Ecological Indicators 141 (2022) 109156

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

How to integrate the soundscape resource into landscape planning? A perspective from ecosystem services

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ARTICLE INFO

Keywords:
Soundscape assessment
Soundscape resource
Ecosystem service
Systematic review
Common preference
Green space

ABSTRACT

In landscape planning and policy-making, environmental sounds have only negative impacts on human health. The natural sounds that promote healthy and supportive environments remain neglected. Although the soundscape concept and approach have considered natural sounds as a resource, the related knowledge has not been employed in landscape planning yet. The purpose of this study is to advance existing state of knowledge to synthesize common preferences for soundscape resources, and then to propose an assessment method for landscape planning. We introduce a planning-oriented soundscape resource evaluation framework to guide a PRISMA systematic literature review. The review includes an in-depth analysis of 74 peer-reviewed journal articles and a meta-analysis for 21 of them. We find that (1) current research has under-explored the soundscape with regard to spatiotemporal evolution, health benefits, and preferences and values; (2) in green spaces, people from different sociocultural contexts exhibit common preferences for soundscape resources. According to these, soundscape formal characters tend towards naturalness, diversity, and appropriateness; (3) exposure to natural sounds does have positive effects on human health and well-being, but the degree of the effects was varied. In addition to birdsongs and water sounds, wind-induced vegetation sounds also have high values. Based on these findings, we suggest basic natural sound scores and categorized indicators for evaluating NSES. It can be implemented in Geographic Information System to produce place-based and comparable results under uncertainty. The results can help landscape planners better consider the contribution of the acoustic environment to human health, well-being, and quality of life, protect the areas of high-quality soundscape resources without actual human uses, and reveal the differences between the actual provision of aesthetic values and demands for nature-based recreation.

1. Introduction

Natural sounds have been neglected in landscape planning (LP) until now, in spite of their obvious positive impact on people's health and well-being (Aletta et al., 2018; Derryberry et al., 2020; Tong and Kang, 2021). This is surprising, because LP as a strong forward-looking action to enhance, restore, and create landscapes (Council of European, 2000), is concerned with protecting natural processes and significant cultural and natural assets (Ogrin, 2010). Natural sounds and their compositions are part of those valuable assets, because they are a dynamic property and resource of ecosystems (Carson, 1962), which are worthy of protection in many national parks, reserves, and wilderness areas (NPS, 2006; Harbrow et al., 2011; Gale et al., 2021). In order to protect landscape assets, functions or ecosystem services (ES), LP evaluates different qualities of biodiversity and ES including landscape aesthetic quality (LAQ) (Hermes et al., 2018), assesses impacts of existing and planned land uses (Mace et al., 1999), and proposes measures for landscape restoration (de Groot et al., 2010). Whereas current LP or environmental impact assessment (EIA), especially the LAQ assessment, only considers the impact of noise, the natural sounds, positively perceived by people and as an essential motivation to visit natural areas (Wenny et al., 2011; Liu et al., 2019), are not included in the assessment. These gaps not only waste an opportunity for strengthening the arguments for protecting valuable ecosystems and landscapes, but also deprive the quality of natural environment of an effective protection that may importantly contribute to human nature-based experiences and

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https://doi.org/10.1016/j.ecolind.2022.109156
Received 30 April 2022; Received in revised form 4 July 2022; Accepted 7 July 2022
Available online 13 July 2022

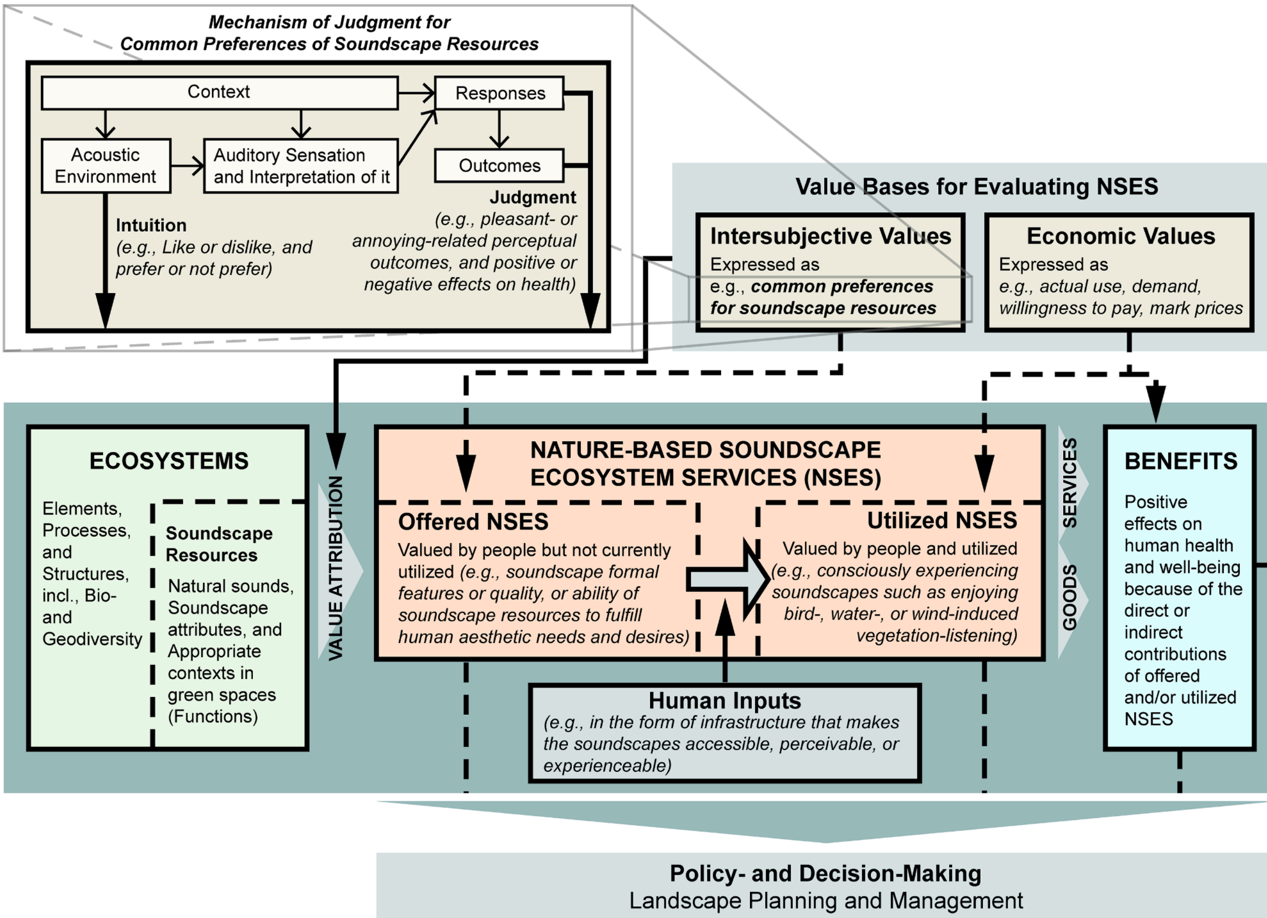

Fig. 1. The Planning-oriented Soundscape Resource Evaluation (PSRE) framework (adapted from Haaren et al., 2014; Albert et al., 2016) with the mechanism of judgment for common preferences of soundscape resources (based on ISO, 2014, 2018, 2019; Ribeiro et al., 2019).

well-being (Hermes et al., 2021).

