Nature's Melody: A Scoping Review of Sound-Based Interventions for Enhancing Child-Nature Connectedness

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Abstract

In the last decades, a strong decline in children's nature connectedness, which describes the affective, experiential connection to nature, is observed. It can be explained by urbanization and consequently the limited access to green spaces. These circumstances underscore the need for innovative interventions to reconnect children with the natural world. This scoping review explores the potential of enhancing nature connectedness through sound-based interventions, for example the display of whale sounds in a nature reserve. It reviews a total of eight interventions, focussing on their characteristics, methodologies, and outcomes. The findings of the interventions highlight the multidimensional facets of nature connectedness, encompassing behavioural, affective, and cognitive dimensions. In addition, this review revealed a fourth aspect of nature connectedness, namely the social dimension. The results indicate that the eight interventions varied in their use of sounds, ranging from natural soundscapes to interactive auditory tools. They effectively support nature connectedness by fostering sensory engagement, emotional connection, and cognitive awareness. The findings suggest that sound-based interventions are a promising approach to bridging the barriers to nature access, particularly in urban contexts. Future research should prioritize long-term studies, examining possible dimensions of nature connectedness and explore cultural factors shaping it.

Content

Over the past few decades, children's connection to nature has significantly diminished (Anggarendra & Brereton, 2016). The primary cause of this decline is traced back to the lack of accessibility to green spaces (Freeman et al., 2015). Research indicates that by 2030, about 83% of the global population will reside in urban areas (Freeman et al., 2015). While cities aim to incorporate green, biodiverse spaces, existing natural spaces are frequently replaced due to urban development, expansion, and hard landscaping (Freeman et al., 2015). Freeman et al. (2015) argue that nature connection can flourish in natural spaces that allow for unstructured play, fostering freedom, independence, and inner strength.

In general, connectedness to nature is defined as a person's affective, experiential connection to nature (Sobko et al., 2018). The need to reconnect children with nature has gained significant attention due to the associated improvements in mental health (Wu et al., 2023). Factors influencing child-nature connectedness include the school environment, family dynamics, exposure to and active time spent in nature, as well as the prevalence of screen use. Interventions are essential for creating this reconnection, thereby enhancing mental health and benefiting public health (Wu et al., 2023).

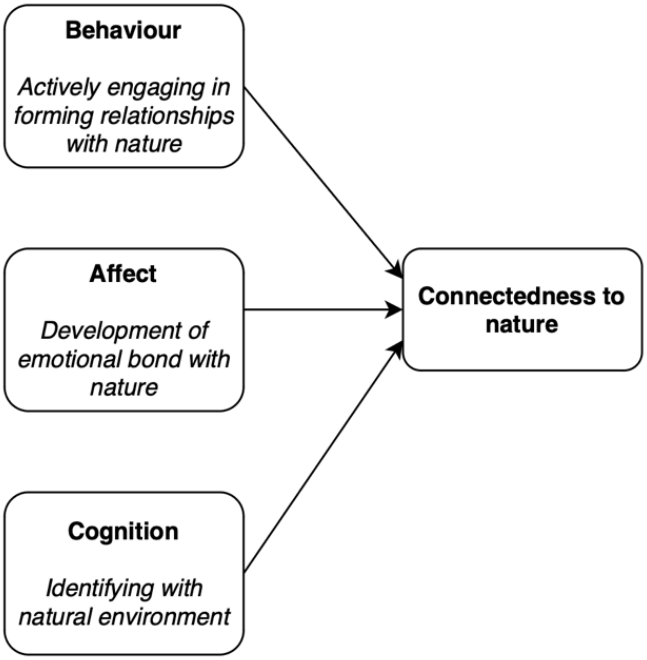
Considering the potential of nature connectedness (NC), a review of existing research is needed, exploring how intervention methods can contribute to reconnect children to nature. An art-based approach provides an alternative to traditional interventions by engaging children's senses and supporting an emotional connection to nature (Moula et al., 2022). More specifically, it was shown that sound-based interventions allow children to interact and connect with nature through auditory exploration (Moula et al., 2022). Therefore, this review aims to examine sound-based approaches that address the limitations of traditional intervention methods to support NC and consider green space access for children.

Theory and Research Child Nature-Connectedness

Connectedness to nature is a complex construct comprising three key dimensions (see Figure 1). These dimensions are combined findings from existing literature by Restall and Conrad (2015) as well as Sobko et al. (2018). First, there is the cognitive dimension, which involves identifying with the natural environment (Restall & Conrad, 2015; Sobko et al., 2018). Second, the behavioural dimension refers to actively engaging in forming relationships with nature. Lastly, the affective dimension describes the creation of an emotional bond (Restall & Conrad, 2015; Sobko et al., 2018). According to Sobko et al. (2018), children's connection to nature primarily involves the development of the 'ecological self' and a 'unique affinity' for the environment. This early bond provides numerous benefits, interacting with the natural environment improves health, reduces stress, enhances social interactions, and results in better learning outcomes (Hallam et al., 2021). These benefits can be attributed to the positive effects of outdoor play on sleep quality, sleep duration, and physical activity (Sobko et al., 2018). However, there has been a shift of children's play from active, outdoor activities to more passive, indoor ones. This shift to passive, indoor play has been associated with negative effects on children's psychological well-being and cognitive development. Reduced opportunities for active, outdoor engagement hinder the development of language, problem-solving, and social interaction skills, which are essential for building self-confidence. Consequently, children who engage less with nature may experience higher levels of stress, lower resilience, and diminished feelings of competence and autonomy (Sobko et al., 2018).

Figure 1

Synthesis of the Three Key Dimensions of Nature Connectedness Based on Sobko et al. (2018) and Restall and Conrad (2015)



Research by Kokkonen et al. (2023) about the effectiveness of child-nature connectedness indicates that visits to natural environments enhance connectedness and subsequently increase children's sense of responsibility to protect their natural surroundings. Thus, creating NC is beneficial both on an individual level and for environmental sustainability.

Comparison of Traditional and Art-based Approaches to increase NC

Traditional interventions on enhancing NC, e.g., naming plants in nature reserves, primarily focus on cognitive learning through nature exposure (Hallam et al., 2021; Dickinson, 2013). Developing ecological awareness is essential to transform the perception of humans and nature as separate entities into an understanding of the interconnectedness between them since humans are part of the natural world (Jeldes et al., 2022). By focusing merely on cognitive learning, an understanding of this interconnectedness is missing. Traditional approaches perpetuate further disconnection by lacking acknowledgment of the interdependence of humans and nature, seeing them as separate (Jeldes et al., 2022). They

tend to fail to establish an emotional bond with nature (Hallam et al., 2021). Furthermore, the traditional type of education overemphasizes science-based activities, often neglecting the integration of cultural and human history (Hallam et al., 2021; Dickinson, 2013).

Art-based approaches in practical education, however, are a promising alternative to traditional nature-based interventions (Hallam et al., 2021). Froebel (1886) was a pioneer in early childhood education with the invention of the kindergarten and the groundwork for incorporating nature as a foundational element in learning. He (1886) proposed a framework to overcome the limitations of traditional nature interventions. It was argued that nature exploration should reveal layers of meaning related to beauty, knowledge, and life. Outdoor experiences should facilitate meaningful interactions with natural objects, promoting aesthetic appreciation, creativity, problem-solving, and symbolic thinking. Froebel (1886) emphasized the importance of understanding the interconnectedness of all living things. Therefore, art-based interventions, as a distinct form of learning, aim to teach children that they are an integral part of nature within an exploratory and meaningful framework. These interventions have the objective of supporting children in developing an emotional and cognitive connection to nature by integrating artistic activities that highlight the beauty and significance of the natural world (Froebel, 1886). Art-based approaches can bridge the gap of traditional methods and address unequal access to green spaces by abstaining from the necessity to be in nature (Jeldes et al., 2022). Another unique feature of art-based approaches lies in the way they engage the senses in the learning process. This helps children to perceive the multifaceted nature of the world around them (Jeldes et al., 2022).

A previous literature review explored the potential of art-based interventions on NC in general (Moula et al., 2022). Art was conducted through creative activities, for instance, drawing, painting, and sound-based art, demonstrating that there are many different art-based approaches. The interventions promoted a strong emotional, cognitive, and sensory

connection to nature. Moula et al. (2022) found that art helps children to perceive themselves as part of the natural world, as it enhances the awareness of nature's interconnectedness. The review compared different methods and found that sound-based methods had the greatest influence on children's creative and spiritual experiences compared to other art-based approaches. Furthermore, according to Renowden et al. (2022), there is a need to examine specific fields of art-based interventions with a focus on the environment, such as musical or visual interventions. Specifically, they recommend investigating the differences in interventions in more detail regarding types, duration, and frequency. An understanding of the heterogeneity of studies would contribute to understanding the unique impact of specific art disciplines, modes, and modalities on nature connectedness (Moula et al., 2022). Therefore, this review will focus on sound-based interventions, a form of art that is less studied but shows significant effects on NC in children.

