A systematic map of systematic reviews and meta-analyses on anthropogenic noise impact on wildlife

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Highlights

- We found 50 syntheses on noise pollution impacts on animals
- Developed countries led most syntheses with collaborations among such countries
- Energy-related noise in marine environments received the most policy document citations
- The reporting and methodological quality of the syntheses were often suboptimal
- The quality of the syntheses were not related to whether they were cited in policy

Abstract

As systematic reviews on the effects of anthropogenic noise on wildlife increasingly inform policy, a critical evaluation of this secondary evidence is essential. We assessed the coverage, methodological quality, and policy relevance of existing syntheses in this field. Following a preregistered protocol, we conducted a systematic search using Scopus, Web of Science, and Google Scholar, that identified 50 syntheses (systematic reviews, maps, and meta-analyses). Of these 50 syntheses, we included 47 in the bibliometric analysis, 23 in the policy attention analysis, and 44 in the critical appraisal. The included syntheses were published between 2008 and 2025, but mainly in the last six years, and focused on behavioural, physiological, and communication outcomes in animals. Most syntheses looked at the effects of transportation and energy industry activities. Syntheses were most likely to review evidence from marine, followed by terrestrial ecosystems. We found critical gaps in the coverage in terms of their taxonomic scope, with notable underrepresentation of invertebrates, amphibians, and reptiles. Most syntheses were first-authored by researchers based in the United Kingdom, Canada, and the United States. Although many syntheses had authors from more than one country, authors from non-English-speaking countries were largely absent. Almost half of syntheses were cited in policy documents, mainly government policies and regulatory submissions. Syntheses of evidence on marine environments received the most policy citations and urban noise the least. There was no significant difference in quality scores between policy-cited and non-cited syntheses, and most of them are rated low due to methodological and reporting shortcomings. Given these

findings, it is critical to fill the synthesis gaps and improve methodology and reporting of future evidence syntheses in this area.

Keywords: Bibliometric analysis; Umbrella review; CEESAT appraisal; Soundscape ecology; Environmental stressors; Conservation policy; Biodiversity management

1. Introduction

We live in a noisy world, with noise from transportation, industry, and resource extraction permeating terrestrial, aquatic, and even subterranean environments (e.g., (Cardoso et al., 2018; Cruz et al., 2022; M. H. L. Duarte et al., 2018). The Earth's soundscape is inescapably anthropogenic. This anthropogenic noise is recognized as a pervasive environmental stressor with well-documented impacts on humans (Chen et al., 2023) and non-human animals (Kight & Swaddle, 2011; Shannon et al., 2016). Anthropogenic noise exposure in humans is linked to a wide range of negative impacts, including hearing loss, sleep disturbance, and cardiovascular problems, stress, and reduced overall well-being (Chen et al., 2023). In animals, noise can disrupt behaviours integral to fitness, such as acoustic communication, foraging, mating, and predator avoidance (e.g., Bee & Swanson, 2007; Jung et al., 2020; Luo et al., 2015), which in turn can alter population dynamics (Kok et al., 2023). These disruptions can scale up to alter species interactions, community structure, and even ecosystem functioning (Kunc et al., 2016; Peng et al., 2015), highlighting anthropogenic noise as a major driver of global environmental change.

As primary research on the impacts of anthropogenic noise on wildlife has grown over recent decades (e.g., Candolin & Wong, 2019; Yao et al., 2023), researchers have turned to secondary syntheses to integrate findings and identify broader trends. Traditional narrative reviews give a broad and interpretive overview, while systematic reviews provide a structured, potentially more comprehensive and less biased synthesis (Foo et al., 2021). Systematic secondary synthesis ("syntheses" thereafter) come in many forms, such as systematic reviews (qualitative synthesis of results), meta-analyses (quantitative syntheses that statistically combine results across studies) and systematic evidence maps (cataloging the scope and characteristics of the existing research; e.g., Hague & McWhinnie, 2024; Sordello et al., 2020). Governments and environmental organizations increasingly use such types of syntheses to inform evidence-based policy (Burke et al., 2023; Cook et al., 2013; Morrison et al., 2025b; O'Leary et al., 2016), underscoring their role in bridging science and decision-making.

Published syntheses on anthropogenic noise effects on wild animals differ considerably in their scope and methodological approaches. Some syntheses focus on a single taxon (Engel et al., 2024), while others include multiple taxonomic groups (Gomes et al., 2022). Some syntheses focus on physiological effects (Davies et al., 2024), others on changes in acoustic signal properties (Duquette et al., 2021), or include multiple types of outcomes (e.g., Sordello et al., 2020). Publications also differ in considered types of noises and even how noise sources are classified (Cox et al., 2018; Kunc & Schmidt, 2021). Although such diversity in the syntheses scope enriches perspectives on this important topic, it may also limit the comparability of findings across syntheses, which in turn constrains their value for conservation and policy applications that rely on consistent, generalizable evidence (Cook et al., 2013). Syntheses may also vary in reporting and conduct quality (Page et al., 2021). Poorly conducted syntheses risk biased conclusions (Morrison, et al., 2025a), leading to misinformed recommendations, policy decisions and scientific research.

Policy influence, as well as academic influence, of scientific literature can be assessed through bibliometric analyses. Bibliometric analyses examine citation and publication patterns, authorship, and topics across a body of publications, thereby revealing impacts, connectedness, and temporal trends (Nakagawa et al., 2019). Combining syntheses with bibliometric analyses forms the basis of research weaving (Nakagawa et al., 2019), which reveals what is published, what is cited, and guides future research directions. This framework emphasizes mapping not only scientific influence, as captured through citations in academic papers, but also the policy reach of scientific literature.

As with primary literature, syntheses themselves can be mapped and analyzed. A second-order synthesis (i.e. an umbrella review; Aromataris et al., 2015) can reveal where syntheses already exist and where further syntheses are needed (Burke et al., 2023; Ricolfi et al., 2024). While second-order synthesis on the impacts of noise on humans exists(Chen et al., 2023), the landscape of secondary literature for non-human animals remains unmapped. To address this gap, we conducted a second-order systematic evidence map and quality assessment of syntheses on the effects of anthropogenic noise on wildlife. Moreover, following the research weaving framework (Nakagawa et al., 2019), we integrated this map with bibliometric and policy analysis to provide an overview of authorship, collaborations, and influence. Specifically, we aimed to: 1) assess the scope and distribution of existing syntheses, 2) examine bibliometric patterns and collaboration networks, 3) explore the policy relevance and uptake of these syntheses, and 4) evaluate reporting and methodological quality using CEESAT v.2.1

(Konno et al., 2021; Woodcock et al., 2014) to compare policy-cited and non-cited syntheses. Overall, our work charts the current landscape of evidence synthesis in this field, highlights research gaps and shortcomings, and tests how the quality of evidence synthesis affects its uptake in policy and decision-making.

2. Methods

2.1 Protocol and reporting

We report this systematic map following the Reporting Standards for Systematic Evidence Syntheses (ROSES; Haddaway et al., 2018). To ensure the feasibility, sensitivity, and transparency of our review methods, we conducted a multi-phase piloting process following the benchmarking approach by Lagisz et al. (2025). We then preregistered the search strategy, screening process, and planned analyses on OSF (https://osf.io/dmjc4/). The reporting of the methodology followed MeRIT to improve author contributions' granularity and accountability (Nakagawa et al., 2023).

2.2 Eligibility criteria

We defined our study scope and eligibility criteria (Table S1 and S2; Fig. S1) using the PECOS framework (Population, Exposure, Comparator—not applicable, Outcomes, Study type; Foo et al., 2021). For the *population*, we included studies on wild, free-living, or wild-captured non-human animals across terrestrial, freshwater, or marine systems. Eligible *exposures* included noise sources from transportation, industry, construction, energy infrastructure, recreational activities, and experimental playbacks of synthetic or recorded sounds emulating anthropogenic noise. Regarding the *study type,* we peer-reviewed systematic reviews, systematic maps, and meta-analyses that synthesised primary observational or experimental studies. We excluded narrative reviews, theoretical papers, primary studies, syntheses based solely on grey or non-peer-reviewed literature, and conference abstracts lacking substantive methods or results. Syntheses were also excluded if they focused exclusively on humans, domestic, or laboratory animals; those examining solely natural or geophysical noise; or reported outcomes where noise effects could not be isolated. We excluded articles if full text was unavailable through open access or institutional subscription, or if written in languages other than English, Spanish, Japanese, Russian, Polish, Portuguese, French, or Italian. Based on our scoping searches, we did not expect to find relevant works in grey (non-peer-reviewed) literature, and therefore focused on peer-reviewed studies, which offer more standardised reporting and comparability.

2.3 Search and screening

We searched Scopus and Web of Science Core Collection (exact search strings provided in Table S4). We used Google Scholar with simplified multilingual strings via Publish or Perish (Harzing, 2007), retrieving the first 100 hits per language understood by our team members (see the languages listed above and search strings in Table S4). We placed no restrictions on publication year, journal, or subject area. To assess sensitivity of the search strategy, we validated the strategy against 16 benchmark systematic reviews, maps, and meta-analyses (Table S3), achieving >80% relative recall (sensitivity; see details in Supplementary Methods - Piloting). We ran our main searches on 29 May 2025, retrieving 1,888 records (Fig. S2). Finally, we supplemented the searches with backward citation tracking and pre-screened syntheses from our benchmarking set that were not indexed in our main search databases.

We screened the retrieved records in Rayyan QCRI (Ouzzani et al., 2016) after deduplication. We screened all English-language records independently in duplicate at the title, abstract, and full-text stages (AL served as the primary reviewer, with AM, EL, KM, ML, SO and SN acting as second reviewers). We resolved all disagreements through discussion and recorded reasons for study exclusion at the full-text stage (Table S5). For searches in languages other than English, AL and SO screened Spanish and Portuguese; ML screened Russian and Polish; AM and SN screened Japanese; and AL screened French and Italian. Due to the high proportion of irrelevant hits in Russian, Polish, French, and Italian, a single reviewer screened those languages, whereas all other searches underwent screening by two reviewers in parallel.

2.4 Data coding and analysis

We piloted the data extraction, policy citation analysis and quality assessment (see Supplementary Methods - Piloting). We implemented predefined extraction tables in Google Sheets and Excel. AL extracted data from all included studies, and the rest of the team (EL, AM, KM, SO, ML, SN) independently cross-checked 10% of the records for each aim to ensure consistency. We resolved inconsistencies in data extraction through discussion until consensus was reached.

For the systematic map, we coded each synthesis using predefined variables (Lenz et al., 2025) and refined these categories post-extraction (see section 2.6 “Deviations from the protocol"; Table S7). We first recorded anthropogenic noise sources following descriptions used by review authors and then grouped them into 10 broader categories (Transportation, Energy, Construction, Industrial, Urban, Recreational, UAV/UAS [i.e., drones], Synthetic, Military, Unclear). We recorded the broad types of environments considered in each included review (Marine, Terrestrial, Freshwater, Urban). We documented the taxonomic scope of each review according to the terminology used by the authors; when only phylum-level information was used, we retained that classification. For broad taxonomic categories such as "Invertebrates," we kept the original label unless species-level detail allowed breaking it down to more specific categories.

For the bibliometric analysis, we extracted bibliographic data for the included syntheses from Scopus on 24 July 2025 (Dataset S2). We excluded three syntheses that were not indexed in Scopus or Web of Science. Extracted data represented publication authorship, first author country, institutional affiliation, citation counts, author- and index-supplied keywords, open-access status, and reported funding sources (Table S8). We conducted a descriptive analysis of this bibliographic data complemented by network, thematic, and geographic mapping of the author affiliation country. We visualized research networks through collaboration links among authors and countries. We harmonized publication keywords via a synonym dictionary before summarizing keyword frequencies to identify dominant research topics.

To evaluate policy attention, we followed methods from (Morrison et al., 2025b). Between 9 and 14 July 2025, we retrieved policy documents citing included syntheses from PlumX (Wong & Vital, 2017). When PlumX listed the same citing policy more than once for a review, we removed duplicates and based our counts on the unique citations (Dataset S3). We then used Overton (2025) and the full text of policy documents to identify the ecological context, topic, document type, and country of publication for each policy document, following our predefined coding variables (Table S9).

We assessed the methodological quality of included syntheses using the Collaboration for Environmental Evidence Synthesis Assessment Tool Version 2.1 (Konno et al., 2021; Woodcock et al., 2014). Using CEESAT, we evaluated syntheses across eight domains, from protocol development and eligibility criteria to synthesis methods and reporting. We appraised all studies that claimed to be systematic reviews, systematic maps, or meta-analyses, provided they included a systematic literature search (Dataset S4). We tested whether methodological quality of a synthesis was associated with its citations in policy documents. To improve comparability of the total CEESAT assessment scores between individual syntheses, we expressed the total score as a proportion of the ideal maximum of 64 points for meta-analyses and 56 points for syntheses without meta-analysis (Dataset S5; see Deviations from the protocol) and then we log-transformed the proportional CEESAT scores to correct for right-skewed distributions for use in a two-sample t-test comparing policy-cited and non-cited syntheses.

We conducted all analyses and visualizations with R version 4.5.1 (R Core Team, 2025) in RStudio version 2025.05.0+496 (Posit team, 2025). For data wrangling, we used *tidyverse* version 2.0.0 (Wickham et al., 2019). To clean and restructure our bibliometric datasets, we used *bibliometrix* version 5.0.0 (Aria & Cuccurullo, 2017). For visualization, we used *ggplot2* version 3.5.2 (Wickham, 2016), *ComplexUpset* version 1.3.3 (Krassowski, 2020), *paletteer* version 1.6.0 (Hvitfeldt, 2021), and *RColorBrewer* version 1.1.3 (Neuwirth, 2022). For geographical mapping, we used *sf* version 1.0.21 (Pebesma, 2018), *rnaturalearth* version 1.1.0 (Massicotte & South, 2025), and *rnaturalearthdata* version 1.0.0 (South et al., 2024). We also used *wordcloud2* version 0.2.1 (Lang & Chien, 2018) for the keyword mapping, and *circlize* version 0.4.16 (Gu et al., 2014) for network and circular visualization.

2.5 Deviations from the protocol

We followed the preregistration as closely as possible; however, we made six minor deviations. First, we adjusted our original Russian search string to fit the Publish and Perish character count limit (see Table S4). Second, we refined our protocol's definitions and categories of extracted variables to improve their clarity and comprehensiveness. Third, for the systematic map, we removed the "Mixed" category from "*noise source*" and "*ecosystem type*" variables due to the high frequency and limited informativeness of the "Mixed" category; instead, we allowed selection of multiple other categories per review. We also expanded the "*noise source*" categories to better reflect the range of anthropogenic noise present in the literature (see Table S7). Fifth, for policy extraction, we similarly removed the "Mixed" category from "*ecological context*" and "*document type*" variables and expanded the "*ecological context*" and "*topic*" lists of categories to better reflect the content of the policy documents (see Table S9). Sixth, although we planned to apply all CEESAT items to all syntheses, we restricted items 7.2 and 7.3 to meta-analyses reporting pooled effect estimates, because they are not applicable to other syntheses.

3 Results and Discussion

3.1 Screening results and temporal trends

Our search yielded 50 eligible syntheses of primary evidence on anthropogenic noise effects on wildlife (Table S10). Most of these syntheses were published in English (n = 48, remaining in Spanish). We found the earliest one from 2008 and the most recent from 2025 (Fig. S3). Notably, the publication rate of syntheses increased markedly after 2016, peaking in 2024 (n = 10), a trend that parallels the growth of primary soundscape research (Chung & To, 2025). This growth suggests a rising recognition of noise as a significant ecological stressor and an enhanced capacity for synthesizing this evidence. Below, we present the results and discussion for our four specific research aims in order.

3.2 Systematic Map

First, we aimed to assess the scope and methodological approaches of existing syntheses. Here, we examined five aspects: type of synthesis used, taxonomic and environmental scope, noise sources considered, and biological effects considered.

