Synthesis of Anthropogenic Impacts on Birds - Systematic Map and Bibliometric Analysis of Meta-Analyses

Running title: Synthesis of Anthropogenic Impacts on Birds

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Abstract

Anthropogenic environmental change is a major driver of global bird declines, affecting species across continents, ecosystems, and life-history strategies. As such, it has drawn much attention in both primary research studies and meta-analyses. Because meta-analyses influence scientific consensus and conservation policy, it is essential to evaluate the representativeness and transparency of this evidence. However, despite the growing number of meta-analyses , these aspects have never been assessed, creating a clear need for a comprehensive global evaluation of meta-analyses on anthropogenic impacts of birds. Here, we present the first global synthesis, including 149 meta-analyses of anthropogenic influences on birds. We analyzed their thematic, taxonomic, ecological, and geographic coverage, evaluated adherence to reporting and methodological standards, and assessed research production, collaboration, and societal visibility using bibliometric and altmetric approaches. Meta-analyses addressed a wide range of anthropogenic pressures and birds' responses, however with uneven attention to different topics. Habitat loss and fragmentation, agriculture, and urbanisation were overrepresented across studies, while light and noise pollution, invasive species, and hunting were largely neglected. Responses focused mainly on species abundance, diversity, and reproduction, with limited attention to behaviour, movement, migration, or phenology. Taxonomic coverage was biased towards Passeriformes, and geographic coverage skewed toward North America and Europe. Reporting standards were not widely followed, and almost half of the meta-analyses would not be possible to repeat or update. Almost none of the meta-analyses were preregistered or estimated risk of bias in primary studies, though most controlled for non-independence, and tested for publication bias. Bibliometric and altmetric analyses revealed high collaboration but geographic imbalance among authors. Overall, meta-analytical research on anthropogenic impacts on birds is extensive - but thematically, taxonomically, ecologically, and geographically uneven, with suboptimal transparency. Addressing these limitations is crucial to improve the reliability, comparability, and policy relevance, ultimately supporting more effective conservation strategies for birds.

Keywords: avian ecology; evidence synthesis; human pressures; biodiversity; conservation science; meta-research; global change; decision-making

1. INTRODUCTION

Anthropogenic environmental change is transforming ecosystems globally, driving rapid shifts in biodiversity, ecological processes, and species interactions (Tylianakis et al. 2008; Traill et al. 2010; Keck et al. 2025). Although human impacts have deep historical roots, their scale and pace have been amplified to unprecedented levels (Tong et al. 2022; Cabernard et al 2024). Birds are among the taxa most visibly affected by these changes (Wikelski and Tertitski, 2016; Richard et al. 2021; McCloy et al. 2024), while their ecological diversity, global distribution, and extensive monitoring history make them key sentinels of environmental change (Smits and Fernie, 2013; Fraixedas et al. 2020; Hazen et al. 2024). A range of anthropogenic pressures such as habitat destruction, agricultural intensification, urbanisation, climate change, and a variety of pollutants (Senzaki et al. 2020; Wilson et al. 2021; Richard et al. 2021; Mainwaring et al 2024) affect individuals disrupting different aspects of their life cycle, such as migration, reproduction, or behaviour (Carey 2009; Nemes et al. 2024). These individual responses can scale up to influence population processes, including demography and population dynamics (Rigal et al. 2023), and ultimately reshape community structures (Solem et al. 2025). Such effects can cascade and disrupt essential ecosystem functions because birds also contribute to seed dispersal, pollination, pest control, and nutrient cycling (Mariyappan et al. 2023; Arya et al. 2024).

Correspondingly, research on anthropogenic impacts on birds has expanded rapidly. Such research includes both primary research, but also syntheses of primary research such as meta-analyses. Meta-analyses are used to quantitatively summarise the findings of primary studies (Gurevitch et al. 2001; Stewart 2010; Haddaway, 2015; Nakagawa et al. 2023), often providing insights into wider trends and patterns (e.g. taxonomic, ecological, geographical), and testing for the reasons behind heterogeneity among results of primary studies (Nakagawa and Santons 2012; Nakagawa et al. 2015; Gurevitch et al. 2018). Numerous meta-analyses have quantified the effects of major anthropogenic pressures on birds, such as habitat loss, urbanisation, climate change, and invasive species (e.g. Bender et al. 1998; Saari et al. 2016; Radchuk et al. 2019; Doherty et al. 2016). They have also examined a wide range of biological responses, spanning individual-level processes (e.g. physiological responses, Messina et al. 2018), population-level dynamics (e.g., population trends, Leung et al. 2017), or community-level patterns (e.g. species richness, Kroeger et al. 2022). This diversity in the thematic, geographic, ecological (e.g. habitat, dietary, migration type etc.), and taxonomic coverage of meta-analytical studies partly reflects the availability of primary research, and partly the meta-analytical research interests. Synthesising this dispersed meta-analytical literature is essential for identifying key areas of research focus, revealing knowledge gaps but also redundancies, and providing guidelines for future primary research and synthesis efforts.

Meta-analyses play a prominent role in shaping scientific understanding and future research, and informing conservation and policy decisions. Thus it is essential that they are methodologically robust and transparently reported (Koricheva and Gurevitch, 2014; Parker et al. 2016; O'Dea et al. 2021), and that they are used by scientists, policy makers, and broader public, which can be captured using citation and altmetric analyses (Garcia et al. 2014; Bornmann and Haunschild 2018). Lack of adherence to important methodological and reporting standards can lead to unreliable meta-analytical results, hamper reproducibility, and prevent updates of existing syntheses with the new primary research (Elliott et al. 2014; Nakagawa et al. 2017; Gurevitch et al. 2018).Finally, the organisation and structure of the research community itself also shapes how evidence is generated and disseminated (Nakagawa et al. 2019). Bibliometric indicators provide insight into how research is organised, where scientific authority is concentrated and which world regions contribute most to evidence synthesis (Nakagawa et al. 2019). Such patterns may include disciplinary geographic biases, or a concentration of outputs in particular publication venues (Nakagawa et al. 2019).

Together, considerations of methodological and reporting rigor, societal reach, and research community structure motivate a systematic assessment of meta-analytical research on anthropogenic impacts on birds, which we conduct in this study. We provide such a first comprehensive overview by systematically mapping the existing meta-analyses. Our main objectives are to: (i) describe the thematic, taxonomic, ecological, and geographic coverage of existing meta-analyses; (ii) assess adherence to important aspects of reporting and methodological standards; (iii) analyse author networks, collaboration patterns, and journal distributions; and (iv) evaluate the broader influence and societal reach of meta-analyses, including their uptake in policy and decision-making documents.

2. MATERIALS AND METHODS

The protocol for this research was preregistered at the Open Science Framework (https://osf.io/txkz7/files/stm5u). Any deviations from the registered protocol are reported in the Appendix, section 1. We collected published meta-analyses on anthropogenic impacts on birds (see the eligibility criteria below) using systematic search of several literature databases. We then used these meta-analyses to: a) systematically map their content by extracting data on their thematic focus (anthropogenic impact type, response type), and taxonomic, ecological, and geographic coverage; b) conduct a critical appraisal of adherence to several aspects of reporting and methodological standards; c) assess the broader societal and policy reach of included meta-analyses, collecting data on mentions in policy documents, news outlets, social media, and other academic and non-academic sources; d) analyse patterns of research output, authorship, collaboration networks, and journal distribution using citation counts, co-authorship networks and publication trends.

We adhered to the ROSES - RepOrting standards for Systematic Evidence Syntheses (Haddaway et al. 2018).

2.1. Eligibility criteria

To be eligible for inclusion in our systematic map, (i) a study had to be a meta-analysis (sensu O'Dea et al. 2021), i.e. a statistical synthesis of effect sizes from multiple independent studies; (ii) published in a peer-reviewed journal at any time; (iii) address anthropogenic impacts on wild, non-domesticated birds, or on ecosystem services provided by birds; and (iv) written in a language spoken by the author team (English, Polish, French, Italian, Japanese, Dutch, and Croatian). Purely comparative analyses, systematic reviews, narrative reviews, and primary empirical studies were not eligible. Studies that did not have the full text available were also excluded. Eligibility criteria were defined using the PECOS (Population, Exposure, Comparator, Outcome, Study design) framework (Richardson et al. 1995; Foo et al. 2021) (Table 1). Each element of PECOS is given in Table 1.

Table 1: Eligibility criteria used for this study defined by the PECOS (Population, Exposure, Comparator, Outcome, Study design) framework. As the Comparator is not applicable in our case, it is not included in the table.

Population	Any wild, non-domesticated bird species. Meta-analyses including additional taxa besides birds were eligible only when effect sizes for birds were presented separately from other taxa.
Exposure	Any anthropogenic impact, such as, but not limited to urbanization, industrial and agricultural pollution (including insecticides, herbicides,

	rodenticides, and similar), light pollution, noise pollution, climate change, habitat loss and fragmentation (e.g. deforestation, desertification, wetland drainage, conversion to agricultural land), wind-farms, solar farms, hunting and poaching, fishing, climate change (e.g. temperature rise, extreme weather, wildfire), ocean acidification, plastic waste, artificial feeding, mining, diseases, vehicle collisions, dams, ecotourism, infrastructure development, invasive and domestic species (e.g. cats).
Outcome	Responses at individual, population or community level, such as, but not limited to behavior (e.g. migration patterns, daily movements, foraging and feeding, nest site choice, vocalization), circadian rhythms, physiology, morphology, reproduction, survival, population structure, population dynamics, species diversity, extinction rates, range shifts, and similar. We also considered avian-mediated ecosystem services, such as pest control, seed dispersal, and similar.
Study Design	Meta-analysis (sensu O’Dea et al. 2021: statistical synthesis of effect sizes from multiple independent studies).

2.2. Search strategy

We conducted a search for eligible studies on the 12th of June 2025 using the Web of Science (Core Collection) and Scopus databases. The search strings in English were developed through pilot searches and refined using 10 benchmark studies (see Appendix, section 2; Kunc & Schmidt, 2019; Fontúrbel et al. 2015; Messina et al. 2018; Paillet et al. 2010; Kroeger et al. 2022; Scridel et al. 2018; Akresh et al. 2020; Matuoka et al. 2020; Barzan et al. 2021; Lu et al. 2024). We provide full strings for both databases in the Appendix, section 2. We placed no restrictions on publication year, subject area, or journal. We conducted additional searches in English (RV), Polish (MS), French (MC), Italian (DD), Japanese (AM), Dutch (MEV), and Croatian (RV) on the 1st of November 2025 via Google Scholar using a simplified search string (see in the Appendix, section 2). We checked the first 50 results of Google Scholar, and if none were eligible, no further results were checked. We also conducted forward and backward citation chasing using citationChaser (Haddaway et al., 2021) on all benchmark articles and repeated the process until no new relevant articles emerged.

2.3. Study screening

We deduplicated all retrieved records via AsySD (Hair et al., 2023) and then imported deduplicated records into Rayyan (Ouzzani et al., 2016) for two stages of screening: title-abstract-keyword screening, followed by full-text screening. We summarised our workflow using a decision tree (Fig. 1). During the initial screening, RV and AC independently screened the same set of 140 records, identifying 10 conflicting decisions that were subsequently resolved through a discussion. The initial disagreement rate on inclusion/exclusion exceeded 5%; therefore, a second set of 140 records was double-screened. After resolving four further conflicts and achieving >95% agreement, RV conducted the remainder of the initial screening. RV and AC conducted full text screening of all the relevant records, and any disagreements (N = 3) were resolved through discussion or, when necessary, consultation with a third reviewer (SN). Reasons for the exclusion at the full text stage were recorded. The screening process is summarised in a ROSES-like flowchart (Figure 1).

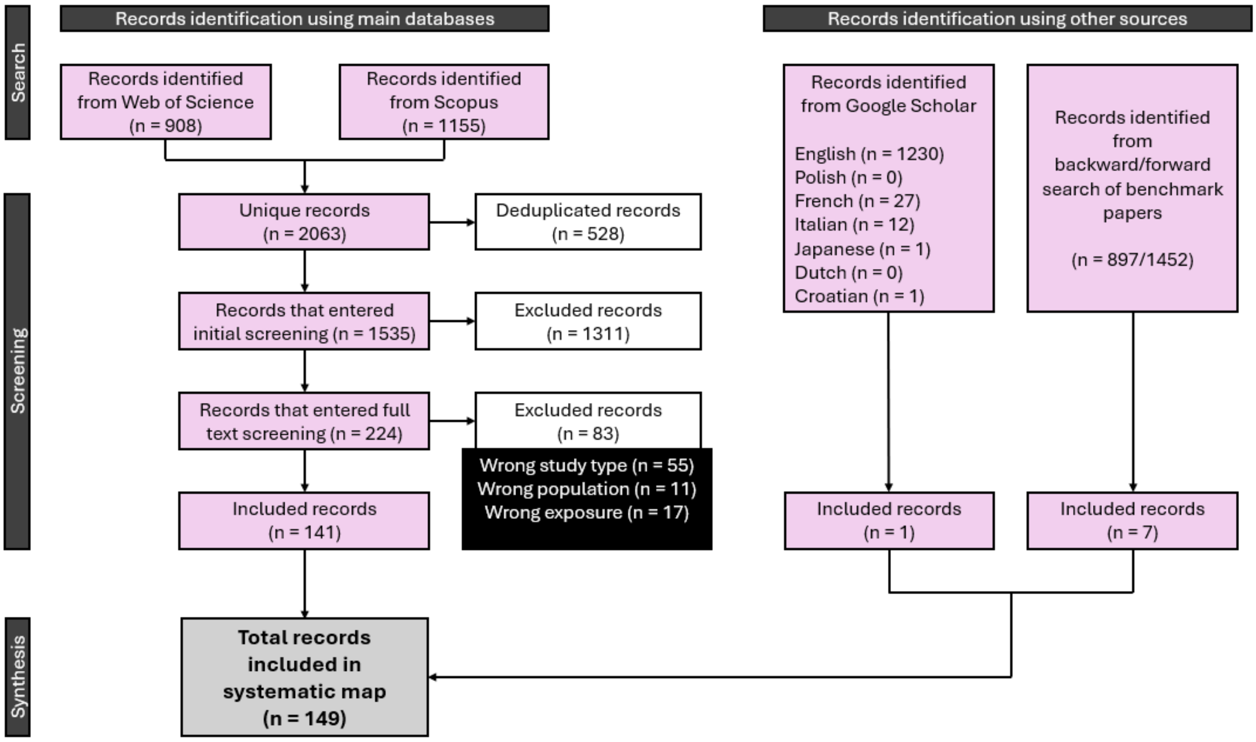


Figure 1. ROSES-like flow diagram illustrating the literature search, the initial, and the full text screening process. The diagram summarises the number of records identified, deduplicated, screened, excluded, and retained for further analysis, along with the main reasons for exclusion at the full text screening stage.

2.4. Data extraction

From studies that met our criteria, we extracted data for three types of analyses: a systematic map, critical appraisal, and bibliometrics and altmetrics analyses. We extracted data for systematic map and critical appraisal via Google Forms. Data extraction templates are available in a registered protocol (https://osf.io/txkz7/files/stm5u). The templates were piloted by RV, AC, MC, and NL using 10 benchmark items. RV extracted data from all meta-analyses (N = 149), while AC, MC, and OS independently extracted data from 32 meta-analyses (20% of the dataset). As the decisions were consistent among the extractors, the remaining meta-analyses were not double extracted. However, AC went through all the records entered in the extraction table to confirm the correctness of the extractions.