In response, landscape planners should consider people's common preferences and needs for the acoustic environment of nature, based on their general perception of certain sound features. However, although CICES V5.1 (Haines-Young and Potschin, 2018) has talked about the enjoyed sounds in the group "physical and experiential interactions with natural environment", natural sounds still do not receive enough attention in the ES context. The concept of "soundscape" (ISO, 2014) is helpful for improving such a state, since it emphasizes the relationship between human perception and the acoustic environment, and chiefly focuses on the meaningful sound compositions rather than equating sounds with noises (Brown et al., 2011). In fact, similar to natural landscapes, the natural soundscape resource contributes to providing the setting or condition that enables aesthetic experiences and nature-based recreation activities (Axelsson, 2015; Hong et al., 2019b; Liu et al., 2019), therefore promoting people's health and well-being (Barber et al., 2016). Such benefits afforded to people by nature belong to the ES realm (Bratman et al., 2012; Francis et al., 2017). In this context, natural sound and soundscape resources should be treated as an integral part of biodiversity (Davies et al., 2020; Holgate et al., 2021) and ES (MEA, 2005; TEEB, 2010), especially cultural ecosystem services (CES) in LP.

In order to find a methodological way to include natural sounds and sound compositions into LP, we have to understand how LP basically works and where possible entry points are. Methodologically, LP incorporates the evaluation of landscape functions (as of yet ES and biodiversity), projecting possible changes of landscape (values), deducting objectives and measures to maintain landscape qualities (ES), and restoring them with regard to driving forces, pressures and impacts of landscape change (Albert et al., 2016). To this end, modelling in Geographic Information System (GIS) is employed, which is based on a set of practice-oriented methods (Haaren et al., 2019) and usually based on easily derived spatial information. This under-complex modelling is necessary, because LP has to bridge the gap between science and practical implementation, thus having to produce place-based, comparable (scaled) results under uncertainty (Neuendorf et al., 2018). Comparability of ES values and impairments is needed in practice to derive priorities for actions and to define the space for public participation. Against this backdrop, an approach to sound assessment will also possess such abilities and is preferably based on readily available information. Integration of natural sounds into LP thus should be sought both in assessments of LAQ and in EIAs, if soundscape resources are threatened by planned land use changes or already deteriorated. Such integration offers the chance to improve the aesthetic value (Wang and Zhao, 2019) as well as the quality of nature-based recreation (Liu et al., 2018a), thus providing restorative benefits for individuals and collectives (Fisher et al., 2021). In general, it may contribute to the conservation of the natural environment (Doser et al., 2020). Finally, landscape planners can deduce sound-related objectives and measures and therefore communicate with stakeholders.

However, it remains insufficient that the state of knowledge regarding methods for incorporating the assessment of soundscape resources into planning phases, since established methods and standards are only for assessing disturbing noise. For instance, the *Environmental Noise Directive* (END 2002/49/EC) was the first EU policy concerning the assessment and management of environmental noise (Directive, 2002). Based on this, the *Good Practice Guides* were published to help related authorities undertake noise mapping (WG-AEN, 2006) and quiet area identification (EEA, 2014). Similar regulations also exist in, e.g., Germany (TA Lärm, 1998), the US (Menge et al., 1998), the UK (Defra, 2010), and China (HJ 2.4, 2009). Nevertheless, all of these solely focus on noise aspects. Only recently, the Welsh government published the *Noise and Soundscape Action Plan*, which firstly involves the soundscape matter (Welsh Government, 2018), but only introduces the masking effect of the natural soundscape on noises. On the other hand, scientists have gradually made progress in identifying positive aspects of the soundscapes (van Kempen et al., 2014; Aletta et al., 2018; Hong et al., 2020a). A good example is the *Positive Soundscape Project*, which acknowledges the importance of positive soundscapes in urban planning (Davies et al., 2007), but is still inadequate in evaluating the soundscape resources of nature for LP. A major current limitation is that existing soundscape approaches, such as interviews, soundwalks, and laboratory experiments (ISO, 2018), are mainly based on individuals' responses to soundscape features. Besides, they are weather-dependent, time-consuming, and cost-intensive (Votsi et al., 2017). Despite such progresses having made contributions to noise mitigation and expanded concerns about positive sounds, they are not planning-oriented and the results are neither comparable nor across LP spatial units (e.g., biotope or habitat), and they do not fully explore the potential of integrating natural sounds into LP from ES perspectives (Haaren et al., 2019).

The aim of this paper is to review and advance the state of knowledge regarding the evaluation of soundscape resources for LP. To this end, we (1) provide a planning-oriented soundscape resource evaluation (PSRE) framework based on a practice-oriented ES evaluation model (Haaren et al., 2014; Albert et al., 2016), to consider the soundscape resource evaluation from the ES perspective, (2) conduct a PSRE-guiding systematic review to synthesize evidence of people's preferences for soundscape compositions in green spaces, and to examine the values of various natural sounds, based on the effect sizes of natural sounds on human health and well-being, and (3) discuss review results and then propose an initial assessment approach, which could be a supplement to the current LAQ assessment and EIAs in LP.