In terms of methodological approaches, among the 50 eligible syntheses, 23 employed quantitative methods, of which 19 specifically conducted meta-analyses. (Fig. 1A). We only found two systematic maps, both published in the past five years, underscoring that this evidence synthesis approach remains relatively recent in noise research despite its value for identifying evidence gaps and clusters in environmental sciences (James et al., 2016).

Regarding the taxonomic scope, syntheses on more than one broad taxonomic group, such as birds and mammals, were common (mean = 2.86 groups, SD ± 1.93; Fig. 2). However, the taxonomic scope was dominated by marine taxa, particularly vertebrates like mammals (e.g., whales and dolphins), seabirds, and fishes (Fig. 2). Other groups, such as invertebrates, amphibians, and reptiles, were comparatively rare. This imbalance may arise from differences in detectability, logistical challenges in monitoring, or variation in research priorities. As noted in previous syntheses (Morley et al., 2014; Roca et al., 2016), this taxonomic bias is a significant concern, as it risks a substantial underestimation of the true ecological effects of noise.

With respect to the environmental scope, more than half of the syntheses (n = 34) focused on marine environments, followed by terrestrial (n = 18), and freshwater (n = 17) ecosystems (17 syntheses considered more than one environment). We only found 9 syntheses that included urban systems (Fig. 1B), despite their global prevalence and ubiquity of anthropogenic noise (Yang & Lu, 2022). Although terrestrial anthropogenic soundscapes have broader spatial coverage, marine environments have been monitored for a longer period (Darras et al., 2024). This greater availability of long-term data may be linked to the higher number of primary studies, potentially explaining a greater number of syntheses focused on marine environments.

In terms of the type of noise, most of the included syntheses (n = 32) covered multiple categories of noise sources (mean = 2.84, SD ± 1.92; Fig.1C). Transportation was the most frequent source category (n = 37), often reviewed together with energy-sector noise sources (n = 23), particularly from marine vessels linked to offshore activities (e.g., wind turbines, oil platforms, and seismic surveys), synthetic noise was also used to simulate marine vessels in this context (e.g., Gomez et al., 2016; Hague & McWhinnie, 2024). In contrast, recreational, military, and UAV/UAS noise were rarely included (≤3 syntheses each). In line with our finding of limited representation of urban environments in the included syntheses, we only found nine syntheses that considered urban background noise. This finding highlights a clear research gap despite a growing encroachment of urbanisation on natural areas (Seto et al., 2012) and a growing body of primary studies on the effects of urban soundscapes on wildlife (Yang & Lu, 2022); e.g. (Francis et al., 2023; Francis & Barber, 2013).

When it comes to biological effects, most syntheses were broad in scope, typically assessing around three outcome categories (mean = 2.78, SD ± 1.50; Fig. 1D), with 37 syntheses covering multiple outcomes. Physiological and behavioural outcomes were the most frequently examined—each appearing in 35 syntheses and often assessed together (n = 30). In contrast, community-level ecological outcomes, such as population density, species richness, and interspecific interactions, were less explored (n = 19), likely reflecting the challenges of measuring responses that require long-term, resource-intensive studies (Jerem & Mathews, 2021). A small number of syntheses (n = 4) collapsed different types of outcomes into a single “animal response” category, potentially obscuring important details about the effects of noise on wildlife.

3.3 Bibliometric Analysis

Second, we aimed to examine research clusters and influences via keyword, citation, authorship and collaboration analyses. The most frequent author and indexed keywords represented broad categories such as “Animals,” “Noise pollution,” and “Noise,” followed by more specific terms like “Fish,” “Invertebrate,” and “Ecosystem” (Fig. S4). Although “Invertebrate” was a highly used keyword, our systematic map of the taxonomic scope showed that invertebrates were usually treated as a single taxonomic group, rather than analyzed in greater detail (see Fig. 2). This observation suggests that while invertebrates are acknowledged as relevant, primary studies may be scarce, as indicated by a recent study of the keyword clusters in soundscape research, where invertebrates were underrepresented despite gaining visibility in the last four years (Chung & To, 2025). However, the issue may reflect not only the scarcity of primary studies but also the way secondary syntheses handle data.

We found that two publications were likely especially influential in shaping the field. Benítez-López et al. (2010) examined road and infrastructure impacts on birds and mammals, while Shannon et al. (2016) synthesized two decades of primary studies on noise pollution’s effects on wildlife. Each has been cited more than 700 times (Fig. S3). More recently, marine noise pollution research became prominent, with (Erbe et al., 2019) and (Duarte et al., 2021) syntheses both cited already over 300 times (Fig. S3). Together, these landmark syntheses have defined key directions in anthropogenic noise research, potentially influencing both scientific inquiry and policy attention.

While the four landmark syntheses were led by the first authors representing five different countries (Fig. 4A), all authors of all syntheses represented a total of 25 countries of institutional affiliations (Fig. 4B), in line with the global relevance of anthropogenic noise pollution research (Fig 4). However, these institutional affiliations were concentrated in the United Kingdom (25%), Canada (19%), and the United States (17%), a pattern mirrored in the international collaboration networks (Fig. 4). Over half of all syntheses involved international co-authors, but these partnerships mostly linked the same hubs in North America and Western Europe. This geographical bias, likely driven by structural barriers like research funding and the dominance of English-language publishing (Amano et al., 2021; Man et al., 2004), risks ignoring ecological perspectives and localized knowledge from underrepresented regions like the tropics. As a result, the global synthesis of noise impacts may be incomplete, underscoring the need to expand collaborations and diversify research to strengthen the evidence base.

In terms of the global accessibility of the findings of included evidence syntheses, most articles were open access (n = 35), and many acknowledged their funding sources. Research funding may have facilitated open-access publishing and thereby increased visibility and dissemination. Similar patterns have been noted in medical and environmental research, where financial and linguistic barriers influence whose perspectives are included in evidence syntheses (Man et al., 2004).

3.4 Policy attention

Third, we aimed to explore the policy relevance and uptake of included syntheses. Here we noted that nearly half of the syntheses (n = 23) were cited in at least one policy document (Fig. S5), with quantitative syntheses cited most often (n = 13). Meta-analyses were the most frequent (n = 11), followed by systematic reviews without a meta-analysis (n = 10). The low number of cited systematic maps (n = 2) reflects their overall scarcity in the literature.

Policy documents that cited the 23 systematic reviews, maps, and meta-analyses (syntheses) represented seven different categories. Out of the 537 policy documents we categorised (Fig. 5), government policies were the most common document type (n = 297), followed by regulatory submissions (n = 109), and intergovernmental policy (n = 84). Less frequent (Fig. S7) were NGO reports (n = 23), think-tank publications (n = 13), academic advisory documents (n = 2), and other document types (n = 9).

In terms of the environmental context of policy documents, we found that most were related to two themes (Fig. 5): conservation (n = 228) and energy (n = 115). Government policies mostly addressed conservation, while regulatory submissions often focused on energy projects. Regarding the ecological context of citing policy documents, marine systems were the most frequently addressed (n = 230), especially after 2015 (Fig. S6B), followed by terrestrial environments (n = 150), and coastal systems (n = 45). The citations in relevant policy documents over the years likely reflects the publication trends of the syntheses themselves, especially in marine and energy contexts (Fig. S9). In particular, the increased citations in conservation-related policy documents (Fig. S6) may reflect the heightened activity of the energy-sector and the stricter permitting rules (Charamis et al., 2025; Tufan & Dalcalı, 2025).

Most of the retrieved policy documents were published in the United States (n = 132), followed by Canada (n = 97; Fig. S8). This geographic concentration mirrors countries with well-developed noise-control legislation but may also reflect biases in policy visibility and language, underrepresenting policy actions in other regions (Mediastika et al., 2025).

3.5 Critical appraisal

Fourth, we aimed to evaluate the methodological quality of included syntheses and to compare it between syntheses cited and not cited in policy documents. Our appraisal of 44 syntheses showed overall low methodological and reporting quality, with most syntheses failing to meet the highest CEESAT standards (gold) (Fig. 6). Across the appraised syntheses, the majority of CEESAT scores fell within the medium and low-quality categories (Amber and Red, respectively), with an average of 38.6% of syntheses rated Amber and 38.2 % rated Red across all assessed items. In comparison, Green (acceptable confidence in findings; Woodcock et al., 2014) scores accounted for 14.9% and Gold scores for just 4.2% of syntheses. For most of the individual CEESAT items, more than 75% of syntheses were rated Amber or Red, indicating substantial gaps in methodological rigour and transparency for most of the assessed quality aspects. The highest-scoring item was CEESAT 7.1, with 40.9% of the syntheses rated as Gold or Green, indicating that many syntheses described and justified their synthesis method well. This was followed by CEESAT 6.2, with 38.7% rated Gold or Green, reflecting sufficient reporting of extracted data. In contrast, assessment scores were very low for the following items: CEESAT 1.1 “clarity of the review question” had 65.1% Amber scores, CEESAT 2.1 “reporting a predefined protocol” had Gold or Green in only 2.3% of syntheses, and CEESAT 5.1 “critical appraisal of included studies” in just 4.6%. Although syntheses cited in policy had a higher maximum quality score (47/64) than those not cited (29/64), there was no statistically significant difference in their average scores (two-sample t-test: $t = -0.31$, df = 37.74, $p = 0.75$, 95% CI: –0.30 to 0.22; Fig. S10). This finding—that reporting and methodological quality are not associated with policy uptake—aligns with broader concerns that low-quality evidence syntheses can misrepresent the state of knowledge and mislead environmental policy (Cook et al., 2013; Morrison et al., 2025b).

The poor CEESAT scores of the assessed syntheses likely stem from inconsistent adoption of reporting standards such as ROSES and PRISMA, a known issue in environmental synthesis (O'Leary et al., 2016). Poor reporting reduces transparency and reproducibility, affecting assessments of methodological quality (Morrison et al., 2025a). To strengthen the evidence base and improve its reliability for policy and management, future syntheses must implement more rigorous reporting and conduct practices. These include a priori protocol registration, adherence to established reporting guidelines (e.g., ROSES), clear question definition using frameworks such as PECO, and the critical appraisal of all included studies, if possible.

4 Limitations and opportunities

Despite the systematic approach of our review, we acknowledge that our work has at least four methodological constraints, which also point to future research opportunities. First, we excluded grey literature from our study. As a result, our dataset underrepresents Master's and PhD theses, as well as technical reports that never reach journals, which often come from regions with limited funding or less charismatic taxa, and thus also may bias the evidence base. Second, several constructs used during data coding might be overlapping (e.g., "urban" versus "terrestrial", "dredging" vs. "mining/industrial"). Alternative categorizations could yield subtly different distributions in our map. Third, our data extractions and analyses were limited by what syntheses reported. For example, about a quarter of syntheses reported noise frequency information in hertz (Hz); most described noise with generalized labels ("low/high frequency") or used decibel (dB) levels without specifying spectral content. Similarly, many syntheses (including some meta-analyses) only defined exposure broadly as "anthropogenic noise" or pooled multiple noise sources into a single category, precluding source-specific effect estimates and moderator tests in quantitative syntheses. This could be because primary studies themselves did not report the measures and sources of noise in a complete and standardized way. Complete and standardized reporting of noise types and measures in both primary and secondary literature would enable more consistent categorization (e.g., infra-/audible/ultrasonic regimes) and statistical analyses. Similarly, many syntheses used coarse taxonomic groupings of study subjects at different taxonomic levels. This practice may obscure differences in the effects of anthropogenic noise at the clade level, and limit species-specific interpretations. Fourth, although we searched the literature using English and eight additional languages, we may have still missed non-English literature in other languages (e.g., Chinese). Therefore, some linguistic bias potentially remains restricting the scope of synthesized evidence and insights. Together, these shortcomings may limit the reliability, usability, and policy relevance of the findings.

5 Conclusions and broader implications

Our evidence map highlights the rapid growth of syntheses on anthropogenic noise and wildlife, but also reveals substantial inconsistencies in methodology, reporting, and scope. These weaknesses limit the ability of current syntheses to provide clear, actionable guidance for conservation and policy. Moving forward, four actions are critical to strengthening evidence synthesis efforts in this expanding research field. First, adherence to established minimum reporting and conduct standards will produce more transparent and reliable evidence syntheses (Page et al., 2021). Second, wider adoption of structured question formulation, protocol registration, and critical appraisal should improve methodological rigour (Shea et al., 2017; Woodcock et al., 2014). Third, pursuing greater granularity in synthesized information could support context- and species-specific conclusions that are meaningful for management. Fourth, fostering inclusive collaborations across linguistic backgrounds can broaden the evidence base. Together, these steps will improve the robustness, transparency, and inclusivity of future syntheses, advancing the field toward a cumulative science capable of guiding effective policies and protecting ecosystems in an increasingly noisy world.

Credit authorship contribution statement

Anna Lenz: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing.

Ayumi Mizuno: Data curation, Formal analysis, Methodology, Validation, Visualization, Funding acquisition, Writing – review & editing.

Erick Lundgren: Data curation, Formal analysis, Methodology, Validation, Visualization, Funding acquisition, Writing – review & editing.

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Malgorzata Lagisz: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing.

Shinichi Nakagawa: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used GPT-5.0 implemented in OpenAI, and Grammarly Gen AI version 14.1254.0 to enhance clarity, readability, and flow of writing. Generative AI (GitHub Copilot-1.236.0 in RStudio version 2025.05.0+496 and GPT-4.0 and GPT-5.0 OpenAI) was also used to aid in annotating code. However, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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.

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Data availability

All data and code are in the GitHub repository: https://github.com/AnnaLenzR/Umbrella_review_noise_impact_on_wildlife.git

Appendix. Supplementary files

A supplementary file containing additional methodological details, figures and tables is provided with the submission.

