

# Meta-analysts must lead by example and embrace all FAIR principles

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## Abstract

Meta-analyses rely on comprehensive reporting of results and data in primary studies. They should therefore also strive for exemplary reporting and follow FAIR principles (Findable, Accessible, Interoperable, Reusable) for data sharing. Yet, despite growing calls for open, reliable, and transparent science, the quality, reporting and FAIRness of meta-analyses in ecology, evolution, and environmental sciences remain poorly characterised. Here, we evaluate features of methodological quality, reporting and data and code sharing practices of

81 meta-analyses published between 2016 and 2020 in ecology, evolution, and environmental sciences. Whilst we found data sharing was relatively common (68%), code sharing was rare (15%). We found low uptake of reporting guidelines (22%), a small proportion of unweighted approaches (17%) and no risk of bias assessments (0%). The FAIRness of data requires urgent attention. Most openly available meta-analytic datasets were Findable and Accessible, but less often Interoperable or Reusable. Low Interoperability and Reusability prevent verification and may explain why data reuse remains uncommon, and ultimately contributes to research waste. We found no evidence of higher FAIRness scores when studies reported having used guidelines, nor that FAIRness associated with citation rates, suggesting a lack of incentives for adopting FAIR principles. Lastly, we provide recommendations for readily implementable methodological improvements applicable to meta-analyses in any field.

**Keywords:** Reproducibility, Open science, Evidence synthesis, Systematic review, Meta-research, Research integrity, Data stewardship, Research standards, Scientific rigour

## Introduction

Evidence synthesis is an increasingly popular research approach. It encompasses a suite of methods, such as systematic review and meta-analysis, designed to provide reliable qualitative and quantitative summaries of research on a given topic while minimising subjectivity and bias (Higgins & Green, 2015; Haddaway et al., 2015a). Systematic reviews use rigorous, ideally predefined methods to identify, critically appraise and synthesise relevant studies on a specific topic. When included studies report comparable quantitative outcomes, meta-analyses can statistically combine their results to estimate an overall effect size (usually weighted by study precision) and understand their generality and sources of variation. By distilling evidence from multiple studies quantitatively, meta-analysis carries considerable authority (Murad et al., 2016; Ioannidis, 2016; Pollo et al., 2025). They are frequently used to help synthesize conflicting results across primary studies, guide research priorities, and, importantly, inform policy and management decisions (Haddaway & Pullin, 2014). In ecology, evolution, and environmental sciences, meta-analyses are routinely used to test fundamental hypotheses (e.g., Kim et al., 2021; Dimri et al., 2026), evaluate conservation interventions (e.g., Vasconcelos et al. 2022; Gan et al. 2025; Moran et al. 2025), quantify human impacts on the environment (e.g., Capilla-Lasheras et al. 2022; Juan-Ovejero et al. 2025), and inform conservation strategies (e.g., Häkkinen et al., 2021). Meta-analysis can also contribute to reducing research waste by identifying gaps in accumulated knowledge and helping determine where additional research is needed (Grainger et al., 2020).

At their best, meta-analyses are powerful statistical tools that can provide reliable syntheses of existing evidence – often preceded by a systematic review – and shape research priorities and policy. At their worst, they risk becoming misleading analyses that mask low quality and subjective bias behind an unwarranted sense of definitive authority (Ioannidis, 2016). The conclusions of a meta-analysis depend both on the quality of the underlying studies and on the methodological decisions made throughout the synthesis process. When these decisions are inappropriate, poorly justified or insufficiently reported, meta-analyses can produce unreliable inference. Rigorous synthesising evidence remains slow and resource-intensive (Haddaway & Westgate, 2019) and is often poorly coordinated (Siontis et al., 2013). The concept of an 'open synthesis community', where data, methods, and outputs are shared

transparently, has been proposed to address these challenges (Haddaway, 2018; Nakagawa et al., 2020), although such practices are still not consistently implemented.

The overall methodological and reporting quality of meta-analyses in ecology, evolution, and environmental sciences has considerable room for improvement. A survey of 102 ecological and evolutionary systematic review and meta-analyses found an average reporting score of approximately 55% across the 27-item PRISMA-EcoEvo framework, which aims to promote transparent and comprehensive reporting of systematic reviews and meta-analyses (O'Dea et al., 2021). Incomplete reporting does not necessarily imply poor quality, however, it makes it difficult to assess the quality of the meta-analysis and reduce confidence in the resulting synthesis. Lack of computational reproducibility is similarly concerning. Previous meta-research indicates that only 27–73% of some meta-analytic results can be computationally reproduced (Kambouris et al., 2024), and just 55% of individual effect-size calculations could be successfully verified (Maassen et al., 2020; see also Pollo et al., 2025; Sánchez-Tójar & D'Amelio, 2026). Perhaps most troubling, a recent study of meta-analyses of organochlorine pesticides found no difference in methodological quality between those meta-analyses cited in policy documents and those that were not (Morrison et al., 2025), suggesting that rigour does not necessarily determine influence.

Transparent methodological reporting, however, is insufficient to assess reliability and allow independent result reproduction, when the data and analytical materials underlying a meta-analysis are unavailable or poorly documented. Previous meta-research on archived data from primary empirical studies in ecology and evolution suggests that more than half of openly available datasets are neither complete nor reusable (Roche et al., 2015), a figure that has barely improved over the past decade (Roche et al., 2022). The FAIR principles provide a framework for assessing whether research data and their associated metadata are Findable, Accessible, Interoperable and Reusable by humans and machines, that is, it should be discoverable and retrievable through persistent and clearly defined access, provided in formats that facilitate computational use and sufficiently documented and licensed to support reuse (Wilkinson et al., 2016). Poor data FAIRness limits researchers' ability to verify results, reuse data for new questions, and build cumulatively on previous work (Chalmers & Glasziou, 2009; Purgar et al., 2022). Reusable data for a meta-analysis is valuable for updating existing syntheses as new evidence accumulates. Access to previously synthesised data can allow new studies to be incorporated into a meta-analysis without reconstructing the synthesis. Poor data FAIRness may partly explain why meta-analysis updating remains rare despite repeated calls for it (e.g., Nakagawa et al., 2017). Such updating is important given the abundant evidence showing that effect sizes can change in both magnitude and direction as evidence accumulates over time (Jennions & Møller, 2002; Koricheva & Kulinskaya, 2019; Brisco et al., 2024). If meta-analyses are to serve as reliable, up-to-date syntheses of evidence, the FAIRness of their underlying data requires urgent attention.

Despite the importance of reusable meta-analytical data, their FAIRness remains poorly characterised in ecology, evolution and environmental sciences. Here, we present a comprehensive and systematic assessment of methodological and reporting quality, transparency, data and code sharing, and data FAIRness in meta-analyses across ecology, evolution, and environmental sciences. Leveraging a community effort, we comprehensively evaluated 81 meta-analyses published between 2016 and 2020 by developing a protocol to efficiently and robustly assess data FAIRness. We also explored whether data FAIRness

predicted citation count and compared overall scores between studies that reported following reporting or conduct guidelines (such as PRISMA, CEE etc.) and those that did not. Based on our findings, we offer practical recommendations for addressing what has been a persistent weakness of meta-analytic practice in our field.

## Methods

### Selection of studies

To identify published meta-analyses in ecology, evolution, and environmental sciences, we searched the Web of Science Core Collection using the terms (“*meta-analy\**” OR “*metaanaly\**” OR “*meta-regression*” OR “*metaregression*”) in article titles, abstracts, and author keywords. The search was restricted using journal identifiers to the same predefined list of relevant journals in the field used by O’Dea et al. (2021). The complete search string and journal identifiers are in Supplement S1. The initial search returned 1,131 records, of which 29 were excluded for having a final publication date equal to 2021, leaving 1,102 eligible records published between 2016 – the year when the FAIR principles were published – and 2020. We focused on this five-year duration to include a recent sample of meta-analyses while also allowing a comparable citation window for all the included articles – by the end of 2025, all included articles had accumulated at least six years over which citation counts could be accessed (see more details below). From the 1,102 records, we selected 96 articles at random using the base R ‘sample’ function (R Core Team, 2024) and screened for eligibility. We excluded 15 articles that were not quantitative meta-analyses (e.g., primary studies, opinion pieces, methodological papers), so our final dataset consisted of 81 articles. Overall, our sample aimed to represent the broader pool of meta-analyses in ecology, evolution, and environmental sciences, rather than to explore differences across journals.

### Assessment of methodological and reporting practices

After finalising the list of 81 eligible articles and an initial assessment performed by two student assistants (MP, VRD), we organised two collaborative hackathons with researchers experienced in evidence synthesis. The first was held as part of ESMARConf2025 on 13<sup>th</sup> June 2025, and the second follow-up hackathon was held on 20<sup>th</sup> August 2025. In total, 19 assessors contributed to the assessments: the two organisers (SD, AST), two student assistants (MP, VRD), and 15 hackathon participants (two of whom opted out of co-authorship). Of the 81 articles assessed, 73 were independently assessed by two to four assessors, whereas the remaining 8 were assessed by only the senior author (AST). All entries of each assessment were verified by either the first or last author (SD, AST).

We used a Google Form to assess methodology and transparency characteristics of the article, its supplementary material, and linked repositories. These included whether (i) inferential statistics were used to calculate effect sizes, (ii) comparability in the direction of the effect sizes was ensured, and (iii) authors reported performing a Risk of Bias assessment (RoB) of included primary studies or any other study-level bias appraisal (full list in Supplement S2). The assessment form was slightly modified between the two hackathons to improve clarity to data coders (e.g., wording of items was clarified).

To assess whether effect size direction was taken into account, we coded this item as applicable only when extracted effect sizes could plausibly take opposite signs across studies. This could occur because studies defined the contrast in opposite ways, such as treatment minus control versus control minus treatment. It could also occur when different outcomes represented the same underlying biological process in opposite ways. For example, when a meta-analysis synthesises fitness effects but some studies measure survival, whereas others measure mortality, the direction of those effect sizes have to be made comparable to avoid these effects cancelling each other (see Supplement S2 for more details). Meta-analyses were coded as “not applicable” when directional harmonisation was not necessary because the effect-size was inherently consistent (e.g., variance, heritability), or all effect sizes already had a consistent directional interpretation. For meta-analyses coded as “applicable”, we then recorded whether authors explicitly reported having considered effect-size directions to ensure all effects carried a consistent interpretation (i.e., to ensure comparability).

Three assessment items proved particularly challenging to code: whether a RoB assessment or an alternative had been performed, whether inferential statistics had been converted into effect sizes, and whether the comparability in the direction of the effect sizes had been ensured. For example, publication bias tests or methodological subgroup analyses were not always straightforward to distinguish from RoB assessment, and effect size direction was only relevant for some outcome types. Therefore, to ensure consistency across assessments, the last author (AST) independently reviewed and verified all 81 entries for these items using the text extracted by the hackathon participants and, where necessary, revised the original assessments.

We also identified whether authors reported registering a protocol/pre-registering or followed a reporting or conduct guideline, and where applicable, the name of the guideline. Additionally, we extracted general methodological descriptors including the type of effect-size measure used, whether statistical software was reported and which software was used, type of meta-analytical model used, and whether effect sizes were weighted by their sampling variances. These data were independently extracted by SD and one of two student assistants (MP, VRD), and all entries were checked by the last author (AST).

## **Data and code sharing, and FAIR assessments**

For all 81 meta-analyses, we recorded whether authors shared processed data, raw data, and analytical code in the article, supplementary materials, or a linked repository. Processed data included the calculated effect sizes together with their associated sampling variances and any accompanying study-level information, and raw data included the summary or inferential statistics required to calculate those effect sizes (e.g., group means, standard deviations, sample sizes or correlations).

For the 55 meta-analyses that shared data, the FAIRness of the shared data (see Results below) was assessed using a protocol developed for this study and shared with the participants as a Google Form (see Supplement S3). FAIRness assessment included eight items: (i) data sharing location (e.g., Zenodo, Dryad, GitHub, Supplementary Material) [F]; (ii) whether the article provided a direct mention of the available data, link, globally unique persistent identifier (PID) or accession number for the underlying data [F]; (iii) presence of metadata other than a data dictionary [F]; (iv) whether the data could be downloaded [A]; (v)

presence of a globally unique persistent identifier (PID), such as a Digital Object Identifier (DOI), which ensures long-term access [A]; (vi) data file format (e.g., .csv/tsv, .txt, .pdf, .docx) [I]; (vii) presence and type of data licence (e.g., CC BY, CC BY-NC, CC0) [R]; and, (viii) presence of data dictionary or codebook (i.e. a documentation explaining the detailed meaning of individual variables, units etc.) [R]. Note that the number of items per FAIR component was unequal (F = 3, A = 2, I = 1, and R = 2 items). Eleven assessors contributed to the FAIR assessment, with 11 (20%) studies being assessed twice independently, and all records verified by the last author (AST). Any disagreements between assessors were resolved by the first and last authors (SD, AST).

## **Exploratory factors associated with data sharing and FAIRness**

To understand whether data FAIRness was associated with citation counts, the last author (AST) manually extracted the citation counts for each of the 81 articles from Google Scholar on 12<sup>th</sup> January, 2026. Google Scholar was used instead of other citation databases to include any citations from grey literature such as policy documents and reports, which can represent an important source of impact, particularly for applied meta-analyses (Haddaway et al., 2015b; Martín-Martín et al., 2018). Citations were recorded annually for each article from 2016 to 2025. The publication year for each meta-analysis refers to the year the article was included in a journal issue. Citations from the preceding year before publication, which were rare, were excluded from our analyses so that the citation count was calculated over the same six-year window for all articles, beginning with the publication year.