For the systematic map, we extracted data that covered four main areas: research question (main question, type of anthropogenic impact studied, type of response studied), scope (what the meta-analysis aimed at in terms of species, geographic area, etc.), coverage (what the meta-analysis actually included, in terms of species, geographic area, etc.), and the main methodological approaches applied in meta-analysis (e.g. type of meta-analytical model used).

We developed an *a priori* list of broad categories of 13 impacts and 13 responses (Table 2). We included explicit guidance for data extractors on placing exact impacts or responses (as stated in the meta-analyses) into each of the main categories (see Appendix, section 3 and the protocol). When a meta-analysis included impacts or responses that did not clearly align with any predefined category, these were broadly classified as ‘Other’. However, we also recorded the exact impact/response as stated in the meta-analyses to be transparent about our decision. Not all of the impact categories were mutually exclusive, as many impacts co-occur. For example, urbanisation often encompasses several concurrent stressors, such as light and noise pollution, reduced habitat quality, or chemical contamination. When meta-analyses were framed within broader urban ecology and did not allow individual pressures to be disentangled, they were classified under “urbanisation” as the primary category. In contrast, when meta-analyses explored agricultural expansion or intensification in relation to a clearly identifiable pressure such as habitat loss and fragmentation, they were categorised according to that focal pressure rather than as ‘Agriculture’. We also encountered some anthropogenic impacts, such as land abandonment, which represent the cessation of human land use rather than what would be traditionally considered a disturbance. However, we retained such a meta-analysis if the original practice that was abandoned (e.g. mowing) mimicked (replaced) a previously present ecological role (grazing by large grazers). Responses were further categorised according to the level at which they were studied (individual, population, community).

Table 2: *A priori* developed list of broad impacts and response categories

Impact or response	**Categories**

Anthropogenic impacts	General, Habitat loss & Fragmentation, Urbanisation, Agriculture, Climate change, Chemical pollution, Noise pollution, Light pollution, Infrastructure, Hunting, Food alteration, Species introduction, and Other
Responses	Survival, Reproduction, Population dynamics, Movement & migration, Behaviour, Trophic interaction & ecological roles, Diversity & abundance, Physiology, Morphology, Genetics & evolution, Communication, Disease, and Other.

For the critical appraisal assessment, we selected variables based on the PRISMA–EcoEvo checklist (O'Dea et al. 2021) and in line with a previous similar assessment applied for ecological meta-analyses (Pollo et al. 2024). These variables relate to (i) the transparency of reporting key methodological aspects (e.g. full search strings) and results (e.g. full reporting of the main effect), (ii) the availability of data and code, and (iii) the use of important methodological practices in meta-analyses: preregistration, testing for publication bias, assessment of quality of included primary studies, and handling non-independent data. We considered two main types of non-independence relevant to ecological meta-analyses (Nakagawa et al. 2017), non-independence due to shared phylogenetic relatedness and non-independence related to effect sizes coming from the same study. We additionally assessed temporal trends (2007-2025) in the reproducibility of search (presence of a full search strings), reporting of study selection process in PRISMA-style flow charts, , public sharing of data, and four methodological aspects (use of more than one database for search, accounting for phylogenetic non-independence or non-independence of effect sizes derived from the same primary study, preregistration, and quality assessment). To calculate the trends we grouped meta-analyses into four publication periods (2007-2011, 2012-2016, 2017-2021, 2022-2025). For each period we calculated the proportion of meta-analyses that complied with each transparency/methodological aspect. If a certain aspect was not applicable to a particular meta-analysis or it was unclear, such a meta-analysis was not included in the calculation of the proportions The complete list of the extracted variables for our systematic map and critical appraisal is available in the preregistration (https://osf.io/txkz7/files/stm5u).

For the bibliometric analysis, we retrieved data from the Scopus database on the 13th of November, 2025. These data included author names and affiliations, citation information, publication year, journal, and open access status. We used these data to examine publication and citation patterns, co-authorship networks, and author-level and country-level collaborations. We quantified publication patterns as annual publication output, cumulative growth over time, distribution across journals, and the proportion of open-access articles. We examined citation patterns using the total citation counts and citations per year to account for publication age. We calculated descriptive statistics (median, interquartile range, minimum and maximum) to characterise citation distributions. We constructed co-authorship networks based on the co-occurrence of authors within the same publication, where nodes represented authors and edges represented co-authorship ties. Edge weights corresponded to the number of shared publications. We quantified author-level collaboration as the number of distinct co-authors per author across the dataset. We assessed country-level collaboration based on author affiliations, with international collaborations defined as publications involving authors from two or more countries. One meta-analysis was not indexed in the Scopus database and was therefore excluded from further analysis. We retrieved data for alternative metrics analysis on 13th of November, 2025 via Altmetric.com. These data included the number of policy documents citing each meta-analysis, Mendeley readership, total Altmetric scores and Wikipedia mentions. We summarised alternatives using descriptive statistics (median, interquartile range, minimum and maximum).

We produced visualisations and descriptive statistics in R version 4.4.2. (R Core Team, 2022). Data analysis was conducted using the tidyverse (version 2.0.0.; Wickham et al. 2019) including dplyr (version 1.1.4.; Wickham et al. 2026), and tidyr (version 1.3.1.; Wickham et al. 2026). We conducted bibliometric analyses using the bibliometrix package (version 5.2.0; Aria and Cuccurello, 2017), and its interactive biblioshiny web interface. We generated figures using the ggplot2 package (version 4.0.1; Wickham, 2016), paletteer (version 1.7.0.; Hvitfeldt, 2021), viridis (version 0.6.5.; Garnier et al. 2024), maps (version 3.4.3.; Becker et al. 2025), tidygraph (version 1.3.1. Pedersen, 2025), ggraph (version 2.2.2.; Pedersen, 2025), patchwork (version 1.2.0.; Pedersen, 2024), and circlize (version 0.4.16.; Gu et al. 2014). All data and scripts are openly available at Zenodo repository (10.5281/zenodo.18768445). Data include the results of database search, deduplicated set of articles that have entered the screening process, articles that have entered the full text screening and those that were excluded in the process with the reasons for the exclusion, the systematic map, critical appraisal, bibliometric and altmetric datasets with accompanying scripts for analyses.

Several minor deviations from the protocol are described in Appendix, section 1.

3. RESULTS AND DISCUSSION

3.1. Summary of the search and screening process

The Web of Science and Scopus search yielded 908 and 1155 records, respectively. After removing 528 duplicates, 1535 unique records remained for title-abstract-keyword screening, during which 1311 records were excluded. The remaining 224 articles were assessed in full text, resulting in the exclusion of 83 records (listed in the Appendix, section 4). A total of 141 meta-analyses were retained from the main database search. One additional eligible meta-analysis was identified through Google Scholar searches, and a further seven were identified through backward and forward citation chasing. In total, 149 eligible meta-analyses published in English were included in the systematic map and critical appraisal. These are all referenced in the separate Reference list. One meta-analysis was not indexed in Scopus and was, therefore, excluded from bibliometric analysis. The study selection process is represented in Fig 1.

3.2. General features of the meta-analyses

The earliest meta-analysis included in the dataset was published in 1998, and the most recent in 2025, documenting more than two decades of synthetic research on anthropogenic impacts on birds (Figure 2). Publication output increased steadily over time and accelerated markedly after 2010. These patterns illustrate the rapid expansion of meta-analytical approaches addressing anthropogenic impacts on birds (Matuoka et al. 2020; Engel et al. 2024), facilitated by the accumulation of primary studies (Matuoka et al. 2020; Terray et al. 2025), the increasing urgency associated with accelerating global change pressures (Wang et al. 2021; Rigal et al. 2023; Kotz et al. 2025), and a broader growth in evidence synthesis across ecology and conservation science (Lortie et al. 2014; Gurevitch et al. 2018).

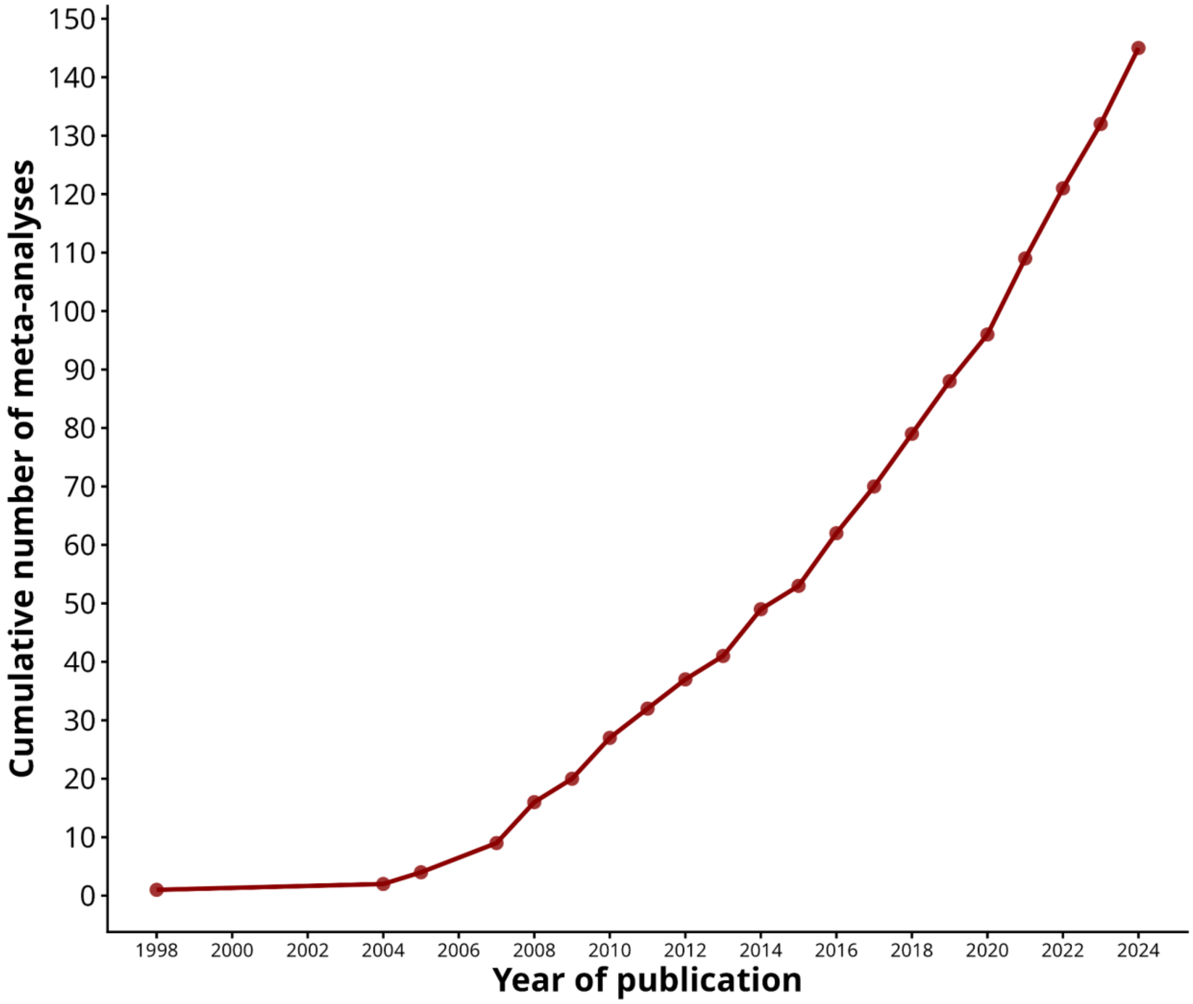


Figure 2. Cumulative number of meta-analyses on anthropogenic impacts on birds published between 1998 (the first published meta-analysis), until 2024. The curve illustrates the temporal accumulation of evidence in this research field. Although four meta-analyses were published in 2025, they are not included because our search was conducted in mid-2025.

Original primary studies used in these meta-analyses were published between 1912 and 2024. Meta-analyses synthesised an average of 27.4 ± 15.8 years of primary evidence, highlighting the long temporal horizon embodied in avian ecological research (Collins 2001; Taig-Johnston et al. 2017; Leroy et al. 2023; Şekercioğlu 2025). On average, they included 30.9 primary studies (SD = 40.5, based on 125 meta-analyses), 165.5 effect sizes (SD = 155.1; mode = 8, based on 87 meta-analyses) and 191.4 species (SD = 428.5; mode = 19, based on 94 meta-analyses) revealing large variation in the amount of data combined across studies.

Most meta-analyses synthesised exclusively observational studies (52.3%) or exclusively experimental ones (24.2%), while 21.5% included both these designs. Such imbalance likely reflects the logistical, spatial and ethical constraints of manipulating large-scale anthropogenic drivers in primary studies (Larsen et al. 2019). However, the dominance of observational evidence also implies that many syntheses rely primarily on correlational relationships, limiting causal inference (Siegel and Dee 2025). Among meta-analyses reporting effect size metrics, standardised mean differences were most commonly used (41.1%), followed by log response ratios (17.2%), correlation coefficients (15.3%) and beta coefficients (6.7%), likely reflecting the diversity of ecological questions and underlying study designs (Nakagawa et al. 2017).

3.3. SYSTEMATIC MAP - the content of meta-analyses

3.3.1. Main research questions

The vast majority of meta-analyses addressed the effects of anthropogenic threats on birds (96%), while a small fraction examined both birds and their ecosystem services (2%), or ecosystem services alone (2%). Although ecosystem services such as pollination, seed dispersal, nutrient cycling, or pest control are tightly linked with bird populations (Whelan et al. 2008; Gaston et al. 2018; Garcia et al. 2024), these connections remain largely absent from global syntheses. Understanding these links is important given that avian declines can generate cascading ecological consequences that are not immediately visible when the focus is solely on birds (Şekercioğlu et al. 2004; Gaston et al. 2018; Weeks et al. 2025).

Included meta-analyses covered 12 out of 13 predefined anthropogenic impact categories (Figure 3), yet with highly uneven research attention. Most meta-analyses focused on a single impact, whereas only a small subset (N = 5) considered two within the same synthesis. These combinations generally involve pressures that are closely linked such as habitat loss and fragmentation in the context of agriculture, climate change, and hunting, as well as urbanisation and chemical pollution. Habitat loss and fragmentation dominated the literature (27.3%, N = 42), followed by agriculture (15.6%, N = 23), urbanisation (10.4%, N = 15), climate change (9.7%, N = 15), general (meta-analyses with no specific anthropogenic pressure outlined; 8.4% = 13) and infrastructure-related impacts (7.1%, N = 11). In contrast, other globally important pressures such as light and noise pollution, invasive species, pathogens, or hunting remain underrepresented despite their substantial ecological effects (Mooney and Cleland 2001; Longcore and Rich 2004; Shannon et al. 2016; Ripple et al. 2016; Ogden et al. 2019). Importantly, these more specific pressures frequently operate within, and interact with, broader processes. For example, light pollution is commonly associated with urbanisation, but also accompanies agricultural intensification (e.g. greenhouse production), and infrastructure development. The lower representations of such drivers in meta-analytical research may partly reflect historical data constraints, as quantifying specific pressures at large spatial scales has traditionally been challenging. In this context, the observed pattern may also signal a gradual shift from documenting broad-scale drivers towards testing more specific ones because global datasets have only recently become available for certain pressures (e.g. global night-time light; Tang et al. 2025), while remaining scarce for others (e.g. noise). Also, this distribution of meta-analytical effort could mirror long-standing conservation priorities. For example, habitat loss in the form of land-use change remains the most pervasive global driver of biodiversity decline (Pimm et al. 2014), with the first meta-analysis on this topic published in 1998 (Bender et al. 1998). On the other hand, urbanisation and climate change have become prominent themes in recent meta-analytical studies (e.g. Batáry et al. 2018; Halupka et al. 2023). Infrastructure-related impacts, including collisions with power lines, wind turbines, or vehicles represent an emerging synthesis theme (e.g. Thaxter et al. 2017; Kroeger et al. 2022; Lamb et al. 2024). The proliferation of meta-analyses on several well-studied topics suggests that some of the syntheses might be overlapping in scope and content, potentially leading to redundancies. However, as we grouped impacts and responses into broader categories, the exact ones studied in individual meta-analyses categorised as having the same impact or response might differ. We thus did a quick qualitative comparison of research questions (exact impacts, responses, scope) that suggested at least partial thematic overlap among some syntheses. However, checking for the exact content overlap was beyond our scope.