Theory and Research on Sound-based Interventions

Sound-based interventions, as a subcategory of art-based approaches, are defined as listening to electronically modified music, nature sounds, or voices using specialized equipment, such as headphones (Villasenor et al., 2018). They enable a direct and visceral connection to the environment since conceptualization, categorizing, or reflection is redundant (Adams & Beauchamp, 2020). Sound-based treatments were originally invented in the 1950s for adults and children with various disorders (Hall & Case-Smith, 2007). The founder, Alfred Tomatis, believed that the ear functions as an integrator of the nervous system. Stimulating the auditory sense thus impacts the body holistically (Hall & Case-Smith, 2007). A narrative review of the mechanisms of the effects of sound vibration demonstrates the working mechanism of nerve stimulation (Bartel & Mosabbir, 2021). It was found that neurons detect every sound wave and convert it into firing patterns in the nerves that affect the whole body. Bartel and Mosabbir (2021) described further that sounds can be seen as a

type of energy, arousing through vibrations. Vibration waves stimulate nitric oxide, which is responsible for blood flow and vascular tone. When listening to sounds, blood circulation increases. Therefore, cells translate the energy of sounds into biochemical signals. Additionally, the review states that vibration stimulation, a technique playing sounds one hour per day for eight days at 8 Hz, leads to the growth of new blood vessels and a decrease in stress (Bartel and Mosabbir, 2021). While traditional sound-related approaches often focus solely on noise reduction, this research highlights the potential of sound as an artistic medium to enhance NC and increase sensory engagement with the natural world (Moula et al., 2022).

Tomatis method was initially developed to improve auditory processing, language acquisition, and learning disorders (Hall & Case-Smith, 2007). Therefore, early treatments were not directly linked to NC but addressed cognitive disorders through auditory stimulation (Hall & Case-Smith, 2007). A shift towards NC was strongly influenced by the Attention Restoration Theory by Kaplan (1995) and the biophilia hypothesis by Wilson (1984). Both theories emphasize the psychological benefits of natural environments (Kaplan, 1995; Wilson, 1984). Sensory experiences through sound-based interventions promote child-nature connectedness by creating awareness of the environment (Jeldes et al., 2022). An intervention program of Jeldes et al. (2022) focused on immersion through auditory experiences in nature by blocking visual input and amplifying the auditory perception. Listening to natural sounds helps establish an interdependent ecological consciousness, enabling children to feel united with the natural world and perceive themselves as part of it (Jeldes et al., 2022). A further study designed natural soundscapes to encourage participants to actively listen to and reflect on those sounds in an urban setting (Valsecci et al., 2024). They found increased empathy with nature as well as curiosity and emotional resonance, demonstrating NC. Valsecci et al. (2024) showed that NC can be improved without the need to be in nature. Therefore, the sound-based approach may overcome barriers to accessing green spaces due to the ubiquity of

sounds in everyday life (Hallam et al., 2021). It remedies a lack of traditional interventions by engaging the participant's auditory senses and creating a more inclusive and holistic connection with nature (Hallam et al., 2021). Thus, sound-based interventions offer the potential to reconnect children with nature. However, sounds may induce annoyance and stress when the volume exceeds a threshold of 55 decibels (Iyendo, 2017). Sound levels that are above 80 decibels could even contribute to aggressive behaviour. Iyendo (2017) emphasizes the importance of no background noises when presenting natural sounds in e.g., an urban setting. Although, individual noise sensitivity differs depending on social, cultural, and linguistic background, affecting if a sound is perceived as pleasant (Iyendo, 2017). This becomes evident with a rural-urban comparison of Mexican children and their perception of the sound of silence (Camacho-Guzmán et al., 2024). Rural children associated silence with positive emotions such as happiness, calm, and relaxation. Urban children had mixed associations, including calm but also negative connotations, e.g., sadness and death (Camacho-Guzmán et al., 2024). It is crucial to investigate the status of the field of interventions that support NC among children and provide an overview. Therefore, this study aims to conduct a literature review to map existing literature regarding how sound-based interventions enhance child-nature connectedness. The focus of this review is to examine what types of sound-based interventions exist by evaluating their use of sound and what they contribute to NC in children. The primary emphasis lies in identifying and analysing methods employed across diverse sound-based interventions.

The research question of this investigation is:

"What is the state of the art of the scientific literature researching sound-based interventions that aim to support child-nature connectedness?"

The corresponding sub-questions that will be examined are:

1. *What are the characteristics of sound-based interventions designed to support child-nature connectedness, including the use of sound, target group, geographic location, and setting?*
2. *What research designs, measurements, and empirical evidence are reported in the literature evaluating the effectiveness of sound-based interventions for child-nature connectedness?*
3. *What key findings and insights are gained regarding the impact of sound-based interventions on child-nature connectedness?*

Methods

The purpose of a scoping review is to map the existing literature on a topic, identify key concepts, gaps, and evidence available (Mak & Thomas, 2022). By systematically reviewing, analysing, and comparing existing studies that utilize sound-based frameworks, this research aims to provide a clearer understanding of the state of the research, including a first idea of whether and how their effectiveness is investigated, and identifying areas where further research is needed. Scoping reviews are designed to combine existing literature on a particular topic (Pham et al., 2014). They summarize the quantity, nature, and characteristics of primary research while identifying gaps in the current knowledge base. This approach is particularly useful for topics that have not been extensively reviewed, or for fields that are complex and diverse (Pham et al., 2014). Because the field of sound-based interventions for increasing child-nature connectedness is relatively new and varied, a scoping review is the most appropriate method to explore and synthesize the available intervention designs.

Study design

The scoping review was conducted based on the Preferred Reporting Items for Systematic Reviews and Meta-analysis extension for Scoping Reviews (PRISMA-ScR) by Page et al. (2021) to reduce bias and ensure the reliability of the results.

Information Sources and Search Strategy

Two different databases were used to search for relevant articles, namely Scopus and Web of Science. Scopus covers a broad range of research areas, which is necessary for the specific research question. The interdisciplinary database provides access to studies across different fields such as psychology, education, and environmental science (Falagas et al., 2007). This diversity is crucial to understand the multifaceted nature of sound-based approaches. Furthermore, it provides mainly peer-reviewed literature, ensuring the quality and reliability of the review. Web of Science, in addition, supplies a multisectoral coverage with high-quality journals. Both databases allow the use of search strings with Boolean operators, enabling targeted and replicable searches (Falagas et al., 2007). Therefore, the iterative process began with an individual search for each concept to develop a search string with suitable keywords and synonyms. The key concepts were sound, child, nature, connectedness, and intervention. The following search string was created based on the research question:

(sound OR "music" OR song* OR "audi*") AND (child* OR infant OR toddler OR teenager) AND (nature OR outdoor* OR plant) AND (connect* OR relat* OR engag* OR interact*) AND ("intervention" OR "workshop" OR "test")*

Occurrence of the key concepts was necessary in the abstract, title, or keywords, and document types were limited to articles, reviews, conference papers, and conference reviews in Scopus.

Exclusion Criteria

This search string resulted in 740 documents in total. After application of the exclusion criteria, eight were included in the final sample (see Figure 1). Four different exclusion criteria were identified during the screening process.

Firstly, literature that did not contain the key variable of NC that is central to the review was excluded. Therefore, 247 articles that failed to measure NC were eliminated due to the focus of this review on how sound-based interventions support NC. Those studies measured, for instance, speech and language perception, reading and memory capacity, social behaviour, and auditory inspection time. They did not explore how sound-based interventions contribute to support a relationship with nature. However, several studies assessed NC indirectly as a motivation to engage with nature or generally an engagement to interact with the natural environment. These studies were included since this behaviour is part of forming a relationship with nature (Restall & Conrad, 2015; Sobko et al., 2018).

Secondly, literature that measured NC of adults, specifically people above the age of 18, instead of children were excluded. These included e.g. studies about adults with mental health conditions, such as depression or anxiety. Based on this criterion 57 studies were excluded.

Thirdly, articles that did not apply a sound-based framework to connect children to nature but used solely another art-based approach or a traditional intervention, were eliminated. Studies using sounds as not the only or main art form were included. A total of 230 articles was excluded due to this reason.

Lastly, the literature needs to be primary research that collected and analyzed original data on NC. Excluding secondary research e.g., reviews ensures that the findings and conclusions presented in this review are derived based on the articles, rather than interpretations made in other reviews. This criterion led to the exclusion of additional 50 articles.