2. Towards a Planning-oriented soundscape resource evaluation (PSRE) framework

We adapted the practice-oriented ES evaluation (PRESET) model to include and highlight the evaluation of soundscape resource in order to set up a "Planning-oriented Soundscape Resource Evaluation (PSRE)" framework (Fig. 1). The main features of this PSRE are outlined as follows. The center is nature-based soundscape ecosystem services (NSES), a CES (Haines-Young and Potschin, 2018), that can be understood as the direct and indirect contributions from soundscape resources of ecosystems to humans (MEA, 2005; TEEB, 2010). It consists of both those "offered" by ecosystems and those actually "utilized" by humans (Albert et al., 2016). The offered NSES represents the aesthetic pleasure that arises from the state of harmony between the imaginative representation of soundscape resources (a Natural Capital) and people's understanding. Such pleasure may provide benefits to people but not necessarily currently utilized (Haaren et al., 2014). This means that the offered NSES is a special "formal quality" dependent on the perceptual properties of soundscape resources, as is the case with LAQ (Hermes et al., 2018). It is a formal purposiveness but not of function — purposiveness without purpose (Lothian, 1999). Utilized NSES are those that are actually enjoyed and/or appreciated by humans. The use may encompass various activities that range from walking, hiking, and cycling in (semi-) natural surroundings to consciously experiencing soundscape resources, and such use may require human inputs (Haaren et al., 2014). This differentiation is important for planning as it allows for protecting high quality areas based on the public's benefits even without actual uses. It also reveals the difference between high demand for nature-based recreation and the actual provision of LAQ in areas such as urban fringes or countryside.

We recommend, as a first explorative approach, applying intersubjective values instead of the non-use value proposed in the original PRESET concept (Haaren et al., 2014). The reason is that CES norms expressed in international legislation are non-existent for evaluating NSES. Intersubjective values (not objectively proven as generally applicable but agreed upon by a majority of people) can refer to core preferences of soundscape compositions for the offered NSES that may even be common to all human beings (Hermes et al., 2018; Haaren et al., 2019). This core can be deduced from the existing literature, and used to compare and rate offered NSES in different areas as an initial criterion. This can inform planning decisions in terms of protecting and maintaining soundscape resources, and developing the tourism potential of a region. In addition, individual, local values and preferences can be captured by economic values that are primarily related to the utilized NSES and obtaining benefits (Albert et al., 2016). The valuation results of utilized NSES can be compared with the offered NSES for planning purposes.

In addition, a judgment mechanism is employed here to indicate how to determine the common preferences for soundscape resources. Preferences and perception are neither synonymous nor two separate dimensions. In fact, the perception process (auditory sensation and interpretation of it), generating responses that may have outcomes (ISO, 2014; Aletta et al., 2018; Erfanian et al., 2019), is the cognitive foundation that can influence preferences (István, 2003). An important point to note here is that perception - the way people perceive a soundscape - is a process. It is influenced but not exclusively determined by the acoustic environment and context. Conversely, preferences are more directly related to the physical elements of the soundscape, such as liking or disliking the attributes of a certain soundscape element through the use (e.g., identifying, listening, or experiencing) of the acoustic environment. In this case, determining common soundscape preferences should also include the potential precursors that lead to preferences, i.e., responses and outcomes (Brown et al., 2011).

3. Method

Our systematic review adheres to the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method (Page et al., 2021). This approach is considered reliable and transparent in terms of collecting scientific evidence based on specific research questions (Mallett et al., 2012) and has also been used for relevant evidence collection for soundscape studies (Aletta et al., 2018; Erfanian et al., 2019; Lionello et al., 2020). It reduces sampling bias by capturing all relevant empirical evidence, and it clearly articulates the eligibility criteria for each step, which allows verification and replication by other researchers (Liberati et al., 2009). The PSRE framework served as a guidance for the PRISMA-based systematic review.

3.1. Eligibility criteria and search strategy

The specific inclusion criteria included: (1) studies should include at least one measure for the determinants of common soundscape preference; (2) studies should be observed in at least one green space (ecosystem) that can generate natural sounds, regardless of whether they are real, recorded, or virtual (ISO, 2018); and (3) reviewed papers should be published in an accessible peer-reviewed journal and written in English (Aletta et al., 2018; Erfanian et al., 2019). Based on the mechanism of judgment (Fig. 1), the common preference for soundscape resources is determined by: (1) direct preferences: like/dislike or prefer/not prefer; (2) perceptual responses: positive (e.g., good, vibrant, pleasant, calm, or similar) or negative (e.g., bad, chaotic, annoying, monotonous, or similar) reactions and emotions (Axelsson et al., 2012; ISO, 2018); and (3) outcomes: restorativeness, stress recovery, and mood state (Aletta et al., 2018; Erfanian et al., 2019). Furthermore, we argue that the effect degree of natural sound on the three aspects above can be a reflection of the intersubjective values for evaluating NSES. Effects include improved (restorativeness and positive affection) and