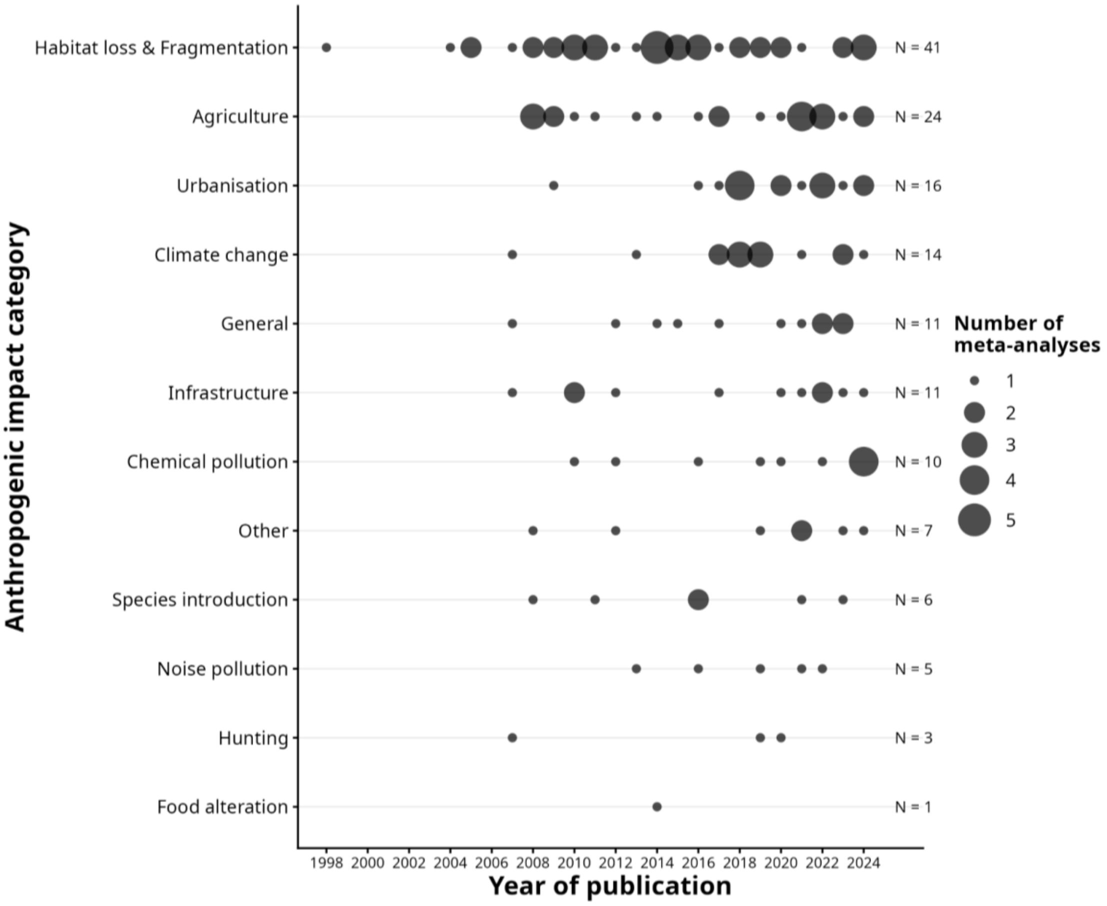


Figure 3. Temporal representation of the publication of meta-analyses for each anthropogenic impact category. The x-axis represents year of publication and the y-axis lists anthropogenic

impact categories, sorted by the overall number of the published meta-analyses belonging to that category, which is stated in parentheses. Bubble size is proportional to the number of meta-analyses published on each impact category in a given year, with larger bubbles indicating larger numbers. Note that meta-analyses published in 2025 were excluded because the literature search was conducted in mid-2025, resulting in an incomplete publication year.

At the response level, meta-analyses covered all 13 predefined categories. Although the majority of meta-analyses examined a single response category, 28 out of 149 (18%) included two or more. Similar to the anthropogenic impacts, research attention was strongly concentrated on a limited subset of responses. Diversity and abundance responses accounted for 40.6% of syntheses (N = 83), followed by reproduction (16.2%, N = 33), physiology (8.8%, N = 17), survival (7.4%, N = 15) and behaviour (6.4%, N = 13). Population-level responses dominated the literature (58.7%), followed by community-level metrics (27.2%), while only 14.1% of meta-analyses examined individual-level responses. Moreover, response categories were unevenly distributed across anthropogenic impacts. As illustrated in Figure 4, syntheses addressing habitat loss and fragmentation, as well as agriculture, were predominantly based on diversity and abundance metrics. This emphasis likely aligns with the variables most commonly reported in primary studies and with traditional demographic indicators used in avian ecology (Speakman et al. 2025). Responses related to movement, migration, communication, phenology, and other finer-scale traits were rarely synthesised, despite their sensitivity to disturbance and the potential to provide mechanistic insight into species' responses to anthropogenic pressures (Merrick and Koprowski 2017; Johnston et al. 2019; Jones et al. 2024). This is particularly notable given that e.g. climate change is expected to disrupt migratory behaviour (Møller et al. 2008; Robinson et al. 2009), phenological timing (Both et al. 2006; Charmantier and Gienapp, 2013), and the spatial availability of key resources for many species (Mayor et al. 2017). Their limited representation, therefore, constitutes a critical gap in current synthetic knowledge.

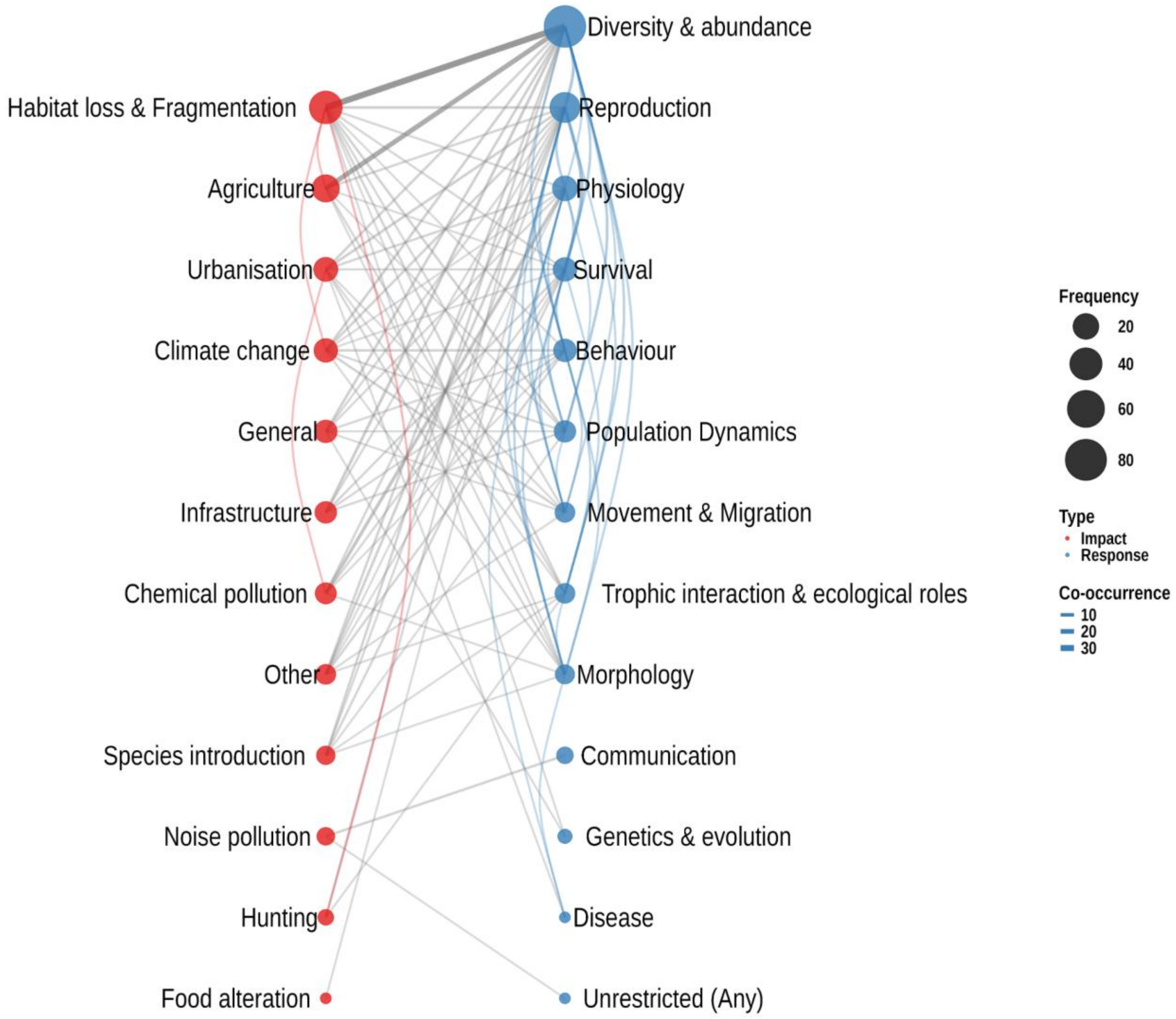


Figure 4. The network illustrates the co-occurrence of anthropogenic impact categories (red nodes on the left) and response categories (blue nodes on the right) across meta-analyses. Node size is proportional to the total frequency with which each impact or response category appears in the dataset. Edge thickness represents the absolute number of meta-analyses in which a given pair of categories co-occurs. Impact and responses are arranged by decreasing frequency. Straight edges indicate connections between impact and response categories, whereas curved edges represent co-occurence within the same category type (i.e. between responses or between impacts). Because edge weights reflect raw co-occurrence counts, categories that occur more frequently overall have a greater maximum potential to form connections and thus to generate thicker edges. Consequently, edge thickness is not independent of node size and should be interpreted as a descriptive measure of literature coverage rather than a normalised estimate of association strength.

3.3.2. Original scope and the achieved coverage

Among the included meta-analyses, 53% (N = 79) examined birds within a synthesis of a larger set of animal or living taxa, while 47% (N = 70) focused exclusively on birds (Figure 5).

Most meta-analyses (92.6%) included species across multiple avian taxonomic orders. Only 6% aimed at a single order, and 1.3% at only one species. Nevertheless, among meta-analyses for which taxonomic proportions could be determined (N = 91), Passeriformes dominated in most (N = 69), while other major avian groups were comparatively underrepresented (Figure 5). Such an imbalance in representation, especially in those meta-analyses that originally aimed at a large taxonomic scope, may constrain generality of synthesis outcomes, especially given that life-history traits, ecological niches, or exposure pathways likely vary widely among clades and species and may influence both the magnitude and direction of responses (Bennet and Owens, 1997; Foden et al. 2013; Pacifici et al. 2015; Rattner et al. 2022; Salvador and Reif, 2023; Germain et al. 2023; Carneiro and Pearmain, 2023). Seabirds and waterbirds, for instance, experience acute pressures from fisheries bycatch, plastic pollution, and marine heatwaves, yet remain sparsely synthesised relative to the severity of threats they face (Troudet et al. 2017; Dias et al. 2019; Pollet et al. 2026). Despite the strong links between anthropogenic impacts and conservation concern (Sherry 2021; Harfoot et al. 2021; Shuai et al. 2024), only 11 of the 149 meta-analyses explicitly considered IUCN status. This represents an important gap, as threatened and non-threatened species often differ in their sensitivity and responses to human pressures (Salvador and Reif 2023; Serrano et al. 2025). This mismatch between research effort and conservation urgency underscores the need for more targeted primary research and synthesis that specifically includes vulnerable clades. However, this imbalance may partly reflect ethical and practical constraints that limit research on endangered species (Shaw et al. 2021).

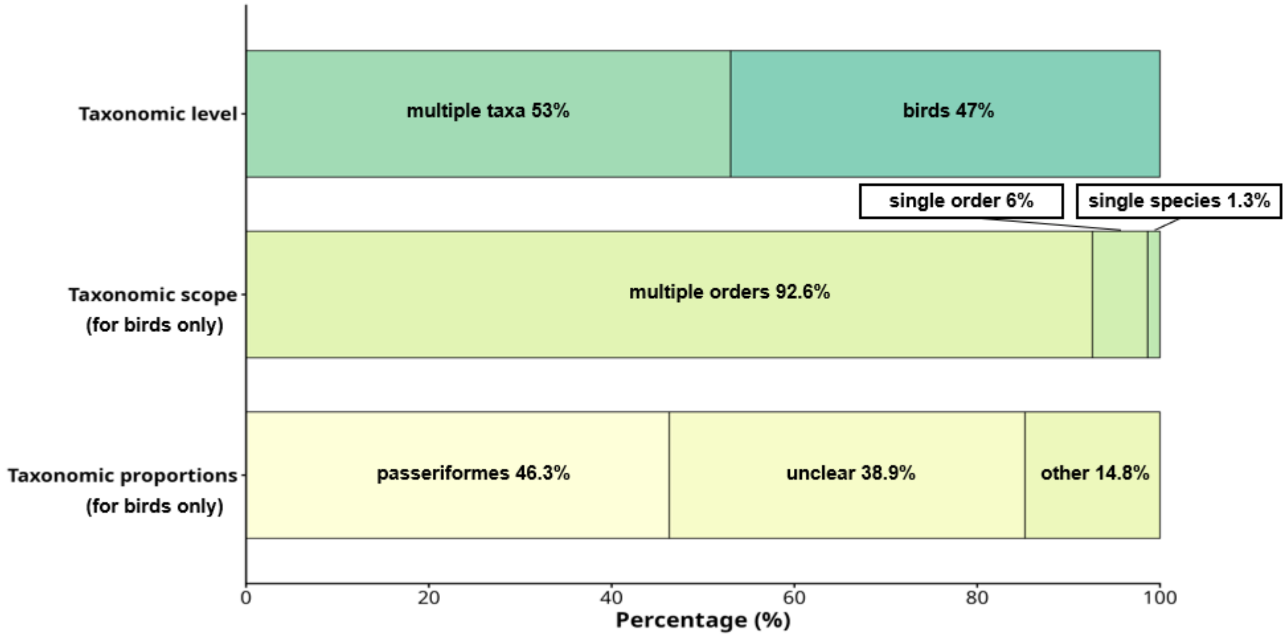


Figure 5. Taxonomic coverage of meta-analyses included in the systematic map. Panels summarise (i) taxonomic levels investigated: meta-analyses including birds only (N = 68

versus multiple taxa, N = 81, (ii) taxonomic scope:whether meta-analyses aimed at a single bird species (N = 2), single bird order (N = 9) or multiple bird orders, N= 138); and (iii) taxonomic proportions (for birds only), showing the proportional representation of different avian orders across meta-analyses (N = 91). Percentages indicate the proportion of meta-analyses falling within each category.

