Synthesis of sexual selection: a systematic map of meta-analyses with bibliometric analysis

Pietro Pollo[1*], Malgorzata Lagisz[1], Yefeng Yang[1], Antica Culina[2], Shinichi Nakagawa[1]

[1]Evolution & Ecology Research Centre, School of Biological, Earth & Environmental Sciences, University of New South Wales, Kensington, Sydney 2052 NSW, Australia
[2]Ruder Boskovic Institute, Zagreb, Croatia
[*]Corresponding author: pietro_pollo@hotmail.com

ABSTRACT

Sexual selection has been a popular subject within evolutionary biology because of its central role in explaining odd and counterintuitive traits found in nature. Consequently, the literature associated with this field of study became vast, with meta-analytical studies attempting to draw inferences from it. These meta-analyses have now accumulated, varying in scope and quality, thus calling for a synthesis of these syntheses. Here, we created a systematic map with a report appraisal of meta-analyses on topics associated with sexual selection, aiming to comprehend the conceptual and methodological gaps in this secondary literature. To further understand these gaps and their potential origins, we also conducted bibliometric analyses that identify the gender and origin of researchers that generated these studies. We included 152 meta-analytical studies in our systematic map as a result of a systematic literature search. We found that most meta-analyses focused on males and on certain animal groups (e.g. birds), indicating severe sex and taxonomic biases. The topics in these studies greatly varied, from proximate (e.g. relationship of ornaments with other traits) to ultimate questions (e.g. formal estimates of sexual selection strength), albeit the former were more common. We also observed several common issues in these studies, such as lack of detailed information regarding searches, screening, and analyses, which ultimately impairs the reliability of many of these meta-analyses. In addition, most of the meta-analyses' authors were men affiliated to institutions from developed countries, pointing to both gender and geographical authorship biases. Many of our findings might simply reflect patterns in the current state of the primary literature and academia, suggesting that our study can serve as an indicator of the issues within the field of sexual selection at large. Still, we provide both conceptual and analytical recommendations to improve future studies in the field of sexual selection, such as to avoid including humans with other animals in meta-analyses, to clarify traits of interest instead of simply using loosely defined lingo, and to properly match studies' questions and meta-analytical models.

Keywords: sexual signals, weapons, mate choice, intrasexual competition, sperm competition, polyandry, extra-pair fertilisations, mating success, taxonomic chauvinism, gender bias.

CONTENTS

I. INTRODUCTION

(1) Background

Colourful and exaggerated body parts have intrigued many long before the foundation of evolutionary biology. The concept of sexual selection emerged to explain the existence of these odd traits, whose evolution by natural selection seemed improbable as some of them appeared only to hinder the survival of their bearers (Hosken & House, 2011; Ruse, 2015). Darwin (1859, 1871) initially postulated sexual selection as the struggle of males for access to females, but later referred to it as the reproductive advantage that some individuals have over same sex conspecifics. Since then, the definition of sexual selection has been repeatedly debated and reformulated, mostly to include relevant post-copulatory processes and to clarify in which scenarios sexual selection indeed occurs (reviewed in Gowaty, 2015; Alonzo & Servedio, 2019; e.g. Andersson, 1994; Clutton-Brock, 2007; Shuker & Kvarnemo, 2021a). Despite the everlasting discussions on what sexual selection encapsulates, a vast field of study has grown within evolutionary biology centred on topics intimately around this concept. From extravagant traits and mechanisms selecting them to formal estimates of sexual selection, the literature related to sexual selection became diverse and deeply interconnected. Summarising our understanding of the entire field thus represents a challenging endeavour, albeit theoretically a possible one.

To be able to generalise results and advance science, one can combine knowledge from different individual investigations (Jennions *et al.*, 2012). Systematic reviews and meta-analysis are considered the gold standard for such comprehensive evidence synthesis (Koricheva, Gurevitch & Mengersen, 2013; Borenstein *et al.*, 2021). This is because systematic reviews aim to detect all the studies conducted on a certain topic, while meta-analyses additionally provide quantitative measures related to the average and dispersion of studies' outcomes by standardising (effect sizes) and weighting them by their precision coupled with solid statistical techniques (Jennions *et al.*, 2012; Gurevitch *et al.*, 2018; Borenstein *et al.*, 2021). It is unsurprising then that several meta-analyses have been conducted to test long standing hypotheses of topics relevant to sexual selection. Jennions *et al.* (2012) reviewed some of these meta-analyses, summarised their content, and identified opportunities for future synthesis studies. Yet, many other meta-analyses in this field have accumulated during the more than a decade since Jennions *et al.* (2012), suggesting that a new audit of the knowledge provided by these studies is warranted. This can be achieved with a systematic map, which is a tool that synthesises research on a broad topic in a user-friendly format (Miake-Lye *et al.*, 2016; O'Leary *et al.*, 2017; Sutherland & Worldley, 2018).

Meta-analyses should follow reporting guidelines to ensure transparency and reproducibility (e.g. PRISMA; Page *et al.*, 2021; O'Dea *et al.*, 2021). However, they often neglect some or all of these directives, especially older meta-analyses (when such guidelines had not been established yet). Therefore, it is crucial to not only understand the content of meta-analyses related to sexual selection relevant topics, but to assess their reporting quality to ensure reliability. This type of appraisal was not present in Jennions *et al.* (2012), leaving an important gap in our comprehension of the field related to sexual selection. Such appraisal will also be useful to determine which meta-analyses might require re-evaluation and updating. Moreover, we can use information on reporting quality in published sexual selection meta-analyses to provide an evidence-based set of recommendations to improve future meta-analytical studies in this and other fields.

Bibliometrics represents another set of tools that can improve our understanding of a field and its patterns. That is because bibliometrics provide quantitative information on authors and collaborative networks. Such information could be used to improve gender and geographical representation of research topics, addressing issues around equity, diversity, and inclusiveness (Davies *et al.*, 2021). Traditionally, systematic reviews (and maps) concentrated on the existing research content, avoiding discussions on who conducted it (Nakagawa *et al.*, 2019). Yet, given historic conceptual 'male-centeredness' in the topic of sexual selection (Ah-King, 2022), it may be of particular importance to examine the diversity and inclusiveness of authors of meta-analyses related to sexual selection. To our knowledge, this has never been done for sexual selection research, uncovering an exciting opportunity for this field.

(2) Objectives

Here, we aimed to provide insights and identify gaps in the sexual selection literature by conducting a systematic map of existing meta-analyses on topics related to this field. We used a novel method called "research weaving", which combines a systematic map with bibliometric analysis (Nakagawa *et al.*, 2019). In addition, we conducted a report appraisal of the included meta-analyses. We aimed to answer the following questions related to sexual selection and associated topics, based on the collated dataset:

1. What is the scope of existing meta-analyses?
    1. Where are the gaps in the evidence syntheses, requiring more attention or updates? See section III.2
    2. Which specific questions have been addressed? See section III.5.
    3. What are the challenges in this field and how to address them? See section III.6.
2. How transparent and robust are existing meta-analyses? See section III.3.
3. Who and from where are researchers that conducted existing meta-analyses? See section III.4.

II. METHODS

Our methodology was described in our pre-registration (Pollo *et al.*, 2023), and we adhered to it as much as possible. However, we adjusted several elements to improve the manuscript. These adjustments are mentioned throughout the manuscript when applicable. We broadly followed the guidelines of ROSES for reporting of systematic maps (Table S1; Haddaway *et al.*, 2018).

(1) Literature searches

We conducted literature searches using six different sources, all on March 15th, 2023. First, we conducted a main database search using Scopus and Web of Science (Core Collection), both accessed through the University of New South Wales, Sydney. For this, we created strings with keywords aimed to capture meta-analytical studies on non-human animals that cover one or more topics relevant to sexual selection (see Supplementary material and section II.2). Second, we retrieved the backward and forward citations from Jennions *et al.* (2012) (i.e. list of citations and papers that cited it, respectively). Third, to find relevant grey literature, we used a simplified keyword string (“meta-analysis” AND “sexual selection”) in Bielefeld Academic Search Engine (BASE), filtering only theses (doctype:18*). Fourth, we conducted several searches in Google Scholar using translations of the string used in BASE in Simplified and Traditional Chinese, Croatian, Japanese, Polish, Portuguese, Russian, and Spanish (see Supplementary material for details). However, we only screened the ten first results from each of these Google Scholar searches, sorted by relevance. We planned to screen 10 more if at least half of the previous 10 contained relevant articles, but that was not the case for any language. Additionally, we manually included four studies that were not captured by our searches (Janicke *et al.*, 2018; Aguiar Del Matto, 2018; Gómez-Llano *et al.*, 2023; Dougherty, 2023). A pilot conducted for our pre-registration (see Pollo *et al.* 2023) found that these searches retrieved relevant benchmark articles, ensuring that our searches were comprehensive.

(2) Screening process and inclusion criteria

Our screening criteria were summarised in Table 1 (but see details in the Supplementary material), while our screening process is shown in Figure 1 (slightly different from the one in our pre-registration but conceptually identical; see Pollo *et al.* 2023). We used Rayyan QCRI (Ouzzani *et al.*, 2016) for both of our initial and full-text screenings. ML and PP independently conducted the initial screening, i.e. assessed the title, abstract, and key-words of retrieved papers. The full-text content of studies that passed this initial screening were then independently assessed by PP and either AC, ML, SN, or YY (in roughly 29%, 14%, 28%, and 29% of the cases, respectively). In both initial and full-text screening, authors solved conflicts through discussion until consensus was reached.

Table 1. Scope of our systematic map of meta-analyses on topics related to sexual selection, according to the PECOS framework.

Population	Non-human animals (occasionally other organisms as well if they are included in meta-analyses with non-human animals)
Exposure	Factors that potentially affect mechanisms and patterns related to sexual selection.
Comparator	Not applicable.
Outcomes	Related to patterns and consequences on core topics of sexual selection, such as sexual traits and signals, mate choice, intrasexual competition, pairing and mating decisions, sexual selection estimates, and interlocus sexual conflict.
Study-design	Meta-analyses (*sensu* O'Dea *et al.* 2021: statistical synthesis of effect sizes from multiple independent studies).

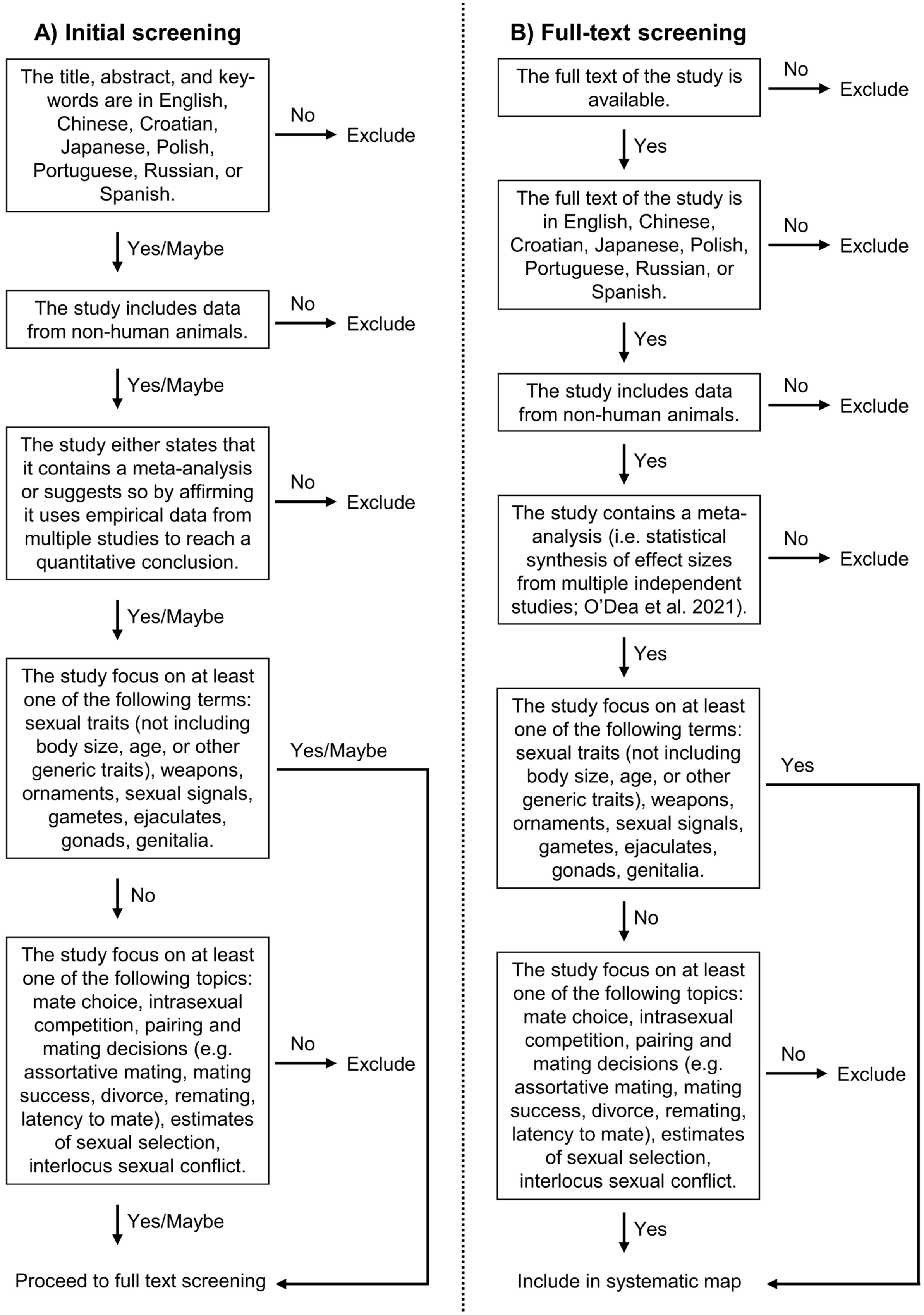
A) Initial screening
The title, abstract, and keywords are in English, Chinese, Croatian, Japanese, Polish, Portuguese, Russian, or Spanish.
No
Exclude
Yes/Maybe
The study includes data from non-human animals.
No
Exclude
Yes/Maybe
The study either states that it contains a meta-analysis or suggests so by affirming it uses empirical data from multiple studies to reach a quantitative conclusion.
No
Exclude
Yes/Maybe
The study focus on at least one of the following terms: sexual traits (not including body size, age, or other generic traits), weapons, ornaments, sexual signals, gametes, ejaculates, gonads, genitalia.
Yes/Maybe
No
The study focus on at least one of the following topics: mate choice, intrasexual competition, pairing and mating decisions (e.g. assortative mating, mating success, divorce, remating, latency to mate), estimates of sexual selection, interlocus sexual conflict.
No
Exclude
Yes/Maybe
Proceed to full text screening
B) Full-text screening
The full text of the study is available.
No
Exclude
Yes
The full text of the study is in English, Chinese, Croatian, Japanese, Polish, Portuguese, Russian, or Spanish.
No
Exclude
Yes
The study includes data from non-human animals.
No
Exclude
Yes
The study contains a meta-analysis (i.e. statistical synthesis of effect sizes from multiple independent studies; O'Dea et al. 2021).
No
Exclude
Yes
The study focus on at least one of the following terms: sexual traits (not including body size, age, or other generic traits), weapons, ornaments, sexual signals, gametes, ejaculates, gonads, genitalia.
Yes
No
The study focus on at least one of the following topics: mate choice, intrasexual competition, pairing and mating decisions (e.g. assortative mating, mating success, divorce, remating, latency to mate), estimates of sexual selection, interlocus sexual conflict.
No
Exclude
Yes
Include in systematic map

Figure 1. Decision tree used for literature screening. The initial screening (A) was based on the examination of the title, abstract, and keywords of retrieved studies, while the full text screening (B) was based on the full content of studies that had passed the initial screening.

(3) Data extraction

PP extracted all data from meta-analyses in our systematic map. Afterwards, YY cross-checked circa 20% of the extracted data to ensure replicability. Details on the extracted variables are given below.

(a) Systematic map

We extracted data from papers included in our study in respect to the scope of their research questions, as well as specific aspects of the data they used in respect to taxa, focus sex, and methodological approach. To do this, we used a Google Form questionnaire for each paper (Table S3). We modified the way we summarised questions from each study from our initial plan to best fit our classification system presented on our systematic map (see sections III.2.e and III.5). Several aspects made the task of describing and classifying questions from meta-analytical studies complex and subjective (see also section III.6.c). For instance, not all questions from included papers were relevant to our systematic map (e.g. Goldberg *et al.*, 2020) contained questions related to paternal care). Similarly, not all variables used within certain questions were relevant (e.g. Leung & Forbes, 1996) mixed mating success with other fitness measures). Therefore, we selected and described the studies' questions relevant to our systematic map without necessarily relying on the exact words used by their original authors (see further details in Supplementary material). We aimed to extract only questions that we considered central to each meta-analytical study. Because of this, we modified or excluded some variables initially extracted (e.g. how main questions were answered; see also section

III.6.c). Furthermore, we described studies' questions without mentioning the taxa or sex investigated when possible, as we discuss these issues separately (sections III.2.a and III.2.f). Moreover, we intentionally discussed meta-analyses' questions without mentioning their results because one of our goals was to show that many of their findings can be problematic due to conceptual and methodological reasons (sections III.3 and III.6).

One particular information that we collected from meta-analyses included in our systematic map was the sex of individuals that were used to extract effect sizes (discussed in section III.2.f). However, our analysis related to this information was made at the level of the questions extracted from meta-analyses (as in section II.2.e) rather than studies. We ultimately classified these meta-analytical questions based on the stereotypes proposed by the idea of sex roles (following Pollo & Kasumovic, 2022). For instance, meta-analytical questions that focused exclusively on males and their traits were deemed "conforming" to the idea of sex roles that poses males as competitive and as the usual sex under sexual selection (Ah-King & Ahnesjö, 2013). Conversely, meta-analytical questions that focused exclusively on females and their traits were classified as "nonconforming" to the idea of sex roles, which poses females as coy (Ah-King & Ahnesjö, 2013). The only exception for this classification was for meta-analytical questions that fitted into the mate choice category (see section III.5.d), in which exclusive focus on females was considered conformist, and exclusive focus on males was nonconformist, as the idea of sex roles proposes that females are choosy while males are unselective (Ah-King & Ahnesjö, 2013). Furthermore, meta-analytical questions that focus on both males and females were classified as "neutral".

(b) Reporting appraisal

We used PRISMA-EcoEvo (O'Dea *et al.*, 2021) to evaluate reporting and methodological aspects of meta-analyses included in our systematic map. Although PRISMA-EcoEvo only provides guidelines and is not an appraisal tool, other appraisal tools (e.g. Woodcock, Pullin & Kaiser, 2014: CEESAT; Shea *et al.*, 2017: AMSTAR 2) do not include items we aimed to quantify. Therefore, we used the PRISMA-EcoEvo checklist for reporting appraisal, choosing a subset of the items that are often deemed key aspects for transparency and robustness of meta-analyses, such as registering planned research (Allen & Mehler, 2019), detailing the search and screening of studies (McGowan *et al.*, 2016; Palpacuer *et al.*, 2019), handling statistical non-independence (Noble *et al.*, 2017), and sharing data (Piccolo & Frampton, 2016), among others (see section III.3). We mainly surveyed whether these elements were described or provided, but for specific aspects we also collected detailed information if possible (e.g. which software was used for statistical inferences). Moreover, although our systematic map included meta-analyses in a broad sense (see section II.2), some may be more restrictive on meta-analyses' definition (Nakagawa *et al.*, 2023a). Thus, we also verified whether studies included in our systematic map were traditional meta-analyses, i.e. used traditional effect sizes and properly modelled heterogeneity using additive weighting (Nakagawa *et al.*, 2023a). We primarily assessed this information based on statistical methods described in studies, including model equations and software used.

(c) Bibliometrics

We extracted author affiliations and names from meta-analyses on topics associated with sexual selection. We retrieved this information from Scopus using the packages *bibliometrix* (Aria & Cuccurullo, 2017) and *rscopus* (Muschelli, 2019) in R (R Core Team, 2022), on August 7th and 14th 2023, respectively. We manually extracted this information for studies that were not yet indexed in Scopus (e.g. theses and recent papers, n = 9). We then determined authors' gender from their first name using the package *genderizeR* (Wais, 2016). Although this approach has its faults (e.g. erroneous label assignment, especially for people that do not identify with binary genders), it includes an estimation of the certainty that a name is associated with a given gender based on real data. Thus, to minimise errors, we only used this automatic labelling when the gender assignment certainty was higher than 95%. For names with ambiguous gender association (i.e. lower certainty), we manually searched the authors' name online to assign gender based on information we could find (e.g. profiles on universities' websites).

III. RESULTS AND DISCUSSION

(1) Number of eligible meta-analytic studies

Our screening process is summarised in Figure 2. Searches from all sources retrieved a total of 1,215 records, although 397 of them were duplicates. We thus assessed the title, abstract, and keywords of the remaining 818 articles, from which 187 met our initial selection criteria (i.e. were initially included). After examining the full-text of these initially included articles, we found that nine of them were duplicates (e.g. theses with published versions already in the dataset), 20 did not meet our broad definition of meta-analysis, seven did not contain a relevant topic to our systematic map, and one was not a formal report (conference extended summary). Therefore, the screening process resulted in the inclusion of 150 records to the systematic map. One of the records (Macedo-Rego, 2020) was a thesis with three relevant chapters (Macedo-Rego, Jennions & Santos, 2020a, 2020b, 2020c), so we counted each of these chapters as distinct studies, tallying 152 studies overall (Figure 3; see also Supplementary material for details on special cases). The first meta-analyses on a topic related to sexual selection was published in the mid-90s, while the increase in their prevalence happened around 2011 (Figure 3).

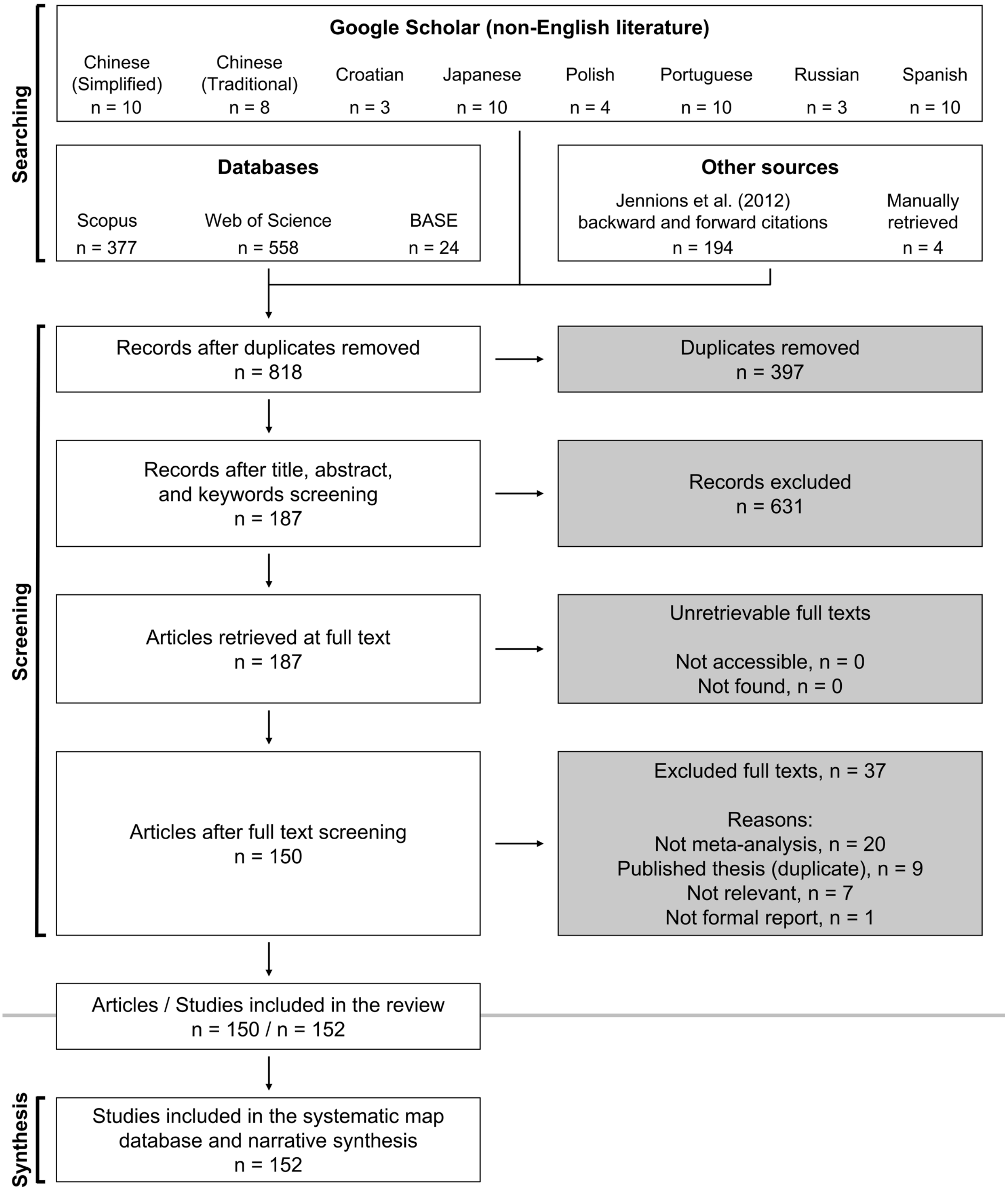

Figure 2. ROSES flow chart of the screening process.

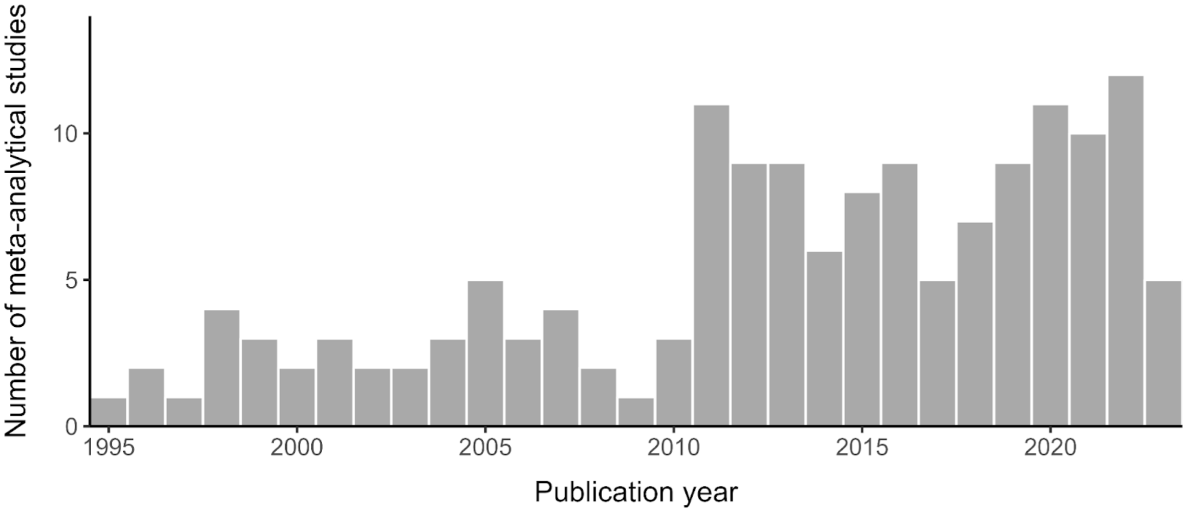

Figure 3. Number of meta-analytical studies on topics related to sexual selection published per year. Our searches were conducted in early 2023 (see section II.1), thus they do not capture publications from the whole year 2023.

