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Discoveries

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Do Manuscripts by Female Evolutionary Biologists Spend Longer Under Review?

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Abstract

Women are under-represented in academia and in STEM careers, especially at senior positions and top institutions. This may be, at least in part, due to the many obstacles that they experience along the academic pipeline. There has been substantial debate as to whether women are treated unfairly during the peer review process. An analysis of over 9,000 research articles published in top Economics journals has recently shown that female-authored articles tend to spend 3 to 6 months longer under review (period from submission to acceptance), and to have more readable abstracts, than male-authored articles, suggesting that female-authored articles are held to higher standards. We set out to determine whether these trends were also present among 49,031 papers published in 11 Evolutionary Biology journals. We found that female representation among article authors substantially increased over the decades. The percentage of women is lower among corresponding authors than among all authors, especially of recent articles. In addition, female first authors were less likely to be corresponding authors than male first authors, and the gender of the first author correlated with the gender of the corresponding author. In some of the journals, female-authored articles spent significantly longer under review; however, most of the observed differences vanish after controlling for the date of publication and the number of authors. In addition, female-authored abstracts are not more readable. Our results suggest that the peer review process in the field of Evolutionary Biology is generally not biased against women.

Keywords: women in science, evolutionary biology, discrimination against women, gender inequality, research productivity, peer review

Introduction

Women are under-represented in academia and STEM fields, especially among its senior ranks and top institutions (Hornig 1980; Ceci et al. 2009, 2014; Holman et al. 2018; Rushworth et al. 2021). This is, at least in part, due to the many difficulties that they experience throughout their careers, which results in a "leaky pipeline" in which women disproportionately abandon academia and STEM careers (Goulden et al. 2011; Shaw and Stanton 2012). Investigating and documenting these obstacles will help the academic and scientific communities be cognizant of them and devise mitigating strategies.

Female academics are often paid less (even after controlling for seniority; Samaniego et al. 2023), face higher teaching and service loads (Guarino and Borden 2017; O'Meara et al. 2017), are less likely to be invited to speak at conferences or to submit articles to journals (Schroeder et al. 2013; Holman et al. 2018), are more likely to receive unfair teaching evaluations (Kreitzer and Sweet-Cushman 2022), are less likely to receive credit for their work (Ross et al. 2022), and are more likely to be the victims of sexual harassment than their male counterparts (Dey et al. 1996; Minnotte and Pedersen 2023). In addition, female academics tend to have smaller professional networks (Mcdowell and Smith 1992; Ductor et al. 2023), and their work is less visible (Damschen et al. 2005; Shor et al. 2015; Adams et al. 2019) and cited (Aksnes et al. 2011; Teich et al. 2022). These many hurdles, together with childbearing and societal demands that are disproportionately placed on women (e.g. childcare and home responsibilities; Ledin et al. 2007; Rhoads and Rhoads 2012; Awung and Dorasamy 2015), may explain, at least in part, why female academics on average publish fewer articles, especially as single or as corresponding authors and in top academic journals (Symonds et al. 2006; Martin 2012; Larivière et al. 2013; West et al. 2013; Holman et al. 2018; Huang et al. 2020; Cole 2024), secure less grant money (Goulden et al. 2011; Martin 2012), are less likely to obtain tenure and, when they do, are promoted more slowly (Weisshaar 2017). This results in fewer female role models for younger scientists, thus perpetuating women under-representation in academia and STEM fields (Herrmann et al. 2016).

Given the importance of publications for academics' career advancement, it is essential to understand whether women experience additional difficulties to publish their research. Indeed, there has been substantial debate as to whether or not the peer review system is biased against women (Fox and Paine 2019; Squazzoni et al. 2021). Recently, by applying readability formulas to the abstracts of over 9,000 research articles published in top Economics journals, Hengel (2022) has shown that female-authored abstracts tend to be more readable than male-authored ones. Throughout their careers, female economists tend to substantially improve the quality of their writing, whereas male economists do not. By comparing published abstracts with preprint versions, she showed that female economists (especially early-career ones) substantially rewrite and improve the quality of their abstracts during the peer review process, whereas male economists do not. In line with

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these observations, when analyzing articles published in two journals that reported articles' submission and acceptance dates, she found that female-authored articles spend on average 3 to 6 months longer under review (defined as the period from submission to acceptance) than male-authored articles (which spend ∼18.5 months under review on average), probably at least in part because women spend a longer amount of time rewriting their articles. Her results are robust to rigorously controlling for confounding factors. A plausible explanation for these observations is that women are held to higher standards by editors and/or referees.

We set out to determine whether these trends were also present among 49,031 papers published in 11 Evolutionary Biology journals since 1905. We found that: (i) Overall, women represent 26.13% of first authors, 26.74% of last corresponding authors, and 27.63% of all authors. These figures significantly increased over the years, and when only articles published since 2013 are analyzed women represent 37.54% of first authors, 29.25% of last corresponding authors and 32.57% of all authors. (ii) Female first authors are less likely than male first authors to act as corresponding authors. (iii) The gender of the first author correlates with the gender of the last corresponding author. (iv) For some of the studied journals, female-authored papers spent a longer amount of time under review; however, after controlling for articles' date of publication and number of authors, most of the differences between female- and male-authored articles disappear. (v) Overall, the abstracts of female-authored articles are not more readable than those of male-authored articles. Taken together, our results suggest that the peer review process in the field of Evolutionary Biology is generally not biased against women.

Methods

Journal Selection

We obtained a list of peer reviewed research journals in the "Evolutionary Biology" category from the 2023 *Journal Citation Reports* (Clarivate, Philadelphia, PA). From the list, we selected 11 journals based on availability of articles' submission and acceptance dates (journals lacking this information, or providing it only for recent articles, were excluded), amenability of the journal's website to automatic data extraction, and scope (we discarded journals that mostly publish reviews and journals whose focus was either too broad—e.g. Biology—or specific to one taxon—e.g. humans or insects). The selected journals include: *Journal of Heredity* (established in 1903), *Evolution* (published since 1947), *Heredity* (published since 1947), *Systematic Biology* (published since 1952), *Journal of Molecular Evolution* (published since 1971), *Journal of Evolutionary Biology* (published since 1988), *BMC Ecology and Evolution* (formerly known as *BMC Evolutionary Biology*, published since 2001), *EvoDevo* (published since 2010), *Evolution, Medicine and Public Health* (published since 2013), *Nature Ecology and Evolution* (published since 2016), and *Evolution Letters* (published since 2017). Journals' impact factors ranged between 2.1 and 16.8. Five of the journals are included in the first quartile, four are included in the second quartile, and two are included in the third quartile of the "Evolutionary Biology" category.

Data Compilation and Filtering

For Nature journals included in our study (*Nature Ecology and Evolution* and *Heredity*), we obtained a list of "research articles" from the journals' websites. For all other journals, we obtained a full list of articles from the journals' websites. For each article, we extracted the title, kind of article, list of authors, list of corresponding authors, and relevant dates (submission, acceptance and publication) from the abstract's website using ParseHub 2.4.35 (North York, Canada) between March and July 2024.

Only articles for which we could recover the title, publication date and author names were retained. We removed articles tagged as certain special types that do not necessarily go through traditional peer review (Addendum, Announcement(s), Author correction, Author index, Book review(s), Books received, Comment and reviews, Correspondence, Corrigendum, Editorial, Erratum, Foreword, From the editor, In Memoriam, Index, Invited editorial, Keyword index, Letter(s) to the editor, Matters arising, Meeting report, Miscellaneous, News and commentary, Notes and comment, Notice, Obituary, Omitted note added in proof and erratum, Referees, Research collection, Retraction note, Reviewer acknowledgement, Species index, Spotlight, and Subject index). We also excluded *Heredity* articles labeled as "British Association, 1948", "Fifth Conference on Plant Breeding", "Genetical Society of Great Britain", or "The Genetical Society".

Gender Inference

We acknowledge that names are not perfect predictors of gender (Karimi et al. 2016; Holman et al. 2018; Santamaría and Mihaljević 2018) and that not all authors identify as male or female (e.g. Rushworth et al. 2021). Nonetheless, for the purpose of our analysis, all authors' first names were classified as "probably female", "probably male", "unisex", "only initial" or "unknown gender" by comparing them with a reference dataset. For all authors whose complete first name was available, we searched the first name in the Genderize.io server (https://genderize.io/, last accessed on July 21, 2024). The server provides information for over 200,000 unique names, extracted from user profiles in social media. For each name, the server provides the most likely gender, the number of occurrences in the database, and the fraction of these occurrences that correspond to the most likely gender. This server is widely used to infer genders from first names, and their predictions have been shown to correlate very well with reference datasets of scientists of known gender (Karimi et al. 2016; Holman et al. 2018; Santamaría and Mihaljević 2018).

If a name was used as a female name over 90% of the time, we inferred authors with that name to be female. If a name was used as a male name over 90% of the time, we inferred authors with that name to be male. In all other cases, the name was considered unisex, and we did not infer the gender of the authors with that name. Author names were deemed as "only initials" if only their initials were available (e.g. "L Margulis" or "T Ohta") or as of "unknown gender" if their names were not represented in the Genderize database.

For each article, we recorded: (i) the inferred gender of the first author; (ii) the inferred gender of the corresponding author (if there were more than one corresponding author, the one listed last in the list of authors was retained); (iii) the total number of authors with "probably female", "probably male", "unisex", "only initial" and "gender unknown" names; and (iv) the fraction of female authors (number of female authors divided by the number of female authors plus the number of male authors). We placed special emphasis on the genders of the first author and the last corresponding author since, in the field of Evolutionary Biology (as in most of the Life Sciences fields), these authors tend to carry the most responsibility in conducting (first author) and supervising (last corresponding author) the research and writing the manuscript. The first author is often more junior than the corresponding author. Most articles have one corresponding author, and in those cases in which there are more than one corresponding author, the main supervisor of the project is often listed in the last position (Wren et al. 2007; Fox et al. 2018).

To evaluate the accuracy of our gender inference method, we randomly selected 125 articles with corresponding authors predicted to be female, 125 with corresponding authors predicted to be male, 125 with corresponding authors with unisex names, and 125 with corresponding authors of unknown gender. For each article, we conducted an online search to find the corresponding author based on the full name and institution, and the gender was determined based on pictures or pronouns available on institutional websites or professional profiles. Articles whose corresponding author's gender could not be verified were replaced by other articles in the same category; thus, we successfully verified the gender of the corresponding authors of a total of 500 articles. We focused on corresponding authors since they are more likely to hold permanent positions, and thus are more easily found online than other authors.