Similarly, migration status, a key determinant of exposure to multiple anthropogenic pressures (Nemes et al. 2023; Cooke et al. 2024; Zuckerberg and Sorte 2024) was rarely incorporated in meta-analyses. Only four meta-analyses were explicitly restricted to migratory bird species, while 28 incorporated migration status as a moderator or explanatory variable. In contrast, most meta-analyses were not restricted by migration strategy nor considered migration status in their analyses (78.5%, N = 117). Given the complex annual cycles and long-distance movements of many species, incorporating migration into future synthesis will be critical for understanding cumulative pressures experienced across flyways (Flack et al. 2022; Saunders et al. 2025; Liang et al. 2025).

Although 71.8% (N = 107) of 149 meta-analyses aimed at global coverage, only slightly more than half (N = 60) managed to achieve it. Overall, 19.5% (N = 29) restricted their initial scope to specific continents, and 8.7% (N = 13) were regional (anything bellow the continental level). Thus, 89 meta-analyses (59.7%) did not aim at or did not achieve global coverage. Studies included in these non-global meta-analysis were most often conducted in North America (22.4%) and Europe (17.6%), with more moderate representation across Asia (11%), South America (10%), Oceania (9.7%), and Africa (7.9%), while Antarctica was almost entirely absent (0.7%) (Figure 6). Note that these percentages do not reflect the exact number of primary studies coming from a certain continent, but rather whether a certain continent was represented by at least one primary study in a meta-analysis. Such spatial biases reflect both the focus of some meta-analyses on specific regions, and the lack of primary studies from certain regions in meta-analyses that were not geographically restricted. Reasons for the lower availability of primary studies may include the lack of research conducted in certain regions, often related to limited funding, accessibility of long-term datasets, and variability in ecological monitoring infrastructures (Martin et al. 2012; Amano et al. 2016; Titley et al. 2017). However, they might also reflect language bias (English literature is most often included in meta-analyses). Geographic skewness like this highlights a structural gap that future primary studies and meta-analyses should prioritise addressing (Hortal et al. 2015; Poisot et al. 2020).

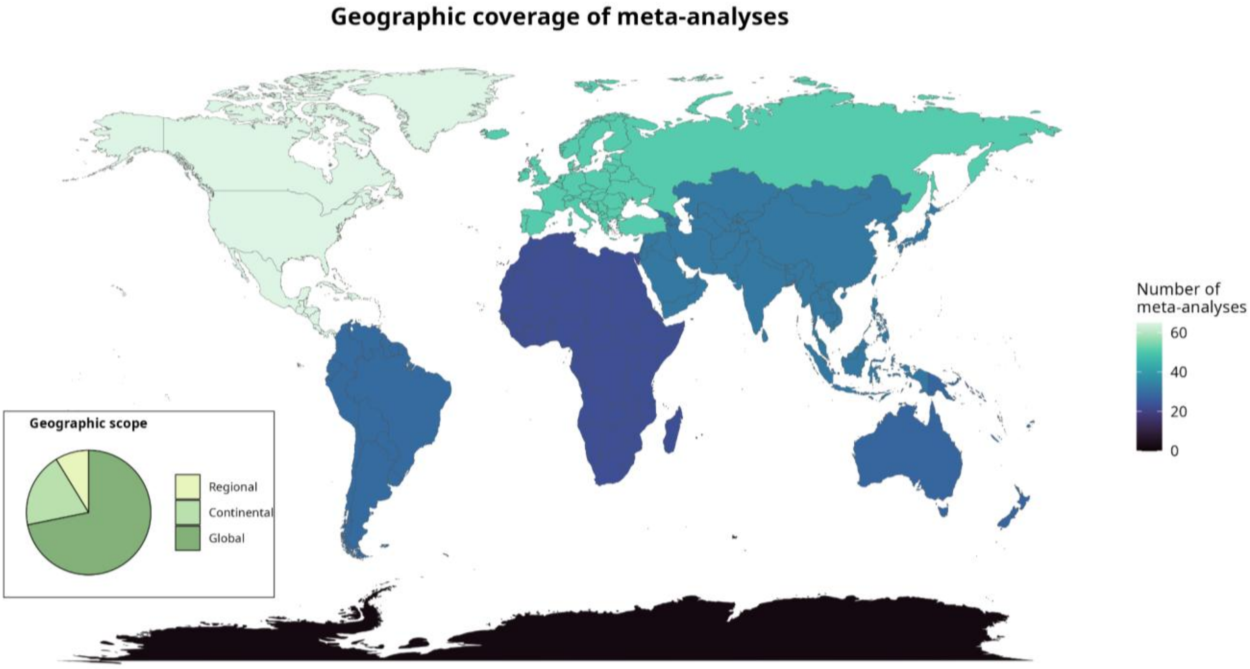


Figure 6. Geographic coverage of meta-analyses. For each continent, the map shows the number of meta-analyses that included data from that continent. Some meta-analyses are counted in multiple continents if they include data from more than one region. This figure is based on 89 meta-analyses that did not have a global coverage. The accompanying pie chart summarises the stated geographic scope (what a meta-analysis originally aimed at) of all 149 meta-analyses (global, continental, regional). Map lines delineate study areas and do not necessarily depict accepted national boundaries.

3.3.3. Policy relevance and uptake

Of the 149 meta-analyses, 48.3% explicitly mentioned their policy-relevance, whereas only 22.8% discussed implications for mitigation measures. Among meta-analyses that mentioned policy relevance, six specifically considered species' conservation status. This disparity reveals that, while synthetic research increasingly contributes to conceptual understanding of anthropogenic impacts, comparatively few aim to translate evidence into actionable guidance (Cook et al. 2013; Pullin et al. 2022).

Around one third of meta-analyses (N = 54) were cited in policy documents, based on information we obtained from Altmetric.com, with most publications referenced only in a few documents (median = 2; IQR = 1-4; max = 30). A small number of syntheses received markedly greater policy attention, most notably a meta-analysis on the impacts of roads and other infrastructure on birds and mammals (Benítez-López et al. 2010), which was cited in 30 documents. Elevated policy uptake was also observed for meta-analyses addressing logging impacts on tropical forest biodiversity (Burivalova et al. 2014) and the effects of wind farms on birds (Stewart et al. 2007; Thaxter et al. 2017), suggesting that direct uptake of avian meta-analytical evidence into formal policy documents remains limited and highly concentrated on a small subset of topics. Interestingly, of 54 meta-analyses that were cited in policy documents, only 24 framed their findings as policy relevant. The other 30 did not discuss their policy relevance but were cited in policy documents. These results indicate a partial disconnect between self-declared policy relevance and actual uptake into formal policy documents.

3.4. CRITICAL APPRAISAL

Critical appraisal revealed several patterns in how the 149 included meta-analyses adhered to reporting and methodological standards. While some aspects of these standards were quite well followed, several recurring limitations continue to constrain reproducibility, robustness, and interpretability of synthesis outputs (Figure 7).

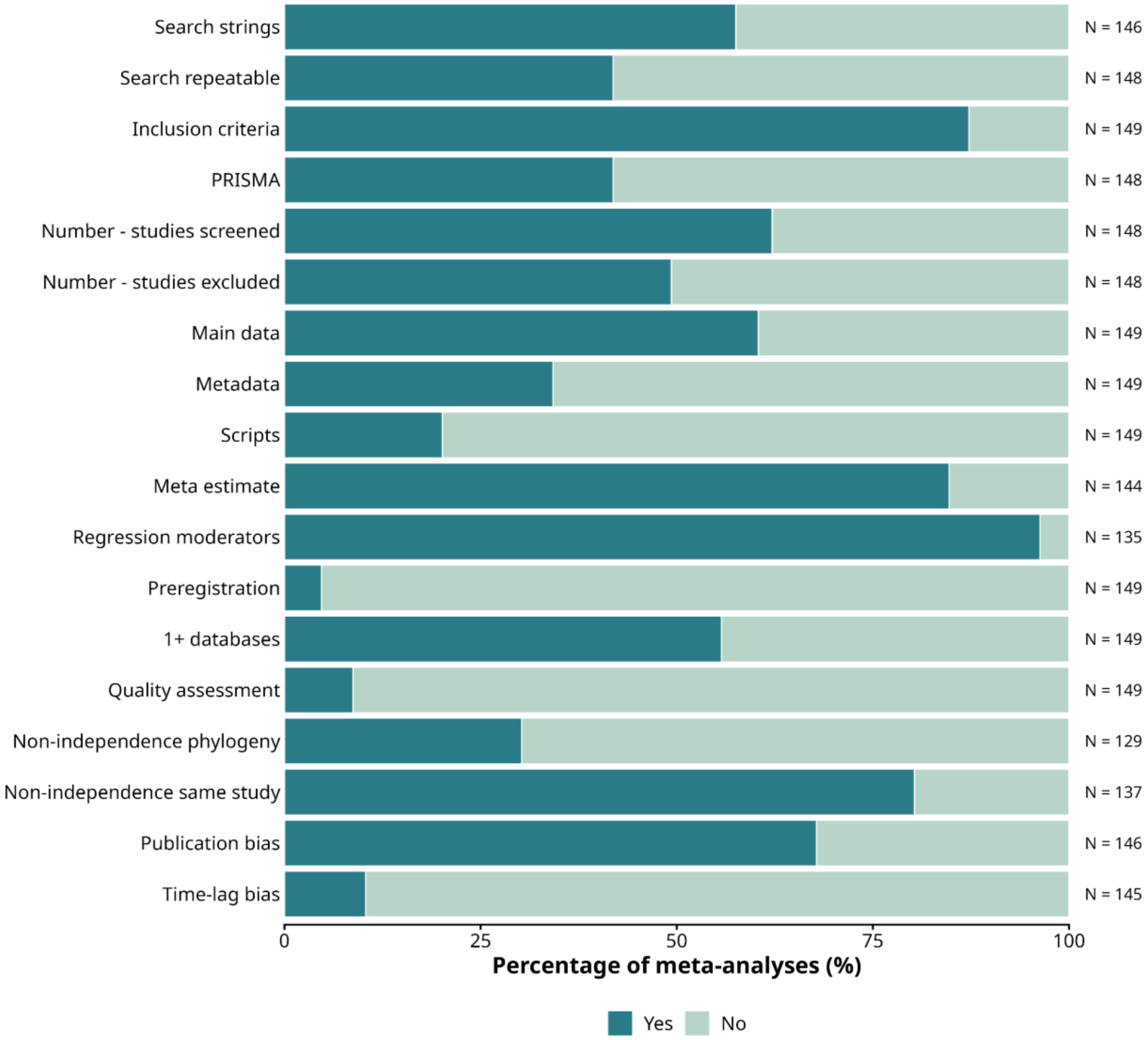


Figure 7. Reporting and methodological characteristics of included meta-analyses based on

the critical appraisal assessment. Each bar represents the proportion of meta-analyses meeting a given reporting or methodological criterion. For simplicity and comparability, all variables were dichotomised into Yes/No categories. Sample sizes (N) vary across variables because cases coded as “unclear” or “not applicable” were excluded from the denominator for the respective item.

3.4.1. Reporting transparency

Transparent reporting is essential for understanding methodological decisions, interpreting results, enabling reproducibility (O’Dea 2021), and updating meta-analyses as new studies on a topic accumulate (Elliott et al. 2021; O’Dea 2021).

Worryingly, the search was repeatable for fewer than a half of the meta-analyses in our sample (41.6%, N = 62). Repeatable searches included details of the complete search strings, search dates, and databases used. Most meta-analyses clearly stated their general inclusion criteria (87.2%); however, more than a half (55.7%) did not specify whether grey literature was considered. The screening process was clearly reported in a PRISMA-style flow diagram in 62 (41.6%) meta-analyses. While 61.7% of meta-analyses reported the number of records entering the initial screening phase, nearly half failed to report how many studies were excluded at subsequent stages. Slightly over half of the meta-analyses (N = 90, 60.4%) shared at least some of the data used; however, 75 (50.3%) shared seemingly all data, 48 provided accompanying metadata, and only 20.1% (N = 30) made analysis code publicly available. Overall, the meta-analysis was potentially analytically reproducible only in 17,4% (N = 26) cases. Such incomplete reporting of search strategies, screening processes, and meta-analytical datasets represents a major barrier to reproducibility and limits the potential for cumulative updating of evidence syntheses (Munafò et al. 2017; Wang et al. 2022; O’Dea et al. 2021).

In contrast, reporting of the main meta-analytical results was generally better than reporting of the methodological aspects. Most meta-analyses reported the main effect sizes fully (81.9%) (e.g. mean effect and CI intervals, or equivalent), and 69.8% (N = 104) reported effect sizes (and measures of uncertainty) for all regression moderators.

3.4.2. Methodological aspects

We estimated the extent to which meta-analyses comply with important methodological standards, namely preregistration, use of more than one database for a literature search, assessment of the quality of the primary studies included in the meta-analyses, dealing with non-independent effect sizes (study or phylogeny), and conducting publication bias tests. Most meta-analyses relied on traditional analytical frameworks (87.9%), which consider effect-size weighting and heterogeneity modelling, while a smaller proportion adopted non-traditional (11.4%) or mixed (0.7%) approaches.

Consistent with the previous estimates of approximately 3% preregistration in ecological syntheses (O'Dea et al. 2021), only 4.7% of meta-analyses in our dataset were preregistered, and less than half of these reported deviations from their original protocol. Preregistration involves specifying research questions, hypotheses, inclusion criteria, and planned analytical approaches before conducting the research (Nosek et al. 2018; Evans et al. 2023; Purgar et al. 2024), commonly in a protocol which is published in a registry (e.g. OSF registries), time stamped, and can be made public. Preregistration improves methodological and reporting quality of published studies, and reduces risks associated with selective reporting or post-hoc analytical decisions (Nosek et al. 2019; Simmons et al. 2020; Purgar et al. 2022; Lakens et al. 2024; Gould et al. 2025). While preregistration is a standard practice in medicine (Simonsen et al. 2025) and increasingly common in psychology (Spitzer and Mueller 2024; van den Akker et al. 2024), it remains rare in ecology (O'Dea et al. 2021; Purgar et al. 2024).

Although searching multiple databases is necessary for a systematic review (Stevinson and Lawlor 2004; Bramer et al. 2017), nearly one quarter of meta-analyses relied on a single database. This reliance on limited search sources increases the risk of missing relevant studies and may bias effect estimates, thereby weakening the reliability of synthesis outputs (Ewald et al. 2022).

An assessment of the quality of studies included in a meta-analysis was conducted in only 8.7% (N = 13) of meta-analyses. Quality assessment can take many forms, including risk-of-bias evaluation or assessment of other aspects of the reliability of the primary literature. This is important because the validity of the evidence synthesis depends on the quality of the underlying studies and should be interpreted accordingly (Khan and Jadad 1996; Conn and Rantz 2003; Rhodes et al. 2017; Culina et al. 2025).

More than one quarter of meta-analyses in the dataset (27.5%, N = 41) did not account for phylogenetic non-independence when it was required (N = 41), and 13.4% (N = 20 out of 149) failed to account for multiple effect sizes derived from the same primary study. Such failure to account for phylogenetic and study-level non-independence represented another recurrent limitation. Ignoring non-independent data structures can inflate precision and increase false positive rates (Stone et al. 2011; Nakagawa and Santos, 2012; Noble et al. 2017; Cheung 2019).

Finally, while most meta-analyses assessed some form of publication bias, nearly one-third did not conduct any such tests, and time-lag bias was almost entirely ignored, with 87.2% of studies failing to assess it. Given accumulating evidence that both forms of bias are pervasive in ecological research (Jennions and Møller 2002; Lortie et al. 2007), these omissions represent a substantial limitation for inference reliability (Nakagawa et al. 2022).