(2) Systematic mapping of meta-analyses on topics related to sexual selection

(a) Taxonomic groups

We verified which animal groups (at the taxonomic class level) were synthesised by the meta-analyses included in our systematic map (Figure 4). We found that more than half of all of these meta-analyses (83 out of 152; 54.6%) limited their scope to a single species (n = 14) or to a specific taxonomic group (n = 69), while the remaining ones (n = 69; 45.4% of the total) did not apply taxonomic filters (i.e. all animal species could be included). We then identified the animal groups investigated by these meta-analyses, although we could not obtain relevant details from nine of them (all taxonomically unrestricted meta-analytical studies). Birds were by far the most popular animal group observed in our systematic map: 12 out of 14 (85.7%) single species meta-analyses focused on a bird species, 34 out of 69 (49.3%) specific taxonomic group meta-analyses focused exclusively on birds, and 30 out of 60 (50%) taxonomically unrestricted meta-analyses for which we obtained taxonomic details showed birds as the first or second most copious group in number of species included in these studies (Figure 4). Insects followed behind, as 2 out of 14 (14.3%) single species meta-analyses focused on an insect species, 13 out of 69 (18.8%) specific taxonomic group meta-analyses focused exclusively on insects, and 47 out of 60 (78.3%) taxonomically unrestricted meta-analyses for which we obtained taxonomic details showed insects as the first or second most copious group in number of species included in these studies (Figure 4). However, note that the actual proportion of species that first or second most popular animal groups represent in taxonomically unrestricted meta-analyses tends to decrease with the total number of species used by a meta-analysis (Figure 5). For instance, Soper, Ekroth & Martins (2021) extracted data from nine species in their study, eight of them being insects and one being a mammal, meaning that the two most abundant animal groups in the study represented all its taxonomic diversity. In contrast, Rios Moura *et al.* (2021) included 341 species, 21.1% birds and 20.8% insects, so that these two groups comprised only less than half of the species represented in the study.

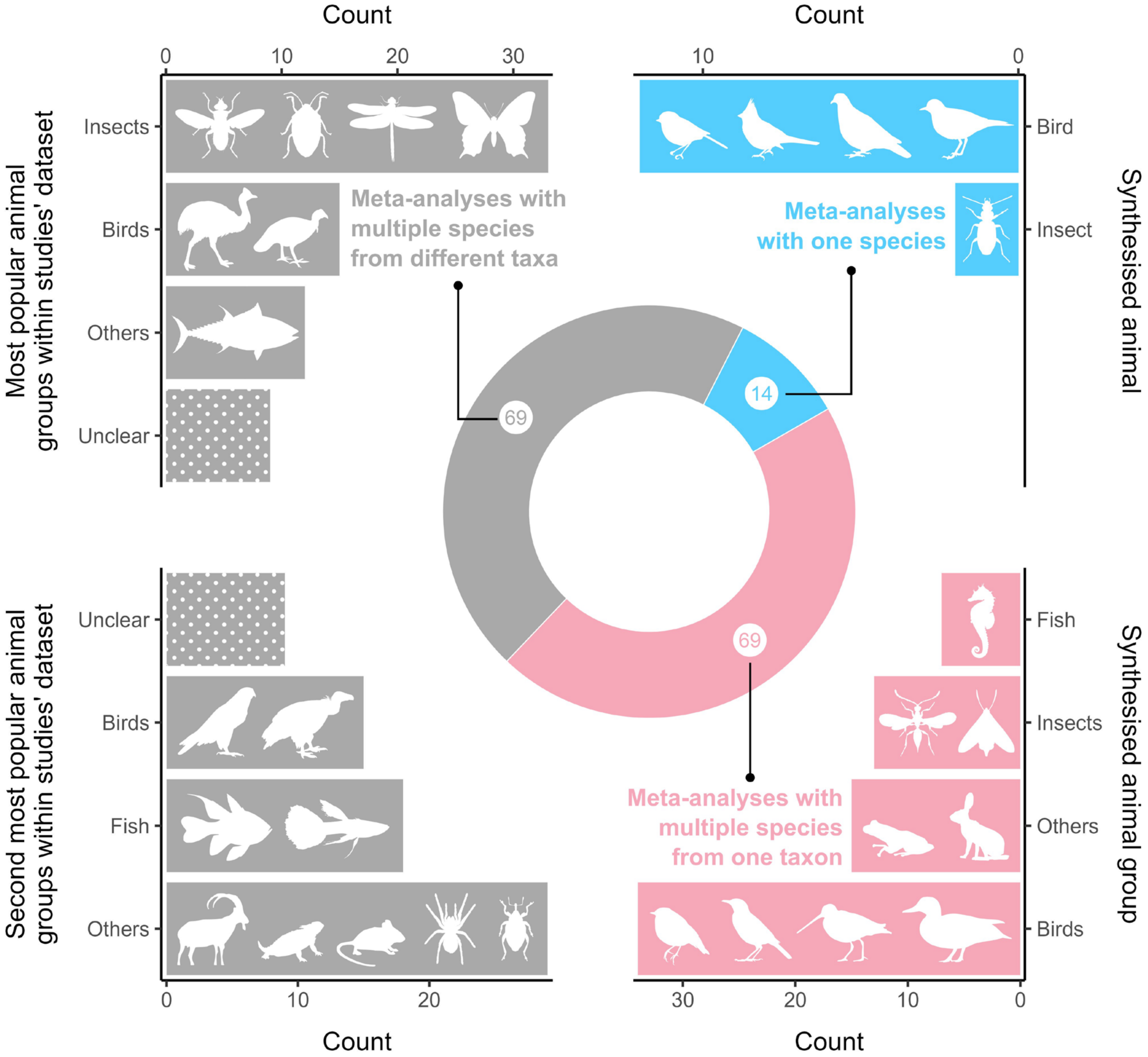

Figure 4. Number of meta-analytical studies related to sexual selection topics per taxonomic scope (centre) and animal groups (bar plots). Animal silhouettes represent broader animal groups and not specific species included in meta-analyses.

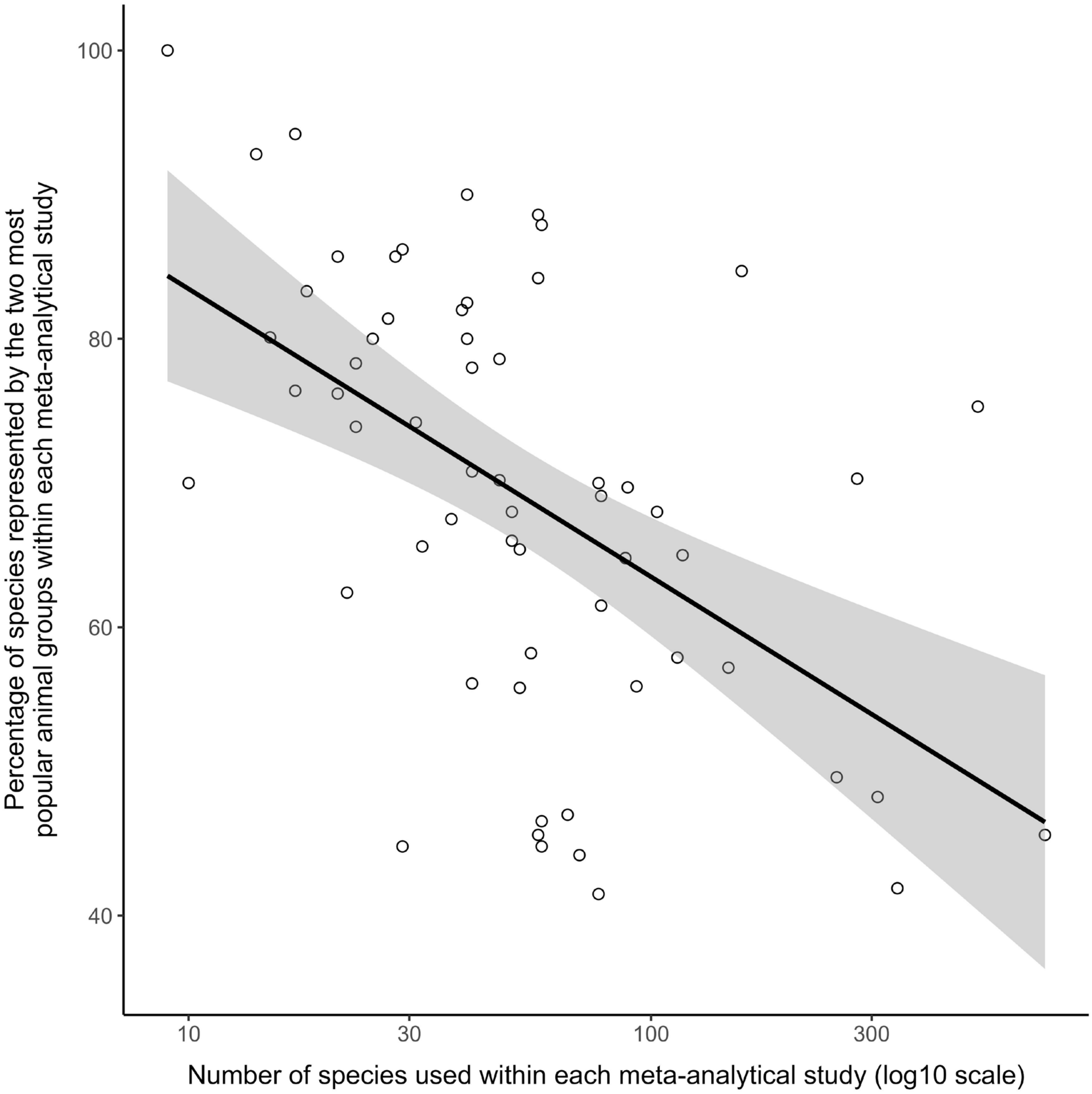

Figure 5. Relationship between the logarithm of the number of species used by meta-analytical studies with multiple species from different taxa and the percentage of species represented by the two most abundant animal groups in these studies.

Our findings are similar to studies that investigated taxonomic coverage in empirical research outputs from sexual selection (Zuk *et al.*, 2013), but also from other biological fields and subfields, such as animal behaviour (Rosenthal *et al.*, 2017; see also Owens, 2006), animal ecology (Bonnet, Shine & Lourdais, 2002), parental care (Stahlschmidt, 2011), biodiversity (Troudet *et al.*, 2017), and conservation (Seddon, Soorae & Launay, 2005). Akin to our results, all of these studies found that some taxonomic groups (usually birds) receive much more research attention than others, revealing taxonomic bias. Yet, our findings represent only the tip of this problematic iceberg, as the sole taxonomic information we extracted from meta-analyses was taxonomic class. As Zuk *et al.* (2013) showed, taxonomic bias is insidious as it occurs at the genus and species level as well. For example, most meta-analyses that include insects have many of their effect sizes from fruit flies (*Drosophila*) and other model species (e.g. de Boer *et al.*, 2021).

Taxonomic bias might stem from distinct sources, such as organisms' conspicuousness and easiness to access (Murray *et al.*, 2015; Yarwood, Weston & Symonds, 2019; Ellison *et al.*, 2021), common human attitudes towards specific animals (e.g. Bjerke & Østdahl, 2004), frequent use of certain organisms whose experimental techniques are well established (i.e. model systems, Zuk *et al.*, 2013), or previous experience with research on a given animal group (Pollo & Kasumovic, 2022). However, accumulating knowledge on only a fraction of the existing animal diversity severely limits our generalisation ability, making this taxonomic hyper focus extremely detrimental to our understanding of natural processes. Surprisingly, it seems that little has been done since the first reports of taxonomic bias more than two decades ago (Bonnet *et al.*, 2002), stressing that solutions to this issue (e.g. incentivizing research on data deficient animal groups at both low and high taxonomic levels) remain urgent.

(b) Inclusion of humans

Our systematic map deliberately required that meta-analytical studies had to explore non-human animals to be included (see section II.2). Yet, humans could be used along other species in these meta-analyses. We found that 18 studies from our systematic map included humans, albeit this number can be higher given that another three studies were unclear regarding this information. Although this number seems low, it represents almost a quarter of studies with relevant taxonomic scope (only 75 studies did not exclude primates *a priori*, see section III.2.a). Even though mixing humans with other animals in meta-analyses related to sexual selection can be taken as a matter of preference, we discuss the potential issues arising from this decision later in the manuscript (see section III.6.a).

(c) Number of empirical studies, effect sizes, and species

When possible, we extracted the number of effect sizes, species, and empirical studies used in meta-analyses on sexual selection related topics. At least one of these numbers was not explicitly provided in 38 (25%) meta-analytical studies. Furthermore, we extracted these numbers manually from tables or data files (rather than from what was explicitly reported in-text) in 57 meta-analyses, highlighting the lack of transparent reporting of important methodological details in meta-analyses in the field. We found that the number of empirical studies, effect sizes, and species increased with taxonomic scope (Figure 6). Along with taxonomic distribution of the data, these numbers are pivotal to address generality limitations in meta-analyses (Spake *et al.*, 2022). However, they are rarely provided. For instance, although Cally, Stuart-Fox & Holman (2019) used a total of 459 effect sizes from 65 empirical studies (both numbers mentioned in-text), these were related to only 15 species. Yet, the authors did not mention this low number of species and did not discuss the impacts of relying on such a limited taxonomic dataset to make a statement for the entire animal kingdom. This often appears as a symptom of a neoliberal academia (Lorenz, 2012), which pushes researchers to publish in high impact factor journals that require bold claims, stimulating the concealment of weaknesses to increase significance.

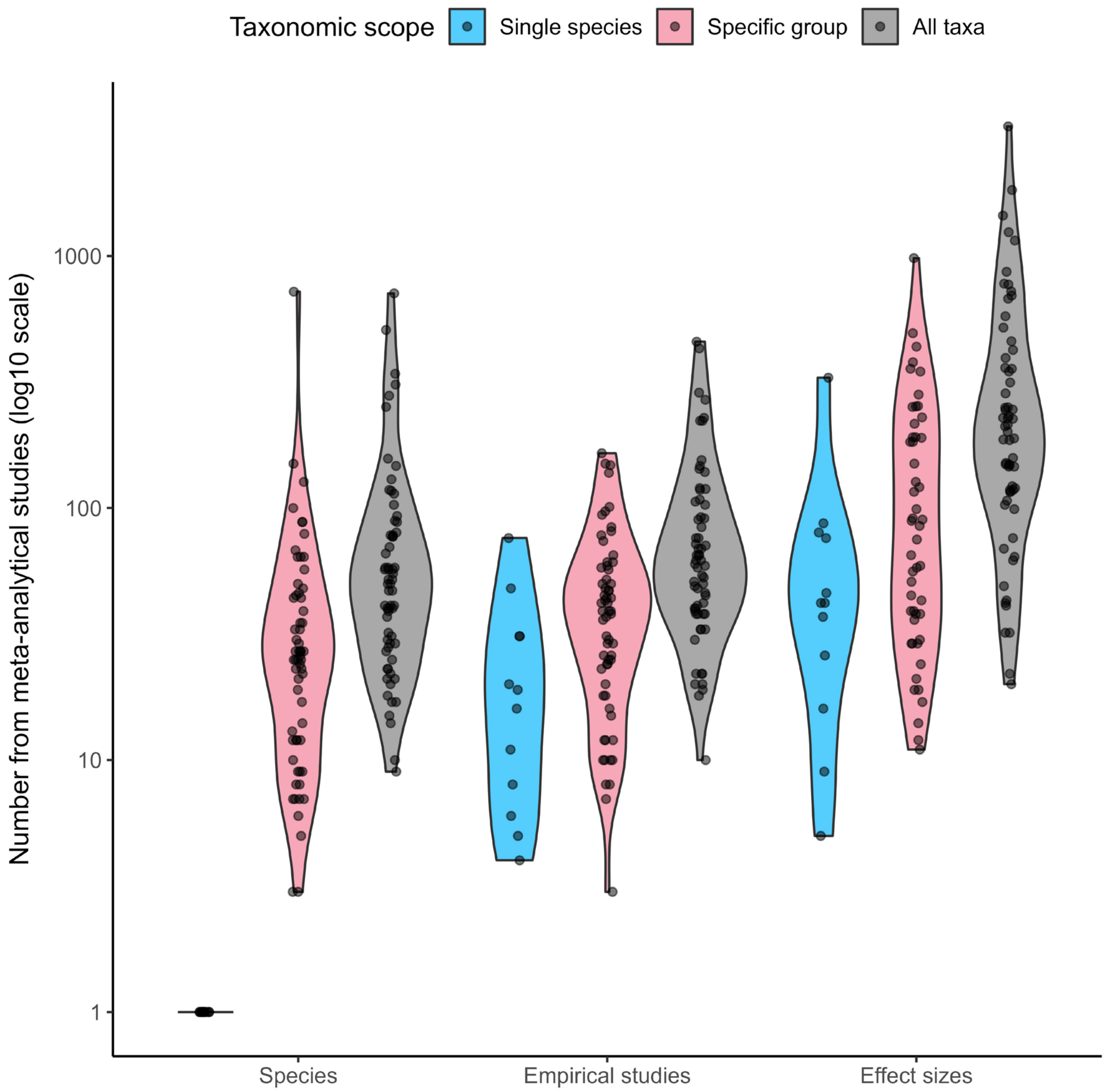

Figure 6. Number of effect sizes, species, and empirical studies found in meta-analytical studies (logarithmic scale) on topics related to sexual selection depending on their taxonomic scope.

(d) Study design

Briefly stating the design employed by selected empirical studies (experiments or field observations) represents the bare minimum of transparency from meta-analyses. Yet, we found that almost 40% (n = 60) of the meta-analytical studies from our systematic map were unclear about this information. From those that specified this information (n = 92), 13 exclusively used field observations, 32 exclusively used experimental investigations, while 47 combined both of these designs. A comprehensive description of included studies' methodology is ideal as it helps meta-analyses' readers to identify some of their limitations (Page *et al.*, 2021). This is because observations and experiments can have multiple peculiarities and vary in the degree of variables controlled, especially when distinct organisms require methodological adjustments. The design type selected by a meta-analysis has direct impacts on what is in fact being evaluated. For instance, to attest mate choice one needs to isolate several variables (e.g. number of individuals present; see section III.5.d), so field observations are much less reliable. Mixing approaches is fine as long as authors use moderators to distinguish one design from another (e.g. mate choice experiments vs. mating success observations), which is another aspect missing in many meta-analyses in the field of sexual selection.

(e) Overview of topics related to sexual selection

We extracted a single research question from most meta-analytical studies (n = 129, ca. 85%) and two to four research questions from the remaining 23 (ca. 15%), resulting in a total of 187 research questions. Figure 7 illustrates the number of questions in each of the categories (i.e. topics connected to sexual selection) we created to classify meta-analytical questions: (1) pre-copulatory sexual traits, (2) pre-copulatory intrasexual competition, (3) post-copulatory intrasexual competition, (4) mate choice, (5) remating and eagerness to mate, (6) mating success, (7) mating patterns, (8) divorce and extra-pair patterns, and (9) sexual conflict and estimates of sexual selection. We assigned up to two topics we deemed most relevant to individual questions rather than to studies (but see Supplementary material). This resulted in 138 questions associated with a single topic and 49 of them associated with two topics (visualised as links between categories in Figure 7). Details of what each category within our classification framework encompass are given and discussed in section III.5.

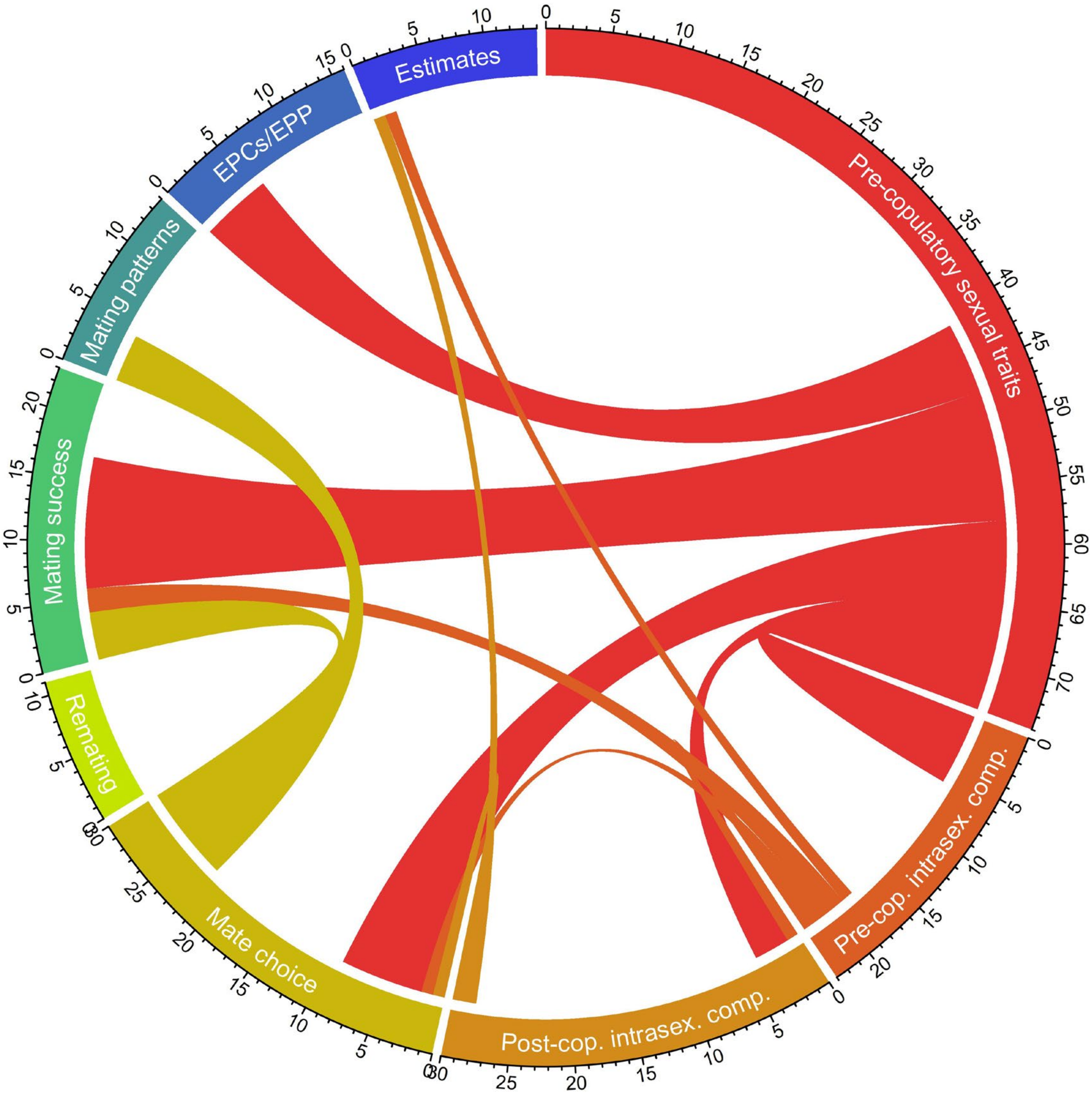

Figure 7. Number of meta-analytical questions for each topic related to sexual selection. Links represent questions that fit into two topics. Topics (clockwise, red to blue): pre-copulatory sexual traits, pre-copulatory intrasexual competition and associated traits, post-copulatory intrasexual competition and associated traits, mate choice, remating and eagerness

to mate, mating success, mating patterns, divorce and extra-pair patterns (EPCs/EPP), sexual conflict and estimates of sexual selection.

(f) Focal sex

Studies with sex roles conformist (i.e. that focus only on males, except for questions on mate choice) and neutral approaches dominate meta-analyses related to sexual selection (Figure 8). A single study exclusively focused on hermaphrodite animals (Graham *et al.*, 2015), and 14 studies did not clarify the sex of individuals they focused on for any of their questions. Non-conformist approaches only preponderate over others on questions regarding remating and eagerness to copulate, as studies on this topic essentially tested the benefits and costs of polyandry (see section III.5.e). Conversely, questions on mating patterns are more sex-neutral than others, but this might simply reflect their inherent approach using data from (heterosexual) social pairs or couples in copula. However, we emphasise that questions from other topics that are answered with sex-neutral data might still show a skewed ratio of males and females in their dataset. For example, White (2020) evaluated whether structural colours are associated with individual quality in both sexes, but 146 effect sizes were from males and only 29 were from females. This sex imbalance is quite common in other (not so) sex-neutral meta-analyses from our systematic map, confirming that sex bias is a reality in the field of sexual selection (see also Tang-Martinez, 2016; Pollo & Kasumovic, 2022).

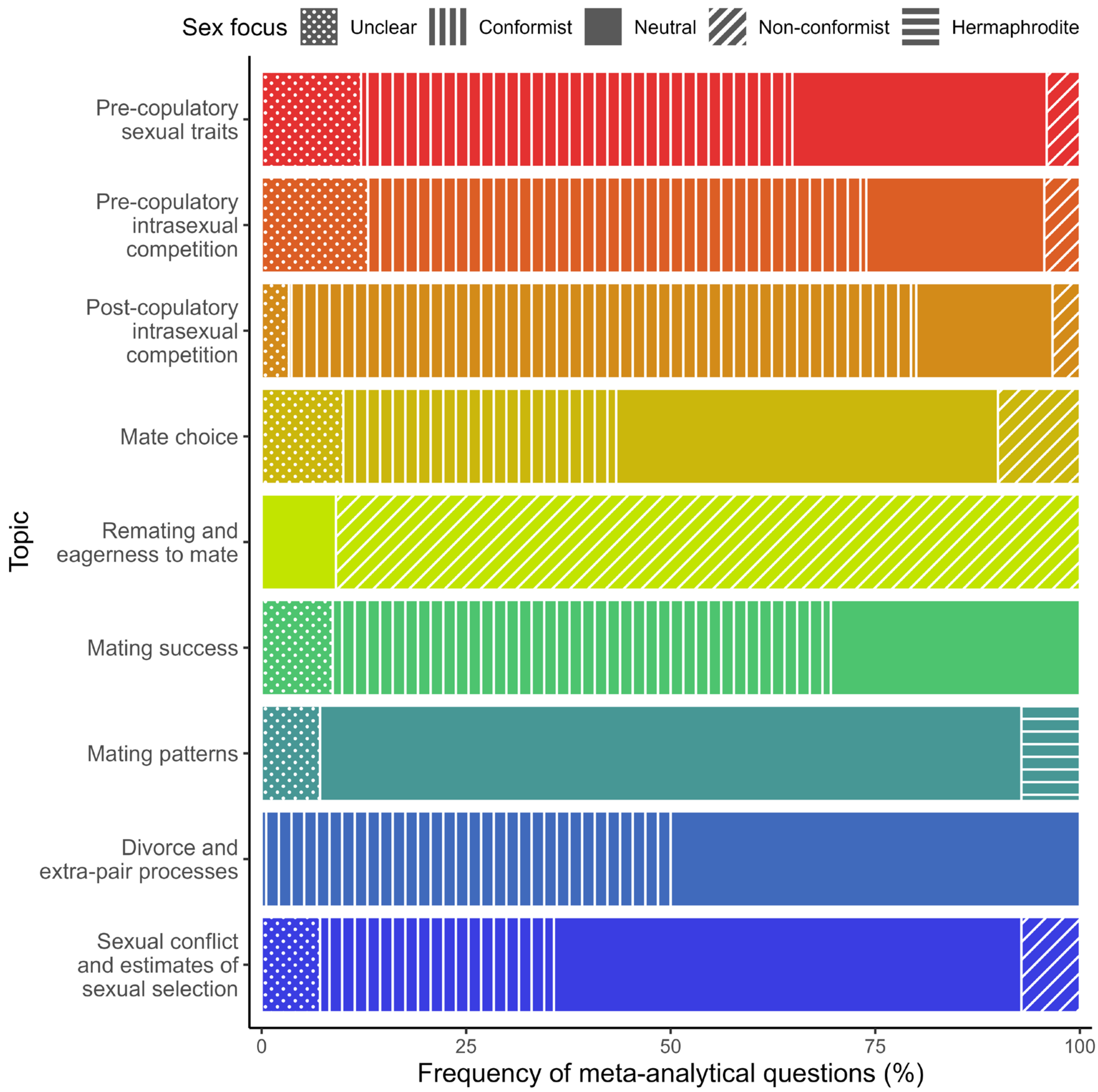

Figure 8. Focus of meta-analytical questions in relation to the sex of individuals used and the topic explored (see details in-text). Conformist refers to exclusive focus on males, and non-conformist refers to exclusive focus on females (except for mate choice, in which this rationale is inverted). Neutral refers to both sexes being focused.

