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Exploring the relationships between soundscape quality and public health using a systems thinking approach

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Urban soundscapes significantly influence public health, with sound quality affecting well-being and social value. While traditional noise control has emphasized harm reduction, soundscape studies propose that managing sound environments can promote health benefits. This study explores the complex relationships between soundscape quality and public health using a systems thinking approach. In a participatory workshop with 21 experts from fields such as urban planning, environmental psychology, and acoustics, a causal loop diagram (CLD) was developed to illustrate the interactions between soundscape quality and public health variables. The CLD revealed key feedback loops and intervention points, organized around themes of socio-economic impact, environmental justice, biodiversity, and soundscape design. Findings highlight that while soundscape quality can enhance community well-being, increased economic value may drive gentrification, altering the social structure and reducing sound source diversity. Additionally, the role of soundscape quality in biodiversity suggests both co-benefits and ecological risks. This study demonstrates the potential of systems thinking to guide interdisciplinary approaches in soundscape management, identifying strategic pathways to inform future research and policy development for equitable and health-promoting urban environments.

Sound environments significantly impact people's health and well-being, especially in urbanized contexts; a fact well-documented in epidemiological studies and supported by data from international agencies and stakeholders[1,2]. Regarding sound, the traditional focus of research and practice has been primarily on noise pollution and its adverse effects on individuals and communities. Previous studies have demonstrated that noise pollution contributes to various health issues, including cardiovascular diseases, sleep disturbance, and mental health problems[3]. These impacts of noise pollution are disproportionately higher among lower socioeconomic status (SES) groups, raising critical concerns about environmental justice[4]. This disparity highlights a broader issue where marginalized communities bear a greater burden of environmental noise, necessitating a more equitable approach to urban planning and public health policies[5].

In contrast, the emerging field of soundscape studies considers environmental sounds as a "resource" (rather than a "by-product") having the potential to elicit positive health effects[6,7]. Soundscapes can enhance urban

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living by promoting healthier and more sustainable environments[8]. For instance, pleasant soundscapes can reduce stress, improve cognitive performance, and foster social interactions[9–11]. Such pleasant soundscapes may be achieved by carefully designing green areas for people to access restorative spaces, which can in turn enhance local biodiversity and support sustainable neighborhoods[12–14].

Although scientific research has extensively documented the importance of soundscapes perception for individuals and communities, these insights have not yet been widely translated into effective policies. The adoption of proactive measures to improve soundscape quality within regulatory frameworks remains limited[15,16]. The social and policymaking dynamics surrounding urban sound environments are complex, involving various stakeholders with differing interests and perspectives[17,18]. Previous attempts to understand and address these dynamics have had limited success, often because approaches are fragmented. For example, urban planning and public health initiatives frequently operate independently, with little integration of soundscape considerations, leading to solutions that overlook the interconnected impacts. To achieve meaningful progress, it is crucial to adopt a holistic perspective that encompasses the multiple interactions and interdependencies between soundscape quality and public health. In this study, we aim to disentangle the complex relationships between soundscape quality and public heath by applying a systems thinking approach—a framework not previously used in soundscape studies, to the best of the authors' knowledge[19].

Systems thinking explores interconnections between elements related to a targeted problem[20], focusing on understanding the full range of system structures and mechanisms that influence each other and contribute to the overall behavior of the system[21]. This approach uses either qualitative maps, such as causal loop diagrams (CLD) that graphically depict complexity[21,22], or formal quantitative modeling, such as system dynamics, to understand these interconnections under different scenarios[23,24].

Under a qualitative approach, systems thinking emphasizes the importance of incorporating the knowledge of various stakeholders, including communities[25], policymakers, and experts[26], to elicit knowledge about the system related to the target problem. A participatory approach in systems thinking, or sometimes referred to as group model building workshops, involves engaging relevant stakeholders to elicit perspectives about the system under investigation[27], often with the use of scripted activities guided by facilitators, to generate model mechanisms[28,29]. Engaging stakeholders in generating systems thinking processes can help elicit various perspectives, thereby improving the system[30].

Participatory system thinking modeling methods have been widely used to integrate health into multiple environmental topics, such as urban planning[31], housing regeneration[32], and water management[33]. A participatory approach is particularly useful for eliciting collective ideas around research gaps and pathways. It facilitates communication across disciplines and fosters potential collaborations for research initiatives. The work discussed in this paper utilized a participatory systems thinking approach to identify research gaps and future pathways emerging from a participatory modeling workshop with topic experts, for linking soundscape quality and public health.

The key notions considered in this study are public health and soundscape quality, and an exploration of how these can be improved. While the concept of "improving public health" may deserve a debate of its own that cannot be easily resolved, defining what "improving soundscape quality" means may prove at least equally challenging. The concept of soundscape itself has been variously defined (e.g., refs. 34,35); for the sake of this study, we tend to interpret it in its broadest possible scope, where soundscape is "*the auditory environment of a place, setting, or community, whose character is the result of the interaction with nonauditory and/or contextual factors.*"[36]. Elaborating further on "improving soundscape quality" is then also difficult, as it poses the question of: "improved for whom/what?". In a study on the soundscape quality of French cities, Guastavino found that the "ideal urban soundscape" should be "*warm-hearted, lively and peaceful, therefore noisy but enjoyable*"[37], but the author also noted that such result was derived from a relatively young cohort of urban residents, and it was not likely to hold for different groups. The focus of this study is on human perception in urban environments but acknowledging the ramifications that urbanity can have for natural ecosystems, and with the understanding that a design intervention to improve the soundscape quality of a place will aim to be as inclusive as possible and intend to benefit the largest possible portion of the public, as opposed to very specific groups or population strata.

