Who are ASM Journals? A Gender-based Analysis

Running title: A gender-based analysis of ASM journals

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Abstract

Evidence has accumulated over the decades that academic research has a representation problem. While at least 50% of biology Ph.D. graduates are women, the number of women in postdoctoral positions and tenure-track positions are below 40% and 30%, respectively. Recently, scientific societies and publishers have begun examining internal submissions data to evaluate representation of, or bias against, women in their peer review processes; however, representation and attitudes differ by scientific field and no studies to-date seem to have investigated academic publishing in the field of microbiology. Using manuscripts submitted between January 2012 and August 2018 to 13 journals published by the American Society for Microbiology (ASM), we describe the representation of women at ASM journals and the outcomes of their manuscripts. We find that senior women authors at ASM journals are underrepresented compared to global and society estimates of microbiology researchers. Additionally, manuscripts submitted by corresponding authors that were women, received more negative outcomes (e.g., editorial rejections, reviewer recommendations, and decisions after review), than those submitted by men. These negative outcomes were somewhat mediated by whether or not the corresponding author was based in the US or not, and by the institution for US-based authors. Nonetheless, the pattern for women corresponding authors to receive more negative outcomes for their submitted manuscripts indicates a pattern of gender-influenced editorial decisions. We conclude with suggestions to improve the representation of, and decrease bias against, women at ASM journals.

Importance

Women are underrepresented as senior scientists at ASM journals. This is due to a combination of both low submissions from senior women authors and increased rejection rates for women compared to men.

Introduction

Evidence has accumulated over the decades that academic research has a representation problem. While at least 50% of biology Ph.D. graduates are women, the number of women in postdoctoral positions and tenure-track positions are less than 40 and 30%, respectively (1). Studies examining other metrics such as race and ethnicity found that in 2011, less than 27% of all science and engineering doctorates were awarded to underrepresented minorities, and less than 25% of associate professors identified as non-white (2, 3). Predictably, the disparities increase with academic rank (4). There have been many proposed reasons for these disparities, particularly with regards to women, which include biases in training and hiring, the impact of children on career trajectories, a lack of support for primary caregivers, a lack of recognition, lower perceived competency, and less productivity as measured by research publications (1, 5–9). These issues do not act independent of each other, instead they are cumulative over time for both individuals and the community, much as advantages accumulate (10, 11). Accordingly, addressing these issues necessitates multi-level approaches from all institutions and members of the scientific community.

Scientific societies play an integral role in the formation and maintenance of scientific communities. They host conferences that provide a forum for knowledge exchange, networking, and opportunities for increased visibility as a researcher. Scientific societies also frequently publish the most reputable journals in their field, facilitating the peer review process to vet new research submissions. Recently, scientific societies and publishers have begun examining internal submissions data to evaluate representation of, and bias against, women in their peer review processes. The American Geological Union found that while the acceptance rate of women-authored publications was greater than publications authored by men, women submitted fewer manuscripts than men and were used as reviewers only 20% of the time (12), a factor influenced by the gender of the editor (13). Several other studies have concluded that there is no significant bias against papers authored by women (13–17). Two recent studies—one of the peer review process at eLife, a broad scope biology journal, and the other of outcomes at six ecology and evolution journals—found that women-authored papers are less likely to have positive peer reviews and outcomes (18, 19).

The representation of women scientists and gender attitudes differ by scientific field, and no studies to-date seem to have investigated academic publishing in the field of microbiology. The American Society for Microbiology (ASM) is one of the largest life science societies, with an average membership of 41,000 since 1990. In its mission statement, the ASM notes that it is "an inclusive organization, engaging with and responding to the needs of its diverse constituencies" and pledges to "address all members' needs through development and assessment of programs and services." One of these services is the publication of microbiology research through a suite of research and review journals. Between January 2012 and August 2018, ASM published 15 different journals: *Antimicrobial Agents and Chemotherapy* (AAC), *Applied and Environmental Microbiology* (AEM), *Clinical and Vaccine Immunology* (CVI), *Clinical Microbiology Reviews* (CMR), *Eukaryotic Cell* (EC), *Infection and Immunity* (IAI), *Journal of Bacteriology* (JB), *Journal of Clinical Microbiology* (JCM), *Journal of Virology* (JV), *mBio*, *Microbiology and Molecular Biology Reviews* (MMBR), *Genome Announcements* (GA, now *Microbiology Resource Annoucements*), *Molecular and Cellular Biology* (MCB), *mSphere*, and *mSystems*. The goal of this research study is to describe the population of ASM journals through the representation of authors, reviewers, and editors by gender and the associated peer review outcomes of their manuscripts.

Results

Over 100,000 manuscript records were obtained for the period between January 2012 and August 2018 (Fig. 1). Many papers are immediately rejected by editors instead of being sent to peer review, often due to issues of scope or perceived quality. These were defined as editorial rejections and identified as manuscripts rejected without record of review. Alternately, editors could send papers out for review by two or three experts in the field selected from a list of potential reviewers in the manuscript records (whether they were author- or editor-suggested is unknown). The reviewers make suggestions to the editor who decides whether the manuscript in question should be accepted, rejected, or sent back for revision. At ASM journals, manuscripts with suggested revisions that are expected to take more than 30 days are rejected, but generally encouraged to resubmit. If resubmitted, the authors are asked to note the previous (related) manuscript and the re-submission is assigned a new manuscript number. Multiple related manuscripts were tracked together by generating a unique grouped manuscript number based on the recorded related manuscript numbers. This grouped manuscript number served dual purposes of tracking a single manuscript through multiple rejections and avoiding duplicate counts of authors for a single manuscript. After eliminating non-primary research articles and linking records for resubmitted articles, there were 81,897 unique manuscripts processed (Fig. 1).

We attempted to assign genders to both peer review gatekeepers (e.g., editor-in-chief, editors, reviewers) and authors on the original research manuscripts evaluated during this time period. We recognize that biological sex (male/female) is not always equivalent to the gender that an individual presents as (man/woman), which is also distinct from the gender(s) that an individual may self-identify as. For the purposes of this manuscript, we choose to focus on the presenting gender (man/woman/unknown) based on their first names (and appearance for editors). Author genders were assigned using a social media-informed predictive algorithm with stringent criteria and validation process (see methods). This method of gender assignment resulted in a category of individuals whose gender could not be reliably predicted. In the interest of transparency, we include those individuals whose names don't allow a high degree of confidence for gender assignment in the "unknown" category of our analysis, which is shown in many of the plots depicting representation of the population, but are not included in the comparison of manuscript outcomes.

Men dominate as gatekeepers and senior authors. We first evaluated the representation of men and women who were gatekeepers at ASM during the study period. Each journal is led by an editor-in-chief (EIC) who manages journal scope and quality standards through a board of editors with field expertise that handle the peer review process. In total, there were 17 EICs, 17.65% of which were women. Two journals, EC and CVI were retired during the period under study. Four years before retirement, the leadership of CVI transferred from a man EIC, to a woman while JVI has had a woman as EIC since 2012. The total number of editors at all ASM journals combined over the duration of our study (senior editors and editors pooled) was 1016, 28.74% of which were women.

Over 40% of both men and women editors were from US-based R1 institutions, defined as doctoral universities with very high research activity, with non-US institutions, and U.S. medical schools or research institutions supplying the next largest proportions of editors (Fig. 2A). Since the start of our study, there has been a slow trend toward equivalent gender representation among editors (Fig. 2B). The trends for each journal studied vary considerably, though most have slow trends toward parity (Fig. S1). CVI and *mSphere* were the only ASM journals to have accomplished equivalent representation of both genders, with CVI having a greater proportion of women editors than men before it was retired. EC is the only journal with an increasing parity gap.