The fact that the research literature investigates certain reproductive behaviours mostly in one sex potentially reflects and contributes to researchers' belief of sex stereotypical perceptions in the animal kingdom (Pollo & Kasumovic, 2022; Ah-King, 2022).

Darwin (1859, 1871) started this process: at first, he defined sexual selection as an evolutionary pressure acting exclusively on males, and frequently employed sexual stereotypes in his work. Although since then researchers have advanced our knowledge and perceptions on both sexes, the need to reduce sex bias in the field of sexual selection remains dire (Pollo & Kasumovic, 2022; Ah-King, 2022). In particular, researchers have emphasised the importance of not neglecting females in the study of sexual selection and related topics (e.g. Gowaty, 1997; Hare & Simmons, 2019; Rosenthal & Ryan, 2022). For instance, even though post-copulatory processes may depend on females as much as on males, female genitalia and reproductive organs have been largely overlooked, highlighted by recent discoveries and definitions (e.g. Folwell *et al.*, 2022; Keeffe & Brennan, 2023). Furthermore, only two meta-analytical studies from our dataset presented questions exploring the interaction between female and male traits in this context: Joly & Schiffer (2010) evaluated whether (female) receptacle length is associated with sperm length, while Myers *et al.* (2020) assessed whether presence of ovarian fluid is associated with sperm motility. Thus, we urge researchers to consider their role in contributing to the construction of a truly sex-neutral literature in the field of sexual selection (see also Ahnesjö *et al.*, 2020).

(3) Reporting appraisal of traditional meta-analyses

Almost 80% (n = 119) of the studies included in our systematic map (i.e. broad sense meta-analyses, see section II.2) were classified as traditional meta-analyses (i.e. used traditional effect sizes and properly modelled heterogeneity using additive weighting rather than multiplicative weighting; see Nakagawa *et al.* (2023a). Remaining studies (n = 33) used other comparative methods, from simple linear regressions on raw data (e.g. Bailey & Hammond, 2003) to more sophisticated statistical approaches (e.g. Wang *et al.*, 2019 used formal effect sizes and mixed effects models with multiplicative weights where heterogeneity cannot be easily obtained). In this section, we evaluated methodological details only from traditional meta-analyses, as other comparative studies commonly do not adhere to classic meta-analytical standards. Figures 9 and 10 summarise results of our appraisal, which are comparable to other similar studies (e.g. Philibert, Loyce & Makowski, 2012; O'Leary *et al.*, 2016; O'Dea *et al.*, 2021; Nakagawa *et al.*, 2023b; Yang *et al.*, 2023a).

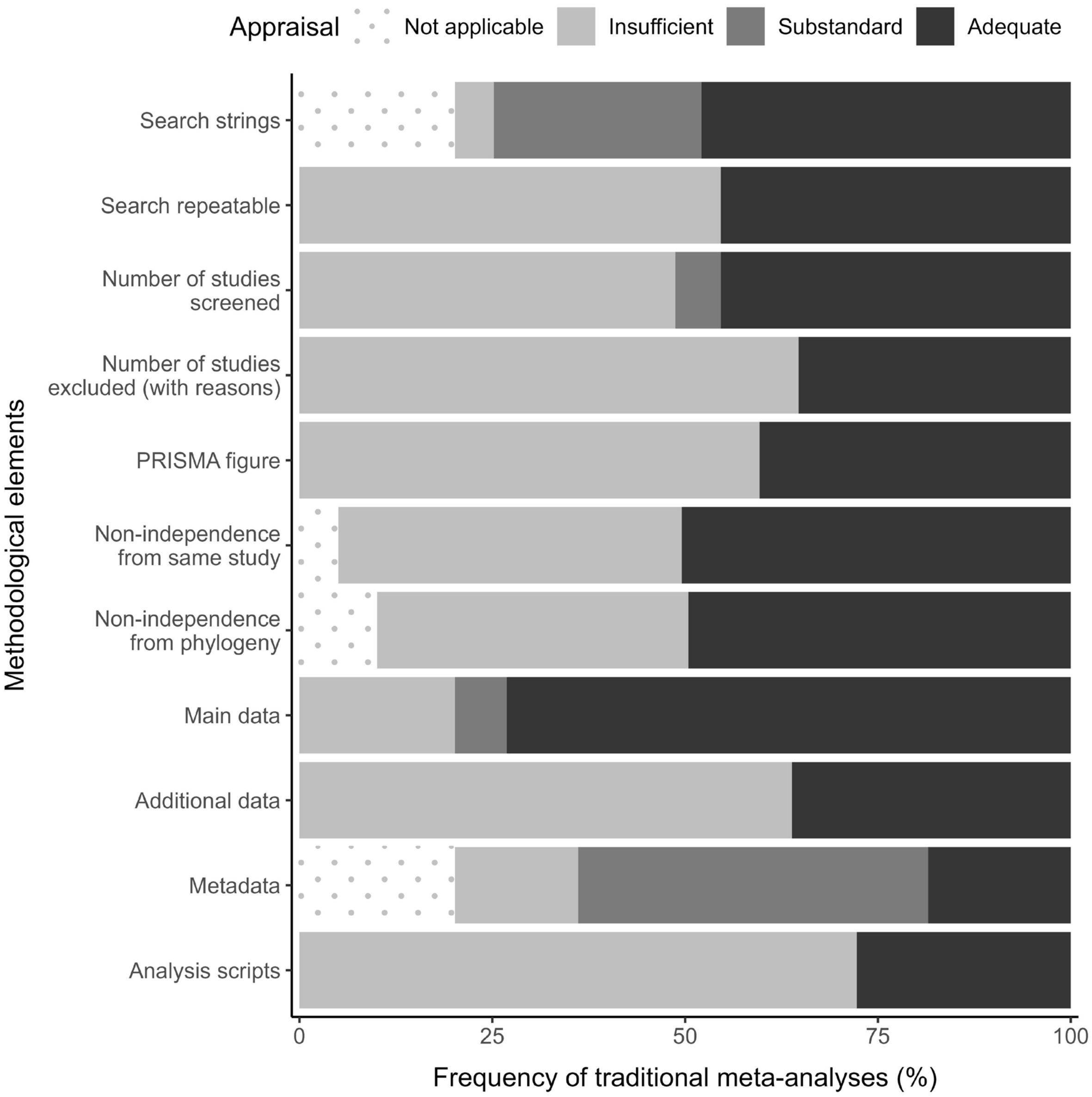

Figure 9. Appraisal of traditional meta-analyses on topics associated with sexual selection regarding several methodological elements. Elements poorly provided or absent were

considered insufficient. Substandard appraisal was given to elements that were provided but with caveats, while adequate appraisal was given to elements competently provided. Certain elements were not applicable to be judged depending on the meta-analytical study (see details on section III.3).

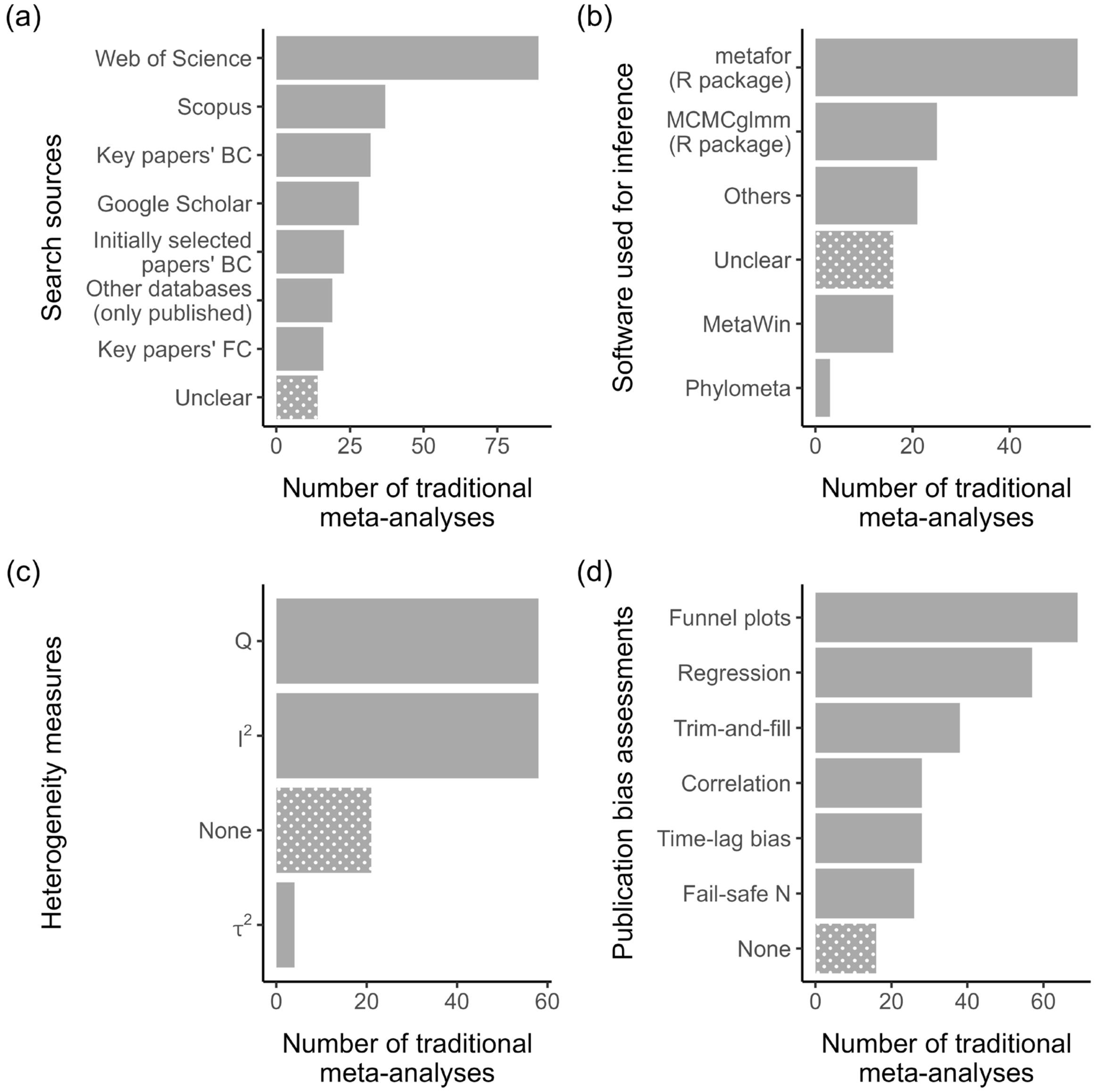

Figure 10. Details of methodological elements used by traditional meta-analyses on topics associated with sexual selection. Note that each meta-analysis could utilise multiple search

sources (A), software (B), heterogeneity measures (C), and publication bias assessment tools (D). In the left top plot (A), 'BC' refers to backward citations and 'FC' to forward citations.

(a) Searches

Meta-analyses should describe their search methods in detail to enable repeatability of the search process (i.e. retrieval of the same set of empirical studies). This first involves describing the exact sources used to conduct searches. We found that 88% of the traditional meta-analyses provided this information. In these meta-analyses, the most popular search sources were databases (e.g. Web of Science, Scopus), followed by backward citations (i.e. reference lists) from relevant key papers or initially selected studies (Figure 10A). These sources usually do not capture grey literature (i.e. unpublished studies). Sources that can capture grey literature (e.g. Google Scholar, BASE, etc) were rarely used in our sample of meta-analyses. Note that every meta-analytical study should use multiple search sources to be comprehensive: we found that 68% of traditional meta-analyses used at least two search sources.

Next, repeatable meta-analytical studies also need to provide the exact queries used in database searches (McGowan *et al.*, 2016). However, less than half (48%) of all traditional meta-analyses complied with this guideline. Another 27% simply provided a list of individual keywords used in database searches without boolean operators connecting them, which represents a substandard provision of information as it hinders search reproducibility (Figure 9). We note that the remaining meta-analyses from our dataset provided no search strings, with the distinction that the ones classified as "not applicable" include cases whose search sources were unclear or did not use online databases (possibly forgoing the need for search queries), whilst the ones classified as "insufficient" conducted database searches.

We further assessed the repeatability of searches conducted in traditional meta-analyses, using the information we collected about search sources and queries (for which substandard string provision was not considered repeatable) coupled with other details. For instance, repeatable searches had to both specify when they were conducted (at least month and year) and their sources had to be accessible in 2023 (some older databases were no longer available). We found that traditional meta-analyses' searches from our dataset were repeatable in approximately 45% of the cases (Figure 9).

(b) Screening process

Meta-analytical studies need to be transparent with their screening decisions, explicitly reporting the number of studies screened and the number of studies excluded at the full-text screening stage with justifications that clarify each of these exclusions. Thus, we first verified whether traditional meta-analyses provided the number of studies screened in at least two screening phases (i.e. initial and full-text). We considered the screening information provided to be insufficient when the number of studies screened were absent, and as substandard when this number was reported for only one phase or when it was not exact (e.g. Hasik & Siepielski, 2022). This resulted in 49%, 45%, and 6% of traditional meta-analyses from our systematic map showing insufficient, adequate, and substandard information on the number of studies screened, respectively (Figure 9).

We then verified details on screening decisions, in which we deemed as insufficient information when studies provided no information, only information for their initial screening phase (e.g. Nolazco *et al.*, 2022), or a list of exclusion reasons with the total number of excluded papers (instead of exclusion reason for each paper, e.g. Weaver *et al.*, 2018). This culminated in only 35% of traditional meta-analyses properly describing the justification for their full-text excluded papers (Figure 9).

Both the number of studies screened and excluded (with justifications) should ideally be presented in a PRISMA-like diagram, which summarises both the search and screening processes (O'Dea *et al.*, 2021). A few papers presented figures that lacked too many necessary diagram elements, so we considered them insufficient (e.g. Harts, Booksmythe & Jennions, 2016; Hasik & Siepielski, 2022). We found that only 40% of the traditional meta-analyses from our dataset showed adequate PRISMA-like diagrams (Figure 9).

(c) Software and data non-independence

Non-independence among effect sizes often occurs in meta-analyses, which can lead to false conclusions if not properly addressed (Noble *et al.*, 2017; Cinar, Nakagawa & Viechtbauer, 2022). We specifically examined whether traditional meta-analyses from our dataset dealt with non-independence from shared study identities (i.e. when at least two effect sizes are extracted from the same study) and from phylogenetic relatedness. We found that approximately half of the meta-analytical studies evaluated dealt with at least one of these non-independence sources (Figure 9), usually through random factors in meta-analytical models. We emphasise that non-independence might be entirely absent (i.e. not applicable; Figure 9) from meta-analyses whose effect sizes are all extracted from different studies (i.e. independent) or when they investigate only a single species (see section III.2.a). Related to this, most meta-analyses were conducted using the R packages *metafor* (Viechtbauer, 2010) and/or *MCMCglmm* (Hadfield, 2010) (Figure 10B). These packages are the most appropriate meta-analytical tools as they can incorporate phylogeny and other types of non-independence.

(d) Analytical reproducibility and transparency

We evaluated whether meta-analyses transparently provided the main components needed for analytical reproducibility: sharing of the main data, metadata, additional data, software information, and analysis scripts. Lack of data transparency is a major obstacle for reproducibility (Wilkinson *et al.*, 2016; Munafò *et al.*, 2017). First, meta-analyses need to provide data with effect size values and all other variables used in their analyses (e.g. moderators). We refer to these datasets as main data, as studies can also provide additional data (e.g. raw measurements or location from which they were extracted in empirical papers). We found that 73% and 7% of traditional meta-analyses on topics related to sexual selection provided all or some (i.e. substandard) of their main data, respectively (Figure 9). These findings are a little more optimistic than those found by a survey of the primary literature in ecology and evolution (Roche *et al.*, 2015). However, we note that many datasets were simply provided in a form of tables in-text (rather than separate data files), which is considered as a suboptimal practice. In addition, data were supposedly provided but could not be accessed in some cases (e.g. due to broken links; Guindre-Parker & Love, 2014; Dougherty, 2023), emphasising that authors must ensure that any resources mentioned in their papers are truly available to readers. Despite main data being shared in most meta-analytical studies, only 36% of meta-analyses evaluated provided additional relevant data (Figure 9), highlighting another obstacle for reproducibility.

To enhance reproducibility, data should ideally be provided with a separate metadata file (i.e. information that fully describes all fields from the main dataset provided). Metadata were provided in only 18% of traditional meta-analyses (Figure 9). Nonetheless, another 45% of the studies showed easily understandable data (e.g. from the study context, no acronyms used) and, even though we considered these cases as substandard for lacking proper metadata (Figure 9), these resources were occasionally clear and informative (e.g. tables in Meunier *et al.*, 2011; Graham *et al.*, 2015). We also note that metadata were not applicable for traditional meta-analyses that did not provide any of their main data (ca. 20%).

At last, sharing analysis scripts is essential for others to reproduce meta-analytical findings (Piccolo & Frampton, 2016; Culina *et al.*, 2020). We found that only 28% of the studies evaluated in our appraisal appropriately shared their code (Figure 9). The remaining 72% either used point-and-click software (n = 27; e.g. MetaWin, Phylometa, etc; Figure 10B), did not mention the software used (n = 16; although some papers might have not used any, e.g. manual calculations), or simply provided no code despite using other software (n = 43). Our finding is similar to recent reports on code availability in ecology (Culina *et al.*, 2020). The low code sharing can be a result of lack of incentives for authors to share their code (see Gomes *et al.*, 2022) or lack of the awareness of the importance of software in research.

(e) Heterogeneity and publication bias

Heterogeneity measures the amount of variation among effect sizes, thus being critical to understanding the generality of overall effect sizes shown in meta-analytical studies (Spake *et al.*, 2022); see section III.6). We found that 82% of traditional meta-analyses calculated at least one heterogeneity measure. Those that did most frequently used Q and/or I^2 (Figure 10C). We note that H^2 (Lynch, 1991) or Pagel's λ were commonly present in phylogenetic regressions, which we did not consider proper stand-alone heterogeneity measures for a meta-analysis.

Meta-analytical studies also must investigate publication bias in their included dataset, as this can drastically impact results' magnitude and sign errors (Yang *et al.*, 2023b). 87% of traditional meta-analyses from our dataset assessed publication bias in some way. Funnel plots were the most popular tool to address publication bias (Figure 10D), similar to Nakagawa *et al.* (2021)'s findings.

(f) Other elements

We verified the occurrence of several other important methodological elements in traditional meta-analyses, but rarely found them. For instance, only one study was pre-registered (e.g. Kim *et al.*, 2021) and none mentioned post-hoc hypotheses (although there were cases of post-hoc analyses; e.g. Winternitz *et al.*, 2017; Parker *et al.*, 2018; Kim *et al.*, 2021). In addition, the quality of empirical data was evaluated in only four traditional meta-analyses: Simons & Verhulst (2011) and Parker *et al.* (2018) examined empirical pseudoreplication, Kim *et al.* (2021) intended to verify the effect of blind data collection (but ironically found that no empirical papers collected data blindly), and Culina, Radersma & Sheldon (2015) evaluated the trustworthiness of empirical studies from which they extracted data. This near absence of quality assessment of primary studies has also been detected in ecological systematic reviews despite being imperative to reduce bias (Stanhope & Weinstein, 2022). However, we emphasise that here we only considered generic quality assessments (i.e. that are relevant for all types of studies), but that there are also more specific assessments (e.g. via experiment design; (Davies, Lewis & Dougherty, 2020; Pollo, Nakagawa & Kasumovic, 2022).

(4) Bibliometric analysis

The 152 meta-analyses included in our study were authored by 326 different authors affiliated to institutions from 31 countries (Figure 11; Figure 12). The median for the number of authors per study was three ($\bar{x}$ = 2.97, 95% CI = 2.71 to 3.24), while the median of the number of countries per study was two ($\bar{x}$ = 1.79, 95% CI = 1.63 to 1.95) (Figure 11). Intuitively, the number of different countries from authors' affiliations increased with the number of authors (Figure 11). We present more results from our bibliometric analysis in the subsections below, but we discuss the impacts of all these findings in section III.6.d.

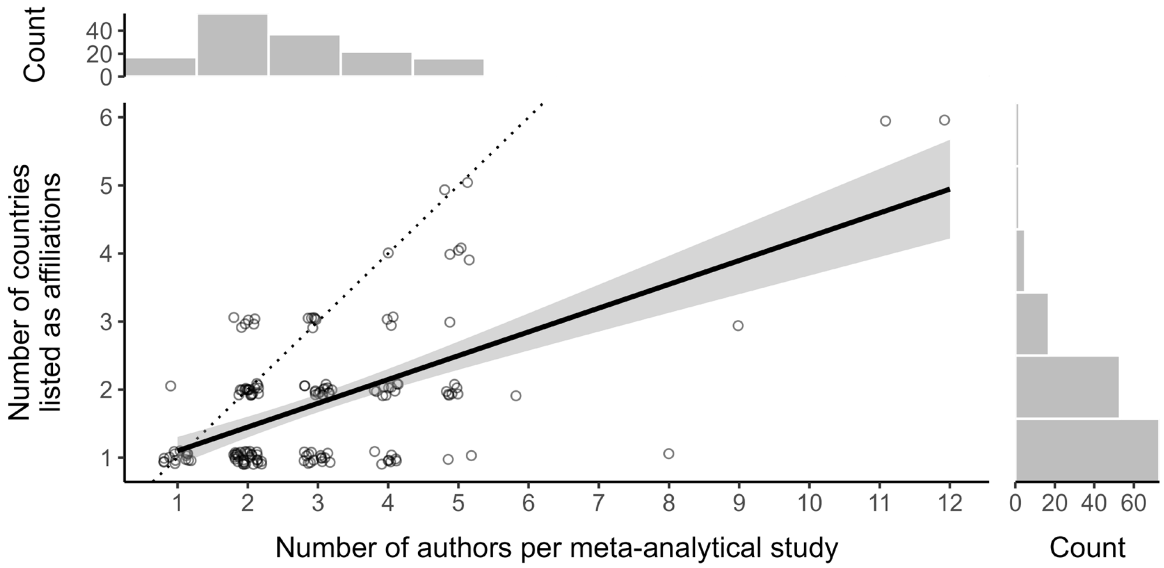

Figure 11. Relationship between number of authors for each meta-analytical study and number of countries listed as affiliations. The dotted line highlights a perfect correlation between these two variables, while the continuous line represents the best fit from a linear regression. Histograms on top and on the right indicate the number of studies for each number of authors and countries listed as affiliations, respectively.

(a) Authors' affiliations

Australia and the United States of America (hereby USA) were the most prolific countries in publishing meta-analyses on topics associated with sexual selection, each with 41 meta-analyses being authored by at least one researcher affiliated to an institution located there (Figure 12). We detected only a few developing countries (i.e. Global South) as affiliations in the evaluated meta-analyses. In fact, the only countries with more than a single study affiliated outside of Anglo-America, Europe, or Oceania, were Brazil and Mexico (Figure 12).

The first affiliation listed in each study, which is usually associated with the lead authorship, revealed a similar authorship pattern. The USA also led with the highest number (n = 25) of studies with one of its institutions as the first affiliation listed in papers, albeit the United Kingdom followed close behind with 24 first affiliations. The proportion of first affiliations to all affiliations seen per country can serve as a proxy of how dependent a country is on international collaborations (Figure 12). For example, despite seven meta-analytical studies being associated with an institution from Spain, only in one of them a Spanish institution was the first affiliation listed. In contrast, Belgian institutions were first listed as affiliations in all of five meta-analyses associated with Belgium. We emphasise, however, that this proportion tends to extreme values (i.e. none or all) with fewer studies associated with a country (Figure 12). Furthermore, we note that almost half of all meta-analyses evaluated (n = 73) were affiliated to a single country (Figure 12).