Abstract Readability Scores

For each article, we retrieved the abstract from the PubMed database. We then used the textstat_readability() function from the quanteda.textstats R package to calculate the following metrics of writing clarity:

1. Flesch Reading Ease Score (Flesch 1948):
$$206.835 - 1.015 \times \frac{\text{words}}{\text{sentences}} - 84.6 \times \frac{\text{syllables}}{\text{words}}.$$
2. Flesch–Kincaid Readability Score (Kincaid et al. 1975):
$$0.39 \times \frac{\text{words}}{\text{sentences}} + 11.8 \times \frac{\text{syllables}}{\text{words}} - 15.59.$$
3. Gunning's Fog Index (Gunning 1952):
$$0.4 \times \left(\frac{\text{words}}{\text{sentences}} + 100 \times \frac{\text{polysyllabic words}}{\text{words}}\right).$$
4. Simple Measure of Gobbledygook (SMOG) (Mc Laughlin 1969):
$$1.043 \times \sqrt{\text{polysyllabic words} \times \frac{30}{\text{sentences}}} + 3.1291.$$
5. Original Dale–Chall Readability Formula (Dale and Chall 1948):
$$0.1579 \times 100 \times \frac{\text{difficult words}}{\text{words}} + 0.0496 \times \frac{\text{words}}{\text{sentences}} + A.$$

These are the same formulas used by Hengel (2022). Polysyllabic words refer to words with more than two syllables, and difficult words are those not included in a list of 3,000 familiar words understood by 80% of fourth graders (Chall and Dale 1995). A equals 0.36365 if difficult words/words >0.05, and 0 otherwise. Highly readable texts tend to score high in the Flesch Reading Ease score but low in the other four scores, which provide estimates of the minimum years of schooling required to confidently understand a given text. Before applying the Dale–Chall Readability Formula, abstracts were modified so that numbers appearing in digit form (including those with multiple digits, decimal points or thousands separators) were interpreted as familiar words. In addition to these scores, for each abstract we computed the average number of words per sentence, the average number of syllables per word and the percentage of difficult words using the quanteda.textstats package, and the average number of letters per word and the percentage of words with seven or more letters using an in-house script.

Statistical Analyses

All statistical analyses were conducted in R 4.4.1. Violin plots were generated using the ggstatsplot package version 0.12.3 (Patil 2021). Multiple testing was corrected for using the Benjamini–Hochberg approach (Benjamini and Hochberg 1995). Partial correlation analyses were conducted using the ppcor package (Kim 2015). ANOVA and ANCOVA analyses were conducted using the rstatix package. Principal component analyses (PCAs) were conducted using the psych package. In partial correlation, multiple regression and ANCOVA analyses, publication dates were treated as continuous variables (e.g. January 10, 2020 was coded as $2020 + 10/365 = 2020.027$).

Results

Representation of Women Among the Authors of Eleven Evolutionary Biology Journals

We obtained information (title, authors, and publication date) for a total of 49,031 articles published in 11 journals. Out of these articles, we inferred the first author to be female in 7,933 cases and male in 22,428 cases based on their first name. In 2,531 cases the first author had a unisex name, in 15,487 cases only a name initial was available, and in 652 cases the author's name was not represented in the Genderize database (https://genderize.io/). Therefore, out of the 30,361 articles for which the first author's gender could be inferred, 26.13% were inferred to have a female first author (see supplementary table S1, Supplementary Material online for journal-specific information).

Out of the 49,031 articles in our dataset, corresponding authors were available for 20,947. If there were more than one corresponding author, the last one was retained, since the last corresponding author tends to be the main supervisor of the project (Wren et al. 2007; Fox et al. 2018). Of these, 3,258 were inferred to be female, 8,928 were inferred to be male, 1,164 had unisex names, for 7,216 only initials were available, and 381 had names that were not represented in the Genderize database. Therefore, out of the 12,186 articles for which the last corresponding author's gender could be inferred, 26.74% were inferred to have a female corresponding author (supplementary table S1, Supplementary Material online).

The 49,031 articles in our dataset had a total of 157,821 non-unique authors (an author that has published x articles in the studied journals will appear x times in the author list), of which 28,063 were inferred to be female, 73,521 were inferred to be male, 9,492 had unisex names, for 44,161 only initials were available, and 2,584 had names that were not represented in the Genderize database. Therefore, out of the 101,584 authors whose gender could be inferred, 27.63% were inferred to be female (supplementary table S1, Supplementary Material online).

For each journal, we represented how the percentage of female first, corresponding and total authors changed over time. In general, the fraction of female authors increased over time, especially for those journals with a longer publication history (Fig. 1). To obtain estimates of female representation among authors of recent articles, we evaluated the percentages among articles published since January 2013 ($n = 12{,}849$), finding higher percentages of female authors: 37.54% among first authors, 29.25% among corresponding authors, and 32.57% among all authors (supplementary table S2, Supplementary Material online).

To evaluate the accuracy of our gender inferences, we randomly selected 125 articles with corresponding authors predicted to be female, 125 with corresponding authors predicted to be male, 125 with corresponding authors with unisex names, and 125 with corresponding authors of unknown gender, and conducted online searches to determine the gender of the corresponding authors. For these articles, the actual fraction of female authors was 98.4%, 0.8%, 26.4% and 16.8%, respectively. Using these fractions and the fraction of articles in each category, we inferred that the overall fraction of women among corresponding authors was 26.57% $[(3{,}258/13{,}731) \times 98.4\% + (8{,}928/13{,}731) \times 0.8\% + (1{,}164/13{,}731) \times 26.4\% + (381/13{,}731) \times 16.8\%]$. These results indicate that our gender inferences are accurate and produce accurate estimates of women's representation in our dataset.

Gender Differences in Corresponding Authorship and Co-authorship

Out of the 4,226 articles with female first authors and with available corresponding author(s), the first author was also the corresponding author (or one of the corresponding authors) of 2,483 (58.76%). Out of the 7,754 articles with male first authors and with available corresponding author(s), the first author was also the corresponding author (or one of the corresponding authors) of 5,241 (67.59%). The fraction of corresponding authors among male first authors was significantly higher than the fraction of corresponding authors among female first authors (Fisher's exact test, $P = 8.06 \times 10^{-22}$). The trend was less pronounced but still significant after removing single-author papers (149 by women and 648 by men): the fraction of corresponding authors among male first authors (59.29%) was significantly higher than the fraction of corresponding authors among female first authors (57.30%; Fisher's exact test, $P = 1.20 \times 10^{-14}$).

After excluding the 14,621 articles for which the first author is a corresponding author, we evaluated whether the gender of the corresponding author correlated with the gender of the first author. Among the 940 articles with a female last corresponding author, the first author was female in 421 cases and male in 390 cases (i.e. 51.91% of authors for which gender could be inferred were inferred to be female). Among the 3,512 articles with a male last corresponding author, the first author was female in 1,153 cases and male in 1,822 cases (i.e. 38.76% of authors for which gender could be inferred were inferred to be female). The fraction of female first authors was significantly higher among articles with a female last corresponding author than among articles with a male last corresponding author (Fisher's exact test, $P = 2.25 \times 10^{-11}$).

For Some Journals, Manuscripts by Female Authors Spent Longer Under Review

Out of the 49,031 articles in our dataset, we could retrieve the submission and acceptance dates for 31,420. For each of these articles, we computed the time under review as the difference between both dates. We removed 55 articles whose reported submission dates were posterior to acceptance dates due to errors in the reported dates, resulting in 31,365 articles. The median time under review was 150 d for all 31,365 articles. No significant differences were found between articles with female first authors and articles with male first authors (median for female-authored articles: 155 d, median for male-authored articles: 156 d; Mann–Whitney's U test, $P = 0.966$; Fig. 2), between articles with all-female authors and articles with all-male authors (median for female-authored articles: 151.5 d, median for male-authored articles: 155 d, $P = 0.096$), or between articles with a female single author and articles with a male single author (median for female-authored articles: 144 d, median for male-authored articles: 143 d, $P = 0.836$). Small but significant differences were found between articles with female corresponding authors and articles with male corresponding authors (median for female-authored articles: 155 d, median for male-authored articles: 152 d, $P = 0.038$; Fig. 2), and between articles with female first authors and female corresponding authors and articles with male first authors and male corresponding authors (median for female-authored articles: 156 d, median for male-authored articles: 153 d, $P = 0.042$).

Since, according to our online searches of 500 authors, 73.6% of authors with unisex names and 83.2% of authors with names of unknown gender are male, we conducted additional analyses comparing (i) the time under review of articles with first authors with female names and articles with first authors with male names, unisex names and names of unknown gender, finding no significant differences (median for female-authored articles: 155 d, median for the other group: 155 d; Mann–Whitney's U test, $P = 0.502$), and (ii) comparing the time under review of articles with last corresponding authors with female names and articles with last corresponding authors with male names, unisex names and names of unknown gender, finding small but significant differences (median for female-authored articles: 155 d, median for the other group: 152 d, $P = 0.029$).

Since the time under review substantially differed among journals (Kruskal-Wallis test, $P < 10^{-300}$), we conducted two ANOVA analyses using the journal as controlling variable. In our first ANOVA, we used the time under review as dependent variable and both the gender of the first author (a factor with two levels) and the journal (a factor with 11 levels) as independent variables. The analysis showed that both factors had a significant effect on the time under review (gender of the first author: $P = 0.005$, journal: $P = 6.55 \times 10^{-48}$). In our second ANOVA, we used the time under review as dependent variable and both the gender of the last corresponding author and the journal as independent variables. Again, we found that both factors had significant effects (gender of the last corresponding author: $P = 0.001$, journal: $P = 8.35 \times 10^{-28}$).

We then conducted a separate analysis for each of the 11 journals. The number of articles ranged from 8,676 for

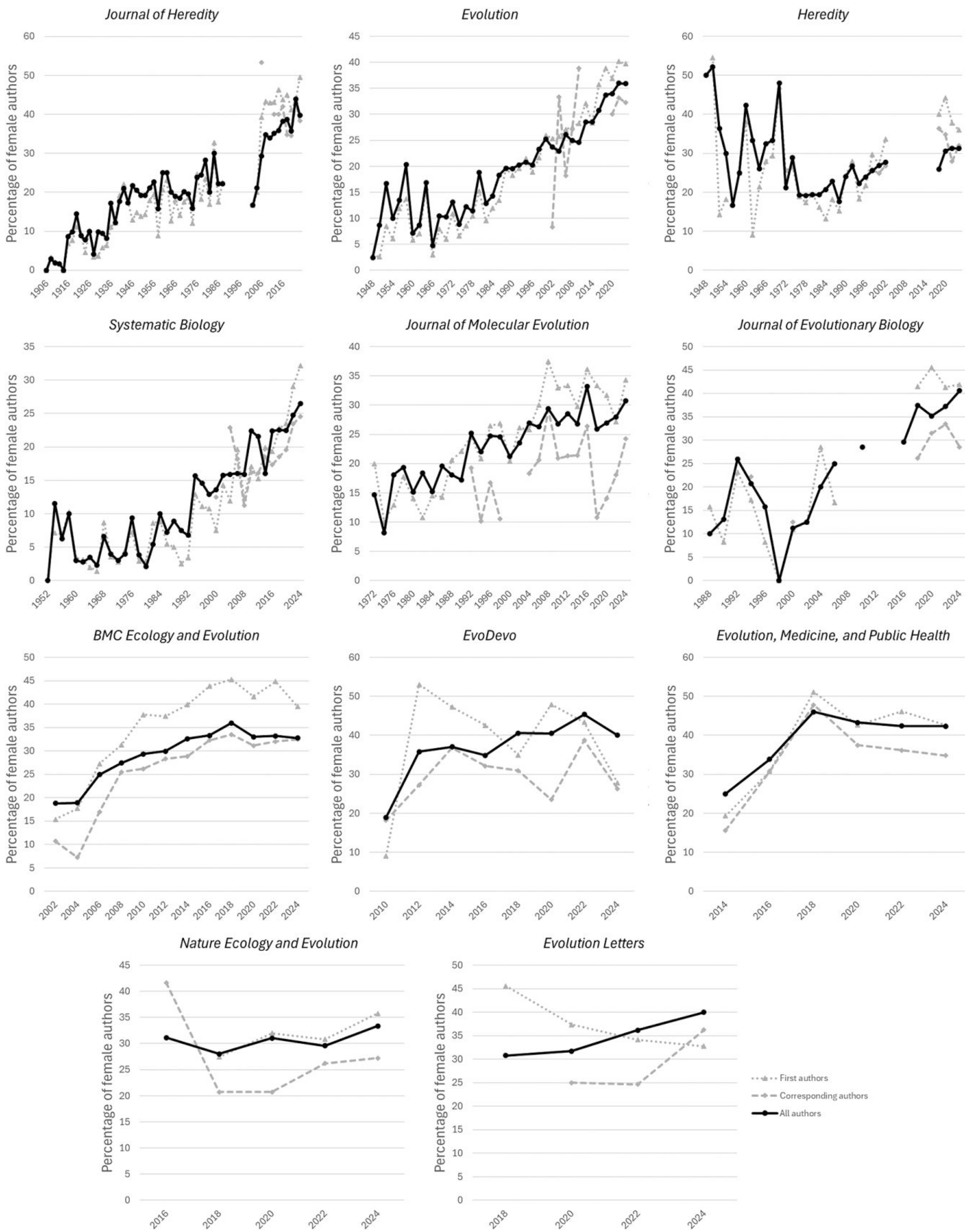

Fig. 1. Change in the fraction of female authors among the authors of 49,031 articles published in 11 journals in the field of Evolutionary Biology. To reduce fluctuations in the graphs, each data point corresponds to the articles published in two consecutive years (articles published in odd years were grouped together with the articles published in the following year). Only biennia with at least 10 articles whose authors' gender could be inferred are represented in the graphs. Gaps in the graphs correspond to periods of the history of the journals for which author's complete names or corresponding author's names are not listed in the abstract websites. Summary statistics are provided in supplementary tables S1 and S2, Supplementary Material online.