Methods

This study employed a qualitative research design, using the systems thinking methodology to develop a CLD that maps the interactions and feedback loops between soundscape quality and public health. The study was approved by the departmental Bartlett School of Energy, Environment and Resources (BSEER) Local Research Ethics Committee at UCL, (low-risk research route, approval no. 20240117_IEDE_STA_ETH, Jan 18th, 2024). All participants were informed about the context of the study and provided informed consent, in accordance with the Declaration of Helsinki.

Due to the exploratory and interdisciplinary nature of the study, the participants' recruitment followed a non-probability strategy: a purposive sampling method was used to select 21 participants who have extensive knowledge and experience related to urban soundscapes, planning and design, environmental psychology, and social sciences. The experts were chosen based on their academic qualifications, professional experience, and previous contributions to the field. The group included mostly researchers, with a diverse range of interdisciplinary perspectives and knowledge – i.e., maximum variation purposive sampling[38].

Workshop procedure

During the participatory modeling workshop, we focused on two key aspects of the systems thinking approach: first, the feedback mechanisms, which is how initial changes in the system can cause further changes after circulating through the system. Feedback mechanisms are fundamental in CLDs as they show how changes within a system can lead to further and often nonlinear changes across different sectoral boundaries[39]. The second aspect we focused on was identifying where to act with "intervention/leverage points", within a complex system, with workshop participants[21]. As we explored the elements that contribute to these research gaps and how they are connected, we could formulate future research pathways to address these gaps holistically.

The data collection process involved two main phases: a pre-workshop to build a small CLD, and the full online workshop. For the pre-workshop session, a sub-group of the workshop experts (represented by UCL IEDE Acoustics & Soundscape theme PhD students and staff) and two CLD experts worked on a preliminary list of variables and developed an initial CLD: this was designed to be relatively small, including eight variables and their relevant links, to capture research gaps in soundscape quality and public health. It was also intended to be used for revision and discussion with the broader external group during the workshop session online. The full online workshop was conducted over a 90-minute session in February 2024, using a virtual meeting platform (Microsoft Teams). Two CLD experts and one professional facilitator conducted the session with the 21 invited participants. The workshop consisted of several structured sessions designed to facilitate the collaborative development of the CLD. It began with an overview of the study objectives, the principles of systems thinking, and the process of creating the initial CLD. Participants subsequently engaged in a facilitated session to revise and discuss additional variables and links influencing soundscape quality and public health and to map the relationships between variables.

Participants were also tasked with identifying causal links and determining the polarity (positive or negative) of each relationship. During the workshop, participants were introduced to the key concepts in CLDs. In CLDs, there are two types of links: positive (+) and negative (−). Positive links indicate that the variables move in the same direction: an increase or decrease in a cause variable will result in a corresponding increase or decrease in the effect variable. Negative links indicate that the variables move in

opposite directions: an increase or decrease in a cause variable will result in a decrease or increase, respectively, in the effect variable. When a variable travels through a loop and returns to itself, it forms a reinforcing loop if the initial change is reinforced, or a balancing loop if the initial change is reversed. The link polarities and loops describe the relationship between variables rather than the actual behavior of the variables. For example, an increase in the birth rate can be linked to population with a "+" sign, indicating that it will increase the population more than it would have otherwise. However, this does not necessarily indicate an actual increase in population, as the actual population changes also depend on the death rate and other variables simultaneously. The links and loops illustrate the complex structures qualitatively, not the strengths or magnitudes of their impact.

The CLD was eventually reviewed and refined through group discussion. Participants were encouraged to critically evaluate the diagram and suggest modifications to improve its accuracy and comprehensiveness. After modifying the model, participants were asked to identify 'research pathways' using the modified CLD. 'Research pathways' in this context refer to one or more points of research areas that can trigger a sequence of impacts throughout the system, depicted by the CLD. Participants were asked to name pathways in circles and then link them to different areas of the CLD. The aim was for participants to discuss areas for future research and understand how the research directions are cross-linked with the CLD.

The final CLD was analyzed offline by the same sub-group of the workshop participants and the CLD experts that conducted the pre-workshop session, to identify major feedback loops and their potential implications for soundscape quality and public health. The data generated from the workshop, including the recorded discussions and the shared virtual whiteboard content, were inspected to identify and extract key themes – i.e., specific stand-alone areas within the main CLD, associated with one or more feedback loops. The variables that emerged either from the pre-workshop session or through discussion among the full online workshop experts were then confirmed/consolidated and associated to relevant themes.

Positionality

All the co-authors involved in this study and workshop were either soundscape-related or CLD experts. They come from diverse academic backgrounds, including acoustics, environmental design and engineering, psychology, sociology, architecture, sound studies, and urban planning. The interdisciplinary expertise of this group has informed its understanding of the multifaceted issues related to urban soundscapes and public health. However, it is important to acknowledge its positionality and the potential influences this may have on the research[40]. Most of the co-authors are affiliated with academic institutions in Europe, North America, and Asia, which may bias the discourse around urban soundscapes towards the contexts and challenges prevalent in these regions. Additionally, the focus on soundscape quality as both a public health issue and an environmental justice concern reflects the authors' commitment to addressing these critical global issues, but it may also introduce a normative stance that prioritizes certain values and outcomes. There is also a risk of disciplinary under-representation in this particular panel (e.g., epidemiologists, policymakers, economists, and professionals of the built environment more broadly). While the participants do not holistically represent the system, the experts' knowledge highlighted the role of interdisciplinary and systems thinking in considering soundscape quality and public health.