Study Selection

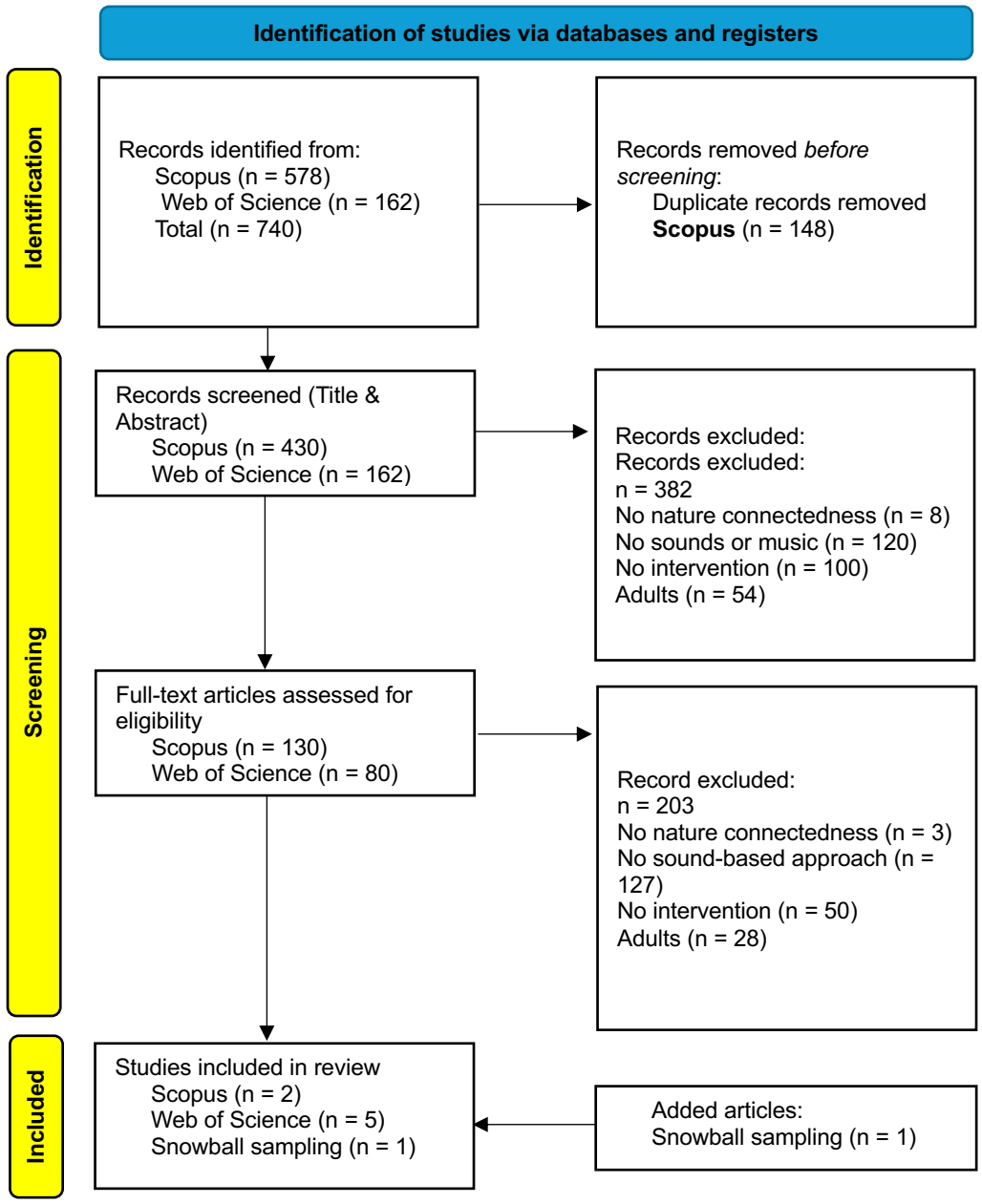
At first, the articles were searched on the aforementioned databases by using the search string. The results were transferred to the app ‘Covidence’, revealing 148 duplicates

that were further removed. 14 articles were found in Web of Science without occurring in Scopus. They cover topics such as human-centred technology for mental health, the therapeutic effects of music therapy, and sound visualization. One coder reviewed the titles and abstracts of the remaining 592 articles. ASReview, an artificial intelligence (AI) tool was used to structure the review systematically. ASReview supports reviewers in the screening process efficiently and transparently by establishing an overview of the most important studies (van de Schoot et al., 2021). It is an open-source learning machine that is free and was therefore used in this review.

Firstly, the coder labeled three relevant and three irrelevant studies. This is the necessary information to be fed into ASReview to train the AI at the beginning of the screening process with literature that is of interest. The three relevant studies covered all inclusion criteria. All three irrelevant studies did not assess NC. Furthermore, one study was secondary research, and two intervention designs missed sound inclusion. The coder selected 130 articles from Scopus and 80 articles from Web of Science for a full-text analysis based on the exclusion criteria met in the abstract and title. The coder examined the remaining 210 studies in full text. The selection of studies resulted in seven articles, whereby the coder reviewed the reference lists of all relevant articles as well. This snow-balling step resulted in one more article that was identified as relevant, leading to a total of eight articles. Figure 2 demonstrates an overview of the screening process.

Figure 2

Overview of the Screening Process According to the PRISMA Guidelines



Data Evaluation

In a scoping review, reporting on the quality and relevance of the final selected studies is crucial to account for reliability (Long et al., 2020). Long et al. (2020) emphasize the application of the tool Critical Appraisal Skills Programme (CASP) to assess the quality of articles for evidence synthesis. The CASP Qualitative Studies Checklist was used to systematically evaluate the eight selected articles since only qualitative research was found. It

provides a useful overview of the data to further synthesize, compare, and analyse it as a pre-step of the actual analysis. An example of the CASP checklists for one article can be found in Appendix A.

Data Extraction

The eight articles were analysed according to the PRISMA-ScR (Tricco et al., 2018). This extension is a specialized guideline to standardize the reporting of scoping reviews to ensure transparency and completeness in scoping reviews. Key differences from the standard PRISMA guidelines (Page et al., 2021) include title and objectives, data presentation, eligibility and study selection, and critical appraisal. Furthermore, broader inclusion criteria are common due to the aim of exploring a wide range of evidence (Tricco et al., 2018).

The data extraction process was systematically aligned with three sub-questions to ensure a comprehensive analysis. Firstly, the data quality was presented. Secondly, the data extraction involved excerpting general information. Thirdly, the first sub-question *'What are the characteristics of sound-based interventions designed to support child-nature connectedness, including the use of sound, target group, geographic location, and setting?'* was addressed. The intervention characteristics concerned the examination of the sounds used in the interventions, such as interactive sound feedback systems, sensory immersion, artistic and creative sound engagement, interactive sound devices, and visual representation. This list of sound uses was inductively coded by summarizing each use in the study and creating overarching themes for similar approaches. The target group was further determined by the number of participants, their age, the location of the study, the intervention type and frequency. In case of missing demographic information, researchers of the studies were contacted to obtain the necessary details

Fourthly, the articles were evaluated regarding the second sub-question, '*What research designs, measurements and empirical evidence are reported in the literature*

evaluating the effectiveness of sound-based interventions for child-nature connectedness?'. Therefore, the study design, the types of measurements, and the working mechanisms for each study were examined to evaluate the primary and secondary outcomes. Here, the analysis focused on how NC was assessed, e.g., observational data, questionnaires, or interviews, and the corresponding outcomes.

Finally, the primary results for each study were reported to answer the last sub-question, '*What key findings and insights are gained regarding the impact of sound-based interventions on child-nature connectedness?'.* This step focused on key insights into the mechanisms through which sound contributes to the enhancement of connection with nature. The relevant outcomes were extracted and reported based on the type of measurement, whereby NC and its diversity in presentation were considered. This involves, for instance, emotional responses, cognitive engagement, or interaction with nature based on research by Restall and Conrad (2015) and Sobko et al. (2018).

Results

The following section presents the findings from the scoping review of sound-based interventions aimed at enhancing child-nature connectedness. The primary goal of this research was to identify and analyze the types, characteristics, and outcomes of interventions that use sounds to improve the relationship between children and the natural environment. Therefore, Tables 2, 3, and 4 were created.

Data Evaluation

The quality assessment of the eight articles, using the CASP Qualitative Studies Checklist, showed that all studies were of high methodological relevance (see Appendix A). In general, all studies aim to support a meaningful engagement with nature, which is crucial in this scoping review. The intervention designs were in line with the corresponding objective, sounds were used to support NC. Data collection methods, such as observation and surveys,

were applied to assess NC and further state the findings appropriately. However, an explicit elaboration of the relationship between children and researchers is missing in all studies. Furthermore, six articles did not explicitly address ethical issues, including consent and participant protection. Merely, Kern & Aldrige (2006) and Yan et al. (2023) elaborated on the ethical processes. CASP suggests assessing the study's overall rigor and relevance regarding the topic of the review rather than relying solely on a numerical score to determine the quality of the articles based on the checklist. Due to the fulfilment of five important quality criteria for this research, namely: a clear aim, a research design and data collection method that suits that aim, a structured data collection, and clear findings, all selected articles were of high quality (Brice, 2024).

Overview of the Studies

The review comprises eight studies conducted between 2006 and 2023 and representing diverse intervention designs, as portrayed in Table 1. Each of the studies employs a unique sound art practice to increase nature awareness, thereby enhancing the ability to form a connection with the natural environment. The interventions apply a variety of artistic modalities, e.g., soundscapes, bio-signaling, music therapy, and AI-assisted collage-making with natural sounds aiming to allow a sensory experience with nature. In three out of eight studies, sounds were incorporated into an object that is usually silent, e.g., plants, smart devices, and a board game. In two interventions, a visual representation was added to the sound-based approach. A further methodology was the amplification of sounds through a tool, which was used in two study designs. Solely one intervention included music as a promoter for NC. It can be seen that adding sounds to an object was the most prominent method used to enhance NC in children. A detailed overview of the content of the literature can be found in Appendix B.

Table 1

General Overview of the Literature

Article number	Author	Publication year	Title	Intervention description
1	Hwang et al.	2010	My green pet: a current-based interactive plant for children	An “interactive plant” was invented that used audio feedback, enhancing nature engagement in children.
2	Huang et al.	2023	Melody oasis: research and design of a nature interactive system for children based on plant electric signals	Bio-signals of plants were translated to sounds and music for children, supporting nature connection.
3	Jeldes et al.	2022	Aconcagua fablab: learning to become with the worlds through design and digital fabrication technologies	Soundscapes were used in workshop with children wearing sound masks to heighten auditory awareness of natural surroundings.