3.4.3. Temporal trends in transparency reporting and methodological aspects

Across the four publication periods (2007-2011, 2012-2016, 2017-2021, 2022-2025), we observed modest improvements in several aspects of methodology and reporting transparency (Table S1, Appendix, section 6). The proportion of meta-analyses reporting full search strings increased from 50% (N = 28) (2007-2011) to 61.5% (N = 39) (2022-2025). Similarly, reporting of PRISMA-style flow diagrams increased slightly from 35.7% (N = 28) to 43.6% (N = 39) over the same period. Data sharing showed the most pronounced improvement, increasing from 39.3% (N = 28) in the earliest period to 62.5% (N = 40) in the most recent one. In contrast, the use of multiple databases did not show a consistent upward trend and remained variable across periods (67.9% (N = 28) in 2007-2011 vs. 57.5% (N = 40) in 2022-2025)). Accounting for phylogenetic non-independence increased gradually (19.2% (N =26) to 38.2%), while handling multiple effect sizes from the same primary study was consistently high across periods (77.8% (N = 27) to 81.6% (N = 38)), showing only minor changes. In contrast, preregistration and quality assessment remained uncommon throughout the entire dataset (4.7%, N = 7 and 8.7%, N = 13, respectively), precluding meaningful temporal comparisons. The first instances of preregistration and quality assessment appeared in 2010.

Several established methodological and reporting guidelines are available to support transparency, reproducibility, and robustness in meta-analytical research. These include structured reporting standards such as the PRISMA-EcoEvo Statement (O'Dea et al. 2021), as well as ecology-specific methodological guidance for conducting and interpreting meta-analyses, effect size calculation, handling non-independence, publication bias assessment, and multilevel modelling approaches (e.g. Gurevitch et al. 2001; Nakagawa and Santos 2012; Nakagawa et al. 2015; Nakagawa et al. 2017; Gurevitch et al. 2018; Nakagawa et al. 2022; Nakagawa et al. 2023). Wider adoption of these recommendations could strengthen future meta-analyses on anthropogenic impacts on birds, and more broadly, in ecology and evolutionary biology.

3.5. BIBLIOMETRIC ANALYSIS

Meta-analyses included in the bibliometric analysis (N=148) were published across 70 journals, and authored by 1009 unique authors from 28 countries, with an average of 7.8 authors per meta-analysis, consistent with broader cross-disciplinary trends towards increasingly collaborative and team-based research (Wuchty et al. 2007; Lariviere et al. 2014).

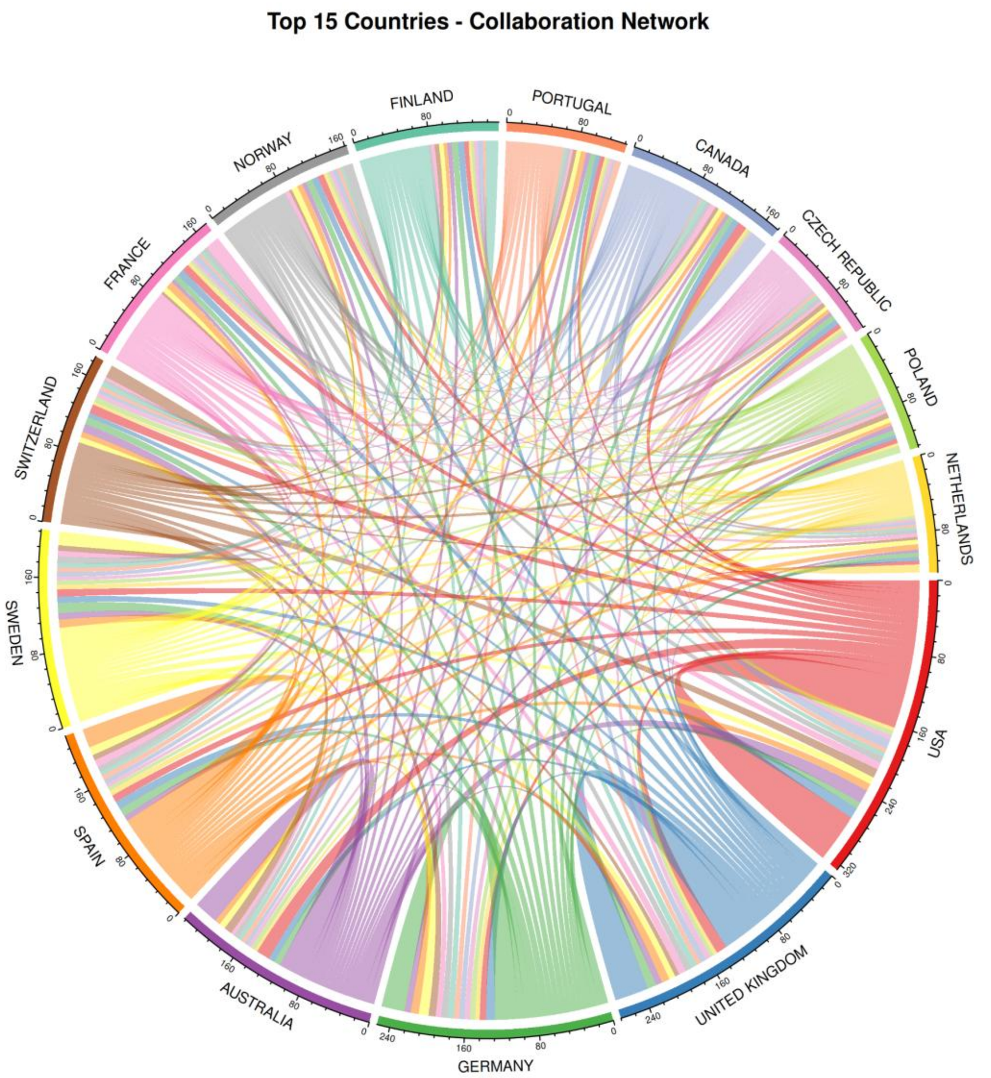
The co-authorship network revealed that many meta-analyses were produced by large research teams. Although the dataset includes over a thousand authors, a significant core (N = 353) collaborated with 50 or more distinct co-authors across the analysed meta-analyses. This connectivity peaked with a small group of central authors (N = 10), each linked to more than 190 unique co-authors in the dataset who were typically involved in large, internationally coordinated syntheses. Such a pattern likely reflects a growing tendency towards collaborative approaches in addressing broad and complex conservation questions (Wuchty, et al. 2007; Hampton and Parker 2011; Borer et al. 2014).

However, the patterns of international versus domestic collaboration varied substantially among countries (Figure 8a). Australia (N = 16), Canada (N = 10) and Argentina (N = 9) exhibited particularly high levels of cross-border collaboration, a pattern commonly observed in medium-sized research production systems that rely more heavily on international partnerships (Glänzel 2001; Wagner and Leydesdorff 2005). The number of meta-analyses authored exclusively by researchers affiliated with institutions within the same country was particularly high in the United States (N = 20), followed by the United Kingdom (N = 11) and Australia (N = 7), indicating strong national research capacity and well-established institutional networks.

Geographic patterns of research production were strongly uneven. First-author affiliations were concentrated in a relatively small number of highly productive countries (Figure 8b), namely Australia (N = 23 meta-analyses), the United States (N = 20), Canada (N = 15), the United Kingdom (N = 14) and Argentina (N = 11). In contrast, first authorship from Asia, Africa, and much of South America (except Argentina) remained comparatively limited, consistent with broader global inequalities in research publishing, and especially publishing in the English language (Man et al. 2004; Amano et al. 2016; Nunez et al. 2019; Amano and Berdejo-Espinola, 2025).

These findings align with similar patterns reported across other recent systematic maps in ecology and evolutionary biology research including those on coral health (Burke et al, 2023), sexual selection (Pollo et al. 2024), animal cognition (Mizuno et al. 2025), and anthropogenic noise (Lenz et al. 2025).

a)


Top 15 Countries - Collaboration Network
FINLAND
PORTUGAL
CANADA
CZECH REPUBLIC
POLAND
NETHERLANDS
USA
UNITED KINGDOM
GERMANY
AUSTRALIA
SPAIN
SWEDEN
SWITZERLAND
FRANCE
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b)

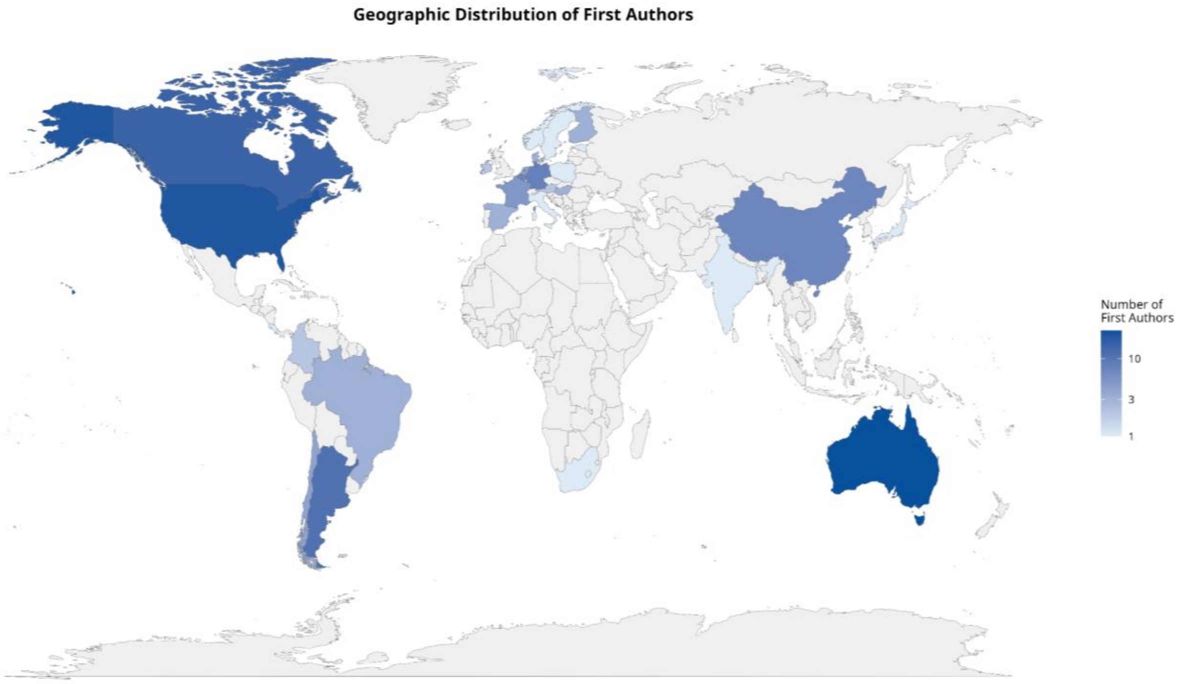

Figure 8. International collaboration and authorship patterns in meta-analyses. (a) Chord diagram illustrating co-authorship between countries. Each segment represents a country, and its width corresponds to the total number of international co-authored meta-analyses involving that country. Connecting ribbons represent collaborative links between pairs of countries, with ribbon width proportional to the number of shared meta-analyses, and (b) Geographic distribution of first authors' affiliations contributing to the meta-analyses included in the dataset (N = 148). Map lines delineate study areas and do not necessarily depict accepted national boundaries.

Collectively, the analysed meta-analyses accumulated 18.155 citations (mean = 122.7 citations per paper, median = 53.5). The mean number of citations per year was 13.7 (min: 0.75; max: 100.3), excluding meta-analyses published in 2024 and 2025 (Figure S1 in the Appendix, section 6). A notable outlier was a meta-analysis on the introduction of invasive species (Doherty et al. 2016) that accumulated 100.3 citations per year. Meta-analyses looking at the impact of agriculture (Beenhouwer et al. 2013), habitat loss and fragmentation (Flynn et al. 2009), and climate change (Radchuk et al. 2019) also received high yearly citation rates. Open access availability was moderately high, with 66.9% of publications freely accessible. Given evidence that it increases visibility, readership and citation rates, this openness level likely facilitates the dissemination and reuse of evidence (McKiernan et al. 2016; Piwowar et al. 2018).

Although meta-analyses were distributed across a wide range of journals (N = 70), several outlets emerged as major publication hubs. Conservation Biology and Biological Conservation published the largest number of meta-analyses (N = 10 each), followed by Global Change

Biology (N = 9), Proceedings of the Royal Society B (N = 7) and Biological Reviews (N = 6). The presence of both high profile generalist journals and specialised conservation outlets demonstrates that syntheses on anthropogenic impacts on birds reach diverse audiences across ecology, evolutionary biology, conservation science and environmental policy.

3.6. SOCIETAL IMPACT

Altmetric indicators provide insights into the societal, policy, and a broader scholarly visibility of publications. However, while the platforms that we used to obtain altmetrics indicators do not index the same subsets of journals and document types, several patterns emerged.

Mendeley readership data, available for 145 meta-analyses, pointed to high levels of scholarly engagement (median = 147; IQR = 65-301; max 2268). Several syntheses attracted more than a thousand readers, including meta-analyses on land-use intensification, habitat fragmentation, invasive predators and infrastructure impacts (e.g., Bender et al. 1998; Prugh et al. 2008; Flynn et al. 2008; Paillet et al. 2010; Doherty et al. 2016 and Benítez-López et al. 2010). Public and media attention measured using the Altmetric Attention Score (AAS) was available for 140 meta-analyses and was highly skewed. Most meta-analyses received modest attention (median = 12; IQR = 5-50.5; min = 1), whereas a small subset achieved exceptionally high visibility. Prominent examples included meta-analyses on invasive predators and biodiversity loss (Doherty et al. 2016; AAS of 3719), animal adaptive responses to climate change (Radchuk et al. 2019; AAS of 2187) and global genetic diversity loss (Shaw et al. 2025; AAS of 1487). These high profile topics closely align with widely communicated global environmental concerns and are likely frequently amplified through news media, science communication outlets and social media platforms, contributing to their disproportionate public reach (Jarić et al. 2020; Perga et al. 2023; Mammides and Campoz-Arceis 2025). Wikipedia mentions were available for only 22 meta-analyses, and remained limited in number (median = 2; IQR = 1-2.75; max = 10), indicating that this platform currently plays a minor, negligible role in disseminating avian meta-analytical findings beyond academic audiences.

These readership patterns highlight a relatively strong academic and public interest and uptake of at least some meta-analyses on anthropogenic impact on birds. In comparison, the meta-analyses show quite a limited presence in policy documents (as discussed earlier), which points to a disconnect between scientific attention and formal policy use. This disparity is consistent with previous evidence of a persistent gap between ecological evidence synthesis and its translation into decision-making and management contexts (Collins et al. 2019; Louder et al. 2021; Cooke et al. 2023; Fang et al. 2024). Further, altmetric patterns indicate that societal and policy attention to avian research is shaped less by the overall volume or maturity of the evidence base and more by a narrow set of issues that resonate with prevailing environmental narratives. As a result, many well-studied anthropogenic pressures on birds remain largely absent from public discourse and formal decision-making, despite the availability of robust meta-analytical evidence.

4. LIMITATIONS

Our work has several limitations. First, the search was restricted to languages spoken by the review team (English, Polish, French, Italian, Japanese, Dutch and Croatian). However, Google Scholar searches in Polish, French, Italian, Japanese, Dutch and Croatian did not uncover a single meta-analysis, indicating that most meta-analyses are published in English. Second, the majority of the data extraction was conducted by a single reviewer (RV), and 20% of the dataset was independently extracted by three additional reviewers (AC, MC, OS) to assess consistency. Agreement between reviewers was high, and all discrepancies were resolved through discussion and consensus. Further AC has cross-checked all the entries that were not double-extracted against the meta-analyses text. Nonetheless, the possibility of occasional extraction oversights cannot be entirely ruled out when a substantial portion of the process relies on a single extractor. Together, these limitations reflect pragmatic constraints. We believe that they have a minimal impact on the comprehensiveness or validity of the systematic map, but they should be considered when interpreting our findings.