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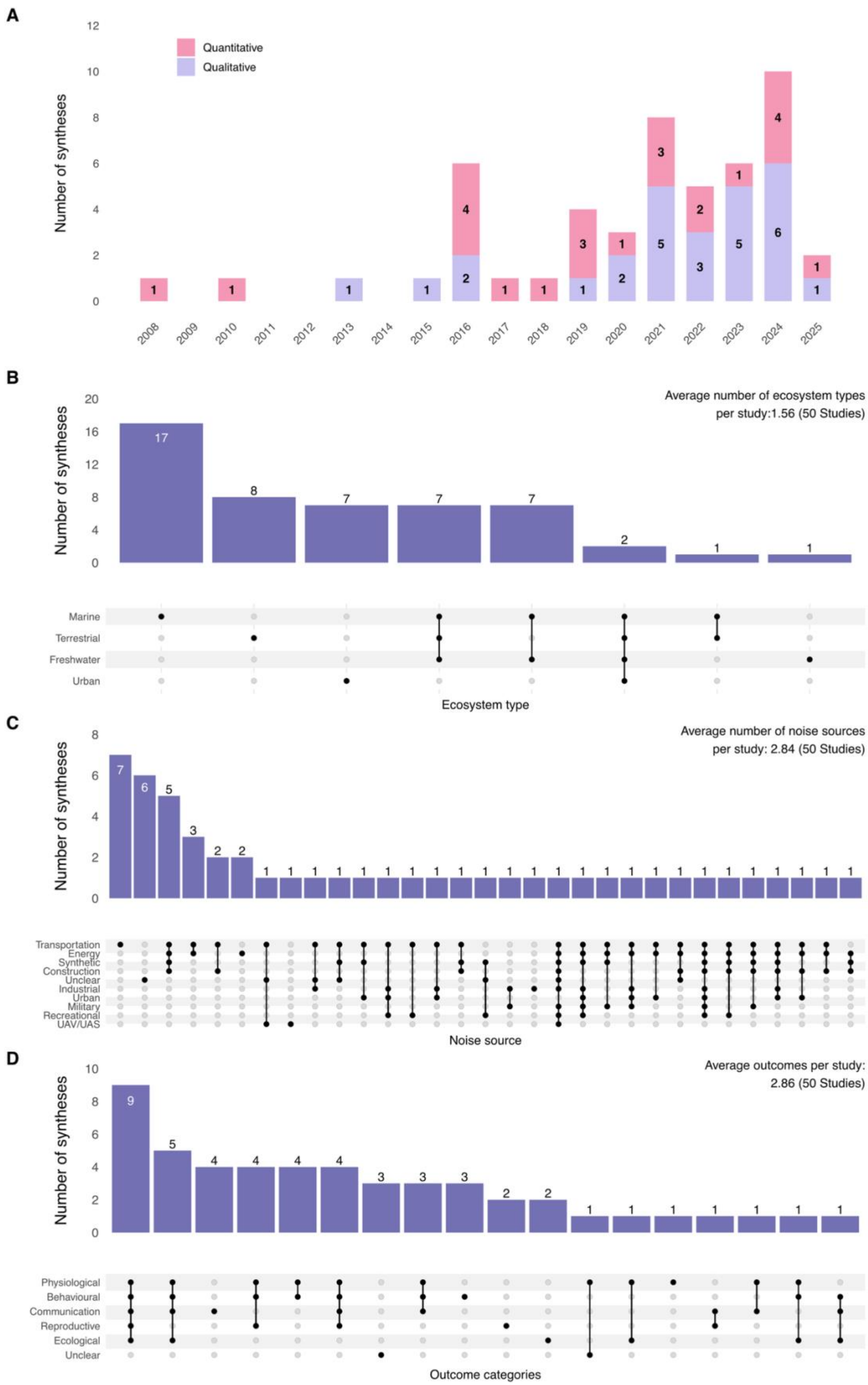
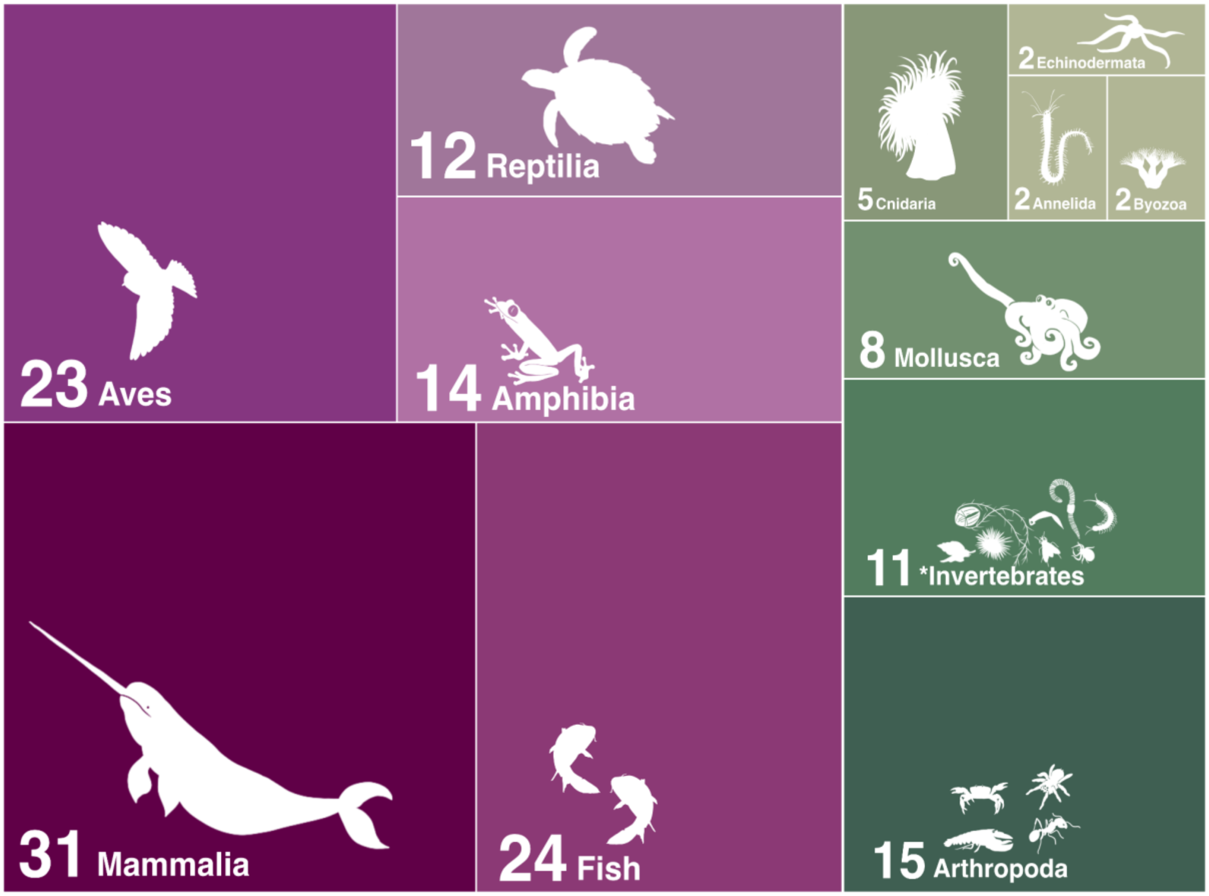

A
Quantitative
Qualitative
Number of syntheses
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
B
Average number of ecosystem types per study:1.56 (50 Studies)
Number of syntheses
Marine
Terrestrial
Freshwater
Urban
Ecosystem type
C
Average number of noise sources per study: 2.84 (50 Studies)
Number of syntheses
Transportation
Energy
Synthetic
Construction
Unclear
Industrial
Urban
Military
Recreational
UAV/UAS
Noise source
D
Average outcomes per study: 2.86 (50 Studies)
Number of syntheses
Physiological
Behavioural
Communication
Reproductive
Ecological
Unclear
Outcome categories

Figure 1. Review characteristics and content mapping. A) The count of syntheses that used a qualitative-only or quantitative synthesis approach (systematic reviews with meta-analysis or other statistical aggregation methods) over the years. B) An upset plot showing the count of categories of ecosystem types and their combinations reported in the systematic reviews. The vertical bars show the counts of the specific outcome combinations indicated by black dots and lines. C) An upset plot showing the count of reviewed anthropogenic noise sources by category and their combinations. The vertical bars show the counts of the noise source combinations indicated by black dots and lines. D) Count of different broad wildlife outcomes and their combinations synthesized in our data set. The vertical bars show the counts of the ecosystem type combinations indicated by black dots and lines.



23 Aves
12 Reptilia
14 Amphibia
31 Mammalia
24 Fish
5 Cnidaria
2 Echinodermata
2 Annelida
2 Byozoa
8 Mollusca
11 *Invertebrates
15 Arthropoda

Figure 2. Taxonomic scope of included syntheses. This treemap displays the taxonomic groups represented in the systematic secondary literature, with box size proportional to the number of unique syntheses (one review can encompass one or more taxonomic groups). Each box is labelled with the group name and review count. Vertebrates (purple) are classified at the class level, except for "Fish," which most syntheses treat as a broad category likely encompassing all three extant classes (Agnatha, Chondrichthyes, Osteichthyes). Invertebrates (green) are grouped by phylum, or into a broader "Invertebrates" category when finer resolution was unavailable. The Arthropoda categories included marine and terrestrial species; in most cases, syntheses did not report species names.

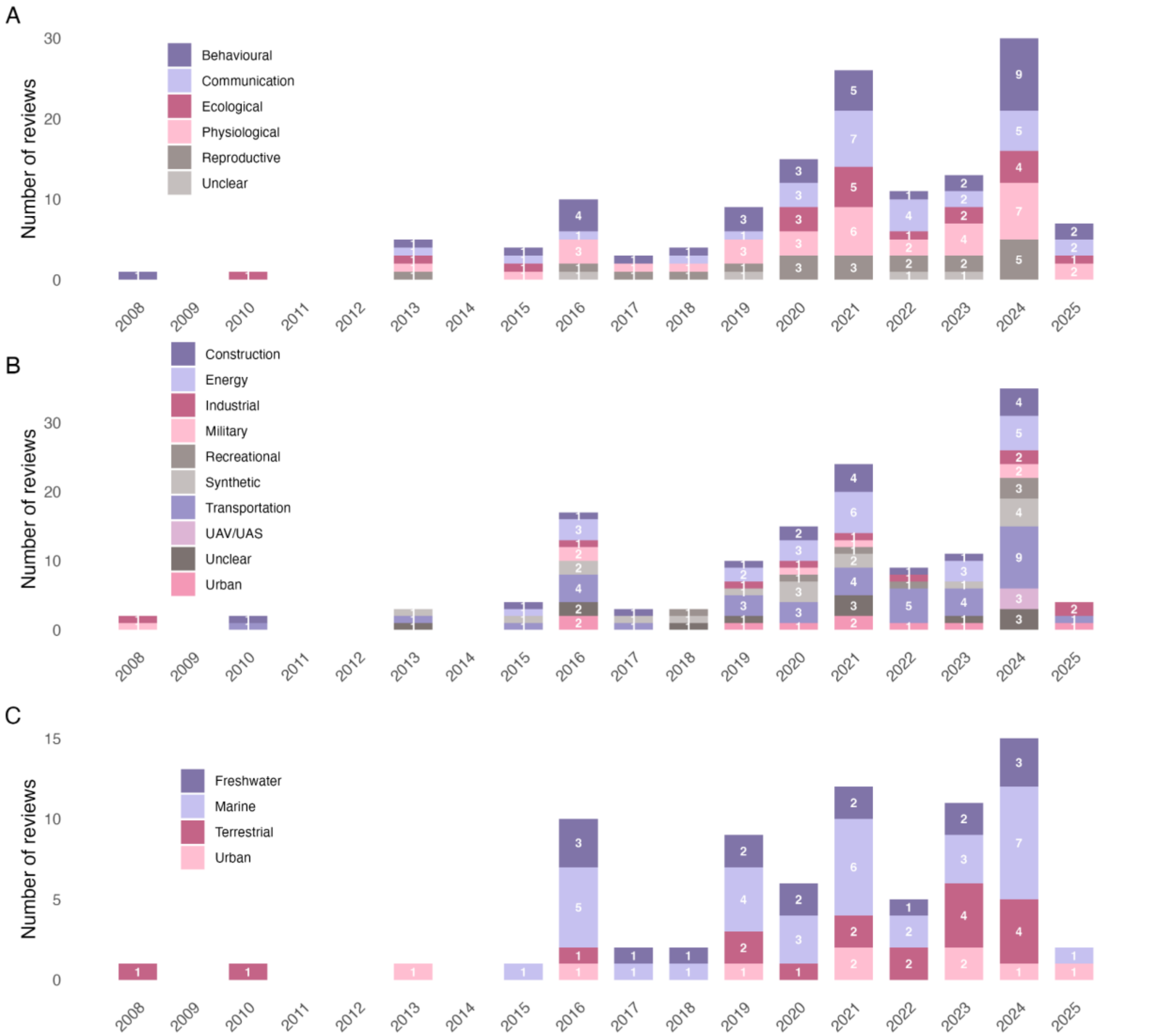

A
Number of reviews
Behavioural
Communication
Ecological
Physiological
Reproductive
Unclear
B
Number of reviews
Construction
Energy
Industrial
Military
Recreational
Synthetic
Transportation
UAV/UAS
Unclear
Urban
C
Number of reviews
Freshwater
Marine
Terrestrial
Urban
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025

Figure 3. Annual trends in synthesized evidence from included syntheses (2008–2025). The figure displays annual trends for three categories of reviewed study characteristics: (A) wildlife outcome type, (B) noise source type, and (C) environment category. The numbers within the bars show the count for each category.

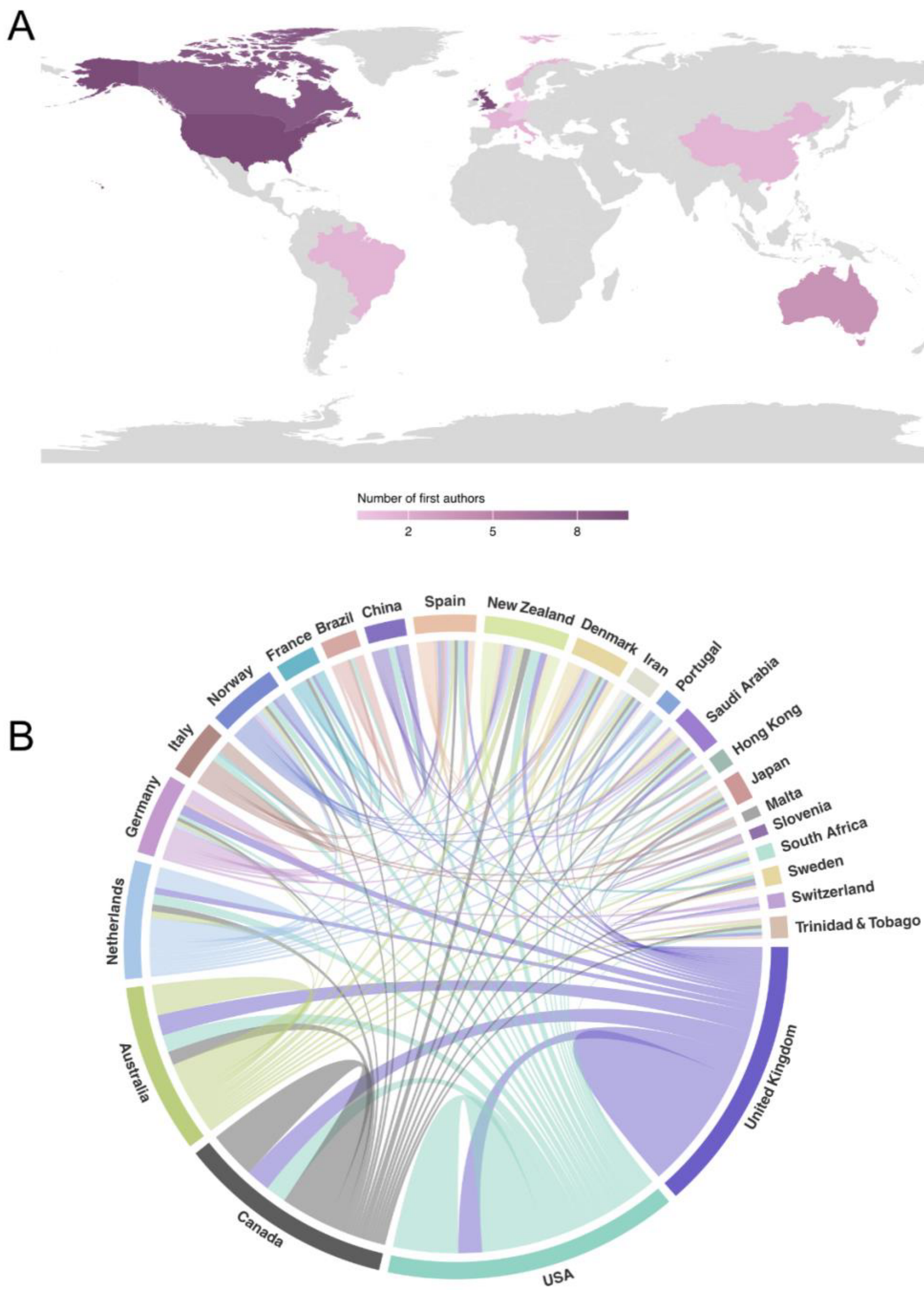

A
Number of first authors
2
5
8
B
Spain
New Zealand
Denmark
Iran
Portugal
Saudi Arabia
Hong Kong
Japan
Malta
Slovenia
South Africa
Sweden
Switzerland
Trinidad & Tobago
United Kingdom
USA
Canada
Australia
Netherlands
Germany
Italy
Norway
France
Brazil
China

Figure 4. Analysis of author affiliation and international collaboration. (A) Geographic map of the affiliation country for each first author. (B) Chord diagram visualizing the co-authorship network. Each segment represents a country, and the connecting chords represent co-authored reviews, with their width scaled to the volume of collaboration between the two countries.