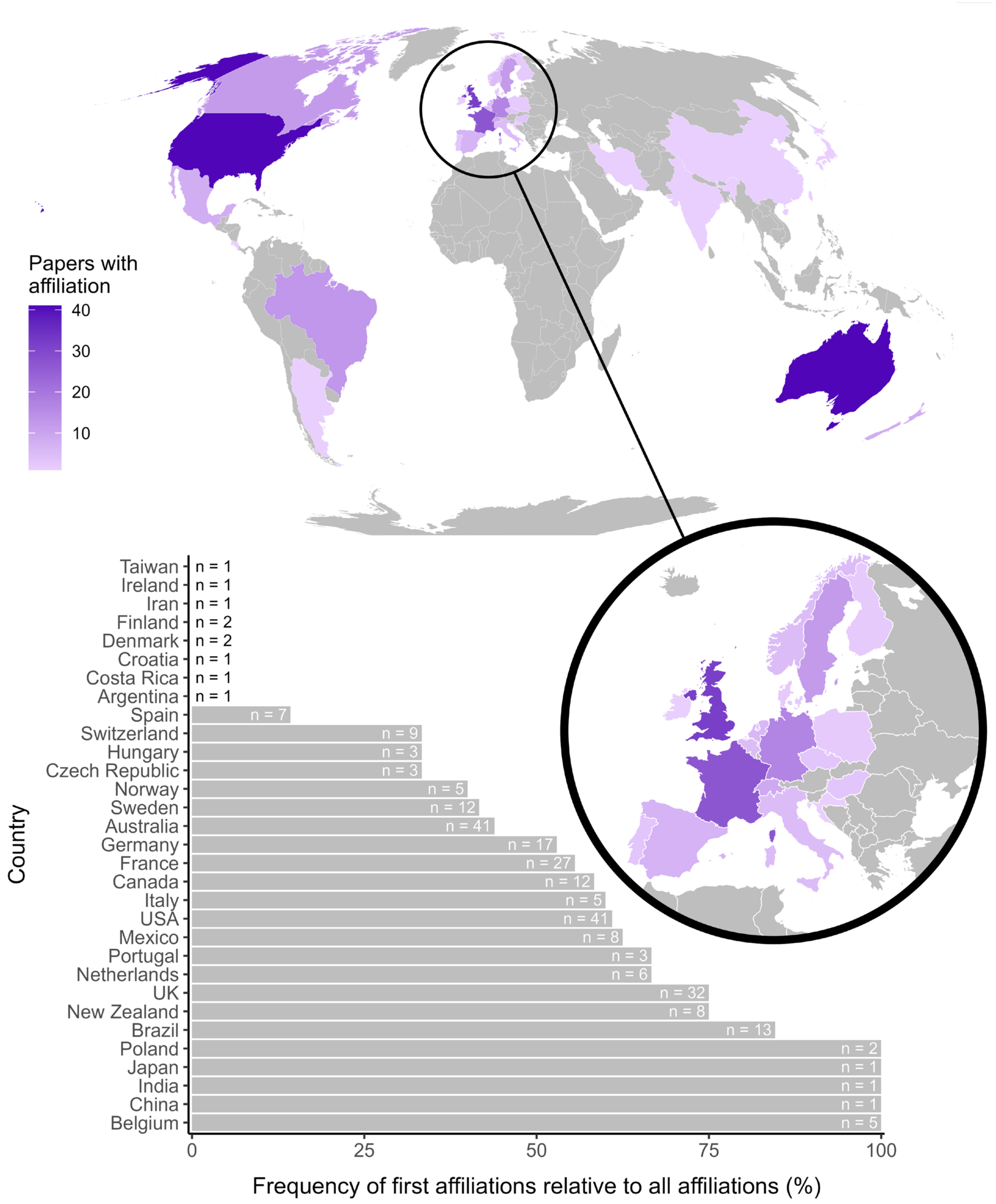

Figure 12. Affiliations reported in meta-analytical studies on topics associated with sexual selection. Colour intensity in maps (top and inset) illustrate the number of papers in which countries' institutions were recorded as authors' affiliations, greyed countries representing zero. Bar plot (bottom) shows the percentage of affiliations that were reported first in papers

(i.e. affiliation of first author) per country, with the total number of affiliations per country given inside each bar.

Shifting the focus to continents, we observed that approximately half (n = 77) of all first affiliations belong to Europe (Figures 12 and 13). Papers with first affiliations located in Europe were also more likely to be associated with institutions from multiple countries (and thus have international collaborations) compared to papers with other continents as first affiliation (Figure 13). However, most of these international collaborations were between countries in the same continent (Figure 13). For example, out of 48 meta-analyses that originated in Europe with multiple countries affiliated to them, 35 had at least one international collaboration with another European institution, while no author from another continent was involved in 25 of them.

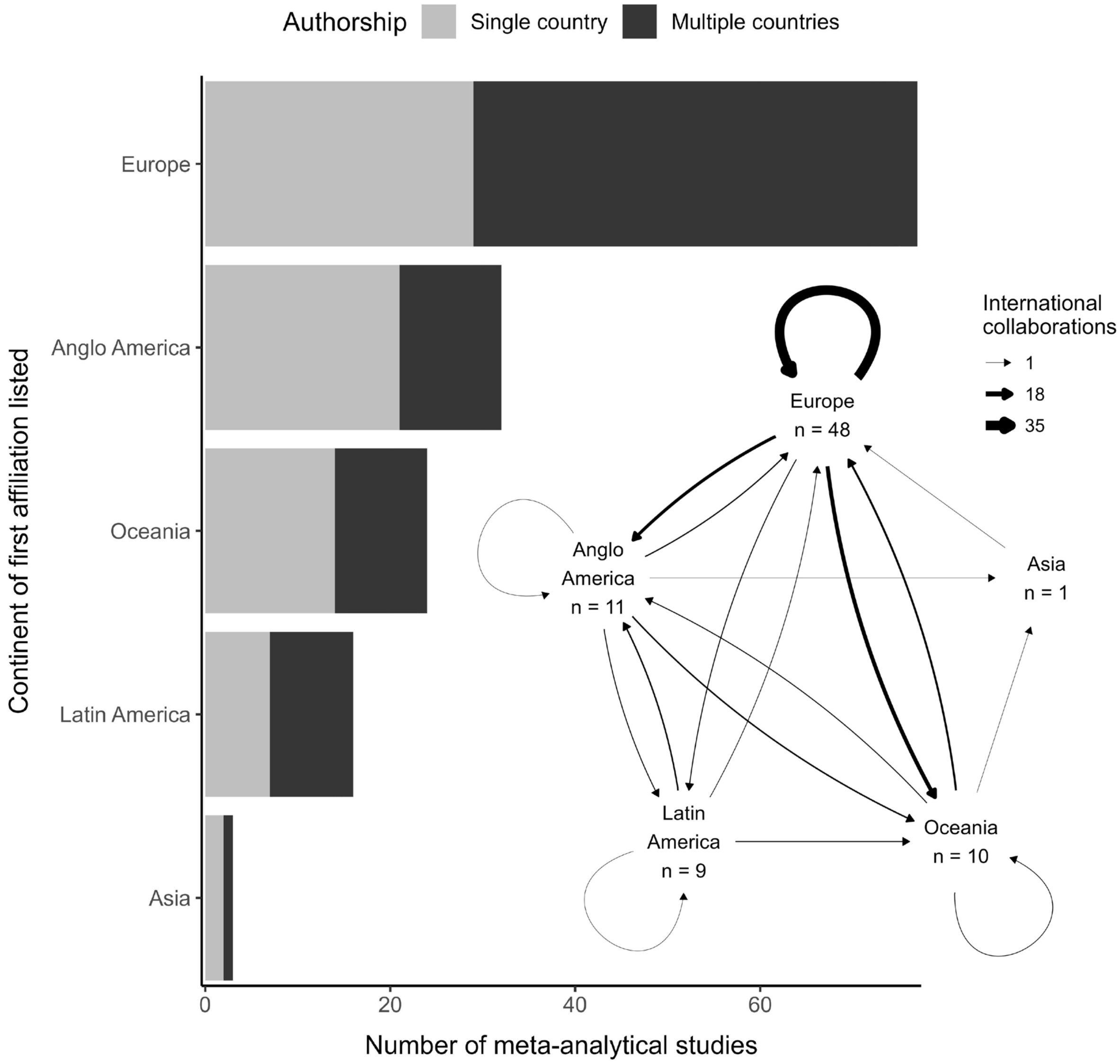

Figure 13. Collaborations on a continental level. The barplot shows the number of meta-analytical studies per continent that listed affiliations from either one or multiple countries. The network shows the number of papers that contain affiliations from multiple countries (same as darker bars in the barplot) per continent, with arrows representing international collaborations (from continent of the first affiliation to the continent of posterior affiliations).

<u>(b) Authors' gender</u>

We found gender bias in authors of meta-analyses on topics related to sexual selection (Figure 14): only 37% of these authors were classified as women (n = 119), opposed to 61%

classified as men (n = 199; gender could not be assigned to the remaining 2% of authors). This gender disparity increased when considering only first authors, as 68% of them were identified as men and 31% as women (1% was unknown). The number of women in multi-authored studies was rarely greater than the number of men, even when women were first authors (Figure 14). On the other hand, men predominated in research projects led by them. In fact, we detected only three studies led by men with a greater number of women than men as participating authors (Figure 14).

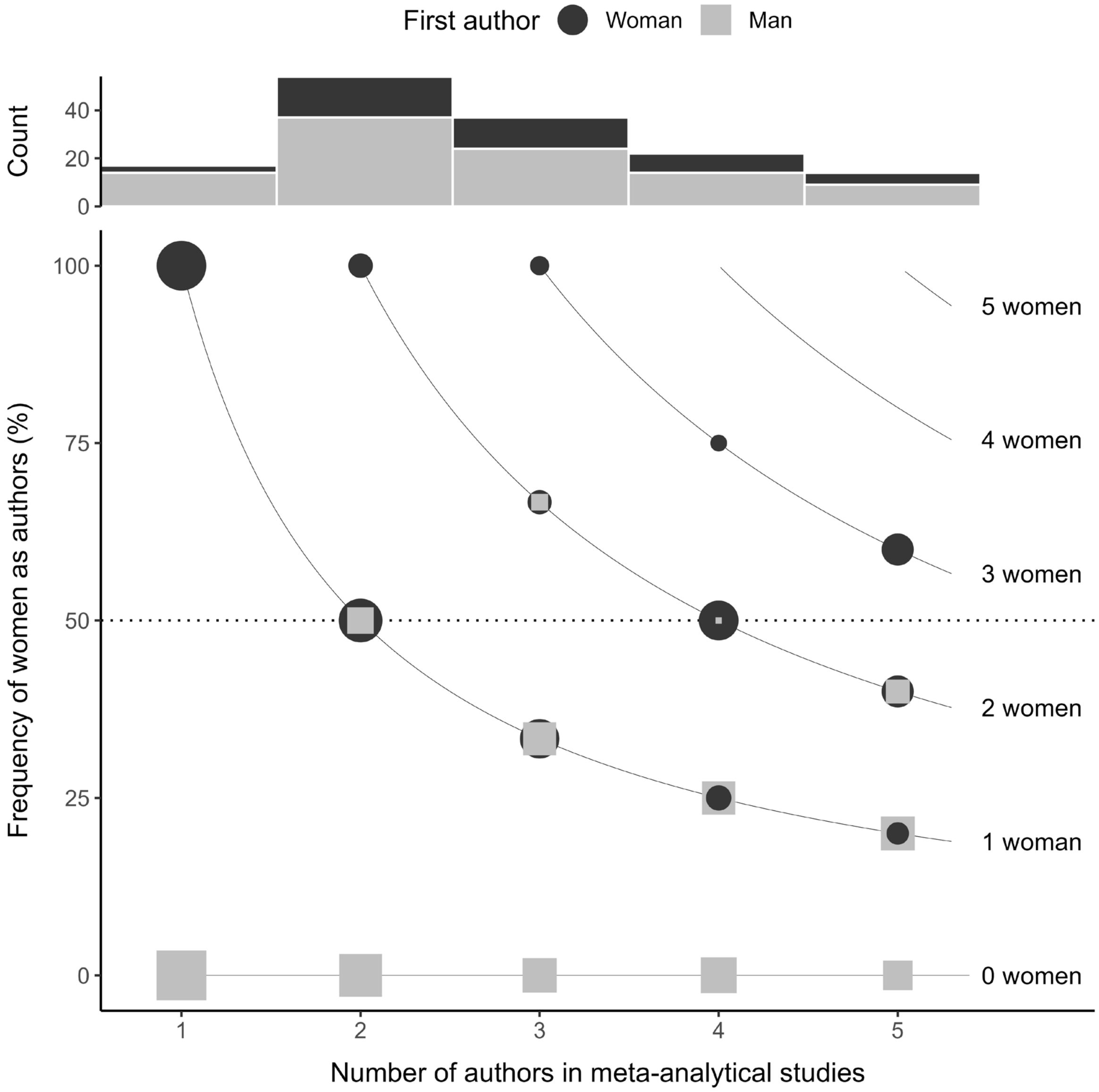

Figure 14. Authorship by gender and number of authors in meta-analytical studies on topics related to sexual selection. Shape size represents the proportion of studies observed for each number of authors and for each first author's gender. Four meta-analytical studies with more than five authors and another four that contained a name that could not be assigned to a binary gender are not shown.

(5) Details and in-depth discussion regarding topics related to sexual selection

In this section, we discuss the study questions (and the research topics they belonged to) that we extracted from meta-analyses related to sexual selection (see section III.2.e, Figure 7). We found that the most popular topic was pre-copulatory sexual traits (74 questions from 59 meta-analyses), followed by mate choice and post-copulatory intrasexual competition (30 questions each, from 29 and 27 meta-analyses, respectively). To improve readability, we limited citing relevant studies related to patterns we described to five citations. In cases in which more than five meta-analytical studies were relevant and should be cited, we instead refer to the Supplementary material to encourage readers to check all questions fully described there. In addition, to avoid repetition, questions that did fit into multiple topics were occasionally omitted from relevant subsections if they had already been mentioned.

(a) Pre-copulatory sexual traits

In this category of our classification framework, we included questions explicitly mentioning pre-copulatory sexual traits, such as secondary sexual characteristics, ornaments, courtship, and sexual signals. Although weapons would technically fit here (see section III.6.b), we noticed that a distinct set of meta-analyses focused on them, so we classified them differently (see section III.5.b). However, we note that some meta-analyses discussed in the current section grouped several different traits under a single label (e.g. secondary sexual traits), and weapons might be inadvertently amongst them. In total, this category encompassed 74 questions from 59 meta-analytical studies, revealing this topic as the most popular in the meta-analytical literature related to sexual selection (Figure 7).

The emphasis on pre-copulatory sexual traits is expected, as Darwin (1871) himself used them to develop the theory of sexual selection (see section III.6.b). He proposed that ornaments and sexual signals evolved via mate choice, an idea that was rejected by his peers at the time (Hoquet & Lewandowsky, 2015). Nonetheless, the literature on ornaments and sexual signals later flourished when a debate among evolutionary biologists was established: whether these traits and signals evolved because they reflect greater genetic quality to prospective mates ("good genes" model and its "handicap principle" extension; Zahavi, 1975, 1977) or simply because they genetically correlate with mate preference for themselves (i.e. Fisherian runaway process; Fisher, 1930; see also Eshel, Volovik & Sansone, 2000; Kokko, 2001; Hoquet & Lewandowsky, 2015). Possibly because the latter is complex and difficult to measure (but see Greenfield *et al.*, 2014), the former has received much more empirical attention.

On one hand, some proponents of the good genes model (e.g. Andersson, 1994) predicted that ornaments and sexual signals would be linked to fitness-impacting measures (e.g. survival, fecundity, viability, overall reproductive success; see Kokko, 2001), which was tested by many different meta-analyses (Table S5). On the other hand, Grafen (1990a, 1990b) popularised Zahavi's (1975, 1977) idea that ornaments and sexual signals must be condition-dependent to be honest (reviewed and contested in Penn & Számadó, 2020; see also Getty, 2006), shifting the attention of the research community to more direct questions. It is unsurprising then that 26 meta-analyses in our systematic map contain at least one question asking whether the expression of ornaments and sexual signals are related to the expression of other traits (e.g. age, body size) or to proxies of individual quality (e.g. parasite load; or their manipulation, e.g. diet supplementation, stress) (Table S5). Questions of this nature do not aim to test whether pre-copulatory sexual traits are indeed under sexual selection, but simply whether they function as reliable cues of good genes to prospective mates.

Conversely, a variety of meta-analytical studies (n = 18) tested whether certain ornaments and sexual signals might be in fact under selection by verifying their relationship with intrasexual competition (e.g. dominance rank or aggression; Nakagawa *et al.*, 2007; Yasukawa *et al.*, 2010; Santos, Scheck & Nakagawa, 2011; Parker, 2013; Sánchez-Tójar *et al.*, 2018), species recognition (Ord & Stamps, 2009; Ord, King & Young, 2011; Parker *et al.*, 2018), attractiveness in mate choice experiments (Parker & Ligon, 2003; Simons & Verhulst, 2011; Hernández *et al.*, 2021), mating success, or extra-pair patterns (see in Table S5). Other meta-analytical studies explored whether courtship behaviours, ornaments, and/or sexual signals are related to specific biotic (e.g. density, predation, etc; Weir, Grant & Hutchings, 2011; De Jong *et al.*, 2012; Dougherty, 2021a; White, Latty & Umbers, 2022) and abiotic conditions (e.g. habitat structure, band colouration, etc; Boncoraglio & Saino, 2007; Seguin & Forstmeier, 2012; Parris & McCarthy, 2013). At last, other specific meta-analytic studies assessed sexual traits' additive genetic variation (Pomiankowski & Møller, 1995) and heritability (Prokop *et al.*, 2012; Prokuda & Roff, 2014), compared the allometry of sexual traits depending on their function and denomination (Voje, 2016; Rodríguez & Eberhard, 2019), verified whether pre-copulatory sexual traits are associated with sperm quality (Mautz, Møller & Jennions, 2013), examined the interplay between call length and reply latency across species (Bailey & Hammond, 2003), and evaluated the association between expression of possibly sexually selected traits and speciation rates (Kraaijeveld, Kraaijeveld-Smit & Maan, 2011).

We found that most questions related to pre-copulatory sexual traits from meta-analyses explored only visual and/or acoustic characteristics (Figure 15; Table S6). In addition, some studies were unclear on the exact traits used (see also section III.6.b). We observed only seven meta-analytical studies with a question focusing on pre-copulatory sexual traits from other modalities (Figure 15; Table S6). Yet, even in these studies, visual and acoustic traits predominate over others, revealing that some sensory modalities (e.g. olfactory) are neglected. We discuss the implications of this pattern in section III.6.b.

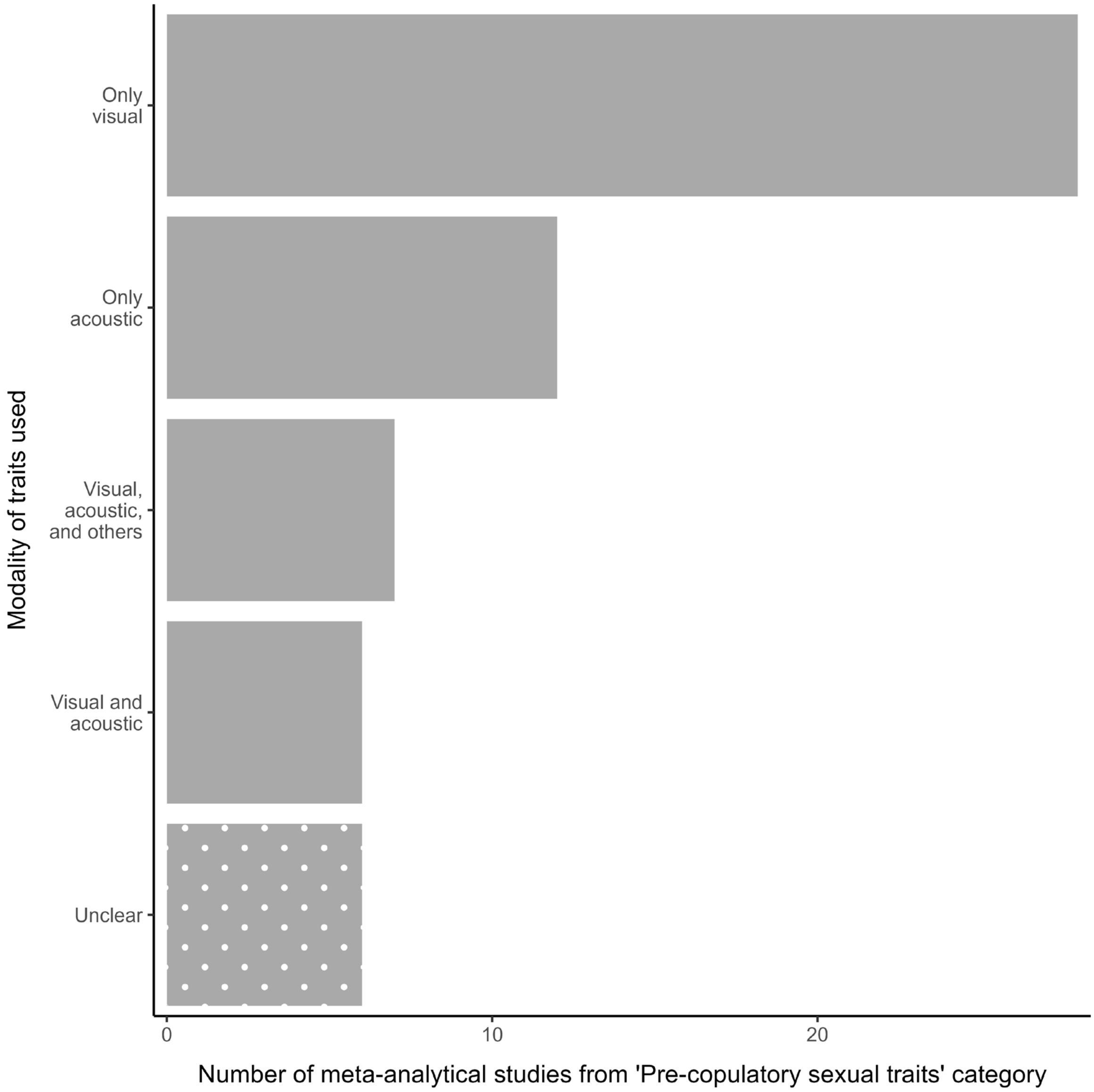

Figure 15. Sensory modality of traits nominated as secondary sexual characteristics, ornaments, or sexual signals from meta-analyses with at least one question categorised as "Pre-copulatory sexual traits". Visual traits include colour, morphology, and visual displays.

(b) Pre-copulatory intrasexual competition and associated traits

Pre-copulatory intrasexual competition refers to the competition among individuals of the same sex for access to individuals of the opposite sex (Darwin, 1871; Andersson, 1994). The existence of this process and its strength as an evolutionary force was fairly accepted by the scientific community when Darwin (1871) shared this idea (Hoquet & Lewandowsky, 2015). Pre-copulatory intrasexual competition includes intrasexual aggression, dominance, mate monopolisation, territoriality, and weaponry, which are subjects covered in this section. Perhaps precisely because this mechanism is perceived as straightforward, relatively few questions explicitly focus on this topic in meta-analyses: only 23 questions from 22 studies were included in this category of our systematic map (Figure 7).

Animal weapons represent the heartthrob of intrasexual competition as these traits are pivotal for intrasexual combat as well as for assessment signalling to avoid physical confrontations in many species (Emlen, 2008; Rico-Guevara & Hurme, 2019). A couple of meta-analyses tested a key assumption related to these traits: whether weapons are indeed related to contest success (Vieira & Peixoto, 2013; Palaoro & Peixoto, 2022; although the first used resource holding potential, which included other traits). Similarly, Kelly (2008) examined the relationship between resource holding potential (considering weapons and other traits), resource value, and reproductive success. Furthermore, some authors explored whether expression of weaponry is associated with certain contexts, such as the type of disputed resource (e.g. mates vs. territory; Maciel, Oliveira & Peixoto, 2023) or the availability of reproductive sites (Alissa, 2018). Moreover, Menezes & Palaoro (2022) investigated whether size and number of spurs are associated with body and wing size, which are traits connected to flight capacity. Lastly, Lüpold *et al.* (2015) verified whether the expression of weapons is linked to sperm length, whereas Rodríguez & Eberhard (2019) compared allometry slopes of weapons with those of ornaments.

As previously mentioned, some studies evaluated whether ornaments are linked to aggression or dominance (Nakagawa *et al.*, 2007; Yasukawa *et al.*, 2010; Santos *et al.*, 2011; Parker, 2013; Sánchez-Tójar *et al.*, 2018). In respect to territoriality, Ord (2021) assessed the costs associated with this behaviour whilst (Ord *et al.*, 2011) verified whether species recognition occurs for territorial signals. Other meta-analytical investigations explored whether different contexts and conditions are associated with the expression and intensity of intrasexual competition, such as operational sex ratio (Weir *et al.*, 2011), environmental stability (Peixoto, Medina & Mendoza-Cuenca, 2014), and availability of reproductive sites (Alissa, 2018). Finally, certain meta-analyses attempted to answer questions involving other topics by examining the following relationships: mating success and fighting frequency (Fiske, Rintamaki & Karvonen, 1998) or social dominance (Majolo *et al.*, 2012), strength of mate choice and traits determinant to intrasexual competition success or attractiveness (Pollo *et al.*, 2022), and mate monopolisation and estimates of sexual selection (Macedo-Rego *et al.*, 2020b) or the effect of body size on reproductive success (Macedo-Rego *et al.*, 2020c).

(c) Post-copulatory intrasexual competition and associated traits

Post-copulatory intrasexual competition, popularly known as sperm competition, occurs when ejaculates from different males compete for a set of ova (Parker, 1970; Parker & Pizzari, 2010). Darwin (1871) did not know this was possible, so this subject emerged much later than pre-copulatory processes in the literature of sexual selection. In this category, we gathered 30 meta-analytical questions (from 27 studies) involving gamete traits, ejaculate traits, primary sexual characteristics (i.e. traits necessary for reproduction, e.g. gonads and genitalia, see section III.6.b), risk and intensity of sperm competition, as well as paternity protection behaviours (e.g. mate guarding) (Figure 7).

Most questions in this category concentrated on the expression of gametes, ejaculates, and/or primary sexual traits. For example, several meta-analyses investigated the relationship between these traits, their allocation, or their production, and either (1) another type of trait (e.g. alternative reproductive tactics: Aguiar Del Matto, 2018; Dougherty *et al.*, 2022; body size or mass: Hayward & Gillooly, 2011; Lüpold & Fitzpatrick, 2015; Kim *et al.*, 2021; mating status: Zhang *et al.*, 2016; secondary sexual traits: Mautz *et al.*, 2013; weapons: Lüpold *et al.*, 2015), (2) a specific context (e.g. contaminants: Marmol, 2022; diet or nutrient intake: Crean & Senior, 2019; Macartney *et al.*, 2019; inbreeding: Losdat, Chang & Reid, 2014; masculinization: Senior, Johnson & Nakagawa, 2016b; mate quality: Kelly & Jennions, 2011; presence of ovarian fluid: Myers *et al.*, 2020; presence of rivals: delBarco-Trillo, 2011; Kelly & Jennions, 2011; sexual cannibalism: Dharmarathne & Herberstein, 2022; temperature: García-Roa *et al.*, 2020), or (3) a potential consequence (e.g. allometry patterns: Voje, 2016; patterns of sperm competition risk: Lüpold *et al.*, 2020; trait selection: Dougherty & Shuker, 2016; speciation rates: Kraaijeveld *et al.*, 2011). In addition, some studies evaluated the relationship between two gamete traits (e.g. Bernasconi & Hellriegel, 2005) or between a gamete trait and a primary sexual trait (especially gonad mass; e.g. Joly & Schiffer, 2010; Lüpold & Fitzpatrick, 2015; Lüpold *et al.*, 2015). The remaining questions that fit this category explored the connection between mate guarding and operational sex ratio (Weir *et al.*, 2011), individual quality, or paternity (Harts *et al.*, 2016); copula duration and sperm transfer (Dharmarathne & Herberstein, 2022) or operational sex ratio (Weir *et al.*, 2011); and diverse measures of sperm competition and availability of reproductive sites (Alissa, 2018).

(d) Mate choice

Mate choice is also known as intersexual competition, but some advise to avoid this term (e.g. Andersson, 2021; Shuker & Kvarnemo, 2021a, 2021b). This is because mate choice consists of competition among individuals of the same sex in which individuals of the opposite sex act as mediators, not competition between the sexes as the term intersexual competition seems to suggest (Andersson, 2021; Shuker & Kvarnemo, 2021a, 2021b). Regardless of its denomination, mate choice is commonly thought as acceptance (or rejection) of individuals of certain phenotypes by individuals of the opposite sex, leading to non-random mating (Halliday, 1983). However, any investment dependent on prospective or realised mates' phenotype before, during, and/or after copula, can be considered mate choice (Bonduriansky, 2001; Edward, 2015). This means that both males and females can express mating preferences inconspicuously by, for example, adjusting courtship effort or sperm allocation depending on a mate's phenotype (Reinhold, Kurtz & Engqvist, 2002), or even selecting gametes from particular individuals inside their reproductive tract (i.e. cryptic choice; Thornhill, 1983; Eberhard, 1996, 2019; Firman *et al.*, 2017). Here, we discuss meta-analytical questions that claim to investigate mate choice or mate attractiveness (but see Supplementary material), even though some of them might also include measures that confound with other topics (see below). In total, this category included 30 questions from 29 studies (Figure 7).