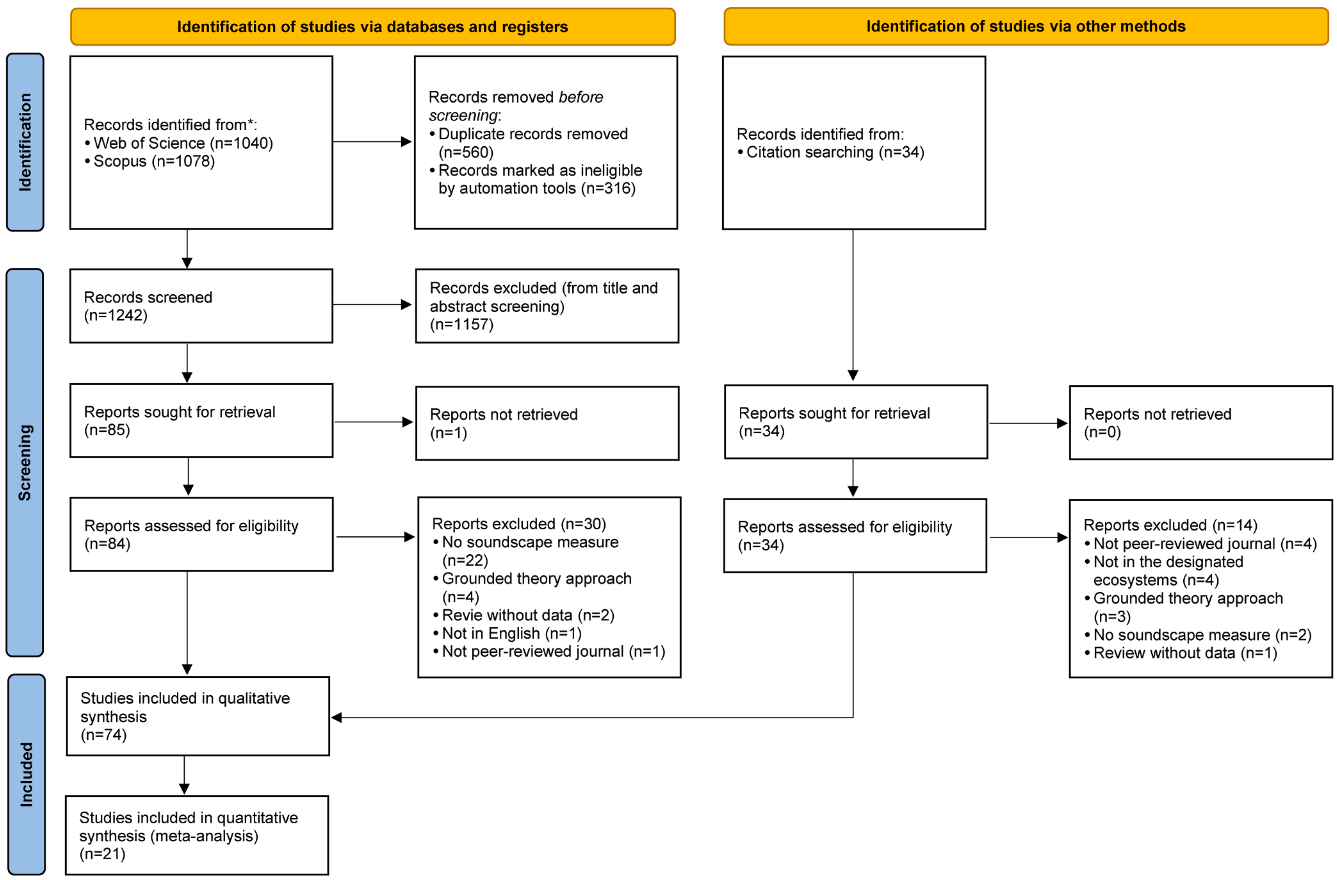

Fig. 2. Workflow of the systematic literature based on the PRISMA approach (Page et al., 2021).

Table 1
Data extraction details.

Data extraction field	Details to consider in data extraction
Study identification	Locations; ecosystem/green space types
Study design	Data collection methods; spatio-temporality of data
Soundscape element	Natural sound types; soundscape measures; influential context factors
Qualitative finding (All 74 articles, for evidence synthesis)	Findings regarding people's perception or preferences for soundscape compositions including natural sound sources, soundscape characteristics, and relevant contexts
Numerical value (The 21 articles, for *meta-*analysis)	Sample size of participants; mean value (M) and standard deviation (SD) from soundscape measures in natural sound exposure (experimental) groups and no sound or noise exposure (control) groups

Notes: For studies that only represented required data by graphs rather than specific values, we used GetData software (https://getdata-graph-digitizer.com/) to extract the values for analysis (Buxton et al., 2021).

reduced (stress and negative mood) effects due to exposure to natural sounds.

We searched Scopus (https://scopus.com) and Web of Science (https://webofknowledge.com), which have been widely used to collect evidence on the practice of the disciplines of landscape architecture and urban planning (Kabisch et al., 2015; Wen et al., 2018). The search scope ("title", "abstract", and "keywords") was set up for searching articles in both databases. The search terms were: ("sound*" OR "soundscape*") AND ("perceive*" OR "percept*" OR "prefer*") AND ("natur* environment*" OR "natur* area*" OR "natur* surrounding*" OR "natur* setting*" OR "green* space*" OR "green* area*" OR "ecosystem*" OR "habitat*" OR "biotope*"), where "*" is a wildcard character that represents all words with the same presented roots. The time frame was limited to 1 January 1990 until 1 October 2021. Each record retrieved was independently screened by the first author in accordance with inclusion criteria. Automation tools were used to filter out the peer-reviewed journal articles.

3.2. Study selection and data extraction protocol

Study selection was accomplished in three steps (Fig. 2): identification, screening, and inclusion. Of the 85 articles initially screened from the databases, only one was not retrievable (Bjerke and Østdahl, 2005). Then, 54 eligible articles were selected after excluding 30 for specific reasons. Moreover, 20 additional articles that were relevant to the research questions but did not show up in the search results were added. Ultimately, a total of 74 eligible articles were selected for evidence synthesis, and 21 of them with randomized controlled trial (RCT) study design were used to perform a meta-analysis (West et al., 2008). The extracted data is shown in Table 1.

3.3. Meta-analysis

The risk of bias assessment indicated that the 21 studies were of good quality and could be used in the meta-analysis (for details see Fig. S1, Supplementary material). The values in terms of M, SD, and sample size of these studies were extracted to compare and statistically analyze the effect degree of natural sounds. We built two models for improved and reduced effects separately. Because these data were continuous variables with non-uniform units, we used standardized mean differences (SMD, Cohen's d) as effect size measures (Magnusson, 2014), and random-effects models (Higgins et al., 2003) for pooling the outcome data of each effect separately. To account for the possibility of multiple comparisons and outcomes in a single study, the study ID was included

Fig. 3. Selected characteristics of the 74 included papers: (a) study location; (b) type of greenspace/ecosystem; (c) data collection method; (d) spatio-temporality of data; (e) studied type of natural sound; (f) soundscape measure; (g) studied context factor.

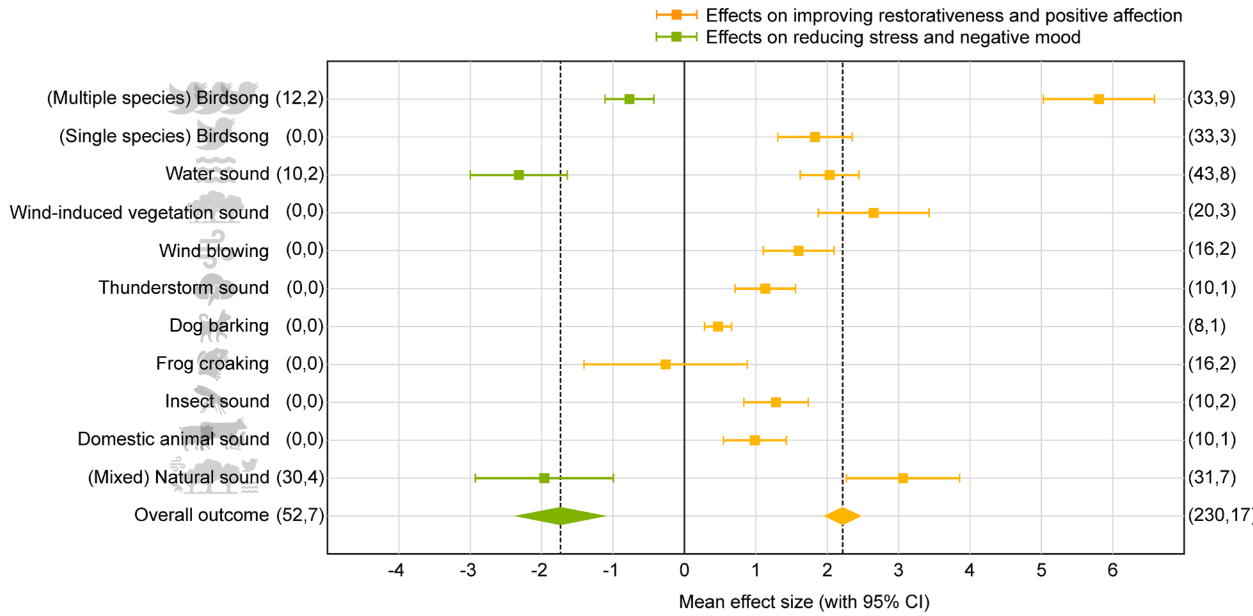

Fig. 4. Mean effect sizes of natural sounds on improving restorativeness and positive affection and reducing stress and negative mood. The horizontal bar around the mean indicates 95% CIs. The first and second numbers in parentheses on both sides indicate the number of outcomes and the number of studies, respectively, for each inclusion calculation. The left and right sides are the reduced model and the improved model, respectively.