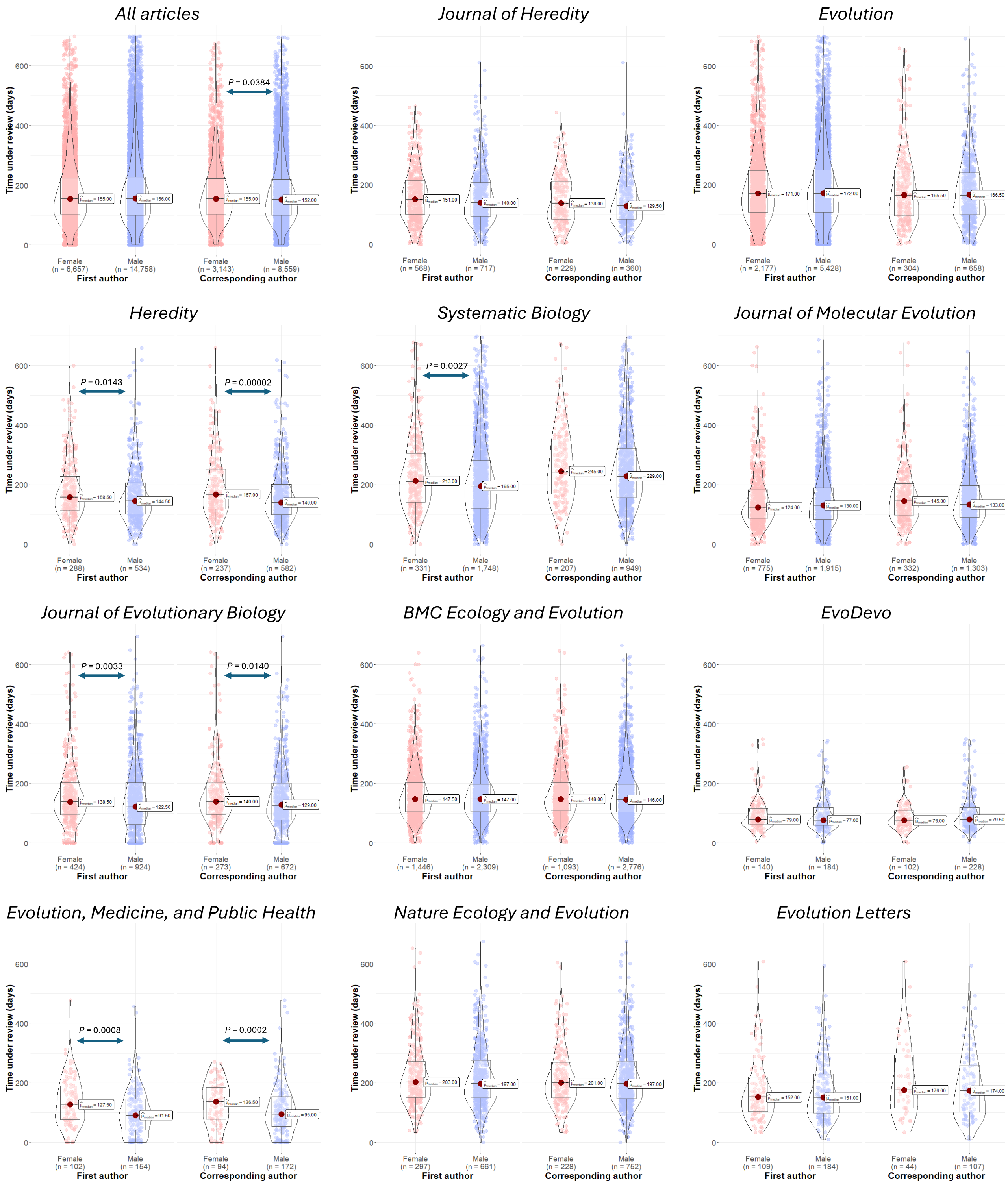

Fig. 2. Time under review (time intervened from submission to acceptance) for articles by female and male authors. Each point represents one article. Articles that were under review for more than 700 d were not represented. Arrows represent significant differences (Mann–Whitney's U test, $P < 0.05$). All median values, P-values and Q-values are provided in supplementary table S3, Supplementary Material online.

Evolution to 282 for *Evolution, Medicine, and Public Health* (supplementary table S3, Supplementary Material online). For each journal, we first computed the median time under review for articles with female first authors and for articles with male first authors. In nine of the journals (all journals except *Evolution* and *Journal of Molecular Evolution*), the median time under review was longer for articles with female first authors (Fig. 2, supplementary table S3, Supplementary Material online). Statistically significant differences were found in four of these journals: *Heredity* (Mann–Whitney's U test, $P = 0.0143$), *Systematic Biology* ($P = 0.0027$), *Journal of Evolutionary Biology* ($P = 0.0033$), and *Evolution, Medicine, and Public Health* ($P = 0.0008$). These results remain significant after controlling for multiple testing ($Q < 0.05$; supplementary table S3, Supplementary Material online).

We next computed, for each journal, the median time under review of articles with female last corresponding authors and for articles with male last corresponding authors. In nine of the journals (all journals except for *Evolution* and *EvoDevo*), the median time under review was longer for articles with female last corresponding authors (Fig. 2, supplementary table S3, Supplementary Material online). Statistically significant differences were found in three of these journals: *Heredity* ($P = 1.52 \times 10^{-5}$), *Journal of Evolutionary Biology* ($P = 0.0140$) and *Evolution, Medicine, and Public Health* ($P = 0.0053$). These results remain significant or marginally significant after controlling for multiple testing (supplementary table S3, Supplementary Material online).

Finally, we evaluated the correlation between articles' fraction of female authors and time under review. When we analyzed all 31,365 articles together, articles' fraction of female authors did not correlate with the amount of time that they spent under review (Spearman's correlation coefficients, $\rho = 0.005$, $P = 0.467$; Fig. 3). When we analyzed articles published in each of the 11 journals separately, Spearman's correlation coefficients were positive ($\rho > 0$) in eight of the journals (all journals except *Evolution*, *Journal of Molecular Evolution*, and *EvoDevo*), and significantly positive in four: *Heredity* ($\rho = 0.099$, $P = 0.0024$), *Systematic Biology* ($\rho = 0.139$, $P = 2.74 \times 10^{-11}$), *Journal of Evolutionary Biology* ($\rho = 0.140$, $P = 5.64 \times 10^{-8}$), and *Evolution, Medicine, and Public Health* ($\rho = 0.221$, $P = 0.0002$; Fig. 3, supplementary table S3, Supplementary Material online). These results remain significant after controlling for multiple testing ($Q < 0.05$; supplementary table S3, Supplementary Material online).

Taken together, these observations indicate that, for some journals, female-authored articles spend a longer amount of time under review than male-authored articles.

Differences Between Female- and Male-Authored Articles Remain Significant After Controlling for Date of Publication

We noticed that the amount of time that articles spend under review significantly changed over time. For six of the journals, articles' amount of time under review positively correlated with their date of publication (supplementary table S4, Supplementary Material online, Fig. 4 and supplementary fig. S1, Supplementary Material online). This, combined with the fact that the fraction of female authors increased over time (Fig. 1, supplementary tables S1 and S2, Supplementary Material online), could be contributing to the observed differences between the amount of time under review spent by female- and male-authored articles (female-authored articles are on average more recent, which may explain, at least to some extent, why they tend to spend longer under review). Conversely, for three of the journals, articles' amount of time under review negatively correlated with their date of publication (supplementary table S4, Supplementary Material online, Fig. 4 and supplementary fig. S1, Supplementary Material online). This could be masking potential differences between the time under review of articles by female and male authors (female-authored articles are on average more recent, and thus tend to spend a shorter amount of time under review).

To remove the potentially confounding effect of the year of publication, we conducted a number of multivariate analyses. Given that the relationship between articles' date of publication and time under review differed among journals (supplementary table S4, Supplementary Material online, Fig. 4 and supplementary fig. S1, Supplementary Material online), we conducted separate analyses for each of the 11 journals. We first used partial Spearman correlation to evaluate the correlation between articles' time under review and the fraction of female authors while controlling for the publication date. Partial correlation coefficients were positive ($\rho > 0$) in nine of the 11 journals, and significantly positive ($P < 0.05$) in 5: *Evolution*, *Heredity*, *Systematic Biology*, *Journal of Evolutionary Biology* and *Evolution, Medicine, and Public Health*. All five correlations remained significant after controlling for multiple testing ($Q < 0.05$; supplementary table S5, Supplementary Material online).

Second, we conducted separate regression analyses for articles with female first authors (red lines in Fig. 4), male first authors (blue lines in Fig. 4), female last corresponding authors (red lines in supplementary fig. S1, Supplementary Material online), and male last corresponding authors (blue lines in supplementary fig. S1, Supplementary Material online). In each regression analysis, articles' time under review was used as the dependent variable and publication date was used as the independent variable. In some cases, regression lines corresponding to female-authored articles ran clearly above those corresponding to male-authored articles, indicating longer times under review for female-authored articles; however, that was not always the case (Fig. 4 and supplementary fig. S1, Supplementary Material online).

Third, we conducted ANCOVA analyses using the time under review as the dependent variable and the gender of the first author and the publication date as independent variables (adding the interaction between gender and publication date resulted in qualitatively equivalent results; data not shown). The gender of the first author had a significant effect on the time under review ($P < 0.05$) for three of the 11 journals (*Evolution*, *Heredity* and *Evolution, Medicine, and Public Health*); however, after controlling for multiple testing, the results only remained significant for one journal (*Evolution*, $Q = 0.011$; supplementary table S6, Supplementary Material online).

Fourth, we conducted ANCOVA analyses using the time under review as the dependent variable and the gender of the last corresponding author and the publication date as independent variables (adding the interaction between gender and publication date resulted in qualitatively equivalent results; data not shown). The gender of the last corresponding author had a significant effect on the time under review for only one of the 11 journals (*Heredity*, $P = 2.03 \times 10^{-5}$); the effect remained significant after controlling for multiple testing ($Q = 0.0002$; supplementary table S6, Supplementary Material online).

