (Raymond et al., 2021), taking account of sensory, affective and cognitive components of people–place relationships (Raymond et al., 2017).

The MSPPGIS also makes important contributions to soundscapes research. Our results challenge 'positive aesthetics' theory (Carlson, 1992) which proposes that acoustic pleasure is related to absence of noise or enhancement of non-human nature sounds (Brady, 2011; Prior, 2017). Rather, we identified multiple non-natural sounds that also contributed to acoustic pleasure, including mapped human sounds of human activity, speech and children, which were all identified primarily as temporary and mixed sounds (e.g. a mix of human and natural sounds). In addition, the KDE analysis and the results from the Jaccard coefficient calculations indicated that soundscape pleasure may not necessarily align with biodiversity values and restoration, potentially because pleasurable soundscapes in cities are affected not merely by ecological elements, but also by morphological indicators such as buildings, roads, open public spaces, and water features (Hong & Jeon, 2017). For example, Sun et al. (2019) found that the level of visual vegetation is not a significant factor for explaining calming soundscapes (i.e. soundscapes perceived as "calm and tranquil").

In addition, new public parks in both of our study sites were hotspots for pleasant sounds (mostly of human and mixed source) but not for restorative sounds, thus resembling what Sun et al. (2019) refer to as "stimulating soundscapes"- those that support the liveliness and activeness of the environment. This is consistent with findings from previous studies showing that human sounds have a key influence in cognition and perception related to eventfulness, vibrancy, loudness and crowd tolerance in urban parks and other recreational spaces (Aletta & Kang, 2018; Axelsson, 2015; Hong & Jeon, 2017; Jo & Jeon, 2020). However, the presence of human sounds may not be the only factor contributing to "stimulating" or "eventful" soundscapes. In our study, there were two types of landscape values that may relate conceptually to eventfulness in the sonic environment: urban life values and outdoor activities values. The Jaccard coefficient calculations indicated moderate spatial overlap between hotspots of pleasant sounds and outdoor activities values, supporting the important role that activity has in sound perception (Nielbo et al., 2013;Andringa & Van Den Bosch, 2013). In addition to hotspots of pleasant sounds, urban parks in the two study sites were also hotspots for outdoor activities (Andringa & Van Den Bosch, 2013). Creating and managing urban green spaces for multifunctionality therefore enhances perceived soundscape quality. On the other hand, urban life values showed very little hotspot overlap with pleasant or even unpleasant sounds. This may be due to the rather broad definition used in this study ("I value this place because I can enjoy city life and variety of services there") that is not necessarily related to activities or action potential.

4.2. Implications for UGI planning

Overall, the MSPPGIS findings demonstrate the importance of remnant green and blue spaces as critical UGI for both healthy ecological functioning and human well-being in the Nordic context. In the two study areas, water elements and the river/seashore were identified by respondents as important hotspots for landscape values, particularly restoration, aesthetics and pleasant sounds. Clustering of aesthetic values and pleasant natural sounds along the seashore was even more pronounced in Kalasatama (Fig. 3), which correlates with previous studies that have demonstrated that the sound of water has a more positive and restorative effect than other natural sounds including bird songs (Benfield et al., 2010; Jeon et al., 2010). This is important information for local planning and management as it highlights the benefit of further development of seashore recreational routes in Kalasatama to elevate pressures from remnant forest ecosystems such as Mustikkamaa, which is expected to experience even higher demand for nature recreation due to the continuous construction and population growth.

The resulting compatibility maps (Fig. 6) can help guide spatial planning by prioritising conservation activities in UGI containing different types and intensities of landscape values and sounds. For example, UGI conservation efforts can be directed to areas containing high densities of landscape values and pleasurable sounds, whereas sound management activities need to occur in UGI containing high landscape value yet high density of unpleasant sounds. Landscape architects may target such areas by decreasing noise through masking (e.g. Coensel et al., 2011; Kang et al., 2016) or using natural barriers such as flower beds, tree lines and wetlands which can also have air purification co-benefits (Xing & Brimblecombe, 2020). UGI planning can also make use of urban forms, biotope design, natural and built elements, and human movement flows to introduce or enhance positive sounds. While the MSPPGIS method was tested and validated in an urban context, it is likely to be equally of use in regional and rural contexts.