Despite the many ways organisms can express mate preferences, assessing mate choice represents a challenge as decisions of individuals of both sexes are often involved (reviewed in Dougherty, 2020). Consider the outcome of an experiment in which a male and a female are put together in a confined space: if they copulate, was it a product of choice or coercion? If they do not, who was responsible for the rejection? The male, the female, or both? As if the confusion form this simple scenario is not concerning enough, several meta-analytical studies combine mate choice experiment outcomes with observations from the field or of mixed groups of individuals regarding individuals' mating success (e.g. Møller & Thornhill, 1998; McLean, Bishop & Nakagawa, 2012; Kamiya *et al.*, 2014; Dougherty, 2023) or mating patterns (e.g. Yukilevich, 2012; Ihle & Forstmeier, 2013; Winternitz *et al.*, 2017; Rometsch, Torres-Dowdall & Meyer, 2020), which can be a product of other processes besides mate choice (see sections III.5.f and III.5.g).

Most questions that fit this category are simply concerned with identifying which aspects or traits are preferred by mates (Table S5). In contrast, other studies attempt to understand the conditions that modulate the strength and/or direction of mate choice expression (e.g. choosers' traits: Pollo *et al.*, 2022; Dougherty, 2023; Richardson & Zuk, 2023; experimental design: Dougherty & Shuker, 2015; conspecifics' choices: Jones & DuVal, 2019; Davies *et al.*, 2020; temperature: Pilakouta & Baillet, 2022; various: Dougherty, 2021b). Although we note that species or population recognition might be a distinct process to mate choice (Rosenthal, 2017), five meta-analyses we included here explored whether individuals prefer conspecifics over others from different populations or species (Ord & Stamps, 2009; Ord *et al.*, 2011; Yukilevich, 2012; Parker *et al.*, 2018; Rometsch *et al.*, 2020). Lastly, other meta-analyses in this category evaluated the heritability of mate preferences (Prokuda & Roff, 2014) and the covariance between mate choice and preferred traits (Greenfield *et al.*, 2014).

(e) Remating and eagerness to mate

In this category, we combined other reproductive aspects that have not yet been covered in the topics already discussed above: remating and eagerness to mate. While these are thought as simple cogs in the reproduction machine and not as mechanisms of sexual selection, they can still be crucial to sexual selection. For example, when females of species with internal fertilisation mate more than once (i.e. are polyandrous), male-male competition may also occur post-copula through sperm competition, affecting sexual selection on males (Parker & Pizzari, 2010; Kvarnemo & Simmons, 2013). Despite the importance of examining factors related to remating and eagerness to mate, we detected only 11 questions (each from a different meta-analysis) that fitted this category (Figure 7).

The majority of the questions from this topic are alike: they evaluate the benefits and/or costs to individuals (or to their offspring) of mating multiple times versus mating once or fewer times (Table S5). Similarly, two other studies verified whether individuals' mating history can influence the available resources they have for further copulas, as well as their subsequent impact on the reproductive success of individuals they copulate with (Torres-Vila & Jennions, 2005; Zhang *et al.*, 2016), which ultimately could influence remating decisions. The remaining studies in this category are slightly distinct: Mori & Evenden (2013) investigated the association between delayed mating and fitness, while Pilakouta & Baillet (2022) assessed whether eagerness to mate is related to temperature.

(f) Mating success

Until now, we have mostly discussed proximate topics that involve individual traits and decisions, from morphological structures to complex sets of behaviours. Yet, sexual selection (and evolution of sexual traits) only occurs when intrasexual competition and mate choice produce variation in individuals' fitness. Darwin (1871) proposed that this occurs when these mechanisms produce skewed mating success, in which only a portion of the best competitors (through force or looks) mate and leave descendants (but see section III.5.i). We found a total of 23 questions focusing on mating success, from 21 meta-analyses (Figure 7). Most of these questions are related to sexual traits and mechanisms of sexual selection, which have already been discussed in previous topics (see above). Other questions in this category explore whether mating success is linked to body size (e.g. Sokolovska, Rowe & Johansson, 2000; Kim *et al.*, 2021) or to specific conditions (e.g. density and sex ratio: Nieberding & Holveck, 2017; lek size: Isvaran & Ponkshe, 2013; parasitism: Hasik & Siepielski, 2022; temperature: Pilakouta & Baillet, 2022).

(g) Mating patterns

While mating success refers to the number of mates obtained (ignoring these mates' traits), mating patterns refer to the arrangement of individuals observed mating (or paired) in relation to their traits. Mating patterns can be influenced by different elements, from mechanisms of sexual selection (intrasexual competition and mate choice) to temporal or spatial segregation (Jiang, Bolnick & Kirkpatrick, 2013). This means that studies on mating patterns usually concentrate on what is observed (often in the field), not necessarily how these patterns happened. Non-random mating patterns are referred to as assortative or disassortative mating, in which traits of mating individuals are positively or negatively related, respectively. Thus, all 14 meta-analytical questions (each from a different study) that fitted this category (Figure 7) explicitly mention assortative or disassortative mating.

Many questions from this topic investigated whether non-random mating patterns occur in respect to a specific trait, such as body size (Arnqvist *et al.*, 1996; Graham *et al.*, 2015; Green, 2019), relatedness (Ihle & Forstmeier, 2013; Pike, Cornwallis & Griffin, 2021), major histocompatibility complex (Winternitz *et al.*, 2017), or population or species identity (Randler, 2008; Rometsch *et al.*, 2020; with some specifically testing population isolation on reproductive isolation: Florin & Ödeen, 2002; Yukilevich, 2012). Conversely, other questions were unrestricted regarding traits evaluated (e.g. Jiang *et al.*, 2013; Janicke *et al.*, 2019; Wang *et al.*, 2019; Rios Moura *et al.*, 2021), with some of them assessing whether observer bias (Wang *et al.*, 2019) and sample pooling methods (Rios Moura *et al.*, 2021) were associated with estimates observed. Lastly, Janicke *et al.* (2019) verified whether assortative mating is related to species richness.

(h) Divorce and extra-pair patterns

All topics discussed so far are relevant for the entire animal kingdom (although taxa are unequally investigated, see section III.2.a). Here, however, we discuss divorce, extra-pair copulations (hereby EPCs), and extra-pair paternity (hereby EPP), which pertain to a specific niche in the sexual selection literature that applies only to socially monogamous animals (forming exclusive social pairs for reproduction). In this context, divorce means re-pairing with another individual whilst the previous partner is still alive (Choudhury, 1995), whereas EPP refers to fertilizations from EPCs (i.e. copulas outside of the social bond; Griffith, Owens & Thuman, 2002). Altogether, this category gathered 16 questions from 16 meta-analyses (Figure 7).

Only three meta-analytical questions involved divorce, verifying the association between this behaviour with breeding failure before and/or after its occurrence (Dubois & Cézilly, 2002; Culina *et al.*, 2015; Culina & Brouwer, 2022). Other questions in this category explored the relationship between EPCs or EPP and certain traits, such as age (Cleasby & Nakagawa, 2012), ornaments or sexual signals (Table S5), parental care (Arnqvist & Kirkpatrick, 2005; Albrecht, Kreisinger & Piálek, 2006), pair relatedness (Arct, Drobniak & Cichoń, 2015; Hsu *et al.*, 2015), or a mix of these traits (Møller & Ninni, 1998; Akçay & Roughgarden, 2007). In addition, a couple of these studies also tested whether offspring fitness is associated with its genetic origin (intra- vs extra-pair; Arnqvist & Kirkpatrick, 2005; Akçay & Roughgarden, 2007).

(i) Sexual conflict and estimates of sexual selection

Here, we briefly review the 14 meta-analytical questions (each from a different study) that focused on the two remaining topics related to sexual selection: sexual selection estimates (see Fitze & le Galliard, 2011; Henshaw, Kahn & Fritzsche, 2016; Anthes *et al.*, 2017) and interlocus sexual conflict (Parker, 1979; Chapman *et al.*, 2003) (Figure 7).

Two meta-analytical studies explored sexual selection on traits using standardised selection gradients (β: regression between standardised trait values and relative fitness, Lande & Arnold, 1983). As a fitness proxy, Hoekstra *et al.* (2001) used mating success, whilst Dougherty & Shuker (2016) used both mating and insemination success. Other estimates of sexual selection, such as Bateman's gradient (β_{ss}: average reproductive success gains from each additional mating; Bateman, 1948) and opportunity of sexual selection (I_s *or* I_{mates}: variance in relative mating success; Wade, 1979; Shuster & Wade, 2003), were much more common in our dataset (Table S5). Macedo-Rego *et al.* (2020a, 2020b) also used the Jones' index (s'_{max}; Jones, 2009), albeit Rios Moura & Peixoto (2013) made their own estimate (I_{dif}: I_s if mating were random minus observed I_s). Aside from verifying the mean estimates of sexual selection found in the literature, several meta-analyses investigated whether these estimates were associated with other variables, like availability of reproductive sites (Alissa, 2018), monopolisation of mates (Macedo-Rego *et al.*, 2020b), operational sex ratio (Rios Moura & Peixoto, 2013; Janicke & Morrow, 2018), sexual size dimorphism (Janicke & Fromonteil, 2021), and species richness (Janicke *et al.*, 2018). Yet, estimates of sexual selection present several constraints regarding how they are computed, which was the main subject of some meta-analyses (e.g. how mating success is measured and whether zero mating success is included; Anthes *et al.*, 2017; Macedo-Rego *et al.*, 2020a). Note that these estimates of sexual selection do not actually take into consideration effects of mate quality (see Fitzpatrick, 2015).

At last, we found two meta-analytical studies with unique perspectives in the literature. First, Cally *et al.* (2019) assessed fitness consequences on a population level from experiments that enforced monogamy or manipulated adult sex ratio, essentially modulating sexual selection. Second, Gómez-Llano *et al.* (2023) evaluated the costs imposed by one sex's on the fitness of the other sex through direct (e.g. traumatic insemination) and/or indirect (e.g. harassment) harm, the only study on sexual conflict in our dataset.

(6) Further challenges and recommendations

Conducting a meta-analysis on a topic related to sexual selection can be an arduous process. This is because this field presents many conceptual and analytical challenges that are rarely addressed. In this section, we discuss these challenges and provide recommendations for future work in the field of sexual selection, both for empiricists and researchers conducting meta-analyses (summarised in Table 2, see also Nakagawa *et al.*, 2017).

Table 2. Recommendations for meta-analytical research projects on topics related to sexual selection. Some of these recommendations can also be applied on projects with other methodological approaches in this field (in grey). FAIR stands for Findable, Accessible, Interoperable, Reusable (see Wilkinson *et al.*, 2016).

Item	**Summarised recommendations**	**Manuscript section(s)**
Research team	• Form diverse and inclusive research teams (e.g. gender equal) • Consider inviting researchers from the Global South for collaborations	III.6.d
Research question and scope	• Be mindful of the extent that certain taxa and topics related to sexual selection have received and your potential contribution to existing biases in the literature	III.2.a, III.2.e, III.5

	• Exclude humans as a study species if the synthesis also involves other animals	III.2.b, III.6.a
	• Avoid limiting (*a priori*) the study to only males (or only females for mate choice)	III.2.f
	• Use the PECOS framework to formalise a research question • Be aware of the trade-offs from the chosen scope	III.6.b
Preregistration or protocol	• Develop a plan for the study and make it publicly available before conducting it	III.3.f
Data search	• Use different search sources (e.g. multiple databases), including grey literature • Provide search details, such as the dates on when it was conducted and the exact queries with Boolean operators used	III.3.a
Screening process	• Provide the number of retrieved, included, and excluded studies at every step of the screening process • Provide individual justification for study exclusions at the full-text screening stage • Make a PRISMA-like figure to summarise the screening process	III.3.b
Analysis	• Use appropriate software (e.g. R packages *metafor* or *MCMCglmm*) • Deal with statistical non-independence (e.g. from phylogeny and shared studies)	III.3.c
	• Quantify heterogeneity • Test for publication bias	III.3.e
	• Ensure that the meta-analytical model reflects the main question • Use moderators to explore sources of heterogeneity and to answer smaller questions	III.6.c
Code and data sharing	• Provide all data used in the study (preferentially in a separate FAIR file rather than in a table in the study)	III.3.d

- Provide metadata for all data shared (in a separate file)
- Provide analysis scripts

(a) Inclusion of humans

Darwin's (1871) book "The descent of man, and selection in relation to sex" addresses human evolution and sexual selection (Ruse, 2015). At times, Darwin (1871) explicitly mixed these topics, using several examples from human society to support his arguments related to sexual selection. Using our own experiences to understand nature is intuitive (Kokko, 2017), and perhaps many scientists believe that studying other animals' reproductive behaviours can help us to comprehend ourselves. However, we show a distinct aspect from other animals: an extremely complex culture that has a strong effect on our behaviours, including the ones related to reproduction (Eagly & Wood, 1999). For instance, culture influences which phenotypes are deemed attractive (Silverstein *et al.*, 1986) and pair formation can be subjected to the decision of others (e.g. parents' influence; Buunk, Pollet & Dubbs, 2012). Additionally, people may choose to have few or no children through celibacy, contraception methods, or abortion, meaning that reproductive success plainly loses its utility in sexual selection studies when compared with other organisms.

Issues from including humans in meta-analyses of sexual selection are not only problematic for behavioural traits: selection on humans has been modified or even nullified as we increasingly control our environment. For instance, crooked teeth in humans became common only recently, after we started eating processed (soft) foods that relaxed selection for large jaws that could accommodate all of our teeth (Corruccini, 1984; Lieberman *et al.*, 2004). Thus, even for traits that are not under direct influence of culture (e.g. sperm traits), the distinct evolutionary pressures on modern humans might mislead comparisons with other organisms. This argument also applies for domesticated animals, as the process of artificial selection applied on them can modify their traits, as noted by Mautz *et al.* (2013).

We ultimately recommend to evolutionary biologists to exclude humans from meta-analyses on topics related to sexual selection with other animals for the reasons above. Furthermore, the thought of humans as "just another species" is humble, but can also lead to anthropomorphisation of other organisms. This might be especially relevant for how we think of males and females (and their reproductive patterns; see section III.2.f), as our gender notions may affect our perceptions of them (Ahnesjö *et al.*, 2020; Pollo & Kasumovic, 2022). For example, Darwin (1871) argued that women are inferior to men, among other conclusions based on his observations from the Victorian society he lived in, which were described as processes emerging from our biology. A potential consequence of this type of rationale is falling into a vortex of self-affirmation, in which our societal views influence our notion of sex differences in nature and *vice versa*. In fact, part of the field of evolutionary psychology, a field born out of evolutionary biology from the 1970s (strongly based on Trivers, 1972; see also Fausto-Sterling *et al.*, 1997), seems to have succumbed to this pattern as they recurrently overemphasise gender differences (Eagly & Wood, 1999; Stewart-Williams & Thomas, 2013). Studies from evolutionary psychologists commonly rely on assumptions related to other animals and ancestral human societies (for which information is scarce) to make hypotheses on current human behaviours (e.g. Geary, 2021). For instance, Lewis *et al.* (2017) claimed that high-heels make women more attractive because they can increase women's lumbar curvature, representing a morphological adaptation for child bearing that would ultimately signal their high-quality to men. Lewis *et al.* (2017), however, barely mentioned alternative non-biological explanations to why women are deemed more attractive in high heels (e.g. influence of media). In addition, the authors completely ignored any historical relevant facts about high-heels, including that they were also used by men and were a symbol of masculinity for seven centuries before being associated with femininity in the 18th century (Semmelhack, 2020). This shows that reducing human behaviours to a simple biological product, which is an assumption implicitly made by meta-analyses related to sexual selection that include them with other species, can have profound consequences. If researchers strongly disagree with our stance of excluding humans from meta-analyses with other animals, we suggest that they at least include additional analyses, in which effect sizes obtained from humans are subsetted to assess their role in the study's conclusions (as in Fromonteil *et al.*, 2023).

(b) Conceptual challenges and recommendations

Darwin (1859, 1871) founded the field of sexual selection using jargon: he extensively used the terms "primary sexual characters" and "secondary sexual characters" in his work (attributing their creation to the surgeon and anatomist John Hunter). These terms, mainly secondary sexual characters, served as the backbone for Darwin's arguments on the existence of sexual selection. Whilst primary sexual characters refer to traits necessary for reproduction (e.g. gonads and genitalia), secondary sexual characters were used by Darwin to refer to traits that would supposedly be linked to mate acquisition but not reproduction itself. Secondary sexual characters are usually classified as ornaments (mate attraction) or weapons (intrasexual combat), which also became ubiquitous terms in the literature related to sexual selection (e.g. Andersson, 1994; Andersson & Iwasa, 1996; Andersson & Simmons, 2006; Shuker, 2010; Hosken & House, 2011; Simmons, Lüpold & Fitzpatrick, 2017; Lindsay *et al.*, 2019). Such popularity can also be seen for the term "sexual signal" (whose exact origin is unknown to us, but probably from the 1980s; e.g. Endler & McLellan, 1988; Endler, 1992), which highlights the communicative function (i.e. role in inter-individual interactions) of secondary sexual traits.

Researchers interested in related topics to sexual selection commonly employ this jargon when describing their question and selection criteria in meta-analyses. However, the expressions mentioned above are vague and loosely used, potentially causing transparency issues. For instance, numerous traits are frequently classified as secondary sexual characteristics simply based on sexual dimorphism, without a proper examination of its role on mate acquisition or reproductive success. This practice creates problematic cases, such as body size, which is explicitly mentioned as a secondary sexual trait by some (e.g. Simmons *et al.*, 2017). Although indeed there is evidence that males in many species benefit from larger bodies in male-male contests, leading to sexual selection on this trait and sometimes male-biassed size dimorphism (Andersson, 1994), this pattern is simply assumed at times. An example can be seen in Moore & Wilson (2002), who relied exclusively on sexual size dimorphism as a proxy for sexual selection without evidence that body size was truly relevant to reproduction in all species investigated. The precarity of this assumption becomes evident when several cases of sexual size dimorphism occur due to other types of selection on body size, such as fecundity selection resulting in females larger than males in many invertebrates (but see Pincheira-Donoso & Hunt, 2017). Furthermore, if secondary sexual characteristics are synonymous with sexually selected traits (see Wiens & Tuschhoff, 2020), then this term could also encompass primary sexual traits, which are often under sexual selection (e.g. genitalia can play a role in post-copulatory competition; Andersson & Simmons, 2006). Similarly, traits related to gametes (e.g. sperm velocity) appear to be in a conceptual limbo, as they are rarely associated with this lingo despite also being determinant for post-copulatory processes (but see Rico-Guevara & Hurme, 2019).

Mentioning sexual ornaments also requires clarification, as this expression simply alludes to shiny, elaborate, or extravagant traits used to attract mates. The fact that the word ornament has a colloquial meaning that predates its scientific (sexual) meaning is not a coincidence: we tend to be fascinated by what catches our eyes or ears, revealing that our own sensory bias might not be reliable to describe all traits and patterns existing in nature. Thus, at least theoretically, other kinds of traits (e.g. chemical, tactile, electric; Kramer, 1990; Johansson & Jones, 2007) can also be classified as ornaments despite being inconspicuous to us. Although we cannot escape our human condition when observing nature (see Kokko, 2017), it is crucial to acknowledge our biases, especially in meta-analyses that claim to explore general patterns related to sexual ornaments (section III.5.a). This also applies for other terms, such as weapons and sexual signalling, which tend to be used for morphological structures and acoustic displays, respectively. Moreover, sexual ornaments and sexual signals seem to be overlapping concepts, although the latter might also encompass signals used during agonistic encounters (e.g. threat signals). Overall, the many inconsistencies in the use of these expressions reveal that their careless application can be dangerous and misleading.

Ultimately, the words researchers choose to describe their questions are pivotal because they define its scope and the required degree of detailing what exactly is being studied. The specific expressions linked to sexual selection we mentioned in this section tend to be quite abstract and thus represent a wider scope than specific terms that depict direct measurements (e.g. sexual signal vs. song frequency, respectively; Figure 16). The larger the scope of a question, the more likely the diversity of measurements included in a meta-analytical study will be (e.g. more distinct traits, methods, taxa), increasing the apparent generality of the results at the cost of its interpretability (Figure 16; Spake *et al.*, 2022). The fact that many meta-analyses have a wide scope possibly explains the common pattern of high heterogeneity found in meta-analytical studies in ecology and evolution (Senior *et al.*, 2016a). Greater heterogeneity means that a global effect size has less reliability and that moderators are decisive in understanding patterns (Spake *et al.*, 2022). In other words, the motto invoked by biologists “it depends” intensifies with heterogeneity. However, studies with wide scope questions receive more attention and usually get published in prestigious journals precisely because they claim to settle theoretical conundrums with a single, concise estimate. Such a practice means that the studies that carry the most responsibility to untangle complex patterns are commonly the ones that highlight superficial results while downplaying their limitations. For instance, García-Roa *et al.* (2020) claimed to examine the effect of temperature on sexual selection, but details of their dataset could only be found in their supplementary material (very little information in-text). A closer inspection on their data reveals that most effect sizes for females were based on fecundity, which is far from being strictly related to sexual selection, casting doubt on the general validity of García-Roa *et al.* (2020)'s claims. Many other meta-analysis in our systematic map show a similar problem, asking wide scope questions with unclear sexual traits or sexual selection proxies (e.g. Møller & Alatalo, 1999; Møller, Christe & Lux, 1999; Weir *et al.*, 2011; Cally *et al.*, 2019; Hasik & Siepielski, 2022).

As we showed, the specific expressions linked to sexual selection refer to diverse traits and patterns found in nature, being inherently loosely defined. Researchers thus need to be careful when using these terms in meta-analyses, clarifying what they truly encompass so readers can understand their study's focus and limitations. Clarification can be done by choosing the appropriate words that describe their research questions and goals (Figure 16) as well as by showing detailed information on the data searched and utilised in the manuscript (not just in the supplementary material). Finally, we emphasise that, as the scope of a question (and consequently of the study) gets wider, moderators and meta-regressions become increasingly necessary to avoid false generalisations (Nakagawa *et al.*, 2017; Spake *et al.*, 2022; see section III.6.c).

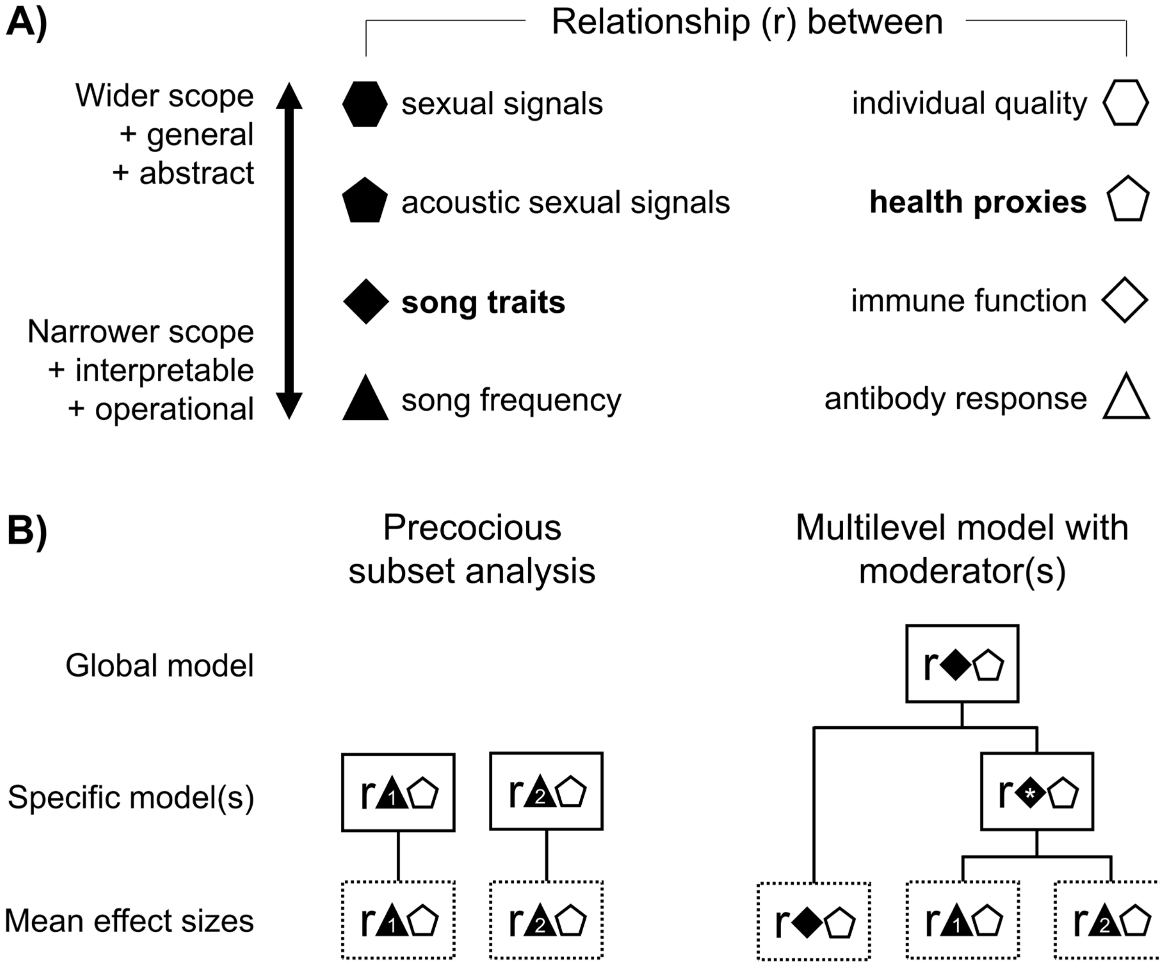

Figure 16. Meta-analytical challenges in sexual selection using (Garamszegi, 2005) as an example. Panel A shows how the scope of a question (e.g. whether two variables are related, denoted as "r") is associated with the exact words used to describe it, in which shapes with more vertices represent wider scope. Terms in bold highlight our suggestion for a general question in (Garamszegi, 2005) (see text). Panel B illustrates possible analytical implementations, with different options of meta-analytical models (solid line boxes) and their respective estimated mean effect sizes (dotted line boxes). A multilevel model with moderator(s) is recommended to estimate a global mean effect size that matches a general question (see text). Numbers inside shapes represent different subgroups (e.g. 1 = song frequency, 2 = song complexity), while a star (*) inside a shape represents the use of a moderator within a meta-analytical model.