as a random factor in each model (Buxton et al., 2021). Both models showed significant heterogeneity between effect sizes, i.e., $I^2 > 50\%$, $p < 0.001$. This may be due to the difference in sample size within the same natural sound source. We examined publication bias by visually assessing funnel plots(Supplementary material, Fig. S2), which are scatter plots of effect sizes versus their precision (Nakagawa and Santos, 2012). The scatter plots seem to indicate publication bias, which may be because natural sounds do have significant effects on human health and well-being. In addition, we also performed sensitivity analysis (Copas and Shi, 2000) for both models, and all recalculated SMD values after removing any of the studies were within the 95% confidence interval (CI) of the combined values, which implies our results are reliable and robust. All statistical analyses were performed with STATA 16.0.

4. Results

4.1. General information

We extracted general information from the 74 articles included. As shown in Fig. 3a to 3d, more than half of the total number of studies came from Europe (n = 38), followed by Asia (n = 19), only one study occurring in Australia (Uebel et al., 2021), but no included study was conducted in Africa. China (n = 14) and the United Kingdom (n = 10) were the two countries with the highest number of studies; Germany and the United States had the same number of studies (n = 4). The included studies more often set their study area in urban green spaces (n = 52), and most of these occurred in urban parks (n = 25). Field interviews (n = 29) and laboratory experiments (n = 25) were the most commonly used methods to collect data; few studies (n = 6) combined two approaches to conduct experiments. Most of the data had no spatial and/or temporal characteristics (n = 59), and studies that considered such accounted for only one-fifth (n = 15) of the total.

For the soundscape elements, we chiefly focused on extracting information from the studies about the natural sound type (Fig. 3e), the soundscape measure (Fig. 3f), and the type of associated contextual factors (Fig. 3g). Usually, multiple types of natural sounds were explored simultaneously in a study. Biological sounds (f = 103) were studied much more often than geophysical sounds (f = 60). Birdsongs and water sounds were the two most studied natural sound sources, with 32 and 31 times, respectively, followed by wind-induced vegetation sounds (f = 21) and wind sounds (f = 18). Most studies combined at least two or more measures to test human experiences in the acoustic environment. Perceived sound intensity/level (f = 19) and identification of sound type (f = 18) were the most frequently used measures, followed by restorativeness (f = 14) and semantic attributes (f = 13). Most studies focused on the perceptual responses to soundscapes, compared to soundscape induced health benefits and preferences and values. The context can be categorized as the place, person, and activity (ISO, 2014), the effects of which on soundscapes were simultaneously explored in some studies. Place-related factors, e.g., naturalness, visual perception or quality, and landscape morphology or pattern, were studied most frequently (f = 97).

4.2. Evidence of soundscape compositions that people preferred

The research evidence suggests that people have common preferences but also differences due to their cultural backgrounds. We classified preferences into three main categories based on the perceptual construct of soundscape (ISO, 2014), including natural sound sources, soundscape characteristics, and contextual features (for details see Table S1, Supplementary material). Each type contains many general preferences, along with some special findings that arise in certain conditions, such as specific places, human groups, or human-nature interactions. In subcategories, single types of natural sounds and landscape aesthetics are the most studied subcategories, followed by natural sound combinations, and physical features and perceptual attributes of soundscapes. A small number of studies focused on contextual elements such as biodiversity, proximity, temporal or seasonal changes, and infrastructure.

4.3. Effects of natural sounds on human health and well-being

The two effect models are shown in Fig. 4. Multi-species birdsongs are those explicitly stated or unspecified species in the studies; single-species birdsongs are those coming from only one type of songbird; sounds of domestic animals come from unspecified animals that were in villages; mixed natural sounds represent the combination of more than one type of natural sound, or natural sounds without explicitly indicated types.

The overall mean effect size for the improved effect was 2.20 (95% CI = 1.98, 2.43), indicating that the group exposed to natural sounds obtained a significant overall improvement in restorativeness and positive affection relative to the control group. The mean overall effect size for the reduced effect was −1.79 (95% CI = -2.41, −1.16), which proves that natural sounds also have a significant overall reduced effect on stress, annoyance, and negative mood. As shown in Fig. 4, bird sounds from multiple species had the strongest effect (4.80, 95% CI = 4.04, 5.56), followed by mixed nature sounds (3.07, 95% CI = 2.30, 3.85) and wind-induced vegetation sounds (2.64, 95% CI = 1.87, 3.40). Water sounds (2.03, 95% CI = 1.63, 2.43) were slightly more enhanced than single-species birdsongs (1.82, 95% CI = 1.30, 2.33). Dog barking exhibited the weakest improved effect (0.45, 95% CI = 0.27, 0.64). Although a reduced effect result was obtained for the frog croaking (-0.30, 95% CI = -1.44, 0.83), its 95% CI intersected with the null line, representing that the result was not statistically significant, i.e., the frog croaking may not have a substantial influence on human health and well-being. Regarding the reduced effects model, water sounds had the strongest reduced effect (-2.33, 95% CI = -3.00, −1.67), followed by mixed natural sounds (-1.99, 95% CI = -2.95, −1.04). However, in contrast to the performance in the improved effect, multi-species birdsongs presented the weakest effect in reduction (-0.77, 95% CI = -1.09, −0.45).