Altogether, editors recruited a total of 30704 reviewers, 24.61% of which were women, to act as manuscript reviewers. The greatest proportion of reviewers (over 50% of both men and women) come from non-US institutions, while R1 institutions supply the next largest cohort of reviewers (Fig. 2C). Over the time period studied, the proportions of each gender have held steady among reviewers at ASM journals (Fig. 2D) and is representative of both the listed potential reviewers at all journals combined, and the actual reviewer proportions at most journals (Fig. S2).

Editorial workloads were not proportionate Across all journals, men handle a slightly greater proportion of manuscripts (blue) than women (orange), relative to their respective editorial representations (Fig. 3A). This trend continues across most journals with varying degrees of difference between workload and representation (Fig. S1). For instance, at *mSphere*, workload and proportions were identical; however, CVI, *mBio*, and JVI, each have points at which the workload for women editors is much higher than their representation, with corresponding decreases in the workload of men. In the years preceding its retirement, the representation of women at CVI increased, which acted to decrease the gap in editorial workload. However, representations and relative workloads for men and women editors at JVI have held steady over time, while the proportionate workload for women at *mBio* has increased.

Between 2012 and 2018, the median number of manuscripts reviewed by individuals in each gender group is equivalent, at 2. Half of those in men, women, or unknown gender groups reviewed between one and 5, 4, or 3 manuscripts each, respectively (Fig. 3B). Conversely, 43.35% of men, 38.97% of women, and 47.45% of unknown gendered reviewers have reviewed only one manuscript. Reviewers of all genders accepted fewer requests to review from women editors (average of 47.91%) than from men (average of 53.4%) and were less likely to respond to women editors than men (no response rate averages of 25.04 and 19.91%, respectively) (Fig. 3C). Editors of both genders contacted reviewers from all three gender groups at equivalent proportions, though women editors contact an average of 76.29% of potential reviewers, while men contact 73.92% on average (Fig. 3D).

Women were underrepresented as authors Globally, microbiology researchers are 60% men and 40% women (20). At ASM in September 2018, 38.37% of members who reported their gender were women. We wanted to determine if these proportions were similar for authors at ASM journals and to understand the distribution of each gender among submitted and published manuscripts. We began by describing author institutions by gender. Over 60% of submitting authors were from non-US institutions, followed by 20% from R1 institutions (Fig. 4A). The proportions of men and women authors at ASM have decreased over time at equivalent rates, with a ratio of men to women authors of 4:3 since 2012 (or, 57% men) (Fig. 4B). The decrease in gendered authors corresponds with an increase in the proportion of unknown gendered authors.

In the field of microbiology, order of authorship on manuscripts signal the type and magnitude of contributions to the finished product with first and last authorship being the most prestigious. First authors are generally trainees (e.g., students or post-docs) or early career research responsible for the bulk of the project, while last authors are lead investigators, supplying conceptual guidance and resources to complete the project. Middle authors are generally responsible for technical analyses and methods. Any author can also be a corresponding author, which we identified as the individual responsible for communicating with publishing staff during peer review (as opposed to an author to whom readers direct questions).

The proportion of papers submitted with men and women first authors have remained constant with averages of 29.64 and 31.08 percent, respectively (Fig. 4C, dashed). Their respective proportions of average published manuscripts were nearly identical at 33.16% for men and 33.85% for women. The proportion of submitted papers with men corresponding authors has remained steady at an average of 42.45% while the proportion with women corresponding authors was at

23.56% (Fig. 4D, dashed). Both men and women corresponding authors have a greater proportion of manuscripts published than were submitted, the difference where men were corresponding authors is 7.4, and 0.79 for women corresponding authors. This trend is similar for middle and last authors (Fig. S3).

Of 39168 manuscripts submitted by men corresponding authors, 23.52% had zero women authors (single author papers excluded). 7403 (36.45%) of papers submitted by women corresponding authors had at least 51% of the authors as women, exceeding those submitted by men corresponding authors in both the number (3305) and percent (8.44) of submissions. Additionally, the proportion of women authors decreases as the number of authors increases (Fig. S4).

We hypothesized that we would be able to predict the gender of the corresponding author from the manuscript metadata. We trained a logistic regression model to predict the gender of the corresponding author using whether or not the corresponding author's institution was in the U.S., the total number of authors, the proportion of authors that were women, whether or not the article was published, the gender of senior editors and editors, the number of revisions, and whether or not the manuscript was editorially rejected as variables to train our model. If there is no bias in collaborations, the model should not perform better than random (0.5) at assigning gender to submissions, as measured by the area under the receiver operating characteristic curve (AUROC). The AUROC value is a predictive performance metric that ranges from 1.0, where the model perfectly distinguishes between outcomes, to 0.0, where the model's predictions completely wrong. The median AUROC value of our model to predict corresponding author gender was 0.7. The variable with the largest weight (i.e., the most predictive value), in our model was the proportion of women authors. These results indicate that manuscript submission data is capable of predicting the gender of the corresponding author, but that prediction is primarily driven by what percentage of authors are women.

To better visualize the 7.52% decrease from the proportion of women who were first authors, to those who were corresponding authors (Fig. 4CD), we asked the proportions at which women have been retained through the peer review system at ASM journals. During the period of time under study, there were 76215 women who participated as junior authors (first/middle) at ASM journals. Of those junior authors who were women, 8.25% also participated as senior authors (last/corresponding), and 8.91% were listed as potential reviewers. 5.39% of the women junior authors later participated as reviewers and 0.25% were an editor. For men, there were a total of 84482 junior authors, where 13.59% were also senior authors, 16.72% considered as reviewers, and 11.11% actually reviewed. 0.66 of men junior authors were also editors at ASM journals. Overall, women are half as likely to move to more prestigious (e.g., senior author, gatekeeper) roles in peer review than men are.

Papers submitted by women have more negative outcomes than those submitted by men. To better understand the differences between published and submitted proportions for men and women authors (Fig. 4CD, Fig. S3), we compared the rejection rates of men and women at each author stage (first, middle, corresponding, and last). Middle authors were rejected at similar rates for men and women, a 0.01 percentage point difference across all journals combined; however, manuscripts with senior women authors were rejected more frequently than those authored by men with -1.6 and -0.92 percentage point differences for corresponding and last authors, respectively (Fig. 5A, vertical line). There were several instances where the overall trend is repeated or even amplified at the journal level (e.g., AAC, IAI, JB, *mBio*, MCB). The greatest effect was observed when comparing the outcome of corresponding authors by gender, so we used this sub-population to further examine the difference in manuscript acceptance and rejection rates between men and women.

We next compared the rejection rates for men and women corresponding authors after two bottlenecks, initial review by the editor and the first peer review. Papers authored by women were editorially rejected as much as 12 percentage points more often than those authored by men (Fig. 5B). The percentage point difference at all ASM journals combined is -3.87 (vertical line), and two journals, MCB and *mBio*, have more extreme percentage point differences. Papers authored by men and women were equally likely to be accepted after the first round of review (Fig. 5C, right panel). However, women-authored papers were rejected more often (left panel) while men-authored papers were more often given revision decisions (center panel). Three journals, JB, AAC, and MCB, have percentage point differences more extreme than for all ASM journals combined in both rejection and revision decisions, (-5.49 and 5.45 respectively; Fig. 5C vertical lines). Percentage point differences were not correlated with journal prestige as measured by impact factors (R^2 = -0.022).

In addition to manuscript decisions, other disparate outcomes may occur during the peer review process (21). To determine whether accepted women-authored manuscripts spent more time between being submitted and being ready for publication, we compared the number of revisions, days spent in the ASM peer review system, and the number of days from submission to being ready for publication to those authored by men. Papers authored by women take slightly longer (from submission to ready for publication) than men at some journals (*mSphere*, *mBio*, *mSystems*, CVI, JB, JCM, AEM) despite spending similar amounts of time in the ASM journal peer review system, and having equivalent median number of revisions prior to acceptance (Fig. S5).