(c) Analytical challenges and recommendations

Several papers and books specifically targeted at ecology and evolutionary biologists provide helpful recommendations on how to conduct meta-analyses. Their focus ranges from initial procedures that are also part of systematic reviews (e.g. search and screening) to specific statistical methods (e.g. Nakagawa & Cuthill, 2007; Nakagawa & Santos, 2012; Koricheva *et al.*, 2013; Noble *et al.*, 2017; Foo *et al.*, 2021; O'Dea *et al.*, 2021; Nakagawa *et al.*, 2021; Spake *et al.*, 2022; Yang *et al.*, 2023b). Nonetheless, we noticed that many meta-analyses included in our systematic map conduct precocious subset analyses (i.e. practice of partitioning the extracted data and then fitting a separate meta-analytical model on each subset without a global model; Figure 16). This procedure often leads to a mismatch between the general question asked in the study and its respective statistical analysis. In this section, we use a fairly simple meta-analysis (Garamszegi, 2005) to illustrate our argument.

Garamszegi (2005) examined the relationship between distinct bird song traits and health proxies (e.g. parasite prevalence or immune function). Intuitively, one can assume that this study asks "is song expression associated with health proxies?". Yet, Garamszegi (2005) shattered the expectation of a single answer (e.g. through a global mean effect size) by presenting four separate mean effect sizes, each related to a different song trait (performance, complexity, duration, and frequency). This exemplifies precocious subset analysis, and we argue that this approach generates two issues.

First, the reader is left without an answer to a general question (even if it is a vague one). Garamszegi (2005) only provides answers to separate, specific questions (e.g. does song frequency reflect health?; does song complexity reflect health?; etc). Second, subset analysis could increase error type I (i.e. rejecting a null hypothesis that is actually true) when compared with a unified, random-effects (multilevel) model (cf. Nakagawa & Santos, 2012;

Nakagawa *et al.*, 2022). Third, effect sizes from groups analysed with different models cannot be statistically compared. Fourth, it limits the test of other moderators and their interactions. For example, Crean & Senior (2019) verified the effect of high-fat diets on model mammals regarding different sperm traits and several measurements of reproductive success, but each of these traits and measurements (17 in total) was analysed separately, meaning that the role of moderators (diet duration, specimen age, etc) could not be assessed across all effect sizes (only within each subset). Why analytical fragmentation has been employed so often is unclear, but we suspect that researchers' concern of being accused of making unfair comparisons through wider-scope models has increased the use of this approach. Alternatively, researchers may simply believe that each sub-question requires a separate meta-analytical model. Regardless of the reason, we believe it is crucial to discuss the benefits and disadvantages of each approach.

Analysing data separately may seem fair at first glance: meta-analyses are often criticised for clumping conceptually distinct data to make inferences (i.e. "mixing apples and oranges"; Arnqvist & Wooster, 1995; Noble *et al.*, 2022). Although meta-analyses in other fields are not exempt from this complaint, the diversity of methodologies, biological traits, mechanisms, and patterns across species and empirical studies makes meta-analyses in the field of ecology and evolution particularly prone to this criticism. However, researchers have little option other than categorising measurements to make comparisons. For example, although Garamszegi (2005) analysed song traits separately, each one of them still included different measurements (e.g. song frequency involved both lowest and highest frequency, as well as frequency range). Moreover, parasite prevalence and immune function were analysed together, revealing that this author deemed them analogous measurements. Therefore, subsetting the analysis did not avail Garamszegi (2005) to entirely escape from mixing apples and oranges, essentially because it is inevitable to do so to a certain extent (Rosenthal, 1991).

We suggest to researchers to, foremost, carefully define a question using the PECO/PICO framework (Richardson *et al.*, 1995; Foo *et al.*, 2021) that encapsulates all subquestions (if possible). Although multiple specific questions can be asked in a single meta-analytical study, they often can be summarised into a more general one, as we have shown for Garamszegi (2005) (Figure 16). This allows researchers to conduct one or few models with predictors (i.e. moderators) that can potentially explain the variation found, emphasising their effectiveness or lack thereof in doing so (Spake *et al.*, 2022), instead of fragmenting the data and analysis into multiple subsets from the start (Figure 16). These moderators fundamentally work as the specific questions that many authors ask when using subset analyses. A global model, however, becomes inadvisable when sub-questions are completely unrelated to one another so a more general question becomes infeasible (although this might be subjective) or when effect sizes calculated are distinct in nature (based on means vs. based on variances). This approach makes it even more critical that authors specify the direction of calculated effect sizes for each measurement before analysis, preferably based on grounded hypotheses (e.g. Dougherty, 2021a). Nonetheless, the direction of effect sizes can be modified ad-hoc if one of the subsets presents an opposite pattern, so that the global mean effect size can focus on magnitude rather than direction.

Researchers might still harbour suspicion over a global model approach in complex cases as, until now, we have only used a meta-analysis with relatively specific questions as an example (Garamszegi, 2005). Thus, consider Alissa (2018), who asked whether limitation in reproductive sites is associated with several measurements related to sexual selection (e.g. pre-copulatory intrasexual competition, sperm competition, selection on male traits, and opportunity for sexual selection). In this study, the author conducted several meta-analyses (i.e. subsets were independently analysed), probably because of wildly distinct measurements included in it. Although it would not be possible to combine opportunity for sexual selection with the other measurements because they are represented by distinct types of effect sizes in the study (lnCVR and Zr, respectively), all else could be grouped together. Grouping the effect sizes to estimate a single mean effect size would allow the author to compare the effect sizes for each measurement related to sexual selection. In truth, this global effect size would represent a more abstract and less interpretable estimate: whether reproductive site limitation is associated with various measurements related to sexual selection (see section III.6.b). However, the existence of a global mean effect size does not preclude researchers to focus on specific, narrow questions, which can be done with moderators and meta-regressions. Doing so would maintain the original conceptual structure in Alissa's (2018) manuscript while correcting its analysis.

Our recommendation to unify multiple, usually related questions to fit a single (or as few as possible) meta-analytical model does not mean to incentivize wider questions, but rather attempts to streamline analyses. In fact, focused meta-analyses (i.e. with narrow questions) can be more reliable because they are easy to interpret (Figure 16). Conversely, as previously mentioned (see section III.6.b), studies with wide questions that employ few or no meta-regressions might be of little use if they show highly heterogeneous estimates. Although the use of moderators might be constrained (e.g. due to too few data points), authors should at least justify these limitations and consider them to avoid misleading conclusions.

(d) Authorship diversity

Our bibliometric analysis suggests that authors conducting meta-analyses on topics associated with sexual selection are often men based in developed countries (see section III.4), which is a pattern often found in academia (Astegiano, Sebastián-González & Castanho, 2019; Huang *et al.*, 2020). We note, however, that our analysis regarding countries is purely based on affiliations listed, meaning that authors could be of a different nationality (i.e. immigrants).

For instance, although four of the authors of the present study are affiliated to the same Australian university, none was born in Australia. Still, the existence of international and intercontinental collaborations we found reiterate the globalisation of science (Gui, Liu & Du, 2019), although concentrated in the Global North (i.e. developed countries).

While patterns of research production for countries may follow economic trends (e.g. amount of public funding to research in each country; Gush *et al.*, 2018), gender inequity in research production has multiple explanations. First, it might be a consequence of a "leaky pipeline" that precludes women from filling higher academic positions as often as men (Shaw & Stanton, 2012; McDermott *et al.*, 2018). This is also seen in boards of scientific societies, in which women are outnumbered by men (Potvin *et al.*, 2018). Intuitively, this entails fewer opportunities for women to conduct research. In addition, there is a gender gap in productivity in which women are outperformed by men, even in gender equal academic faculties (Astegiano *et al.*, 2019). This can be a consequence of differential pressures on women, compared with men, from inside (e.g. lower salary and more time spent in administrative tasks; DesRoches *et al.*, 2010) and outside (e.g. family caring; Fox, Fonseca & Bao, 2011) of academia.

The patterns we found regarding countries and gender are not limited to this specific literature, but simply another example of a more generalised problem in academia and research production overall. Yet, this does not mean we should accept this pattern idly. Rather, it emphasises that actions are needed to change this precarious situation as diversity can promote creativity (McLeod, Lobel & Cox, 1996) and innovation (Nieto & Santamaría, 2007), ultimately being beneficial to science (Intemann, 2009; Cheruvelil *et al.*, 2014). The most obvious example of benefits brought by diversity in the context of meta-analyses comes from the inclusion of people with distinct language skills (e.g. from different countries) that can increase the coverage of the literature retrieved beyond just papers in English (Amano *et* *al.*, 2023). Furthermore, people of distinct nationalities can also vary in how they perceive stereotypes related to sexual behaviours in nature, making diverse teams more open to various perspectives (Pollo & Kasumovic, 2022).

Several solutions have been proposed to ameliorate these diversity issues. For instance, researchers from the Global North should actively and fairly collaborate with researchers from the Global South (see more suggestions in Haelewaters, Hofmann & Romero-Olivares, 2021 and in Nakamura *et al.*, 2023). Furthermore, many actions are being employed by different institutions to address gender disparity observed in academia, but they are rarely applied on a large scale or are ineffective (see Casad *et al.*, 2021) and references within). Yet, gender and country of affiliation or origin are just a few of several aspects that matter to diversity. For instance, people of colour (Evangelista *et al.*, 2020) and from lower economic backgrounds (Lee, 2016) are commonly excluded from academia, revealing a need to develop ways to include these marginalised groups as well.

(e) Beyond meta-analyses

Throughout our manuscript, we identified several biases related to the content of meta-analyses on topics related to sexual selection (e.g. on specific questions, taxonomic groups, focal sex, etc). However, this might simply be a reflection of biases that already occur in the primary literature on sexual selection. For instance, although researchers might be interested in meta-analytical questions that can encompass all animals, data available are highly concentrated in certain animal groups (e.g. birds; see section III.2.a). Thus, it might be fruitless to expect that researchers interested in meta-analyses can solve these biases alone if the raw material (primary evidence) remains unchanged. In fact, proper meta-analyses are also systematic reviews, highlighting gaps in the primary literature and therefore serving as indicators of the extent of our empirical knowledge.

One source of generalised biases in the literature may lie in the current publishing system, which shows an obsession with "novelty" (Cohen, 2017; Brembs, 2019; Ottaviani *et al.*, 2023). Paradoxically, novelty is rarely defined by journals that request it, but possibly refers to new and impactful discoveries, albeit this is highly subjective (Brembs, 2019). On one hand, this can encourage the production of meta-analyses because of their great power to test hypotheses (but see section III.6.c). Indeed, meta-analytical studies are often published in prestigious journals (e.g. Weaver *et al.*, 2018; Nolazco *et al.*, 2022). However, as previously mentioned, meta-analyses in ecology and evolution commonly detect high heterogeneity among effect sizes and often fail to find factors that can explain it, mainly because data are scarce. This means that continuing to generate empirical data is almost always necessary, regardless of the subject. Yet, the pursuit of novelty only reduces the reward of further empirical research on a topic, especially with methods, organisms (even if not the same species or even genus), or results that resemble already published papers. For example, a study on mate choice with a spider species becomes less valuable to the publishing system the more studies on mate choice there are with other spiders (even though there are more than 50,000 species of spiders). This perspective makes empirical research harder to publish in top-tier journals, ultimately discouraging scientists from producing empirical data that would be extremely valuable to build a solid foundation of the theory. In a system that hampers research endeavours because of some similarity with previous work, replication becomes almost impossible despite being pivotal to science (Kelly, 2006; Nakagawa & Parker, 2015; Fraser *et al.*, 2020).

Limited research replication has many negative impacts on meta-analyses. Not only does it reduce the amount and robustness of empirical data available, but also precludes updates of meta-analyses as this can be seen as "not novel". Our study actually shows that many meta-analyses on topics related to sexual selection should be redone, both because new data has accumulated since they were published and because of their substandard methods and reporting (see section III.3). Moreover, the fact that numerous decisions in a research project can generate different outputs (Gelman & Loken, 2013) also applies to meta-analyses. For instance, some meta-analytical studies addressed almost identical questions but had their own particularities and sometimes reached distinct conclusions (e.g. Pollo *et al.*, 2022; Dougherty, 2023). This only emphasises that how research is conducted is as important, if not more, than how novel the question or methods are. Therefore, we deem innovation as pivotal to advancements in the field of sexual selection as long as it does not sacrifice further research of superficially explored topics.

IV. CONCLUSIONS

(1) The vastness of the field of sexual selection can be seen in more than 150 meta-analyses on topics associated with it. Although the first of these studies was published more than 25 years ago, most of them were conducted in the last decade.

(2) We found numerous biases in these meta-analytical studies. Most of them concentrated on birds or insects (taxonomic bias) and on male traits or patterns (conforming sex bias). Furthermore, although the questions asked in these studies were diverse, many concentrated on pre-copulatory sexual traits, such as weapons and ornaments. Thus, we call for greater research attention to females, underexplored animals, and neglected topics such as post-copulatory processes.

(3) The reporting quality of meta-analyses in the field of sexual selection is often poor, indicating that many might be unreliable. This problem is particularly strong for sharing of raw data and analysis scripts, revealing a dire need to improve these issues in future meta-analyses.

(4) We observed both geographical and gender bias in respect to researchers that conducted meta-analyses on topics related to sexual selection. Specifically, most of these papers were authored by men based in developed countries, signalling that gender and socio-cultural diversity might be lacking in the field of sexual selection. This reiterates the need for including minority groups in academia.

(5) We noticed that meta-analyses on topics related to sexual selection commonly employ detrimental conceptual and methodological approaches. We therefore recommend to authors to avoid including humans with other species in meta-analytical studies in this field, to be careful with loose terms that are part of the sexual selection jargon, and to use global meta-analytical models with moderators to make inferences. This, however, should be a consequence of a well thought plan that starts at the inception of the study, with a well formulated question and specific hypothesis.

(6) Despite our focus on meta-analyses, many of the issues pointed out here can be an extension of problems occurring in the primary literature (content) and in academia (authors). Thus, our manuscript possibly serves as a status report for the whole field of sexual selection.

V. ACKNOWLEDGEMENTS

PP, ML, YY, and SN were supported by ARC (Australian Research Council) Discovery Project grants (DP210100812 and DP230101248). The authors declare no conflict of interests.

VI. AUTHOR CONTRIBUTIONS

Conceptualisation: P.P., M.L., S.N.; data curation: P.P.; formal analysis: P.P.; funding acquisition: S.N.; investigation: P.P., M.L., Y.Y., A.C., S.N.; methodology: P.P., M.L., S.N.;

project administration: P.P., S.N.; software: P.P.; supervision: S.N.; visualisation: P.P.; writing - original draft: P.P., S.N.; writing - review & editing: P.P., M.L., Y.Y., A.C., S.N.

VII. DATA AVAILABILITY

The supplementary material is available at https://pietropollo.github.io/map_sexual_selection.

VIII. REFERENCES

References with asterisks were meta-analyses retrieved by our study and used for analysis.

AGUIAR DEL MATTO, L. (2018) Sperm competition games between majors and minors: a meta-regression of fishes with alternative mating tactics. Universidade de São Paulo, São Paulo.*

AH-KING, M. (2022) The history of sexual selection research provides insights as to why females are still understudied. *Nature Communications* **13**, 6976.

AH-KING, M. & AHNESJÖ, I. (2013) The 'sex role' concept: an overview and evaluation. *Evolutionary Biology* **40**, 461–470.

AHNESJÖ, I., BREALEY, J.C., GÜNTER, K.P., MARTINOSSI-ALLIBERT, I., MORINAY, J., SILJESTAM, M., STÅNGBERG, J. & VASCONCELOS, P. (2020) Considering gender-biased assumptions in evolutionary biology. *Evolutionary Biology* **47**, 1–5.

AKÇAY, E. & ROUGHGARDEN, J. (2007) Extra-pair paternity in birds: review of the genetic benefits. *Evolutionary Ecology Research* **9**, 855–868.*

ALBRECHT, T., KREISINGER, J. & PIÁLEK, J. (2006) The strength of direct selection against female promiscuity is associated with rates of extrapair fertilizations in socially monogamous songbirds. *The American Naturalist* **167**, 739–744.*

ALISSA, L.M. (2018) Effect of reproductive site limitation on the intensity of sexual selection and the quality of paternal care: a meta-analysis. Universidade de São Paulo, São

Paulo.*

ALLEN, C. & MEHLER, D.M.A. (2019) Open science challenges, benefits and tips in early career and beyond. *Plos Biology* **17**, e3000246.

ALONZO, S.H. & SERVEDIO, M.R. (2019) Grey zones of sexual selection: why is finding a modern definition so hard? *Proceedings of the Royal Society B: Biological Sciences* **286**, 20191325.

AMANO, T., BERDEJO-ESPINOLA, V., AKASAKA, M., DE ANDRADE JUNIOR, M.A.U., BLAISE, N., CHECCO, J., ÇILINGIR, F.G., CITEGETSE, G., CORELLA TOR, M., DROBNIAK, S.M., GIAKOUMI, S., GOLIVETS, M., ION, M.C., JARA-DÍAZ, J.P., KATAYOSE, R., *ET AL.* (2023) The role of non-English-language science in informing national biodiversity assessments. *Nature Sustainability* **6**, 845-854.

ANDERSSON, M. (1994) *Sexual selection*. Princeton University Press, Princeton, New Jersey.

ANDERSSON, M. (2021) Amending Darwin on "sexual selection": a comment on Shuker and Kvarnemo. *Behavioral Ecology* **32**, 797–797.

ANDERSSON, M. & IWASA, Y. (1996) Sexual selection. *Trends in Ecology & Evolution* **11**, 53–58.

ANDERSSON, M. & SIMMONS, L.W. (2006) Sexual selection and mate choice. *Trends in Ecology & Evolution* **21**, 296–302.

ANTHES, N., HÄDERER, I.K., MICHIELS, N.K. & JANICKE, T. (2017) Measuring and interpreting sexual selection metrics: evaluation and guidelines. *Methods in Ecology and Evolution* **8**, 918–931.

ARCT, A., DROBNIAK, S.M. & CICHOŃ, M. (2015) Genetic similarity between mates predicts extrapair paternity-a meta-analysis of bird studies. *Behavioral Ecology* **26**, 959–968.*

ARIA, M. & CUCCURULLO, C. (2017) *bibliometrix*: an R-tool for comprehensive science mapping analysis. *Journal of Informetrics* **11**, 959–975.

ARNQVIST, G. & KIRKPATRICK, M. (2005) The evolution of infidelity in socially monogamous passerines: the strength of direct and indirect selection on extrapair copulation behavior in females. *The American Naturalist* **165**, S26–S37.*

ARNQVIST, G. & NILSSON, T. (2000) The evolution of polyandry: multiple mating and female fitness in insects. *Animal Behaviour* **60**, 145–164.*

ARNQVIST, G., ROWE, L., KRUPA, J.J. & SIH, A. (1996) Assortative mating by size: a meta-analysis of mating patterns in water striders. *Evolutionary Ecology* **10**, 265–284.*

ARNQVIST, G. & WOOSTER, D. (1995) Meta-analysis: synthesizing research findings in ecology and evolution. *Trends in Ecology & Evolution* **10**, 236–240.

ASTEGIANO, J., SEBASTIÁN-GONZÁLEZ, E. & CASTANHO, C. DE T. (2019) Unravelling the gender productivity gap in science: a meta-analytical review. *Royal Society Open Science* **6**, 181566.

BAILEY, W.J. & HAMMOND, T.J. (2003) Duetting in insects - does call length influence reply latency? *Journal of Zoology* **260**, 267–274.*

BATEMAN, A.J. (1948) Intra-sexual selection in *Drosophila*. *Heredity* **2**, 349–368.

BERNASCONI, G. & HELLRIEGEL, B. (2005) Fertilization competence and sperm size variation in sperm-heteromorphic insects. *Evolutionary Ecology* **19**, 45–54.*

BJERKE, T. & ØSTDAHL, T. (2004) Animal-related attitudes and activities in an urban population. *Anthrozoos* **17**, 109–129.

DE BOER, R.A., VEGA-TREJO, R., KOTRSCHAL, A. & FITZPATRICK, J.L. (2021) Meta-analytic evidence that animals rarely avoid inbreeding. *Nature Ecology and Evolution* **5**, 949–964.

BONCORAGLIO, G. & SAINO, N. (2007) Habitat structure and the evolution of bird song: a meta-analysis of the evidence for the acoustic adaptation hypothesis. *Functional Ecology* **21**, 134–142.*

BONDURIANSKY, R. (2001) The evolution of male mate choice in insects: a synthesis of ideas and evidence. *Biological Reviews* **76**, 305–339.

BONNET, X., SHINE, R. & LOURDAIS, O. (2002) Taxonomic chauvinism. *Trends in Ecology & Evolution* **17**, 2000–2002.

BORENSTEIN, M., HEDGES, L. V., HIGGINS, J.P.T. & ROTHSTEIN, H.R. (2021) *Introduction to meta-analysis*. John Wiley & Sons, Hoboken, NJ.

BREMBS, B. (2019) Reliable novelty: new should not trump true. *PLOS Biology* **17**, e3000117.

BUUNK, A.P., POLLET, T. V. & DUBBS, S. (2012) Parental control over mate choice to prevent marriages with out-group members. *Human Nature* **23**, 360–374.

CALLY, J.G., STUART-FOX, D. & HOLMAN, L. (2019) Meta-analytic evidence that sexual selection improves population fitness. *Nature Communications* **10**, 2017.*

CASAD, B.J., FRANKS, J.E., GARASKY, C.E., KITTLEMAN, M.M., ROESLER, A.C., HALL, D.Y. & PETZEL, Z.W. (2021) Gender inequality in academia: problems and solutions for women faculty in STEM. *Journal of Neuroscience Research* **99**, 13–23.

CHAPMAN, T., ARNQVIST, G., BANGHAM, J. & ROWE, L. (2003) Sexual conflict. *Trends in Ecology & Evolution* **18**, 41–47.

CHERUVELIL, K.S., SORANNO, P.A., WEATHERS, K.C., HANSON, P.C., GORING, S.J., FILSTRUP, C.T. & READ, E.K. (2014) Creating and maintaining high-performing collaborative research teams: the importance of diversity and interpersonal skills. *Frontiers in Ecology and the Environment* **12**, 31–38.

CHOUDHURY, S. (1995) Divorce in birds: a review of the hypotheses. *Animal Behaviour* **50**, 413–429.

CINAR, O., NAKAGAWA, S. & VIECHTBAUER, W. (2022) Phylogenetic multilevel meta-analysis: a simulation study on the importance of modelling the phylogeny. *Methods in*

Ecology and Evolution **13**, 383–395.

CLEASBY, I.R. & NAKAGAWA, S. (2012) The influence of male age on within-pair and extra-pair paternity in passerines. *Ibis* **154**, 318–324.*

CLUTTON-BROCK, T. (2007) Sexual selection in males and females. *Science* **318**, 1882–1885.

COHEN, B.A. (2017) How should novelty be valued in science? *eLife* **6**, 1–7.

CORRUCCINI, R.S. (1984) An epidemiologic transition in dental occlusion in world populations. *American Journal of Orthodontics* **86**, 419–426.

CREAN, A.J. & SENIOR, A.M. (2019) High-fat diets reduce male reproductive success in animal models: a systematic review and meta-analysis. *Obesity Reviews* **20**, 921–933.*

CULINA, A., VAN DEN BERG, I., EVANS, S. & SÁNCHEZ-TÓJAR, A. (2020) Low availability of code in ecology: a call for urgent action. *PLoS Biology* **18**, 1–9.

CULINA, A. & BROUWER, L. (2022) No evidence of immediate fitness benefits of within-season divorce in monogamous birds. *Biology Letters* **18**.*

CULINA, A., RADERSMA, R. & SHELDON, B.C. (2015) Trading up: the fitness consequences of divorce in monogamous birds. *Biological Reviews* **90**, 1015–1034.*

DARWIN, C. (1859) *On the origin of species by means of natural selection*. John Murray, London, UK.

DARWIN, C. (1871) *The descent of man, and selection in relation to sex*. John Murray, London, UK.

DAVIES, A.D., LEWIS, Z. & DOUGHERTY, L.R. (2020) A meta-analysis of factors influencing the strength of mate-choice copying in animals. *Behavioral Ecology* **31**, 1279–1290.*

DAVIES, S.W., PUTNAM, H.M., AINSWORTH, T., BAUM, J.K., BOVE, C.B., CROSBY, S.C., COTE, I.M., DUPLOUY, A., FULWEILER, R.W., GRIFFIN, A.J., HANLEY, T.C., HILL, T., HUMANES, A., MANGUBHAI, S., METAXAS, A., *ET AL.* (2021) Promoting inclusive metrics of success and impact to dismantle a discriminatory reward system in science. *PLoS Biology* **19**, 1–

15.

DELBARCO-TRILLO, J. (2011) Adjustment of sperm allocation under high risk of sperm competition across taxa: a meta-analysis. *Journal of Evolutionary Biology* **24**, 1706–1714.*

DESROCHES, C.M., ZINNER, D.E., RAO, S.R., IEZZONI, L.I. & CAMPBELL, E.G. (2010) Activities, productivity, and compensation of men and women in the life sciences. *Academic Medicine* **85**, 631–639.

DHARMARATHNE, W.D.S.C. & HERBERSTEIN, M.E. (2022) Limitations of sperm transfer in the complex reproductive system of spiders. *Biological Journal of the Linnean Society* **135**, 417–428.*

DOUGHERTY, L.R. (2020) Designing mate choice experiments. *Biological Reviews* **95**, 759–781.

DOUGHERTY, L.R. (2021a) Meta-analysis reveals that animal sexual signalling behaviour is honest and resource based. *Nature Ecology and Evolution* **5**, 688–699.*

DOUGHERTY, L.R. (2021b) Meta-analysis shows the evidence for context-dependent mating behaviour is inconsistent or weak across animals. *Ecology Letters* **24**, 862–875.*

DOUGHERTY, L.R. (2023) The effect of individual state on the strength of mate choice in females and males. *Behavioral Ecology* **34**, 197–209.*

DOUGHERTY, L.R. & SHUKER, D.M. (2015) The effect of experimental design on the measurement of mate choice: a meta-analysis. *Behavioral Ecology* **26**, 311–319.*

DOUGHERTY, L.R. & SHUKER, D.M. (2016) Variation in pre- and post-copulatory sexual selection on male genital size in two species of lygaeid bug. *Behavioral Ecology and Sociobiology* **70**, 625–637.*

DOUGHERTY, L.R., SKIRROW, M.J.A., JENNIONS, M.D. & SIMMONS, L.W. (2022) Male alternative reproductive tactics and sperm competition: a meta-analysis. *Biological*

Reviews **97**, 1365–1388.*

DUBOIS, F. & CÉZILLY, F. (2002) Breeding success and mate retention in birds: a meta-analysis. *Behavioral Ecology and Sociobiology* **52**, 357–364.*

EAGLY, A.H. & WOOD, W. (1999) The origins of aggression sex differences: evolved dispositions versus social roles. *Behavioral and Brain Sciences* **22**, 223–224.

EBERHARD, W.G. (1996) *Female control: sexual selection by cryptic female choice*. Princeton University Press, Princeton, New Jersey.

EBERHARD, W.G. (2019) Cryptic female choice. In *Encyclopedia of Animal Behavior* (ed J.C. CHOE), pp. 441–446. Elsevier, Amsterdam, Netherlands.

EDWARD, D.A. (2015) The description of mate choice. *Behavioral Ecology* **26**, 301–310.

ELLISON, G., JONES, M., CAIN, B. & BETTRIDGE, C.M. (2021) Taxonomic and geographic bias in 50 years of research on the behaviour and ecology of galagids. *PLoS ONE* **16**, 1–22.