Results

The discussions elicited four themes including three reinforcing loops and three balancing loops. In the following Figs. 1–4, we highlight the links for each theme. Table 1 outlines the key themes and variables identified in the study of soundscape quality and public health interactions. Each variable is associated with specific feedback loops in the causal loop diagram (CLD), indicating its role in the system's dynamics. The table also provides a concise definition or a possible scope for each variable.

For the theme of noise pollution and soundscape quality, centered and highlighted in Fig. 1, soundscape design and sound source diversity are both

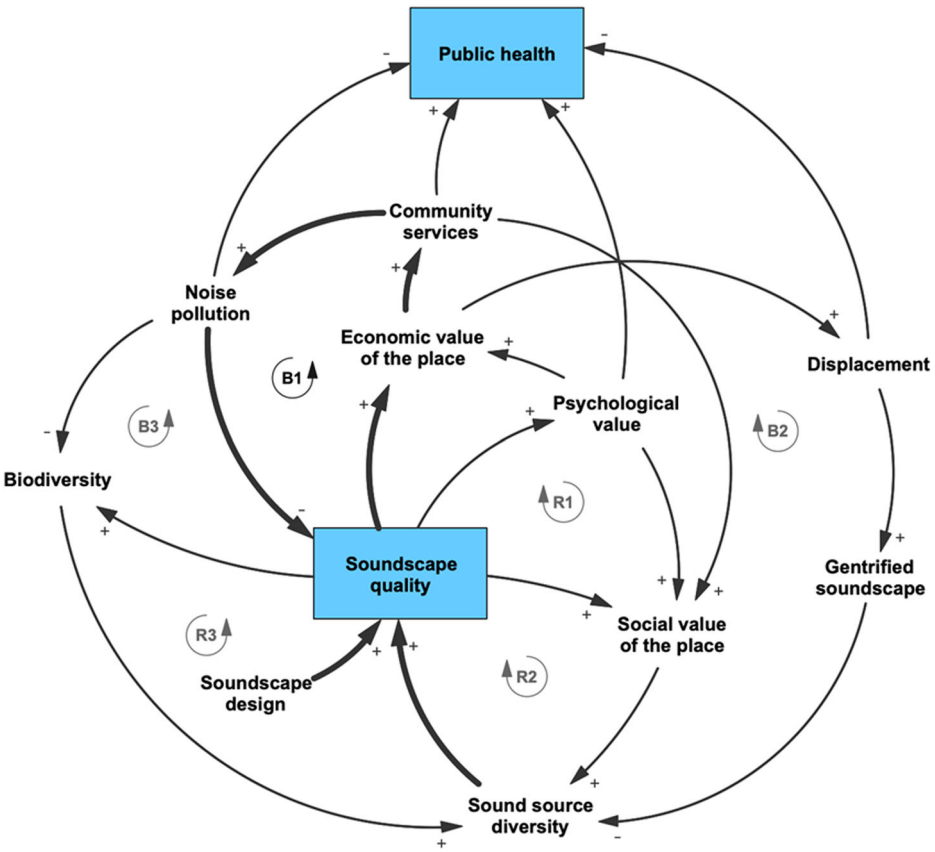

Fig. 1 | Causal loop diagram resulting from a workshop with experts. Highlighted: Noise pollution and soundscape quality. The variables in blue boxes at the centre of the diagram represent the two key variables that we are interested in. The thickness of the lines represents the highlighted mechanisms for illustrative purposes and does not indicate the strength of the connections.

Table 1 | Key themes, variables, and their roles in the interactions between soundscape quality and public health, with affected feedback loops, definitions, and supporting references

Theme	Variable	Affected loops	Scope	Reference
Noise pollution and soundscape quality	Soundscape design	R3	Attitude and practice to implement soundscape interventions, which are a "site-specific design, aimed at preserving or improving an acoustic environment".	70
	Sound source diversity	B2, R2, R3	Degree a variety within a soundscape, where different sound sources can be experienced in a sound environment that is enjoyably non-uniform but still structured.	37
	Noise pollution	B1, B3	Unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, industrial activities, and recreational activities.	1
	Community services	B1	Initiatives, infrastructure and facilities designed to address social, health, and economic needs, enhance quality of life, and support community well-being through coordinated planning and equitable access.	71
Socio-economic dimension of soundscape	Economic value of the place	B1, B2, B3, R1	Potential of a place to generate income and/or support economic activities and the overall development of an area.	68
	Psychological value of the place	R1	Emotional and mental benefits that individuals derive from their interactions with that location, including feelings of attachment, identity, well-being, and comfort that a place provides.	72
	Social value of the place	R1, R2	Significance that a location holds for a community due to its role in fostering social interactions, cultural identity, collective memory, and overall well-being: this value is often derived from the place's ability to facilitate social cohesion, provide spaces for community activities, and support cultural and heritage preservation.	73
Soundscape and environmental justice	Displacement	B2	Process where residents are forced or feel compelled to relocate from their original neighborhood due to structural changes, such as housing redevelopment or urban renewal programs.	74
	Gentrified soundscape	B2	A soundscape characterized by the prominence (or imposed absence) of specific sound sources, following the desire of a smaller wealthier community.	65
Biodiversity and soundscape quality	Biodiversity	B3, R3	Variety of life forms on Earth, encompassing the diversity within species, between species, and of ecosystems.	75

positively linked with soundscape quality. Noise pollution is negatively linked with public health. Balancing loop B1 connects these variables: soundscape quality, economic value of the place, community services, and noise pollution. Specifically, an increase in soundscape quality raises the economic value of the place, which in turn increases community services and noise pollution, subsequently decreasing soundscape quality, forming the loop B1.