4.3. Limitations and future directions

One important limitation of the approach in this study is that the mapping could indicate the spatial distribution, density and overlap of landscape values and sounds, but not necessarily the meanings (both soundscape meanings and other place meanings) as to why these were identified by respondents. 'Place as a centre of meaning' is the third pillar of senses of place scholarship (Raymond et al, 2017, 2021). Future studies could explore how soundscapes and other place meanings individually form, are collectively shared or are disseminated within and across places in order to provide a deeper and more qualitative perspective on multi-sensory landscape perception and new theories on how people share their perceptions to soundscapes. Although out of scope in this study, it is also crucial to further investigate the effect of socio-demographics on the mapping since literature has continuously demonstrated the significant role of e.g. age, gender, household type and income on green space use, values and preference (e.g. Hasanzadeh et al., 2019; Liu et al., 2017).

Further, this study did not investigate the temporal variability in landscape values and soundscapes, nor their relationship with land use patterns. Various PPGIS studies have indicated that landscape values are strongly associated with specific land use types (e.g. Brown et al., 2018; Zaman et al., 2022). Recent research on soundscapes has shown that sounds are also associated with land use patterns. They can be related to the spatial distribution of manmade features (such as density or distance to major roads) and green space coverage (Margaritis et al., 2020). Even though research has considered the temporal variability of soundscapes (Hong & Jeon, 2017), such as response to shock events like hurricanes (Gottesman et al., 2021), the spatial and temporal variability in landscape values, soundscapes and land-use patterns have not been studied together. Future MSPPGIS research could study the spatial and temporal interplay between soundscapes, landscape values and the urban fabric to guide a more holistic and integrated assessment of value formation and change over time and with respect to shock events.

5. Conclusions

This paper aimed to test and validate a multi-sensory PPGIS (MSPPGIS) methodology that integrates landscape values (assigned values to places) and soundscapes (i.e. human perception and experience of sounds in a place) of UGI. In both case areas, MSPPGIS provided a complementary way of understanding socio-cultural values for UGI compared to traditional landscape value elicitation using PPGIS mapping. The method enabled a systematic spatial comparison of landscape values and pleasant/unpleasant sounds with respect to location of domicile (objective 1). Soundscapes were more pronounced closer to one's location of domicile, whereas positive landscape values were more densely distributed further from domicile. Combining landscape value and soundscape elements better reflects residents' diverse ways for appreciating, listening and experiencing nature in 'near' and 'far' places.

It was possible to identify hotpots and areas of overlap of different landscape values and sounds (objective 2), even in case areas with contrasting tree cover densities, but there were also areas of low spatial overlap suggesting that soundscape elicitation is complementary to landscape value elicitation using markers. We urge researchers and planners to develop and implement multi-sensory approaches (including different sense modalities) in PPGIS research for urban green/blue space planning, and to test these methods in other landscape contexts.

Declaration of Competing Interest

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

Data availability

The authors do not have permission to share data.

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Supporting Material

Appendix A, Table 1
List of criteria used in the Analytical Evaluation workshop.