EMLEN, D.J. (2008) The evolution of animal weapons. *Annual Review of Ecology, Evolution, and Systematics* **39**, 387–413.

ENDLER, J.A. (1992) Signals, signal conditions, and the direction of evolution. *The American Naturalist* **139**, S125–S153.

ENDLER, J.A. & MCLELLAN, T. (1988) The processes of evolution: toward a newer synthesis. *Annual Review of Ecology and Systematics* **19**, 395–421.

ESHEL, I., VOLOVIK, I. & SANSONE, E. (2000) On fisher-Zahavi's handicapped sexy son. *Evolutionary Ecology Research* **2**, 509–523.

EVANGELISTA, D.A., GOODMAN, A., KOHLI, M.K., BONDOCGAWA MAFLAMILLS, S.S.T., SAMUEL-FOO, M., HERRERA, M.S., WARE, J.L. & WILSON, M. (2020) Why diversity matters among those who study diversity. *American Entomologist* **66**, 42–49.

EVANS, S.R., HINKS, A.E., WILKIN, T.A. & SHELDON, B.C. (2010) Age, sex and beauty:

methodological dependence of age- and sex-dichromatism in the great tit *Parus major*. *Biological Journal of the Linnean Society* **101**, 777–796.*

FAUSTO-STERLING, A., GOWATY, P.A., ZUK, M., WRIGHT, R., SMALL, M., LANCASTER, J. & SMUTS, B. (1997) Evolutionary psychology and darwinian feminism. *Feminist Studies* **23**, 402.

FIRMAN, R.C., GASPARINI, C., MANIER, M.K. & PIZZARI, T. (2017) Postmating female control: 20 years of cryptic female choice. *Trends in Ecology & Evolution* **32**, 368–382.

FISHER, R.A. (1930) *The genetical theory of natural selection*. Oxford University Press, Oxford, UK.

FISKE, P., RINTAMAKI, P.T. & KARVONEN, E. (1998) Mating success in lekking males: a meta-analysis. *Behavioral Ecology* **9**, 328–338.*

FITZE, P.S. & LE GALLIARD, J.F. (2011) Inconsistency between different measures of sexual selection. *American Naturalist* **178**, 256–268.

FITZPATRICK, C.L. (2015) Expanding sexual selection gradients: a synthetic refinement of sexual selection theory. *Ethology* **121**, 207–217.

FLORIN, A.B. & ÖDEEN, A. (2002) Laboratory environments are not conducive for allopatric speciation. *Journal of Evolutionary Biology* **15**, 10–19.*

FOLWELL, M.J., SANDERS, K.L., BRENNAN, P.L.R. & CROWE-RIDDELL, J.M. (2022) First evidence of hemiclitores in snakes. *Proceedings of the Royal Society B: Biological Sciences* **289**, 1–7.

FOO, Y.Z., O'DEA, R.E., KORICHEVA, J., NAKAGAWA, S. & LAGISZ, M. (2021) A practical guide to question formation, systematic searching and study screening for literature reviews in ecology and evolution. *Methods in Ecology and Evolution* **12**, 1705–1720.

FOX, M.F., FONSECA, C. & BAO, J. (2011) Work and family conflict in academic science: patterns and predictors among women and men in research universities. *Social Studies of*

Science **41**, 715–735.

Fraser, H., Barnett, A., Parker, T.H. & Fidler, F. (2020) The role of replication studies in ecology. *Ecology and Evolution* **10**, 5197–5207.

Fromonteil, S., Marie-Orleach, L., Winkler, L. & Janicke, T. (2023) Sexual selection in females and the evolution of polyandry. *Plos Biology* **21**, e3001916.*

Garamszegi, L.Z. (2005) Bird song and parasites. *Behavioral Ecology and Sociobiology* **59**, 167–180.*

Garamszegi, L.Z. & Eens, M. (2004) Brain space for a learned task: strong intraspecific evidence for neural correlates of singing behavior in songbirds. *Brain Research Reviews* **44**, 187–193.*

Garamszegi, L.Z. & Møller, A.P. (2004) Extrapair paternity and the evolution of bird song. *Behavioral Ecology* **15**, 508–519.*

Garamszegi, L.Z., Török, J., Hegyi, G., Szöllõsi, E., Rosivall, B. & Eens, M. (2007) Age-dependent expression of song in the collared flycatcher, *Ficedula albicollis*. *Ethology* **113**, 246–256.*

García-Roa, R., Garcia-Gonzalez, F., Noble, D.W.A. & Carazo, P. (2020) Temperature as a modulator of sexual selection. *Biological Reviews* **95**, 1607–1629.*

Geary, D.C. (2021) *Male, female: the evolution of human sex differences*. American Psychological Association, Washington, DC.

Gelman, A. & Loken, E. (2013) The garden of forking paths: why multiple comparisons can be a problem, even when there is no “fishing expedition” or “p-hacking” and the research hypothesis was posited ahead of time. *Bulletin of the American Society for Information Science and Technology*.

Getty, T. (2006) Sexually selected signals are not similar to sports handicaps. *Trends in Ecology and Evolution* **21**, 83–88.

GOLDBERG, R.L., DOWNING, P.A., GRIFFIN, A.S. & GREEN, J.P. (2020) The costs and benefits of paternal care in fish: a meta-analysis. *Proceedings of the Royal Society B: Biological Sciences* **287**, 20201759.*

GOMES, D.G.E., POTTIER, P., CRYSTAL-ORNELAS, R., HUDGINS, E.J., FOROUGHIRAD, V., SÁNCHEZ-REYES, L.L., TURBA, R., MARTINEZ, P.A., MOREAU, D., BERTRAM, M.G., SMOUT, C.A. & GAYNOR, K.M. (2022) Why don't we share data and code? Perceived barriers and benefits to public archiving practices. *Proceedings of the Royal Society B: Biological Sciences* **289**.

GÓMEZ-LLANO, M., FARIA, G.S., GARCÍA-ROA, R., NOBLE, D.W.A. & CARAZO, P. (2023) Male harm suppresses female fitness, affecting the dynamics of adaptation and evolutionary rescue. *Evolution Letters*, 1–12.*

GONTARD-DANEK, M.-C. & MØLLER, A.P. (1999) The strength of sexual selection: a meta-analysis of bird studies. *Behavioral Ecology* **10**, 476–486.*

GOWATY, P.A. (1997) *Feminism and evolutionary biology*. Springer US, Boston, MA.

GOWATY, P.A. (2015) Standing on Darwin's shoulders: the nature of selection hypotheses. In *Current perspectives on sexual selection* (ed T. HOQUET), pp. 103–118. Springer, Dordrecht, Netherlands.

GRAFEN, A. (1990a) Biological signals as handicaps. *Journal of Theoretical Biology* **144**, 517–546.

GRAFEN, A. (1990b) Sexual selection unhandicapped by the fisher process. *Journal of Theoretical Biology* **144**, 473–516.

GRAHAM, S., CHAPUIS, E., MECONCELLI, S., BONEL, N., SARTORI, K., CHRISTOPHE, A., ALDA, P., DAVID, P. & JANICKE, T. (2015) Size-assortative mating in simultaneous hermaphrodites: an experimental test and a meta-analysis. *Behavioral Ecology and Sociobiology* **69**, 1867–1878.*

GREEN, D.M. (2019) Rarity of size-assortative mating in animals: assessing the evidence with anuran amphibians. *American Naturalist* **193**, 279–295.*

GREENFIELD, M.D., ALEM, S., LIMOUSIN, D. & BAILEY, N.W. (2014) The dilemma of Fisherian sexual selection: mate choice for indirect benefits despite rarity and overall weakness of trait-preference genetic correlation. *Evolution* **68**, 3524–3536.*

GRIFFITH, S.C., OWENS, I.P.F. & THUMAN, K.A. (2002) Extra pair paternity in birds: a review of interspecific variation and adaptive function. *Molecular Ecology* **11**, 2195–2212.*

GUI, Q., LIU, C. & DU, D. (2019) Globalization of science and international scientific collaboration: a network perspective. *Geoforum* **105**, 1–12.

GUINDRE-PARKER, S. & LOVE, O.P. (2014) Revisiting the condition-dependence of melanin-based plumage. *Journal of Avian Biology* **45**, 29–33.*

GUREVITCH, J., KORICHEVA, J., NAKAGAWA, S. & STEWART, G. (2018) Meta-analysis and the science of research synthesis. *Nature* **555**, 175–182. Nature Publishing Group.

GUSH, J., JAFFE, A., LARSEN, V. & LAWS, A. (2018) The effect of public funding on research output: the New Zealand Marsden Fund. *New Zealand Economic Papers* **52**, 227–248. Taylor & Francis.

HADDAWAY, N.R., MACURA, B., WHALEY, P. & PULLIN, A.S. (2018) ROSES reporting standards for systematic evidence syntheses: pro forma, flow-diagram and descriptive summary of the plan and conduct of environmental systematic reviews and systematic maps. *Environmental Evidence* **7**, 7. BioMed Central.

HADFIELD, J.D. (2010) MCMC methods for multi-response generalized linear mixed models: the MCMCglmm R package. *Journal of Statistical Software* **33**.

HAELEWATERS, D., HOFMANN, T.A. & ROMERO-OLIVARES, A.L. (2021) Ten simple rules for Global North researchers to stop perpetuating helicopter research in the Global South. *PLOS Computational Biology* **17**, e1009277.

HALLIDAY, T. (1983) The study of mate choice. In *Mate choice* (ed P. BATESON), pp. 3–32. Cambridge University Press, Cambridge.

HAMILTON, W.J. & POULIN, R. (1997) The Hamilton and Zuk hypothesis revisited: a meta-analytical approach. *Behaviour* **134**, 299–320.*

HARE, R.M. & SIMMONS, L.W. (2019) Sexual selection and its evolutionary consequences in female animals. *Biological Reviews* **94**, 929–956.

HARTS, A.M.F., BOOKSMYTHE, I. & JENNIONS, M.D. (2016) Mate guarding and frequent copulation in birds: a meta-analysis of their relationship to paternity and male phenotype. *Evolution* **70**, 2789–2808.*

HASIK, A.Z. & SIEPIELSKI, A.M. (2022) Parasitism shapes selection by drastically reducing host fitness and increasing host fitness variation. *Biology Letters* **18**.*

HAYWARD, A. & GILLOOLY, J.F. (2011) The cost of sex: quantifying energetic investment in gamete production by males and females. *Plos One* **6**, e16557.*

HEGYI, G., KÖTÉL, D. & LACZI, M. (2015) Direct benefits of mate choice: a meta-analysis of plumage colour and offspring feeding rates in birds. *The Science of Nature* **102**, 62.*

HENSHAW, J.M., KAHN, A.T. & FRITZSCHE, K. (2016) A rigorous comparison of sexual selection indexes via simulations of diverse mating systems. *Proceedings of the National Academy of Sciences of the United States of America* **113**, E300–E308.

HERNÁNDEZ, A., MARTÍNEZ-GÓMEZ, M., BEAMONTE-BARRIENTOS, R. & MONTOYA, B. (2021) Colourful traits in female birds relate to individual condition, reproductive performance and male-mate preferences: a meta-analytic approach. *Biology Letters* **17**.*

HOEKSTRA, H.E., HOEKSTRA, J.M., BERRIGAN, D., VIGNIERI, S.N., HOANG, A., HILL, C.E., BEERLI, P. & KINGSOLVER, J.G. (2001) Strength and tempo of directional selection in the wild. *Proceedings of the National Academy of Sciences of the United States of America* **98**, 9157–9160.*

HOQUET, T. & LEWANDOWSKY, M. (2015) Utility vs beauty: Darwin, Wallace and the subsequent history of the debate on sexual selection. In *Current perspectives on sexual selection* (ed T. HOQUET), pp. 19–44. Springer, Dordrecht, Netherlands.

HOSKEN, D.J. & HOUSE, C.M. (2011) Sexual selection. *Current Biology* **21**, R62–R65.

HSU, Y.H., SCHROEDER, J., WINNEY, I., BURKE, T. & NAKAGAWA, S. (2015) Are extra-pair males different from cuckolded males? A case study and a meta-analytic examination. *Molecular Ecology* **24**, 1558–1571.*

HUANG, J., GATES, A.J., SINATRA, R. & BARABÁSI, A.L. (2020) Historical comparison of gender inequality in scientific careers across countries and disciplines. *Proceedings of the National Academy of Sciences of the United States of America* **117**, 4609–4616.

IHLE, M. & FORSTMEIER, W. (2013) Revisiting the evidence for inbreeding avoidance in zebra finches. *Behavioral Ecology* **24**, 1356–1362.*

INTEMANN, K. (2009) Why diversity matters: understanding and applying the diversity component of the national science foundation's broader impacts criterion. *Social Epistemology* **23**, 249–266.

ISVARAN, K. & PONKSHE, A. (2013) How general is a female mating preference for clustered males in lekking species? A meta-analysis. *Animal Behaviour* **86**, 417–425. The Association for the Study of Animal Behaviour.*

JANICKE, T. & FROMONTEIL, S. (2021) Sexual selection and sexual size dimorphism in animals. *Biology Letters* **17**, 20210251.*

JANICKE, T., HÄDERER, I.K., LAJEUNESSE, M.J. & ANTHES, N. (2016) Darwinian sex roles confirmed across the animal kingdom. *Science Advances* **2**, e1500983.*

JANICKE, T., MARIE-ORLEACH, L., AUBIER, T.G., PERRIER, C. & MORROW, E.H. (2019) Assortative mating in animals and its role for speciation. *American Naturalist* **194**, 865–875.*

JANICKE, T. & MORROW, E.H. (2018) Operational sex ratio predicts the opportunity and direction of sexual selection across animals. *Ecology Letters* **21**, 384–391.*

JANICKE, T., RITCHIE, M.G., MORROW, E.H. & MARIE-ORLEACH, L. (2018) Sexual selection predicts species richness across the animal kingdom. *Proceedings of the Royal Society B: Biological Sciences* **285**, 20180173.*

JENNIONS, M.D., KAHN, A.T., KELLY, C.D. & KOKKO, H. (2012) Meta-analysis and sexual selection: past studies and future possibilities. *Evolutionary Ecology* **26**, 1119–1151.

JENNIONS, M.D., MØLLER, A.P. & PETRIE, M. (2001) Sexually selected traits and adult survival: a meta-analysis. *The Quarterly Review of Biology* **76**, 3–36.*

JIANG, Y., BOLNICK, D.I. & KIRKPATRICK, M. (2013) Assortative mating in animals. *The American Naturalist* **181**, 125–138.*

JOHANSSON, B.G. & JONES, T.M. (2007) The role of chemical communication in mate choice. *Biological Reviews* **82**, 265–289.

JOLY, D. & SCHIFFER, M. (2010) Coevolution of male and female reproductive structures in *Drosophila*. *Genetica* **138**, 105–118.*

JONES, A.G. (2009) On the opportunity for sexual selection, the bateman gradient and the maximum intensity of sexual selection. *Evolution* **63**, 1673–1684.

JONES, B.C. & DUVAL, E.H. (2019) Mechanisms of social influence: a meta-analysis of the effects of social information on female mate choice decisions. *Frontiers in Ecology and Evolution* **7**, 1–14.*

DE JONG, K., FORSGREN, E., SANDVIK, H. & AMUNDSEN, T. (2012) Measuring mating competition correctly: available evidence supports operational sex ratio theory. *Behavioral Ecology* **23**, 1170–1177.*

KAMIYA, T., O'DWYER, K., WESTERDAHL, H., SENIOR, A. & NAKAGAWA, S. (2014) A quantitative review of MHC-based mating preference: the role of diversity and dissimilarity. *Molecular Ecology* **23**, 5151–5163.*

KEEFFE, R.M. & BRENNAN, P.L.R. (2023) Vaginas. *Current Biology* **33**, R670–R674.

KELLY, C.D. (2006) Fighting for harems: assessment strategies during male e male contests in the sexually dimorphic Wellington tree weta. *Animal Behaviour* **72**, 727–736.

KELLY, C.D. (2008) The interrelationships between resource-holding potential, resource-value and reproductive success in territorial males: how much variation can we explain? *Behavioral Ecology and Sociobiology* **62**, 855–871.*

KELLY, C.D. & JENNIONS, M.D. (2011) Sexual selection and sperm quantity: meta-analyses of strategic ejaculation. *Biological Reviews* **86**, 863–884.*

KIM, B., MORAN, N.P., REINHOLD, K. & SÁNCHEZ-TÓJAR, A. (2021) Male size and reproductive performance in three species of livebearing fishes (*Gambusia* spp.): a systematic review and meta-analysis. *Journal of Animal Ecology* **90**, 2431–2445.*

KOCH, R.E., WILSON, A.E. & HILL, G.E. (2016) The importance of carotenoid dose in supplementation studies with songbirds. *Physiological and Biochemical Zoology* **89**, 61–71.*

KOKKO, H. (2001) Fisherian and "good genes" benefits of mate choice: how (not) to distinguish between them. *Ecology Letters* **4**, 322–326.

KOKKO, H. (2017) Give one species the task to come up with a theory that spans them all: what good can come out of that? *Proceedings of the Royal Society B: Biological Sciences* **284**, 20171652.

KORICHEVA, J., GUREVITCH, J. & MENGERSEN, K. (2013) *Handbook of meta-analysis in ecology and evolution*. Princeton University Press, Princeton, NJ.

KRAAIJEVELD, K., KRAAIJEVELD-SMIT, F.J.L. & MAAN, M.E. (2011) Sexual selection and speciation: the comparative evidence revisited. *Biological Reviews* **86**, 367–377.*

KRAMER, B. (1990) Sexual signals in electric fishes. *Trends in Ecology & Evolution* **5**, 247–

250.

KVARNEMO, C. & SIMMONS, L.W. (2013) Polyandry as a mediator of sexual selection before and after mating. *Philosophical Transactions of the Royal Society B: Biological Sciences* **368**, 20120042.

LANDE, R. & ARNOLD, S.J. (1983) The measurement of selection on correlated characters. *Evolution* **37**, 1210.

LEE, J.J. (2016) Is science only for the rich? *Nature* **537**, 466–470.

LEE, P.L.M., SHERMAN, C.D.H., ROLLINS, L.A., WAPSTRA, E. & PHILLIPS, K.P. (2022) Do female amphibians and reptiles have greater reproductive output if they have more mates? *Behavioral Ecology and Sociobiology* **76**.*

LEUNG, B. & FORBES, M.R. (1996) Fluctuating asymmetry in relation to stress and fitness: effects of trait type as revealed by meta-analysis. *Écoscience* **3**, 400–413.*

LEWIS, D.M.G., RUSSELL, E.M., AL-SHAWAF, L., TA, V., SENVELI, Z., ICKES, W. & BUSS, D.M. (2017) Why women wear high heels: evolution, lumbar curvature, and attractiveness. *Frontiers in Psychology* **8**, 1–7.

LIEBERMAN, D.E., KROVITZ, G.E., YATES, F.W., DEVLIN, M. & ST. CLAIRE, M. (2004) Effects of food processing on masticatory strain and craniofacial growth in a retrognathic face. *Journal of Human Evolution* **46**, 655–677.

LINDSAY, W.R., ANDERSSON, S., BERERHI, B., HÖGLUND, J., JOHNSEN, A., KVARNEMO, C., LEDER, E.H., LIFJELD, J.T., NINNES, C.E., OLSSON, M., PARKER, G.A., PIZZARI, T., QVARNSTRÖM, A., SAFRAN, R.J., SVENSSON, O., *ET AL.* (2019) Endless forms of sexual selection. *PeerJ* **7**, 1–54.

LORENZ, C. (2012) If you're so smart, why are you under surveillance? Universities, neoliberalism, and new public management. *Critical Inquiry* **38**, 599–629.

LOSDAT, S., CHANG, S.M. & REID, J.M. (2014) Inbreeding depression in male gametic performance. *Journal of Evolutionary Biology* **27**, 992–1011.*

LÜPOLD, S., DE BOER, R.A., EVANS, J.P., TOMKINS, J.L. & FITZPATRICK, J.L. (2020) How sperm competition shapes the evolution of testes and sperm: a meta-analysis. *Philosophical Transactions of the Royal Society B: Biological Sciences* **375**.*

LÜPOLD, S. & FITZPATRICK, J.L. (2015) Sperm number trumps sperm size in mammalian ejaculate evolution. *Proceedings of the Royal Society B: Biological Sciences* **282**.*

LÜPOLD, S., SIMMONS, L.W., TOMKINS, J.L. & FITZPATRICK, J.L. (2015) No evidence for a trade-off between sperm length and male premating weaponry. *Journal of Evolutionary Biology* **28**, 2187–2195.*

LYNCH, M. (1991) Methods for the analysis of comparative data in evolutionary biology. *Evolution* **45**, 1065–1080.

MACARTNEY, E.L., CREAN, A.J., NAKAGAWA, S. & BONDURIANSKY, R. (2019) Effects of nutrient limitation on sperm and seminal fluid: a systematic review and meta-analysis. *Biological Reviews* **94**, 1722–1739.*

MACEDO-REGO, R.C. (2020) When and how do episodes of sexual selection occur in animal species? A meta-analytical investigation. University of Sao Paulo, São Paulo.

MACEDO-REGO, R.C., JENNIONS, M.D. & SANTOS, E.S.A. (2020a) Post-mating episodes of sexual selection are ubiquitous in animal species and the way we measure mating success matters: a meta-analysis. In *When and how do episodes of sexual selection occur in animal species? A meta-analytical investigation* (ed R.C. MACEDO-REGO), pp. 28–75. Universidade de São Paulo, São Paulo, Brazil.*

MACEDO-REGO, R.C., JENNIONS, M.D. & SANTOS, E.S.A. (2020b) Females are not monopolized by males: a meta-analysis contrasting mating systems in non-human animals. In *When and how do episodes of sexual selection occur in animal species? A meta-analytical investigation* (ed R.C. MACEDO-REGO), pp. 76–147. Universidade de

São Paulo, São Paulo, Brazil.*

Macedo-Rego, R.C., Jennions, M.D. & Santos, E.S.A. (2020c) Larger females and larger males produce more offspring, regardless of the social mating system: a meta-analyses on animals. In *When and how do episodes of sexual selection occur in animal species? A meta-analytical investigation* (ed R.C. Macedo-Rego), pp. 148–187. Universidade de São Paulo, São Paulo, Brazil.*

Maciel, D., Oliveira, R. & Peixoto, P.E.C. (2023) Do reproductive characteristics of the species explain differences in the investment in weapon size present in males? *Ethology* **129**, 99–106.*

Majolo, B., Lehmann, J., De Bortoli Vizioli, A. & Schino, G. (2012) Fitness-related benefits of dominance in primates. *American Journal of Physical Anthropology* **147**, 652–660.*

Marmol, S.A.Q. (2022) Impacto de los contaminantes en la calidad espermática de los peces: revisión literaria y meta-análisis. Benemérita Universidad Autónoma De Puebla, Puebla, Mexico.*

Mautz, B.S., Møller, A.P. & Jennions, M.D. (2013) Do male secondary sexual characters signal ejaculate quality? A meta-analysis. *Biological Reviews* **88**, 669–682.*

McDermott, M., Gelb, D.J., Wilson, K., Pawloski, M., Burke, J.F., Shelgikar, A. V. & London, Z.N. (2018) Sex differences in academic rank and publication rate at top-ranked US neurology programs. *JAMA Neurology* **75**, 956.

McGowan, J., Sampson, M., Salzwedel, D.M., Cogo, E., Foerster, V. & Lefebvre, C. (2016) PRESS peer review of electronic search strategies: 2015 guideline statement. *Journal of Clinical Epidemiology* **75**, 40–46.

McLean, M.J., Bishop, P.J. & Nakagawa, S. (2012) Male quality, signal reliability and female choice: assessing the expectations of inter-sexual selection. *Journal of*

Evolutionary Biology **25**, 1513–1520.*

McLeod, P.L., Lobel, S.A. & Cox, T.H. (1996) Ethnic diversity and creativity in small groups. *Small Group Research* **27**, 248–264.

Menezes, J.C.T. & Palaoro, A. V. (2022) Flight hampers the evolution of weapons in birds. *Ecology Letters* **25**, 624–634.*

Meunier, J., Pinto, S.F., Burri, R. & Roulin, A. (2011) Eumelanin-based coloration and fitness parameters in birds: a meta-analysis. *Behavioral Ecology and Sociobiology* **65**, 559–567.*

Miake-Lye, I.M., Hempel, S., Shanman, R. & Shekelle, P.G. (2016) What is an evidence map? A systematic review of published evidence maps and their definitions, methods, and products. *Systematic Reviews* **5**. Systematic Reviews.

Møller, A.P. & Alatalo, R. V. (1999) Good-genes effects in sexual selection. *Proceedings of the Royal Society B: Biological Sciences* **266**, 85–91.*

Møller, A.P., Christe, P. & Lux, E. (1999) Parasitism, host immune function, and sexual selection. *The Quarterly Review of Biology* **74**, 3–20.*

Møller, A.P. & Jennions, M. (2001) How important are direct fitness benefits of sexual selection? *Naturwissenschaften* **88**, 401–415.*

Møller, A.P. & Ninni, P. (1998) Sperm competition and sexual selection: a meta-analysis of paternity studies of birds. *Behavioral Ecology and Sociobiology* **43**, 345–358.*

Møller, A.P. & Thornhill, R. (1998) Bilateral symmetry and sexual selection: a meta-analysis. *The American Naturalistaturalist* **151**, 174–192.*

Moore, F.R., Shuker, D.M. & Dougherty, L. (2016) Stress and sexual signaling: a systematic review and meta-analysis. *Behavioral Ecology* **27**, 363–371.*

Moore, S.L. & Wilson, K. (2002) Parasites as a viability cost of sexual selection in natural populations of mammals. *Science* **297**, 2015–2018.

MORI, B.A. & EVENDEN, M.L. (2013) When mating disruption does not disrupt mating: fitness consequences of delayed mating in moths. *Entomologia Experimentalis et Applicata* **146**, 50–65.*

MUNAFÒ, M.R., NOSEK, B.A., BISHOP, D.V.M., BUTTON, K.S., CHAMBERS, C.D., PERCIE DU SERT, N., SIMONSOHN, U., WAGENMAKERS, E.J., WARE, J.J. & IOANNIDIS, J.P.A. (2017) A manifesto for reproducible science. *Nature Human Behaviour* **1**, 1–9. Macmillan Publishers Limited.

MURRAY, H.J., GREEN, E.J., WILLIAMS, D.R., BURFIELD, I.J. & DE BROOKE, M.L. (2015) Is research effort associated with the conservation status of European bird species? *Endangered Species Research* **27**, 193–206.

MUSCHELLI, J. (2019) rscopus: Scopus database 'API' interface.

MYERS, J.N., SENIOR, A., ZADMAJID, V., SØRENSEN, S.R. & BUTTS, I.A.E. (2020) Associations between ovarian fluid and sperm swimming trajectories in marine and freshwater teleosts: a meta-analysis. *Reviews in Fisheries Science & Aquaculture* **28**, 322–339.*

NAKAGAWA, S. & CUTHILL, I.C. (2007) Effect size, confidence interval and statistical significance: a practical guide for biologists. *Biological Reviews* **82**, 591–605.