The theme relevant to the socioeconomic dimension of soundscape is highlighted in Fig. 2. Three categories of "value" are presented as variables: economic value of the place; social value of the place; and psychological value of the place. The latter is positively connected with multiple variables: public health, economic value of the place, and social value of the place. Both reinforcing loops R1 and R2 are connected to soundscape quality. As soundscape quality increases, psychological value increases, which enhances the social value of the place, provides more sound source diversity (e.g., more inclusive space with coexistence of a broader range of users and "acceptable" sound sources), and further improves soundscape quality, forming reinforcing loop R1. Additionally, community services and psychological value both increase the social value of the place, which can increase sound source diversity, soundscape quality, and reinforce the social value of the place, forming reinforcing loop R2. These two loops illustrate the interconnected nature of different values within the place that relate to soundscape quality. Community services enhance the social value of a place by fostering opportunities for social interaction, cultural activities, and community engagement, which in turn strengthens the collective identity and cohesion of the community. Psychological value contributes to social value by promoting emotional attachment, comfort, and a sense of belonging among residents. These elements encourage the use and appreciation of shared spaces, which can amplify social interactions and supports inclusive sound environments. Together, community services and psychological value create a synergistic effect that enriches the social fabric, enhancing sound source diversity and improving overall soundscape quality.

In the theme of soundscape and environmental justice, described in Fig. 3, it is highlighted that the economic value of the place can increase displacement, potentially leading to a gentrified soundscape, decreasing sound source diversity, and reducing soundscape quality and economic value of the place. This forms balancing loop B2, showing the risks of gentrification in soundscape and public health. The increased economic value of a place can change its social structure and increase displacement of those who can no longer afford to live there. This can lead to a gentrified soundscape where there is a commodification of silence, leading to uneventful soundscapes, where diverse sound sources are not welcome.

For the theme of biodiversity and soundscape quality (Fig. 4), balancing loop B3 shows that, with an increase in noise pollution, biodiversity is reduced, which reduces sound source diversity, lowering soundscape quality, and thereby decreasing the economic value of the place and community services. This ultimately reduces noise pollution. This loop highlights the risks of noise pollution depleting soundscape quality and community economic value. Furthermore, an increase in soundscape quality enhances biodiversity, which increases sound source diversity and further improves soundscape quality, forming reinforcing loop R3, showcasing the co-benefits of soundscape quality for biodiversity.

The different forms of value (social, psychological, and economic) appear central to the diagram and are the most connected variables. For example, economic value and community services are connected with soundscape quality (B1 via noise pollution, B2 via gentrification, and B3 via biodiversity and sound source diversity). Soundscape quality is also directly connected with psychological value (R1) and social value of the place (R2). The complex interconnections show the potential unintended consequences of gentrification when focusing solely on economic value (B2) (e.g., ref. 41).

The green circles in Fig. 5 represent various research pathways linked to the CLD. Epidemiology is linked to public health and noise pollution. Soundscape action plans are connected to noise pollution and soundscape design, focusing on strategies to mitigate noise pollution and enhance soundscape quality. Ecoacoustics is tied to biodiversity, and so are urban studies and practice[42]. The pathway concerning individual versus community needs in soundscape is associated with the social, economic, and