## **Data processing and analysis**

Before the data could be analysed, we performed data cleaning and recategorisation. Data shared within an article or its supplementary materials, rather than through a repository, were classified as not having a PID (i.e., not findable). Data file formats were classified based on their alignment with the FAIR principles, with particular emphasis on interoperability and reusability. Thus, non-proprietary, machine-readable formats (.csv/tsv), structured text files (.txt), and domain-standard phylogenetic formats (.tre) were classified as FAIR-aligned ('Yes'). Spreadsheet formats were classified as partially FAIR ('Partial') because, although .xlsx is based on an open specification and is machine-readable in principle, spreadsheet files may use features such as multiple worksheets, merged cells, formatting, or embedded formulas that hinder consistent automated interpretation and reuse (Broman & Woo, 2018). Document formats for sharing data (.pdf, .doc/docx) were classified as non-FAIR-aligned ('No'), as they primarily support human readability rather than machine interoperability. For articles sharing multiple data file formats, the classification reflected the least FAIR data format present, for example, if an article provided some data files as .xlsx and some as .csv, it was classified as "Partial". Data shared only within an article or its supplementary materials were classified as not having a data licence unless a separate data licence was explicitly provided. Before analysis, FAIR assessments were converted to numeric scores: "Yes" = 1, "Partial" = 0.5, and "No" = 0. The overall FAIRness score of each article was calculated as the mean of the eight indicators and expressed as a percentage.

For all other assessment items coded as binary outcomes, we calculated the percentage of articles for which each outcome was present/true, and the 95% confidence intervals (95% CI) were calculated using the Wilson score interval using the function 'binom.confint' from the 'binom' v1.1-2 package (Dorai-Raj & Cascone, 2026), which can handle extreme proportions

(0% or 100%). The association between reporting or conduct guideline use (such as PRISMA, CEE) and FAIRness scores was assessed using Wilcoxon rank-sum tests. Associations between FAIRness scores and citation counts accumulated during the first six years after publication were assessed using Kendall rank correlations. We used the citation counts from the first six years after publication to ensure comparability across articles. Because these comparisons correspond to observational data and involve relatively small sample sizes, they should be interpreted with caution. All data processing and analyses were conducted in R v.4.4.2 (R Core Team, 2024).

## Results

We assessed 81 articles categorised as meta-analyses published between 2016 and 2020 across 35 journals in ecology, evolution, and environmental sciences. The number of articles ranged from 14 to 20 per year (median = 16). Since articles were randomly selected rather than stratified by journal, the number of articles per journal ranged from 1 to 18 (median = 1). The three most represented journals were *Global Change Biology* (18), *Agriculture, Ecosystems & Environment* (6), and *Ecology Letters* (6).

### Methodological and reporting assessments

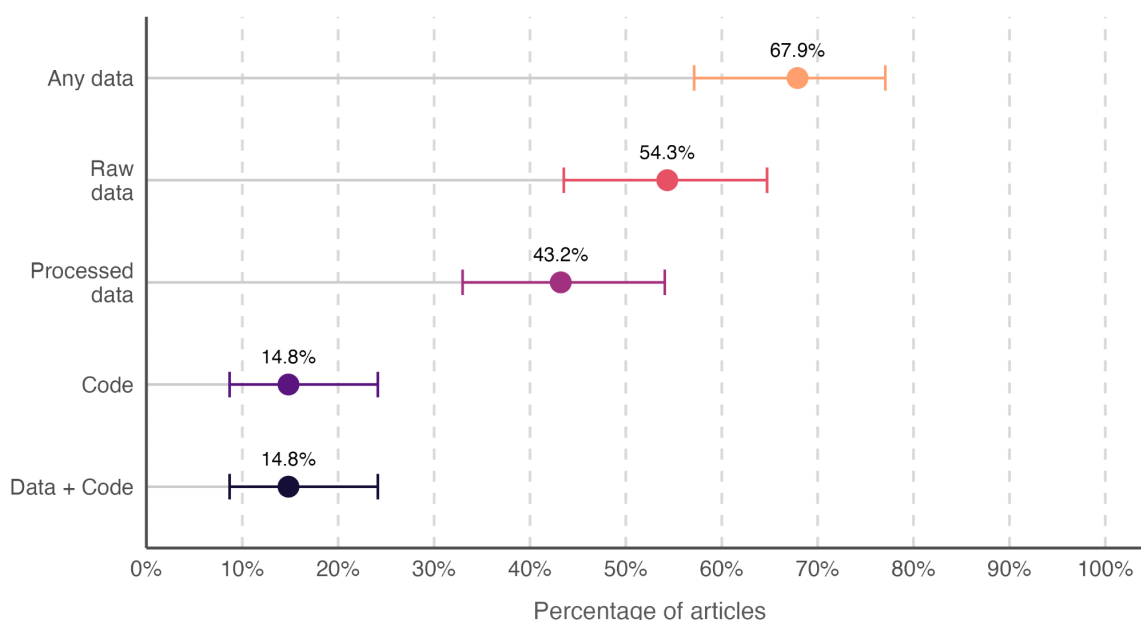
Of the 81 meta-analyses, only one reported having registered a protocol (1.2%, 95% CI = 0.2–6.7%). Eighteen meta-analyses cited having followed a reporting or conduct guideline for evidence synthesis (22.2%, 95% CI = 14.5–32.4%), such as PRISMA (n = 11), CEE (n = 1) or others (n = 6). Most meta-analyses reported the statistical software used (95.1%; 95% CI, 88.0–98.1%), with R being the most commonly used (n = 57).

The type of effect size used differed across meta-analyses. Mean comparisons were the most common outcome, followed by correlations (lnRR = 31, SMD = 17, correlations = 8, odds ratios = 2), while 23 meta-analyses used other, less common effect sizes (e.g., standardised biodiversity indices, element concentrations, etc.). Our methodological assessment suggested that 18 meta-analyses (22.2%, 95% CI = 14.5–32.4%) presumably should have addressed comparability in the direction of the effect sizes, yet only 12 of these (66.7%, 95% CI = 43.7–83.7%) reported having done so. Most meta-analyses, though not all, used weighted approaches (82.7%; 95% CI, 73.1–89.4%). Zero meta-analyses reported having performed a RoB assessment; however, 12 meta-analyses (14.8%, 95% CI = 8.7–24.1%) examined methodological differences among primary studies as a potential source of heterogeneity, suggesting their authors considered whether variation in study methods might explain variation in effect sizes.

### Data and code sharing

Most meta-analyses shared data (67.9%, 95% CI = 57.1–77.1%), either raw alone or together with processed data (54.3%, 95% CI = 43.5–64.7%), or processed data alone (43.2%, 95% CI = 33.0–54.1%; Figure 1). However, code sharing was substantially lower, with only 14.8% (95% CI = 8.7–24.1%) of meta-analyses sharing code. All meta-analyses that shared code, also shared data. The reproducibility potential, defined as providing both data and code, of the assessed meta-analyses was limited entirely by code availability to 14.8% (95% CI = 8.7–24.1%; Figure 1).

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**Figure 1. Data and code sharing across 81 meta-analyses in ecology, evolution, and environmental sciences.** “Any data” includes the raw data, processed data, or both. Points represent the percentage of articles coded as sharing type of data and code, and horizontal error bars represent 95% Wilson score confidence intervals.

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### FAIR assessments

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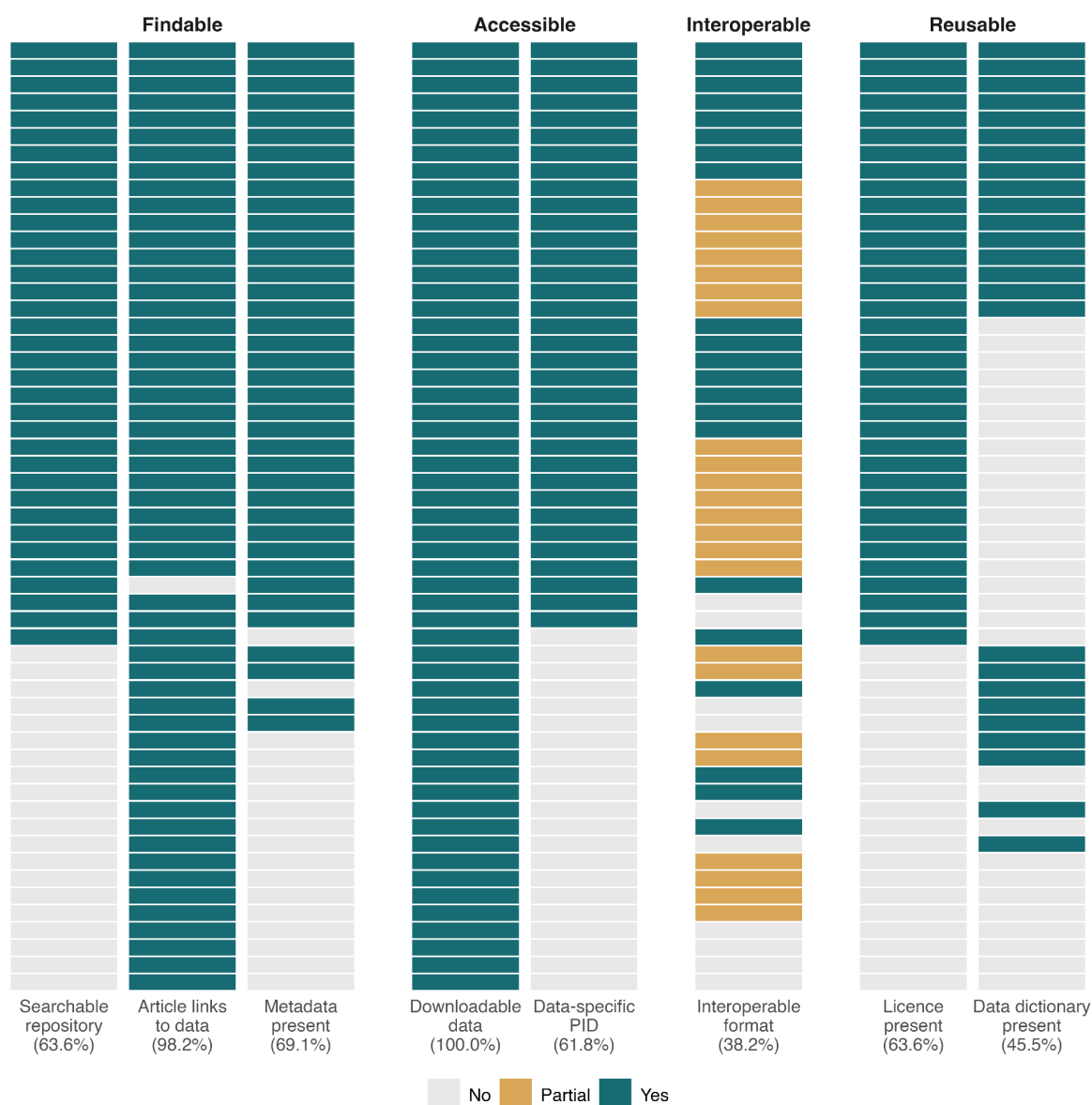
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Among the 55 meta-analyses that shared data, Findability and Accessibility indicators were the most commonly met across the 55 meta-analyses that shared data, whereas Interoperability and Reusability indicators showed frequent gaps (Figure 2). The overall FAIR score ranged from 2 to 8 fulfilled items (range = 25 to 100%), with the median being 6.5 (81%; mean = 5.6, 70%).

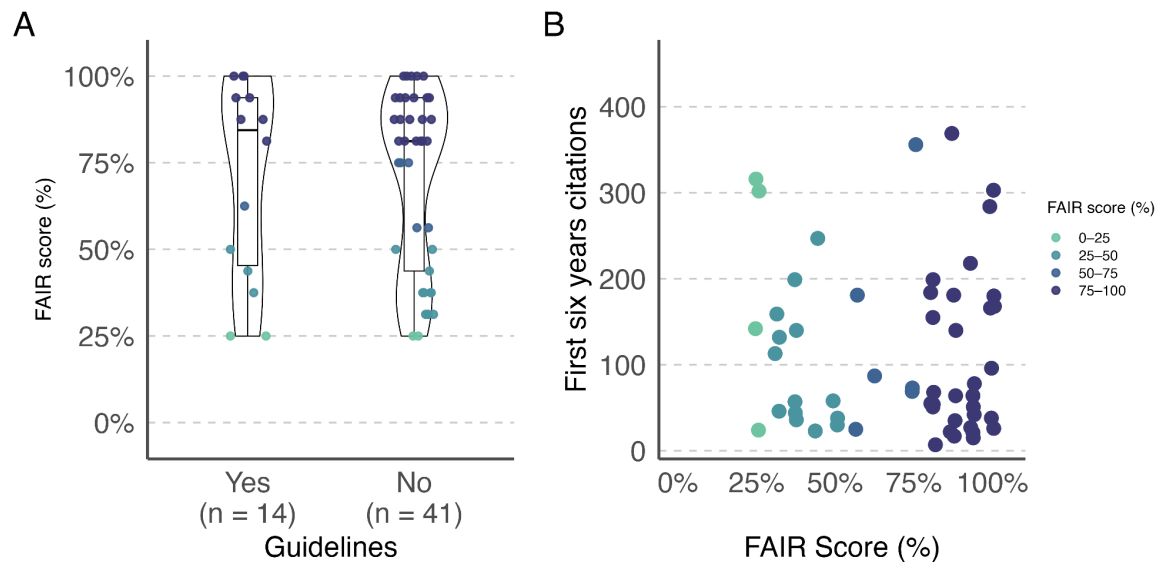
Findability and Accessibility indicators were generally more frequently met than Interoperability and Reusability indicators (Figure 2). Our FAIR assessment of the data showed that: (i) 63.6% (95% CI = 50.4–75.1%) deposited data in an external repository, with Dryad being the most common ( $n = 22$ ); (ii) 98.2% (95% CI = 90.4–99.7%) mentioned having shared data; (iii) 69.1% (95% CI = 56.0–79.7%) provided metadata associated with the data; (iv) 100.0% (95% CI = 93.5–100.0%) could be downloaded; (v) 61.8% (95% CI = 48.6–73.5%) of the data were assigned a globally unique persistent identifier (DOI = 33, Handle = 1) to ensure long-term access; (vi) 38.2% (95% CI = 26.5–51.4%) used only fully interoperable data formats such as .csv/tsv, whereas 43.6% (95% CI = 31.4–56.7%) used data formats with lower interoperability such as .xls/xlsx, and 18.2% (95% CI = 10.2–30.3%) shared data exclusively in non-interoperable document formats (.pdf, .doc/.docx); (vii) 63.6% (95% CI = 50.4–75.1%) provided a licence permitting data reuse, with CC0 licence being the most popular ( $n = 26$ ); and (viii) 45.5% (95% CI = 33.0–58.5%) provided a data dictionary to facilitate data reuse.