NAKAGAWA, S., LAGISZ, M., JENNIONS, M.D., KORICHEVA, J., NOBLE, D.W.A., PARKER, T.H., SÁNCHEZ-TÓJAR, A., YANG, Y. & O'DEA, R.E. (2021) Methods for testing publication bias in ecological and evolutionary meta-analyses. *Methods in Ecology and Evolution* **2021**, 1–18.

NAKAGAWA, S., NOBLE, D.W.A., LAGISZ, M., SPAKE, R., VIECHTBAUER, W. & SENIOR, A.M. (2023a) A robust and readily implementable method for the meta-analysis of response ratios with and without missing standard deviations. *Ecology Letters* **26**, 232–244.

NAKAGAWA, S., NOBLE, D.W.A., SENIOR, A.M. & LAGISZ, M. (2017) Meta-evaluation of meta-analysis: ten appraisal questions for biologists. *BMC Biology* **15**, 18.

NAKAGAWA, S., OCKENDON, N., GILLESPIE, D.O.S., HATCHWELL, B.J. & BURKE, T. (2007) Assessing the function of house sparrows' bib size using a flexible meta-analysis method. *Behavioral Ecology* **18**, 831–840.*

NAKAGAWA, S. & PARKER, T.H. (2015) Replicating research in ecology and evolution: feasibility, incentives, and the cost-benefit conundrum. *BMC Biology* **13**, 1–6. BMC Biology.

NAKAGAWA, S., SAMARASINGHE, G., HADDAWAY, N.R., WESTGATE, M.J., O'DEA, R.E., NOBLE, D.W.A. & LAGISZ, M. (2019) Research weaving: visualizing the future of research synthesis. *Trends in Ecology & Evolution* **34**, 224–238.

NAKAGAWA, S. & SANTOS, E.S.A. (2012) Methodological issues and advances in biological meta-analysis. *Evolutionary Ecology* **26**, 1253–1274.

NAKAGAWA, S., SENIOR, A.M., VIECHTBAUER, W. & NOBLE, D.W.A. (2022) An assessment of statistical methods for nonindependent data in ecological meta-analyses: comment. *Ecology* **103**, 1–5.

NAKAGAWA, S., YANG, Y., MACARTNEY, E.L., SPAKE, R. & LAGISZ, M. (2023b) Quantitative evidence synthesis: a practical guide on meta-analysis, meta-regression, and publication bias tests for environmental sciences. *Environmental Evidence* **12**, 1–19.

NAKAMURA, G., SOARES, B.E., PILLAR, V.D., DINIZ-FILHO, J.A.F. & DUARTE, L. (2023) Three pathways to better recognize the expertise of Global South researchers. *npj Biodiversity* **2**, 17.

NIEBERDING, C.M. & HOLVECK, M.J. (2017) Laboratory social environment biases mating outcome: a first quantitative synthesis in a butterfly. *Behavioral Ecology and Sociobiology* **71**. Behavioral Ecology and Sociobiology.*

NIETO, M.J. & SANTAMARÍA, L. (2007) The importance of diverse collaborative networks for the novelty of product innovation. *Technovation* **27**, 367–377.

NOBLE, D.W.A., LAGISZ, M., O'DEA, R.E. & NAKAGAWA, S. (2017) Nonindependence and sensitivity analyses in ecological and evolutionary meta-analyses. *Molecular Ecology* **26**, 2410–2425.

NOBLE, D.W.A., POTTIER, P., LAGISZ, M., BURKE, S., DROBNIAK, S.M., O'DEA, R.E. & NAKAGAWA, S. (2022) Meta-analytic approaches and effect sizes to account for 'nuisance heterogeneity' in comparative physiology. *Journal of Experimental Biology* **225**.

NOLAZCO, S., DELHEY, K., NAKAGAWA, S. & PETERS, A. (2022) Ornaments are equally informative in male and female birds. *Nature Communications* **13**, 5917.*

O'DEA, R.E., LAGISZ, M., JENNIONS, M.D., KORICHEVA, J., NOBLE, D.W.A., PARKER, T.H., GUREVITCH, J., PAGE, M.J., STEWART, G., MOHER, D. & NAKAGAWA, S. (2021) Preferred reporting items for systematic reviews and meta-analyses in ecology and evolutionary biology: a PRISMA extension. *Biological Reviews* **96**, 1695–1722.

O'LEARY, B.C., KVIST, K., BAYLISS, H.R., DERROIRE, G., HEALEY, J.R., HUGHES, K., KLEINSCHROTH, F., SCIBERRAS, M., WOODCOCK, P. & PULLIN, A.S. (2016) The reliability of evidence review methodology in environmental science and conservation. *Environmental Science and Policy* **64**, 75–82.

O'LEARY, B.C., WOODCOCK, P., KAISER, M.J. & PULLIN, A.S. (2017) Evidence maps and evidence gaps: evidence review mapping as a method for collating and appraising evidence reviews to inform research and policy. *Environmental Evidence* **6**, 1–9.

ORD, T.J. (2021) Costs of territoriality: a review of hypotheses, meta-analysis, and field study. *Oecologia* **197**, 615–631.*

ORD, T.J., KING, L. & YOUNG, A.R. (2011) Contrasting theory with the empirical data of species recognition. *Evolution* **65**, 2572–2591.*

ORD, T.J. & STAMPS, J.A. (2009) Species identity cues in animal communication. *The American Naturalist* **174**, 585–593.*

OTTAVIANI, G., MARTINEZ, A., BON, M.P. & MAMMOLA, S. (2023) On the quest for novelty in ecology. *bioRxiv*, 2023.02.27.530333.

OUZZANI, M., HAMMADY, H., FEDOROWICZ, Z. & ELMAGARMID, A. (2016) Rayyan-a web and mobile app for systematic reviews. *Systematic Reviews* **5**, 1–10. Systematic Reviews.

OWENS, I.P.F. (2006) Where is behavioural ecology going? *Trends in Ecology and Evolution* **21**, 356–361.

PAGE, M.J., MCKENZIE, J.E., BOSSUYT, P.M., BOUTRON, I., HOFFMANN, T.C., MULROW, C.D., SHAMSEER, L., TETZLAFF, J.M., AKL, E.A., BRENNAN, S.E., CHOU, R., GLANVILLE, J., GRIMSHAW, J.M., HRÓBJARTSSON, A., LALU, M.M., *ET AL.* (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *The BMJ* **372**.

PALAORO, A. V. & PEIXOTO, P.E.C. (2022) The hidden links between animal weapons, fighting style, and their effect on contest success: a meta-analysis. *Biological Reviews* **97**, 1948–1966.*

PALPACUER, C., HAMMAS, K., DUPREZ, R., LAVIOLLE, B., IOANNIDIS, J.P.A. & NAUDET, F. (2019) Vibration of effects from diverse inclusion/exclusion criteria and analytical choices: 9216 different ways to perform an indirect comparison meta-analysis. *BMC Medicine* **17**, 174.

PARKER, G.A. (1970) Sperm competition and its evolutionary consequences in the insects. *Biological Reviews* **45**, 525–567.

PARKER, G.A. (1979) Sexual selection and sexual conflict. In *Sexual selection and reproductive competition in insects* (eds M.S. BLUM & N.A. BLUM), pp. 123–166. Academic Press, New York, NY.

PARKER, G.A. & PIZZARI, T. (2010) Sperm competition and ejaculate economics. *Biological*

Reviews **85**, 897–934.

PARKER, T.H. (2013) What do we really know about the signalling role of plumage colour in blue tits? A case study of impediments to progress in evolutionary biology. *Biological Reviews* **88**, 511–536.*

PARKER, T.H., BARR, I.R. & GRIFFITH, S.C. (2006) The blue tit's song is an inconsistent signal of male condition. *Behavioral Ecology* **17**, 1029–1040.*

PARKER, T.H., GREIG, E.I., NAKAGAWA, S., PARRA, M. & DALISIO, A.C. (2018) Subspecies status and methods explain strength of response to local versus foreign song by oscine birds in meta-analysis. *Animal Behaviour* **142**, 1–17.*

PARKER, T.H. & LIGON, J.D. (2003) Female mating preferences in red junglefowl: a meta-analysis. *Ethology Ecology and Evolution* **15**, 63–72.*

PARRIS, K.M. & MCCARTHY, M.A. (2013) Predicting the effect of urban noise on the active space of avian vocal signals. *American Naturalist* **182**, 452–464.*

PEIXOTO, P.E.C., MEDINA, A.M. & MENDOZA-CUENCA, L. (2014) Do territorial butterflies show a macroecological fighting pattern in response to environmental stability? *Behavioural Processes* **109**, 14–20.*

PENN, D.J. & SZÁMADÓ, S. (2020) The Handicap Principle: how an erroneous hypothesis became a scientific principle. *Biological Reviews* **95**, 267–290.

PHILIBERT, A., LOYCE, C. & MAKOWSKI, D. (2012) Assessment of the quality of meta-analysis in agronomy. *Agriculture, Ecosystems and Environment* **148**, 72–82.

PICCOLO, S.R. & FRAMPTON, M.B. (2016) Tools and techniques for computational reproducibility. *GigaScience* **5**, 1–13. GigaScience.

PIKE, V.L., CORNWALLIS, C.K. & GRIFFIN, A.S. (2021) Why don't all animals avoid inbreeding? *Proceedings of the Royal Society B: Biological Sciences* **288**.*

PILAKOUTA, N. & BAILLET, A. (2022) Effects of temperature on mating behaviour and mating success: a meta-analysis. *Journal of Animal Ecology* **91**, 1642–1650.*

PINCHEIRA-DONOSO, D. & HUNT, J. (2017) Fecundity selection theory: concepts and evidence. *Biological Reviews* **92**, 341–356.

POLLO, P. & KASUMOVIC, M.M. (2022) Let's talk about sex roles: what affects perceptions of sex differences in animal behaviour? *Animal Behaviour* **183**, 1–12.

POLLO, P., LAGISZ, M., CULINA, A., YANG, Y. & NAKAGAWA, S. (2023) Synthesis of sexual selection: registration for a systematic map and bibliometric analysis of meta-analyses.

POLLO, P., NAKAGAWA, S. & KASUMOVIC, M.M. (2022) The better, the choosier: a meta-analysis on interindividual variation of male mate choice. *Ecology Letters* **25**, 1305–1322.*

POMIANKOWSKI, A. & MØLLER, A.P. (1995) A resolution of the lek paradox. *Proceedings of the Royal Society B: Biological Sciences* **260**, 21–29.*

POTVIN, D.A., BURDFIELD-STEEL, E., POTVIN, J.M. & HEAP, S.M. (2018) Diversity begets diversity: a global perspective on gender equality in scientific society leadership. *PLOS ONE* **13**, e0197280.

POWERS, M.J., WILSON, A.E., HEINE, K.B. & HILL, G.E. (2020) The relative importance of various mating criteria in copepods. *Journal of Plankton Research* **42**, 19–30.*

PROKOP, Z.M., MICHALCZYK, Ł., DROBNIAK, S.M., HERDEGEN, M. & RADWAN, J. (2012) Meta-analysis suggests choosy females get sexy sons more than 'good genes'. *Evolution* **66**, 2665–2673.*

PROKUDA, A.Y. & ROFF, D.A. (2014) The quantitative genetics of sexually selected traits, preferred traits and preference: a review and analysis of the data. *Journal of Evolutionary Biology* **27**, 2283–2296.*

R CORE TEAM (2022) R: a language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria. Https://www.r-project.org/.

RANDLER, C. (2008) Mating patterns in avian hybrid zones - A meta-analysis and review. *Ardea* **96**, 73–80.*

REINHOLD, K., KURTZ, J. & ENGQVIST, L. (2002) Cryptic male choice: sperm allocation strategies when female quality varies. *Journal of Evolutionary Biology* **15**, 201–209.

RICHARDSON, J. & ZUK, M. (2023) Unlike a virgin: a meta-analytical review of female mating status in studies of female mate choice. *Behavioral Ecology* **34**, 165–182.*

RICHARDSON, W.S., WILSON, M.C., NISHIKAWA, J. & HAYWARD, R.S.A. (1995) The well-built clinical question: a key to evidence-based decisions. *ACP Journal Club* **123**, A12.

RICO-GUEVARA, A. & HURME, K.J. (2019) Intrasexually selected weapons. *Biological Reviews* **94**, 60–101.

RIOS MOURA, R., OLIVEIRA GONZAGA, M., SILVA PINTO, N., VASCONCELLOS-NETO, J. & REQUENA, G.S. (2021) Assortative mating in space and time: patterns and biases. *Ecology Letters* **24**, 1089–1102.*

RIOS MOURA, R. & PEIXOTO, P.E.C. (2013) The effect of operational sex ratio on the opportunity for sexual selection: a meta-analysis. *Animal Behaviour* **86**, 675–683.*

ROBINSON, C.M. & CREANZA, N. (2019) Species-level repertoire size predicts a correlation between individual song elaboration and reproductive success. *Ecology and Evolution* **9**, 8362–8377.*

ROCHE, D.G., KRUUK, L.E.B., LANFEAR, R. & BINNING, S.A. (2015) Public data archiving in ecology and evolution: how well are we doing? *PLOS Biology* **13**, e1002295.

RODRÍGUEZ, R.L. & EBERHARD, W.G. (2019) Why the static allometry of sexually-selected traits is so variable: the importance of function. *Integrative and Comparative Biology* **59**, 1290–1302.*

ROMANO, A., COSTANZO, A., RUBOLINI, D., SAINO, N. & MØLLER, A.P. (2017a) Geographical and seasonal variation in the intensity of sexual selection in the barn swallow *Hirundo* *rustica*: a meta-analysis. *Biological Reviews* **92**, 1582–1600.*

ROMANO, A., SAINO, N. & MØLLER, A.P. (2017b) Viability and expression of sexual ornaments in the barn swallow Hirundo rustica: a meta-analysis. *Journal of Evolutionary Biology* **30**, 1929–1935.*

ROMETSCH, S.J., TORRES-DOWDALL, J. & MEYER, A. (2020) Evolutionary dynamics of pre- and postzygotic reproductive isolation in cichlid fishes: reproductive isolation in cichlid fishes. *Philosophical Transactions of the Royal Society B: Biological Sciences* **375**.*

ROSENTHAL, G.G. (2017) *Mate choice: the evolution of sexual decision making from microbes to humans*. Princeton University Press, Princeton, NJ.

ROSENTHAL, G.G. & RYAN, M.J. (2022) Sexual selection and the ascent of women: mate choice research since Darwin. *Science* **375**.

ROSENTHAL, M.F., GERTLER, M., HAMILTON, A.D., PRASAD, S. & ANDRADE, M.C.B. (2017) Taxonomic bias in animal behaviour publications. *Animal Behaviour* **127**, 83–89.

ROSENTHAL, R. (1991) *Meta-analytic procedures for social research*. SAGE publications, Thousand Oaks, CA.

RUSE, M. (2015) Sexual selection: why does it play such a large role in the descent of man? In *Current perspectives on sexual selection* (ed T. HOQUET), pp. 3–17. Springer, Dordrecht, Netherlands.

SÁNCHEZ-TÓJAR, A., NAKAGAWA, S., SÁNCHEZ-FORTÚN, M., MARTIN, D.A., RAMANI, S., GIRNDT, A., BÓKONY, V., KEMPENAERS, B., LIKER, A., WESTNEAT, D.F., BURKE, T. & SCHROEDER, J. (2018) Meta-analysis challenges a textbook example of status signalling and demonstrates publication bias. *eLife* **7**, 1–26.*

SANTOS, E.S.A., SCHECK, D. & NAKAGAWA, S. (2011) Dominance and plumage traits: meta-analysis and metaregression analysis. *Animal Behaviour* **82**, 3–19.*

SEDDON, P.J., SOORAE, P.S. & LAUNAY, F. (2005) Taxonomic bias in reintroduction projects.

Animal Conservation **8**, 51–58.

SEGUIN, A. & FORSTMEIER, W. (2012) No band color effects on male courtship rate or body mass in the zebra finch: four experiments and a meta-analysis. *Plos One* **7**.*

SEMMELHACK, E. (2020) Withering heights: high heels and hegemonic masculinity. In *Crossing gender boundaries* (eds A. REILLY & B. BARRY), pp. 60–75. Intellect, Bristol, UK.

SENIOR, A.M., GRUEBER, C.E., KAMIYA, T., LAGISZ, M., O'DWYER, K., SANTOS, E.S.A. & NAKAGAWA, S. (2016a) Heterogeneity in ecological and evolutionary meta-analyses: its magnitude and implications. *Ecology* **97**, 3293–3299.

SENIOR, A.M., JOHNSON, S.L. & NAKAGAWA, S. (2016b) Sperm traits of masculinized fish relative to wild-type males: a systematic review and meta-analyses. *Fish and Fisheries* **17**, 143–164.*

SHAW, A.K. & STANTON, D.E. (2012) Leaks in the pipeline: separating demographic inertia from ongoing gender differences in academia. *Proceedings of the Royal Society B: Biological Sciences* **279**, 3736–3741.

SHEA, B.J., REEVES, B.C., WELLS, G., THUKU, M., HAMEL, C., MORAN, J., MOHER, D., TUGWELL, P., WELCH, V., KRISTJANSSON, E. & HENRY, D.A. (2017) AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. *BMJ* **358**, j4008.

SHUKER, D.M. (2010) Sexual selection: endless forms or tangled bank? *Animal Behaviour* **79**, e11–e17.

SHUKER, D.M. & KVARNEMO, C. (2021a) The definition of sexual selection. *Behavioral Ecology* **32**, 781–794.

SHUKER, D.M. & KVARNEMO, C. (2021b) The definition of sexual selection: a response to comments on Shuker and Kvarnemo. *Behavioral Ecology* **32**, 801–802.

SHUSTER, S.M. & WADE, M.J. (2003) *Mating system strategies*. Princeton University Press, Princeton, NJ.

SILVERSTEIN, B., PERDUE, L., PETERSON, B. & KELLY, E. (1986) The role of the mass media in promoting a thin standard of bodily attractiveness for women. *Sex Roles* **14**, 519–532.

SIMMONS, L.W. (2005) The evolution of polyandry: sperm competition, sperm selection, and offspring viability. *Annual Review of Ecology, Evolution, and Systematics* **36**, 125–146.*

SIMMONS, L.W., LÜPOLD, S. & FITZPATRICK, J.L. (2017) Evolutionary trade-off between secondary sexual traits and ejaculates. *Trends in Ecology & Evolution* **32**, 964–976.

SIMONS, M.J.P., COHEN, A.A. & VERHULST, S. (2012) What does carotenoid-dependent coloration tell? Plasma carotenoid level signals immunocompetence and oxidative stress state in birds-a meta-analysis. *Plos One* **7**.*

SIMONS, M.J.P. & VERHULST, S. (2011) Zebra finch females prefer males with redder bills independent of song rate–a meta-analysis. *Behavioral Ecology* **22**, 755–762.*

SOKOLOVSKA, N., ROWE, L. & JOHANSSON, F. (2000) Fitness and body size in mature odonates. *Ecological Entomology* **25**, 239–248.*

SOMA, M. & GARAMSZEGI, L.Z. (2011) Rethinking birdsong evolution: meta-analysis of the relationship between song complexity and reproductive success. *Behavioral Ecology* **22**, 363–371.*

SOPER, D.M., EKROTH, A.K.E. & MARTINS, M.J.F. (2021) Direct evidence for increased disease resistance in polyandrous broods exists only in eusocial Hymenoptera. *BMC Ecology and Evolution* **21**, 189. BioMed Central.*

SOUTH, A. & LEWIS, S.M. (2011) The influence of male ejaculate quantity on female fitness: a meta-analysis. *Biological Reviews* **86**, 299–309.*

SPAKE, R., O'DEA, R.E., NAKAGAWA, S., DONCASTER, C.P., RYO, M., CALLAGHAN, C.T. &

BULLOCK, J.M. (2022) Improving quantitative synthesis to achieve generality in ecology. *Nature Ecology and Evolution* **6**, 1818–1828. Springer US.

STAHLSCHMIDT, Z.R. (2011) Taxonomic chauvinism revisited: insight from parental care research. *Plos One* **6**, 6–9.

STANHOPE, J. & WEINSTEIN, P. (2022) Critical appraisal in ecology: what tools are available, and what is being used in systematic reviews? *Research Synthesis Methods*, 1–15.

STEWART-WILLIAMS, S. & THOMAS, A.G. (2013) The ape that thought it was a peacock: does evolutionary psychology exaggerate human sex differences? *Psychological Inquiry* **24**, 137–168.

STREET, S.E., CROSS, C.P. & BROWN, G.R. (2016) Exaggerated sexual swellings in female nonhuman primates are reliable signals of female fertility and body condition. *Animal Behaviour* **112**, 203–212.*

SUTHERLAND, W.J. & WORLDLEY, CL.F. (2018) A fresh approach to evidence. *Nature* **558**, 364–366.

TANG-MARTINEZ, Z. (2016) Rethinking Bateman's principles: challenging persistent myths of sexually reluctant females and promiscuous males. *The Journal of Sex Research* **53**, 532–559.

THORNHILL, R. (1983) Cryptic female choice and its implications in the scorpionfly *Harpobittacus nigriceps*. *The American Naturalist* **122**, 765–788.

THORNHILL, R. & MØLLER, A.P. (1998) The relative importance of size and asymmetry in sexual selection. *Behavioral Ecology* **9**, 546–551.*

TORRES-VILA, L.M. & JENNIONS, M.D. (2005) Male mating history and female fecundity in the Lepidoptera: do male virgins make better partners? *Behavioral Ecology and Sociobiology* **57**, 318–326.*

TORRES-VILA, L.M., RODRÍGUEZ-MOLINA, M.C. & JENNIONS, M.D. (2004) Polyandry and fecundity in the Lepidoptera: can methodological and conceptual approaches bias outcomes? *Behavioral Ecology and Sociobiology* **55**, 315–324.*

TRIVERS, R.L. (1972) Parental investment and sexual selection. In *Sexual selection and the descent of man: 1871-1971* (ed B. CAMPBELL), pp. 136–179. Aldine Publishing Company, Chicago, IL.

TROUDET, J., GRANDCOLAS, P., BLIN, A., VIGNES-LEBBE, R. & LEGENDRE, F. (2017) Taxonomic bias in biodiversity data and societal preferences. *Scientific Reports* **7**, 9132.

VIECHTBAUER, W. (2010) Conducting meta-analyses in R with the metafor. *Journal of Statistical Software* **36**, 1–48.

VIEIRA, M.C. & PEIXOTO, P.E.C. (2013) Winners and losers: a meta-analysis of functional determinants of fighting ability in arthropod contests. *Functional Ecology* **27**, 305–313.*

VOJE, K.L. (2016) Scaling of morphological characters across trait type, sex, and environment: a meta-analysis of static allometries. *The American Naturalist* **187**, 89–98.*

WADE, M.J. (1979) Sexual selection and variance in reproductive success. *The American Naturalist* **114**, 742–747.

WAIS, K. (2016) Gender prediction methods based on first names with genderizeR. *The R Journal* **8**, 17.

WANG, D., FORSTMEIER, W., VALCU, M., DINGEMANSE, N.J., BULLA, M., BOTH, C., DUCKWORTH, R.A., KIERE, L.M., KARELL, P., ALBRECHT, T. & KEMPENAERS, B. (2019) Scrutinizing assortative mating in birds. *Plos Biology* **17**, 1–20.*

WEAVER, R.J., SANTOS, E.S.A., TUCKER, A.M., WILSON, A.E. & HILL, G.E. (2018) Carotenoid metabolism strengthens the link between feather coloration and individual quality. *Nature Communications* **9**.*

WEIR, L.K., GRANT, J.W.A. & HUTCHINGS, J.A. (2011) The influence of operational sex ratio on the intensity of competition for mates. *American Naturalist* **177**, 167–176.*

WHITE, T.E. (2020) Structural colours reflect individual quality: a meta-analysis. *Biology Letters* **16**.*

WHITE, T.E., LATTY, T. & UMBERS, K.D.L. (2022) The exploitation of sexual signals by predators: a meta-analysis. *Proceedings of the Royal Society B: Biological Sciences* **289**.*

WIENS, J.J. & TUSCHHOFF, E. (2020) Songs versus colours versus horns: what explains the diversity of sexually selected traits? *Biological Reviews* **95**, 847–864.

WILKINSON, M.D., DUMONTIER, M., AALBERSBERG, IJ.J., APPLETON, G., AXTON, M., BAAK, A., BLOMBERG, N., BOITEN, J.-W., DA SILVA SANTOS, L.B., BOURNE, P.E., BOUWMAN, J., BROOKES, A.J., CLARK, T., CROSAS, M., DILLO, I., *ET AL.* (2016) The FAIR Guiding Principles for scientific data management and stewardship. *Scientific Data* **3**, 160018.

WINTERNITZ, J., ABBATE, J.L., HUCHARD, E., HAVLÍČEK, J. & GARAMSZEGI, L.Z. (2017) Patterns of MHC-dependent mate selection in humans and nonhuman primates: a meta-analysis. *Molecular Ecology* **26**, 668–688.*

WOODCOCK, P., PULLIN, A.S. & KAISER, M.J. (2014) Evaluating and improving the reliability of evidence syntheses in conservation and environmental science: a methodology. *Biological Conservation* **176**, 54–62.

YANG, Y., MACLEOD, M., PAN, J., LAGISZ, M. & NAKAGAWA, S. (2023a) Advanced methods and implementations for the meta-analyses of animal models: current practices and future recommendations. *Neuroscience and Biobehavioral Reviews* **146**, 105016.

YANG, Y., SÁNCHEZ-TÓJAR, A., O'DEA, R.E., NOBLE, D.W.A., KORICHEVA, J., JENNIONS, M.D., PARKER, T.H., LAGISZ, M. & NAKAGAWA, S. (2023b) Publication bias impacts on effect size, statistical power, and magnitude (Type M) and sign (Type S) errors in ecology and evolutionary biology. *BMC Biology* **21**, 71. BioMed Central.

YARWOOD, M.R., WESTON, M.A. & SYMONDS, M.R.E. (2019) Biological determinants of research effort on Australian birds: a comparative analysis. *Emu* **119**, 38–44. Taylor & Francis.

YASUKAWA, K., ENSTROM, D.A., PARKER, P.G. & JONES, T.C. (2010) Male Red-winged Blackbirds with experimentally dulled epaulets experience no disadvantage in sexual selection. *Journal of Field Ornithology* **81**, 31–41.*

YUKILEVICH, R. (2012) Asymmetrical patterns of speciation uniquely support reinforcement in drosophila. *Evolution* **66**, 1430–1446.*

ZAHAVI, A. (1975) Mate selection—a selection for a handicap. *Journal of Theoretical Biology* **53**, 205–214.

ZAHAVI, A. (1977) The cost of honesty: further remarks on the handicap principle. *Journal of Theoretical Biology* **67**, 603–605.

ZHANG, S., LI, D., ZENG, J., WU, X. & LIU, X. (2016) Effect of male mating history on female reproductive fitness in moths: a meta-analysis. *Chinese Journal of Ecology* **35**, 551–558.*

ZUK, M., GARCIA-GONZALEZ, F., HERBERSTEIN, M.E. & SIMMONS, L.W. (2013) Model systems, taxonomic bias, and sexual selection: beyond Drosophila. *Annual Review of Entomology* **59**, 321–338.