Fifth, we evaluated the differences between the amount of time spent under review by articles with female versus male first authors, and with female versus male last corresponding authors published since 2013 (a period in which women representation in Evolutionary Biology was relatively constant; Fig. 1). The amount of time under review was significantly higher for articles with female first authors (Mann–Whitney's U test, $P < 0.05$) for three journals (*Evolution*, *Heredity and Evolution*, *Medicine, and Public Health*); these differences remained significant after controlling for multiple testing ($Q < 0.05$; supplementary table S7, Supplementary Material online). The amount of time under review was significantly higher for articles with female last corresponding

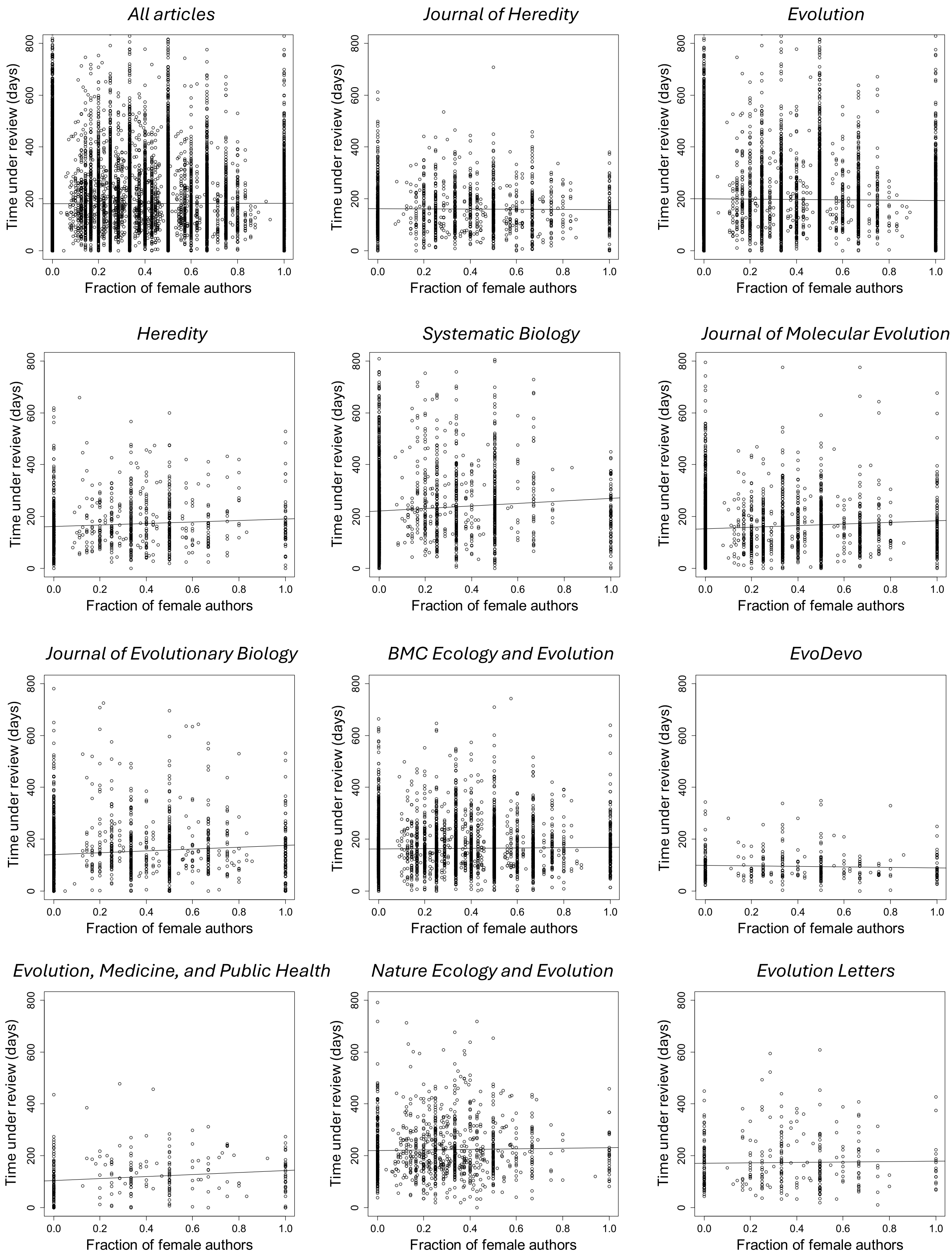

Fig. 3. Correlation between the time under review and the fraction of female authors. Each point represents one article. Articles that were under review for more than 800 d were not represented. The correlation is only significant (Sperman's correlation, *P*-value < 0.05) for *Systematic Biology*, *Journal of Evolutionary Biology*, *Evolution, Medicine, and Public Health* and *Heredity*. Correlation coefficients and the corresponding *P*-values and *Q*-values are provided in supplementary table S3, Supplementary Material online.

authors for two journals (*Heredity* and *Evolution, Medicine, and Public Health*); these differences remained significant after controlling for multiple testing ($Q < 0.05$; supplementary table S7, Supplementary Material online).

Last, we evaluated the correlation between the fraction of female authors and the amount of time under review among articles published since 2013. Correlation coefficients were positive ($\rho > 0$) in 10 of the 11 journals, and significantly

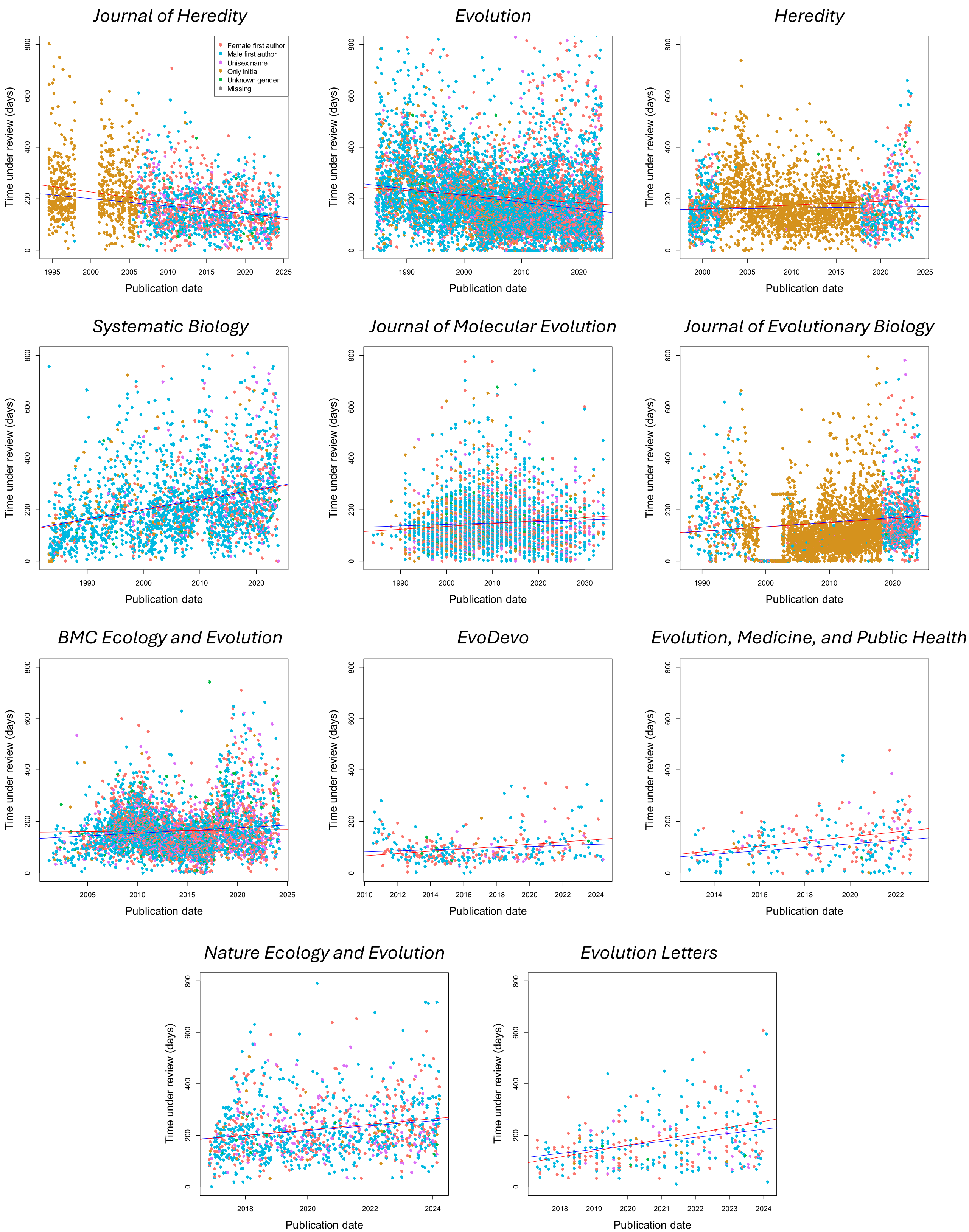

Fig. 4. Time under review as a function of publication date and the gender of the first author. Each point represents one article. Articles that were under review for >800 d were not represented but were used to compute correlations and regression lines (with the only exception of the biggest outlier for the *Journal of Molecular Evolution*, which was excluded). Correlation coefficients and the corresponding *P*-values and *Q*-values are provided in supplementary table S4, Supplementary Material online. For each journal, the effect of the gender of the first author was evaluated using an ANCOVA, and the results are shown in supplementary table S5, Supplementary Material online. Regression lines for articles with female and male first authors are represented in red and blue, respectively. Gaps in the graphs correspond to periods of the history of the journals for which submission and/or acceptance dates are not listed in the abstract websites.

positive ($P < 0.05$) in 3: *Heredity*, *Systematic Biology*, and *Evolution, Medicine, and Public Health*. All three correlations remained significant after controlling for multiple testing ($Q < 0.05$; supplementary table S7, Supplementary Material online).

Taken together, these observations indicate that the differences in the amount of time spent under review by female- and male-authored articles are not entirely due to differences in their dates of publication.

Differences Between Female- and Male-Authored Articles Weaken After Controlling for the Number of Authors

We found that, for nine of the 11 studied journals, articles with female first authors tended to have more authors than articles with male first authors, and that, for five of the journals, articles with female last corresponding authors tended to have more authors than articles with male corresponding authors (supplementary table S8, Supplementary Material online). In addition, we found that for 10 of the studied journals, articles' amount of time under review positively correlated with the number of authors (however, a negative correlation was found for *Journal of Heredity*; Fig. 5 and supplementary fig. S2, table S9, Supplementary Material online). Taken together, these results may explain why, for some journals, female-authored articles tend to spend longer under review.

To remove the potentially confounding effect of the number of authors, we conducted a number of multivariate analyses. Given that the relationship between authors' gender, number of authors and time under review differed among journals (Fig. 5 and supplementary fig. S2, tables S8 and S9, Supplementary Material online), we conducted separate analyses for each of the 11 journals. We first used partial Spearman correlations to evaluate the correlation between articles' time under review and the fraction of female authors while controlling for the number of authors. Correlation coefficients were positive ($\rho > 0$) in eight of the 11 studied journals and significantly positive ($P < 0.05$) in four (*Heredity*, *Systematic Biology*, *Journal of Evolutionary Biology* and *Evolution, Medicine, and Public Health*). After controlling for multiple testing, correlations remained significant in two journals: *Heredity* and *Systematic Biology* ($Q < 0.05$, supplementary table S10, Supplementary Material online).