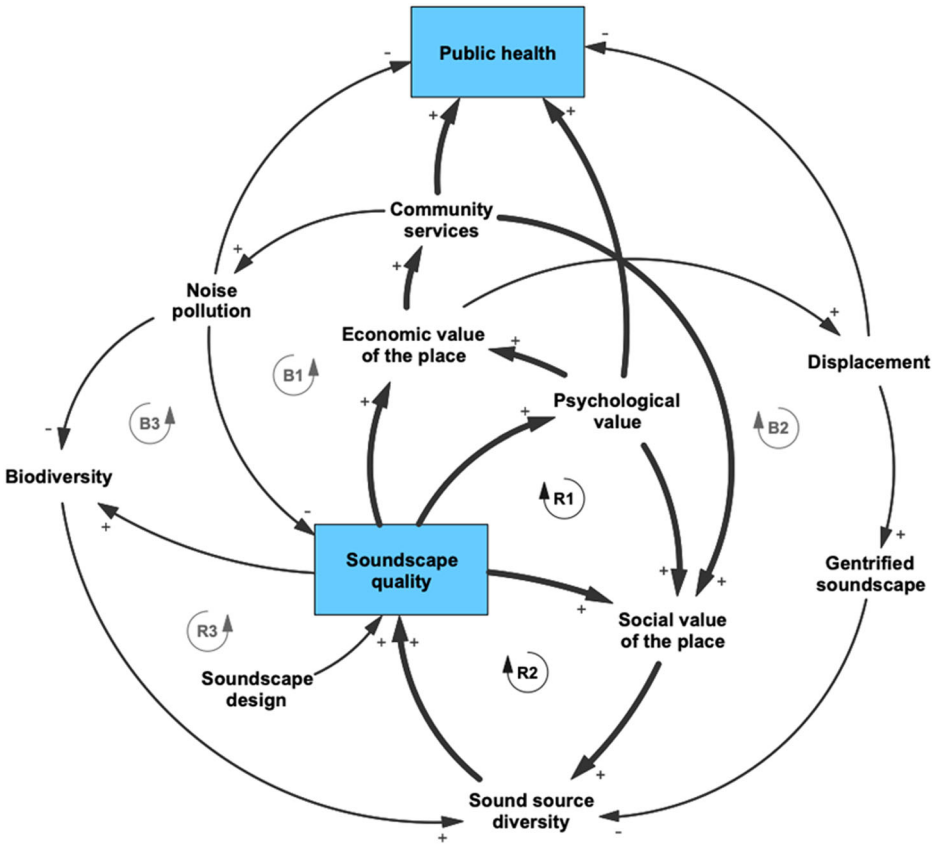

Fig. 2 | Causal loop diagram resulting from a workshop with experts. Highlighted: Socio-economic dimension of soundscape. The variables in blue boxes at the centre of the diagram represent the two key variables that we are interested in. The thickness of the lines represents the highlighted mechanisms for illustrative purposes and does not indicate the strength of the connections.

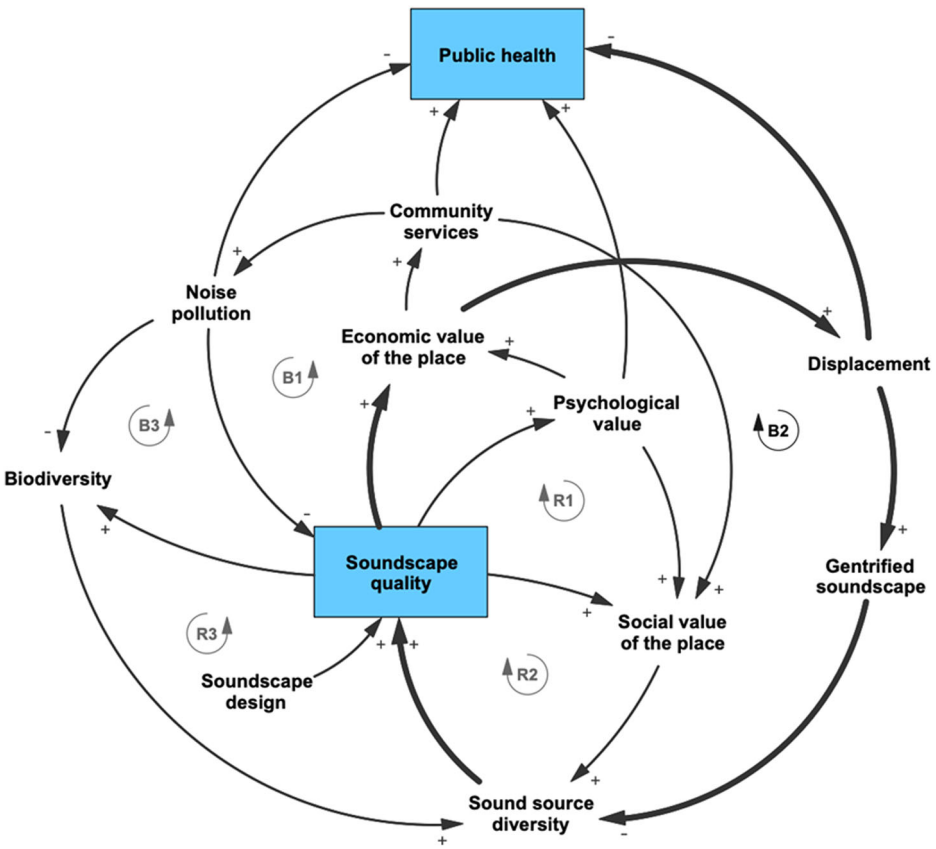

Fig. 3 | Causal loop diagram resulting from a workshop with experts. Highlighted: Soundscape and environmental justice. The variables in blue boxes at the centre of the diagram represent the two key variables that we are interested in. The thickness of the lines represents the highlighted mechanisms for illustrative purposes and does not indicate the strength of the connections.