To understand how gatekeeper (editor/reviewer) genders influence decisions (e.g., Fig. 5C), we grouped editor decisions and reviewer suggestions according to the gatekeeper gender. Both men and women editors rejected proportionally more women-authored papers, with men editors making revise decisions on papers authored by men more often than those authored by women (Fig. 6A). Reviewers were more likely to suggest rejection for women-authored manuscripts as compared to men, though no difference in revise suggestions were observed (Fig. 6B). Both men and women reviewers recommended rejection more often for women-authored manuscripts though only men recommended acceptance more often for men-authored manuscripts (Fig. 6C). Women reviewers suggested revision on women-authored papers more often than men-authored manuscripts.

To evaluate if gender played a role in manuscript editorial decisions, we trained a L2-regularized logistic regression model to predict whether or not a manuscript was reviewed (i.e. editorially rejected or not). We used the genders of senior editor, editor, and corresponding author, as well as the proportion of authors that were women as variables to train the model. The median AUROC value was 0.62, which indicated that editorial decisions were not completely random. However, the AUROC value is relatively low indicating that there are factors other than the variables we included in our model that influence editorial decisions.

Country and institute of origin contribute to overperformance by men. The issue of non-random, gender-based manuscript decisions could be attributed to gender bias by journal gatekeepers, however, there are other types of bias that may contribute to, or obscure, overt gender bias; for instance, a recent evaluation of peer-review outcomes at *eLife* found evidence of geographic homophily. That is, reviewers exhibited preference for research submitted by authors from their own country or region (18). Other studies have documented prestige bias, where men are over-represented in more prestigious (i.e., more respected and competent) programs (22). It is therefore possible, that what seems to be gender bias could be geographic or prestige bias interacting with the increased proportion of women submitting from outside the US or at lower prestige institutions (e.g., low research institutions) (Fig. 4A).

To try to separate how these factors affect manuscript decisions, we next looked at the outcome of papers submitted only by corresponding authors at US institutions. When only considering US-based authors, the difference in percentage points for editorial rejections changes from -3.87 to -1.51, though trends across journals were largely consistent (Fig. 7A). Similarly, the difference in percentage point trends of decisions after review for US-based authors mirror those seen for all corresponding authors at the journal level (Fig. 6B). The over-performance of women in rejection decisions decreases from -5.49 to -4.07, and the over-performance of men in revise only decisions decreased to 3.95 from 5.45 (Fig. 7B). The rate of accept decisions changed from -1.51 to 0.09 after restricting the analysis to US-based authors. These results suggest that the country of origin (e.g, US versus not) accounts for some gender bias, particularly for editorial rejections, though not all of it.

To address prestige bias, we next split the US-based corresponding authors according to their institution and re-evaluated the difference in percentage points for men and women. Editorial rejections occurred most often for women from medical schools or institutes, followed by those from R2 institutions (Fig. 7C). Manuscripts submitted by men from medical schools or institutes were accepted proportionally more often than those submitted by women. The difference in percentage points for corresponding authors from medical schools or institutes seems to be spread across most ASM journals, while the editorial rejection of papers from R2 institutions seems to be driven primarily by JCM (Fig. S6AB). Rejections after review occurred more often for manuscripts submitted by women than those submitted by men, regardless of editor gender (Fig. 7D).

To evaluate if these factors affect manuscript decisions, we trained a L2-regularized regression model to predict if a manuscript was editorially rejected or not, using the variables: origin (US vs non), institution (US institution type), number of authors, proportion of authors that were women, and the genders of both gatekeepers and authors. The model had a median AUROC value of 0.68 which indicated that there is a non-random interaction between these factors and editorial decisions. To investigate the relationship of each variable to the model prediction, we reviewed the signs of the variable weights of the trained model. Authors from U.S. “other” institutions, men EICs, men that are corresponding authors from “other” U.S. institutions, and women from medical schools and institutes were all variables with positive weights, which means they increased the likelihood of an editorial rejection. Conversely, authors from R1 institutions, authors from the U.S., EiCs that are women, and the number of authors were variables with negative weights, which increased the likelihood of a manuscript going to review. These results confirm that the country of origin and prestige bias impact decisions in a non-random manner.

Discussion

In this paper we described the representation of men and women at ASM journals between January 2012 and August 2018, and compared editorial outcomes according to the author gender. We found that women were consistently under-represented (30% or less in all levels of the peer review process) excluding first authors, where women represented were about 35% of authors (Fig. 2/4). Women and men editors had proportionate workloads across all ASM journals combined, but those workloads were disproportionate at the journal level and the overburdened group varied according to the journal (Fig. 3/S1). Additionally, manuscripts submitted by corresponding authors that were women, received more negative outcomes (e.g., editorial rejections, reviewer recommendations, and decisions after review), than those submitted by men (Fig. 5/6). These negative outcomes were somewhat mediated by whether or not the corresponding author was based in the US or not and by the institution for US-based authors (Fig. 7). However, the trend for women corresponding authors to receive more negative outcomes held, indicating a pattern of gender-influenced editorial decisions.

While the proportion of women as first authors is equivalent to data obtained globally and from self-reported ASM membership data, it was higher than the proportion of senior women authors at ASM journals. Only half as many women who were junior authors at ASM journals were also senior authors when compared to men, and the representation of women decreased as the prestige (e.g., reviewer, editor) increased. These observations are consistent with representation of senior women in academic biological sciences and the observation that women are more likely to leave academia during the transition from postdoc to investigator (23). These data indicate that microbiology (as represented by ASM journals) is not exempt from the issues that limit the promotion of women to academic faculty.

How to define representation and determine what the leadership should look like are recurring questions in STEM. Ideally, the representation for men and women corresponding authors, reviewers, and editors would reflect the number of Ph.D.s awarded (about 50% each, when considered on a binary spectrum). However, that is not (yet) the case, so we argue that the goal should depend on the workload and visibility of the position(s). Since high visibility positions (e.g., editor, EIC) are filled by a smaller number of individuals that are responsible for recruiting more individuals into leadership, filling these positions should be done aspirationally (i.e., 50% should be women if the goal were an aspirational leadership). This allows greater visibility for women as experts, expansion of the potential reviewer network, and recruitment into those positions (24–26). Conversely, lower visibility positions (e.g., reviewers) require a greater number of individuals and should thus be representational of the field to avoid overburdening the minority population (i.e., since 23.5% of corresponding authors to ASM journals are women, then 23-24% of reviewers should be women). Balancing the workload is particularly important given the literature indicating that women faculty have higher institutional service loads than their counterparts who are men (27).

In contrast to institutional service, the editing workload at ASM journals seems to be predominantly borne by men, according to the proportion of gendered representation. A possible explanation for the difference in gatekeeper representation and editor workloads is that women are more likely to conduct research on the fringes of research fields (28–30). Their separation from the historical center of a field decreases their perceived competency, which could result in research typecasting and lower manuscript handling responsibilities. Other possibilities are that the increased service load decreases their ability to handle larger editorial loads or that since status as an editor is "prestigious", the workload is preferentially diverted to editors that are men (31). Any of these situations can be compounded by the increased proportion of potential reviewers that either do not accept, or do not respond to, requests to review from women editors. This increases the proportion of reviewers that women editors must contact, adding additional time and work to their editorial burdens. Three journals, *mBio*, CVI, and JVI are exceptions with regards to editorial workloads. At these journals, the editorial workloads of women exceeds their representation. A possible explanation for CVI and JVI is that both of these journals have been led by women EICs, who perhaps have increased confidence in their women editors. Alternately, the tendency for reviewers to reject requests to review from editors that are women extends to editors that are men rejecting requests to handle manuscripts from EiCs that are women. Our data differ from those of Fox, Burns, and Meyer who found that the gender of the editor influenced the gender of the contacted reviewers, but supports findings that women editors contact more reviewers than men (13, 32).