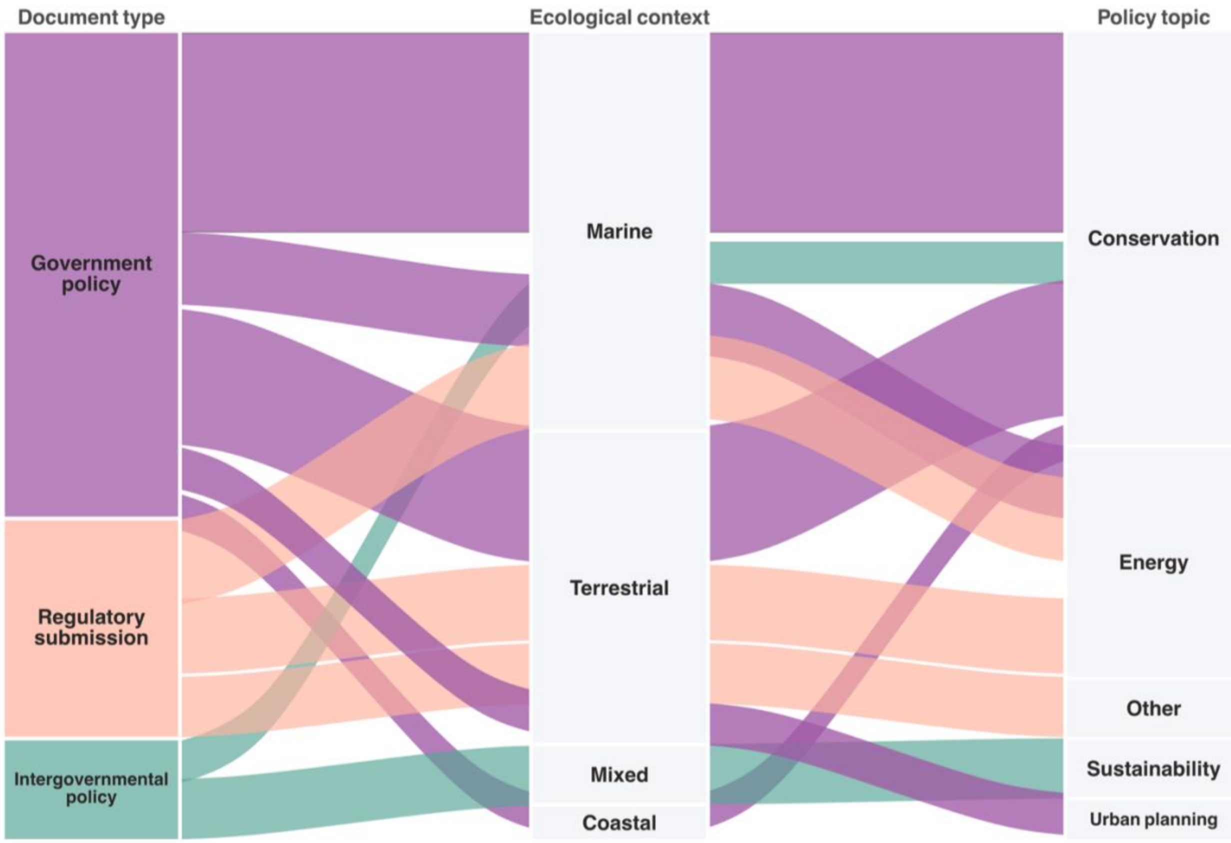
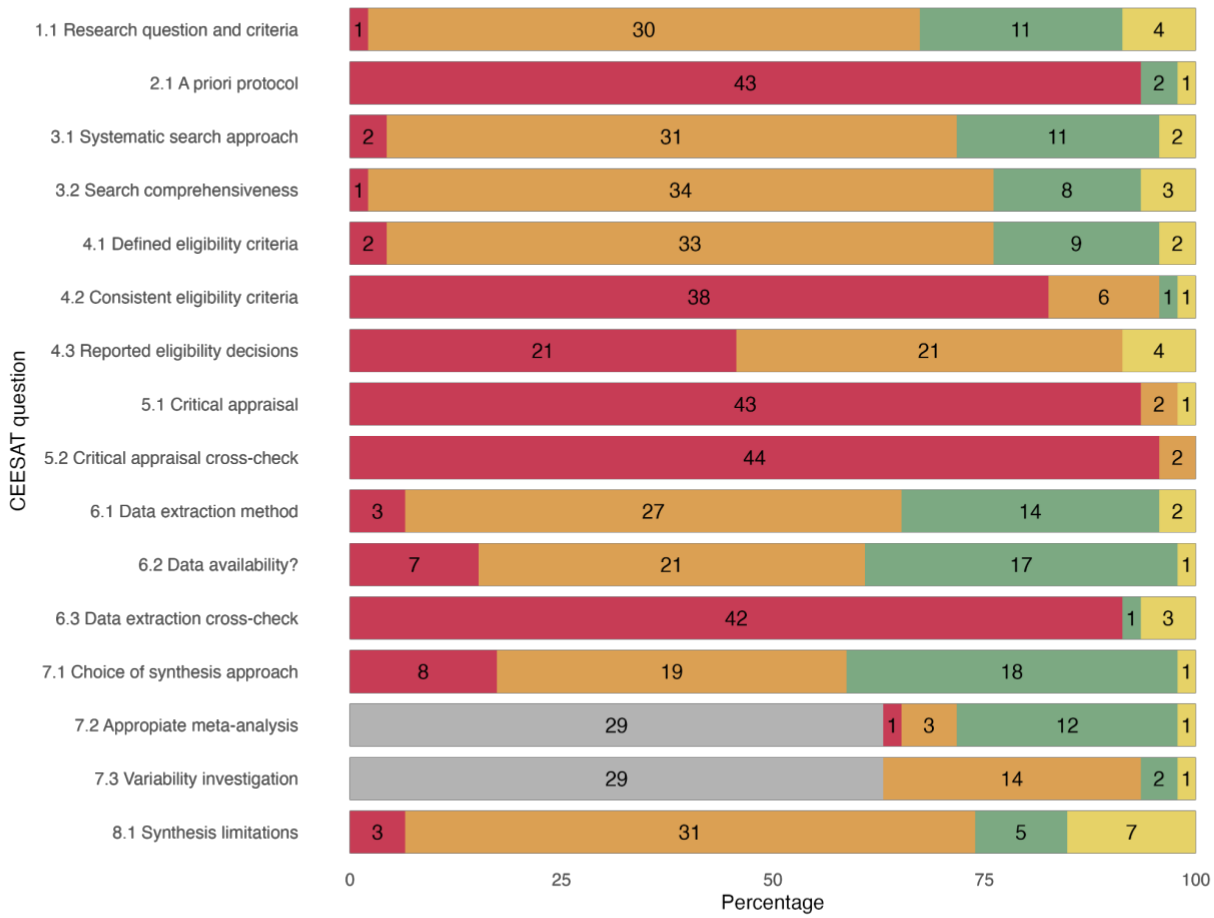

Document type
Ecological context
Policy topic
Government policy
Regulatory submission
Intergovernmental policy
Marine
Terrestrial
Mixed
Coastal
Conservation
Energy
Other
Sustainability
Urban planning

Figure 5. Scope of the policy documents that cited the included synthesis on noise impacts on wildlife. Alluvial plot showing the connections between Policy document types (left), Ecological contexts (middle), and Policy topics (right). Flow widths are proportional to the number of documents linking categories. Government policies mostly addressed marine conservation, regulatory submissions (permit applications) focused on marine and terrestrial energy projects, and intergovernmental policies emphasized sustainability in mixed contexts; overall, marine–conservation and terrestrial–energy linkages dominated, while urban contexts were rarely considered. Only the most common categories are shown for each scope aspect – for a plot with all categories, see Fig. S7.



1.1 Research question and criteria
2.1 A priori protocol
3.1 Systematic search approach
3.2 Search comprehensiveness
4.1 Defined eligibility criteria
4.2 Consistent eligibility criteria
4.3 Reported eligibility decisions
5.1 Critical appraisal
5.2 Critical appraisal cross-check
6.1 Data extraction method
6.2 Data availability?
6.3 Data extraction cross-check
7.1 Choice of synthesis approach
7.2 Appropiate meta-analysis
7.3 Variability investigation
8.1 Synthesis limitations
CEESAT question
Percentage
0
25
50
75
100

Figure 6. Reporting and methodological quality of included syntheses. Distribution of scores for each CEESAT 2.1 (Woodcock et al., 2014) item across all assessed syntheses (n = 47), with scores represented by colour (highest to lowest: Gold, Green, Amber, and Red). Numbers inside the bars show the count of syntheses achieving each score. The gray colour (n = 29) represents synthesis with no pooled effect meta-analysis, where we did not apply items 7.2 and 7.3.

Supplementary Methods

Piloting

For full details of project development, please see our protocol archived in (https://osf.io/dmjc4/).

The workflow is summarised in Table S6. In brief, we validated our search strategy against a predefined benchmark of 18 systematic reviews, systematic maps, and meta-analyses on the impact of anthropogenic noise on wildlife, identified through open-access platforms such as Google Scholar and ResearchGate (see Table 3). We tested our preliminary search strings in both Scopus and Web of Science to determine whether search strings can retrieve benchmark studies, and we refined the terms iteratively to maximize sensitivity while minimizing irrelevant results (Table S4).

We used the final search strings on Scopus and Web of Science on May 29, 2025. We tested preliminary search strings in both databases using 16 benchmark studies. In Scopus, all 16 studies were indexed, and the final search string retrieved 14 of them, yielding a relative recall of 87.5%. The two missing studies were not retrieved because of the limited indexing of synthesis-related terms. In Web of Science, only 14 of the 16 benchmark studies were indexed. The final search string retrieved 12 of these, giving a relative recall of 85.7%. The two excluded studies were not indexed in Web of Science (DOIs: 10.1121/2.0000291 and 10.1121/2.0001217).

We then piloted the screening process by drawing a random sample of 100 records from the Scopus search. We performed screening of titles and abstracts, followed by full-texts, in Rayyan QCRI (Woodcock et al., 2014). Double screening these records enabled us to assess the clarity and consistency of our PECOS eligibility criteria and to identify inclusion rules for challenging cases, such as studies with mixed populations or multiple environmental stressors.

Finally, we piloted data extraction for both the systematic map and policy relevance aims. For Aim 1, we tested the extraction table on five studies, which resulted in refinements to the variable definitions and structure. For Aim 3, we pilot-extracted PlumX metrics and sampled several policy documents per review to test and finalize our attention analysis variables.

For Aim 4, the scope search and screening pilot helped refine our study type inclusion criteria by identifying syntheses that provided sufficient methodological detail to be appraised using CEESAT 2.1 (Woodcock et al., 2014).

Supplementary Figures

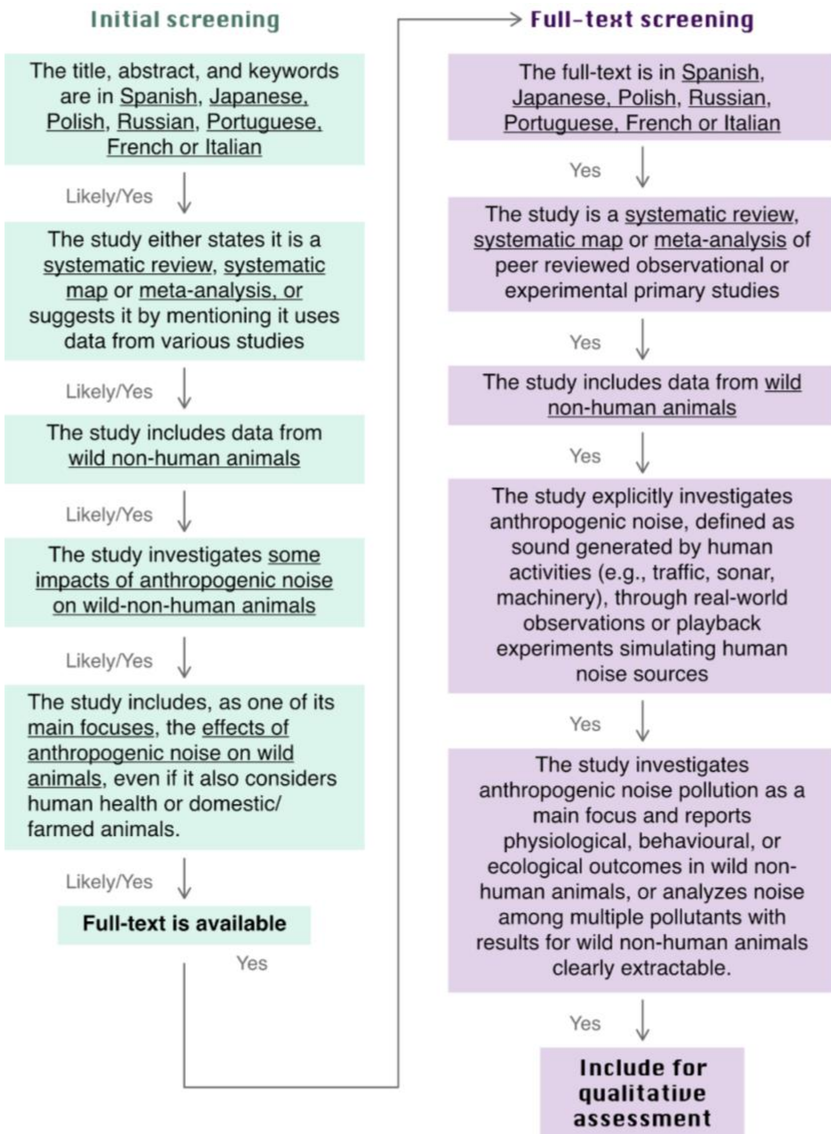


Figure S1. Criteria and Decision Tree for Review Eligibility. This flowchart illustrates the eligibility of syntheses for inclusion in the systematic map during the two screening stages: initial (based on title, abstract, and keywords) and full text. The criteria for inclusion are based on the Population, Exposure, Comparator, and Outcome (PECO) framework (details in Tables S1 and S2), and this decision tree was applied by at least two screeners in both screening stages.