**Figure 2. FAIRness of shared data across 55 meta-analyses.** Each row represents one meta-analysis that shared data, and each column represents one FAIR indicator assessed in this study. The percentage shown indicates the proportion of the 55 meta-analyses that met that indicator.

### ***Are guidelines associated with a higher FAIR score?***

For the 55 meta-analyses that shared data, those that reported following a reporting or conduct guideline (mean = 70.5%, range = 25 to 100%, n = 14) had a similar data FAIR score than those that did not (mean = 70.1%, range = 25 to 100%, n = 41; Wilcoxon rank sum test:  $W = 268.5$ ,  $p = 0.73$ ; Figure 3A). We found no clear evidence of a difference in their score distribution, and the results were robust to a different statistical approach (Chi-square test:  $\chi^2 = 9.44$ ,  $p = 0.58$ ).



**Figure 3. Associations between data FAIRness, methodological or reporting guidance, and citation count.** (A) Reporting or conduct guidelines are not clearly associated with data FAIRness. Violin plots show the score distributions, and boxplots show the median and interquartile range. (B) Data FAIRness was not associated with the number of citations accumulated during the first six years after publication. In both panels, points represent individual meta-analyses and point colours indicate four FAIRness score categories (0–25%, 25–50%, 50–75%, and 75–100%).

### *Is FAIRness associated with a higher citation count?*

The number of citations accumulated during the first six publication years ranged from 1 to 435 (median = 68). The average annual citation rate during this six-year period ranged from 0.2 to 72.5 (median = 11.3), with annual citations showing a non-linear pattern that peaked, on average, between the 4<sup>th</sup> and 5<sup>th</sup> years (Figure S1 in Supplement S4). For the 55 meta-analyses that shared data, there was no statistical evidence of an association between the data FAIRness score and the number of citations accumulated during the first six years after publication of each meta-analysis (Kendall's rank: tau = -0.04, p = 0.65; Figure 3B).

## **Discussion**

Meta-analysis has become an important tool for quantitatively synthesising evidence across multiple studies, exploring sources of heterogeneity, and addressing broader questions that cannot be answered by individual studies alone (Gurevitch et al., 2018). However, the term “meta-analysis” itself has been used inconsistently in ecology, evolution, and environmental sciences, being regularly confused with other summary analyses such as vote-counting, unweighted multiple regression methods, or other statistical analyses (Vetter et al., 2013; O’Dea et al., 2021). The misuse of the term “meta-analysis” was also apparent during our screening, which excluded articles self-identified as meta-analyses but using vote-counting, summaries of survey observations, or single dataset analyses. The statistical approaches used across the 81 meta-analyses we assessed also varied considerably. Although most meta-analyses weighted effect sizes by precision or sample size, 17% used unweighted analyses such as ANOVA, calling their validity into question. Weighting effect sizes by

precision is important to account for differences in sampling uncertainty among estimates, although alternative weighting methods or unweighted analyses, in limited cases, can be justified (e.g., Morrissey, 2016; Pappalardo et al., 2023). Of the 18 meta-analyses in our sample identified as needing to address the directionality of effect sizes, only two-thirds explicitly reported doing so, calling their validity into question. Consistent direction coding is essential to make results biologically comparable without artificially cancelling one another or incorrectly combining them (Morrissey, 2016; Nakagawa & Lagisz, 2016; O'Dea et al., 2021). Recent re-analyses of published meta-analytic datasets illustrate more broadly how decisions made during effect size calculation and, specifically, inconsistent or nonexistent processes to ensure comparability in effect size direction can substantially change the evidence produced by a meta-analysis (e.g., Maassen et al., 2020; Sánchez-Tójar et al., 2020a, 2020b; Sánchez-Tójar & D'Amelio, 2026).

Formal Risk of Bias (RoB) assessments of included primary studies, which evaluate the internal validity of each primary study, is uncommon in ecology, evolution and environmental sciences (Culina et al., 2026). Since meta-analytical conclusions depend on the primary studies synthesised; RoB assessments are crucial. In our sample, although 15% of meta-analyses considered some methodological aspects of the primary studies as potential sources of variation, none conducted a formal RoB assessment, which is consistent with previous assessments (Stanhope & Weinstein, 2023; Frampton et al., 2022; Culina et al., 2026). Culina et al. (2026) recently found that only 12% of surveyed researchers with experience in evidence synthesis correctly interpreted RoB, while 40% of those who had heard the term confused it with publication bias. On the positive side, our results suggest that even though formal RoB assessments are not established practice in the field, some meta-analysts explore study-level methodological features important for the internal validity of the studies. This suggests openness to the underlying principles of RoB assessment, which together with the recently developed RoB assessment frameworks (Frampton et al., 2022; Culina et al., 2026), may help make RoB assessments routine in the field.

### ***Data sharing is relatively common, but code sharing lags behind***

Representing two-thirds of meta-analyses, data sharing was relatively common and, on average, close to five times more common than code sharing. Our findings of greater data sharing is consistent with ecology and evolution studies showing that data sharing is much more common than code sharing (e.g., Culina et al., 2020; Kambouris et al., 2024; Pollo et al., 2024; Sánchez-Tójar et al., 2025; Cooper et al., 2026). However, data availability alone is not enough to ensure reproducibility. Reproducibility assessments across disciplines consistently identify missing or inaccessible data as the major barrier to reproducing published results, followed by missing or inaccessible code (Archmiller et al., 2020; Minocher et al., 2021; Trisovic et al., 2022). When data can be accessed, code accessibility has been shown to increase reproducibility by about twofold (Miske et al., 2026). In meta-analysis, code is an essential part of the synthesis process that documents decisions about data cleaning, effect size calculation, data transformations, and model specification that may not be recoverable from the article alone (see, e.g., Maassen et al., 2020; Kambouris et al., 2024). For a form of synthesis that is not only influential but largely a computational endeavour, code availability is particularly relevant (Haddaway & Pullin, 2014; Nakagawa et al., 2017) and the code should be shared.

### ***Shared data are Findable and Accessible, but less Interoperable and Reusable***

Data and code availability, however, does not guarantee reproducibility or reusability. Even when code is shared, it is often poorly documented or fails to run (Trisovic et al., 2022; Kellner et al., 2025), while shared data require adequate documentation, structure and licensing to facilitate their interpretation and reuse. The FAIR principles provide a framework for ensuring that digital research objects are Findable, Accessible, Interoperable and Reusable by both humans and machines (Wilkinson et al., 2016). The mean FAIR score in our study was 70%, which is at the upper end of the range reported in FAIR assessments from other fields (43–71%; Poljak Bilić & Posavec, 2024; Sofi-Mahmudi et al., 2024; Hutchison et al., 2024). Findability and Accessibility were generally high, and almost all articles indicated where their data could be found, and all datasets were downloadable. However, only around two-thirds deposited data in a searchable repository, provided associated metadata, assigned a persistent identifier or included an explicit reuse licence. Fewer than half provided a data dictionary, and only 38% used exclusively non-proprietary, machine-readable formats such as .csv or .tsv. Searchable repositories and persistent identifiers support stable data discovery and citation; metadata and data dictionaries allow data to be interpreted for reusability; machine-readable formats are key for computational processing by humans and machines; and explicit licences clarify the conditions under which data may be reused. Our results indicate that the key shortcomings in shared meta-analytic datasets were Interoperability and Reusability: datasets could usually be located and opened, but were not consistently documented, structured or licensed for independent reuse. This is consistent with earlier assessments in ecology and evolution, where archived data were often incomplete (56% of archived datasets), and 56–64% of datasets lacked information that partially or entirely prevented reuse (Roche et al., 2015; Roche et al., 2022).

Meta-analysts invest considerable effort in searching for studies, extracting information, and harmonising heterogeneous data. Well-curated meta-analytic datasets could subsequently support verification, updating, and entirely new syntheses (Nakagawa et al., 2020). Merely depositing files only captures a small part of the potential value of data sharing. The observed pattern may partly reflect compliance-oriented journal and funder policies that emphasise whether data and code are made available (Sholler et al., 2019; Roche et al., 2022; Ivimey-Cook et al., 2025). Meeting such sharing requirements does not necessarily ensure that deposited files are sufficiently complete, documented or structured for reuse (Cooper et al., 2026). Applying FAIR-aligned practices would allow meta-analytic datasets to function as cumulative research objects. Ensuring the reusability of shared datasets is therefore a critical next step for improving the transparency, verification and updating of evidence syntheses (Burgard et al., 2022; Pollo et al., 2025).

Reporting and conduct guidelines, such as PRISMA, CEE guidance, and ROSES, require authors to report key features of review conduct, including search and screening decisions, synthesis methods, protocol registration, statistical software, and, increasingly, the availability of data and code (Collaboration for Environmental Evidence, 2022; Haddaway et al., 2018; Page et al., 2021). In our study, only 22% of the meta-analyses reported following a reporting guideline. Among meta-analyses sharing data, we found no evidence that studies reporting guideline use had higher FAIR scores. These tools are essential for improving the completeness of reporting in systematic reviews and meta-analyses (Pappalardo et al., 2023; Morrison et al., 2025). Nonetheless, previous assessments found that systematic reviews and meta-analyses reported, on average, only approximately 42–55% of the evaluated reporting items across fields (Polanin et al., 2020; O’Dea et al., 2021; Ivaldi et al., 2024). These

guidelines, however, do not directly address how to prepare data to meet the FAIR principles (Wilkinson et al., 2016). Reporting guidance for evidence synthesis and FAIR guidance are complementary rather than interchangeable. While the former makes a synthesis more transparent and comprehensible, the latter attempts to make the underlying materials reusable for validating and updating evidence synthesis as new evidence accumulates, thereby enabling fuller use of existing research and reducing research waste (Grainger et al., 2020; Purgar et al., 2022).

Lastly, our exploratory analyses found no association between data FAIRness and citations accumulated during the first six years after publication. Some studies have reported a citation advantage when data is shared (Piwowar et al., 2007; Piwowar & Vision, 2013), including recent evidence from ecology and evolution (Maitner et al., 2024). However, those studies generally compared whether data were shared rather than investigating data FAIRness. More recently, Morrison et al. (2025) found no difference in the methodological quality of meta-analyses cited in policy documents versus those not. Citation count therefore cannot be assumed to be associated with methodological quality or data reusability, strengthening the case for journals and funders to establish these practices as expectations rather than relying primarily on researchers to adopt them for individual academic incentives such as citation benefits.

### ***Limitations of our study***

Several limitations should be considered when interpreting our findings. First, although the 81 articles were randomly selected from our eligible pool, they represent a small sample of all meta-analyses published between 2016 and 2020 in a predefined set of journals, limiting the extrapolation of our results to the wider literature or to more recent practice. Second, our FAIR assessment protocol only evaluated eight FAIR indicators, with an uneven number of items per component (F = 3, A = 2, I = 1, and R = 2 items). Different studies and different areas of research have used different criteria and scoring systems. For example, assessments based on automated tools such as F-UJI evaluated additional machine-reusability features such as standardised access protocols and controlled vocabularies (Poljak Bilić & Posavec, 2024; Sofi-Mahmudi et al., 2024). Although these criteria are valuable for assessing FAIRness across a broad range of digital research objects and for large interoperable data infrastructures, they may not always capture the features most relevant for reusability in meta-analytic datasets in ecology, evolution and environmental sciences. The FAIR principles are intentionally broad and are intended to be operationalised by research communities in ways that reflect domain-specific data types, standards and reuse needs. Our protocol therefore prioritised key practical features such as clear links to the shared data, interoperable file formats, persistent identifiers, licensing, metadata and variable-level documentation.