Our data support findings of previous studies that women are more likely to collaborate with other women (33). In our linear regression models, the number of authors on a manuscript was the largest contributor to avoiding editorial rejections, suggesting that highly collaborative research is preferred by editors, an observation supported by the increase of citations with author count (34). It is, therefore, disturbing that when the number of authors exceed 30 on a manuscript, the proportion of women is always below 51%, despite equivalent numbers of trainees in the biological sciences (Fig. S4). Additionally, while women corresponding authors submit fewer papers, more of them (both numerically and proportionally), have greater than 50% women authors, compared to those submitted by men corresponding authors. Previous research suggests that women who collaborate with other women receive less credit for these publications than when they collaborate with men (35), and that women are more likely to yield corresponding authorship to colleagues that are men (19). The gender-based segregation of collaborations at ASM journals likely has consequences in pay and promotion and could be a factor in the decreased retention of senior women at ASM journals.

The under representation of women as corresponding authors in publication at ASM journals has negative consequences for their careers and microbiology, since their role as senior author can impact their status in the field. Buckley et al, suggest that being selected as a reviewer increases visibility of a researcher, which has a direct and significant impact on salary (17). Therefore, the under representation of women as senior authors and reviewers hampers their career progression and even their desire to progress since status in the peer review process also signals adoption of the researcher into the scientific community (17). Retention of women in science is important to the progress of microbiology since less diversity in science limits the diversity of perspectives and approaches, thus stunting the search for knowledge. In addition to boosting productivity and knowledge, more diverse and equitable organizations are more inclusive and supportive for all members (4).

The support of academic research journals for women has been the topic of many papers, which note the lack of women authors relative to men (36–39). However, submissions data is required to determine if the lack of representation is due to low submissions or bias during peer review. We have shown that there is a disparity in submissions from senior women in microbiology compared to men, but this does not fully account for the difference in publications by men and women corresponding authors at ASM journals. There is also a consistent trend favoring positive outcomes for manuscripts submitted by corresponding authors that are men. Manuscripts submitted by corresponding authors who are women are editorially rejected at greater rates, and gatekeepers of both genders favor revisions for manuscripts authored by men but rejection for those authored by women. Neither geographic (e.g., US or not) nor prestige bias can fully account for the gender-based bias observed. Instead, the presence of bias favoring men over women from U.S. medical schools and institutes demonstrates that the bias persists even in environments with excellent resources and infrastructure for research. The scientific endeavor and peer review system select for rapid decisions that are often based in the assumption that scientists are objective, impartial experts. As a result, scientists who believe themselves immune to biases are making decisions that rely on biases to speed the process. The types of biases at play and their potential roles in peer review are well documented (40, 41). For instance, previous studies document that a greater burden of proof is required for women to achieve similar competency as men and that women are less likely to self-promote (and are penalized if they do) (8, 42, 43). These might lead women to be more conservative in manuscript submissions, making the observed bias even more concerning.

Even if a gatekeeper doesn't personally know the corresponding author, there are still ample avenues for implicit bias during peer review. The stricter standard of competency has led women to adopt different writing styles from men, resulting in manuscripts with increased explanations, detail, and readability than those authored by men (21, 44). These differences in writing can act as subtle cues to the author's gender. Additionally, significant time, funds, and staff are required to be competitive in highly active fields (e.g., *Clostridium difficile*, HIV), but women are often at a disadvantage for these resources due to the cumulative affects of bias (10, 11). As a result, corresponding authors that are women may be spending their resources at the fringes of research fields where competition impacts are mitigated. This has the disadvantage of further decreasing perceived competency of these women scientists to those at the established center of the field (28–30). These observations are reflected in our data, since while the median of manuscript versions before publication is identical for both men and women, manuscripts authored by women have increased rejection rates and time between submission and publication. This suggests that manuscripts submitted by women are receive more revisions (i.e., work) from reviewers and/or their competency to complete revisions within the prescribed 30 days is doubted, when compared to men.

Few papers have found disparities between rejection rates of men and women and to our knowledge, this is the first paper to collectively examine this issue with either meta-submissions data from this many journals or on the field of microbiology. A limitation to our methodology is the use of an algorithm to assign gender by first names, which left us with a category of unknown gendered individuals. The increase in unknown gendered authors corresponds to an increase in submissions to ASM journals from Asian countries, particularly China. Anecdotally, most editorial rejections are of poor quality papers from Asia and our method has low performance on non-gendered languages from this region (see Supplemental Text). As a result, many manuscripts from Asia were excluded from the analysis on decision outcomes, increasing our confidence that the trends observed are gender-based. Another concern might be the small effect size observed in many analyses. Nonetheless, the consistency of decisions to benefit men corresponding authors over women, across all journals included in this study, in addition to accumulated literature to-date, confirms that this descriptive study is highly relevant for the ASM as a society. Our findings offer opportunities to address gendered representation in microbiology and systemic barriers to peer review at our journals.

We feel that all parties have an opportunity (and obligation) to advance underrepresented groups in science and begin with suggestions for the society and ASM journals (4). First, we suggest the development of a visible mission, vision, or other commitment to equity and inclusion that includes a non-discrimination clause regarding decisions made by editors and editors-in-chief. This non-discrimination clause would be backed by a specific protocol for the reporting of, and responding to, instances of discrimination and harassment. In the long term, society journals should begin collecting additional data about authors and gatekeepers (e.g., race, ethnicity, sexual orientation, gender identity, and disabilities). Such author data should not be readily available to journal gatekeepers, but instead kept in a disaggregated manner that allows the public presentation to track success of inclusive measures and maintain accountability. Society journals can also implement mechanisms to explicitly provide support for women and other minority groups, e.g, by providing article processing fee waivers, reduced copy editing services, reward inclusive behavior by gatekeepers, encourage women to take up leadership positions and provide gender-neutral, non-exclusive social activities. Gatekeepers, and authors, can help advance women (and other minority groups) within the peer review system by changing how they select experts in their field. For instance, authors can suggest more women as reviewers using "Diversify" resources, while reviewers can agree to review for women editors more often (45). Editors can rely more on manuscript reference lists and data base searches than personal knowledge, and journals can improve the interactivity and functionality of the peer review selection software (46).

Addressing bias (gender, geographic, prestige, or otherwise) during peer review process is a more difficult challenge, since it is partially the result of accumulated disadvantages and microaggressions (the actions resulting from implicit biases). Most approaches focus on choices made by individuals, such as double-blinded reviews and implicit bias training, but these cannot fully remedy the effects of bias and may even worsen outcomes (47, 48). We hope that this report will help to counteract the bias against women through the transparency of accountability that provides our gatekeepers with the evidence of bias. However, the adaptation of women (and other minority groups) to bias (e.g., area of research and communication styles), make it impossible to level the playing field at the individual level. We must also work to change the fundamental structure and goals of peer review to minimize bias.

Broadly, peer review is a nebulous process with expectations and outcomes that vary considerably, even within a single journal. Academic writing courses suffer similar issues and have sought to remedy them through the use of rubrics. When implemented correctly, rubrics can reduce bias during evaluation and enhance the evaluation process for both the evaluator and the evaluatee (49–52). We argue that rubrics could be implemented in the peer review process to both focus reviewer comments, clarify editorial decisions, and improve the author experience. Such rubrics should increase the emphasis on **solid** research, as opposed to novel or “impactful” research, the latter of which is a highly subjective measure. This might also serve to change the overall attitude toward replicatitive research and negative results, thus bolstering the field through reproduciblity. We also argue that reconsidering journal scope and expanding editorial boards might help address structural barriers bias against women in peer review. Expanding journal scope and adding more handling editors would improve the breadth of research published, thus providing a home for more non-traditional research fields. Implementing these steps to decrease bias–review rubrics, increased focus on solid research, expansion of journal scopes, and editorial boards–will also standardize competency standards for researchers at ASM journals and improve microbiology as a whole.