5. CONCLUSIONS

This systematic evidence map demonstrates that meta-analyses on anthropogenic impacts on birds have reached a high level of maturity and breadth, providing powerful syntheses of how birds respond to anthropogenic pressures. However, despite the scale of this literature, the current evidence landscape is far from comprehensive or evenly developed. Instead, it reflects a combination of historical research priorities, availability of primary studies, and methodological conventions that collectively shape what is known, what is generalised, and what remains largely invisible.

Our synthesis reveals that research effort is strongly concentrated on a limited subset of anthropogenic pressures, particularly habitat loss and fragmentation, agriculture and urbanisation, while other pervasive and potentially severe stressors receive comparatively little synthetic attention. Similarly, the dominance of Passeriformes and the limited representation of seabirds, waterbirds, threatened or endemic species highlight a disconnect between synthesis activity and conservation urgency. Furthermore, most meta-analyses tend to overlook the migratory nature of birds and the cumulative pressures they face across entire flyways. The lack of a full life-cycle perspective means that the threats encountered during migration remain largely invisible in current syntheses, potentially masking the true vulnerability of migratory species to global change. An imbalance is also present in the types of responses synthesised, which predominantly focus on population- and community-level metrics, such as diversity and abundance, while behavioural, phenological, and other individual-level responses that can provide early or mechanistic signals of impact (Johnston et al. 2019) remain comparatively underrepresented. In addition, only a very small fraction of meta-analyses explicitly examined the consequences of anthropogenic pressures for bird-mediated ecosystem services. Although birds contribute to processes such as seed dispersal, pollination, pest control and nutrient cycling (Whelan et al. 2008), these functional dimensions remain comparatively underrepresented within current synthetic research. As a result, the broader ecosystem-level implications of avian responses to anthropogenic change remain only partially integrated into the evidence base. Geographic biases in underlying primary studies further constrain the generality of conclusions, particularly for biodiverse regions where anthropogenic pressures are likely intensifying most rapidly.

Equally important, our critical appraisal reveals that many avian meta-analyses do not fully meet established reporting and methodological standards. Incomplete reporting of search strategies, rare preregistration, near absence of formal study quality assessment, and inconsistent treatment of non-independence may limit confidence in synthesised effect estimates and hinder cumulative knowledge building. As meta-analyses increasingly inform conservation practices and environmental policy, strengthening these methodological foundations is essential to avoid overconfident or biased inference, and to enable evidence updates.

The way avian meta-analyses are produced and disseminated might further influence which evidence becomes visible and influential. Although the field is highly collaborative, synthesis activity remains concentrated within a limited segment of the global research community. In turn, policy and public attention tends to focus on a narrow set of widely communicated topics, while many anthropogenic pressures that are well documented in the literature remain peripheral to broader discourse.

Looking forward, advancing avian evidence synthesis under global change will require a shift from simply increasing the number of meta-analyses to strategically improving their scope, coverage, and conduct. Future syntheses should integrate consequences for ecosystem services; prioritise underrepresented pressures, responses, taxa and regions; explicitly incorporate life-history traits, migration strategies, and conservation status; and also adopt open science practices that facilitate reproducibility and updating. By clarifying where evidence is abundant, where it is lacking and how synthesis practices can be improved, this map provides a framework for more balanced, reliable and impactful meta-analytical research. Strengthening both the content and the conduct of avian meta-analyses will be key to ensuring that evidence synthesis keeps pace with the scale and urgency of anthropogenic environmental change.

Author contributions (CRediT)

Renato Vidić: Conceptualization, Data Curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – Original Draft Preparation, Writing - Review & Editing. **Marion Chatelain**: Conceptualization, Data Curation, Investigation, Methodology, Writing - Review & Editing. **Olivia M. Smith**: Conceptualization, Data Curation, Investigation, Methodology, Writing - Review & Editing. **Martha Szulkin**: Conceptualization, Methodology, Writing - Review & Editing. **Danijela Žanko**: Formal analysis, Software, Validation, Visualization, Writing - Review & Editing. **Nicole Lussier**: Data Curation, Investigation, Writing - Review & Editing. **Ayumi Mizuno**: Conceptualization, Methodology, Writing - Review & Editing. **Marcel Visser**: Conceptualization, Methodology, Writing - Review & Editing. **Davide M. Dominoni**: Conceptualization, Methodology, Writing - Review & Editing. **Shinichi Nakagawa**: Conceptualization, Methodology, Writing - Review & Editing. **Antica Čulina**: Conceptualization, Data Curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing - Original Draft Preparation, Writing - Review & Editing

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Conflicts of Interest

The authors declare no conflicts of interest.

Data and code availability

The data and code needed to reproduce the analyses have been deposited at Zenodo repository under the DOI 10.5281/zenodo.18768445.

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APPENDIX to **Synthesis of Anthropogenic Impacts on Birds - Systematic Map and Bibliometric Analysis of Meta-Analyses**

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This appendix includes: 1) Deviations from protocol, 2) The full search strings used across bibliographic databases and the list of benchmark studies, 3) Predefined categories of anthropogenic impacts and responses, 4) Excluded studies and reasons for exclusion, 5) Meta-analyses on strategies to mitigate threats to birds, and 6) A supplementary results figure (normalised citation counts) and table (temporal trends in adherence to standards).

1) Deviations from protocol

All deviations from the preregistered protocol (https://osf.io/txkz7/files/stm5u) are documented here, including rationale for each change. We followed the preregistered protocol closely throughout the conduct of the study. However, we had several deviations from the protocol. First, the preregistered protocol planned backward and forward citation chasing based on all eligible meta-analyses. However, the cumulative reference list obtained from the 149 meta-analyses exceeded 10,000 records, which was beyond the available human and temporal resources. We thus conducted citation chasing only on a set of benchmark meta-analyses selected to represent the full breadth of anthropogenic pressures. While this approach made our work feasible, and captured additional meta-analyses, it might have left some undetected.

Second, we originally planned to conduct a non-systematic analysis of the meta-analyses on the impacts of mitigation measures on birds. We decided this because while developing the search strategy, we realised the search string (designed to capture anthropogenic impacts), also captured some interesting meta-analyses on the effectiveness of mitigation strategies. We originally planned to retain these studies and report on them narratively, without conducting full data extraction, because they seemed to contain interesting information linked to our main aim, yet were not systematically captured by the search string. However, after the full text screening, we identified a substantial number of such meta-analyses. Given their conceptual relevance and the diversity and importance of these studies, it became evident that narrative summaries without a dedicated systematic search would be insufficient to capture this complex literature. We therefore decided to exclude these studies from the narrative review. Instead, we provide the full list of excluded mitigation strategy meta-analyses as a separate resource for future research in this Appendix (see section 4). This decision ensured consistency in our dataset while maintaining transparency and enabling future reuse.

Third, the systematic map data extraction protocol included the category ‘Any’ for several variables that described the scope of meta-analyses (e.g., habitat, dietary, conservation, and migration scope). This category aimed to indicate that a meta-analysis did not restrict its focus within a given domain. However, once the coding began, it became apparent that the term “Any” was ambiguous. The term “Any” could imply either a specified broad inclusion, the absence of restriction, or a lack of clearly defined scope, which risked inconsistent interpretation. To improve clarity and ensure methodological coherence across extraction fields, we replaced it with the more precise “Not restricted”. This term better reflects the actual intention (i.e. scope not limited to specific subcategories) and increased interpretability and consistency across the dataset.

Fourth, we extracted an additional variable that coded for whether a meta-analysis focused exclusively on birds or included other taxonomic groups. We considered this distinction important for interpreting the specificity of the evidence base and the extent to which conclusions about birds are derived from bird-focused versus broader, cross-taxa syntheses. This addition did not affect study inclusion but provided additional context for interpreting patterns in the evidence base.

Fifth, we made some adjustments to the bibliometric analyses. Our protocol prespecified that bibliometric analyses would include co-citation analysis, co-word analysis, and bibliographic coupling. However, for simplicity, we restricted the bibliometric component to the core and easily interpretable analyses such as publication and citation trends, authorship patterns, collaboration networks, and journal metrics. This provided a robust overview of the structure and evolution of the field without forcing unreliable inferences from sparse or incoherent citation structures.

Sixth, we slightly changed the approach to altmetrics data extraction. The preregistered protocol stated that we would retrieve policy citations and other indicators using PlumX. During data retrieval, however, we found out that only a small proportion of included meta-analyses were published by Elsevier (the publisher for which PlumX provides data). This would have resulted in an incomplete and systematically biased coverage. Additionally, PlumX counts multiple mentions within a single policy document as separate “citations”, rather than a number of documents in which a certain meta-analysis is cited. We thus used Altmetric.com to extract policy-related attention. Altmetric.com reports the number of unique documents in which a study is cited. This deviation increased both the completeness and interpretability of our altmetric dataset.

2) Full search strings and benchmark studies

The section provides complete search strings used in Web of Science, Scopus and Google Scholar (for all languages contributed by collaborators), and lists 10 benchmark studies that were used for creating the final search strings. Search strings reflect database-specific adaptations while retaining consistent conceptual structure.

Web of science database:

TS = (("meta-anal*" OR "metaanal*" OR "metaregres*" OR "meta-regres*" OR "quantitativ* review*" OR "quantitative* synthe*" OR "global* synthe*" OR "quantitativ* evidence synthe*") AND (bird* OR avian OR aves OR avifauna OR ornitho*) AND (anthropocene OR "anthropogenic impact*" OR "anthropogenic effect*" OR "anthropogenic disturbance*" OR "anthropogenic change*" OR "anthropogenic stress" OR "anthropogenic activit*" OR "anthropogenic factor*" OR "anthropogenic alteration*" OR "anthropogenic pressure*" OR "anthropogenic threat*" OR "anthropogenic intervention*" OR "human–induced" OR "human impact*" OR "human influence*" OR "human activit*" OR "human intervention*" OR "human disturbance*" OR "human footprint" OR "human induced" OR "human driven" OR "human altered" OR "environmental degradation*" OR "habitat degradation*" OR "habitat destruction*" OR fragmentation* OR "edge effect*" OR logging OR "habitat loss" OR "land use" OR "landcover" OR livestock

OR grazing OR deforestation OR urban* OR agricul* OR silviculture OR "land conversion" OR mining OR "wetland drainage" OR "climate change" OR warming OR "precipitation shift*" OR drought OR desertification OR desiccation OR heatwave OR "heatstress" OR "heat island" OR stressors OR "sea level rise" OR "ocean acidification" OR "extreme weather" OR "climate variability" OR wildfire OR pollution OR pollutant* OR PFA* OR waste OR microplastic* OR contamin* OR "heavy metal" OR "trace metal" OR agrochemical OR fertilizer OR pesticide OR herbicide OR fungicide OR insecticide OR rodenticide OR industrial OR drainage OR "endocrine disruptor chemical*" OR "nitrogen oxide*" OR NOx OR "Particulate matter" OR PM OR "Polycyclic Aromatic Hydrocarbon*" OR PAH* OR "Persistent Organic Pollutant*" OR POP* OR Electromagnetic OR "artificial light" OR ALAN OR "traffic noise" OR "artificial noise" OR "anthropogenic noise" OR hunting OR poaching OR "wildlife trade" OR fishing OR "artificial feeding" OR "supplementary feeding" OR "Food availability" OR fishing OR "anthropogenic food" OR road* OR railway OR highway OR infrastructure OR wind*farm OR "wind turbines" OR "renewable energy" OR "solar farm*" OR "hydroelectric dam*" OR electrocution OR collision* OR "powerline*" OR aviation OR airline OR "invasive species" OR "exotic species" OR "non*native species" OR "introduced predators" OR "predator introduction" OR tourism))

Scopus database:

TITLE-ABS-KEY(("meta-anal*" OR "metaanal*" OR "metaregres*" OR "meta-regres*" OR "quantitativ* review*" OR "quantitative* synthe*" OR "global* synthe*" OR "quantitativ* evidence synthe*") AND (bird* OR avian OR aves OR avifauna OR ornitho*) AND (anthropocene OR "anthropogenic impact*" OR "anthropogenic effect*" OR "anthropogenic disturbance*" OR "anthropogenic change*" OR "anthropogenic stress" OR "anthropogenic activit*" OR "anthropogenic factor*" OR "anthropogenic alteration*" OR "anthropogenic pressure*" OR "anthropogenic threat*" OR "anthropogenic intervention*" OR "human–induced" OR "human impact*" OR "human influence*" OR "human activit*" OR "human intervention*" OR "human disturbance*" OR "human footprint" OR "human induced" OR "human driven" OR "human altered" OR "environmental degradation*" OR "habitat degradation*" OR "habitat destruction*" OR fragmentation* OR "edge effect*" OR logging OR "habitat loss" OR "land use" OR "land cover" OR livestock OR grazing OR deforestation OR urban* OR agricul* OR silviculture OR "land conversion" OR mining OR "wetland drainage" OR "climate change" OR warming OR "precipitation shift*" OR drought OR desertification OR desiccation OR heatwave OR "heat stress" OR "heat island" OR stressors OR "sea level rise" OR "ocean acidification" OR "extreme weather" OR "climate variability" OR wildfire OR pollution OR pollutant* OR PFA* OR waste OR microplastic* OR contamin* OR "heavy metal" OR "trace metal" OR agrochemical OR fertilizer OR pesticide OR herbicide OR fungicide OR insecticide OR rodenticide OR industrial OR drainage OR "endocrine disruptor chemical*" OR "nitrogen oxide*" OR NOx OR "Particulate matter" OR PM OR "Polycyclic Aromatic Hydrocarbon*" OR PAH* OR "Persistent Organic Pollutant*" OR POP* OR Electromagnetic OR "artificial light" OR ALAN OR "traffic noise" OR "artificial noise" OR "anthropogenic noise" OR hunting OR poaching OR "wildlife trade" OR fishing OR "artificial feeding" OR "supplementary feeding" OR "Food availability" OR fishing OR "anthropogenic food" OR road* OR railway OR highway OR infrastructure OR wind*farm OR "wind turbines" OR "renewable energy" OR "solar farm*" OR "hydroelectric dam*" OR electrocution OR collision* OR "power line*" OR aviation OR airline OR "invasive species"

OR "exotic species" OR "non*native species" OR "introduced predators" OR "predator introduction" OR tourism))

Google Scholar search engine:

English ("meta-analysis" AND "birds" AND "anthropogenic impact")
Polish ("meta-analiza" AND "ptaki" AND "antropogeniczny wpływ")
French ("méta-analyse" AND "oiseaux" AND" impact anthropique")
Italian ("meta-analisi" AND "uccelli" AND "impatto antropico")
Japanese ("メタ分析" AND "鳥類" AND "人為的影響")
Dutch ("meta-analyse" AND "vogels" AND "antropogene invloed")
Croatian ("meta-analiza" AND "ptice" AND "antropogeni utjecaj")

Benchmark studies

The table lists all articles used for testing and adjusting the search strategy. Benchmark studies were identified through an initial scoping search in Google Scholar search engine, and selected to represent a range of anthropogenic impacts and responses.