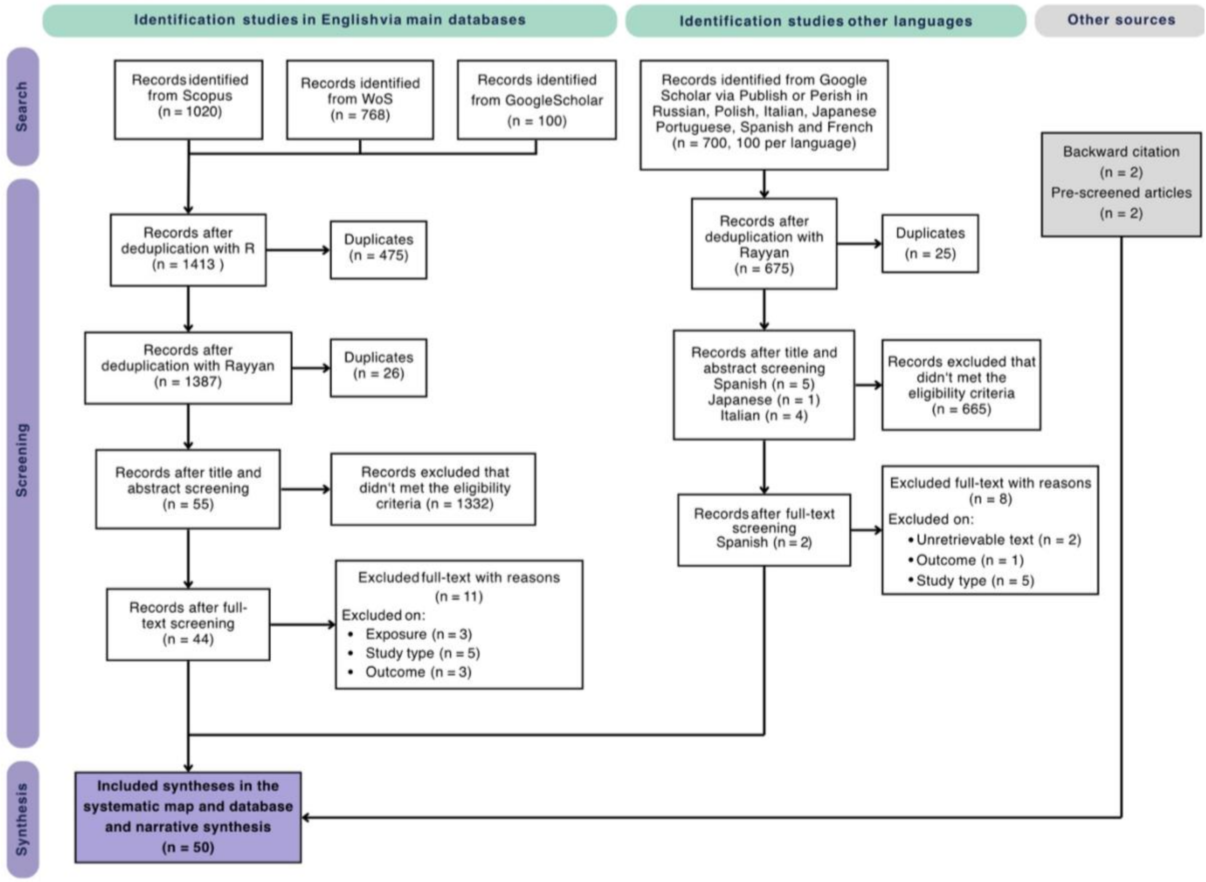


Figure S2. PRISMA flow diagram of study identification, screening, and inclusion. Searches of Scopus, Web of Science, and Google Scholar yielded 1,888 English-language records, and Publish or Perish searches identified 700 non-English records across seven languages (100 per language). After deduplication, 1,387 English and 675 non-English records were screened by title and abstract. Fifty-five English and ten non-English articles proceeded to full-text screening, resulting in 44 English and two Spanish articles that met the inclusion criteria. An additional four records were included from other sources (two backward citations and two pre-screened articles from the benchmarking set), resulting in a final dataset of 50 syntheses. All records were screened independently by at least two team members, with disagreements or special cases resolved by a third screener. Reasons for exclusion at the full-text screening stage are provided in Table S6.

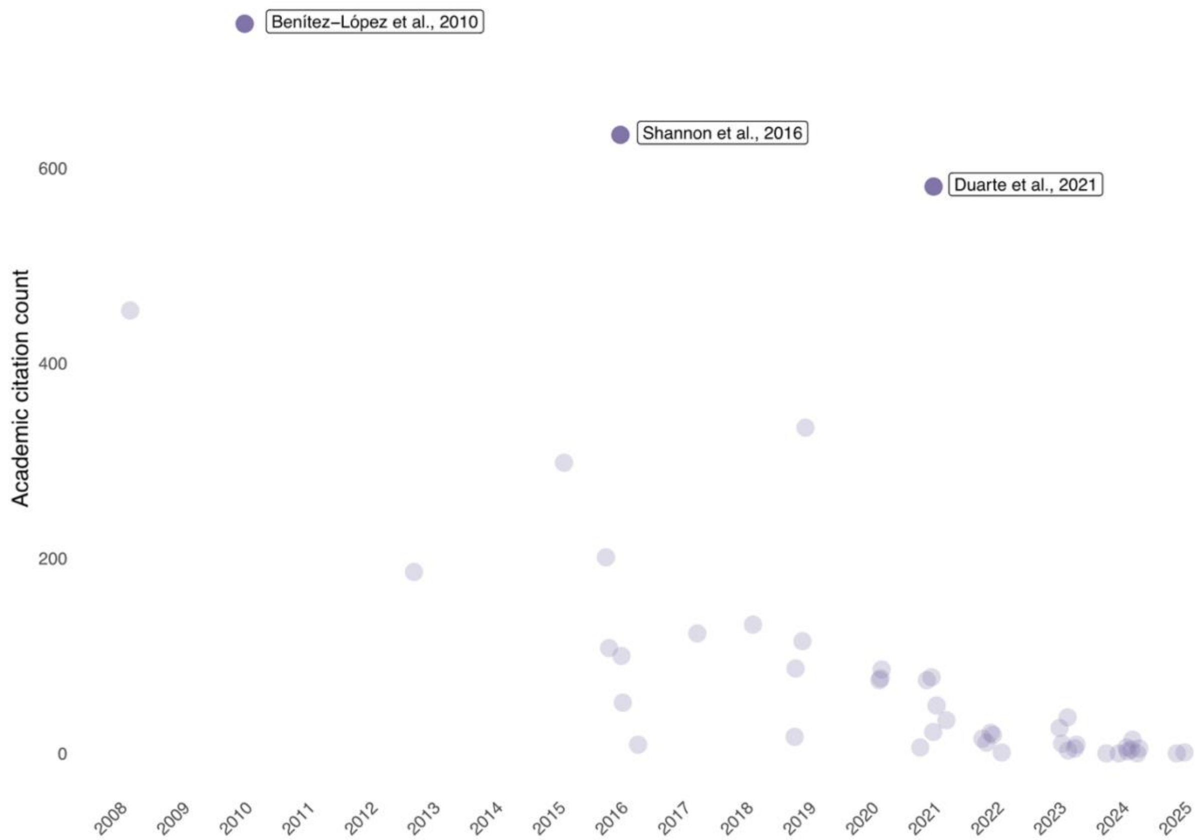


Figure S3. Total citation counts for the 50 included syntheses on the impact of noise pollution on wildlife. The citation metrics were obtained from Scopus on July 24, 2025. The x-axis represents the synthesis publication year, and the y-axis represents the total citation count per synthesis. The three syntheses with the most citations are labelled with their shorthand references.

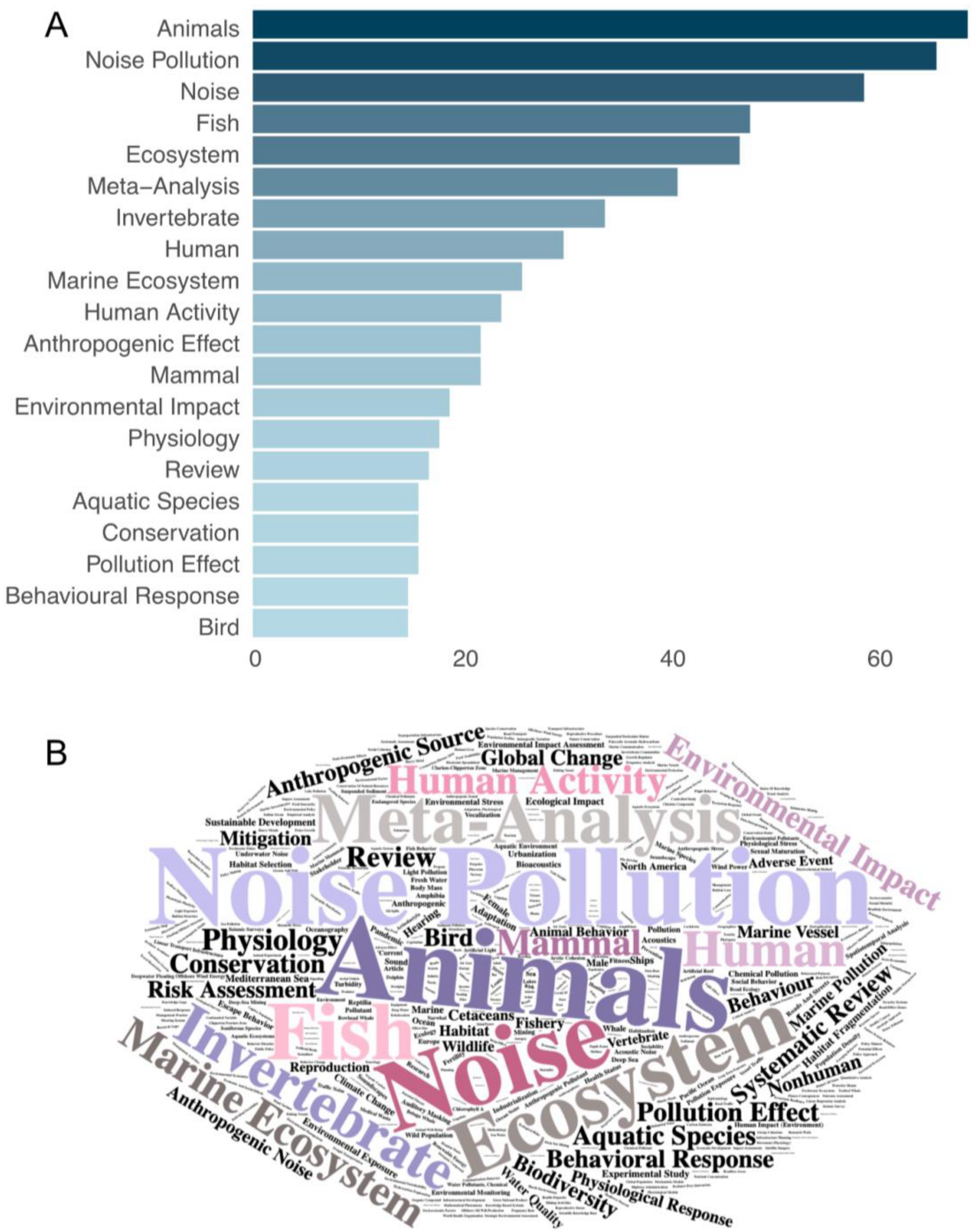


Figure S4. Topic analyses. (A) counts of the top 20 most common keywords. (B) Word cloud of the combined author and indexed keywords.

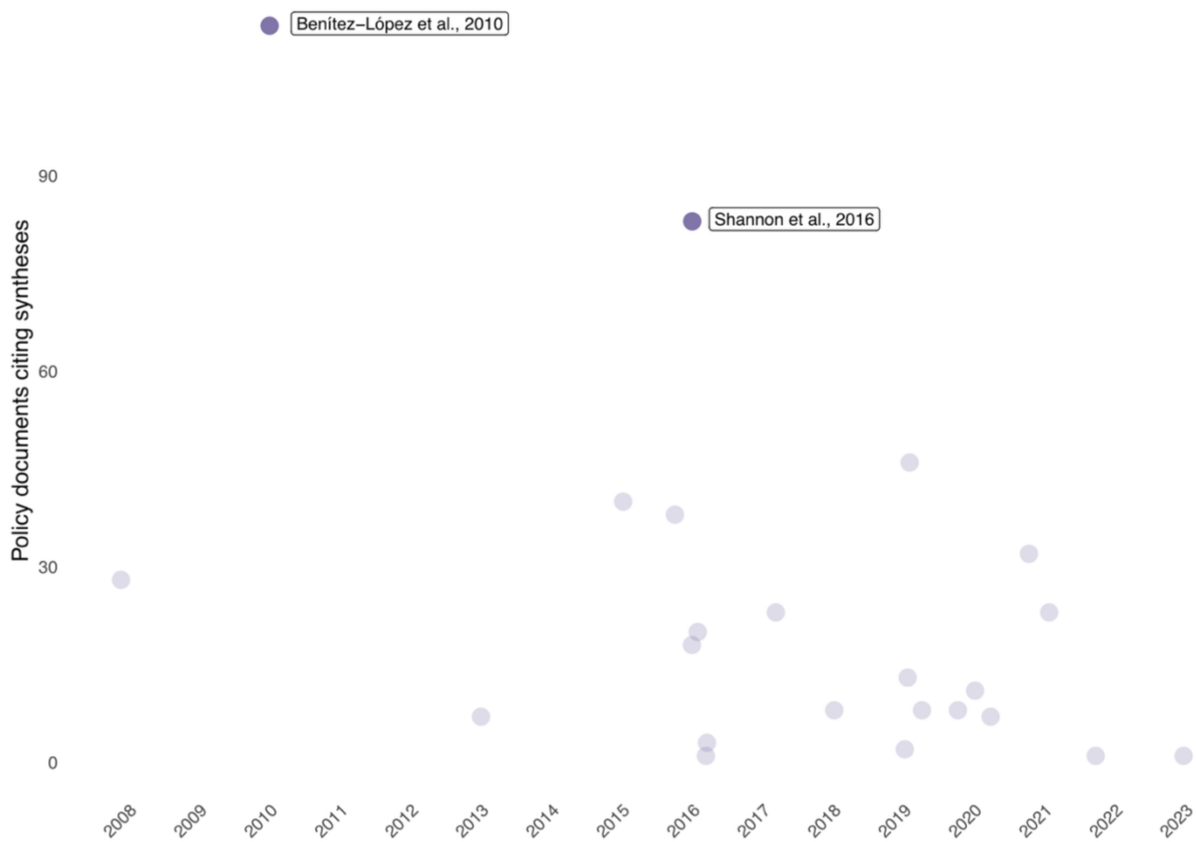


Figure S5: Total count of policy document citations for 50 included syntheses on the impact of noise pollution on wildlife. We obtained the citation data from PlumX on July 9, 2025. The x-axis represents the publication year of the synthesis, and the y-axis represents the total count of policy document citations per synthesis. The two syntheses with the most citations in policy documents are labelled with their shorthand references.

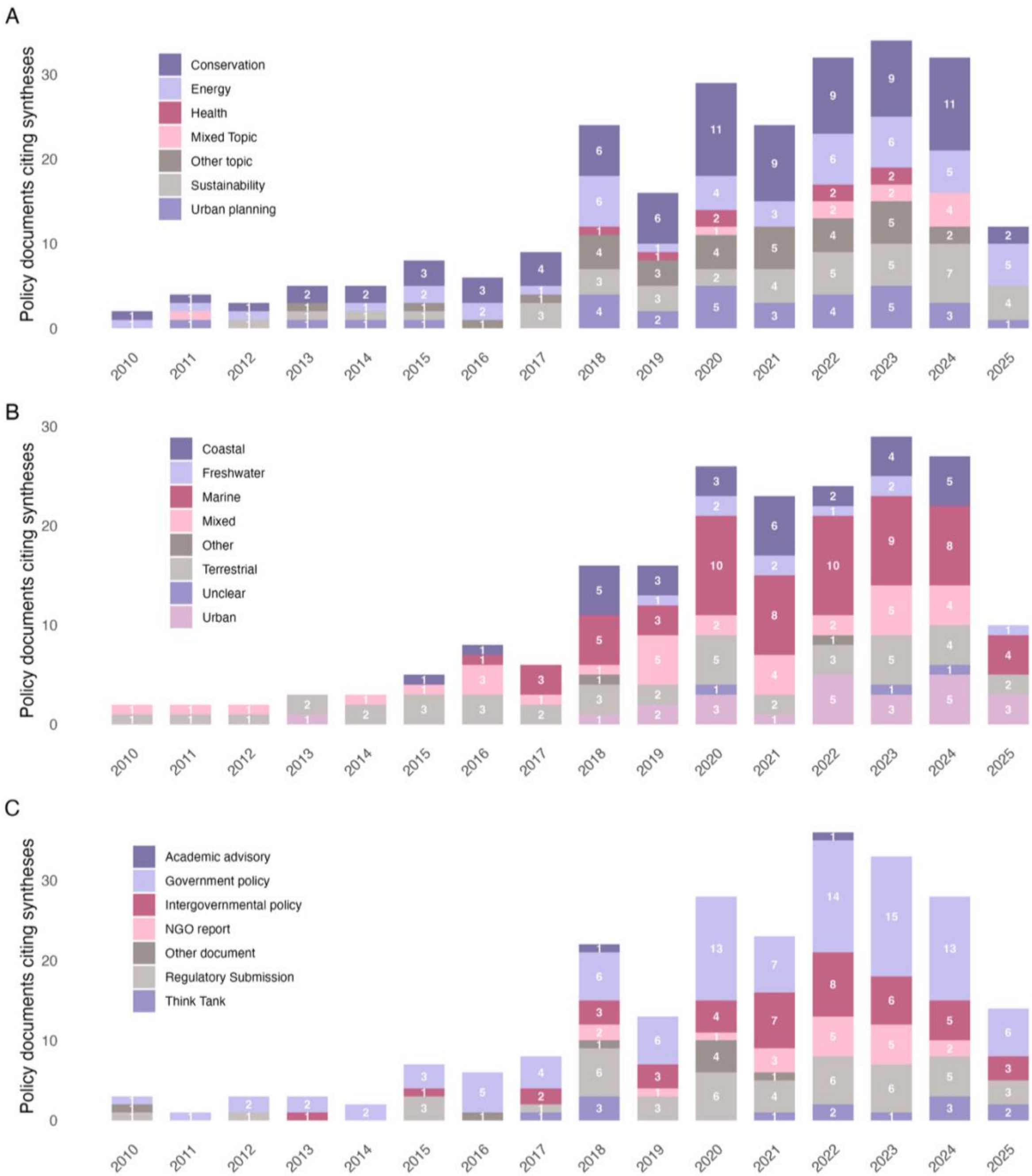


Figure S6. Annual trends in the policy documents that cited the secondary literature on noise pollution. (A) Annual trends in topics, with numbers in bars indicating counts of each topic covered. (B) Annual trends in the ecological context of the policy documents, with numbers in bars indicating counts of each ecological context category. (C) Annual trends in document type across years, with numbers in bars indicating counts of each document type.