Data and Methods

Data All manuscripts handled by ASM journals (e.g., *mBio*, *Journal of Virology*) that received an editorial decision between January 1, 2012 and August 31, 2018 were supplied as XML files by ASM’s publishing platform, eJP. Data were extracted from the XML documents provided, manipulated, and visualized using R statistical software (version 3.4.4) and relevant packages

(53–67). Variables of interest included: the manuscript number assigned to each submission, manuscript type (e.g., full length research, erratum, editorial), category (e.g., microbial ecology), related (i.e., previously submitted) manuscripts, number of versions submitted, dates (e.g., submission, decision), author data (e.g., first, last, and corresponding authorship, total number of authors), reviewer data (e.g., reviewer score, recommendation, editor decision), and personal data (names, institutions, country) of the editors, authors, and reviewers. For this analysis, only original, research-based manuscripts were included, e.g., long- and short-form research articles, New-Data Letters, Observations, Opinion/Hypothesis articles, and Fast-Track Communications.

Institution classification To identify the communities represented, we used Carnegie classifications to group US-based academic institutions into R1 research (very high research activity), R2 research (high research activity), four-year medical schools or low research (i.e., not R1, R2, or medical school) (68). Research institutes (e.g., Mayo Clinic, Cold Springs Harbor), industry (e.g., pharmaceutical), and federal (e.g., NIH, CDC) research groups were identified using the internet. Four-year medical schools and research institutions were grouped together since these share research prestige and have considerable resources to support research. Industry and federal research were grouped separately. The “Other” category represents uncategorized US institutions. Non-US institutions are a category on their own.

Gender prediction and assignment The gender assignment API genderize.io was used to predict an individual’s gender based on their given names, and country where possible. The genderize.io platform uses data gathered from social media to predict gender based on given names with the option to include an associated language or country to enhance the odds of successful prediction. Since all manuscripts are submitted in English, precluding language association for names with special characters, names were standardized to ASCII coding (e.g., “José” to “Jose”). We next matched each individuals’ country against the list of 242 country names accepted by genderize.io. Using the GenderGuesser package for R (69), all unique given names associated with an accepted country were submitted to the genderize.io API and any names returned without a predictive assignment of either male or female were resubmitted without an associated country. The data returned include the name, predicted gender (male, female, na), the probability of correct gender assignment (ranging from 0.5 to 1.0), and the number of instances the name and gender were associated together (1 or greater). The predicted genders of all given names (with and without an associated country) whose probabilities were greater or equal to a modified probability (pmod) of 0.85 were used to assign predicted genders to the individuals in our data set (see Supplemental Text). Predicted genders were assigned to individuals in the following order: first names and country, first names, middle names and country, middle names (Fig. S7). The presenting gender (man/woman) of editors and senior editors in our data set was hand validated using Google where possible.

Manuscript outcome analysis To better visualize and understand the differences in outcomes according to author gender, we calculated the difference in percentage points between the proportion of that outcome for men and women. To correct for the disparity in the participation of women relative to men at ASM journals, all percentage point comparisons are made relative to the gender and population in question. For instance, the percentage point difference in acceptance rates is the acceptance rate for men minus the acceptance rate for women. A positive value indicates that men receive the outcome more often than women, whereas a negative value indicates that women outperform men in the given metric.

Logistic regression models For the L2-regularized logistic regression models, we established modeling pipelines for a binary prediction task. First, we randomly split the data into training and test sets so that the training set consisted of 80% of the full data set while the test set was composed of the remaining 20% of the data. To maintain the distribution of the two model outcomes found with the full data set, we performed stratified splits. The training data was used to build the models and the test set was used for evaluating predictive performance. To build the models, we performed an internal five-fold cross-validation where we tuned the cost hyper-parameter, which determines the regularization strength where smaller values specify stronger regularization. This internal cross-validation was repeated 100 times. Then, we trained the full training data set with the selected hyper-parameter values and applied the model to the held-out data to evaluate the testing predictive performance of each model. The data-split, hyper-parameter selection, training and testing steps were repeated 25 times to get a reliable and robust reading of model performance. Models were trained using the machine learning wrapper caret package (v.6.0.81) in R (v.3.5.0) (70).

Code and data availability Anonymized data and code for all analysis steps, logistic regression pipeline, and an Rmarkdown version of this manuscript, is available at https://github.com/SchlossLab/Hagan_Gender_mBio_2019/

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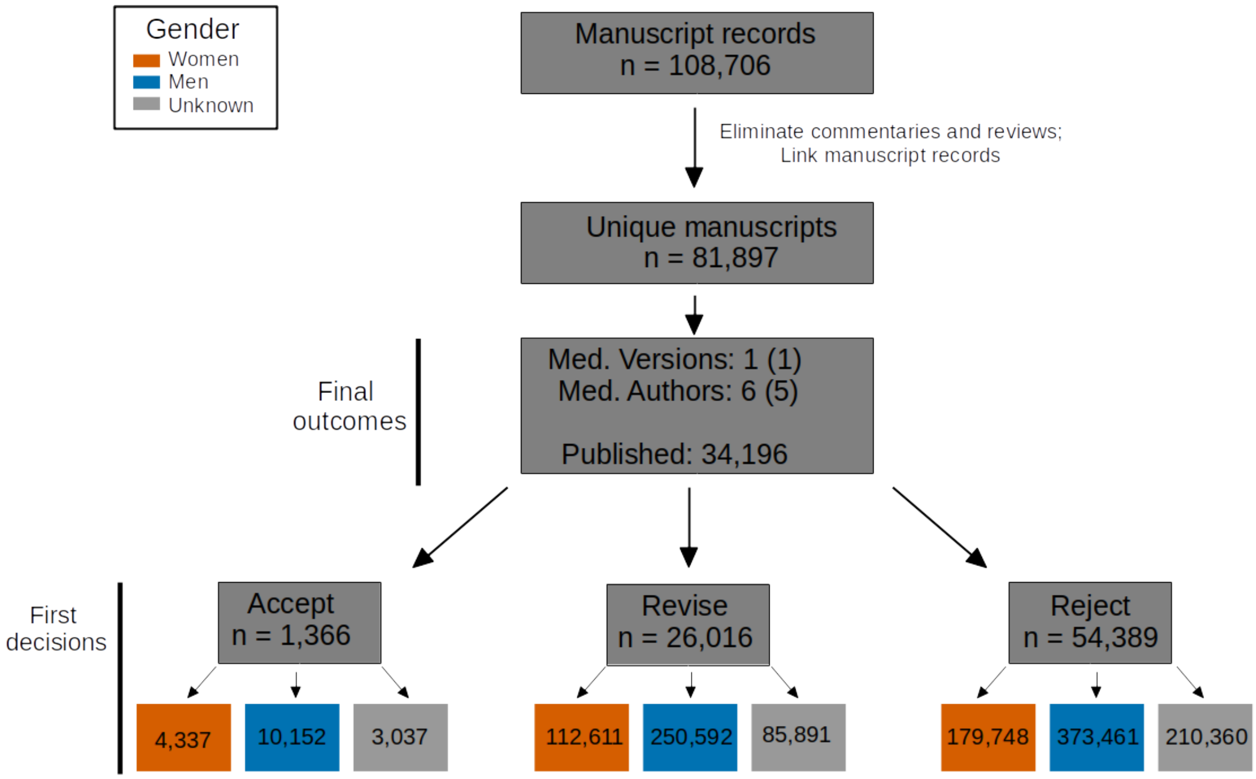


Figure 1. Overview of manuscript outcomes. Over 100,000 manuscript records were obtained for the period between January 2012 and August 2018. After eliminating non-primary research articles and linking records for resubmitted articles, there were 81,897 unique manuscripts processed. The median number of versions was 1 (iqr=1) with a median of 6 (iqr=5) authors per manuscript. 34,196 of these were published as of August 2018. Over 1,000 of the manuscripts were accepted without revisions at their first submission and there were 4,337 women (orange), 10,152 men (blue), and 3,037 unknown gendered individuals associated with their records (e.g., author, editor, reviewer). Revisions were requested for 26,016 manuscripts and 54,389 manuscripts were rejected at their first submission.