Number	Reference
1	Kunc, H. P., & Schmidt, R. (2019). The effects of anthropogenic noise on animals: a meta-analysis. Biology Letters, 15(11), 20190649. doi:10.1098/rsbl.2019.0649
2	Fontúrbel, F. E., Candia, A. B., Malebrán, J., Salazar, D. A., González-Browne, C., & Medel, R. (2015). Meta-analysis of anthropogenic habitat disturbance effects on animal-mediated seed dispersal. Global Change Biology, 21(11), 3951 – 3960. doi:10.1111/gcb.13025
3	Messina, S., Edwards, D. P., Eens, M., & Costantini, D. (2018). Physiological and immunological responses of birds and mammals to forest degradation: A meta-analysis. Biological Conservation, 224, 223–229. doi:10.1016/j.biocon.2018.06.002
4	Paillet, Y., Bergès, L., Hjältén, J., Ódor, P., Avon, C., Bernhardt-Römermann, M., ...Virtanen, R. (2010). Biodiversity Differences between Managed and Unmanaged Forests: Meta-Analysis of Species Richness in Europe. Conservation Biology, 24(1), 101–112. doi:10.1111/j.1523-1739.2009.01399.x
5	Svenja B. Kroeger, Hans M. Hanslin, Tommy Lennartsson, Marcello D'Amico, Johannes Kollmann, Christina Fischer, Elena Albertsen, James D.M. Speed, (2022). Impacts of roads on bird species richness: A meta-analysis considering road types, habitats and feeding guilds, Science of The Total Environment, Volume 812, 151478, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2021.151478.
6	Scridel, D., Brambilla, M., Martin, K., Lehikoinen, A., Iemma, A., Matteo, A., ...Chamberlain, D. (2018). A review and meta-analysis of the effects

	of climate change on Holarctic mountain and upland bird populations. Ibis, 160(3), 489–515. doi:10.1111/ibi.12585
7	Akresh, M. E., King, D. I., Lott, C. A., Larkin, J. L., & D'Amato, A. W. (2020). A meta-analysis of the effects of tree retention on shrubland birds. Forest Ecology and Management, 118730. doi:10.1016/j.foreco.2020.118730
8	Matuoka, M. A., Benchimol, M., Almeida-Rocha, J. M. de, & Morante-Filho, J. C. (2020). Effects of anthropogenic disturbances on bird functional diversity: A global meta-analysis. Ecological Indicators, 116, 106471. doi:10.1016/j.ecolind.2020.106471
9	Flavia R. Barzan, Laura M. Bellis, Sebastián Dardanelli, (2021). Livestock grazing constrains bird abundance and species richness: A global meta-analysis, Basic and Applied Ecology, Volume 56, Pages 289-298, ISSN 1439-1791,https://doi.org/10.1016/j.baae.2021.08.007.
10	Lu, X., Jia, Y. & Wang, Y. (2024). The effect of landscape composition, complexity, and heterogeneity on bird richness: a systematic review and meta-analysis on a global scale. Landsc Ecol 39, 132. https://doi.org/10.1007/s10980-024-01933-w

3) Predefined categories of anthropogenic impacts and responses

The section describes the predefined categories used to classify anthropogenic impact types and biological response variables during data extraction and analysis. It lists the main impact categories together with the examples of specific impacts/responses that fit each category.

MAIN IMPACT CATEGORY	EXAMPLES OF THE SPECIFIC IMPACTS
GENERAL	General anthropogenic/human impact/effect/disturbance/pressure/threat etc.
HABITAT LOSS & FRAGMENTATION	Environmental degradation, Habitat degradation, Habitat destruction, fragmentation, Edge effects, Logging, Habitat loss, Land use, Deforestation, Silviculture, Land conversion, Mining, Wetland drainage etc...
URBANISATION	Urban sprawl, Urban expansion, Suburbanisation, Impervious surface increase, Infrastructure development. This will usually go together with some other

	category (e.g. habitat loss, or light pollution), it is important to distinguish when it is urbanisation related.
AGRICULTURE	Pasture expansion, Livestock grazing, Monoculture, Plantation, Agricultural intensification, Agricultural expansion... (Also same as for urbanisation).
CLIMATE CHANGE	Climate change, Warming, Storm surge, Flooding, Precipitation shift, Drought, Desertification, Desiccation, Heatwave, Heat stress, Stressors, Sea level rise, Ocean acidification, Extreme weather, Climate variability, Wildfire etc.
CHEMICAL POLLUTION	Chemical Pollution, PFA’s, Waste, Microplastics, Contamination, Heavy metal, Trace metal, Agrochemical, Fertilizer, Pesticide, Herbicide, Fungicide, Industrial, Drainage, Oil spill, Sewage, Leachate, Runoff, PCB, POP, Endocrine disruptor chemicals etc.
NOISE POLLUTION	Traffic noise, Road noise, Railway noise, Aircraft noise, Shipping noise.
LIGHT POLLUTION	Artificial light at night (ALAN), Artificial lighting, Streetlights, Building lights, Skyglow, Light trespass, Light spillover.
INFRASTRUCTURE	Road, Railway, Infrastructure, Windfarm, Wind turbines, Renewable energy, Solar farms, Hydroelectric dams, Electrocution, Collision, Power line, Aviation, Airline, Transmission lines, Pipelines, Canals, Waterways, Fences, Barriers.
HUNTING	Hunting (Trophy, Bushmeat, Traditional, Subsistence...), Poaching, Wildlife trade, Bycatch.
FOOD ALTERATION	Feeding stations, Provisioning, Garbage feeding, Rubbish dumps, Fish stocking, overfishing, supplementary feeding
SPECIES INTRODUCTION	Introduced predators, Introduced competitors, Introduced pathogens, Invasive species, Exotic species.
OTHER	Indirect effects like tourism, recreation etc.

RESPONSE CATEGORY:	EXAMPLES OF THE SPECIFIC RESPONSES
SURVIVAL	Survival (Juvenile, Nestling, Adult, Annual...), Mortality, Life expectancy, Longevity, Death.
REPRODUCTION	Hatching success, Egg viability, Egg laying rate, Egg mass, Copulation frequency, Nest site, Nesting, Breeding, Productivity, Clutch size, Brood, Incubation, Parental investment, Fledging rate, Fledging success, Courtship displays, Mate choice, Parental behaviour, Recruitment rate, Fitness.
POPULATION DYNAMICS	Recruitment, Immigration, Emigration, Turnover rates, Population density, Population fragmentation, Bottleneck events, Population size, Population dynamics, Population viability, Extirpation risk, Population fluctuation, Sex ratio, age structure, Population abundance.
MOVEMENT & MIGRATION	Migration (distance, timing, speed...), Migratory connectivity, Philopatry, Site fidelity, Movement, Stopover, Flyways, Dispersal patterns, Natal dispersal, Breeding dispersal, Home range, Territory size, Territoriality, Habitat selection.
BEHAVIOUR	Exploration, Boldness, Aggression, Vigilance, Anti-predator behaviour, Nest defense, Flocking, Roosting, Foraging, Feeding, Food consumption, Phenology, Diurnal activity, Nocturnal activity, Daily activity, Activity budget, Neophobia.
TROPHIC INTERACTION & ECOLOGICAL ROLES	Trophic interactions, Ecological roles, Prey selection, Predation, Scavenging, Feeding guilds, Diet composition, Gut microbiome, Guild structure, Interspecific competition, Intraspecific competition, Niche partitioning, Mutualism, Commensalism, Seed dispersal, Pollination, Biocontrol, Ecosystem engineering.
DIVERSITY & ABUNDANCE	Community composition, Diversity, Species abundance, Range shift, Species richness, Alpha diversity, Beta diversity, Gamma diversity, Species evenness, Occupancy.
PHYSIOLOGY	Chronobiology, Melatonin regulation, Metabolism, Metabolic rate,

	Thermoregulation, Hibernation, Endocrinology, Corticosterone, Hormones, Stress, Physiology, Immunity, Aging, Senescence, Body condition, Body mass index, Hematocrit, Glucose levels, Oxidative stress, Energetic reserves.
MORPHOLOGY	Body mass, Length (Tarsus, Wing, Beak...), Sexual dimorphism, Morphometrics, Morphology, Plumage, Coloration, Mimicry.
GENETICS & EVOLUTION	Heritability, Genetic variation, Outbreeding depression, Gene expression, Microevolution, Evolution, Adaptation, Genetic drift, Speciation rates, Selective pressures, Gene flow, Epigenetics, Plasticity, Inbreeding depression, Hybridization.
COMMUNICATION	Visual signaling, Chemical communication, Vocal communication, Vocalization, Song, Calls, Display behaviour.
DISEASE	Prevalence, Pathogen load, Immune response, Host susceptibility, Zoonotic risk, Disease, Infection, Parasitism.
OTHER	…

4) Excluded studies and reasons for exclusion

The table lists all articles (N = 83) excluded during the full-text screening process, alongside standardized reasons for exclusion.

DOI	TITLE OF ARTICLE	EXCLUSION CRITERIA
https://doi.org/10.1111/j.1523-1739.1998.96373.x	A meta-analysis of forest cover, edge effects, and artificial nest predation rates	wrong study type
10.1046/j.1523-1739.1994.08020555.x	Metaanalysis - A Valuable Tool in Conservation Research	wrong study type
https://doi.org/10.1371/journal.pone.0101565	Refining Estimates of Bird Collision and Electrocution Mortality at Power Lines in the United States	wrong study type

10.1088/1748-9326/ac22be	Land-use change from food to energy: meta-analysis unravels effects of bioenergy on biodiversity and cultural ecosystem services	wrong exposure
https://doi.org/10.1016/j.ecoenv.2024.117166	Potential toxicity of microplastics on vertebrate liver: A systematic review and meta-analysis	wrong population
10.1590/1676-0611-bn-2024-1676	Predation effect by cats and rodents on the reproductive success of seabirds: a global systematic review and meta-analysis	wrong exposure
https://doi.org/10.1016/j.envpol.2022.119179	Does exposure to environmental 2,4-dichlorophenoxyacetic acid concentrations increase mortality rate in animals?	wrong population
https://doi.org/10.1016/j.biocon.2025.111190	Responses of birds with different habitat preferences to urban blue-green spaces: A systematic review and meta-analysis at a global scale	wrong exposure
https://doi.org/10.1890/0012-9658(2000)081[0734:IARTRB]2.0.CO;2	Individuals-area relationships: The relationship between animal population density and area	wrong exposure
10.1038/523163a	Hidden impacts of logging	wrong study type
https://doi.org/10.1111/j.1365-2486.2007.01404.x	Influences of species, latitudes and methodologies on estimates of phenological response to global warming	wrong study type
10.5751/ACE-01924-160212	Secretive marsh bird habitat associations in the Mississippi Flyway: a meta-analysis	wrong exposure
https://doi.org/10.1073/pnas.2117809119	A meta-analysis on the evolution of the Lombard effect reveals that amplitude adjustments are a widespread vertebrate mechanism	wrong exposure
https://doi.org/10.1098/rspb.2009.1011	Shifting latitudinal clines in avian body size correlate with global warming in Australian	wrong study type

	passerines	
https://doi.org/10.1890/14-0362.1	Relative effects of landscape-scale wetland amount and landscape matrix quality on wetland vertebrates: a meta-analysis	wrong exposure
https://doi.org/10.1016/j.jhazmat.2024.136607	Species-specific accumulation of microplastics in different bird species from South China: A comprehensive analysis	wrong study type
10.1371/journal.pone.0257370	Short-term elevations in glucocorticoids do not alter telomere lengths: A systematic review and meta-analysis of non-primate vertebrate studies	wrong exposure
https://doi.org/10.1046/j.1523-1739.2002.00308.x	Nest predators and fragmentation: a review and meta-analysis	wrong study type
https://doi.org/10.1111/conl.12904	Long-term fallows rate best among agri-environment scheme effects on farmland birds-A meta-analysis	wrong exposure
https://doi.org/10.1073/pnas.2203385119	Complex agricultural landscapes host more biodiversity than simple ones: A global meta-analysis	wrong exposure
https://doi.org/10.1371/journal.pone.0064282	The Effects of Winter Recreation on Alpine and Subalpine Fauna: A Systematic Review and Meta-Analysis	wrong population
https://doi.org/10.2193/2007-518	Postlogging Succession and Habitat Usage of Shrubland Birds	wrong study type
NA	Forest bird mortality and baiting practices in New Zealand aerial 1080 operations from 1986 to 2009	wrong study type
https://doi.org/10.1111/gcb.13736	Species' traits as predictors of range shifts under contemporary climate change: A review and meta-analysis	wrong population
https://doi.org/10.1111/gc	Sublethal consequences of	wrong population

b.16848	ultraviolet radiation exposure on vertebrates: Synthesis through meta-analysis	
https://doi.org/10.1111/gcb.13837	Wildlife species benefitting from a greener Arctic are most sensitive to shrub cover at leading range edges	wrong study type
https://doi.org/10.1111/1365-2664.12943	The importance of scattered trees for biodiversity conservation: A global meta-analysis	wrong population
https://doi.org/10.1111/gcb.12648	Phenological response to climate change in China: a meta-analysis	wrong study type
https://doi.org/10.1111/j.1365-2664.2005.01005.x	The effects of organic agriculture on biodiversity and abundance: a meta-analysis	wrong exposure
https://doi.org/10.1016/j.biocon.2012.01.063	Nest predation in New Zealand songbirds: Exotic predators, introduced prey and long-term changes in predation risk	wrong study type
10.1098/rstb.2011.0050	Ecological impacts of tropical forest fragmentation: how consistent are patterns in species richness and nestedness?	wrong study type
10.1017/S0376892905002304	Grit selection in waterfowl and how it determines exposure to ingested lead shot in Mediterranean wetlands	wrong study type
https://doi.org/10.1021/es400478k	Persistent Toxic Burdens of Halogenated Phenolic Compounds in Humans and Wildlife	wrong study type
10.1002/etc.5858	Methylmercury Effects on Birds: A Review, Meta-Analysis, and Development of Toxicity Reference Values for Injury Assessment Based on Tissue Residues and Diet	wrong study type
https://doi.org/10.1111/j.1523-1739.2006.00557.x	The response of avian feeding guilds to tropical forest disturbance	wrong study type
https://doi.org/10.1007/s1	Impacts of non-oil tree	wrong population

0531-015-1022-5	plantations on biodiversity in Southeast Asia	
10.1007/s10980-020-01053-1	The impact of artificial light at night on human and ecosystem health: a systematic literature review	wrong study type
https://doi.org/10.1371/journal.pone.0027785	Forest Fragmentation and Selective Logging Have Inconsistent Effects on Multiple Animal-Mediated Ecosystem Processes in a Tropical Forest	wrong study type
https://doi.org/10.1525/cond.2010.090026	Exposure of Nonbreeding Migratory Shorebirds to Cholinesterase-inhibiting Contaminants in the Western Hemisphere	wrong study type
https://doi.org/10.1007/s10980-017-0487-x	The future demographic niche of a declining grassland bird fails to shift poleward in response to climate change	wrong study type
https://doi.org/10.1016/j.gecco.2023.e02700	Climate-induced shifts in grassland bird nesting phenology have implications for grassland management	wrong study type
https://doi.org/10.1007/s00484-013-0711-6	Climate as a driver of phenological change in southern seabirds	wrong study type
https://doi.org/10.1111/geb.12638	Quantifying the influence of urban land use on mangrove biology and ecology: A meta-analysis	wrong study type
https://doi.org/10.1016/j.envint.2010.05.013	A global review of polybrominated diphenyl ether flame retardant contamination in birds	wrong study type
https://doi.org/10.1111/geb.13901	Climatic Predictors of Long-Distance Migratory Birds Breeding Productivity Across Europe	wrong exposure
https://doi.org/10.1111/acv.12568	Land-use intensification promotes non-native species in a tropical island bird assemblage	wrong study type
https://doi.org/10.1046/j.1	Are urban bird communities	wrong study type