Analytical Evaluation of the PPGIS survey (experts)	
Criteria	Description
Ecological validity	Survey elements (text descriptions or audio-visuals) are representative of real-life environments
Social validity	The survey accommodates a diversity of users and responds to context-specific demographics and social rules, norm and practices
Technological validity	The survey is user-friendly (i.e. understandable, easy to use)
Content validity	The survey elements are relevant i.e. reflect the topic of interest
Construct validity	The survey elements measure the intended construct (e.g. restoration questions measuring restoration)
Criteria validity	The survey elements are selected through clear scientific criteria
Internal validity	Inherent biases in the questions or mapping elements are minimized (e.g., leading or double barrel questions)
External Validity	The method could be scaled up to other contexts, groups or geographic areas
Ethical validity	The survey is conducted in accordance with high ethical standards (i.e. according to GDPR regulation)

Appendix A, Table 2
List of criteria used in the Applicability Evaluation workshop.

Applicability Evaluation of the PPGIS survey (planners)	
Criteria	Description
Timing	The timing of the survey supports ongoing planning processes
Inclusiveness	The survey aims to reach a representative sample of the population in the study area
Privacy and data protection	The survey is conducted in accordance with high ethical and data protection standards (i.e. according to GDPR regulation)
Relevance	The survey elements are relevant i.e. reflect a topic of planning and research interest
Integrating knowledge	The collected survey data is complementary and can be integrated into other types of available planning data (e.g. other available GIS datasets)
External validity	The method could be scaled up to other contexts, groups or geographic areas.
Transparency	Information is shared and communicated clearly about the objectives of the survey and how it is related or is not related to current planning processes.

Appendix A, Table 3
List of criteria used in the Usability Evaluation process.

Usability Evaluation of the PPGIS survey (users)	
Criteria	Description
Benefits	It is clear to me what the benefits of the survey are (e.g. collecting local knowledge, "somebody listens to my opinion", information can impact planning and decision-making in the future)
Mapping instructions	There is clear guidance on how to navigate, zoom in/out of the map, and place point markers
Orientation	I can easily orientate on the map
Simplicity and clarity	The survey elements (including text, visual and audio) are easy to understand and I can complete the required steps with minimal action
Adaptability	The survey can be tailored to match my personal preferences (e.g. changing the map view, zooming in and out, language options)
Descriptiveness	The survey and the different tasks/questions are clearly explained
Length	The survey is of a suitable length
Engagement	The survey is interactive and includes pleasant elements
Access to information	There is clear information on how I can access the results of the survey and who to contact
Privacy & Security	The survey provides clear information on how my personal information is used and protected

Appendix B, Table 1
Socio-demographic characteristics of respondents in the survey.

Socio-demographic variables	All (N = 508)	Kalasatama (n = 305)	Kuninkaantammi (n = 202)
Female	58 %	57 %	59 %
Male	39 %	40 %	38 %
18–29-y	17 %	22 %	10 %
30–44-y	37 %	37 %	38 %
45–64-y	28 %	27 %	30 %
65+ y	17 %	13 %	21 %
Finnish	82 %	82 %	82 %
Swedish	5 %	5 %	3 %
English	2 %	2 %	2 %
Russian	2 %	1 %	4 %
German	0.4 %	1 %	0 %
Estonia	0.4 %	1 %	0 %
Somali	0.4 %	1 %	0 %
Other	1 %	2 %	0 %
Single household	23 %	25 %	22 %
Single parent family	2 %	2 %	3 %
Couple	39 %	40 %	37 %
Family with children	28 %	26 %	30 %
Working	64 %	64 %	63 %
Unemployed	3 %	4 %	2 %
Student	12 %	14 %	8 %
Stay at home parent	3 %	3 %	4 %
Retired	14 %	11 %	19 %
No formal schooling completed	2 %	2 %	1 %
Upper secondary education	7 %	8 %	6 %
Trade/Technical/Vocational school	11 %	8 %	15 %
Bachelor's degree	25 %	25 %	25 %
Master's degree	43 %	45 %	40 %
Doctoral degree	3 %	4 %	2 %
0–19,000 €	13 %	15 %	10 %
20–29,000 €	10 %	10 %	10 %
30–39,000 €	16 %	13 %	20 %
40–59,000 €	28 %	27 %	28 %
> 60,000 €	19 %	20 %	17 %

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