5. Discussion

5.1. Theory: Framework for integrating natural sounds in landscape planning

In this study, a PSRE framework was introduced as a methodology for incorporating soundscape resources into LP. The framework is based on the PRESET model (Haaren et al., 2014; Albert et al., 2016) and considers the soundscape assessment from an ES perspective so that it can be more smoothly and closely linked to established LP tools. This framework incorporates natural sound sources, differentiated NSES, relevant human inputs, and potential benefits of NSES. It indicates the interrelationships between these components, and theoretically they can be evaluated using separate indicators. This differentiated approach suggests that a portion of the NSES, namely the offered NSES, is already included in planning considerations and is therefore more adaptable to the established planning process. In this way, based on the ES-in-Planning framework (Albert et al., 2016), predicting future states of the soundscape resources becomes possible. Such prediction can help capture the effects of land use planning, change, or degradation on the values of soundscape resources. With the support of PSRE, landscape planners can not only effectively identify and evaluate high-value soundscape resources, but also develop conservation measures, even in the absence of human use. These processes can also reveal the discrepancy between actual aesthetic value provision and recreational needs in the area, and description of the results can be incorporated into the public participation. In addition, PSRE broadens the framework of *ISO 12,913* (ISO, 2014, 2018) by suggesting concerns in terms of the monetary and non-monetary values of soundscapes, as well as health benefits from soundscape, so that landscape planners and researchers can realize the deeper contributions of soundscape resources.

5.2. Evidence: common soundscape preferences

5.2.1. Current challenges for introducing soundscape into landscape planning

As presented in the characteristics of the included studies (Fig. 3), for the purpose of including soundscape evaluation in LP, some shortcomings in the focuses and research methods still exist. First, limitations still exist in the selection of study area. Due to the differences in sociocultural backgrounds, cross-regional studies can provide more comprehensive information for planning (Jeon et al., 2018), thus improving the rationality of planning objectives setting, especially in developed countries with diverse populations, such as Germany (Green, 2013). In addition, the concerns are mostly located in urban green spaces. However, natural green spaces also provide rich soundscape resources but could suffer from some negative effects (Abbott et al., 2016), which fall under the scope of Nature-based solution (NBS) (Hanson et al., 2020). LP can provide complementary contributions to NBS (Albert et al., 2019), therefore a greater focus on the soundscape of natural green spaces in the context of LP can also contribute to the development and implementation of NBS.

Second, the studies lacked expansion based on ISO 12913-2 (ISO, 2018) in terms of data collection and studied sound types. Most included studies evaluated the acoustic environment by collecting people's responses through questionnaires. Although this is the advocated approach, it still suffers from being time-consuming and labor-intensive (EEA, 2014). This issue may also potentially limit the ongoing exploration and evaluation of the spatiotemporal dynamics of the soundscape. For the studied sound sources, less attention has been paid to specific species or types of sound sources that fall under main sound categories. For example, different species of birdsongs (Zhao et al., 2020), or different types of water sounds such as ocean, stream, and waterfall sounds (Galbrun and Ali, 2013; Rådsten-Ekman et al., 2013). Such precise classification may lead to different physiological and psychological reactions in humans.

Third, few studies focused on human value and preferences, health, and well-being for soundscapes. Such aspects are not even mentioned in the ISO 12913 documents (ISO, 2014, 2018, 2019), nonetheless it is particularly important in ES-informed LP. Because LP is more concerned with the public preferences, needs, and well-being, it evaluates and selects valuable natural resources based on collective values (Haaren et al., 2019). For incorporating into LP, soundscape researchers should expand the study horizon and applicable indicators, and summarize the general public values and preferences (Hermes et al., 2018), so as to interface well with planning rules and also be able to advance relevant legislation and policy development.

5.2.2. Formal characteristics of soundscape resources based on common preferences

Our evidence synthesis essentially responds to some findings from previous studies. It suggests that people have common core preferences of soundscape compositions for NSES. In addition, people with different sociocultural backgrounds may differ in the degree of preference (e.g., the difference between liking very much and liking in general). Based on the evidence, the formal characteristics of soundscape resources can converge into three categories: naturalness, diversity, and appropriateness.

The naturalness of the soundscape is considered by Carles et al. (1999) to be one of the most important components of the soundscape preference, which is consistent with our results. We argue that naturalness is rather a "fundamental" characteristic from which a variety of positive attributes (e.g., pleasantness and calmness) can be derived. The evidence indicates that the naturalness is highly dependent on the type or dominance of the natural sounds that comprise soundscapes (Benfield et al., 2010; Pérez-Martínez et al., 2018), which may explain in part why the natural sounds provide many positive attributes. Nevertheless, not all types of natural sounds can be perceived positively. The evidence shows that humans generally dislike dog barking and frog croaking (Liu et al., 2019; Wang and Zhao, 2019), which may be because they make people feel noisy and unsafe. In general, such animals need to ward off enemies by raising their voices when threatened or attacked. However, such aversion can be mitigated after adding preferred natural sounds. This phenomenon can be regarded as a positive "masking effect", and it is generally accepted that natural sound source combinations have a high degree of harmony (Liu et al., 2018b; Hong et al., 2019a). These may be expressions of the naturalness. Therefore, the role of soundscape naturalness as an integral part of landscape naturalness should receive

Table 2
Assignment of value scores to natural sounds for evaluating NSES.

Natural sound type	Weight (improved)	Effect size (improved)	Weight (reduced)	Effect size (reduced)	Overall	Value score
Bird (multiple species)	0.73	4.80	0.27	−0.77	3.73	Very high
Vegetation	1.00	2.64	0.00	0.00	2.64	High
Water	0.81	2.03	0.19	−2.33	2.09	Rather high
Bird (single species)	1.00	1.82	0.00	0.00	1.82	Rather high
Wind	1.00	1.59	0.00	0.00	1.59	Medium
Insect	1.00	1.28	0.00	0.00	1.28	Rather low
Thunderstorm	1.00	1.12	0.00	0.00	1.12	Low
Domestic animal	1.00	0.99	0.00	0.00	0.99	Low
Dog	1.00	0.45	0.00	0.00	0.45	Very low

more attention especially in LAQ assessments.

The soundscape diversity is usually closely related to biodiversity and acoustic features. In fact, these two can be discussed together. For instance, some evidence suggests that birdsongs of different species varied from hardness and timbres, leading to the perception of either friendliness or aggression (Ratcliffe et al., 2013). In addition, the combination of bird calls from different species can present variable acoustic features (e.g., with regard to frequencies or fluctuation strengths) and is more likely to be appreciated (Hong et al., 2021). We speculate that people may be able to perceive the energetic atmosphere or euphoric state of mind due to exposure to such sounds. This may also be a possible reason why humans prefer multi-species birdsongs to single-species birdsongs. Theoretically, the preference for vegetation sounds of different species can also be explored. However, most of the vegetation is planted in combination, and it may be difficult to distinguish species-specific vegetation sounds. Interestingly, one study found that humans cannot identify more than four types of bird sounds simultaneously (Hong et al., 2021), which indicates that current data collection methods may be flawed in exploring the diversity of soundscapes.