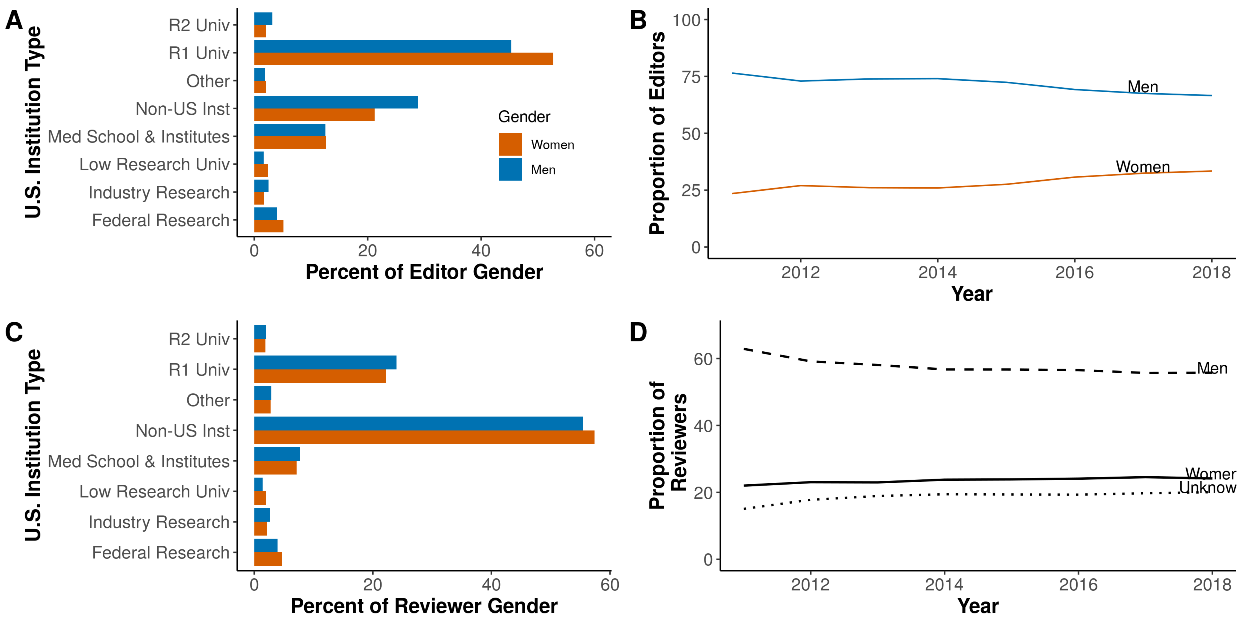


Figure 2. Gendered representation among gatekeepers. Proportion of editors from (A) institution types and (B) over time from 2012 to 2018. Editors and senior editors are pooled together. Proportion of reviewers from (C) institution types and (D) over time from 2012 to 2018. (A,C) Each gender equals 100% when all instiutions are summed.(B,D) Each individual was counted once per calendar year, proportions of each gender add to 100% per year.

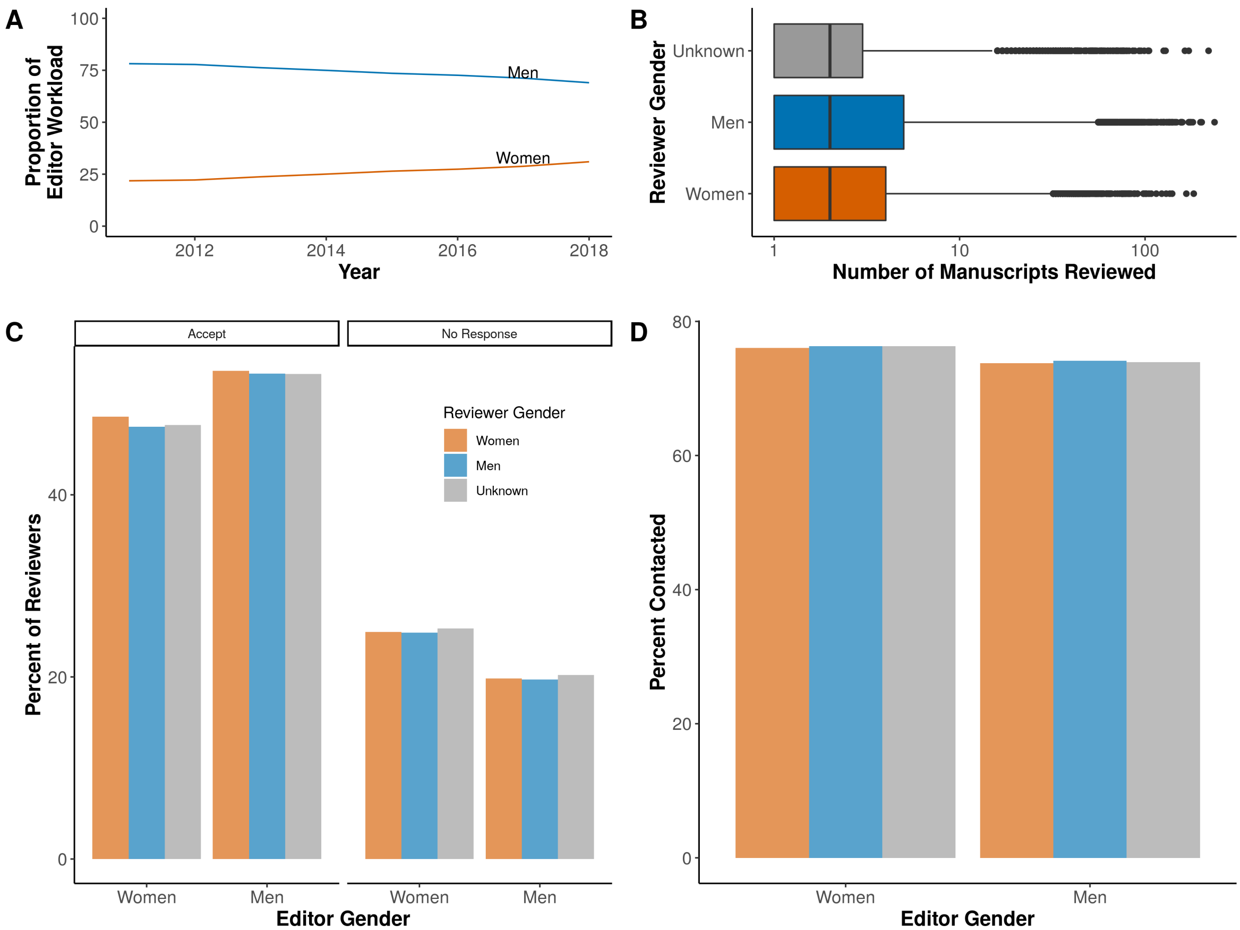


Figure 3. Gatekeeper workload and response to requests to review. (A) Proportion of manuscript workloads by men and women editors, editorial rejections excluded. (B) Box plot comparison of all manuscripts reviewed by individuals according to gender. (C) The percent of reviewers by gender that either accepted the opportunity to review or did not respond to a request to review, split according to the editor's gender. (D) Percent of each potential reviewer gender contacted to review, according to the editor's gender.