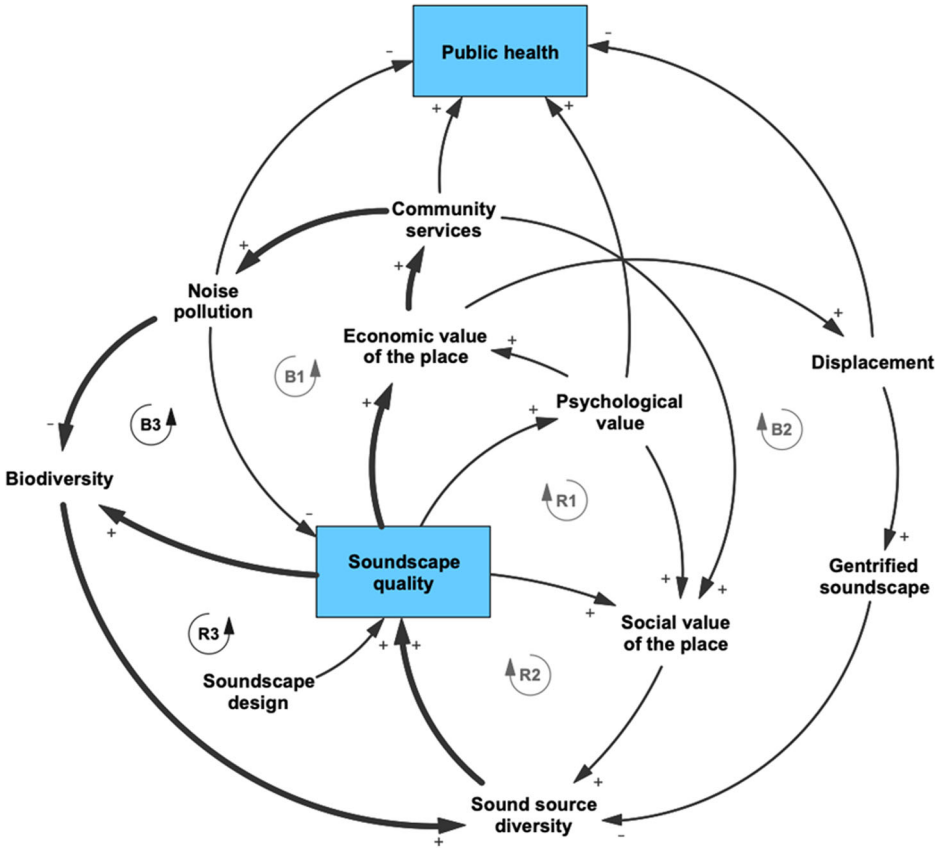

Fig. 4 | Causal loop diagram resulting from a workshop with experts. Highlighted: Biodiversity and soundscape quality. The variables in blue boxes at the centre of the diagram represent the two key variables that we are interested in. The thickness of the lines represents the highlighted mechanisms for illustrative purposes and does not indicate the strength of the connections.

psychological value of the place, examining the different formats of value in planning community needs. Prediction models are linked to soundscape design, psychoacoustics, and methods of using big data and city-scale research. The field of urban studies and practice is connected to soundscape design, social value of the place and community services, showing the importance of researching urban studies integrating with community needs and design. Each of these pathways represents a strategic area of research designed to trigger a sequence of impacts throughout the soundscape system, as depicted in the CLD.

Discussion

The CLD developed in this study highlights the complex relationships between soundscape quality and public health. Systems thinking makes a case for a comprehensive approach that integrates multiple perspectives and disciplines to address these interconnected challenges. The identification of future research pathways provides a roadmap for advancing research and practice in this field.

Ecoacoustics focuses on the interactions between soundscapes and ecological systems[43]. Human-made sounds impact biodiversity and ecosystem health, and ecoacoustics can provide critical insights into maintaining ecological balance within urban environments. This pathway can help mitigate the negative impacts of noise pollution on wildlife, as highlighted in balancing loop B3, and promote the co-benefits of enhanced biodiversity for soundscape quality and public health (reinforcing loop R3)[44]. Enhancement and conservation of biodiversity can also be achieved through comprehensive urban planning to create a "City in Nature" that supports rich biodiversity[42]. Additionally, soundscape design using conspecific or heterospecific acoustic playbacks can actively increase biodiversity[13]. However, the use of acoustic playbacks for soundscape design (which has often been discussed in the literature) presents both opportunities and risks, as highlighted in recent studies. While playback can attract certain bird species and increase their populations in specific areas, it may not necessarily enhance overall species richness or biodiversity. In some cases, conspecific playbacks can lead to the dominance of particular species, potentially reducing diversity within the ecological community. Additionally, heterospecific playbacks, including predator calls, may alter animal behaviors in ways that negatively impact biodiversity[13]. The risks of playback extend to disrupting social structures and territorial dynamics within bird populations[45,46]. These artificial stimuli can interfere with natural communication, creating stress and competition, as noted in studies on playback use by birdwatchers[47]. Moreover, the acoustic niche hypothesis suggests that such interventions may overlap with existing vocalizations, placing undue strain on species to adapt to altered sound environments[48,49]. Despite these concerns, carefully designed playback systems, such as those at Nauener Platz in Berlin, demonstrate that integrating ecological considerations—such as timing, seasonality, and the nature of the calls—can minimize risks and promote soundscape quality as an ecosystem service. Future studies should prioritize strategies to mitigate potential adverse effects of playback on avian communities and ensure that its use aligns with conservation goals.

On the "human" side, *psychoacoustics* examines the psychological and physiological effects of sound on individuals[50]. This pathway is essential for understanding how different soundscape elements influence human perception, cognition, behavior, and emotional responses, addressing the psychological value of soundscapes (reinforcing loop R1)[51–54]. Additionally, this research can contribute to developing soundscape action plans that promote human health and comfort in urban environments, thereby addressing the negative health impacts of noise pollution identified in balancing loop B1. On a related point, there is also a need for further research on contextual (e.g., situational and person-related factors), which is not necessarily captured in psychoacoustics studies[55].