Furthermore, we suggest focusing on the appropriateness of the soundscape based on the evidence synthesis, which is consistent with Axelsson's conclusion (Axelsson, 2015). Appropriateness focuses more on how the soundscape interacts with the non-acoustic environment, and can provide information beyond whether the soundscape is good or bad. It can be reflected in the soundscape spatial and temporal dimensions, and the soundscape and human multi-sensory interactions. For the spatial dimension, natural sounds are appropriate for green spaces. The evidence demonstrates that the magnitude of natural sound levels in green spaces does not reduce human preferences (Nicolosi et al., 2021; Uebel et al., 2021) and may even contribute to tranquility (Liu et al., 2018b). We speculate that it may be because the natural sounds provide a high level of perceived naturalness, which is an important metric for calculating tranquility (Watts and Marafa, 2017). Assuming that the sound pressure level is kept within a certain range (Watts and Pheasant, 2015), even relatively loud natural sounds can enhance the tranquility of green spaces. For the temporal dimension, some sounds have been found to be better suited to particular seasons, such as woodpecker sounds in summer and sparrow sounds in winter (Putman and Blumstein, 2019). Such vocalization depend largely on the habits and needs of the singer (Hao et al., 2021). For multi-sensory interactions, the evidence indicates that good visual quality, consistency in audio-visual or audio-visual-olfactory, and good provision of service facilities can all contribute to soundscape quality (Hong et al., 2020b; Zhao et al., 2020; Kogan et al., 2021).

5.2.3. Quantified common preferences for various natural sounds

The results of the meta-analysis indicate that exposure to nature sounds has positive effects on human health and well-being, which is consistent with those of previous studies (Bratman et al., 2012; Swaffield and McWilliam, 2013; Buxton et al., 2021). This finding, when interpreted from an evolutionary perspective (Katcher and Wilkins, 1993), suggests that humans are instinctively concerned with the safety provided by the environment in which they reside. Preferred natural soundscapes may provide a safe and orderly environment (Wang and Zhao, 2019; Fisher et al., 2021), in which people can more easily control their emotional state and find mental nourishment and satisfaction. Conversely, people may dislike an acoustic environment that lacks natural sounds or delivers disturbing information (as described in Section 5.2.2), because such surrounding may cause people to experience increased mental tension and stress. This also reflects another determinant "alarm" of soundscape preference proposed by Carles et al. (1999).

The data show that multi-species birdsongs and water sounds possess the greatest improved and reduced effect sizes, respectively (Fig. 4), which more objectively echoes some findings that bird and water sounds are the most preferred types of natural sounds (Krzywicka and Byrka, 2017; Liu et al., 2019). However, our results are not entirely consistent with the findings of Buxton et al. (2021). We speculate the differences arise from two possible sources: On the one hand, the studied types of sound sources were different. We focused on all types of natural sounds examined in green spaces instead of just bird and water sounds, and bird sounds were further distinguished from single and multiple species in our study. On the other hand, the included outcomes were different. We completely considered all possible outcomes that determine common preferences based on PSRE, but Buxton et al. focused only on the health outcomes. Nonetheless, we also have similar findings. For the acquired dataset, we shared the same finding as Buxton et al.: the supporting data for the reduced model were smaller than those of the improved model. This again echoes our discussion in Section 5.2.1.

Additionally, we unexpectedly found that wind-induced vegetation sounds outperformed even water sounds in the improved effect model (Fig. 4). The vegetation sound, like birdsong, is also an important representation of biodiversity (Ng et al., 2018). Interestingly, we found no mention of vegetation sounds in the natural sound category proposed by *ISO 12913-2* (ISO, 2018). Even though Fig. 3e shows that there were many studies measuring vegetation sounds, in the review process we found that few of them considered and discussed deeply. In addition, small amount of the data for the reduced model (Fig. 4) delivers a similar information to Fig. 3f, namely that most of the current studies are only at the perception stage and do not further consider soundscape health or soundscape values and preferences. The results of the reduced model also quantitatively illustrate that perceiving nature sounds are stress-reducing and relaxing, which may also explain their contribution to tranquility (Section 5.2.2). Besides, the performances of mixed natural sounds in the two models (Fig. 4) echo the speculation in Section 5.2.2: The positive "masking effect" and high harmony produced by the combined natural sounds. The results of meta-analysis can be considered as a proxy for intersubjective values, thus providing the basic data base for determining the public general preferences for natural sound sources.

5.3. Application: basic natural sound scores and proposed indicators for assessing NSES

Based on our results, we suggest a relatively rough but effective approach to NSES evaluation. In the context of LP, the soundscape resources of any given ecosystem should be able to be modeled and mapped based on geographic data and landscape ecological knowledge. Therefore, we are committed to constructing a preliminary but generally applicable standardized evaluation, including: (1) an assignment of value scores to natural sounds (Table 2), derived from the outcomes of the two effect models, and (2) a series of proposed indicators for assessing differentiated NSES (Table 3), classified according to the PSRE framework and corresponding to soundscape common preferences. We

Table 3
Proposed indicators for assessing offered and utilized NSES, human inputs required, and potential NSES benefits.