4	Yan et al.	2023	NaCanva: exploring and enabling the nature-inspired creativity for children	AI-assisted nature collages with pictures and sounds stimulated creative expression to establish an emotional bond between children and nature.
5	Gennari et al.	2019	Interactive nature: designing smart devices for nature exploration by children	Sounds were incorporated in smart devices and board games to promote natural exploration among children.
6	Bulduk	2012	A workshop proposal on the visualization of sound concepts	Children created visual representation of daily sounds to grasp and understand sound concepts.
7	Hug et al.	2016	Sonic playgrounds – exploring principles and tools for outdoor sonic interaction	Sound-amplifying tools in playgrounds encouraged the exploration of their acoustic environment.
8	Kern & Aldrige	2006	Using embedded music therapy interventions to support outdoor play of young children with	Music therapy in playgrounds supported outdoor engagement and social play for children with autism.

autism in an inclusive community- based childcare program

Characteristics of Sound-based Interventions

This section provides the answer to the first sub-question about the characteristics of sound-based interventions that are designed to support child-nature connectedness. Table 2 entails the most important intervention characteristics, focusing on the use of sounds, the target group of the intervention, the place, and background information about the context.

The sound-based interventions in the reviewed studies incorporated sound in various ways, with each study employing unique auditory elements to enhance child-nature connectedness. First, three interventions feature natural sounds[3,5,7], by developing elements for outdoor spaces where children could perceive or engage with nature-based sounds. In these three studies, soundscapes were either presented naturally in the environment or digitally to create an immersive sensory experience. They aimed to increase children's awareness and appreciation of the natural surroundings. One intervention was conducted in a semi-controlled outdoor setting on a playground[5]. This setup provided children with structured guidance through sound-enabled exploration. The goal was a higher engagement with the environment. The other intervention took a similar approach within a semi-public playground in Switzerland, introducing auditory interaction prototypes which triggered or altered sounds in response to children's movements[7]. This interactive playground setup allowed children to actively explore their surroundings, transforming familiar play elements into sensory experiences to enhance their connection with nature. This might indicate that sounds enhance NC by increasing the awareness of natural surroundings. Children seem to be able to concentrate and perceive due to effortless attention-giving.

Second, three studies employed sound creatively with artistic activities to increase the connection between children and nature[4,6,8]. In one intervention, children explored nature through an AI-based tool, which allowed them to create nature-inspired digital collages incorporating recorded natural sounds[4]. It reinforced their sensory experiences with nature

through sound-based art. A second study with an artistic approach employed sound visualization to help children with hearing impairments understand sound concepts[6]. This approach provided a bridge for children to understand sounds through sight. Sound was also used with a therapeutic and educational focus to support specific needs, particularly in one study with children with autism[8]. The therapeutic, creative approach incorporated music therapy into outdoor play to support children with autism by using an outdoor music center as part of a therapeutic playground intervention[8]. Two of the interventions were conducted in an indoor setting, without exposure to nature. This could indicate that fostering creativity with nature might have similar effects on NC than being creative in nature. Furthermore, it can be suggested that children who conduct creative tasks involving nature, use their imaginative skills to understand the natural world, leading to an increase in NC.

The last approach to sound inclusion was through real-time interactive auditory feedback based on children's touch interactions with plants[1,2]. In the two studies using this immediate auditory feedback system, children engaged with a plant that produced sounds in response to touches, simulating human-like responses such as laughter or discomfort. The researchers aimed to humanize plants, a concept known as anthropomorphizing, to increase curiosity and change the perception that humans and nature are two separate entities. A crucial factor to support NC is the creation of an emotional bond. It can be suggested that anthropomorphism of nature is a successful strategy to promote the affective component in children.

Across these interventions, most studies (n=4) focused on children aged 4 to 12 years[1,2,4,7]. The intervention targeted children with autism, focusing on the ages 3 to 5[8]. The researcher of two studies did not provide information about the age of their target group[3,6]. While age ranges varied slightly, the primary demographic was school-aged children, emphasizing the role of sound-based interventions in early childhood development.

Geographically, the studies spanned diverse locations, including Asia [1,2,6], Central-Europe[5,7], and South America[3]. The international distribution proves the global relevance of sound-based interventions with a dominant occurrence in Asia. It demonstrates the cross-cultural interest in sound-based interventions as a possibility to support NC in children.

The settings of these studies were equally distributed, ranging from controlled indoor environments[1,2,4,6] to more natural outdoor settings, such as playgrounds, school gardens, and nature reserves[3,7,5,8]. Each context influenced the study's design, with outdoor settings aimed at enhancing direct interaction with nature while controlled indoor environments focused on simulating natural experiences to compensate for limited outdoor access. These approaches demonstrate the flexibility of sound-based interventions in promoting sensory engagement with nature across diverse educational, therapeutic, and creative contexts.

In sum, interactive sound feedback systems were predominantly used in studies from East Asia[1,2]. These studies emphasized dynamic interaction and creative engagement, allowing children to respond to auditory stimuli in real time. Furthermore, they were both conducted indoors, which might be explained by the high urbanization of both South Corea and China (Zhang et al., 2019). Studies conducted in Europe[5,7] and South America[3] involved more passive listening to, e.g., soundscapes, aiming to promote sensory immersion. In general, these demographic differences influenced the design of the intervention. Indoor interventions were more common in urbanized regions with limited access to green spaces. Outdoor settings were widely used in studies conducted in regions with accessible green spaces, e.g., South America[3] and Europe[5,7], allowing direct engagement with natural elements.

Table 2

Intervention Characteristics of the Literature

Article number	Use of sounds	N children	Age range	Place	Context
1	Interactive sound feedback system	15 (7M, 7F)	8 -12 (M = 10.8)	South Korea	Non-controlled setting Indoor
2	Interactive sound feedback system	12	6 -12	China	Controlled setting Primary school Indoor
3	Sensory immersion			Chile	Non-controlled setting Nature reserve Outdoor
4	Artistic and creative sound engagement	30	7 - 11		Controlled setting Outdoor Urban park

5	Interactive sound devices	ABBOT: 170 GAIA: 72	3 -7 5 - 8	Milan, Italy	Semi-controlled setting Outdoor School garden, park, playground
6	Visual representation			Turkey	Controlled setting Indoor University
7	Interactive sound devices and sensory modulation	15	4 - 8	Zurich, Switzerland	Semi-controlled setting Outdoor Semi-public playground
8	Artistic and creative sound engagement	4	3 - 5		Controlled setting Outdoor Playground

Research Designs, Measurements, and Empirical Evidence of Sound-based Interventions

The following section addresses the second sub-question regarding research designs, measurements, and empirical evidence to evaluate the effectiveness of sound-based interventions for child-nature connectedness. Table 3 summarizes the key characteristics of the reviewed studies, highlighting their design methodologies, working mechanisms, measurement tools, and reported outcomes.

The reviewed studies employed a range of research designs, for instance, exploratory descriptive studies[3,5,7]. These designs aimed to observe children's spontaneous responses to sounds added in natural settings, focusing on how sound-based interventions could support their connection to nature. Observations revealed that sound-enabled devices sustained children's sensory engagement and heightened attentiveness to their natural surroundings. Furthermore, technology in a natural setting increases motivation to explore the environment. In addition to observation, the researchers conducted interviews and a questionnaire to assess satisfaction with the devices. Another intervention used an exploratory approach on a playground[7]. A progressive approach encouraged both active engagement and creative interaction with the natural sound environment. Two articles found that auditory immersion strengthened children's levels of awareness of the interdependence between humans and nature, demonstrating the efficacy of soundscapes in increasing NC[3,7]. Furthermore, two studies demonstrated that by changing the natural environment through additional sounds, children's level of exploration as well as appreciation increased[5,7]. Therefore, sounds are a helpful tool to alter the perception of the environment. The intervention using soundmasks supported, besides NC, an enhanced ecological awareness. In general, exploratory, descriptive designs are used for research areas that need further understanding and examination (Hunter et al., 2019). The review revealed that this type of design is mostly used, which indicates that

the concept of NC is multifaceted and its support with sound-based interventions needs further exploration.

Following these, two evaluative studies[2,4] provided structured designs with outcome analyses through surveys about the effect of the intervention on NC. Participants were introduced to the task or product and how to use it to try it out themselves. Beforehand, preliminary studies were conducted as a baseline for both interventions. One study implemented plant bio-signals that were converted into musical sounds[2]. The effect was measured through the experiential activity questionnaire, including several dimensions of NC. Similarly, a questionnaire, observations and semi-structured interviews were used to measure the influence of the AI-based collage tool "NaCanva" on children's connection to nature and their creative processes. These evaluative studies demonstrate the importance of a consistent assessment of NC through standardized surveys. The questionnaires provide measurable information about the influence of sound feedback and sensory tools on NC. In both studies, enhanced curiosity and exploration of nature were found. The plant intervention discovered that children expanded their knowledge about instruments as well[2]. The other study assessed a stronger emotional bond with nature after using "NaCanva" as well as a stimulation of creative processes[4]. While both studies confirmed that sound-based interventions increased NC, they differ in their specific survey structure. One intervention focused on experiential scales to directly assess engagement and sensory connection, emphasizing immediate interactive responses[2]. In contrast, in the other article, NC was measured using a comprehensive framework that considered three levels of relational engagement with nature[4]. This allowed a nuanced analysis of NC to include children's perceived roles, responsibilities, and emotional connection towards and with nature. Furthermore, the AI-based study merely used surveys to measure NC[4], while in the other intervention, interviews and observation were conducted as well[2]. When assessing NC with only a survey, the results are limited to its

single outcome (Gilmartin-Thomas et al., 2018). Due to the complexity of NC, a survey might miss important other factors that determine the construct. Although, a survey reduces possible biases that observations in comparison could evoke.