Second, we conducted separate regression analyses for articles with female first authors (red lines in Fig. 5), male first authors (blue lines in Fig. 5), female last corresponding authors (red lines in supplementary fig. S2, Supplementary Material online), and male last corresponding authors (blue lines in supplementary fig. S2, Supplementary Material online). In each regression analysis, articles' time under review was used as the dependent variable and the number of authors was used as the independent variable. In some cases, regression lines corresponding to female-authored articles run clearly above those corresponding to male-authored articles, indicating longer times under review for female-authored articles; however, that was not always the case, and the opposite trend was also observed in many cases (Fig. 5 and supplementary fig. S2, Supplementary Material online).

Third, we conducted ANCOVA analyses using the time under review as the dependent variable and the gender of the first author and the number of authors as independent variables (adding the interaction between gender and number of authors resulted in qualitatively equivalent results; data not shown). The gender of the first author had a significant effect on the time under review ($P < 0.05$) for three of the 11 journals (*Heredity*, *Systematic Biology* and *Evolution, Medicine, and Public Health*), but all three correlations vanished after controlling for multiple testing (supplementary table S11, Supplementary Material online).

Last, we conducted ANCOVA analyses using the time under review as the dependent variable and the gender of the last corresponding author and the number of authors as independent variables (adding the interaction between the gender and the number of authors resulted in qualitatively equivalent results; data not shown). The gender of the last corresponding author had a significant effect on the time under review ($P < 0.05$) for two of the 11 journals (*Heredity* and *Journal of Evolutionary Biology*). After controlling for multiple testing, the effect remained significant only for *Heredity* ($Q = 0.0002$; supplementary table S11, Supplementary Material online).

Taken together, these observations indicate that the differences in the amount of time spent under review by female- and male-authored articles are to some extent due to differences in their number of authors.

Most of the Differences Between Female- and Male-Authored Articles Vanish After Simultaneously Controlling for Publication Date and Number of Authors

We next evaluated the differences in the amount of time under review spent by articles authored by female and male authors while controlling simultaneously for articles' date of publication and number of authors. Again, given that the relationship between the author's gender and the amount of time under review and these factors differs among journals, we conducted separate multivariate analyses for each journal. We first used partial Spearman correlations to evaluate the correlation between articles' time under review and the fraction of female authors while controlling simultaneously for publication date and number of authors. Correlation coefficients were positive ($\rho > 0$) in eight of the 11 studied journals but they were only significantly positive ($P < 0.05$) in one: *Heredity*. After controlling for multiple testing, none of the correlations were significant (supplementary table S12, Supplementary Material online).

Third, we conducted ANCOVA analyses using the time under review as the dependent variable and the gender of the first author, the date of publication, and the number of authors as independent variables. The gender of the first author had a significant effect on the time under review ($P < 0.05$) for only one journal: *Evolution*. The correlation remained significant after controlling for multiple testing (supplementary table S13, Supplementary Material online).

Last, we conducted ANCOVA analyses using the time under review as the dependent variable and the gender of the last corresponding author, the date of publication, and the number of authors as independent variables. The gender of the last corresponding author had a significant effect on the time under review ($P < 0.05$) for only one journal: *Heredity*. The correlation remained significant after controlling for multiple testing (supplementary table S13, Supplementary Material online).

Taken together, these observations indicate that the differences in the amount of time spent under review by female- and male-authored articles are mostly due to the combined

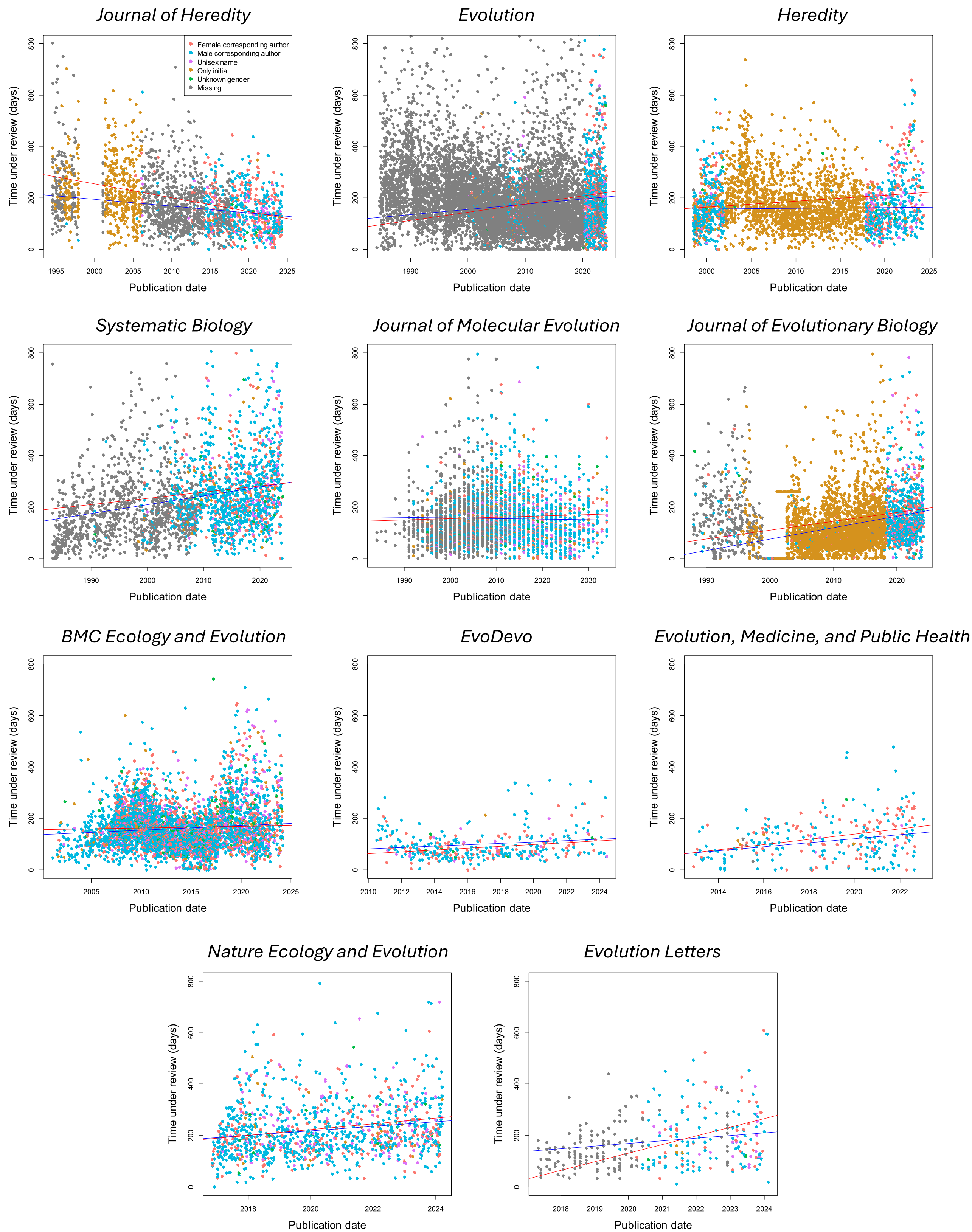

Fig. 5. Time under review as a function of number of authors and the gender of the first author. Each point represents one article. Articles that were under review for >800 d were not represented but were used to compute correlations and regression lines (with the only exception of the biggest outlier for the *Journal of Molecular Evolution*, which was excluded). Correlation coefficients and the corresponding *P*-values and *Q*-values are provided in supplementary table S9, Supplementary Material online. For each journal, the effect of the gender of the first author was evaluated using an ANCOVA, and the results are shown in supplementary table S11, Supplementary Material online. Regression lines for articles with female and male first authors are represented in red and blue, respectively.

Table 1 Readability scores of abstracts by female and male authors

Readability score	First author					Corresponding author					Correlation quality score-fraction female authors	
	Female name		Male name		*P*-value[b]	Female name		Male name		*P*-value[b]		
	n[a]	Median	*n*[a]	Median		*n*[a]	Median	*n*[a]	Median		ρ[c]	*P*-value[d]
Flesch	6,609	12.19	13,849	12.37	0.7012	3,117	11.48	8323	11.48	0.4632	−0.007	0.2753
Flesch–Kincaid	6,609	17.91	13,849	17.91	0.7406	3,117	18.06	8323	18.10	0.3996	−0.002	0.7690
FOG	6,609	21.92	13,849	21.94	0.9397	3,117	22.00	8323	22.06	0.3421	−0.001	0.8578
SMOG	6,609	18.63	13,849	18.63	0.6916	3,117	18.70	8323	18.71	0.6081	0.001	0.8639
Dale–Chall	6,609	12.28	13,849	12.20	1.11×10^{-8}*	3,117	12.34	8323	12.34	0.9765	0.058	1.28×10^{-18}*
Words per sentence	6,609	25.30	13,849	25.33	0.5745	3,117	25.60	8323	25.50	0.9424	−0.009	0.1898
Syllables per word	6,609	25.30	13,849	25.33	0.5745	3,117	25.60	8323	25.50	0.9424	−0.009	0.1898
Letters per word	6,609	5.84	13,849	5.82	$2.66\text{E} \times 10^{-5}$*	3,117	5.86	8323	5.87	0.4130	0.042	2.23×10^{-10}*
%Words with >7 syllables	6,609	40.55	13,849	40.10	2.19×10^{-7}*	3,117	40.91	8323	40.67	0.0385*	0.049	2.01×10^{-13}*
%Difficult words	6,609	46.77	13,849	46.21	7.31×10^{-11}*	3,117	47.03	8323	46.98	0.7655	0.066	1.29×10^{-23}*

[a]This table includes all articles for which we could retrieve the title, authors, publication date and abstract, and that did not belong to certain special types.
[b]P-values corresponding to the Mann–Whitney's *U* test.
[c]Spearman's rank correlation coefficient between the quality score and the fraction of female authors.
[d]*P*-values corresponding to the Spearman's rank correlation coefficient test.
**P*-values < 0.05.

effect of differences in their publication date and number of authors. Nonetheless, some differences persist for *Evolution* and *Heredity* articles after simultaneously controlling for both factors.

Abstracts of Articles by Male and Female Authors do Not Consistently Differ in Their Readability

Hengel (2022) found that the abstracts of research articles written by female economists tend to be more readable, which may explain why they tend to spend a longer time under review (female economists tend to put more effort into improving the quality of their writing during the peer review process). We evaluated whether the abstract readability of articles in our dataset depended on the gender of the authors. Out of the 49,031 articles in our dataset, we could retrieve an abstract from the PubMed database for 30,518 (of note, PubMed was first released in 1996). For each abstract, we computed five readability scores (the same ones used by Hengel (2022)): Flesch Reading Ease Score (Flesch 1948), Flesch–Kincaid readability score (Kincaid et al. 1975), Gunning's Fog Index (Gunning 1952), SMOG (Mc Laughlin 1969), and the original Dale–Chall readability formula (Dale and Chall 1948). In addition to these scores, for each abstract we computed the average number of words per sentence, the average number of syllables per word, the average number of letters per word, the percentage of difficult words and the percentage of words with seven or more letters.

On average, abstracts of articles with female first authors exhibited slightly but significantly higher Dale–Chall scores, numbers of letters per word, and percentages of difficult words (Table 1). Abstracts of articles with female corresponding authors exhibited a slightly but significantly higher percentage of words with seven or more letters (Table 1). Articles' fraction of female authors exhibited a weak but significant positive correlation with their abstracts' Dale–Chall scores, number of letters per word, percentage of words with seven or more letters and percentage of difficult words (Table 1). These results suggest that, on average, female-authored articles tend to be slightly less readable than male-authored articles.