### ***Study conclusions and recommendations***

Our study shows that, in contrast to code sharing, data sharing is relatively common among meta-analyses in ecology, evolution and environmental sciences. Shared data were generally Findable and Accessible, whereas Interoperability and Reusability were more frequently limited. The FAIR principles provide the broad foundation for improving data stewardship, and FAIR4RS extends a similar framework to research software (Wilkinson et al., 2016; Barker et al., 2022). Additionally, the TADA and SORTEE guidelines provide field-relevant guidance to

improve credibility, reproducibility, and reusability (Ivimey-Cook et al., 2025; Pick et al., 2026). The recently developed Meta-analysis Appraisal Tool for Environmental Sciences (MATES; Morrison et al., 2026) can further be used to evaluate reporting completeness in meta-analyses. Together with evidence synthesis guidelines, these frameworks can help shift practices from simply reporting what was done towards documenting and sharing the materials needed to verify and extend the synthesis for future use (Moreau et al., 2024). Since evidence syntheses increasingly inform research priorities, conservation and environmental management, their underlying data and analytical workflows must be sufficiently reusable for others to check, update, and build on as evidence accumulates (Haddaway, 2018). By distinguishing transparency from FAIRness, our study offers a more granular picture, and shows that considerable work remains before open meta-analytic datasets in ecology, evolution, and environmental sciences can be considered truly reusable.

## **Data and code availability statement**

All data and code associated with this manuscript are available in the Github repository [https://github.com/ASanchez-Tojar/FAIR\\_meta-analysis](https://github.com/ASanchez-Tojar/FAIR_meta-analysis) [will insert Zenodo link after review]

## **AI Use Declaration:**

The authors declare that AI was not used to generate the ideas or initial draft of this manuscript. GPT-5.6 Luna was used only to improve the readability of selected portions of the human-authored text. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content within this manuscript.

## **Authors contributions (CRediT)**

SD: Data Curation (equal), Investigation (lead), Methodology (equal), Project administration (equal), Software, Validation, Visualization (equal), Writing – original draft (equal), Writing – review & editing (equal).

MP, VD, HB, AC, RF, AJF, MG, EI-C, MLJ, ML, NPM, NP-J, PP, GW, YY, CZ: Investigation (equal), Writing – review & editing (equal)

AST: Conceptualization, Data Curation (equal), Formal analysis, Funding acquisition, Investigation (lead), Methodology (equal), Project administration (equal), Software (lead), Supervision, Visualization (equal), Writing – original draft (equal), Writing – review & editing (equal).

## **Acknowledgments**

We thank the organisers of the Evidence Synthesis and Meta-Analysis in R Conference (ESMARConf) for providing us with the opportunity to host the hackathon. We thank Meagan Harper (0000-0002-8462-2039) and Christel Hellberg for their valuable contributions in collecting the data during the hackathon. We thank Klaus Reinhold (0000-0002-0249-8346) for his support. SD and AST were funded by the DFG (Deutsche Forschungsgemeinschaft) as part of the SFB TRR212 (NC<sup>3</sup>) Second Phase 2022-2025 (Project number 316099922). AST was also partially supported by Portuguese national funds via Fundação para a Ciência e a Tecnologia (FCT) under projects LA/P/0058/2020, UID/PRR/4539/2025 and UID/04539/2025, and project EXCELSIOR, funded by the EU's Horizon Europe under

Grant Agreement No. 101087416. ML was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grant (RGPIN-2026-05996).

## Conflict of interest

The authors declare having no conflict of interest.

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# Supplement S1: Complete Search String

We searched the same set of ecology and evolutionary biology journals used in O’Dea et al. (2021). Those journals were derived from a list of journals classified under the “Ecology” and “Evolutionary Biology” categories in the 2017 ISI InCites Journal Citation Reports. Duplicate journals were removed, and both print and electronic ISSNs were included where available. We used the following string in our Web of Science search:

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(TI = ("meta-analy*" OR "metaanaly*" OR "meta-regression" OR "metaregression") OR AB = ("meta-analy*" OR "metaanaly*" OR "meta-regression" OR "metaregression") OR AK = ("meta-analy*" OR "metaanaly*" OR "meta-regression" OR "metaregression")) AND IS= ("13652486" OR "14610248" OR "01678809" OR "16000706" OR "14668238" OR "00063207" OR "14321939" OR "14712954" OR "15231739" OR "20457758" OR "13652664" OR "09218009" OR "13652745" OR "16161599" OR "1365294X" OR "14209101" OR "19395582" OR "13652435" OR "17264189" OR "2041210X" OR "15585646" OR "13652656" OR "21508925" OR "15375323" OR "17517370" OR "16000587" OR "13652699" OR "1744957X" OR "14657279" OR "15731464" OR "15577015" OR "22120416" OR "14350629" OR "15738477" OR "13652427" OR "14712148" OR "15729710" OR "09258574" OR "03043800" OR "14724642" OR "17524571" OR "16541103" OR "1526100X" OR "10958312" OR "15749541" OR "23519894" OR "15735052" OR "01695347" OR "14391791" OR "14320762" OR "21619549" OR "16171381" OR "0022541X" OR "15729761" OR "14338319" OR "14429993" OR "09123814" OR "17083087" OR "17545048" OR "01401963" OR "01692046" OR "15371719" OR "2397334X" OR "14726785" OR "15733017" OR "15409309" OR "1432184X" OR "10968644" OR "1654109X" OR "16161564" OR "19360592" OR "13652540" OR "17550998" OR "00314056" OR "1438390X" OR "15507424" OR "00652504" OR "17596653" OR "10959513" OR "14691795" OR "15891623" OR "20511434" OR "11769343" OR "19342845" OR "22132244" OR "22244662" OR "00220981" OR "14657333" OR "19413300" OR "14697831" OR "01106465" OR "13653008" OR "24501395" OR "15731642" OR "10353712" OR "0003455X" OR "15452069" OR "17447429" OR "11645563" OR "03672530" OR "00472484" OR "17529921" OR "08000395" OR "16083334" OR "1076836X" OR "19385455" OR "13652028" OR "17279380" OR "20412851" OR "10301887" OR "02757540" OR "14230445" OR "10960031" OR "15882756" OR "22145753" OR "15735133" OR "14390574" OR "15220613" OR "19339747" OR "13504509" OR "15731561" OR "14321432" OR "08858608" OR "21996881" OR "14753057" OR "10369872" OR "23524855" OR "02497395" OR "15482324" OR "19968175" OR "18741746" OR "10960325" OR "13991183" OR "19436246" OR "18094392" OR "1146609X" OR "24108200" OR "00030031" OR "13488570" OR "15735125" OR "18185487" OR "03051978" OR "00030090" OR "0079032X" OR "1065657X" OR "19954263" OR "1432041X" OR "2073106X" OR "16423593" OR "1476945X" OR "14427001" OR "19399170" OR "11956860" OR "20419139" OR "1525142X" OR "21553874" OR "1876312X" OR "03781844" OR "14455226" OR "17513758" OR "00220930" OR "15525015" OR "1944687X" OR "02705060" OR "14645262" OR "14772019" OR "14390469" OR "1860188X" OR "17451019" OR "20513933" OR "00280712" OR "19385307" OR "0029344X" OR "16181077" OR "19385331" OR "0340269X" OR
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"14421984" OR "14322056" OR "18739652" OR "01380338" OR " 19385293" OR "18397263" OR "07176317" OR "19385412" OR "00384909" OR " 13653113" OR "05643295" OR "02408759" OR "15270904" OR "09096396" OR " 14636409" OR "13541013" OR "1461023X" OR "00301299" OR "1466822X" OR " 477525" OR "00298549" OR "09628452" OR "08888892" OR "00218901" OR " 00220477" OR "01718630" OR "09621083" OR "1010061X" OR "10510761" OR " 02698463" OR "17264170" OR "00143820" OR "00218790" OR "00030147" OR " 17517362" OR "09067590" OR "03050270" OR "17449561" OR "10452249" OR " 13873547" OR "2818182" OR "14329840" OR "02697653" OR "00465070" OR " 09603115" OR "13669516" OR "11009233" OR "10612971" OR "00244066" OR " 13850237" OR "03405443" OR "09212973" OR "14429985" OR "07374038" OR " 09639292" OR "15409295" OR "00953628" OR "2769667" OR "14022001" OR " 09483055" OR "19360584" OR "0018067X" OR "1755098X" OR "14383896" OR " 10557903" OR "13679430" OR "00713260" OR "15659801" OR "00221503" OR " 00224561" OR "02664674" OR "00306053" OR "15052249" OR "10838155" OR " 1543592X" OR "623257" OR "10674136" OR "10635157" OR "00840173" OR " 01416707" OR "10220119" OR "09377409" OR "07483007" OR "15858553" OR " 22145745" OR "03781909" OR "16124642" OR "00980331" OR "00222844" OR " 03782697" OR "00322474" OR "03636445" OR "00400262" OR "18741738" OR " 00405809" OR "21933081" OR "02775212" OR "00445967" OR "24107220" OR " 09187960" OR "13862588" OR "17986540" OR "19954255" OR "0949944X" OR " 2833888" OR "1520541X" OR "19344392" OR "1399560X" OR "15525007" OR " 00222933" OR "09475745" OR "18601871" OR "17451000" OR "10926194" OR " 14396092" OR "00948373" OR "0913557X" OR "07224060" OR "00973157" OR " 0370047X" OR "0716078X" OR "15287092" OR "03076970" OR "03003256")

#### List of Journals with the iSSN:

| ISSN as in the search string | Formatted ISSN | Journal Name                            |
|------------------------------|----------------|-----------------------------------------|
| 13652486                     | 1365-2486      | Global Change Biology                   |
| 14610248                     | 1461-0248      | Ecology Letters                         |
| 01678809                     | 0167-8809      | Agriculture, Ecosystems and Environment |
| 16000706                     | 1600-0706      | Oikos                                   |
| 14668238                     | 1466-8238      | Global Ecology and Biogeography         |

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|----------|-----------|---------------------------------------------------------|
| 00063207 | 0006-3207 | Biological Conservation                                 |
| 14321939 | 1432-1939 | Oecologia                                               |
| 14712954 | 1471-2954 | Proceedings of the Royal Society B: Biological Sciences |
| 15231739 | 1523-1739 | Conservation Biology                                    |
| 20457758 | 2045-7758 | Ecology and Evolution                                   |
| 13652664 | 1365-2664 | Journal of Applied Ecology                              |
| 09218009 | 0921-8009 | Ecological Economics                                    |
| 13652745 | 1365-2745 | Journal of Ecology                                      |
| 16161599 | 1616-1599 | Marine Ecology Progress Series                          |
| 1365294X | 1365-294X | Molecular Ecology                                       |
| 14209101 | 1420-9101 | Journal of Evolutionary Biology                         |
| 19395582 | 1939-5582 | Ecological Applications                                 |
| 13652435 | 1365-2435 | Functional Ecology                                      |
| 17264189 | 1726-4189 | Biogeosciences                                          |
| 2041210X | 2041-210X | Methods in Ecology and Evolution                        |
| 15585646 | 1558-5646 | Evolution                                               |
| 13652656 | 1365-2656 | Journal of Animal Ecology                               |
| 21508925 | 2150-8925 | Ecosphere                                               |
| 15375323 | 1537-5323 | American Naturalist                                     |

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| 17517370 | 1751-7370 | ISME Journal                  |
| 16000587 | 1600-0587 | Ecography                     |
| 13652699 | 1365-2699 | Journal of Biogeography       |
| 1744957X | 1744-957X | Biology Letters               |
| 14657279 | 1465-7279 | Behavioral Ecology            |
| 15731464 | 1573-1464 | Biological Invasions          |
| 15577015 | 1557-7015 | Ecological Monographs         |
| 22120416 | 2212-0416 | Ecosystem Services            |
| 14350629 | 1435-0629 | Ecosystems                    |
| 15738477 | 1573-8477 | Evolutionary Ecology          |
| 13652427 | 1365-2427 | Freshwater Biology            |
| 14712148 | 1471-2148 | BMC Evolutionary Biology      |
| 15729710 | 1572-9710 | Biodiversity and Conservation |
| 09258574 | 0925-8574 | Ecological Engineering        |
| 03043800 | 0304-3800 | Ecological Modelling          |
| 14724642 | 1472-4642 | Diversity and Distributions   |
| 17524571 | 1752-4571 | Evolutionary Applications     |
| 16541103 | 1654-1103 | Journal of Vegetation Science |
| 1526100X | 1526-100X | Restoration Ecology           |

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| 10958312 | 1095-8312 | Biological Journal of the Linnean Society                |
| 15749541 | 1574-9541 | Ecological Informatics                                   |
| 23519894 | 2351-9894 | Global Ecology and Conservation                          |
| 15735052 | 1573-5052 | Plant Ecology                                            |
| 01695347 | 0169-5347 | Trends in Ecology and Evolution                          |
| 14391791 | 1439-1791 | Basic and Applied Ecology                                |
| 14320762 | 1432-0762 | Behavioral Ecology and Sociobiology                      |
| 21619549 | 2161-9549 | Freshwater Science                                       |
| 16171381 | 1617-1381 | Journal for Nature Conservation                          |
| 0022541X | 0022-541X | The Journal of wildlife management                       |
| 15729761 | 1572-9761 | Landscape Ecology                                        |
| 14338319 | 1433-8319 | Perspectives in Plant Ecology, Evolution and Systematics |
| 14429993 | 1442-9993 | Austral Ecology                                          |
| 09123814 | 0912-3814 | Ecological Research                                      |
| 17083087 | 1708-3087 | Ecology and Society                                      |
| 17545048 | 1754-5048 | Fungal Ecology                                           |
| 1401963  | 0140-1963 | Journal of Arid Environments                             |
| 1692046  | 0169-2046 | Landscape and Urban Planning                             |
| 15371719 | 1537-1719 | Molecular Biology and Evolution                          |