Developing *prediction models* for soundscape perception can enable city planners and policymakers to anticipate the impact of different soundscape configurations on public health and well-being, and thus predict how changes in the sound environment will affect communities[56,57]. Such

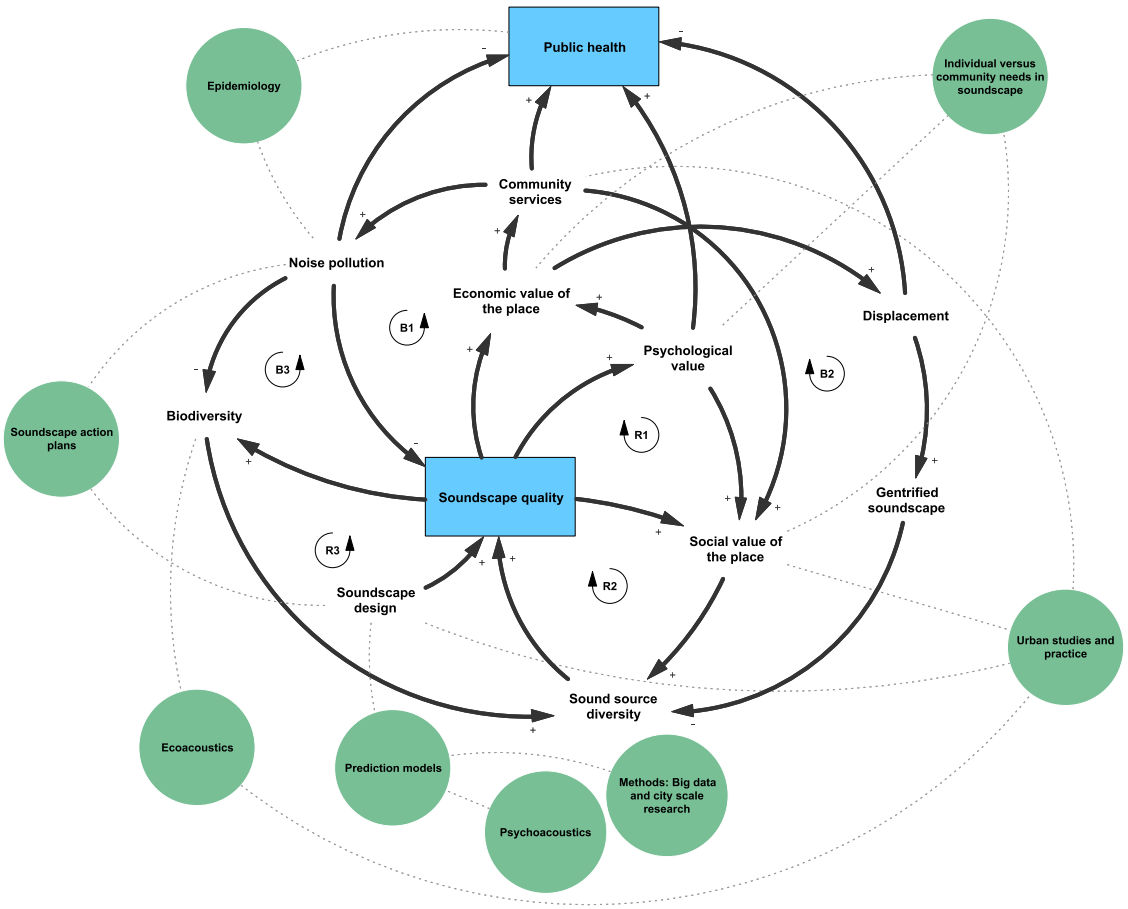

Fig. 5 | Research pathways for the causal loop diagram resulting from a workshop with experts. Research pathways are represented as green circles in the diagram, connected by dotted lines to different parts of the system. The dotted lines do not indicate any causal relationships here; they only show how the targeted areas of study can influence various parts of the system as research pathways.

models would likely require large, standardized datasets for training, and the research community is already making efforts in this direction[58,59]. This would help mitigate negative impacts such as noise pollution and displacement (i.e., via the gentrification mechanism), and enhance positive outcomes such as improved psychological and social value (reinforcing loops R1 and R2). Prediction models would be a direct consequence of *soundscape action plans*, which would involve the strategic planning and management of urban sound environments. These strategic plans, which some countries have already adopted[16], can improve the socio-economic and psychological value of urban spaces (reinforcing loops R1 and R2). Indirectly, they can also address potential gentrification issues (balancing loop B2) by ensuring equitable access to high-quality soundscapes for all socioeconomic groups. Soundscape gentrification may lead to deliberate actions or interventions that suppress or eliminate specific sound sources to align the sound environment with the preferences of a wealthier, often more influential, community. These interventions may include regulatory measures, urban design decisions, or active noise control technologies aimed at silencing sounds associated with certain social or cultural groups, such as street vendors, live performances, or industrial activities. While these actions may enhance the soundscape for some, they can marginalize or exclude other groups, reducing the diversity and inclusivity of the urban acoustic environment.

Indeed, when it comes to soundscape quality, it is often a matter of *balancing individual and community needs in soundscape design*. Future research should explore how to harmonize these needs by designing soundscapes that cater to diverse preferences and promote social cohesion. Engaging communities in participatory soundscape planning can ensure that interventions are responsive to local needs and values[60]. Advancing the discourse on these design considerations, would enable a better integration of soundscape research into *urban studies and practice*[12,18].