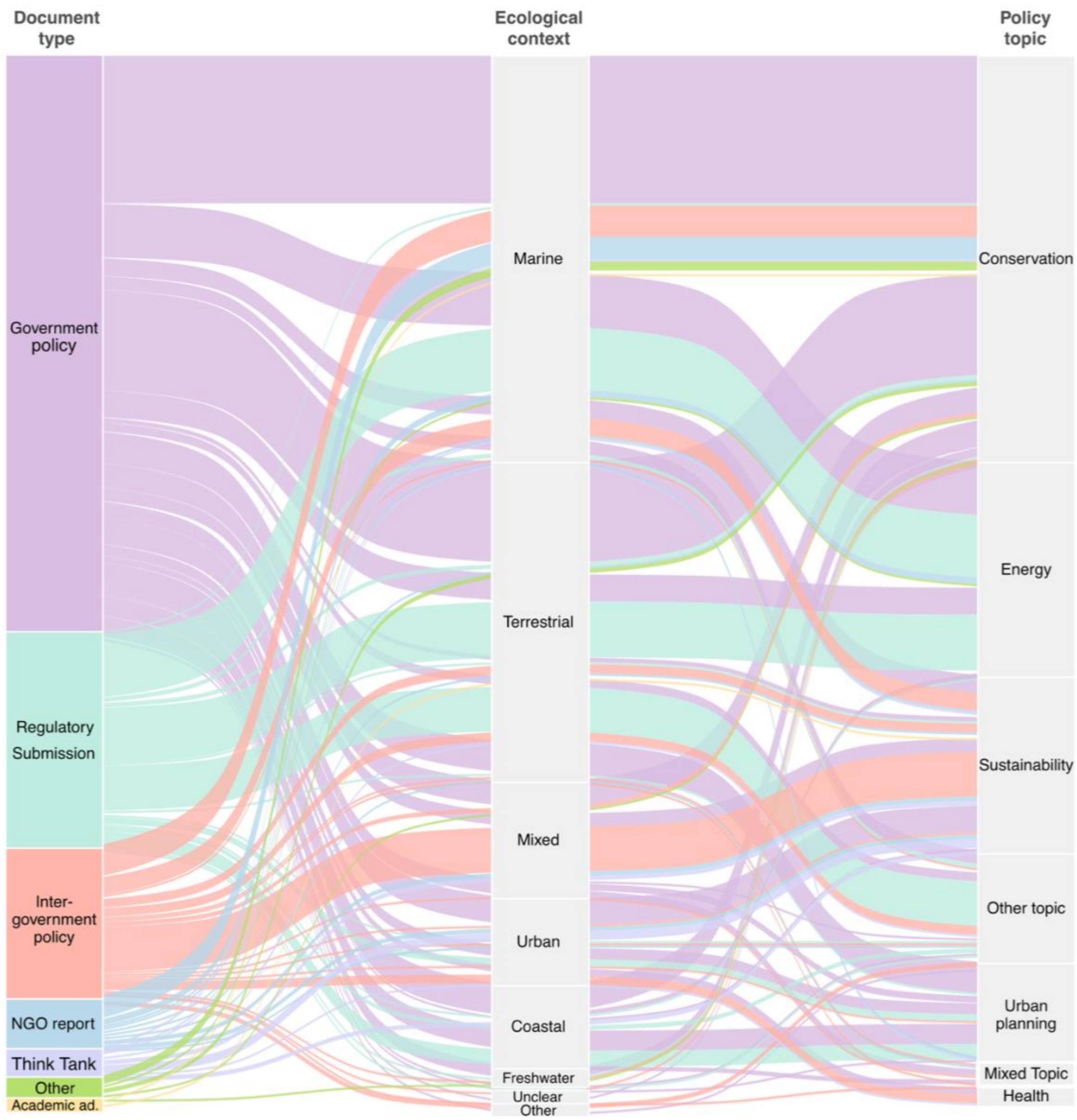


Figure S7. Analysis of the policy documents that cited the included synthesis on noise impacts on wildlife. Alluvial plot showing the connections between Policy document types (left), Ecological contexts (middle), and Policy topics (right). The widths of connectors are proportional to the number of documents linking categories.

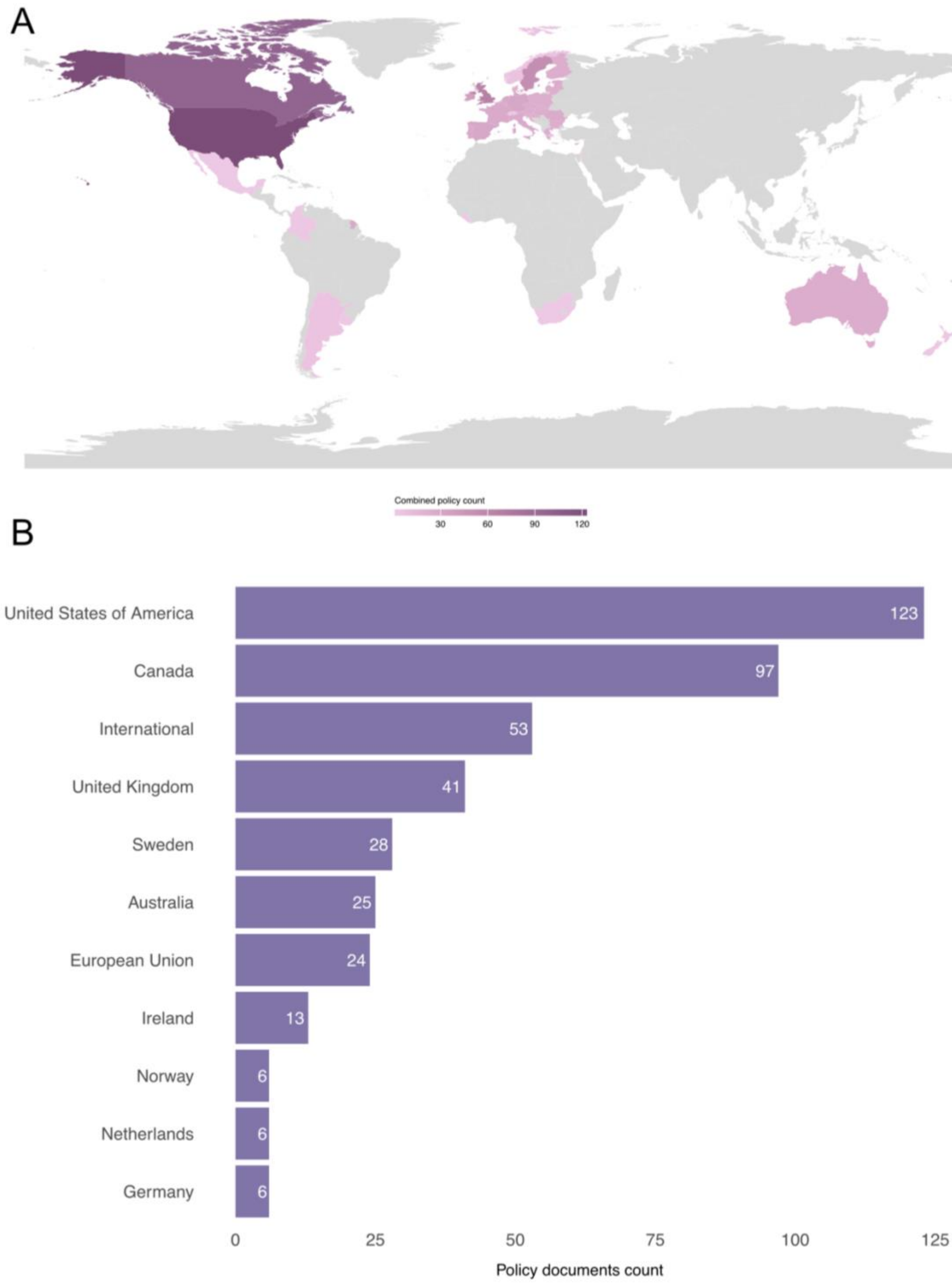


Figure S8. Geographical distribution of the policy documents. (A) Map showing the countries and regions where the policy documents citing the included syntheses are published. (B) Bar graph showing the top ten countries that published policy documents.

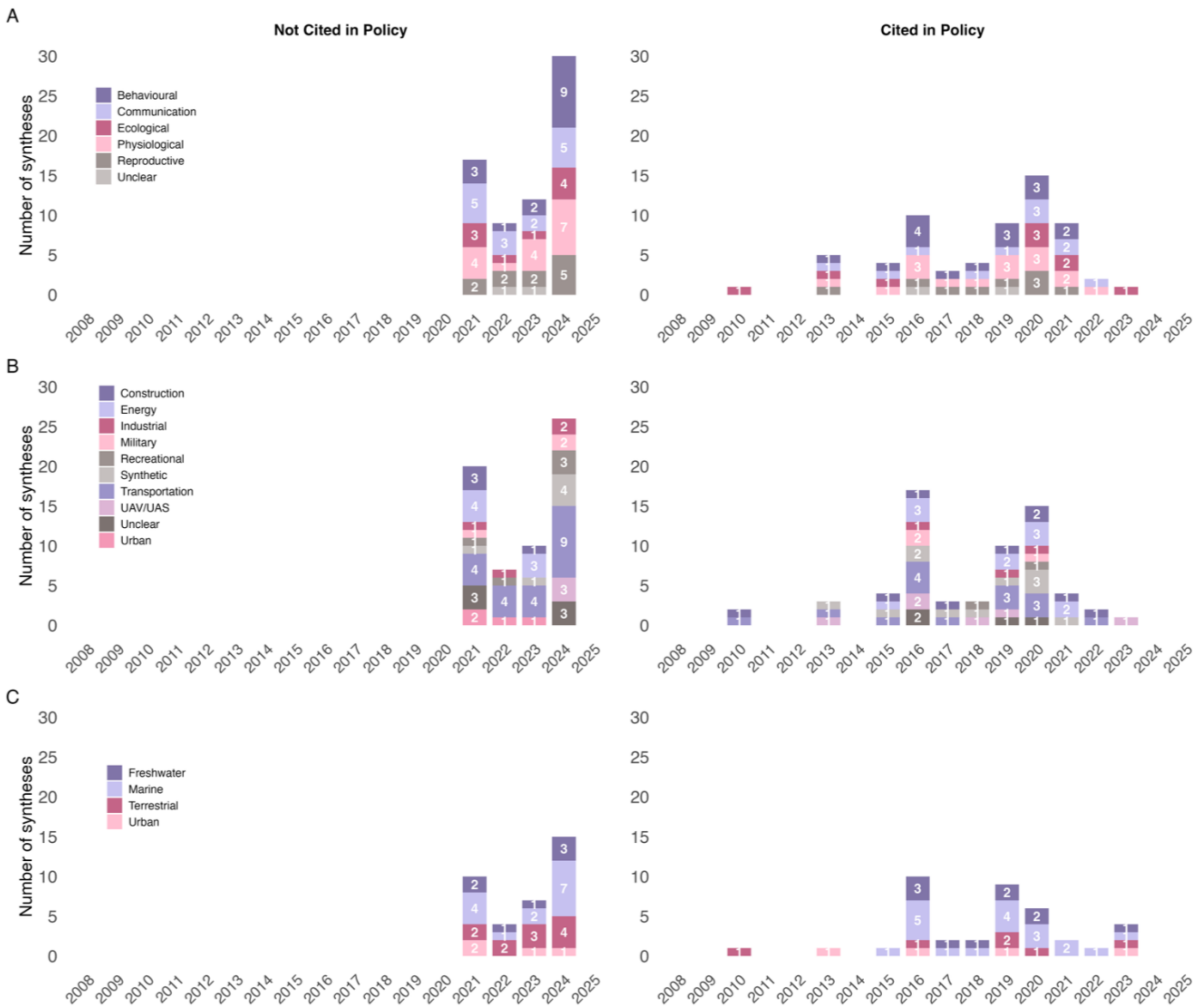


Figure S9. Annual trends in synthesized categories from included syntheses (2008–2025) for syntheses cited (left) and not cited in policy documents (right). The figure compares syntheses across their scopes regarding: (a, b) outcome, (c, d) noise source, and (e, f) ecosystem type. The numbers within the bars show the count of mentions for each category.

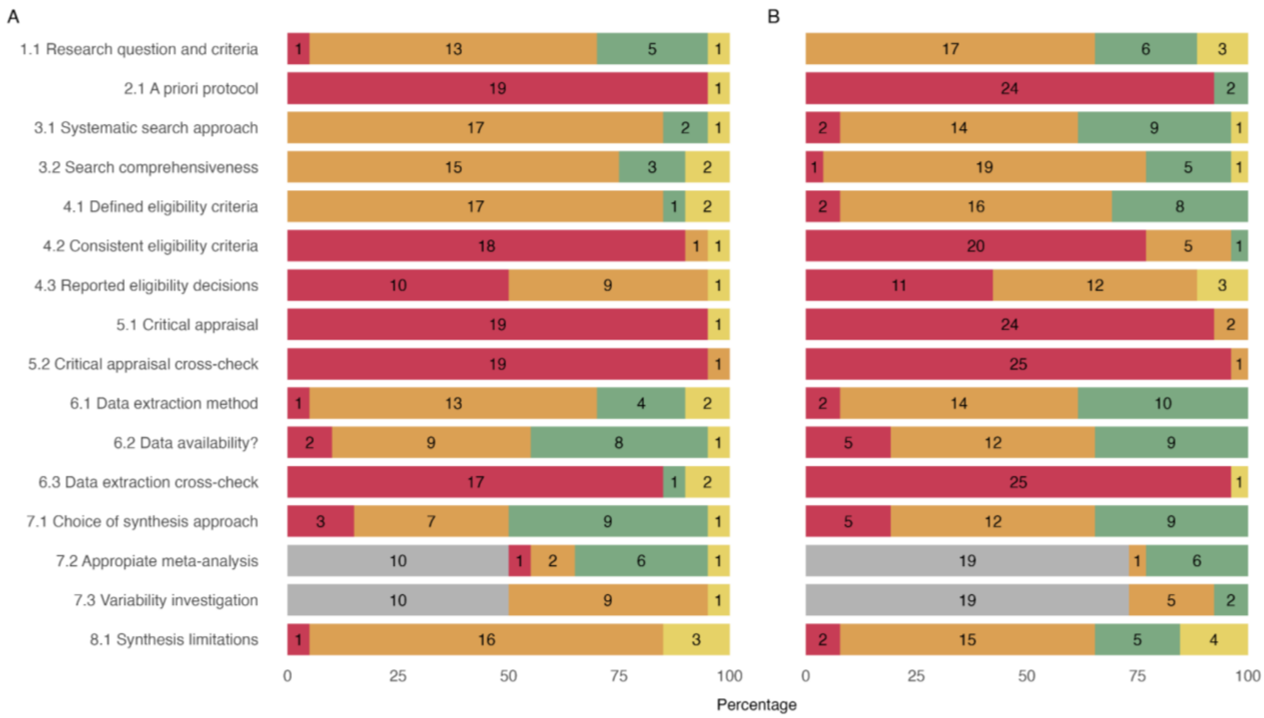


Figure S10. Comparison of reporting and methodological quality of included syntheses for policy-cited and not policy-cited syntheses. The figure displays the results of the assessment of syntheses using CEESAT 2.1 (Woodcock et al., 2014). (A) CEESAT scores for syntheses that were cited in policy documents (n = 2) (B) CEESAT scores for syntheses not cited in policy documents (n = 26). A Welch two-sample t-test was used to compare the overall scores between these two groups, revealing no significant difference ($t = -0.31$, $df = 37.74$, $p = 0.756$, 95% CI: –0.30 to 0.22). The gray colour (n = 29) represents synthesis with no pooled effect meta-analysis, where we did not apply items 7.2 and 7.3.