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| 2397334X | 2397-334X | Nature Ecology & Evolution                 |
| 14726785 | 1472-6785 | BMC Ecology                                |
| 15733017 | 1573-3017 | Ecotoxicology                              |
| 15409309 | 1540-9309 | Frontiers in Ecology and the Environment   |
| 1432184X | 1432-184X | Microbial Ecology                          |
| 10968644 | 1096-8644 | American Journal of Physical Anthropology  |
| 1654109X | 1654-109X | Applied Vegetation Science                 |
| 16161564 | 1616-1564 | Aquatic Microbial Ecologyn                 |
| 19360592 | 1936-0592 | Ecohydrology                               |
| 13652540 | 1365-2540 | Heredity                                   |
| 17550998 | 1755-0998 | Molecular Ecology Resources                |
| 00314056 | 0031-4056 | Pedobiologia                               |
| 1438390X | 1438-390X | Population Ecology                         |
| 15507424 | 1550-7424 | Rangeland Ecology & Management             |
| 00652504 | 0065-2504 | Advances in Ecological Research            |
| 17596653 | 1759-6653 | Genome Biology and Evolution               |
| 10959513 | 1095-9513 | Molecular Phylogenetics and Evolution      |
| 14691795 | 1469-1795 | Animal Conservation                        |
| 15891623 | 1589-1623 | Applied Ecology and Environmental Research |

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| 20511434 | 2051-1434 | Conservation Physiology                                        |
| 11769343 | 1176-9343 | Evolutionary Bioinformatics                                    |
| 19342845 | 1934-2845 | Evolutionary Biology                                           |
| 22132244 | 2213-2244 | International Journal for Parasitology: Parasites and Wildlife |
| 22244662 | 2224-4662 | Israel Journal of Ecology & Evolution                          |
| 00220981 | 0022-0981 | Journal of Experimental Marine Biology and Ecology             |
| 14657333 | 1465-7333 | Journal of Heredity                                            |
| 19413300 | 1941-3300 | Journal of Soil and Water Conservation                         |
| 14697831 | 1469-7831 | Journal of Tropical Ecology                                    |
| 01106465 | 0110-6465 | New Zealand Journal of Ecology                                 |
| 13653008 | 1365-3008 | Oryx                                                           |
| 24501395 | 2450-1395 | Polish Journal of Ecology                                      |
| 15731642 | 1573-1642 | Urban Ecosystems                                               |
| 10353712 | 1035-3712 | Wildlife Research                                              |
| 0003455X | 0003-455X | Annales Zoologici Fennici                                      |
| 15452069 | 1545-2069 | Annual Review of Ecology, Evolution, and Systematics           |
| 17447429 | 1744-7429 | Biotropica                                                     |
| 11645563 | 1164-5563 | European Journal of Soil Biology                               |
| 03672530 | 0367-2530 | Flora                                                          |

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| 00472484 | 0047-2484 | Journal of Human Evolution                |
| 17529921 | 1752-9921 | Journal of Plant Ecology                  |
| 08000395 | 0800-0395 | Polar Research                            |
| 16083334 | 1608-3334 | Russian Journal of Ecology                |
| 1076836X | 1076-836X | Systematic Biology                        |
| 19385455 | 1938-5455 | Wildlife Monographs                       |
| 13652028 | 1365-2028 | African Journal of Ecology                |
| 17279380 | 1727-9380 | African Journal of Range & Forage Science |
| 20412851 | 2041-2851 | AoB PLANTS                                |
| 10301887 | 1030-1887 | Australian Systematic Botany              |
| 02757540 | 0275-7540 | Chemistry and Ecology                     |
| 14230445 | 1423-0445 | Chemoecology                              |
| 10960031 | 1096-0031 | Cladistics                                |
| 15882756 | 1588-2756 | Community Ecology                         |
| 22145753 | 2214-5753 | Current Opinion in Insect Science         |
| 15735133 | 1573-5133 | Environmental Biology of Fishes           |
| 14390574 | 1439-0574 | European Journal of Wildlife Research     |
| 15220613 | 1522-0613 | Evolutionary Ecology Research             |
| 19339747 | 1933-9747 | Fire Ecology                              |

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| 13504509 | 1350-4509 | International Journal of Sustainable Development & World Ecology |
| 15731561 | 1573-1561 | Journal of Chemical Ecology                                      |
| 14321432 | 1432-1432 | Journal of Molecular Evolution                                   |
| 08858608 | 0885-8608 | Natural Areas Journal                                            |
| 21996881 | 2199-6881 | Österreichische Botanische Zeitschrift                           |
| 14753057 | 1475-3057 | Polar Record                                                     |
| 10369872 | 1036-9872 | The Rangeland Journal                                            |
| 23524855 | 2352-4855 | Regional Studies in Marine Science                               |
| 02497395 | 0249-7395 | Revue d'Écologie                                                 |
| 15482324 | 1548-2324 | Systematic Botany                                                |
| 19968175 | 1996-8175 | Taxon                                                            |
| 18741746 | 1874-1746 | Theoretical Ecology                                              |
| 10960325 | 1096-0325 | Theoretical Population Biology                                   |
| 13991183 | 1399-1183 | Web Ecology                                                      |
| 19436246 | 1943-6246 | Wetlands                                                         |
| 18094392 | 1809-4392 | Acta Amazonica                                                   |
| 1146609X | 1146-609X | Acta Oecologica                                                  |
| 24108200 | 2410-8200 | African Journal of Wildlife Research                             |
| 00030031 | 0003-0031 | The American Midland Naturalist                                  |

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| 13488570 | 1348-8570 | Anthropological Science                            |
| 15735125 | 1573-5125 | Aquatic Ecology                                    |
| 18185487 | 1818-5487 | Aquatic Invasions                                  |
| 03051978 | 0305-1978 | Biochemical Systematics and Ecology                |
| 00030090 | 0003-0090 | Bulletin of the American Museum of Natural History |
| 0079032X | 0079-032X | Bulletin of the Peabody Museum of Natural History  |
| 1065657X | 1065-657X | Compost Science & Utilization                      |
| 19954263 | 1995-4263 | Contemporary Problems of Ecology                   |
| 1432041X | 1432-041X | Development, Genes and Evolution                   |
| 2073106X | 2073-106X | eco.mont                                           |
| 16423593 | 1642-3593 | Ecohydrology & Hydrobiology                        |
| 1476945X | 1476-945X | Ecological Complexity                              |
| 14427001 | 1442-7001 | Ecological Management & Restoration                |
| 19399170 | 1939-9170 | Ecology                                            |
| 11956860 | 1195-6860 | Écoscience                                         |
| 20419139 | 2041-9139 | EvoDevo                                            |
| 1525142X | 1525-142X | Evolution & Development                            |
| 21553874 | 2155-3874 | Human-Wildlife Interactions                        |
| 1876312X | 1876-312X | Insect Systematics & Evolution                     |

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| 03781844 | 0378-1844 | Interciencia                                                                  |
| 14455226 | 1445-5226 | Invertebrate Systematics                                                      |
| 17513758 | 1751-3758 | Journal of Biological Dynamics                                                |
| 00220930 | 0022-0930 | Journal of Evolutionary Biochemistry and Physiology                           |
| 15525015 | 1552-5015 | Journal of Experimental Zoology Part B: Molecular and Developmental Evolution |
| 1944687X | 1944-687X | Journal of Fish and Wildlife Management                                       |
| 02705060 | 0270-5060 | Journal of Freshwater Ecology                                                 |
| 14645262 | 1464-5262 | Journal of Natural History                                                    |
| 14772019 | 1477-2019 | Journal of Systematic Palaeontology                                           |
| 14390469 | 1439-0469 | Journal of Zoological Systematics and Evolutionary Research                   |
| 1860188X | 1860-188X | Landscape and Ecological Engineering                                          |
| 17451019 | 1745-1019 | Marine Biology Research                                                       |
| 20513933 | 2051-3933 | Movement Ecology                                                              |
| 00280712 | 0028-0712 | Natural History                                                               |
| 19385307 | 1938-5307 | Northeastern Naturalist                                                       |
| 0029344X | 0029-344X | Northwest Science                                                             |
| 16181077 | 1618-1077 | Organisms Diversity & Evolution                                               |
| 19385331 | 1938-5331 | Paleobiology                                                                  |
| 0340269X | 0340-269X | Phytocoenologia                                                               |

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|----------|-----------|----------------------------------------------------------------|
| 14421984 | 1442-1984 | Plant Species Biology                                          |
| 14322056 | 1432-2056 | Polar Biology                                                  |
| 18739652 | 1873-9652 | Polar Science                                                  |
| 01380338 | 0138-0338 | Polish Polar Research                                          |
| 19385293 | 1938-5293 | Proceedings of the Academy of Natural Sciences of Philadelphia |
| 18397263 | 1839-7263 | Proceedings of the Linnean Society of New South Wales          |
| 07176317 | 0717-6317 | Revista Chilena de Historia Natural                            |
| 19385412 | 1938-5412 | Southeastern Naturalist                                        |
| 00384909 | 0038-4909 | The Southwestern Naturalist                                    |
| 13653113 | 1365-3113 | Systematic Entomology                                          |
| 05643295 | 0564-3295 | Tropical Ecology                                               |
| 02408759 | 0240-8759 | Vie et Milieu                                                  |
| 15270904 | 1527-0904 | Western North American Naturalist                              |
| 09096396 | 0909-6396 | Wildlife Biology                                               |
| 14636409 | 1463-6409 | Zoologica Scripta                                              |
| 13541013 | 1354-1013 | Global Change Biology                                          |
| 1461023X | 1461-023X | Ecology Letters                                                |
| 00301299 | 0030-1299 | Oikos                                                          |
| 1466822X | 1466-822X | Global Ecology and Biogeography                                |

|          |           |                                                         |
|----------|-----------|---------------------------------------------------------|
| 477525   |           | Unknown                                                 |
| 00298549 | 0029-8549 | Oecologia                                               |
| 09628452 | 0962-8452 | Proceedings of the Royal Society B: Biological Sciences |
| 08888892 | 0888-8892 | Conservation Biology                                    |
| 00218901 | 0021-8901 | Journal of Applied Ecology                              |
| 00220477 | 0022-0477 | Journal of Ecology                                      |
| 01718630 | 0171-8630 | Marine Ecology Progress Series                          |
| 09621083 | 0962-1083 | Molecular Ecology                                       |
| 1010061X | 1010-061X | Journal of Evolutionary Biology                         |
| 10510761 | 1051-0761 | Ecological Applications                                 |
| 02698463 | 0269-8463 | Functional Ecology                                      |
| 17264170 | 1726-4170 | Biogeosciences                                          |
| 00143820 | 0014-3820 | Evolution                                               |
| 00218790 | 0021-8790 | Journal of Animal Ecology                               |
| 00030147 | 0003-0147 | American Naturalist                                     |
| 17517362 | 1751-7362 | ISME Journal                                            |
| 09067590 | 0906-7590 | Ecography                                               |
| 03050270 | 0305-0270 | Journal of Biogeography                                 |
| 17449561 | 1744-9561 | Biology Letters                                         |

|          |           |                                           |
|----------|-----------|-------------------------------------------|
| 10452249 | 1045-2249 | Behavioral Ecology                        |
| 13873547 | 1387-3547 | Biological Invasions                      |
| 2818182  |           | Unknown                                   |
| 14329840 | 1432-9840 | Ecosystems                                |
| 02697653 | 0269-7653 | Evolutionary Ecology                      |
| 00465070 | 0046-5070 | Freshwater Biology                        |
| 09603115 | 0960-3115 | Biodiversity and Conservation             |
| 13669516 | 1366-9516 | Diversity and Distributions               |
| 11009233 | 1100-9233 | Journal of Vegetation Science             |
| 10612971 | 1061-2971 | Restoration Ecology                       |
| 00244066 | 0024-4066 | Biological Journal of the Linnean Society |
| 13850237 | 1385-0237 | Plant Ecology                             |
| 03405443 | 0340-5443 | Behavioral Ecology and Sociobiology       |
| 09212973 | 0921-2973 | Landscape Ecology                         |
| 14429985 | 1442-9985 | Austral Ecology                           |
| 07374038 | 0737-4038 | Molecular Biology and Evolution           |
| 09639292 | 0963-9292 | Animal Welfare                            |
| 15409295 | 1540-9295 | Frontiers in Ecology and the Environment  |
| 00953628 | 0095-3628 | Microbial Ecology                         |

|          |           |                                                      |
|----------|-----------|------------------------------------------------------|
| 2769667  |           | Unknown                                              |
| 14022001 | 1402-2001 | Ecography                                            |
| 09483055 | 0948-3055 | Aquatic Microbial Ecology                            |
| 19360584 | 1936-0584 | Ecohydrology                                         |
| 0018067X | 0018-067X | Heredity                                             |
| 1755098X | 1755-098X | Molecular Ecology Resources                          |
| 14383896 | 1438-3896 | Population Ecology                                   |
| 10557903 | 1055-7903 | Molecular Phylogenetics and Evolution                |
| 13679430 | 1367-9430 | Animal Conservation                                  |
| 00713260 | 0071-3260 | Evolutionary Biology                                 |
| 15659801 | 1565-9801 | Israel Journal of Ecology & Evolution                |
| 00221503 | 0022-1503 | Journal of Heredity                                  |
| 00224561 | 0022-4561 | Journal of Soil and Water Conservation               |
| 02664674 | 0266-4674 | Journal of Tropical Ecology                          |
| 00306053 | 0030-6053 | Oryx                                                 |
| 15052249 | 1505-2249 | Polish Journal of Ecology                            |
| 10838155 | 1083-8155 | Urban Ecosystems                                     |
| 1543592X | 1543-592X | Annual Review of Ecology, Evolution, and Systematics |
| 623257   |           | Unknown                                              |