Offered NSES (Naturally diverse, characteristic, meaningful soundscapes)	Utilized NSES (Those parts, which are actually used/experienced for recreation)	Human input (Human factors and infrastructures)	NSES benefit (Physiological and psychological health)
Natural sound sources - Types of natural sounds within a greenspace - Dominance of natural sounds within a soundscape *Acoustic features* - Sound level/loudness/intensity/ sharpness of natural sound sources, which enable people have opportunities to perceive, identify, or experience natural soundscapes *Soundscape formal characters* - Soundscape naturalness, based on e.g., the type, percentage, or dominance of natural sound within a soundscape - Soundscape diversity, reflected by e.g., types, features, or combination forms derived mainly from various natural sounds - Soundscape appropriateness, mainly reflected by the interactions between soundscapes and contexts, see below for the influential context features *Contextual features affecting soundscape quality* - Landscape naturalness, e.g., perceived land cover naturalness, absence of disturbing elements - Landscape diversity, e.g., land cover diversity, structure diversity, relief diversity - Landscape morphology, e.g., landscape fragmentation, continuity and evenness, heterogeneity, and density of vegetation, roads, or buildings - Species of organisms, including vocal animals and plants, the sounds of which are preferred by people - Consistency, e.g., congruency/suitability of visual and audio elements - Biodiversity of the environment, e.g., species richness of songbird and/or vegetation - Diurnal variation, e.g., in the daytime, dusk, or night - Seasonal difference, e.g., in spring, summer, autumn and winter	*Experienced natural sounds* - Perceived/identified types of natural sounds - Perceived dominance of natural sounds within a soundscape *Experienced soundscape attributes* - Perceived loudness/level/ intensity of natural sounds - Perceived affective quality of a soundscape, e.g., pleasantness and eventfulness - Perceived positiveness of a soundscape, e.g., calmness and vibrancy - Perceived overall soundscape quality, e.g., acoustic comfort, harmony among sound sources, or simply good or bad quality *Experienced context features affecting soundscapes* - Perceived visual features of a landscape, e.g., percentage/ presence of natural components, brightness, and openness - Quality of visual landscape, e.g., good or bad, and like or dislike - Perceived biodiversity, based on people's visual and/or auditory sensation to recognize the species richness - People's distance from the areas where liked or disliked sound sources are located	*Personal factors* - Demographic factors, e.g., the nationality, language, gender and age - Personal reasons, e.g., numbers of visitors, visitors' attitudes to nature, visual attention, safety concerns, sensitivity/ awareness to sounds, visiting frequency and motivation, or length of exposure times to natural sounds - Human activities for recreation, e.g., walking, biking, hiking in greenspaces and experiencing the natural soundscape simultaneously *Infrastructures and facilities* - Presence of human infrastructures with relevance for recreation and information, e.g., the areas for visitors' pets to stay, signposts marked 'Enter Quietly', wetland paths enabling tourists to experience natural sounds	*Physiological health* - Stress recovery, usually measured by physiological metrics such as (high-frequency) heart rate variability, skin conductance level, and respiration rate *Psychological health* - Soundscape restorativeness, based on Perceived Restorativeness Soundscape Scale (PRSS) items adapted from Attention Restoration Theory components, including fascination, being-away-to, being-away from, compatibility, coherence, and scope - Mood state, based on the measurement taken from the Short Form of The Profile of Mood States (POMS-SF) representing tension, anger, fatigue, depression, esteem-related affect, vigor, and confusion

exclude the mixed natural sounds to only focus on individual ones. The natural breaks (jenks) method was employed for the division of the value score, which aims to maximize the variation among each category (Chen et al., 2013). Due to the research limitations mentioned above, the preliminary evaluation methods suggested here are temporarily unable to achieve a very detailed distinction across species of sound sources.

To spatially evaluate NSES, Table 2 and Table 3 should be combined. Table 2 is able to examine the initial values of identified natural sounds. The indicators in Table 3 are used to assess the "simulated" values (based on the initial values) of such sounds in a spatial unit (e.g., biotope) of a given green space. Because such values or preferences of sounds for people may change due to variations in soundscape characteristics and contextual factors in a place. Theoretically, natural sounds or soundscapes with their value scores can be located and assigned to spatial units in GIS, and the relevant components can be layered, superimposed, and evaluated through spatial analysis methods, if the required indicators are filled by specific metrics. However, the selection of such metrics is beyond the scope of this study, but we will carry out the exploration in the subsequent research. Also, a spatial sound database, or called the "audiotope", that contains corresponding recordings should be built to support the model, which needs validation and refinement by knowledge of specific vocal species. Based on the model, it is possible to implement the user-independent approach for assessing the soundscape resources in LP.

5.4. Limitations and future studies

The set scope and the outcomes of meta-analysis may be the main sources of the limitations of this study. For the former, we focused on the soundscape resources only in green spaces, but some natural sounds may also be perceived e.g., roads or urban squares. Besides, our research was limited to peer-reviewed articles that were published in English, which might lead to missed studies. For the latter, significant heterogeneity and publication bias were observed among the included studies, which could not be avoided and might have some effects on the results. Moreover, the included studies provided relatively small sample sizes for building the reduced effect model.

Based on the review, we suggest the following three aspects for future studies:

(1) More studies need to explore the preferences for species-specific sounds. Although some studies have focused on species-specific birdsongs, most do not follow certain criteria in species selection. Future studies could, for instance, consider all bird species that may occur in a given season or biotope type, thus enhancing the completeness and validity of the data and making it easier to use in planning practices. By the same token, we also suggest a more in-depth exploration of species-specific differentiation of the preferences for vegetation sounds.
(2) More research could focus on the formal characteristics of soundscapes. In contrast to the dominant user-dependent subjectivist approach currently, user-independent formal assessments can more efficiently capture community or collective preferences for the soundscape resources (Daniel, 2001), and provide place-specific and comparable results for regions and areas (Hermes et al., 2018), thus supporting decisions regarding soundscape resource conservation or regional tourism development. However, this does not mean that only one or the other can exist. The two approaches serve different purposes in planning and can be combined to obtain the best planning results.
(3) More studies could explore the non-monetary and monetary values of soundscape resources based on ES concepts. At this stage, soundscape studies are mostly at the level of individuals' perceptions, but future research could focus more on the collective values or preferences for soundscapes, impact of soundscapes on human health, well-being, and quality of life, and their interrelationships. In terms of the monetary value, the attention should not only be paid on how much people were willing to invest in noise reduction (Calleja et al., 2017), but could also be the willingness to invest in soundscape resource measures. For example, the survey of people's willingness to invest economically in the preservation, restoration, and creation of valuable or locally-distinctive soundscapes.

6. Conclusion

This study provides an enhanced point for incorporating the concept and evaluation of soundscape resources into LP from the perspective of ES. As a supplement to *ISO12913* documents that consider soundscape as the acoustic environment that people perceive instantly, we advocate that soundscape resources can also be an inherent property or capability possessed by green spaces. The introduced PSRE framework proposes the concept of NSES and distinguishes different modules, linking the dimension of intersubjective and economic values as value bases for evaluating differentiated NSES. The PRISMA method was employed to collect qualitative and quantitative empirical evidence based on the PSRE framework. We summarized the current challenges in incorporating soundscape evaluation into LP, revealed and advanced the state of knowledge about people's soundscape preferences, and quantified the value of different natural sound sources for human benefits. Finally, we propose a preliminary assessment method for NSES based on the study results, for the soundscape assessment in LP. The results of this study can help landscape planners to better address people's needs for the acoustic environment, more effectively protect soundscape resources even in the absence of human use, and more comprehensively conduct LAQ assessments and EIAs. In our next research, we will further deepen the construction of user-independent models and conduct case studies, and obtain actual perception data through immersive experiments to verify and calibrate the modelresults.

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

Data will be made available on request.

Acknowledgements

The authors would like to thank the China Scholarship Council (grant number: 202108080105) for supporting this research. The publication of this article was supported by the Open Access Publishing Fund of Leibniz Universität Hannover.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2022.109156.

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