Supplementary Tables

Table S1. Population, Exposure, Comparator, and Outcome (PECO) framework. For detailed inclusion and exclusion criteria, see Table S2.

PECOS elements	Evidence
Population (P)	**Peer-reviewed published studies that synthesize evidence** on wild terrestrial and aquatic fauna, defined as free-living non-human, multicellular animals (Kingdom Animalia), which may include other animal sources (e.g., lab-reared, domestic, or farmed), but only if the focus remains on wild populations and the relevance to wild systems is clear.
Exposure (E)	Anthropogenic noise, defined as any acoustic waves generated by human activities, encompasses infrasound (<20 Hz), audible (20 Hz to 20 kHz), and ultrasonic frequencies (>20 kHz).
Comparator (C)	Not applicable
Outcome (O)	Any measures of wildlife's physiological function, behaviour, communication, reproduction or ecology.
Study type (S)	Secondary literature, specifically systematic reviews, maps, and meta-analyses, synthesizes primary observational and experimental studies. Because we conduct a critical appraisal of all included studies, we focus on peer-reviewed papers, excluding grey literature based on our scoping searches; we do not expect to find relevant works in grey literature. Furthermore, peer-reviewed studies are

	typically published in standardized formats, making appraisal outcomes more comparable.

Table S2. PECOS-structured inclusion and exclusion criteria.

PECOS components	Inclusion criteria	Exclusion criteria
Population (P)	Include syntheses on wild terrestrial, aquatic, and marine animals, including mammals, birds, reptiles, amphibians, fish, insects, and other invertebrates. Encompassing free-living and naturally occurring populations and individuals studied in mesocosms or enclosures that maintain semi-natural conditions with minimal interference. Include syntheses on mixed source populations (e.g., laboratory, domestic, or farmed) if they substantially address wild populations.	Exclude studies whose analytical focus is exclusively on humans, lab-reared animals kept under highly controlled conditions for many generations (e.g., biomedical models), domestic species (e.g., pets), or farmed animals, as these are not relevant to wild populations or ecosystems.
Exposure (E)	Include anthropogenic sounds across infrasound, audible, and ultrasonic frequencies. Sources can be, but are not limited to, transportation (road traffic, railways, aircraft, and marine vessels), industrial activities (factories, mining, drilling, and fracking), energy infrastructure (wind turbines, hydroelectric dams, and power plants),	Exclude studies focusing solely on naturally occurring noise (e.g., thunder, volcanic activity, earthquakes) or environmental sounds not generated by human activity (e.g., wind, rain, ocean waves, river currents, glacial movements, and biological sounds like animal vocalizations

	communication (sonar, low-frequency communication systems), construction (pile driving, tunnelling, and demolition), and recreational sources (fireworks, music, motorized watercraft, and underwater tourism). We also consider acoustic waves and vibrations as part of the exposure resulting from these noise sources. Additionally, playback studies using synthetic sounds that explicitly simulate human noise contribute to research on anthropogenic sound exposure. Include syntheses that consider multiple pollutants if anthropogenic noise is explicitly analyzed as a distinct exposure, with extractable data, separate conclusions, or clearly interpretable results relevant to noise impacts.	in natural settings). Additionally, exclude studies examining geophysical or atmospheric sounds (e.g., geomagnetic storms, auroral sounds, or underwater tectonic activity) without a direct anthropogenic component. Exclude synthetic sounds unrelated to anthropogenic noise sources (e.g., hearing range assessment or artificial stressors). Exclude if anthropogenic noise is not clearly distinguished from other stressors (e.g., combined “pollution” effects without disaggregation), or where noise-related outcomes cannot be isolated.
Comparator (C)	Not applicable.	
Outcome (O)	Include measures of anthropogenic noise’s behavioural, ecological, physiological, and communication-related effects on wildlife. These can include changes in vocalization	Exclude studies that focus solely on sound measurement methods without biological or ecological impact, such as noise

	characteristics (e.g., frequency shifts, amplitude adjustments), alterations in foraging behaviour, physiological stress responses (e.g., hormone levels, immune function), reproductive success, or habitat displacement.	propagation models or hearing mechanics.
Study type (S)	Include systematic reviews, maps, and meta-analyses synthesizing peer-reviewed observational or experimental studies, including single and multi-taxon studies.	Exclude traditional narrative reviews, theoretical papers, primary studies, or those relying solely on grey literature or biomedical/human health data.

Table S3. Benchmarking set of eligible publications. To collate this set, we conducted a systematic review, systematic map, and meta-analysis on the effects of anthropogenic noise on wildlife through manual searching of Google Scholar, ResearchGate, and institutional repositories.

Benchmarking set
Arcangeli G et al. Neurobehavioral Alterations from Noise Exposure in Animals: A Systematic Review. International Journal of Environmental Research and Public Health. 2022;20(1):591. https://doi.org/10.3390/ijerph20010591
Cox KD, Brennan LP, Dudas SE, Juanes F. Assessing the effect of aquatic noise on fish behavior and physiology: a meta-analysis approach. Proceedings of Meetings on Acoustics. 2016;27(1):010024. https://doi.org/10.1121/2.0000291
Cox K et al. Sound the alarm: A meta-analysis on the effect of aquatic noise on fish behavior and physiology. Global Change Biology. 2018;24(7):3105–3116. https://doi.org/10.1111/gcb.14106
Davies HL et al. Marine and Freshwater Sounds Impact Invertebrate Behavior and Physiology: A Meta-Analysis. Global Change Biology. 2024;30(11):e17593. https://doi.org/10.1111/gcb.17593
Duquette CA, Loss SR, Hovick TJ. A meta-analysis of the influence of anthropogenic noise on terrestrial wildlife communication strategies. Journal of Applied Ecology. 2021;58(6):1112–1121. https://doi.org/10.1111/1365-2664.13880

Engel MS et al. A Systematic Review of Anthropogenic Noise Impact on Avian Species. Current Pollution Reports. 2024 Sep 11 [accessed 2024 Sep 20]. https://doi.org/10.1007/s40726-024-00329-3.

Gomes L, Solé M, Sousa-Lima RS, Baumgarten JE. Influence of Anthropogenic Sounds on Insect, Anuran and Bird Acoustic Signals: A Meta-Analysis. Frontiers in Ecology and Evolution. 2022;10:827440. https://doi.org/10.3389/fevo.2022.827440

Gomez C et al. A systematic review on the behavioural responses of wild marine mammals to noise: the disparity between science and policy. Canadian Journal of Zoology. 2016;94(12):801–819. https://doi.org/10.1139/cjz-2016-0098

Guenat S, Dallimer M. A global meta-analysis reveals contrasting impacts of air, light, and noise pollution on pollination. ECOLOGY AND EVOLUTION. 2023;13(4). https://doi.org/10.1002/ece3.9990

Harding HR et al. Causes and consequences of intraspecific variation in animal responses to anthropogenic noise Simmons L, editor. Behavioral Ecology. 2019;30(6):1501–1511. https://doi.org/10.1093/beheco/arz114

Jerem P, Mathews F. Trends and knowledge gaps in field research investigating effects of anthropogenic noise. Conservation Biology. 2021;35(1):115–129. https://doi.org/10.1111/cobi.13510

Kunc HP, Schmidt R. The effects of anthropogenic noise on animals: a meta-analysis. Biology Letters. 2019;15(11):20190649. https://doi.org/10.1098/rsbl.2019.0649

Kunc H, Schmidt R. Species sensitivities to a global pollutant: A meta-analysis on acoustic signals in response to anthropogenic noise. GLOBAL CHANGE BIOLOGY. 2021;27(3):675–688. https://doi.org/10.1111/gcb.15428

Murchy KA et al. Impacts of noise on the behavior and physiology of marine invertebrates: A meta-analysis. Proceedings of Meetings on Acoustics. 2020;37(1):040002. https://doi.org/10.1121/2.0001217

Roca IT et al. Shifting song frequencies in response to anthropogenic noise: a meta-analysis on birds and anurans. Behavioral Ecology. 2016;27(5):1269–1274. https://doi.org/10.1093/beheco/arw060

Shannon G et al. A synthesis of two decades of research documenting the effects of noise on wildlife. Biological Reviews. 2016;91(4):982–1005. https://doi.org/10.1111/brv.12207

Table S4. Final search strings for Scopus and Web of Science. We used these search strings in our final searches on Scopus and Web of Science on May 29, 2025. We tested preliminary search strings in both databases using 16 benchmark studies. In Scopus, all 16 studies were indexed, and the final search string retrieved 14 of them, yielding a relative recall of 87.5%. The two missing studies were not retrieved because of the limited indexing of synthesis-related terms. In Web of Science, only 14 of the 16 benchmark studies were indexed. The final search string retrieved 12 of these, giving a relative recall of 85.7%. The two excluded studies were not indexed in Web of Science (DOIs: 10.1121/2.0000291 and 10.1121/2.0001217). We created a simplified version of the main English search query for each language by identifying the four conceptual domains of our Scopus search strategy: type of evidence synthesis, noise terminology, anthropogenic noise source, and wildlife/ecological relevance. We searched on Google Scholar through Publish or Perish on May 29, 2025, except for Russian (June 9, 2025), as we refined the string.

Scopus
(TITLE-ABS-KEY ((meta-analy* OR meta-regres* OR metaanal* OR metaregres* OR (quantitativ* W/3 synthes*) OR (systematic* W/3 review*) OR "evidence-based review" OR "systematic map") AND (noise OR sound* OR ultrasound* OR acoustic* OR infrasound*) AND (pollut* OR anthrop* OR urban* OR industr* OR traffic* OR road* OR highway* OR disturb*) AND (response* OR wild* OR animal* OR biodivers* OR specie* OR ecologic* OR biota OR ecosystem* OR terrestrial OR marine OR underwater* OR aquatic OR invertebrate* OR vertebrate* OR habitat* OR bird* OR avian OR aves OR pup* OR mammal* OR marsupial* OR bat* OR amphib* OR frog* OR reptil* OR fish* OR cetacean* OR dolphin* OR whale* OR fish* OR mollusc* OR cnidar* OR arachn* OR *fly OR *flies OR arthropo* OR insect* OR carnivor* OR herbivo* OR omnivo* OR forag* OR courtsh* OR reproduct* OR mating OR offspring* OR communicat* OR call* OR song OR *behavio* OR physiolog* OR stress* OR immun* OR inflam* OR avoid* OR attract* OR aversi* OR pollinat* OR *neuro* OR cognit* OR vocal* OR intraspecifi* OR navigat* OR prey OR predat* OR fitness*)))

Web of Science
TS=((meta-analy* OR meta-regres* OR metaanal* OR metaregres* OR (quantitativ* NEAR/3 synthes*) OR (systematic* NEAR/3 review*) OR "evidence-based review" OR "systematic map") AND (noise OR sound* OR ultrasound* OR acoustic* OR infrasound*) AND (pollut* OR anthrop* OR urban* OR industr* OR traffic* OR road* OR highway* OR disturb* OR response*) AND (wild* OR animal* OR biodivers* OR specie* OR ecologic* OR biota OR ecosystem* OR terrestrial OR marine OR aquatic OR invertebrate* OR vertebrate* OR habitat* OR bird* OR avian OR aves OR pup* OR mammal* OR marsupial* OR bat* OR amphib* OR frog* OR reptil* OR fish* OR cetacean* OR dolphin* OR whale* OR mollusc* OR cnidar* OR arachn* OR *fly OR *flies OR arthropo* OR insect* OR carnivor* OR herbivo* OR omnivo* OR forag* OR courtsh* OR reproduct* OR mating OR offspring* OR communicat* OR call* OR *behavio* OR physiolog* OR stress* OR immun* OR inflam* OR avoid* OR attract* OR aversi* OR pollinat* OR *neuro* OR cognit* OR vocal* OR intraspecifi* OR navigat* OR prey OR predat*))

Google Scholar
Spanish
Meta-análisis|sistemática ruido|sonido|ultrasonido|infrasonido|acústico antropogénico|urbano|tráfico|industrial|contaminación fauna|animales|especies|biodiversidad|ecología|fisiología|comportamiento
Portuguese
Meta-análise|sistemática ruído|som|ultrassom|infrassom|acústico antrópico|urbano|tráfego|industrial|poluição fauna|animais|espécies|biodiversidade|ecologia|fisiologia|comportamento
Japanese
メタ解析|メタアナリシス|システマティック 騒音|音|超音波|低周波音|音響 人為的|都市|交通|産業|汚染 野生動物|動物|種|生物|生物多様性|生態|生態系|生理|行動

Polish
Meta-analiza|systematyczny hałas|dźwięk|ultradźwięk|infradźwięk|akustyczny antropogeniczny|miejski|ruch|drogowy|przemysłowy|zanieczyszczenie dzika|przyroda|zwierzęta|gatunki|bioróżnorodność|ekologia|fizjologia|zachowanie
Russian
Метаанализисис|систематический шум|звук|"шумовое загрязнение" Животные|виды|"дикая природа" физиология|поведение
Italian
Meta-analisis|sistematica rumore|suono|ultrasuono|infrasuono|acustico antropico|urbano|traffico|industriale|inquinamento fauna|animali|specie|biodiversità|ecologia|fisiologia|comportamento
French
Méta-analyse|systématique bruit|son|ultrason|infrason|acoustique anthropique|urbain|trafic|industriel|pollution faune|animaux|espèces|biodiversité|écologie|physiologie|comportement
English
Meta-analysis|systematic noise|sounds|ultrasound|infrasound|acoustic anthropogenic|urban|traffic|road|industrial|pollution wild|nature|animals|species|biodiversity|ecology|physiology|behaviour