|          |           |                                           |
|----------|-----------|-------------------------------------------|
| 10674136 | 1067-4136 | Russian Journal of Ecology                |
| 10635157 | 1063-5157 | Systematic Biology                        |
| 00840173 | 0084-0173 | Wildlife Monographs                       |
| 01416707 | 0141-6707 | African Journal of Ecology                |
| 10220119 | 1022-0119 | African Journal of Range & Forage Science |
| 09377409 | 0937-7409 | Chemoecology                              |
| 07483007 | 0748-3007 | Cladistics                                |
| 15858553 | 1585-8553 | Community Ecology                         |
| 22145745 | 2214-5745 | Current Opinion in Insect Science         |
| 03781909 | 0378-1909 | Environmental Biology of Fishes           |
| 16124642 | 1612-4642 | European Journal of Wildlife Research     |
| 00980331 | 0098-0331 | Environmental Conservation                |
| 00222844 | 0022-2844 | Journal of Molecular Evolution            |
| 03782697 | 0378-2697 | Plant Systematics and Evolution           |
| 00322474 | 0032-2474 | Polar Record                              |
| 03636445 | 0363-6445 | Systematic Botany                         |
| 00400262 | 0040-0262 | Taxon                                     |
| 18741738 | 1874-1738 | Theoretical Ecology                       |
| 00405809 | 0040-5809 | Theoretical Population Biology            |

|          |           |                                                             |
|----------|-----------|-------------------------------------------------------------|
| 21933081 | 2193-3081 | Web Ecology                                                 |
| 02775212 | 0277-5212 | Wetlands                                                    |
| 00445967 | 0044-5967 | Acta Amazonica                                              |
| 24107220 | 2410-7220 | African Journal of Wildlife Research                        |
| 09187960 | 0918-7960 | Anthropological Science                                     |
| 13862588 | 1386-2588 | Aquatic Ecology                                             |
| 17986540 | 1798-6540 | Aquatic Invasions                                           |
| 19954255 | 1995-4255 | Contemporary Problems of Ecology                            |
| 0949944X | 0949-944X | Development, Genes and Evolution                            |
| 2833888  |           | Unknown                                                     |
| 1520541X | 1520-541X | Evolution & Development                                     |
| 19344392 | 1934-4392 | Human-Wildlife Conflicts                                    |
| 1399560X | 1399-560X | Insect Systematics & Evolution                              |
| 15525007 | 1552-5007 | Journal of Experimental Zoology Part A                      |
| 00222933 | 0022-2933 | Journal of Natural History                                  |
| 09475745 | 0947-5745 | Journal of Zoological Systematics and Evolutionary Research |
| 18601871 | 1860-1871 | Landscape and Ecological Engineering                        |
| 17451000 | 1745-1000 | Marine Biology Research                                     |
| 10926194 | 1092-6194 | Northeastern Naturalist                                     |

|          |           |                                                                   |
|----------|-----------|-------------------------------------------------------------------|
| 14396092 | 1439-6092 | Organisms Diversity & Evolution                                   |
| 00948373 | 0094-8373 | Paleobiology                                                      |
| 0913557X | 0913-557X | Plant Species Biology                                             |
| 07224060 | 0722-4060 | Polar Biology                                                     |
| 00973157 | 0097-3157 | Proceedings of the Academy of Natural Sciences<br>of Philadelphia |
| 0370047X | 0370-047X | Proceedings of the Linnean Society of New<br>South Wales          |
| 0716078X | 0716-078X | Revista Chilena de Historia Natural                               |
| 15287092 | 1528-7092 | Southeastern Naturalist                                           |
| 03076970 | 0307-6970 | Systematic Entomology                                             |
| 03003256 | 0300-3256 | Zoologica Scripta                                                 |

# Supplement S2: Hackathon Google Form

Participants will receive by email a set of **5 meta-analyses** to extract data from after contacting Shreya Dimri at [shreyadimriofficial@gmail.com](mailto:shreyadimriofficial@gmail.com). Please submit **one form entry per meta-analysis**.

If you finish your assigned set and are willing to contribute further, feel free to request an additional set by emailing Shreya.

This form is designed to guide data extraction during the hackathon, where participants will contribute to a meta-research project investigating potential issues in published meta-analyses in ecology and evolution.

These include several transparency indicators such as data- and code-sharing, and quality indicators such as the failure to properly adjust effect size directions across studies, as well as undisclosed inferential statistics conversions into effect sizes. Importantly, what we are trying to do here is to categorise meta-analyses that may have incurred in certain quality issues that we will further explore after the hackathon (e.g., using their data and code, if any provided). For example, meta-analyses that do not mention any sign adjustments will be further explored to understand if they actually forgot to or simply did not have to adjust effect sizes direction. Last, we also want to investigate the prevalence of Risk of Bias assessment in the field. We have provided more information, along with some examples, in this [Google Docs](#).

We do not send the **supplementary material associated with each published article but remember to check it out yourselves (by going to the DOI of the article)**. For example, information about the methods used (e.g., details of the effect size calculation and other conversions) could be provided in the Supplementary Material/Appendix.

All questions are mandatory, so if you come across a situation where the **section to describe does not apply to you, please type 'NA' (Not applicable)**. This is to ensure that every question is seen, assessed and thoughtfully answered by all participants.

## Section 1: Participant Information :

*This information will be used to reach out to you for follow-up if needed and to generate an extractor ID for the analysis later.*

i. Your name (e.g., Shreya Dimri). Please make sure to use the exact same name (copy-paste recommended) for each form submission.

- ii. Email (e.g., may be used for follow-up, if needed). Please make sure to use the exact same email (copy-paste recommended) for each form submission.
- iii. Would you like to be invited as co-author and further contribution should these data be used in an eventual manuscript?: Yes/No
- iv. Meta-analysis ID, which you can find in the list of meta-analyses you will receive by email.
- v. Meta-analysis Title (please copy and paste the title exactly as it appears in the published article)

## Section 2: Effect Size Direction and Handling

In meta-analyses, effect sizes from different studies must have **consistent directions (i.e. signs) to be meaningfully combined**. That is, the signs associated with each effect size (positive or negative) must reflect the real underlying relationship between the two variables being synthesized to avoid effect sizes cancelling each other out. When necessary, this often involves flipping effect size signs (e.g., multiplying by  $-1$ ), standardizing reference groups, or re-coding variables. Proper handling ensures that a “positive” or “negative” effect carries the same meaning across all studies. **We are interested in whether and how authors reported addressing this issue**—did they mention aligning directions, adjusting signs, or re-coding treatment and control groups or variables?

(For more information, including several examples from published meta-analyses, please see this [Google Docs](#).)

**Please remember**, the aim of this data extraction is to assess whether authors explicitly report how they dealt with the effect size direction. We do not imply that if they did not report the effect size direction handling they did not deal with it. We will further explore the data if they have provided it to make such an assessment.

There will be cases where the direction is not applicable to the effect size in consideration. For such a case please use **NA (Not applicable)** and describe your assessment of why it is not applicable.

1. Did the authors explicitly address whether effect size directions were adjusted to ensure consistency across the entire meta-analytic dataset?
  - Yes
  - No
  - I do not know
  - Not applicable/ NA (remember to describe the reasoning behind your choice)
  - Other (please describe this below)
2. If you chose Other as the option above, please describe it here; otherwise type NA.
3. Comments

## Section 3: Handling inferential statistics

In many meta-analyses, effect sizes (e.g., correlations) or summary statistics (means and variances) are not directly reported in the original studies. Instead, authors often extract inferential statistics—such as p-values, t-values, F-values, or  $\chi^2$ -values—and convert them into standardised effect sizes (e.g., Cohen's d, Hedges' g). We're interested in whether the meta-analysis you're reviewing used such conversions and, if so, whether the methods for doing so were clearly described.

(For more information, please see example in [Google Docs](#).)

1. Did the authors report extracting inferential statistics (e.g., p-values, t-values, F-values, or  $\chi^2$ -values) from primary studies to calculate effect sizes?
  - Yes
  - No
  - I do not know
  - Not applicable/ NA (this could apply for cases where effect size is an absolute value or an effect size such as correlation coefficient)
2. If yes, what types of inferential statistics were used to calculate effect sizes?
  - P-values
  - T-values
  - F-values
  - $X^2$ -values
  - $R^2$
  - U
  - Wald
  - Not applicable/ NA (if you did not choose Yes above, please use this option)
  - Others
3. If you chose Others above, please specify the inferential statistics used by the authors; otherwise type 'NA'.
4. Were the statistical transformations or formulas used to convert inferential statistics into effect sizes clearly reported in the main text or supplementary materials?
  - Yes, all formulas were provided
  - Yes, but only some formulas were provided
  - No, formulas were not provided, but the authors referenced the sources they used
  - No, formulas were not provided and the authors did not reference any sources
  - Not applicable/ NA (Use this for cases when you chose NA for inferential statistics type)
5. Please copy-paste the text from the article that you used to make the decision above; otherwise type 'NA'.
6. Comments

## Section 4: Data and code sharing

We are interested in whether the authors publicly shared the meta-analytic dataset (either processed or raw) and the analysis code—via a repository (e.g., Dryad, Zenodo, Figshare, GitHub), a website (e.g., personal or institutional), or the article's supplementary materials.

**Processed data** refers to the calculated effect sizes and their associated sampling variances. These are often labeled as  $y_i$  and  $v_i$ , respectively, or may appear as more specific terms such as  $\ln RR$  and  $V \ln RR$ ,  $Z_r$  and  $V Z_r$ , or  $d$  and  $V d$ , among others. Processed data would include **mainly the effect sizes, sampling variance associated with the effect size** and some other details.

**Raw data** refers to the summary or inferential statistics used to compute the effect sizes. For example:

- In a meta-analysis of Fisher's Z-transformed correlations, the authors should report the original correlations (e.g., Pearson, Spearman). If they also converted inferential statistics into correlations before applying the Fisher's Z transformation, those inferential statistics should also be reported.
- For a meta-analysis using standardized mean differences (e.g., Cohen's  $d$  or Hedges'  $g$ ), the underlying group means, standard deviations, and sample sizes for each group (e.g., treatment vs. control) should be reported.

**Remember**, we do not require you to go through the entire shared dataset but if you find some essential information missing please respond **No** to the questions below (e.g. if authors did not share the sampling variance but only the effect size answer No for processed data, if authors did not share the sample size or variance answer No for raw data)

1. Did the authors share the **processed data** used in the meta-analysis (e.g., effect sizes and their associated sampling variances, if applicable)? Note that often times but not always these may correspond to columns  $y_i$  and  $v_i$ . -
  - Yes
  - No
2. If you answered "Yes," where can the **processed data** be accessed? Please provide the link(s). If the data is available in the article's supplementary materials, include the article's link. If there is more than one link (e.g., GitHub and Dryad), please list all links separated by a semicolon ";" (e.g., [https://github.com/ASanchez-Tojar/meta-analysis\\_egg\\_hormones\\_and\\_fitness](https://github.com/ASanchez-Tojar/meta-analysis_egg_hormones_and_fitness); <http://doi.org/10.5281/zenodo.14930059>); otherwise type NA.
3. Did the authors share the **raw data** extracted from the primary studies (e.g., means, variances, sample sizes, inferential statistics values, etc.)?
  - Yes
  - No
4. If you answered "Yes," where can the **raw data** be accessed? Please provide the link(s). If the data is available in the article's supplementary materials, include the article's link. If there is more than one link (e.g., GitHub and Dryad), please list all links separated by a semicolon ";" (e.g., [https://github.com/ASanchez-Tojar/meta-analysis\\_egg\\_hormones\\_and\\_fitness](https://github.com/ASanchez-Tojar/meta-analysis_egg_hormones_and_fitness); <http://doi.org/10.5281/zenodo.14930059>); otherwise type NA.

*analysis\_egg\_hormones\_and\_fitness*; <http://doi.org/10.5281/zenodo.14930059>); otherwise type NA.

5. Did the authors share any **programming code** (e.g., R scripts)? You don't need to confirm if all code was provided—just whether at least some code was made available. If the authors used a click-based program and did not report a clear step-by-step guide on how to generate the estimates, you should answer "No".
  - Yes
  - No
6. If you answered "Yes," where can the **programming code** be accessed? Please provide the link(s). If the data is available in the article's supplementary materials, include the article's link. If there is more than one link (e.g., GitHub and Dryad), please list all links separated by a semicolon ";" (e.g., [https://github.com/ASanchez-Tojar/meta-analysis\\_egg\\_hormones\\_and\\_fitness](https://github.com/ASanchez-Tojar/meta-analysis_egg_hormones_and_fitness); <http://doi.org/10.5281/zenodo.14930059>); otherwise type 'NA'.
7. Comments

## Section 5: Risk of Bias Assessment

Risk of Bias (RoB) assessment (sometimes called Critical Appraisal, though the two are not identical) in systematic reviews and meta-analyses involves evaluating potential methodological biases (systematic errors) within individual studies—that is, their internal validity. This process helps us interpret research findings in the context of these biases. We are interested in how frequently meta-analysts in the field conduct Risk of Bias assessments and, if so, which specific tools or methods they use.

Please note that Risk of Bias refers to assessments made at the individual study level within a meta-analysis. **Publication bias, which concerns the entire set of studies, is not included here**, as our focus is on biases affecting individual studies.