Since the five readability scores are correlated to each other (|ρ| ranged from 0.514 to 0.992), we conducted two PCAs. Our first PCA was restricted to articles whose first author was predicted to be female or male. The analysis showed no visible differences between female- and male-authored articles (supplementary fig. S3, Supplementary Material online). In addition, none of the five principal components significantly differed between female- and male-authored articles (Mann–Whitney's *U* test, $P < 0.05$). Our second PCA was restricted to articles whose last corresponding author was predicted to be female or male. Results were very similar (supplementary fig. S4, Supplementary Material online), and only the fourth principal component significantly differed between female- and male-authored articles ($P = 0.048$).

We then conducted a separate analysis for each score and for each of the 11 studied journals. For each journal and readability score (11 journals × 5 scores), we compared the scores of articles with female and with male first authors. Seven of the comparisons were statistically significant (Mann–Whitney's *U* test, $P < 0.05$) in a direction that would indicate less readability (lower Flesch Reading Ease Score or higher Flesch–Kincaid readability Score, Gunning's Fog Index, SMOG, or Dale–Chall readability score) for female-authored articles, whereas two comparisons were statistically significant in the opposite direction. Nonetheless, only two of the comparisons remained significant after controlling for multiple testing (both in a direction that would indicate a lower readability for female-authored articles; supplementary table S14, Supplementary Material online).

We next compared, for each journal and score (11 × 5), the scores of articles with female and with male last corresponding authors. Eight of the comparisons were significant in a direction that would indicate that female-led articles are more readable, whereas four of the comparisons were significant in the opposite direction. Nonetheless, none of the comparisons remained significant after controlling for multiple testing (supplementary table S14, Supplementary Material online).

Finally, for each journal and score (11 × 5), we evaluated the correlation between the score and the fraction of female authors. In 10 cases, we found correlations that indicate that articles with a high fraction of female authors tend to be less readable (the fraction of female authors correlated negatively with the Flesch Reading Ease Score, or positively with the other scores). Three of these correlations remained significant after correcting for multiple testing. In four cases, we found correlations that indicate that articles with a high fraction of female authors tend to be more readable (the fraction of female authors correlated positively with the Flesch Reading Ease Score, or negatively with the other scores). None of these correlations remained significant after correcting for multiple testing. Figure 6 displays the correlations between the fraction of female authors and the original Dale–Chall readability score (the score for which we found the highest number of significant correlations). Correlation coefficients, *P*-values and *Q*-values for all five scores are shown in supplementary table S14, Supplementary Material online.

We observed that abstracts' readability scores often correlated with articles' date of publication. In most of the cases in which significant correlations were found, they indicated that abstracts became less readable over time (however, the opposite trend was found for articles published in *Evolution Letters*; supplementary table S15, Supplementary Material online). These observations, combined with the fact that female representation in the field of Evolutionary Biology increased over the years (Fig. 1, supplementary tables S1 and S2, Supplementary Material online), may be impacting the differences between the readability of abstracts written by female and male authors (female-authored articles in our dataset are on average more recent, and recent abstracts tend to be less readable).

To control for the potential effect of the date of publication, for each journal and readability score (11×5), we first used partial Spearman correlation to evaluate the correlation between abstracts' readability scores and articles' fraction of female authors while controlling for publication dates. Out of the 55 partial correlations, 10 were statistically significant ($P < 0.05$), including seven indicating that female-authored articles are more readable, and three indicating the opposite (supplementary table S16, Supplementary Material online). However, none of the partial correlations remained significant after controlling for multiple testing. Second, we evaluated the differences between the abstract readability scores of articles with female versus male first authors, and with female versus male last corresponding authors published since 2013. After controlling for multiple testing, we found that articles published in *Heredity* with female first authors had generally less readable abstracts than articles with male first authors (Mann–Whitney's *U* test, $Q < 0.05$). No significant differences were found among articles with female and male last corresponding authors after controlling for multiple testing (supplementary table S17, Supplementary Material online). Last, we evaluated the correlation between the fraction of female authors and readability scores among articles published since 2013. After controlling for multiple testing, we found that: (1) among articles published in *Evolution*, the fraction of female authors positively correlated with the Dale–Chall readability score, indicating that female-authored abstracts tend to be less readable; (2) among articles published in *Heredity*, the fraction of female authors positively correlated with the Flesch–Kincaid readability score, indicating that female-authored abstracts tend to be less readable; (3) among articles published in the *Journal of Evolutionary Biology*, the fraction of female authors correlates positively with the Flesch reading ease score and negatively with the FOG and SMOG scores, indicating that female-authored abstracts tend to be more readable (supplementary table S17, Supplementary Material online).

Taken together, our analysis of readability scores reveals no clear differences in the abstract readability of female- and male-authored articles. Most of the observed differences are not significant, and the ones that are significant are small, contradictory (indicating differences in both directions depending on the journal), and vanish after controlling for the date of publication.

Discussion

Representation of Women Among Authors of Evolutionary Biology Research Articles

We observed that women accounted for 26.13% of first authors, 26.74% of last corresponding authors, and 27.63% of all authors of articles published in 11 evolutionary journals since 1905 (supplementary table S1, Supplementary Material online). Women representation significantly increased over the decades (Fig. 1), and when we analyzed articles published since 2013, women accounted for 37.54% of first authors, 29.25% of last corresponding authors and 32.57% of all authors (supplementary table S2, Supplementary Material online). Our observations are in line with previous studies that have documented an increase in women representation in most academic fields, including Ecology and Evolution (Ceci et al. 2014; Holman et al. 2018; Fox et al. 2019).

Holman et al. (2018) evaluated the gender ratio among authors of research articles of 115 STEMM disciplines, including Biology. Across all disciplines, they found that women currently accounted for 44% of first authors, 30% of last authors, and 41% of all authors (we calculated these numbers by averaging values in their Dataset S1). In the field of Biology, women currently accounted for 43% of first authors, 28% of last authors, and 38% of all authors. Comparison of these figures with our estimates indicates that women are less represented in the field of Evolutionary Biology than in Biology or STEM as a whole (Fig. 1, supplementary tables S1 and S2, Supplementary Material online).

By analyzing articles published between 2003 and 2015 in six Ecology and Evolutionary Biology journals (including *Evolution*), Fox et al. (2019) found that women's representation increased over time, reaching 23% for last authors and 31% for all authors in 2015. Women also became more represented among editors (29% in 2015) and reviewers (27% in 2015). Similarly, Edwards et al. (2018) found that women represented 42% of first authors, 25% of last authors, 37% of corresponding authors, 32% of editors and 22% of reviewers of articles submitted to the *Journal of Evolutionary Biology* between January 2012 and February 2016.

An analysis of the lists of members of three scientific societies, the Society for the Study of Evolution (which publishes *Evolution* and *Evolution Letters*), the European Society for Evolutionary Biology (which publishes the *Journal of Evolutionary Biology* and *Evolution Letters*), and the American Society of Naturalists, showed that women represented 40%, 43% and 37% of the members, respectively, and that female representation was 52% to 55% among students, 51% among postdocs and 24% to 31% among faculty (Débarre et al. 2018). Rushworth et al. (2021) surveyed the

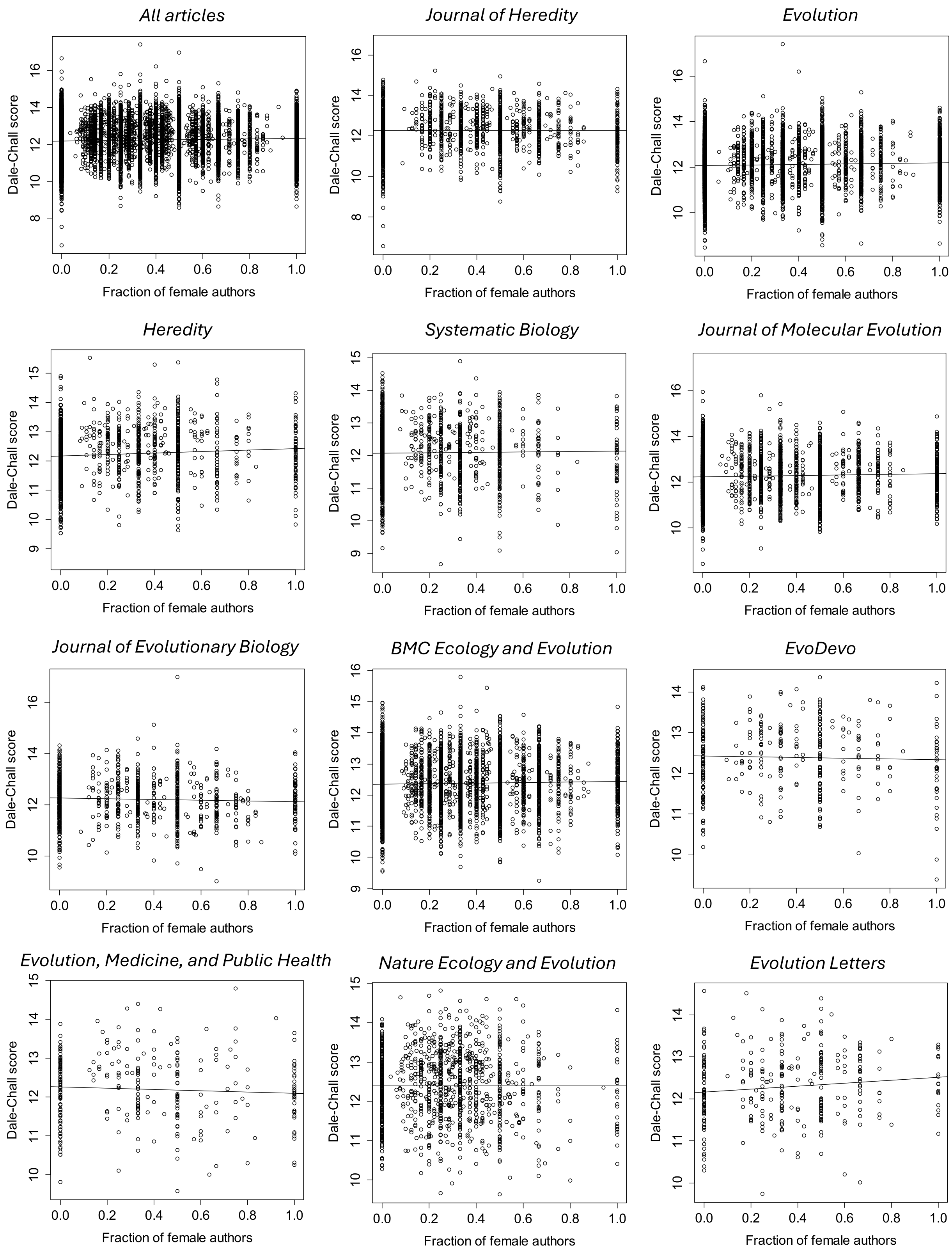

Fig. 6. Correlation between abstracts' original Dale–Chall readability scores and the fraction of female authors. Each point represents one article. The correlation is significant (Sperman's correlation, *P*-value < 0.05) for *Evolution*, *Heredity*, *Systematic Biology*, *Journal of Molecular Evolution*, *BMC Ecology and Evolution* and *Evolution Letters*. Correlation coefficients and the corresponding *P*-values and *Q*-values are provided in Table 1 and supplementary table S14, Supplementary Material online.

attendees of the Evolution 2019 meeting (jointly organized by the American Society of Naturalists, the Society for the Study of Evolution and the Society of Systematic Biologists), and 57% of the respondents were women; however, it is likely that women and other minorities responded to the survey at a higher rate than men.