Another approach was an experimental design with a survey evaluation. There was one study using it, involving a controlled comparison of children's engagement with a regular plant versus an interactive plant that produced auditory and visual feedback[1]. Observational data and questionnaires assessed emotional and cognitive responses to both interactions. In general, children spent more time engaging with the interactive plant compared to the regular plant. Additional questions were posed to investigate the level of personification of the regular and interactive plant, proving a significant difference. This indicated emotional interactions between children and the interactive plant through the addition of human-like sounds. Furthermore, social interaction increased when introducing the human-like plant. Similar to other designs[3,5,7,] this study added sounds to nature[1]. However, it differs in objective and implementation. The other designs[3,5,7]aimed to use sounds in a natural environment to increase motivation to engage with nature as well as curiosity to explore it. This study added sounds to personify a plant[1]. Therefore, the child might develop the view seeing humans and nature as interdependent. The study used surveys as a methodology to assess NC[1], similar to two other articles of this review[2,4]. However, the experimental design study compared the same group of participants to measure if the perception of the plant changes when sounds are added[1].

A further study conducted an educational intervention design[6] that provides structured activities in controlled indoor settings. Although less immersive than other approaches, this intervention still enhanced children's awareness of sound and facilitated an understanding of auditory experiences concerning the environment. This shows the possibilities regarding inclusiveness and diversity of sound-based interventions to establish a relationship with the

environment. The outcomes of this study highlight the importance of understanding sound concepts, which might be categorized as part of the cognitive component of NC. It demonstrates the necessity of adapting intervention structures depending on the needs of participants.

Lastly, one study used a multiple baseline design across four children[8]. In general, they assessed music therapy's effects on nature engagement among children with autism by sequentially introducing the intervention across participants. Through observational data, it was found that musical adaption of the playground facilitated play, motivation, and involvement by attracting children to the sound and providing opportunities to use instruments. Hence, this study differs in sound inclusion compared to other studies of the review[1, 3, 5, 6]. Children were able to produce the sounds themselves with instruments. Three other studies[2, 4,7] used a similar approach, where participants took an active role in sound production. When comparing the outcomes of both approaches, active sound inclusion resulted in increased interest in nature, enhanced engagement, emotional connection, and greater awareness of nature. Passive sound inclusion strengthened curiosity, motivation to explore nature, and positive emotional responses.

Across these designs, observational data were the primary measurement tool, with four studies[1,3,4,7] collecting real-time observations to capture behavioural, cognitive, and emotional responses. Five studies used supplementary tools, such as questionnaires[1,2,4] and interviews[5] to assess children's cognitive and emotional engagement. This reliance on observational data highlights a shared emphasis on understanding sensory and emotional interactions with nature. Furthermore, the studies were of a qualitative nature. Additionally, five studies[1,2,3,4,7]evaluated NC through multiple measurements. This might indicate the complexity of NC with its different components. Focusing on merely one measurement tool led to observable outcomes such as increased engagement with nature or the motivation to

explore[5,8]. Other studies with multiple assessments found cognitive and affective components, e.g., the awareness of the interdependence between humans and nature[3] or the appreciation of the environment[7].

Empirical evidence from three studies suggests that sound-based interventions significantly enhance children's engagement with nature[1,2,5]. For instance, two studies demonstrated that translating plant signals into sounds increased children's interaction with plants[1,2]. The introduction of sound into natural exploration led to greater sensory engagement, making children more attentive to their surroundings[5]. A notable outcome across four studies was the increased motivation and curiosity for outdoor play and exploration due to interactions with sound-based systems[1, 2, 5, 7]. Furthermore, facilitating the listening to sounds with sound masks or electroacoustic mobile devices increased the awareness of the natural environment[3,4].

Table 3

Study Characteristics of the Literature

Article number	Design	Measurements	Working mechanisms	Primary Outcomes	Secondary Outcomes
1	Experimental design Survey design	Observations Questionnaire	Anthropomorphizing plant with human-like sounds	Enhanced engagement and interest in nature and plants Positive emotional response	Increased social interaction
2	Quasi-experimental design Survey design	Experiential scale Questionnaire	Integration of music into plants	Increased curiosity about and interest in nature Higher engagement through musical interaction	Learning of relevant music knowledge Enhanced relaxation Imaginative play
3	Exploratory descriptive design	Observations Participant feedback	Sensorial immersion walks with a soundmask, playing soundtraps	Improved awareness of interdependence with nature through soundscapes	Strengthened ecological consciousness
4	Survey design	Structured tasks Post-study surveys	Creation of AI-based collages with self-	Interest and curiosity about nature	Stimulation of creative thinking

		Observations Semi-structured interviews	collected natural images, videos and sounds	Enhanced exploration and play in nature Increased feeling of interconnectedness between child and nature	
5	Exploratory descriptive design	Observations Questionnaire Interview	Application of interactive games to explore nature	Enhanced motivation to explore nature Prolonged engagement with natural surroundings	Environmental consciousness
6	Quasi-experimental design	Observations	Visualization of sound concepts	Increased understanding of (natural) sound concepts Establishing a relationship with (natural) surroundings	Strengthened interpretative and conceptual skills related to sounds
7	Exploratory descriptive design	Observations Interviews Focus groups	Integration of sound elements into a playground	Greater awareness of natural sounds	Promoted teamwork and inclusive social interactions

				Motivated outdoor engagement Heightened appreciation of natural sounds	Expression of concentration and happiness Creative immersion
8	Multiple baseline design	Video observations	Creation of therapeutic playground and song composition	Increased interaction with natural world	Enhanced peer interactions Improvement of social skills

Key Findings and Insights on the Impact of Sound-based Interventions

All eight studies of this review reported positive effects of sound-based interventions on children's connection to nature. For example, one study enhanced children's engagement with plants by anthropomorphizing them through human-like sounds, which led to a more meaningful connection and increased well-being[1]. Similarly, another intervention demonstrated that translating plant bio-signals into musical sounds heightened children's interest in plants, establishing both curiosity and an emotional connection with nature[2]. Other studies showed that natural sounds, interactive devices, and music systems effectively increased children's motivation to engage with nature and explore their surroundings[4,5,7].

The integration of sounds, especially in natural and interactive forms, serves as a bridge between children and their natural surroundings, enhancing sensory engagement. One study for instance, incorporated sounds within a playground environment which made children more attuned to their acoustic environment, increasing further exploration[7]. A similar study used smart devices with sound capabilities in outdoor settings, which sustained children's attention and motivated them to explore their environment beyond the initial game-like interaction[5].

Music therapy facilitated social interaction and play, particularly enhancing nature accessibility for children with autism[8]. This suggests that sound, and specifically music, can provide inclusive opportunities within outdoor settings, making nature more approachable for children with special needs. Additionally, one study employed sound visualization to help children, including those with hearing impairments, understand sound concepts[6]. This approach highlights the potential of sound-based interventions for inclusivity, especially within structured environments such as schools or kindergartens, which also contributes to cost-effectiveness by enabling integration into daily activities. A soundmask restricted children's visual input to focus on environmental sounds, helping them to experience their

surroundings with heightened mindfulness[3]. This intervention underscored the value of learning outside traditional classrooms by promoting a mindful, sensory-focused interaction with nature.

Overall, these findings indicate that sound interventions tailored to various sensory experiences address different aspects of NC. These include enhanced behavioural engagement and motivation, positive emotional responses, and an increased cognitive understanding of the natural world. Active sound engagement[1,2,4,8] generally enhanced emotional connection, while passive listening experiences[3, 5, 6, 7] encouraged curiosity and sensory awareness, demonstrating the role sound can play in supporting children's connection to nature.

This review discovers that some studies lack a focus on affect, when comparing the findings to the dimensions of NC proposed by Restall and Conrad (2015) as well as Sobko et al. (2018) (see Figure 1). Although the formation of an emotional bond is crucial to support NC, five out of eight studies primarily explore cognitive and behavioural aspects[3,5,6,7,8]. These studies mainly used observations as measurement tools, which might explain the focus on obtrusive aspects of NC (as seen in Table 4). However, the components are often difficult to assign to one specific aspect, e.g., the motivation to explore. This led to the conclusion that a separation of dimension that influence NC seems to be difficult. Multiple studies highlighted one other dimension independently of the theory, namely social interactions. Multiple studies found increased nature engagement and emotional bonds, when peer interaction was integrated. This indicates that the feeling of connectedness to peers leads to NC or vice versa. Due to the results of this review, social interactions could play a role in developing NC. An overview of the dimensions, corresponding examples and the type of measurement used is given in Table 4. It is noticeable that five out of eight studies found a behavioural engagement, such as engagement and nature exploration[1,2,5,7,8]. The affective dimension was

studied in five articles as well[1,3,4,7,8]. The cognitive dimension was examined in six articles[1,2,4,5,6,7] and the social dimension was mentioned in five studies out of eight[2,3,5,7,8].