1. Did the authors explicitly report performing a Risk of Bias (RoB) assessment on the individual primary studies included in the meta-analysis?
  - Yes
  - No
  - I do not know
2. If yes, which Risk of Bias (RoB) tool(s) did they use? You'll find a list of common options below, along with a link to a more comprehensive list [here](#). (Please note that PRISMA and other reporting guidelines are not Risk of Bias tools.)
  - CEESAT (Collaboration for Environmental Evidence Synthesis Assessment Tool)
  - COSMIN ROB

- COSMIN ROB for PROMS
- PROBAST
- QUADAS-2
- QUADAS-C
- QUAPAS
- RoB 2
- ROBINS-E
- ROBINS-I
- ROBIS
- ROBVALU
- Not applicable/ NA
- Others

3. If you selected Others above, please specify the tool here; otherwise type 'NA'.

4. Beyond using explicit Risk of Bias tools, did the meta-analysis **address/assess potential biases at the individual study level through other methods?**

For example, by categorizing effect sizes/studies and comparing them based on whether the original studies used or were affected by.

**Please keep in mind publication bias tests are not RoB assessment.**

Some examples of what **would not be included here** are..

- Authors imputed SD, SE
- Authors excluded studies that did not provide data
- Authors plotted a funnel plot to understand sampling bias

- Blinding Vs. Non-Blinding in data collection
- Selective Reporting Vs. Non-selective Reporting
- Missing Data Vs. Complete Data
- Other
- None

5. If you selected other, please provide information on the potential bias that the authors accounted for; otherwise type 'NA'.

Please note examples such as comparisons of effect sizes between studies with different data-collection protocols, selective reporting checks (but not publication bias test), or any analytical adjustment aimed at study-level bias.

6. Comments

**Google Document describing Effect Size Handling**

### **Effect Size Direction and Handling:**

*In meta-analyses, effect sizes from different studies must have consistent directions to be meaningfully combined. For example, if one study reports a treatment increases a trait (positive effect) while another reports it decreases the same trait (negative effect), these effects need to be made directionally comparable to avoid cancelling each other out. When necessary, this often involves flipping effect size signs (e.g., multiplying by  $-1$ ), standardizing reference groups, or re-coding variables. Proper handling ensures that a “positive” or “negative” effect carries the same meaning across all studies. We are interested in whether and how authors addressed this issue—did they mention aligning directions, adjusting signs, or re-coding treatment and control groups or variables? (For more information, please see the Hackathon Protocol.)*

Did the authors explicitly state or address whether effect size directions were adjusted to ensure consistency across the entire meta-analytic dataset?: Yes/No/I do not know/Other(please describe)

.....

Hackathon Google Form Updated:

ESMARConf2025 Hackathon:

### **Extent of Incomparable Effect Size Transformations and Directions in Ecology and Evolution**

We insist you begin data extraction by reading through this document to familiarise yourself with some of the concepts that will be required to answer the question. You can always come back to this document when you get stuck at a particular question that you wish to assess and see if the confusing scenarios you are facing are already described in the examples here.

#### **Effect Size Direction and Handling**

Here is an excerpt from Cooper et al. 2019: The Handbook of Research Synthesis and Meta-analysis, that should help better understand the importance of considering the direction of the effect sizes.

#### **11.2.3 Direction of the Effect**

*The discussion that follows applies to all the effect-size indices in this section—that is,  $D$ ,  $d$ , and  $g$ . The direction of the effect (for example, group 1 versus group 2 or group 2 versus group 1) is arbitrary, except that it must be consistent from one study to the next. That is, if a mean difference above 0 in study A indicates that group 1 did better,*

then a mean difference above 0 in studies B, C, [ . . . ] must also indicate that group 1 did better. Although the direction is arbitrary, several useful conventions make it easier to interpret the results. When we are comparing treated versus control, it is conventional to compute the difference as treatment minus control. For a pre- or post-design this would be post minus pre. When we follow this convention, the direction of the effect will be as follows: if the treatment increases the mean score, the mean difference will be positive; if the treatment decreases the mean score, the mean difference will be negative. As a general rule, it is a good idea to follow this convention because the results will follow the usual pattern. For example, if the treatment is intended to boost scores, we expect to see the mean difference to right of zero. Similarly, if the treatment is intended to lower scores, we expect to see the mean difference to the left of zero. Although the convention is therefore useful, it is arbitrary. If we chose to reverse the position of the two groups, the effect-size format would change but the substantive meaning would remain the same. Concretely, the three effects sizes would be modified as follows. If we switched the position of the two groups, the new raw mean difference would be  $D_{\text{New}} = -D_{\text{Old}}$  , (11.32) the standardized mean difference would be  $d_{\text{New}} = -d_{\text{Old}}$  , (11.33) and Hedges'  $g$  would be  $g_{\text{New}} = -g_{\text{Old}}$  . (11.34) That the decision to put one group or the other first is arbitrary, is especially important when we are comparing two active treatments, rather than a treatment and a control. If some studies compute A minus B and others compute B minus A, we need to ensure that all the results are in the same direction before we enter them into the meta-analysis. We could apply formulas (11.32) to (11.34) to the effect size and confidence interval as needed, to reverse the direction of the effect for any given study.

## **Example of effect size calculation reporting**

### **Example 1**

Original article: <https://doi.org/10.1111/ele.70100>

Based on what is reported in that article, here are the answers to the following questions:

- Did the authors explicitly address whether effect size directions were adjusted to ensure consistency across the entire meta-analytic dataset?
  - **Yes**
- Did the authors report extracting inferential statistics (e.g., p-values, t-values, F-values, or  $\chi^2$ -values) from primary studies to calculate effect sizes?
  - **Yes**
- Were the statistical transformations or formulas used to convert inferential statistics into effect sizes clearly reported in the main text or supplementary materials?
  - **Yes, all formulas were provided**
- Did the authors explicitly report performing a Risk of Bias (RoB) assessment on the individual primary studies included in the meta-analysis?
  - **No**
- Beyond using explicit Risk of Bias tools, did the meta-analysis address/assess potential biases at the individual study level through other methods?
  - **Other: e.g., comparing experimental vs observational studies, selective vs nonselective reporting, complete vs incomplete reporting**

## 2.6 Effect Size Calculation

*To quantify the relationship between egg hormones and fitness, we combined both Pearson's correlation coefficients  $r$  and biserial correlations  $r_{bis}$ —throughout we refer to simply  $r$  for simplicity. First, for correlation coefficients other than Pearson's  $r$  (e.g., Spearman's rho correlation coefficient), percentages, absolute values or inferential statistics (e.g., F-value, t-value, Chi-square value), we calculated Pearson's  $r$  using the equations from Nakagawa and Cuthill (2007) and Lajeunesse (2013; Supporting Information S7). For tests that lacked information on directionality, we determined it from the text, figures, or by directly asking the authors via email. We then calculated the variance in Pearson's  $r$  ( $V_r$ ) as  $V_r = (1 - r^2)^2 \div (N - 1)$  (Borenstein et al. 2009). Second, for experimental studies in which two groups were compared (control vs treatment), we transformed the means, SDs and sample sizes of the fitness proxies of interest of each group into biserial correlations coefficients and calculated their sampling variance following Jacobs and Viechtbauer (2017) with the function 'escalc' from the R package 'metafor' v.2.4-0 (Viechtbauer 2010).*

[...]

*In all cases, effect sizes were coded so that fitness proxies were positively correlated with overall fitness. Specifically, for 'egg mortality,' 'hatching failure,' and 'offspring*

mortality,' the sign of the effect sizes ( $k = 5$  effect sizes,  $N = 3$  studies) was inverted to ensure comparability across all fitness proxies.

[...]

We performed three phylogenetic multilevel meta-regressions to investigate the impact of methodological differences on the relationship between maternal egg hormones and both maternal and offspring fitness proxies. In the first model (MP.1), we included 'hormone type' (levels: androgens, glucocorticoids and thyroids), 'study type' (levels: correlational and experimental) and their interaction as moderators ( $k = 397$ ,  $N = 53$ ).

[...]

In addition, to test whether effect sizes are larger in studies that selectively or incompletely report statistically significant results, we conducted two meta-regression models. To test the effect of partial or selective reporting, we included 'partial or selective reporting' (levels: yes and no), 'hormone type,' and their interaction as moderators. To examine the effect of data reporting completeness, we initially planned to include 'data reporting completeness' (levels: complete and incomplete), 'hormone type,' and their interaction as moderators. However, due to insufficient data for glucocorticoids and thyroids, we could only test this for androgens ( $k = 333$ ,  $N = 46$ ), so our final model included 'data reporting completeness' as the only moderator. We also had pre-registered a meta-regression to test if blind data collection leads to smaller effect sizes as shown in previous studies (Freeberg et al. 2024; Holman et al. 2015; Keaney et al. 2024), but we could not perform this test because only 3 studies reported to have used a blind data collection protocol.

## Example 2

Original article: <https://doi.org/10.1093/evlett/qrae051>

Based on what is reported in that article, here are the answers to the following questions:

- Did the authors explicitly address whether effect size directions were adjusted to ensure consistency across the entire meta-analytic dataset?
  - **Not applicable/ NA**
- Did the authors report extracting inferential statistics (e.g., p-values, t-values, F-values, or  $\chi^2$ -values) from primary studies to calculate effect sizes?
  - **Not applicable/ NA**

- Were the statistical transformations or formulas used to convert inferential statistics into effect sizes clearly reported in the main text or supplementary materials?
  - **Not applicable/ NA**
- Did the authors explicitly report performing a Risk of Bias (RoB) assessment on the individual primary studies included in the meta-analysis?
  - **No**
- Beyond using explicit Risk of Bias tools, did the meta-analysis address/assess potential biases at the individual study level through other methods?
  - **None**

### **Effect Size Calculation**

*Our effect sizes of interest were: (i) the relative magnitude of DGEs (narrow-sense heritability or  $h^2$ ) and IGEs (social  $h^2$ ; aims 1, 3, and 4), (ii) unstandardized variances associated with DGEs (VA) and IGEs (VIGE), which we log-transformed prior to the analyses to better match model assumptions (aim 3), (iii) DGE and IGE evolvability (IDGE and IIGE; aim 3), (iv) DGE-IGE correlation ( $r_{DGE-IGE}$ ; aim 4), which when not reported, was calculated as  $COVA-IGE$  divided by the square root of the product of VA and VIGE, and (v) total heritable variance,  $\tau^2$  (i.e., the ratio of total heritable variation and phenotypic variance, aim 4), which was calculated as  $[VA + CovA-IGE*2*(n - 1) + VIGE*(n - 1)^2]/VP$ , where  $n$  is group size (Bijma, 2010; Bijma et al., 2007b). As in previous meta-analyses (e.g., Dochtermann et al., 2019; Holtmann et al., 2017), for most of our analyses, we treated intra-class correlations as equivalent to Pearson's correlation coefficients ( $r$ ) and applied Fisher's  $Z$  transformation to obtain our main effect size of interest (i.e.,  $Z_r$  and its associated sampling variance,  $VZ_r$ ).*

### **Example 3**

Original article: <https://doi.org/10.7554/eLife.37385>

Based on what is reported in that article, here are the answers to the following questions:

- Did the authors explicitly address whether effect size directions were adjusted to ensure consistency across the entire meta-analytic dataset?
  - **No**
- Did the authors report extracting inferential statistics (e.g., p-values, t-values, F-values, or  $\chi^2$ -values) from primary studies to calculate effect sizes?
  - **Yes**
- Were the statistical transformations or formulas used to convert inferential statistics into effect sizes clearly reported in the main text or supplementary materials?
  - **No, formulas were not provided, but the authors referenced the sources they used**
- Did the authors explicitly report performing a Risk of Bias (RoB) assessment on the individual primary studies included in the meta-analysis?
  - **No**
- Beyond using explicit Risk of Bias tools, did the meta-analysis address/assess potential biases at the individual study level through other methods?
  - **Other: e.g., testing the effect of sampling effort**

### **Summary data extraction**

*Some studies had more than one effect size estimate per group of birds studied. When the presence of multiple estimates was due to the use of different statistical analyses on the same data, we chose a single estimate based on the following order of preference: (1) direct reports of effect size per group of birds studied (e.g., correlation coefficient), (2) inferential statistics (e.g., t, F and  $\chi^2$  statistics) from analyses where group ID was accounted for and no other fixed effects were included, (3) direct reports of effect size where individuals from different groups were pooled together, (4) inferential statistics from models including other fixed effects.*

[...]

### **Effect size coding**

*Regardless of their source (primary or summary data), we transformed all estimates (e.g., p, F statistics, etc) into Pearson's correlation coefficients (r), and then into standardized effect sizes using Fisher's transformation (Zr) for among-study comparison. We used the equations from Nakagawa et al., 2007 and Lajeunesse, 2013.*

[...]

*For the subset of studies for which the primary data of the agonistic dyadic interactions were available (12 out of 19 studies; Table 1), we ran a multilevel meta-regression including sampling effort and its squared term as z-transformed moderators (Schielzeth, 2010). The squared term was included because of the observed*

*logarithmic relationship between sampling effort and the method's performance (Sánchez-Tójar et al., 2018b). This meta-regression tested whether sampling effort had an effect on the meta-analytic mean: (i) a positive estimate would indicate that the meta-analytic mean may have been affected by the inclusion of studies with unreliable estimates of dominance rank. In contrast, (ii) a negative estimate would indicate that effect sizes were larger when based on unreliable estimates of dominance rank and hence provide evidence for the existence of publication bias.*

# Supplement S3: FAIR Checklist

The purpose of FAIR principles is to make data not just reusable for human scientists but also machine findable and usable. Please see [Wilkinson et. al 2016](#) (and/or <https://www.go-fair.org/fair-principles/>) for more information about the FAIR principles.