It should be noted that the gender ratio among article authors depends not only on the gender ratio of researchers working in a field, but also on the relative publication rates of female and male authors. Whereas some studies have found no differences in the publication rate of women and men (van Arensbergen et al. 2012; Huang et al. 2020), other studies have found that women publish at a lower rate (Guyer and Fidell 1973; Addessi et al. 2012; McGuire et al. 2012; Cole 2024), including one study of a cohort of 168 ecologists and evolutionary biologists that showed that men's rate of publication was on average 40% higher than that of women (Symonds et al. 2006).

A number of analyses of research articles from different fields have revealed an under-representation of women among last and corresponding authors compared with middle authors (West et al. 2013; Fox et al. 2018; Holman et al. 2018) (in Evolutionary Biology, as in most of the Life Sciences, project leaders tend to sign as last and corresponding authors, which are two of the authorship positions that confer the most prestige; Wren et al. 2007; Fox et al. 2018). Whereas some studies of articles from various fields have shown that women are also under-represented among first authors (also a position of prestige) (Larivière et al. 2013; West et al. 2013), others have found an overrepresentation (Fox et al. 2018; Holman et al. 2018). Surprisingly, we do not observe any substantial trend when we analyze all the articles in our dataset: the gender ratio is very similar among first, last corresponding, and all authors (however, we do see individual differences in many of the studied journals; supplementary table S1, Supplementary Material online). However, when we analyzed articles published since 2013, women were clearly overrepresented among first authors and under-represented among last corresponding authors compared to all authors (supplementary table S2, Supplementary Material online). These results are somewhat in line with previous observations that the women under-representation among first authors weakened over time and is not visible among articles published after 1990 (West et al. 2013).

The under-representation of women among corresponding authors that we observe is consistent with the well documented fact that women are especially under-represented in the top positions of academia (whose members tend to act as corresponding authors) (Hornig 1980; Ceci et al. 2009, 2014; Holman et al. 2018; Rushworth et al. 2021). In addition, it has been suggested that women may be less likely to be offered or to request corresponding authorship (Babcock and Laschevar 2003; Edwards et al. 2018; Holman et al. 2018), and that trainees may be less likely to select women as supervisors (Holman et al. 2018), a possibility that we further discuss below.

Female First Authors are Less Likely to be Corresponding Authors Than Male First Authors

We found that first authors were one of the corresponding authors 58.76% of the time if they were female and 67.59% of the time if they were male. The gap is reduced, but remains significant, after removing single-author articles. In an analysis of articles submitted to the *Journal of Evolutionary Biology*, Edwards et al. (2018) also found that male first authors were more likely to be corresponding authors than female first authors, and similar trends have also been found among articles submitted to other journals (Heckenberg and Druml 2010; Fox et al. 2016, 2018). As discussed above, this may be due to women being less likely to be offered or to request corresponding authorship (Babcock and Laschevar 2003; Edwards et al. 2018; Holman et al. 2018), or to the under-representation of women in senior academic positions (Hornig 1980; Ceci et al. 2009, 2014; Holman et al. 2018; Rushworth et al. 2021), which makes female authors in our dataset expected to be on average less experienced than male authors in our dataset. It has also been proposed that women may be more likely to leave academia and defer corresponding authorship to their male advisors (Fox et al. 2016).

The Gender of First Authors Correlates With the Gender of Last Corresponding Authors

We found that, among articles with female first authors, 51.91% had female last corresponding authors, whereas among articles with male first authors, only 38.76% had female last corresponding authors. This correlation between the genders of the first and the last corresponding authors is in agreement with a number of studies showing that researchers tend to collaborate with other researchers of the same gender (Mcdowell and Smith 1992; Araújo et al. 2017; Holman and Morandin 2019). This effect is observed even after controlling for the fact that women are better represented in certain fields, which makes female-female collaboration more likely (Wang et al. 2023). More specifically, it has been observed that male principal investigators tend to supervise fewer women (Sheltzer and Smith 2014) and that male corresponding authors tend to publish fewer articles with women (Salerno et al. 2019; Frances et al. 2020). It has also been shown that female trainees perceive that having female mentors is important (Blake-Beard et al. 2011). These results underscore one potential benefit of promoting a better representation of women in Science: they have the potential to attract other women and to promote their retention (Herrmann et al. 2016).

Female-Authored Articles Published in Some Evolutionary Biology Journals Spend Longer Under Review, but the Trend Mostly Disappears After Controlling for Confounding Factors

The amount of time that a manuscript spends under review (which we defined as the amount of time intervened between submission and acceptance) depends on many factors, including the speed at which editorial office processes the submission and assign an editor, the speed at which the editor evaluates the manuscript and finds referees (typically two or three in the field of Evolutionary Biology), the speed at which referees evaluate the manuscript (which is affected by the deadline given by the journal, which is typically 2 to 3 weeks), the amount and complexity of changes and additional work requested by the referees, the speed at which the authors produce a revised manuscript (which is affected by the deadline given by the journal, which is typically 2 months), and how long it takes for all authors to approve the manuscript before resubmission. In addition, the editor may decide to subject the manuscript to multiple cycles of review.

It is possible that some of these steps are affected by bias. For instance, editors and/or referees may spend longer evaluating female-authored manuscripts, and/or hold female-authored manuscripts to higher standards and ask them to conduct a high amount of additional work. If present, the differential treatment could be due to different reasons; for instance, it could be due to editors and/or referees harboring inaccurate stereotypes about women's research, using heuristics that tend to disadvantage women (such as institutional prestige) to evaluate research, or being relatively unfamiliar or uncomfortable with the topics, terminology, methodology or conclusions of female-authored articles. Alternatively, female authors may spend longer revising their manuscripts (which may require additional data generation, additional analyses, rewriting some parts of the manuscript, and/or adding new parts) due to external factors (duties other than research; Ledin et al. 2007; Rhoads and Rhoads 2012; Awung and Dorasamy 2015; Guarino and Borden 2017; O'Meara et al. 2017) and/or internal factors (e.g. women having a higher risk aversion, having lower self-confidence, or being more critical of their own work; e.g. Croson and Gneezy 2009; Coffman 2014; Born et al. 2022; Exley and Kessler 2022; Möbius et al. 2022; Shastry and Shurchkov 2024).

Hengel (2022) has recently shown that the abstracts of female-authored articles published in four top Economics journals are more readable because women (especially early-career ones) significantly improve their writing during peer review and because women become better at writing during their careers, whereas men do not. In addition, she found that female-authored articles published in two journals spent on average 3 to 6 months longer under review than male-authored articles, probably because women spend longer rewriting their manuscripts. A plausible explanation for Hengel's findings is that, in the field of Economics, female-authored articles are held to higher standards by editors and/or referees during the review process, and that women adapt to these higher standards.

In agreement with Hengel's findings in the field of Economics (Hengel 2022), we found that four of the 11 Evolutionary Biology journals that we studied (*Heredity*, *Systematic Biology*, *Journal of Evolutionary Biology* and *Evolution, Medicine, and Public Health*) exhibit some evidence of female-authored articles taking longer under review. In these journals, articles with female first authors spend significantly longer under review (Fig. 2, supplementary tables S3 and S7, Supplementary Material online), articles with female corresponding authors spend longer under review (Fig. 2, supplementary tables S3 and S7, Supplementary Material online), and/or there is a positive correlation between articles' fraction of female authors and the amount of time that they spent under review (Fig. 3, supplementary tables S3 and S7, Supplementary Material online).

We found that, for six of the studied journals, the amount of time that articles spend under review has increased over time, in agreement with similar observations in other fields (Ellison 2002) (however, for three of the journals we found the opposite effect; Fig. 4 and supplementary fig. S1, table S4, Supplementary Material online). This observation, combined with our observations (and those of others; Fox et al. 2019) that women have become better represented over time among authors of Evolutionary Biology journals (Fig. 1, supplementary tables S1 and S2, Supplementary Material online), made it necessary to re-evaluate the association between authors' gender and articles' time under review while controlling for the date of publication (Fig. 4 and supplementary fig. S1, tables S5 to S7, Supplementary Material online). In addition, we found that articles with female first or last corresponding authors have in general more co-authors (supplementary table S8, Supplementary Material online), and that articles with more co-authors tend to spend longer under review (perhaps because submission of revised articles requires coordinating more co-authors, and that delays resubmission; Fig. 5 and supplementary fig. S2, table S9, Supplementary Material online). Combined, these findings made it necessary to control for the number of authors (Fig. 5 and supplementary fig. S2, tables S10 and S11, Supplementary Material online).

While Hengel's observation that female-authored articles tend to spend longer under review are robust to controlling for confounding factors (Hengel 2022), the similar tendencies that we observed in our dataset are mostly not: when controlling simultaneously for publication date and number of authors, most of the differences vanish. Indeed, our ANCOVA analyses using the time under review as the dependent variable and the gender of the first author, the date of publication, and the number of authors as independent variables showed that the first author's gender had a significant effect only among articles published in *Evolution* (supplementary table S13, Supplementary Material online). Similarly, our ANCOVA analyses using the time under review as the dependent variable and the gender of the last corresponding author, the date of publication, and the number of authors as independent variables showed that the last corresponding author's gender had a significant effect only among articles published in *Heredity* (supplementary table S13, Supplementary Material online). In addition, the Spearman's partial correlation between the fraction of female authors and the amount of time under review controlling for publication date and number of authors was only significant for *Heredity*, and the correlation disappeared after controlling for multiple testing (supplementary table S12, Supplementary Material online).

Our results suggest that, for most of the journals in which female-authored articles take longer under review, the trend is not primarily due to the gender of the authors, but to the fact that female-authored articles are on average more recent (Fig. 1, supplementary tables S1 and S2, Supplementary Material online) and/or because female-authored articles have on average more co-authors. Thus, while robust for the field of Economics, Hengel's main results cannot be extended to the field of Evolutionary Biology. It should be noted that the fields of Economics and Evolutionary Biology differ in at least two key aspects: women are much less represented in Economics departments (only a quarter to a third of assistant and associate professors, and less than 15% of professors, are women; Lundberg and Stearns 2019; Gamage et al. 2020) and among authors of top Economics journals (the percent of female authors per paper was 3% to 4% in the late 1980s and ~15% in 2015; Hengel 2022), and the peer review process is on average much slower in the field of Economics (Ellison 2002; Hengel 2022). Future work will be required to determine how often (in how many and in which fields) female-authored articles spend longer under review than male-authored articles.

Our results thus do not point to a pervasive bias against female-authored articles in the field of Evolutionary Biology, at least at the level of the time that they spend under review (we do not discard, however, other forms of bias). Our findings resonate with a number of analyses of articles submitted to different Life Sciences journals showing that articles' acceptance rates do not depend, or depend only very weakly, on the gender of the authors, the editors or the referees (Gilbert et al. 1994; Primack et al. 2009; Heckenberg and Druml 2010; Fox et al. 2016; Edwards et al. 2018; Fox and Paine 2019; Squazzoni et al. 2021).

After Controlling for Confounding Factors, Some Differences Persist in Two of the Journals

As discussed above, our ANCOVA analyses did show that, for articles published in *Heredity*, having a female last corresponding author results in a longer amount of time under review (supplementary table S13, Supplementary Material online). Indeed, *Heredity* is one of the journals for which we found the largest difference between articles with female last corresponding authors (median time under review: 167 d) and male last corresponding authors (median time under review: 140 d; Fig. 2, supplementary table S3, Supplementary Material online). Published since 1947, *Heredity* is one of the oldest journals included in our dataset; nonetheless, the difference is even more pronounced among articles published since 2013 (median for articles with female last corresponding authors: 171.5 d, median for articles with male last corresponding authors: 138 d; supplementary table S7, Supplementary Material online).