Table S5. Excluded papers in the full-text stage with reasons

	References	Reasons
English		
1	Liu, Q., Gelok, E., Fontein, K., Slabbekoorn, H., & Riebel, K. (2022). An experimental test of chronic traffic noise exposure on parental behaviour and reproduction in zebra finches. *Biology Open*, *11*(4), bio059183. https://doi.org/10.1242/bio.059183	Wrong study type (not a systematic review/map/meta-analysis of peer-reviewed primary studies, or not disaggregated)
2	Kriengwatana, B. P., Nager, R. G., South, A., Ullrich, M., & Doolittle, E. L. (2025). Playing music to animals: An interdisciplinary approach to improving our understanding of animals' responses to music. *Animal Behaviour*, *221*, 123074.	No wildlife-relevant or extractable outcomes
3	Domingos, F. P. F., Lotfi, |A., Ihianle, I. K., Kaiwartya, O., & Machado, P. (2024). Underwater Communication Systems and Their Impact on Aquatic Life—A Survey. *Electronics*, *14*(1), 7. https://doi.org/10.3390/electronics14010007	Wrong study type (not a systematic review/map/meta-analysis of peer-reviewed primary studies, or not disaggregated)
4	Parris, K. M., & McCarthy, M. A. (2013). Predicting the Effect of Urban Noise on the Active Space of Avian Vocal Signals. *The American Naturalist*, *182*(4), 452–464. https://doi.org/10.1086/671906	Wrong study type (not a systematic review/map/meta-analysis of peer-reviewed primary studies, or not disaggregated)

5	Petit, K., Dunoyer, C., Fischer, C., Hars, J., Baubet, E., López-Olvera, J. R., Rossi, S., Collin, E., Le Potier, M., Belloc, C., Peroz, C., Rose, N., Vaillancourt, J., & Saegerman, C. (2020). Assessment of the impact of forestry and leisure activities on wild boar spatial disturbance with a potential application to ASF risk of spread. *Transboundary and Emerging Diseases*, *67*(3), 1164–1176. https://doi.org/10.1111/tbed.13447	Wrong study type (not a systematic review/map/meta-analysis of peer-reviewed primary studies, or not disaggregated)
6	Schlacher, T. A., Lucrezi, S., Connolly, R. M., Peterson, C. H., Gilby, B. L., Maslo, B., Olds, A. D., Walker, S. J., Leon, J. X., Huijbers, C. M., Weston, M. A., Turra, A., Hyndes, G. A., Holt, R. A., & Schoeman, D. S. (2016). Human threats to sandy beaches: A meta-analysis of ghost crabs illustrates global anthropogenic impacts. *Estuarine, Coastal and Shelf Science*, *169*, 56–73. https://doi.org/10.1016/j.ecss.2015.11.025	No anthropogenic noise (or not disaggregated)
7	Seebacher, F. (2022). Interactive effects of anthropogenic environmental drivers on endocrine responses in wildlife. *Molecular and Cellular Endocrinology*, *556*, 111737. https://doi.org/10.1016/j.mce.2022.111737	No anthropogenic noise (or not disaggregated)
8	Tsionas, I., Llaguno-Munitxa, M., & Stephan, A. (2025). Environmental effects of urban wind energy	No wildlife-relevant or extractable outcomes

	harvesting: A review. *Buildings & Cities*, *6*(1). https://doi.org/10.5334/bc.491	
9	Turlington, K., Suárez-Castro, A. F., Teixeira, D., Linke, S., & Sheldon, F. (2024). Exploring the relationship between the soundscape and the environment: A systematic review. *Ecological Indicators*, *166*, 112388. https://doi.org/10.1016/j.ecolind.2024.112388	No anthropogenic noise (or not disaggregated)
10	Wang, S., & Wang, S. (2015). Impacts of wind energy on environment: A review. *Renewable and Sustainable Energy Reviews*, *49*, 437–443. https://doi.org/10.1016/j.rser.2015.04.137	No anthropogenic noise (or not disaggregated) and no wildlife-relevant or extractable outcomes
11	Williams, R., Veirs, S., Veirs, V., Ashe, E., & Mastick, N. (2019). Approaches to reduce noise from ships operating in important killer whale habitats. *Marine Pollution Bulletin*, *139*, 459–469. https://doi.org/10.1016/j.marpolbul.2018.05.015	Wrong study type (not a systematic review/map/meta-analysis of peer-reviewed primary studies, or not disaggregated)
Italian		
12	Gianoni, P. (2020/2021). *Valutazione dell'inquinamento acustico di un tratto di metropolitana di superficie* [Master's thesis, Politecnico di Milano]. POLITesi. https://hdl.handle.net/10589/177384	Wrong study type (not a systematic review/map/meta-analysis of peer-reviewed primary studies, or not disaggregated)

13	La Manna, G. (2012). *Effetto del traffico marittimo e del rumore antropico sui mammiferi marini* [Doctoral thesis, Università degli Studi di Parma]. DSpaceUnipr. https://hdl.handle.net/1889/1835	Wrong study type (not a systematic review/map/meta-analysis of peer-reviewed primary studies, or not disaggregated)
14	Mazzotta, G. (2023). *Gli effetti dell'inquinamento acustico antropogenico sui mammiferi marini: una revisione sistematica* [Master's thesis, Università Politecnica delle Marche]. Università Politecnica delle Marche Tesi Online. https://tesi.univpm.it/bitstream/20.500.12075/13649/1/Giulia_Mazzotta_Tesi.pdf	Wrong study type (not a systematic review/map/meta-analysis of peer-reviewed primary studies, or not disaggregated)
15	Rotta, A. (2009). *Stato di benessere delle popolazioni di cetacei e marangone dal ciuffo nel Nord Sardegna* [Doctoral thesis, Università degli Studi di Sassari]. Depositolegale. https://tesidottorato.depositolegale.it/bitstream/20.500.14242/156303/1/Rotta_A_Tesi_Dottorato_2009_Stato.pdf	Wrong study type (not a systematic review/map/meta-analysis of peer-reviewed primary studies, or not disaggregated)
Japanese		
16	Ueno, Y., Hasegawa, K., Oshiro, N., Kanda, M., Inoue, R., & Kurihara, M. (2015). Evaluation of environmental conservation measures using meta-analysis: Breeding success and failure of three species of rare raptors	No anthropogenic noise or not disaggregated

	around road projects in Japan. *土木学会論文集 G (環境システム研究論文集), 71*(6), II_65–II_72. https://doi.org/10.2208/jscejer.71.II_65	
Spanish		
17	André, M. (2004). *El hombre y los cetáceos: entre ruido y silencios*. ULPGC AccedaCRIS. https://accedacris.ulpgc.es/jspui/handle/10553/388	Full-text not available
18	Carrasco-Jocope, R. R., Vigil-Requena, S. V., Valiente-Saldaña, Y. M., & González-González, D. G. (2023). Contaminación urbano ambiental y espacio público del centro de Piura, Perú: Revisión sistemática. *Revista Arbitrada Interdisciplinaria Koinonía*, *8*(16), 171–183. https://doi.org/10.35381/r.k.v8i16.2542	No wildlife-relevant or extractable outcomes
19	Contreras-Lefihuala, J. B. (2023). Efectos del ruido antropogénico en anuros: una revisión sistemática.	Full-text not available

Table S6. Workflow for piloting and validating the search, screening, and data extraction strategy. We validated our search strategy against a benchmark set of 18 systematic reviews, systematic maps, and meta-analyses (Dataset S1), tested preliminary search strings in Scopus and Web of Science, and refined terms iteratively. We piloted screening by evaluating 100 randomly selected Scopus records in Rayyan QCRI, with double screening to refine the PECOS eligibility criteria. We then piloted data extraction for both the systematic map (Aim 1) and policy relevance (Aim 3), refining variable definitions, PlumX metrics, and policy coding. Finally, we used the pilot to refine the appraisal criteria for CEESAT 2.1.

Steps	**Aim**	**Activity**	**Purpose**	**Tools**	**Suppl Dataset**
1	Search strategy	Benchmark validation: 18 reviews	Refined Scopus and Web of Science search strings; calculated relative recall	Google Scholar, ResearchGate for finding benchmark papers; Scopus and Web of Science for benchmarking	Dataset 1: Benchmarking set and Dataset 2: Sheet 3-Search strings
2	Screening+eligibility	Screening pilot: 100 random Scopus records	Refined PECOS eligibility criteria; inclusion rules for mixed cases	Rayyan QCRI; Excel; Google Sheets	N/A
3	Aim 1	Data extraction pilot 5 studies	Refined extraction table variables and structure	Extraction Table (Dataset S)	

4	Aim 3	Policy attention pilot	Tested Plum X metrics; sampled policy documents; finalized coding	PlumX and direct link of policy documents
5	Aim 4	Critical appraisal decisions refinement	Defined criteria for CEESAT 2.1 assessment	CEESAT v2.1

Table S7. Systematic map data extraction codebook. The "Variable" column shows the name of the extracted/coded variable. "Multicategory allowed" indicates that more than one answer option can be selected for this variable. The "Category" column specifies possible options. The "Definition" column explains the meaning of each answer option.

Variable	Category	Definition
review_type	Systematic review	Structured evidence synthesis using a search strategy (keywords + databases), predefined criteria to identify and analyze studies, which often answer a question or make a recommendation about what they are reviewing.
	Systematic map	Provides a structured overview of existing evidence to identify research clusters, gaps, and trends without quantitative synthesis
	Meta-analysis	Statistical combination of effect sizes from multiple studies using statistical techniques to estimate overall trends and variation
study_designs	Experimental	Includes manipulations with controlled conditions
	Observational	Observes variables in natural settings without manipulation
	Mixed	Includes both experimental and observational studies
	Other	Includes theory or modelling, not empirical studies
	Unclear	No information reported on study design
ecosystem_type	Terrestrial	Land-based ecosystems, excluding urban areas, but can include rural and natural area.s

[Multicategory allowed]		
	Freshwater	Lakes, rivers, wetlands, estuaries
	Marine	Saltwater environments like the ocean
	Urban	Human-dominated environments, cities, or industrial zones
	Other	Ecosystems that don't fit above (e.g., caves, polar)
	Unclear	Ecosystem type is not explicitly mentioned
noise_source [Multicategory allowed]	Transportation	Traffic, car, aircraft, roadway, marine vessels (includes cruise ships, drillships, freight/passenger vessels), recreational boats
	Energy	Air gun, Water gun, seismic survey, drilling, turbines, wind turbines, wind farm, gas compressor, hydroelectric turbines, energy infrastructure
	Construction	Pile driving, dredging, construction, pier noise, road construction
	Industrial	Mining, industry, industrial, compressor, generator
	Urban	Whole urban soundscape/background noise
	Recreational	Music, tourism, Fireworks, Human voices
	UAV/UAS	Drones, Unmanned Aerial Vehicles (UAVs) or Unmanned Aircraft Systems (UASs)
	Synthetic	White noise, brown noise, synthetic tones, linear sweeps, sine waves, and playback tones
	Military	Missile launch, military sonar, sonic boom, military activity

	Unclear	Not specified
noise_frequencies	Infrasonic	Below 20 Hz
	Audible	Between 20 Hz and 20 kHz
	Ultrasonic	Above 20 kHz
	Mixed	Covers more than one range
	Other	Unclassified or ambiguous range
	Unclear	Not specified in the review
sp_source_category [Multicategory allowed]	Wild	Free-living animals in natural/semi-natural environments
	Domestic	Pets, livestock, and working animals
	Laboratory	Animals bred for use in lab-controlled settings (e.g. rodent models for health research)
	Mixed	Combination of multiple categories above
	Other	Captive but not domestic or laboratory (e.g., zoo animals)
	Unclear	Not clearly reported
outcome_category [Multicategory allowed]	Behavioural	Observable behaviours (e.g., vigilance, foraging)
	Physiological	Biological responses (e.g., hormones, immune system)
	Ecological	Population- or community-level impacts (e.g. spatial distribution, abundance, occupancy)
	Reproductive	Fertility, mating, or offspring effects

Communication	Vocal/acoustic signalling changes (e.g. higher frequencies or temporal changes in calls)
Other	Does not fit any above
Unclear	Not enough information

Table S8. Variables extracted for the bibliometric map from Scopus.

Variable	Description	Format
doi	Digital Object Identifier	Text
authors	Full list of authors	Free text
affiliations	Institutional and country affiliations	Free text or structured
corr_country_affiliation	Country of first or corresponding author	Country name
n_authors	Number of authors	Integer
citations_scopus	Citation counts from Scopus	Integer
citations_scholar	Citation counts from Google Scholar	Integer
keywords_author	Author-supplied keywords	Free text
keywords_indexed	Indexed keywords (e.g., MeSH, WoS)	Free text
funding_source	Funding agencies, if reported	Free text or "Not Reported"
open_access	Whether the paper is open access	Yes No

Table S9. Policy extraction codebook. Variables, definitions, and categories extracted from policy documents that cited the included syntheses.

Variable	Category	Definition
Policy_document_type	Government Policy	Published by national or subnational governments (e.g, branches, departments, secretariats, etc.)
	Intergovernmental policy	Published by multinational organizations (e.g., UNEP, EU, WHO)
	NGO report	Published by non-profit, NGO organizations
	Academic advisory	Published by academic expert panels. Can be a synthesis or technical advice
	Regulatory submission	Formal applications or impact statements submitted to authorities by proponents—independent from the government—seeking permits or approvals
	Think Tank	Published by declared Think Tank organizations
	Other	Doesn't match any above
	Unclear	Not identifiable
Policy_level_category	International	Applies to multiple countries or globally
	Regional	Applies to a multi-country region (e.g., European Union)

	National	Country-wide application
	Subnational	Applies to a province, state, and/or municipal level
	Mixed	More than one level
	Other	Special categories (e.g., sector-specific)
	Unclear	Not clearly stated
ecological_context	Terrestrial	Policy about land-based environments
	Marine	Marine systems (e.g. Pacific Ocean, bahias)
	Freshwater	Freshwater systems (e.g., rivers, lakes, ponds)
	Coastal	Coastal systems (e.g. Estuaries, Urban coast)
	Urban	Built or human-modified environments (e.g. cities)
	Mixed	Covers more than one context
	Other	Not clearly ecological or atypical settings (e.g. rural areas)
	Unclear	Not clearly specified (e.g. when the policy talked about computer tools used for any environment)

policy_topic	Conservation	Biodiversity protection, habitat or species policies
	Urban planning	Infrastructure or land use in urban areas
	Sustainability	Meeting economic and social goals without compromising the environment, wildlife and natural resources
	Health	Public health and well-being impacts of noise
	Energy	Industry involved in producing and supplying fuel and power, including extraction, generation, transmission, and distribution (e.g. fossil fuels, nuclear, renewables, infrastructure like energy grids, pipelines)
	Mixed	Multiple focus areas (e.g. Energy + Conservation)
	Other	Topics like defence or education (e.g. mineral mining, animal welfare)

Table S10. Included syntheses. List of the 50 systematic reviews, maps, and meta-analyses included in our systematic map (umbrella review).

Included syntheses	
1	Affatati, A., & Camerlenghi, A. (2023). Effects of marine seismic surveys on free-ranging fauna: A systematic literature review. Frontiers in Marine Science, 10, 1222523. https://doi.org/10.3389/fmars.2023.1222523
2	Afridi, S., Hlebowicz, K., Cawthorne, D., & Lundquist, U. P. S. (2024). Unveiling the Impact of Drone Noise on Wildlife: A Crucial Research Imperative. 2024 International Conference on Unmanned Aircraft Systems (ICUAS), 1409–1416. https://doi.org/10.1109/ICUAS60882.2024.10557094
3	Arcangeli, G., Lulli, L. G., Traversini, V., De Sio, S., Cannizzaro, E., Galea, R. P., & Mucci, N. (2022). Neurobehavioral Alterations from Noise Exposure in Animals: A Systematic Review. International Journal of Environmental Research and Public Health, 20(1), 591. https://doi.org/10.3390/ijerph20010591
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Supplementary datasets

Find the supplementary datasets in our GitHub repository:

https://github.com/AnnaLenzR/Umbrella_review_noise_impact_on_wildlife.git

1. Dataset S1: Map data extraction
2. Dataset S2: Bibliometric data extracted from Scopus
3. Dataset S2.1: Bibliometric data extracted from Scopus in ".bib" format
4. Dataset S3: Policy documents data extraction
5. Dataset S3.1. Policy tracker, policy citation count
6. Dataset S4: CEESAT assessments for the included syntheses
7. Dataset S5: CEESAT processed data: final scores for analysis