Table 4

Dimensions of Nature Connectedness with the Corresponding Examples Found in Literature

Dimension of NC	Examples found in studies	Type of measurement
Behavioural	Enhanced engagement in nature and plants	Observation
	Higher engagement through musical interaction	Observation
	Enhanced exploration and play in nature	Observation
	Enhanced motivation to explore nature	Observation, questionnaire
	Prolonged engagement with natural surroundings	Observation
	Motivated outdoor engagement	Observation
	Increased interaction with natural world	Observation, questionnaire
	Greater awareness of natural sounds	Observation
Affective	Positive emotional response	Observation, questionnaire
	Increased feeling of interconnectedness between child and nature	Observation, post study survey
	Heightened awareness of interdependence with nature through soundscapes	Observation
	Establishing a relationship with natural surroundings	Observation
Cognitive	Increased curiosity about and interest in nature	Observation, questionnaire

	Increased understanding of natural sound concepts	Observation
	Enhanced motivation to explore nature	Observation
	Motivated outdoor engagement	Observation, questionnaire
	Greater awareness of natural sounds	Observation
Social	Group activities encouraged shared exploration and interaction with nature	Observation, focus groups
	Collaborative outdoor games motivated to explore surroundings	Observation, questionnaires
	Social experiences in nature enhanced emotional bonds with nature	Video analysis, semi-structured interviews
	Social interactions increased curiosity in nature	Observation, post-intervention survey
	Collaborative sound explorations heightened sensitivity to natural auditory cues	Observation

Note. Examples that apply for more than one component are termed twice.

Additionally, creativity was used as a medium for building connections with nature[2,4,6,7]. All four studies that incorporated creativity addressed the cognitive component of NC with, e.g., higher levels of curiosity. The impact of nature itself led to increased awareness and understanding of the environment and greater curiosity. Therefore, it can be assumed that creativity is part of the cognitive dimension. The cognitive dimension shows the highest prevalence, that might be explained by the creative demand.

There are patterns visible when looking at aspects that are researched more concerning certain contexts, groups, and types of sound interventions. Studies in urban contexts often use

indoor interventions with tools like sound feedback systems or visualization to compensate for limited access to green spaces[1,2,6]. In special needs groups, interventions focus on therapeutic goals, e.g., promoting social interactions or understanding sound concepts[6,8]. Interactive interventions are often employed in controlled environments, leading to increased creativity, emotional bonds, learning outcomes, and social interaction, while passive interventions are used in natural outdoor settings, increasing calmness, relaxation, sensory awareness, curiosity and motivation, and emotional resonance. Seven studies focus on school-aged children with variations in methodology when addressing younger children[1,2,3,4,5,6,7]

Discussion

This scoping review examined the characteristics, methodologies, and effectiveness of sound-based interventions that were designed to enhance child-nature connectedness. Furthermore, it aimed to identify gaps in existing research and explored how sound-based approaches contribute to emotional, behavioural, and cognitive as well as social engagement in nature. Therefore, this review provided insights into how these interventions can overcome barriers to nature access resulting from urbanization.

Main Findings

This review revealed the diversity of sound-based intervention designs with differences in active and passive approaches to support NC. Active interventions require direct participation and engagement, as demonstrated in studies by Kern and Aldridge (2006) and Hwang et al. (2010), which utilized music instruments and other sound production tools. Passive interventions focus on listening to and visualizing sounds. Active sound engagement leads to emotional connections, while passive listening to, for instance, soundscapes increase sensory awareness and curiosity. A meta-analysis from 2022 (Sheffield et al.) examined the effects of direct and indirect contact with nature, active and passive sound engagement, and the timing of engagement, including single sessions and repeated practice on NC. The studies reviewed

conducted interventions with adults, applying visual- and sound-based approaches. They found no difference between the type of contact, the quality, and the timing of engagement in NC (Sheffield et al., 2022). The outcomes are partly in line with the findings of this review, where active and passive approaches both supported NC. However, they differ in the specific components, namely cognition, affect, and behaviour of NC they are enhancing. Passive listening provides an inclusive opportunity for children in urban settings with limited access to direct nature experiences, while active interventions offer dynamic and immersive interactions. In general, interactive sound tools were applied in urban areas in comparison to passive soundscapes used in rural parts. Therefore, these approaches enhance NC on different levels, addressing diverse needs and contexts.

In general, while natural sounds seem to increase awareness of the interdependence between humans and nature, sound production and amplifiers led to increased attention and engagement. According to the Attention Restoration Theory, adding and amplifying natural sounds in an environment facilitates involuntary attention (Kaplan, 1995). Abbott, Newman, and Benfield (2015) investigated this theory and proposed that natural sounds evoke fascination, which diverts attention effortlessly and promotes a cognitive recovery from fatigue. Furthermore, research by Camacho-Guzmán et al. (2024) looked into the role of specific sounds and their potential mechanisms of action in supporting NC. Particularly, listening to natural soundscapes such as bird songs and running water was found to enhance the awareness of the environment and strengthen the affective component of NC. Interactive auditory experiences heightened engagement and attention. The review emphasizes that children who grew up in rural environments were found to spend significantly more time outdoors than urban children. A higher exposure supported rural children to develop a stronger behavioural engagement, resulting in an emotional connection to nature. Urban environments often limit access to green spaces, which hinder children from engaging

meaningfully with nature (Camacho-Guzmán et al., 2024). These findings are in line with the results observed in this review. Natural sounds seem to be crucial to increase an emotional connection. An exception and, therefore, alternative for urban spaces provides the study by Hwang et al. (2010) that anthropomorphized a plant, leading to emotional responses by the participants. Research from 2023 (Kozłowska & Czapla) examined the effect of anthropomorphizing nature by attributing human characteristics to plants. They found that it increases the perception of nature as similar to humans, thus creating empathy, compassion, and emotional connections.

The sound-based interventions investigated in this review differ in their application of sounds, varying from interactive feedback, music, amplifiers, and natural soundscapes. All interventions commonly share the aim of supporting child-nature connectedness. The differences in conductance could be explained by the difference used in the terminology, such as ‘Melody-based’ or ‘Music therapy’. These designations provide an explanation of the type of sound that was used. Nevertheless, using different terminologies could lead to confusion. It indicates a possible disagreement about the term ‘Sound-based intervention’ and its facets. Furthermore, current art-based research focusses mainly on visual-centric narratives to support NC (Renowden et al., 2022). Traditionally, they incorporate visual elements that are immediately apparent and easily captured for the analysis. Auditory experiences are more challenging to assess and link them to NC outcomes due to its subjective and ephemeral nature. Additionally, visual stimuli are straightforward to measure through developed standardized methods. Renowden et al. (2022) claim that there is a lack of established theories and methodologies to directly connect auditory experiences to NC, which discourages researchers from prioritizing sounds as art-based medium. Additional research by Howes and Classen (2013) examined senses in society. They claimed that many non-Western cultures view listening as a central and integrative sensory practice, which is often tied to community,

spirituality, and mindfulness. By contrast, in Western society sight has historically been the dominant sense, associated with knowledge, enlightenment, and power. The visual-centric paradigm relegates other senses, such as hearing, to secondary importance. Western educational and cultural systems prioritize passive listening or listening for functional purposes. Therefore, practices encouraging active, reflective, or mindful listening are less emphasized (Howes & Classen, 2013). The overreliance on sight could explain why the use of sound-based approaches to increase NC is still limited.