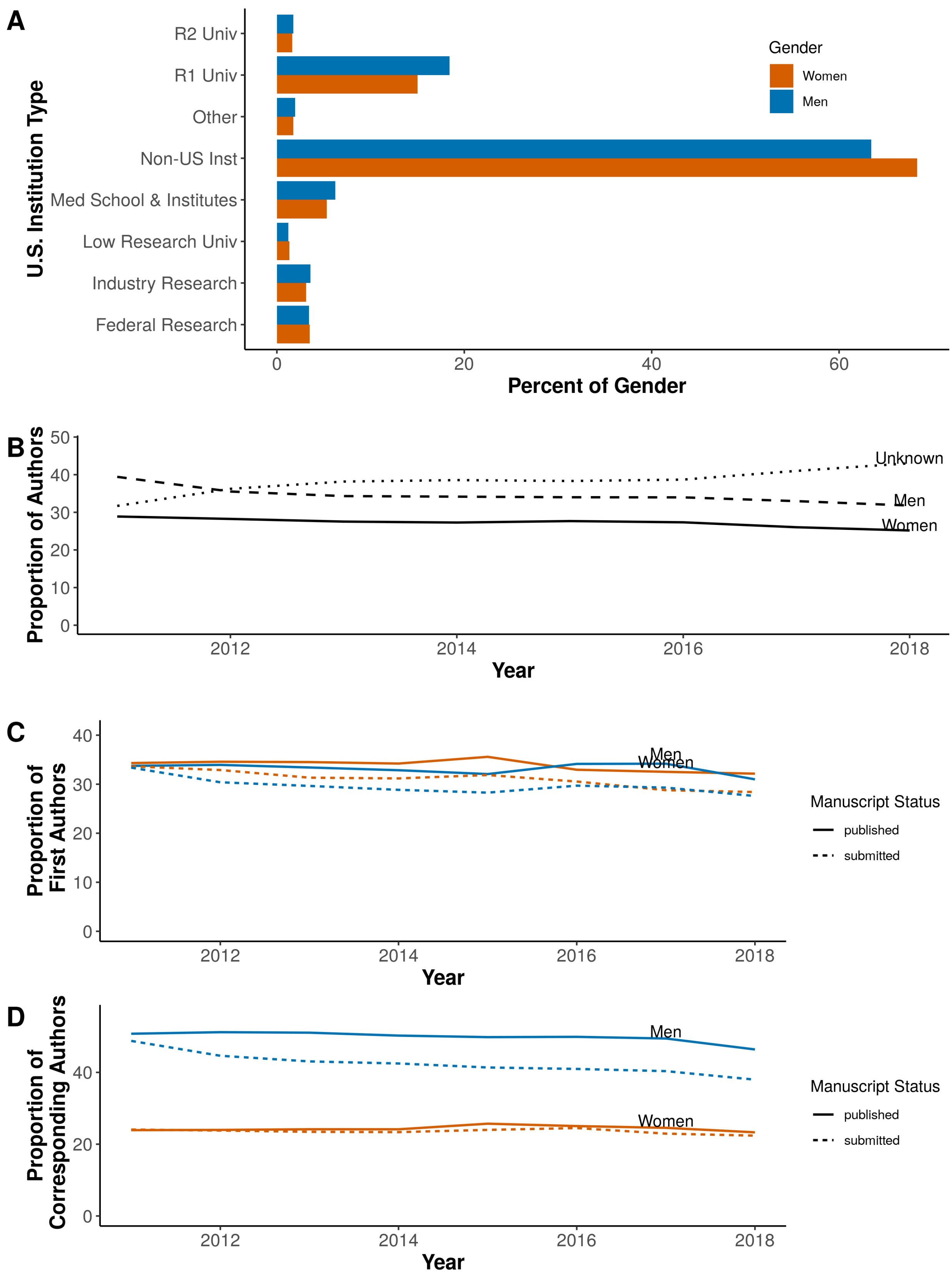


Figure 4. Author representation by gender. The proportion of (A) men and women authors from

each institution type, (B) men, women, and unknown authors from 2012 - 2018. Each individual was counted once per calendar year. The proportion of (C) first authors and (D) corresponding authors from 2012 - 2018 on submitted (dashed) and published (solid) manuscripts.

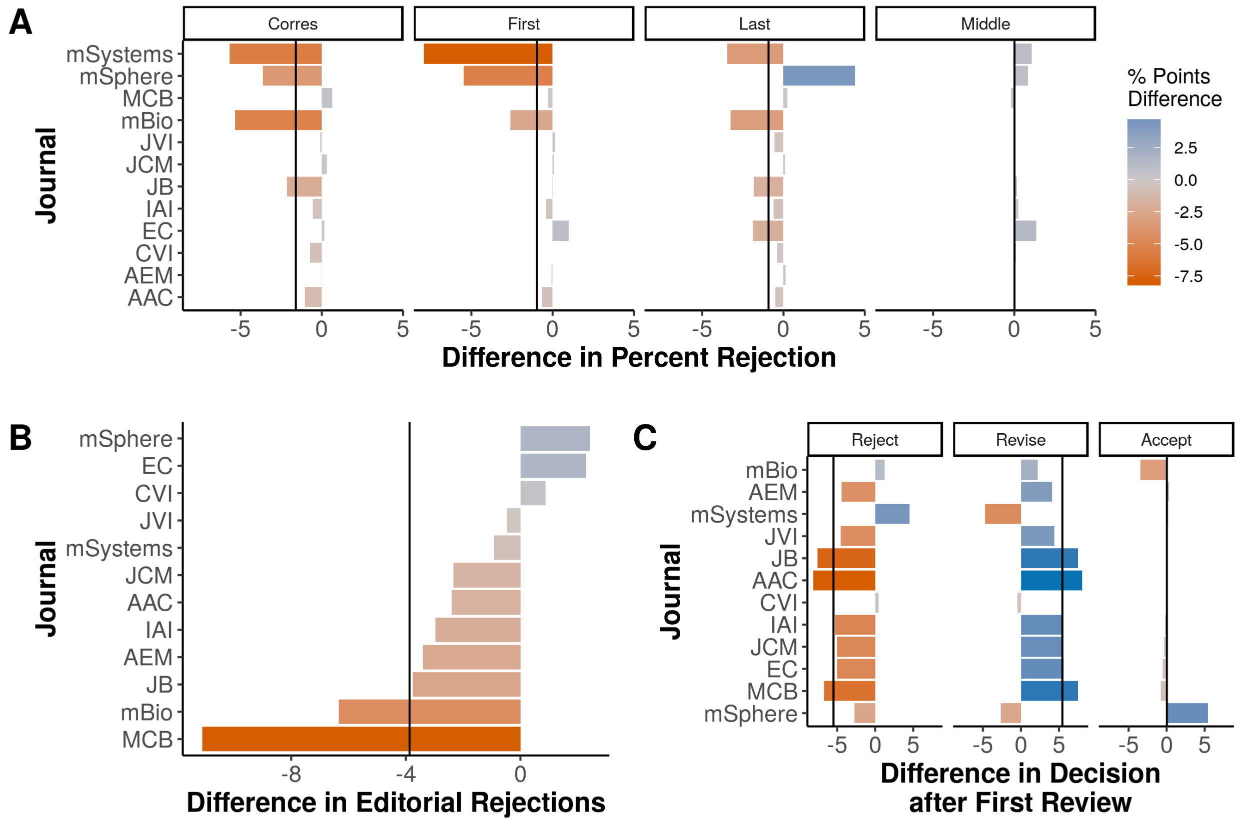


Figure 5. Difference in rejection rates by corresponding author gender. The percent of manuscripts rejected by author gender and type (e.g., corresponding, first, last, middle) at (A) all journals combined where 0 corresponds to equal rates of rejection (the variation from parity is shown). (B) The difference in percent editorial rejection rates for corresponding authors at each journal, vertical line indicates the difference for all journals combined. (D) The difference in percentage points between each decision type for corresponding authors following the first peer review, vertical lines indicate the difference value for all journals combined. Absence of a bar indicates parity.