365-2664.2001.00666.x	influenced by the bird diversity of adjacent landscapes?	
10.5751/ACE-00223-030105	Survival of Adult Songbirds in Boreal Forest Landscapes Fragmented by Clearcuts and Natural Openings	wrong study type
https://doi.org/10.1111/cobi.13456	Responses of New Zealand forest birds to management of introduced mammals	wrong exposure
https://doi.org/10.1111/1365-2664.12841	Density dependence and marine bird populations: are wind farm assessments precautionary?	wrong study type
https://doi.org/10.1371/journal.pone.0143070	Impact of Non-Native Birds on Native Ecosystems: A Global Analysis	wrong study type
https://doi.org/10.1016/j.earscirev.2021.103728	Biological albedo reduction on ice sheets, glaciers, and snowfields	wrong study type
https://doi.org/10.1111/ibi.12949	A global synthesis of the impacts of urbanization on bird dawn choruses	wrong study type
https://doi.org/10.1016/j.avrs.2022.100036	Does bird photography affect nest predation and feeding frequency?	wrong study type
https://doi.org/10.1111/geb.70040	Remotely Sensed Fire Heterogeneity and Biomass Recovery Predicts Empirical Biodiversity Responses	wrong population
https://doi.org/10.1016/j.landurbplan.2021.104122	Piecing together cities to support bird diversity: Development and forest edge density affect bird richness in urban environments	wrong study type
https://doi.org/10.1016/j.marpolbul.2022.114030	The hidden cost of following currents: Microplastic ingestion in a planktivorous seabird	wrong study type
https://doi.org/10.1111/j.1523-1739.2010.01480.x	How Area Sensitivity in Birds is Studied	wrong study type
https://doi.org/10.15845/on.v47.3626	Effects of artificial light and latitude on the dawn foraging	wrong exposure

	activity of Great Tits Parus major during winter in northern Europe	
NA	Spatial and temporal variations in the diet of the Eurasian Kestrel Falco tinnunculus in the Western Palearctic	wrong study type
https://doi.org/10.1016/j.envadv.2020.100026	Online tool to integrate evidence-based knowledge into cumulative effects assessments: Linking human pressures to multiple nature assets	wrong study type
https://doi.org/10.1111/nph.15789	Demystifying dominant species	wrong population
https://doi.org/10.1021/acs.est.9b06119	Synthesis of Maternal Transfer of Mercury in Birds: Implications for Altered Toxicity Risk	wrong study type
10.3354/meps09806	Seabirds and climate change: Roadmap for the future	wrong study type
https://doi.org/10.1016/j.foreco.2011.04.028	Tree cavities in forests - The broad distribution pattern of a keystone structure for biodiversity	wrong population
https://doi.org/10.1038/ncomms2380	The impact of free-ranging domestic cats on wildlife of the United States	wrong study type
https://doi.org/10.1007/s10336-007-0177-6	Food supplementation and timing of reproduction: Does the responsiveness to supplementary information vary with latitude?	wrong study type
10.1007/s00442-008-1091-1	Latitude affects degree of advancement in laying by birds in response to food supplementation: A meta-analysis	wrong study type
https://doi.org/10.1016/S0141-1136(98)00110-X	Contemporary patterns of mercury contamination in the Portuguese Atlantic inferred from mercury concentrations in seabird tissues	wrong study type

https://doi.org/10.1111/j.1523-1739.2010.01450.x	A Meta-Analytic Review of Corridor Effectiveness	wrong exposure
https://doi.org/10.1111/cobi.13156	Meta-analysis of the effects of rice-field abandonment on biodiversity in Japan	wrong population
https://doi.org/10.1111/ele.12427	Biodiversity in cities needs space: a meta-analysis of factors determining intra-urban biodiversity variation	wrong exposure
10.1007/s10144-003-0155-7	Local survival after fire in Mediterranean shrublands: Combining capture-recapture data over several bird species	wrong study type
https://doi.org/10.1139/x06-017	Changes in bird communities throughout succession following fire and harvest in boreal forests of western North America: literature review and meta-analyses	wrong study type
https://doi.org/10.1016/j.gecco.2021.e01876	A review of avian experimental translocations that measure movement through human-modified landscapes	wrong exposure
10.2307/3061087	Evaluating the effects of ecosystem management: a case study in a Missouri Ozark forest	wrong study type
https://doi.org/10.1111/j.1755-263X.2012.00242.x	Sustaining conservation values in selectively logged tropical forests: the attained and the attainable	wrong study type
10.1007/s10021-008-9217-1	The Role of Golf Courses in Biodiversity Conservation and Ecosystem Management	wrong study type
https://doi.org/10.1007/s13165-020-00279-2	To what extent does organic farming promote species richness and abundance in temperate climates? A review	wrong study type
https://doi.org/10.1016/j.biocon.2009.05.035	The future of tropical species in secondary forests: A quantitative review	wrong study type
https://doi.org/10.1371/jou	Egg Production in a Coastal Seabird, the Glaucous-Winged	wrong study type

rnal.pone.0022027	Gull (Larus glaucescens), Declines during the Last Century	
https://doi.org/10.1080/24750263 2025.2462445	The effect of research activities on nest predation in the Eurasian Reed Warbler Acrocephalus scirpaceus	wrong study type
https://doi.org/10.1111/j.1365-2486.2011.02538.x	Avian body size changes and climate change: warming or increasing variability?	wrong study type

5) Meta-analyses on strategies to mitigate threats to birds

The table contains meta-analyses uncovered through our search, and that focused on measures to mitigate anthropogenic impacts on birds. Although not included in the main synthesis of anthropogenic impacts, these studies are reported here as a resource for future research.

DOI	TITLE OF META-ANALYSIS
10.1088/1748-9326/ac22be	Land-use change from food to energy: meta-analysis unravels effects of bioenergy on biodiversity and cultural ecosystem services
10.1590/1676-0611-bn-2024-1676	Predation effect by cats and rodents on the reproductive success of seabirds: a global systematic review and meta-analysis
https://doi.org/10.1016/j.biocon.2025.111190	Responses of birds with different habitat preferences to urban blue-green spaces: A systematic review and meta-analysis at a global scale
https://doi.org/10.1111/conl.12904	Long-term fallows rate best among agri-environment scheme effects on farmland birds-A meta-analysis
https://doi.org/10.1073/pnas.2203385119	Complex agricultural landscapes host more biodiversity than simple ones: A global meta-analysis
https://doi.org/10.1111/cobi.13456	Responses of New Zealand forest birds to management of introduced mammals
https://doi.org/10.1111/j.1523-1739.2010.01450.x	A Meta-Analytic Review of Corridor Effectiveness

https://doi.org/10.1111/ele.12427	Biodiversity in cities needs space: a meta-analysis of factors determining intra-urban biodiversity variation
https://doi.org/10.1016/j.jenvman.2019.109651	Re-assessing the effectiveness of wire-marking to mitigate bird collisions with power lines: A meta-analysis and guidelines for field studies
10.1111/j.1523-1739.2011.01699.x	Meta-Analysis of the Effectiveness of Marked Wire in Reducing Avian Collisions with Power Lines
https://doi.org/10.1016/j.scitotenv.2024.169882	Effect of shade on biodiversity within coffee farms: A meta-analysis
https://doi.org/10.1890/08-2064.1	Are forested buffers an effective conservation strategy for riparian fauna? An assessment using meta-analysis
https://doi.org/10.1111/rec.70085	Assessing restoration strategies for the recovery of Colombian Moist Forests: a meta-analysis
https://doi.org/10.1007/s11258-016-0619-4	Artificial perches promote vegetation restoration
10.1111/j.1523-1739.2012.01883.x	A Meta-Analysis of the Effects of Common Management Actions on the Nest Success of North American Birds
https://doi.org/10.1016/j.biocon.2010.05.008	Is nest predator exclusion an effective strategy for enhancing bird populations?
https://doi.org/10.1016/j.agee.2024.109453	Accounting for the biodiversity benefits of woody plantings in agricultural landscapes: A global meta-analysis
https://doi.org/10.1111/1365-2664.13475	The contribution of constructed green infrastructure to urban biodiversity: A synthesis and meta-analysis
https://doi.org/10.1111/j.1523-1739.2009.01421.x	Effectiveness of Predator Removal for Enhancing Bird Populations
https://doi.org/10.1016/j.baae.2022.01.009	Impacts of coastal realignment on biodiversity. A systematic review and meta-analysis
https://doi.org/10.1016/j.envpol.2022.120589	A meta-analysis of environmental responses to freshwater ecosystem restoration in China (1987-2018)
https://doi.org/10.1111/j.1523-1739.2004.00359.x	Enhancement of farmland biodiversity within set-aside land
https://doi.org/10.1071/WR15132	A review of biodiversity outcomes from possum-focused pest control in New Zealand

https://doi.org/10.1186/s13750-023-00308-z	How effective are perches in promoting bird-mediated seed dispersal for natural forest regeneration? A systematic review protocol
https://doi.org/10.1111/1365-2664.12590	Which landscape size best predicts the influence of forest cover on restoration success? A global meta-analysis on the scale of effect
https://doi.org/10.1111/oik.06252	Recovery of amphibian, reptile, bird and mammal diversity during secondary forest succession in the tropics
https://doi.org/10.1046/j.1523-1739.1997.95410.x	The effectiveness of removing predators to protect bird populations
https://doi.org/10.1016/j.jenvman.2019.109391	Towards ecologically functional riparian zones: A meta-analysis to develop guidelines for protecting ecosystem functions and biodiversity in agricultural landscapes
https://doi.org/10.1186/s40657-019-0168-3	A global consistent positive effect of urban green area size on bird richness
https://doi.org/10.1016/j.landurbplan.2022.104552	Biodiversity significance of small habitat patches: More than half of Indian bird species are in academic campuses
https://doi.org/10.1016/j.biocon.2017.05.004	Dynamics of avian species and functional diversity in secondary tropical forests
https://doi.org/10.1016/j.biocon.2021.109393	Restoration of plant-animal interactions in terrestrial ecosystems
10.1126/sciadv.1701345	Ecological restoration success is higher for natural regeneration than for active restoration in tropical forests
https://doi.org/10.1371/journal.pbio.3002166	Insights into the coexistence of birds and humans in cropland through meta-analyses of bird exclosure studies, crop loss mitigation experiments, and social surveys
https://doi.org/10.1111/j.1523-1739.2010.01606.x	Assessing the value of the umbrella-species concept for conservation planning with meta-analysis; [Evaluación del Valor del Concepto de Especie Sombrilla para la Planificación de la Conservación Mediante Meta-Análisis]

6) Supplementary results

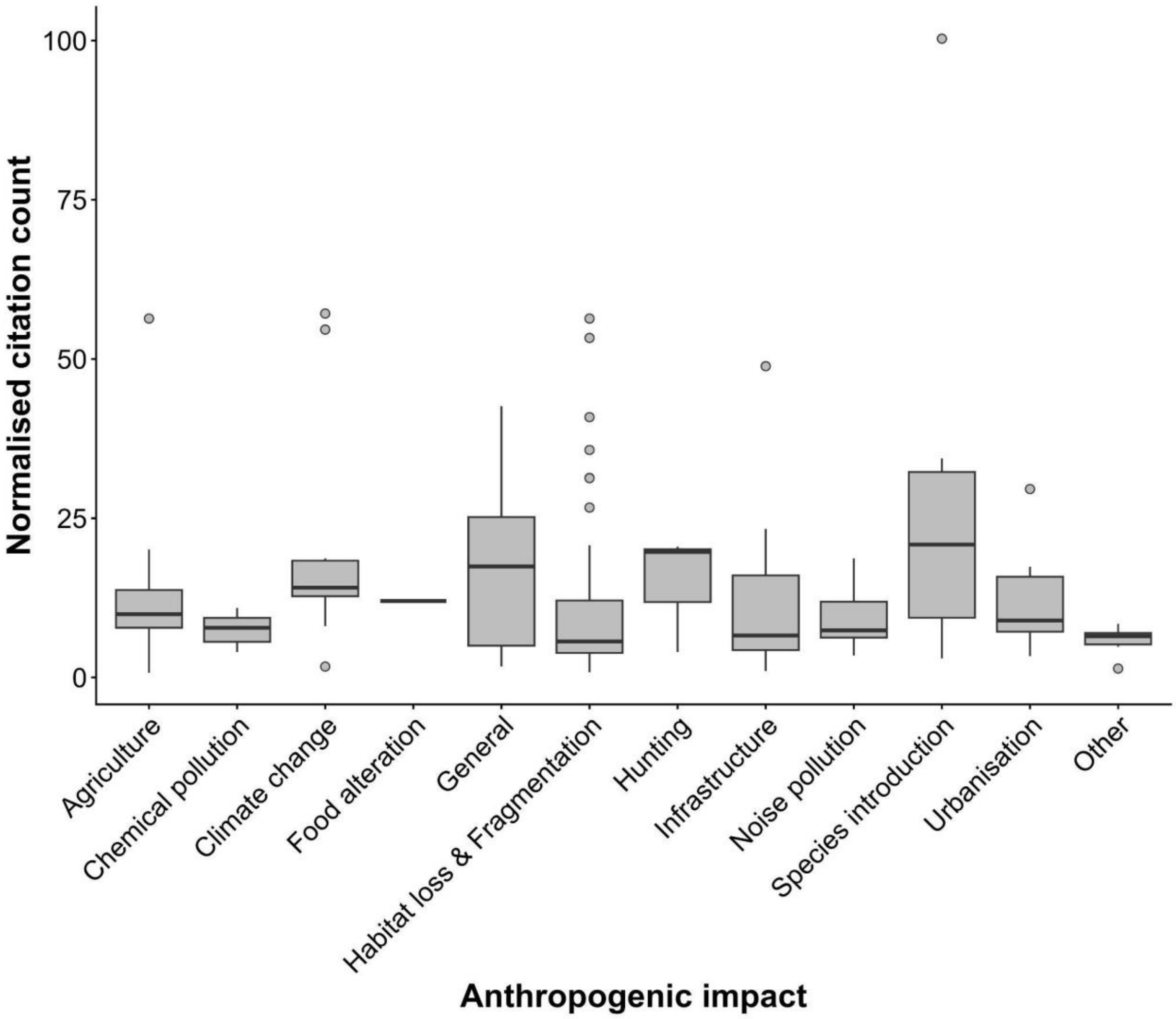

Figure S1. Distribution of normalised citation counts (citations per year) for 132 meta-analyses across anthropogenic impact categories. Our assessment excluded meta-analyses published in 2024 and 2025, as they were too recent to accumulate citations. Boxplots show the median and interquartile range (25-75%), whiskers indicate min-max, and points represent outliers.

	Full search string % of papers (N = sample size)	**PRISMA** % of papers (N = sample size)	**Main data** % of papers (N = sample size)	**1 or more databases** % of papers (N = sample size)	**Non-independence phylogeny** % of papers (N = sample size)	**Non-independence same study** % of papers (N = sample size)
2007-2011	50% (28)	35.7% (28)	39.3% (28)	67.9% (28)	19.2% (26)	77.8% (27)
2012-2016	50% (30)	33.3% (30)	66.7% (30)	46.7% (30)	26.1% (23)	79.2% (24)
2017-2021	62.2% (45)	48.9% (47)	68.1% (47)	51.1% (47)	31% (42)	80% (45)
2022-2025	61.5% (39)	43.6% (39)	62.5% (40)	57.5% (40)	38.2% (34)	81.6% (38)

Table S1. Temporal trends (2007-2025) in selected reporting and methodological practices among ecological meta-analyses. Those published prior to 2007 were excluded from temporal comparisons due to the small sample size (N = 4). Values represent the percentage of papers within each publication period that fulfilled a given criterion. N indicates the number of meta-analyses for which the assessment was applicable (e.g. excluding cases coded as “not applicable” or “unclear”).

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