In this assessment, **we will not evaluate all the FAIR principles** because we will focus on “simply” assessing **the quality of the datasets that were already shared** - the FAIR principles generally apply more broadly. That is, here we want to assess how well the data and their accompanying information support understanding and reuse, and we want to do that by using some of the FAIR principles.

## Glossary Terms

We would like to clarify what we imply by each term to allow for more objective evaluations of the criteria.

1. **Data:** To evaluate these criteria, we will consider both raw (i.e., values extracted from individual articles for calculating the effect size(s) of interest, or in some cases, used directly as effect sizes in the meta-analytic models) and processed data (i.e., already-calculated effect sizes and associated sampling variances) as data.
2. **Metadata:** For our purposes, metadata refers to information for a user to understand the content of the repository (or folder/zip) where the data (and other materials) were shared, specifically:
  - Title of the dataset(s)
  - Authors/creators
  - Contact information
  - Abstract or description
  - Keywords,
  - Date of creation/publication
  - Language
  - Licensing
  - Funding sources
  - Access restrictions, etc.
3. **Data Dictionary/Code Book:** A data dictionary or code book explains what each variable means in more or less detail, including a clear description of

variables, units, and coding (e.g., sex: male, female). Strictly speaking, a data dictionary is a type of metadata, because it provides “data about the data.” However, for the purpose of our assessment, it is useful to consider it as a **separate, more detailed layer of documentation**. We will evaluate metadata and data dictionaries separately in two different questions.

| Box 2   The FAIR Guiding Principles                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>To be Findable:</b></p> <p>F1. (meta)data are assigned a globally unique and persistent identifier<br/>F2. data are described with rich metadata (defined by R1 below)<br/>F3. metadata clearly and explicitly include the identifier of the data it describes<br/>F4. (meta)data are registered or indexed in a searchable resource</p> <p><b>To be Accessible:</b></p> <p>A1. (meta)data are retrievable by their identifier using a standardized communications protocol<br/>A1.1 the protocol is open, free, and universally implementable<br/>A1.2 the protocol allows for an authentication and authorization procedure, where necessary<br/>A2. metadata are accessible, even when the data are no longer available</p> <p><b>To be Interoperable:</b></p> <p>I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation.<br/>I2. (meta)data use vocabularies that follow FAIR principles<br/>I3. (meta)data include qualified references to other (meta)data</p> <p><b>To be Reusable:</b></p> <p>R1. (meta)data are richly described with a plurality of accurate and relevant attributes<br/>R1.1. (meta)data are released with a clear and accessible data usage license<br/>R1.2. (meta)data are associated with detailed provenance<br/>R1.3. (meta)data meet domain-relevant community standards</p> |

## Our adjusted FAIR principle checklist

Once the list is finalised, we will create a corresponding Google Form that all participants will use to assess the FAIRness of the shared datasets (one entry per study).

### 1. Findable

“To be **Findable**, any Data Object should be uniquely and persistently identifiable”

- Dataset (s) has a **globally unique and persistent identifier** (e.g., DOI, Handle, ARK, Accession Number [e.g., *omics* data], etc) that is separate from the persistent identifier (DOI) of the published article.

*What is a persistent identifier? A **persistent identifier** is a **permanent, globally unique, and stable digital label** that always points to the same data object — even if its location changes.*

*Usually, in our field, DOI is the most common persistent identifier. Remember, GitHub repository links are not persistent identifiers, and, although OSF projects provide a DOI, the DOI refers to the live, editable project rather than a fixed, time-stamped version, so it is not ideal for formally sharing or citing*

*data, and thus, we will treat OSF sharing as NOT complying with having a persistent identifier.*

- Rich metadata accompanies the dataset(s), usually added to a recognised repository along with the data (e.g., Zenodo, Dryad, Figshare, institutional repository).

*What constitutes rich metadata? **Rich metadata** provides clear, detailed information about a dataset's content, context, and structure.*

*Assessing the completeness of the metadata is beyond our purposes, and thus, here, we only want to know if some metadata is available and clearly identifiable (i.e., if the data is not in a repository that requires metadata by default (see examples below), is there a "README", "metadata", etc. file providing some of the fields outlined above?).*

*In repositories like Dryad and Zenodo, basic metadata is required upon submission (usually including title, abstract, and authors' name, how and when the data was collected and a brief description of the dataset); thus, metadata would be required by default. Sometimes, metadata may appear (as a standalone or in addition to the repository's required metadata) as a README file within the shared folder.*

- Data is registered/indexed/shared in a **searchable resource**.

*What is a searchable resource? Repositories like Dryad, Zenodo, Figshare, OSF, etc. can be searched using the repositories' search engine/search query. However, Supplementary Materials of an article, Private Links (e.g., personal websites), etc. are not searchable or permanent resources.*

*Where is the data shared:*

- DataVerse
- Dryad
- Figshare
- GBIF
- NCBI GenBank
- Zenodo
- PANGEA
- OSF
- Institutional repository
- GitHub or GitLab
- Personal website
- Supplementary materials
- Other (please specify)

## 2. Accessible

“Data is **Accessible** in that it can always be obtained by machines and humans”

- The dataset(s) can be **downloaded**.

*For example, if a DOI is provided (e.g., 10.5281/zenodo.14930059), you should be able to access and download the data by visiting the corresponding link (<https://doi.org/10.5281/zenodo.14930059>).*

## 3. Interoperable

For data to be considered interoperable:

- Data should be provided in standard, **non-proprietary formats** (e.g., .csv, .tsv, .txt, .json, .jsonld, .parquet, .arrow, .xml; **NOT**: .xls, .xlsx, .numbers, .sps, .pdf, .doc, .docx, .RData).

*PDF, screenshots, etc. are not machine-readable formats, and .xlsx, .xls, .numbers etc. are not non-proprietary formats. Although .RData can be used with open source software (i.e., R), this data format restricts its use, as it requires knowledge of R to extract the data, and may be dependent on the version of R that was used to save it.*

Please choose the data format used:

- .csv/tsv
- .doc(x)
- .txt
- .xls(x)
- .numbers
- .RData
- .Rds
- .pdf
- .sql(ite)
- .sps
- .nex
- .odt
- .ods
- Other (please specify)

## 4. Reusable

- Dataset includes a clear and accessible **license** (e.g., CC-BY, CC0).

*Absence of a license does not allow users to legally use the data. “Available upon request”, “Contact the authors” or “Rights reserved by publishers” would also imply that the data is not accessible and lacks an open use license.*

Please choose which license was used:

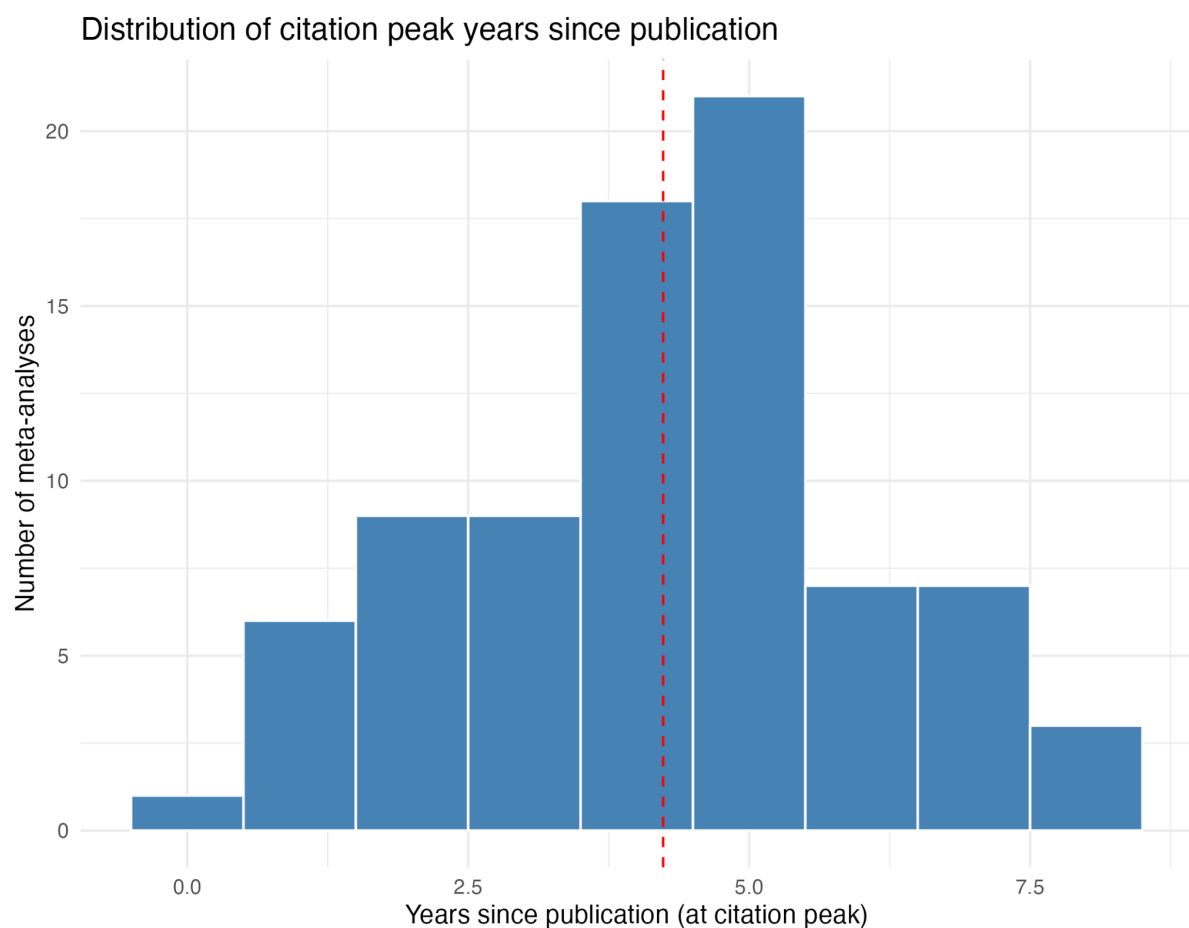
- CC0 (Public Domain Dedication)
  - CC BY (Attribution)
  - CC BY-SA (Attribution, ShareAlike)
  - Open Data Commons PDDL
  - Open Data Commons ODC-BY (Attribution)
  - Open Government License (OGL)
  - CC BY-NC (Attribution, NonCommercial)
  - CC BY-NC-SA (Attribution, NonCommercial, ShareAlike)
  - CC BY-ND (Attribution, NoDerivatives)
  - CC BY-NC-ND (Attribution, NonCommercial, NoDerivatives)
  - GNU GPL/MIT/Apache 2.0 (*ideally used for code rather than data*)
  - Publisher copyright/Rights reserved
  - Available upon request/Contact the authors
  - No license present
  - Other (*please specify*)
- A **data dictionary or code book** is provided to explain what each variable means in more or less detail, including a clear description of variables, units, and coding (e.g., sex: male, female).

*Note that here we are not referring to metadata (see above), even though sometimes variable descriptions are provided as part of the README.*

# Supplement S4: Additional citation and journal-policy information

## Citation Information

The 2018 five-year impact factor, which we extracted from Web of Science for these 35 journals, ranged from 0.7 to 14.8 (median = 4.3). The total citation counts across all years (i.e., from 2016 to 2025) ranged from 1 to 793 (median = 96), whereas those for the first six years after publication of each meta-analysis ranged from 1 to 435 (median = 68).



**Figure S1. Distribution of the observed annual citation peak year among 81 meta-analyses.** For each meta-analysis, annual Google Scholar citation counts were relative to the formal year of publication. Bars show the number of meta-analyses with an observed maximum in each year since publication, and the dashed vertical line indicates the mean observed peak year. Because articles published later in the 2016–2020 sampling period had shorter citation follow-up through 2025, the distribution may be affected by right truncation and does not reflect the distribution of lifetime citation peaks.

# Journal Policy Information

To explore whether journal requirements were associated with data-sharing, we determined the data-sharing policy in place at each journal when each article was published. We used the classification developed by Berberi and Roche (2022), which categorised journal policies as “none,” “weak,” or “strong.” We accessed their dataset on 3 October 2025. For 9 of the 35 journals in our sample, no policy implementation date was recorded in the dataset. We contacted these journals using a standardised email template (see below), sent up to 3 reminders when necessary, and obtained implementation dates for 6 of the 9 journals that were missing this information. For the remaining three journals, the implementation year was coded as “NA,” and articles from these journals were excluded from the analyses.

## ***Is data sharing associated with journal policy requirements?***

Most meta-analyses (61.3%, 95% CI = 50.0–71.5%) were published in journals with a data-sharing policy in place at the time of publication (strong = 39, weak = 7, none = 29, NA = 6).

## **Email template for contacting the journals:**

Dear Editorial Office and Production Team of XXX,

I hope this message finds you well.

I am writing on behalf of our research team conducting a study on data-sharing practices across ecology and evolution journals. Your journal has been identified as having an excellent record in terms of promoting data-sharing, and we sincerely appreciate the efforts you have made to support open research.

As part of our analysis, we are interested in understanding when your journal implemented its data-sharing policy. Could you kindly let us know the year in which the policy came into effect? This information is crucial for accurately interpreting trends in data-sharing behavior over time in our study.

We greatly appreciate your time and assistance and would be happy to acknowledge your journal in our study if appropriate.

Thank you very much for your help.

Warm regards,  
Dr. Alfredo Sánchez-Tójar