Our ANCOVA analyses also showed that, for articles published in *Evolution*, having a female first author results in a longer time under review. The positive impact of female gender on the time under review was confirmed by conducting a multiple linear regression analysis using the time under review as the dependent variable and first author's gender (coded as a binary variable taking the values of 0 and 1 for male and female, respectively), publication date and number of authors as independent variables (effect of having a female first author: $\beta = 10.70$, $P = 0.003$). Finding that effect was surprising, since our initial analyses (not controlling for confounding factors) did not find any substantial difference between the time spent under review by articles with female and male first authors for that journal. Actually, among articles published in that journal, those with female first authors spent *less* time under review (median: 171 d) than those with male first authors (median: 172 d; Fig. 2, supplementary table S3, Supplementary Material online); however, the opposite trend was found among articles published since 2013 (median for articles with female first authors: 160 d, median for articles with male first authors: 153 d; supplementary table S7, Supplementary Material online). Of note, *Evolution* was one of the three journals for which the peer review process has accelerated over time (Fig. 4 and supplementary fig. S1, table S4, Supplementary Material online). Thus, for that journal, the fact that female-authored articles are on average more recent (Fig. 1, supplementary tables S1 and S2, Supplementary Material online) means that, all other things being equal, female-authored articles should spend a significantly shorter amount of time under review—an effect that we do not observe. Thus, for that journal, our ANCOVA analyses uncover an effect of the first author's gender on time under review that was initially masked by confounding factors.

The significant effects of authors' gender observed in *Heredity* and *Evolution* may indeed be the result of direct or indirect bias against female-authored articles. Alternatively, they could be explained, at least in part, by women in our dataset being on average less experienced than men in our dataset—since women are under-represented at the highest academic ranks (Hornig 1980; Ceci et al. 2009, 2014; Holman et al. 2018; Rushworth et al. 2021)—or by women spending a longer amount of time revising their manuscript due to external or internal factors.

The Potential Impact of Double-blind Peer Review

Most of the journals included in our analysis subject manuscripts to traditional single-blind peer review (i.e. the referees know the identity of the authors). The *Journal of Evolutionary Biology* and *Evolution* implemented double-blind peer review policies (i.e. the referees do not know the identity of the authors) in February 2016 and January 2017, respectively (Ritchie 2016; Noor 2017). In addition, authors submitting their articles to Nature journals can opt for double-blind peer review since March 2015 (Nature 2015). Since these policies are recent, they only affect a small number of the articles published in our study (*Journal of Evolutionary Biology*: 1,172 articles submitted since February 2016, *Evolution*: 1,524 articles submitted since January 2017, *Nature Ecology and Evolution*: all 1,158 articles published in the journal, of which an unknown number were subjected to double-blind peer review), and thus are not expected to have a substantial effect on our results.

In addition, a number of analyses have shown that the acceptance rate of female-authored articles is essentially indistinguishable from that of male-authored articles, regardless of whether or not double-blind peer review is implemented (Bruce et al. 2016) (other studies, however, have found an effect of double-blind peer review; Kern-Goldberger et al. 2022). For instance, starting in 2019, the journal *Functional Ecology* (not included in our analysis) started randomly assigning all submitted articles to two groups; the first was subjected to the traditional single-blind peer review and the second was subjected to double-blind peer review. Comparison of both groups showed that female- and male-authored articles were equally affected by double-blind peer review (Fox et al. 2023).

In Evolutionary Biology, Female-Authored Abstracts are Not More Readable Than Male-authored Abstracts

Abstracts' readability has been shown to correlate with the readability of other parts of academic articles (Hartley et al. 2003; Plavén-Sigray et al. 2017; Hengel 2022), and writing highly readable articles takes time (Hartvigsen 1981; Kroll 1990). Hengel (2022) found that, in the field of Economics, female-authored abstracts are on average more readable than male-authored abstracts. The trend becomes more pronounced as authors become more experienced, since women become better at writing over time whereas men do not. She also found that early-career female authors significantly improve the readability of their articles during the peer review period. A plausible explanation for her findings is that female-authored articles are held to higher standards by editors and referees and that, as a result, women (especially early-career ones) have to devote more effort to rewriting their articles during peer review. This may explain, at least in part, why their articles spend on average a longer amount of time under review (Hengel 2022).

In contrast, our analysis of 30,518 abstracts does not show that female-authored abstracts are more readable than male-authored ones: our analysis of all abstracts combined show that female-authored articles tend to be subtly less readable (Table 1), and our journal-specific tests are often non-significant, and when they are significant, they go in both directions (depending on the specific journal and readability metric chosen, some tests indicate that female-authored articles are more readable, whereas some indicate the opposite), and most of the time vanish after controlling for multiple testing (supplementary table S14, Supplementary Material online).

In agreement with previous reports for other fields (Plavén-Sigray et al. 2017), we found that articles readability often decreased over time (supplementary table S15, Supplementary Material online). This, together with our findings (and those of others; Fox et al. 2019) that women became better represented among authors of Evolutionary Biology journals over time (Fig. 1, supplementary tables S1 and S2, Supplementary Material online), made it necessary to reassess the association between author genders and abstracts' readability while controlling for the date of publication. Once we applied that control and controlled for multiple testing, all the differences in the readability scores of female- and male-authored abstracts disappeared (supplementary table S16, Supplementary Material online). In addition, restricting our analyses to abstracts published since 2013 resulted in significant differences being few and contradictory (supplementary table S17, Supplementary Material online).

Even though several studies have found some (often subtle) differences in the writing styles of men and women (e.g. Mulac and Lundell 1994; Haswell and Haswell 1996; Francis et al. 2001; Argamon et al. 2003; Bozic Lenard 2018), analyses of grant proposals, abstracts and research articles have only found small and inconsistent differences (Hartley et al. 2003; Saragih and Hutajulu 2020; Horbach et al. 2022), which is in agreement with our results.

Limitations of our Study

Our work is subject to some limitations. First, our binary gender inferences are not appropriate to classify non-binary, gender fluid, gender neutral, and gender non-conforming individuals, which represented 1.5% of the respondents of Rushworth et al.'s survey (Rushworth et al. 2021).

Second, inferring genders from names, even when using established, validated and widely used datasets like the Genderize database (https://genderize.io/), is not a perfect method. Some authors have conducted internet searches to infer the genders of all the researchers in their datasets (e.g. Hengel 2022). Applying this approach to our substantially larger dataset (49,031 articles and 157,821 authors) would not only have been unfeasible, but it would also have introduced biases (e.g. people that lived before the internet or that left academia after a short academic career—among which women are overrepresented—would have often been hard or impossible to find). Nonetheless, similar to other authors (Débarre et al. 2018; Edwards et al. 2018; Fox et al. 2018, 2019; Holman et al. 2018), we conducted internet searches to determine the gender of a subset of the authors in our dataset, showing that our gender inferences are accurate in most cases. In addition, it has been argued that the small fraction of errors introduced by name-based inferences are expected to partially cancel out (some women may have been misclassified as men, while some men may have been misclassified as women; Holman et al. 2018). In any case, the gender ratios that we obtained are similar to those previously found among authors of Ecology and Evolution journals (Edwards et al. 2018; Fox et al. 2019).

Third, it is possible that, for those journals with fewer published articles, the statistical power of our tests might have been limited. However, this does not seem to be the case, since one of the journals for which our analyses revealed significant differences between the amount of time under review of female- and male-authored articles is *Evolution, Medicine, and Public Health*—the journal with the smallest number of articles for which time under review could be inferred ($n = 282$; Fig. 2, supplementary table S3, Supplementary Material online). In addition, after controlling for confounding variables, some of the trends remained significant not only for *Evolution* (the journal with most analyzable articles; $n = 8690$), but also for *Heredity* (with 2,874 analyzable articles, which is very close to the average across all journals, 2,856.4; supplementary table S3, Supplementary Material online).

Fourth, even though all the journals included in our study are important venues for the publication of Evolutionary Biology articles, some of them partially focus on other topics. Indeed, two of the journals included in our study focus on both Evolutionary Biology and Ecology (*BMC Ecology and Evolution* and *Nature, Ecology and Evolution*). In addition, *Evolution, Medicine and Public Health* focuses on the intersection between Evolutionary Biology and Biomedicine, and *Heredity* focuses on Genetics (including Evolutionary Genetics, Population Genetics, Molecular Evolution, Phylogenetics, Conservation Genetics and Adaptation Genomics). The *Journal of Heredity* is the journal of the American Genetic Association (known as the American Breeder's Society until 2014) and, while its first issues heavily focused on artificial selection, it currently focuses on Genetics with a special emphasis on Biodiversity Genetics and Genomics, Conservation Genetics and Genomics, and Genome Evolution.

Fifth, our results may be somewhat affected by women in our dataset being on average less experienced than men in our dataset, since women are under-represented at senior academic positions (Hornig 1980; Ceci et al. 2009, 2014; Holman et al. 2018; Rushworth et al. 2021). This could potentially increase the average time under review of female-authored articles and/or reduce the readability of female-authored abstracts. However, we mostly do not observe these trends in our dataset. In addition, our comparison of articles with female and male corresponding authors mostly did not detect significant differences once we controlled for confounding factors. Corresponding authors are expected to be relatively experienced: on average, newly hired faculty members in the fields of Ecology and Evolution have published 11.75 research articles (Marshall et al. 2009), newly hired faculty members at American universities in the field of Ecology have a *h*-index of 8.7, and newly hired faculty members at American R1 universities in the field of Ecology have authored 9.5 research articles as first authors (Fox 2020). This provides some level of control for seniority (however, not all corresponding authors are faculty members).

Sixth, we did not attempt to control for other potential confounding factors such as whether women in our dataset gave birth, were on maternal leave or had young children during the peer review period (Hengel did control for these factors in her analysis of over 9,000 Economics articles). First, doing so would have been unfeasible, given the size of our dataset (49,031 articles and 157,821 authors) and the fact that it extends back to 1905. Second, childbirth and motherhood are expected to result in female-authored papers spending longer under review, an effect that we generally do not observe.

Last, abstracts obtained from abstract databases may contain errors, including typos, transcription errors, and the inclusion of typesetting code. Hengel (2022) proofread abstracts before readability scores calculation. However, applying this approach to our substantially larger dataset (30,518 abstracts) would have been unfeasible. Nonetheless, while such errors may have added noise to our readability scores, errors in the abstracts are expected to equally affect female- and male-authored abstracts.

Conclusion

In some Evolutionary Biology journals, female-authored articles spend longer under review. However, the trend mostly vanishes after controlling for confounding factors. In addition, the abstracts of female-authored articles are in general not more readable. Our results do not point to a pervasive bias against female-authored articles in the field of Evolutionary Biology, at least at the level of the time that they spend under review—we do not discard, however, other forms of bias. Thoroughly and periodically auditing the peer review process is necessary to ensure its fairness. Further work will be required to evaluate how common biases in the peer review process are across academia as a whole and in its different fields, to elucidate their reasons, and to devise mitigating strategies.

Supplementary Material

Supplementary material is available at *Molecular Biology and Evolution* online.

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Author Contributions

DA-P conceived and designed the study, analyzed data, generated images and tables and wrote the manuscript. JV was responsible for data extraction. Both authors approved the final version of the manuscript.

Data Availability

All data used in this study are publicly available, as described in the Methods section.

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