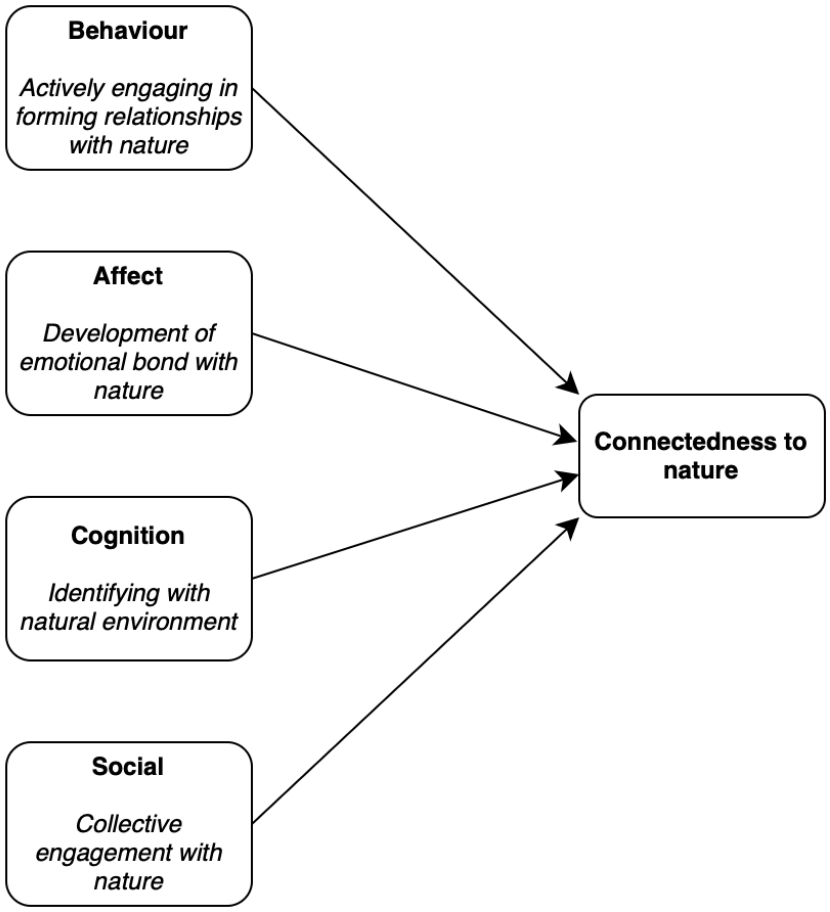
The assessment of NC was mostly conducted with a combination of multiple measurements such as observation, questionnaires, and interviews. There seems to be no adequate guidelines addressing an evaluation method to assess one or multiple dimensions of NC. This review revealed four dimensions of NC, namely behaviour, affect, cognition, and social whereby the boundaries and classifications were partly unclear for specific findings. A review of art-based approaches involving, e.g., drawing, dance, music, and role-play, examined existing research about art-based interventions that enhance NC (Muhr, 2020). The review corroborated the challenges in defining and categorizing NC as a multidimensional construct. Similarly to this review, it was stated that mixed-method assessments, including different surveys, interviews, and observations, were applied to evaluate NC. The use of various assessments within these studies underlines the complexity of the construct. Using multiple methods ensures the reliability of the findings, while validity is questionable due to the lack of universal assessments (Muhr, 2020). In addition, Muhr (2020) highlighted the imprecise boundaries among the behavioural, cognitive, and emotional dimension. This demonstrates the difficulties in isolating findings to a single dimension within the complexity of NC.

This review found a fourth dimension explaining the development of NC, namely the influence of the social environment the child is placed in (see Figure 3). Five articles state that

group interaction in nature increased NC by strengthening the motivation to explore and enhancing emotional bonds with nature. In general, the social dimension is conceptualized as an extension of the need to relate, which is fundamental to human behaviour (Petersen et al., 2019). A literature review of 2019 (Petersen et al.) examined the relationship between social connectedness and NC. They found that social relational emotions, e.g., awe, compassion, and gratitude, are integral to both social and nature connectedness. Petersen et al. (2019) presume that these emotions activate the same psychological mechanisms when connecting to peers and natural surroundings. Therefore, nature experiences evoke similar emotions to those experienced in meaningful human connections. Additionally, Moreton (2018) found that social collaboration in nature-centric activities reinforces emotional and cognitive engagement with the environment. He claimed that the social dimension is not explicitly studied as a separate category, because it is suggested that social interactions play a role in strengthening the emotional affinity to nature (Moreton, 2018). This indicates a conceptual ambiguity since social relational emotions and its impact on NC are difficult to isolate and study. The social dimension seems to be categorized under the construct of affect due to its impact on emotions. Furthermore, it can be presumed that research underestimates the role of collective or social experiences and focus merely on individual experiences in nature.

Figure 3

Expanded Model of the Dimensions of Nature Connectedness



Recommendations for Future Research

The main findings demonstrate the multidimensionality and complexity of NC (Richardson et al., 2019) with a fourth social dimension revealed in this review. The examination of the role of the social environment in NC is recommended to establish to gain knowledge about the different dimensions beyond current research reducing it to behaviour, cognition, and affect. Research about the occurrence of the social dimension is advocated with regards to the target group and the intervention type. To clarify, it could be investigated if the social environment is found in other age groups as well and if only sound-based interventions influence this dimension. In addition, in this review it was difficult to understand which of the dimensions are met after intervention conduction due to an overlap between them. Therefore,

understanding its complexity by providing an overarching theoretical framework that comprises all elements of NC would be beneficial. Besides a complete framework, suitable assessments to measure these dimensions are recommended by developing a diversified, precise methodological repertoire to compare further findings (Richardson et al., 2019).

Secondly, the exploration of cultural influences on NC is recommended. The main findings suggest that children differ in their needs depending on their cultural background. It is important to understand these needs regarding NC to further develop art-based interventions that specifically target them. Therefore, research that examines the impact of culture on NC and how it influences the perception of, e.g., natural sounds is recommended. Subsequently, passive and active sound inclusion could be adapted to the children's cultural background.

Lastly, it is recommended to determine what the long-term impacts of sound-based interventions are to understand if the positive outcomes on NC are sustained. Observations of children's behaviour that go beyond the duration of the intervention by using longitudinal studies would help to assess the long-term effect. This is essential for the development of art-based intervention designs and environmental education in general since they aim for sustainable changes in NC. It could be important to prepare children for the time after the intervention and provide opportunities to strengthen NC afterwards.

Contributions to the Field

This review provides an extensive and structured insight into various sound-based intervention programs that supported NC. It demonstrates the unique advantages of art-based approaches compared to traditional programs. The two main benefits found are accessibility, and inclusivity. For instance, urbanization often limits children's exposure to the natural environment. Sound-based interventions overcome these physical barriers to nature access with auditory tools that create nature experiences in indoor and urban settings as well.

Examples are recorded soundscapes (Hug et al., 2016; Gennari et al., 2019) and interactive tools (Huang et al., 2023) that enable nature engagement in classrooms, therapy rooms, or community centres. Furthermore, soundscapes can be delivered through portable devices, making them accessible in areas with limited green spaces. In general, auditory tools are cost-effective and easier to implement than infrastructure changes, e.g., building green spaces. Moreover, sound-based methods can be tailored to children with special needs, proving inclusivity. This was demonstrated by two interventions from Kern and Aldrige (2006) and Bulduk (2012). Children with autism and hearing impairments benefitted from a sound-based approach. These intervention types provide an alternative to traditional nature interventions. It can be concluded that sounds are a tool to support NC without the need to be in nature. Furthermore, the review discovered a fourth dimension that is part of NC. Current research found three dimensions that are part of NC, namely behaviour, cognition, and affect (Restall & Conrad, 2015; Sobko et al., 2018). The interventions that were analysed in this review were conducted in group sessions with multiple children participating. Therefore, social interactions were observed to influence NC. This indicates that the traditional view of NC comprising of only three dimensions is limited.

Limitations of the Scoping Review

This review carefully followed the PRISMA guidelines for scoping reviews. However, several limitations still need to be addressed. It included eight studies in total, which may not fully capture the diversity of sound-based interventions across different regions, populations, or contexts. The generalizability of the results is reduced due to a limited sample size that can be explained by the search string. Moher et al. (2009) provided guidelines to construct search strings in systematic reviews and reviews for intervention evaluations. They emphasized the importance of including synonyms and related terms to capture a comprehensive, complete dataset (Moher et al., 2009). The keyword ‘intervention’ lacks corresponding synonyms, such

as program, practice, or activity, in the search string. This might influence the results and lead to a sample missing relevant sound-based interventions. Furthermore, the term ‘nature-connectedness’ was separated into two keywords. A review by Van Heel et al. (2023) examined the topic of interventions to increase NC as well. They combined the concept of NC in their search string to guarantee that the interventions investigate NC. Instead of looking for synonyms for the terms ‘nature’ and ‘connectedness,’ they found similar designations for NC, e.g., attachment to nature or nature alienation. The search process might be influenced by the comprehensiveness of the concept of NC. Currently, NC is not clearly defined, and multiple synonyms for the same concept exist, explaining the difficulty in creating a search string that covers all necessary synonyms. Lastly, only one single researcher conducted the review, which may lead to an overlook of relevant articles.

Conclusion

This review aimed to explore the state of the art of sound-based interventions in enhancing child-nature connectedness. This aim was partially achieved. Specifically, it examined the characteristics, methodologies, and outcomes of these interventions, focusing on their ability to support the behavioural, affective, and cognitive, and the emerging social dimensions of NC. The research was qualitative, synthesizing findings from eight short-term studies that revealed promising but varied results.

The review highlights that music and sound-based approaches hold significant potential to support NC by engaging children’s sensory capacities. Interestingly, the studies predominantly relied on inconsistent and non-standardized assessment tools, such as observation, and interviews. This emphasizes on the one hand the need for a unified theoretical framework that comprehensively integrates all dimensions of NC. On the other hand, different evaluation methods provide diverse insights into the impact of sound-based interventions on NC.

While further investigation is needed, the findings underscore their potential to reconnect children with nature regardless of barriers to nature access. Future research should prioritize long-term studies and the development of culturally adapted methodologies to build on this foundation.

In conclusion, sound-based interventions represent an innovative and inclusive approach to overcoming the barriers to nature access, particularly in urban and green space limited contexts. A sound-based approach provides an alternative for children who are disadvantaged in society. While the system is unchangeable due to unequal power dynamics, a creative program seems promising to increase NC within it.