As for most environmental factors, the use of *big data and city-scale research methods* for urban soundscapes can provide comprehensive insights into their impacts[61,62]. Gathering data from sensors, mobile devices, and social media, can expose soundscape "trends" at a granular level and across large geographic areas[63,64]. This approach can reveal spatial and temporal patterns in sound exposure, identify hotspots of noise pollution, and evaluate the effectiveness of soundscape interventions aimed at improving the environmental quality of places. This is possibly how soundscape studies can bridge to *epidemiological research*, to provide robust evidence on the links between soundscape quality and public health outcomes[2]. This pathway can help address the disproportionate burden of noise pollution on lower SES groups (balancing loop B1) and promote environmental justice by advocating for equitable soundscape interventions.

While the study aimed to gather diverse expert opinions via purposive sampling, the findings may be influenced by the specific composition of the participant group, which, although diverse, may still introduce bias due to the specific expertise and perspectives represented. The online workshop format itself may have changed the dynamics and depth of the discussions. Although virtual platforms facilitate participation from geographically dispersed experts, they can also limit the richness of interaction compared to in-person workshops. Additionally, the CLD may not fully capture all nuances of the relationships between soundscape quality and public health. While the CLD provides a comprehensive overview, some variables and feedback loops might be oversimplified or omitted due to the constraints of

the workshop format and the limitations of the participants' collective knowledge. For example, an increase in economic value of a place could also lead to an increase in the quality of the built environment (e.g., road maintenance, better infrastructure) which reduces noise pollution, while complaints could still increase (even if noise pollution doesn't increase) as people feel more empowered to complain.

The workshop CLD can serve as a starting point for creating a framework to map existing studies using systems thinking. The workshop represents only a partial exploration of experts' knowledge and should be further validated and expanded. For example, biodiversity should also be directly linked to public health, and soundscape design can be used to increase biodiversity[13]. However, these aspects were not thoroughly discussed at the workshop due to time constraints. For these reasons, further exploration and validation with additional stakeholders and different workshop formats would be desirable.

Additionally, future validation should engage local communities to further understand the complexity in practice and integrate community knowledge. Our CLD can facilitate such future work in this area by providing an initial starting point for engaging with communities and understanding participants' experiences. Readers are encouraged to consider these factors when interpreting the findings of this work, and to view this study as one contribution to the broader dialog on urban soundscapes and public health.

The overall goal of this study was to explore the concept of soundscape quality within a broader system, recognizing its multifaceted impact as documented in epidemiological, design, and environmental studies.

While framing soundscapes in a positive light has its benefits in the urban context, this study aimed to show that it also risks turning soundscape quality into a commodity meant to attract specific groups, such as affluent newcomers in regenerated urban areas. This approach can inadvertently contribute to gentrification, displacing lower SES residents and widening social inequalities[65–67]. By emphasizing the soundscape's appeal for select groups, cities may reinforce economic divides, making certain sound environments accessible only to wealthier populations[68]. Additionally, desirable soundscapes in urban areas are often tied to natural ecosystems, as elements like birdsong and flowing water are frequently valued in urban design[69]. However, the introduction of human-generated sounds to enhance these soundscapes can disrupt natural environments, impacting wildlife and altering ecological balance. Consequently, soundscape quality should not only focus on human enjoyment but also consider the health of local ecosystems. In light of these concerns, soundscape management must be integrated into broader environmental and public health practices. This holistic approach can ensure that efforts to improve urban soundscapes promote equitable access, support community well-being, and respect ecological sustainability, ultimately benefiting both human health and the environment[14].

This research represents the first attempt to apply a systems thinking approach to soundscape quality, as a new way to address its intrinsic interdisciplinarity as a field. A key contribution of this work is making the mechanisms that link soundscape quality to public health explicit and transparent. Mapping these interactions facilitates a clearer understanding of how different variables and feedback loops contribute to soundscape outcomes, offering valuable insights for policymakers, urban planners, and public health professionals. The CLD developed in this study can serve as a starting point for other researchers and practitioners to guide new studies into the links between the social, environmental, and economic impacts of soundscape quality.

One significant advantage of the systems thinking approach is its ability to expose unintended consequences of actions aimed at improving soundscape quality. For instance, while soundscape design is often seen as a way to enhance the quality of a place, the current analysis reveals that it can also lead to gentrification if other forms of value—such as social and psychological—are not adequately considered. This highlights the need for a balanced and holistic approach that integrates diverse values to ensure equitable and sustainable urban soundscapes. Further interdisciplinary research and stakeholder engagement are essential to refine these insights and translate them into effective policies and practices.

Data availability

Data are available upon request.

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Author contributions

Conceptualization: F.A., K.Z., A.M., T.O., I.P., S.T., G.C., J.K.; Methodology: F.A., K.Z., A.M., T.O., I.P., J.K.; Software: K.Z.; Data curation: K.Z.; Investigation: F.A., K.Z., A.M., T.O., I.P., S.T., G.C., J.K., B.L., A.C., C.G., C.T., C.L., B.S.F., M.C., M.B., L.N., S.R.P., E.R., R.B., M.H., H.M.; Writing-Original draft preparation: F.A., K.Z.; Visualization: K.Z.; Supervision: F.A.; Validation: F.A., K.Z., A.M., T.O.; Writing—Reviewing and Editing: F.A., K.Z.

Competing interests

The authors declare no competing interests.

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