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Appendix A

Table 4

Overview of the Quality Assessment of the Articles based on CASP

Questions	Kern & Aldridge (2006)	Yan et al. (2003)	Jeldes et al. (2022)	Hwang et al. (2010)	Gennari et al. (2019)	Huang et al. (2023)	Hug et al. (2016)	Bulduk (2012)
Was there a clear statement of the aims of the research?	Y	Y	Y	Y	Y	Y	Y	Y
Is a qualitative methodology appropriate?	Y	Y	Y	Y	Y	Y	Y	Y
Was the research design appropriate to address the aims of the research?	Y	Y	Y	Y	Y	Y	Y	Y
Was the recruitment strategy appropriate to aims of the research?	Y	Y	Y	Y	Y	Y	Y	CT
Was the data collected in a way that addressed the research issue?	Y	Y	Y	Y	Y	Y	Y	Y
Has the relationship between researcher and participants been adequately considered?	CT	CT	CT	CT	CT	CT	CT	CT
Have ethical issues been taken into consideration?	Y	Y	CT	CT	CT	CT	CT	CT
Was the data analysis sufficiently rigorous?	Y	Y	Y	Y	Y	Y	Y	Y

Questions	Kern & Aldridge (2006)	Yan et al. (2003)	Jeldes et al. (2022)	Hwang et al. (2010)	Gennari et al. (2019)	Huang et al. (2023)	Hug et al. (2016)	Bulduk (2012)
Is there a clear statement of the findings?	Y	Y	Y	Y	Y	Y	Y	Y
Score out of 9	**8**	**8**	**7**	**7**	**7**	**7**	**7**	**6**

Note. Y = Yes, CT = Can't Tell.

Question 10 of the CASP tool is open-ended and is therefore not included in Table 1.

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CASP Checklist: 10 questions to help you make sense of a Qualitative research

How to use this appraisal tool: Three broad issues need to be considered when appraising a qualitative study:

- Are the results of the study valid? (Section A)
- What are the results? (Section B)
- Will the results help locally? (Section C)

The 10 questions on the following pages are designed to help you think about these issues systematically. The first two questions are screening questions and can be answered quickly. If the answer to both is "yes", it is worth proceeding with the remaining questions. There is some degree of overlap between the questions, you are asked to record a "yes", "no" or "can't tell" to most of the questions. A number of italicised prompts are given after each question. These are designed to remind you why the question is important. Record your reasons for your answers in the spaces provided.

About: These checklists were designed to be used as educational pedagogic tools, as part of a workshop setting, therefore we do not suggest a scoring system. The core CASP checklists (randomised controlled trial & systematic review) were based on JAMA 'Users' guides to the medical literature 1994 (adapted from Guyatt GH, Sackett DL, and Cook DJ), and piloted with health care practitioners.

For each new checklist, a group of experts were assembled to develop and pilot the checklist and the workshop format with which it would be used. Over the years overall adjustments have been made to the format, but a recent survey of checklist users reiterated that the basic format continues to be useful and appropriate.

Referencing: we recommend using the Harvard style citation, i.e.: *Critical Appraisal Skills Programme (2018). CASP (insert name of checklist i.e. Qualitative) Checklist. [online] Available at: URL. Accessed: Date Accessed.*

CASP
Critical Appraisal Skills Programme

Paper for appraisal and reference: My green pet

Section A: Are the results valid?

1. Was there a clear statement of the aims of the research?

Yes ✔
Can't Tell
No

HINT: Consider
- what was the goal of the research
- why it was thought important
- its relevance

Comments: The research clearly aimed to enhance children's perception of plants as living entities through an interactive system.

2. Is a qualitative methodology appropriate?

Yes ✔
Can't Tell
No

HINT: Consider
- If the research seeks to interpret or illuminate the actions and/or subjective experiences of research participants
- Is qualitative research the right methodology for addressing the research goal

Comments: The qualitative methodology was appropriate for exploring children's subjective experiences and interactions with the system.

Is it worth continuing?

3. Was the research design appropriate to address the aims of the research?

Yes ✔
Can't Tell
No

HINT: Consider
- if the researcher has justified the research design (e.g. have they discussed how they decided which method to use)

Comments: The design allowed direct comparison of interactions with a regular plant and an interactive plant.

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4. Was the recruitment strategy appropriate to the aims of the research?

Yes	✔
Can't Tell	
No	

HINT: Consider
- If the researcher has explained how the participants were selected
- If they explained why the participants they selected were the most appropriate to provide access to the type of knowledge sought by the study
- If there are any discussions around recruitment (e.g. why some people chose not to take part)

Comments: The participants were suitable for the aims of the research, but the recruitment process lacked detailed explanation.

5. Was the data collected in a way that addressed the research issue?

Yes	✔
Can't Tell	
No	

HINT: Consider
- If the setting for the data collection was justified
- If it is clear how data were collected (e.g. focus group, semi-structured interview etc.)
- If the researcher has justified the methods chosen
- If the researcher has made the methods explicit (e.g. for interview method, is there an indication of how interviews are conducted, or did they use a topic guide)
- If methods were modified during the study. If so, has the researcher explained how and why
- If the form of data is clear (e.g. tape recordings, video material, notes etc.)
- If the researcher has discussed saturation of data

Comments: Data collection through observation, video recording, and questionnaires addressed the reseatch goals effectively.

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6. Has the relationship between researcher and participants been adequately considered?

Yes	
Can't Tell	✔
No	

HINT: Consider
- If the researcher critically examined their own role, potential bias and influence during (a) formulation of the research questions (b) data collection, including sample recruitment and choice of location
- How the researcher responded to events during the study and whether they considered the implications of any changes in the research design

Comments: The relationship between researchers and participants and its potential influence were not discussed.

Section B: What are the results?

7. Have ethical issues been taken into consideration?

Yes	
Can't Tell	✔
No	

HINT: Consider
- If there are sufficient details of how the research was explained to participants for the reader to assess whether ethical standards were maintained
- If the researcher has discussed issues raised by the study (e.g. issues around informed consent or confidentiality or how they have handled the effects of the study on the participants during and after the study)
- If approval has been sought from the ethics committee

Comments: Ethical considerations were not explicitly addressed in the study.

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8. Was the data analysis sufficiently rigorous?

Yes	✔
Can't Tell	
No	

HINT: Consider
- If there is an in-depth description of the analysis process
- If thematic analysis is used. If so, is it clear how the categories/themes were derived from the data
- Whether the researcher explains how the data presented were selected from the original sample to demonstrate the analysis process
- If sufficient data are presented to support the findings
- To what extent contradictory data are taken into account
- Whether the researcher critically examined their own role, potential bias and influence during analysis and selection of data for presentation

Comments: Data analysis was rigorous, involving clear comparisons and statistical evaluation (ANOVA).

9. Is there a clear statement of findings?

Yes	✔
Can't Tell	
No	

HINT: Consider whether
- If the findings are explicit
- If there is adequate discussion of the evidence both for and against the researcher's arguments
- If the researcher has discussed the credibility of their findings (e.g. triangulation, respondent validation, more than one analyst)
- If the findings are discussed in relation to the original research question

Comments: The findings are explicit and directly related to the research aims.

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Section C: Will the results help locally?

10. How valuable is the research?

HINT: Consider
- If the researcher discusses the contribution the study makes to existing knowledge or understanding (e.g. do they consider the findings in relation to current practice or policy, or relevant research-based literature
- If they identify new areas where research is necessary
- If the researchers have discussed whether or how the findings can be transferred to other populations or considered other ways the research may be used

Comments: The research provides valuable insights into educational tools for nature connectedness, with potential applications in similar contexts.

Appendix B

Table 5

Detailed Description of the Content of the Literature

Study number	Content
1	This study used an interactive plant equipped with audio feedback to engage children. The plant emitted human-like sounds in response to touch, creating an anthropomorphized experience. This encouraged children to perceive plants as dynamic, responsive, and "living" entities.
2	The researchers used sensors attached to plants to translate electric signals into musical sounds, which provided children with a sensory connection to the plants. These real-time sound feedback systems allowed children to experience plants as responsive, dynamic entities, reinforcing the concept of plants as "living" components of their environment. The study implemented plant bio-signals that were converted into musical sounds.
3	This study conducted an immersive workshop in a nature reserve where soundscapes were introduced to increase children's awareness of environmental sounds. Participants created sound masks to focus merely on hearing during a walk in the reserve, whereby different soundscapes, fitting and non-fitting (e.g., whale's call), were played along the way to challenge and increase participants' attention.
4	In this study they first collected the sounds and pictures themselves in an outdoor urban park that they subsequently used for digital collages. This creative intervention enabled children to include auditory elements as part of their visual creations.
5	This study used smart devices to guide nature exploration, incorporating sounds as auditory feedback that encouraged children to interact playfully with natural materials. They introduced smart sound devices (ABBOT and GAIA) in outdoor settings.
6	A controlled indoor workshop was conducted using visual representations to illustrate daily auditory experiences.

	Sound visualization was used in workshops, where children, including those with hearing impairments, created visual representations of daily sounds.
7	They employed a three-step intervention where children first explored sound sources using an electroacoustic mobile device, then interacted with the sounds, and finally manipulated them through digital effects.
8	Four conditions were replicated, namely baseline condition, adaption of the playground, teacher-mediated intervention, and peer-mediated intervention. In the baseline condition, children explored the playground without musical addition. The outdoor music center “Music Hut” was provided to explore in the second condition. Original songs were composed for each participant, creating a tailored musical experience aimed at supporting social engagement and comfort in outdoor settings. The intervention was implemented collaboratively with teachers who were trained in music therapy techniques. Initially, the teachers guided the children in the third phase and sang their composed songs. In the last condition, the children played independently with each other in the music center.