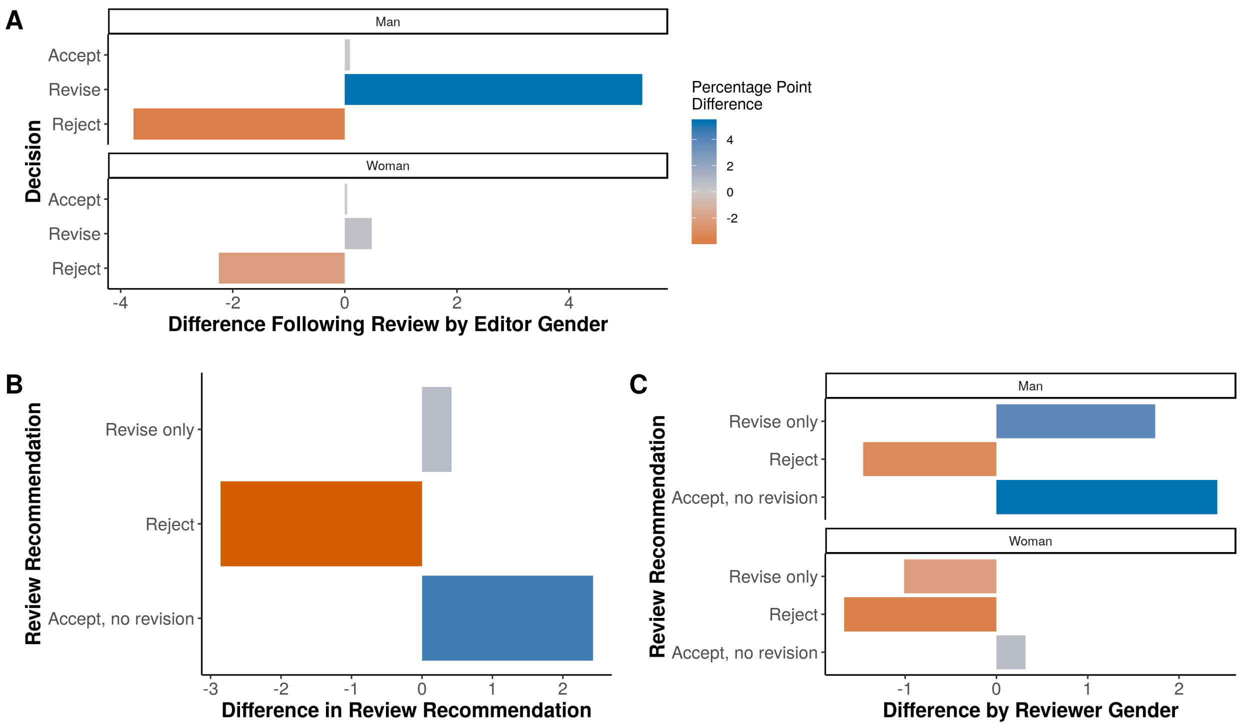


Figure 6. Difference in decisions or recomendations according to the gatekeeper gender. (A) Effect of editor gender on the difference in percentage points for decisions following review. (B) Difference in percentage points for review recommendations and (C) how that is affected by reviewer gender. (A-C) All journals combined.

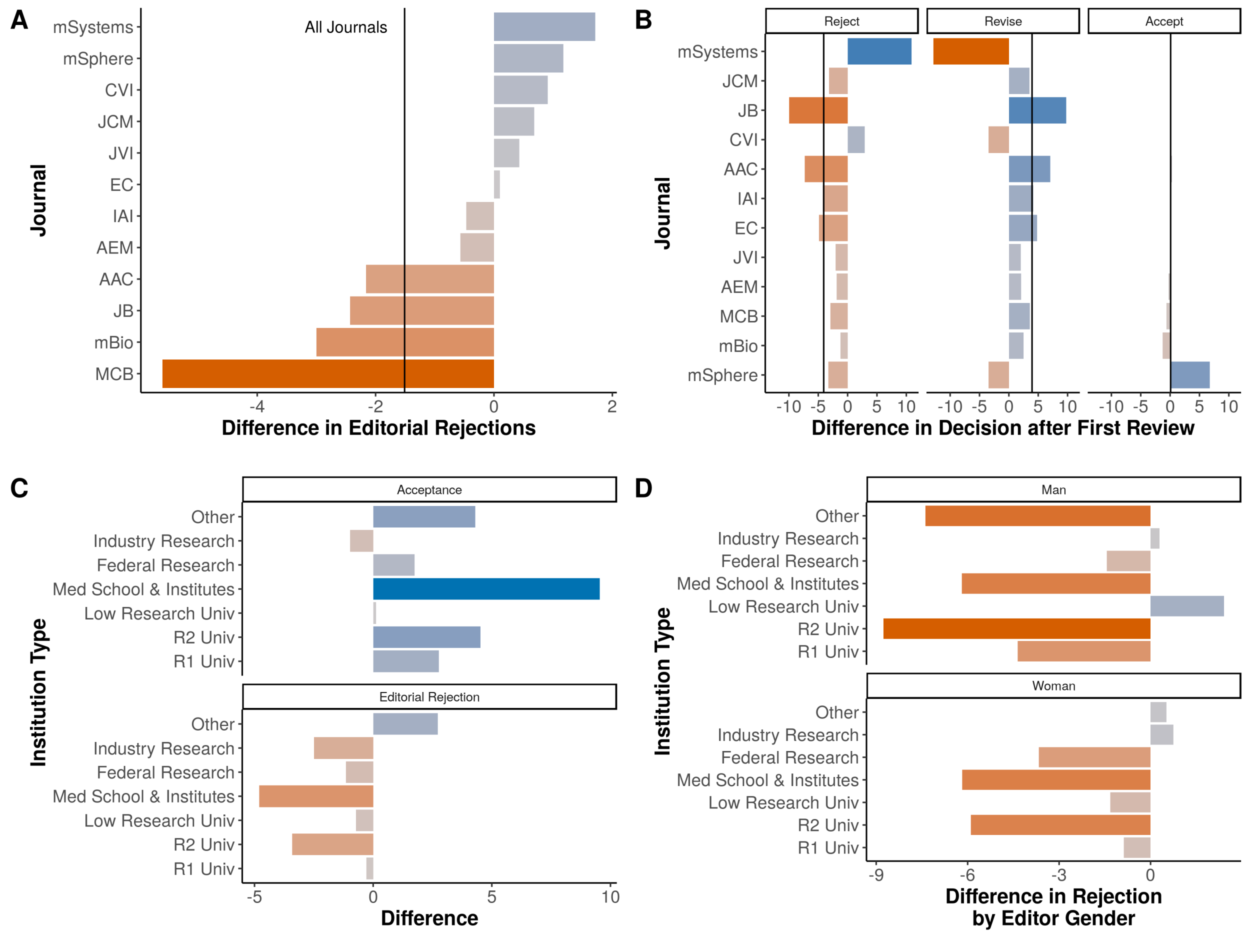


Figure 7. Impact of origin and U.S. institution type on manuscript decisions by gender. Difference in percentage points for (A) editorial rejections and (B) following first review of manuscripts submitted by US-based corresponding authors. Vertical line indicates value for all ASM journals combined. (C) Difference in percentage points for acceptance and editorial rejections according to institution types and (D) acceptance decisions by to editor gender and institution types.

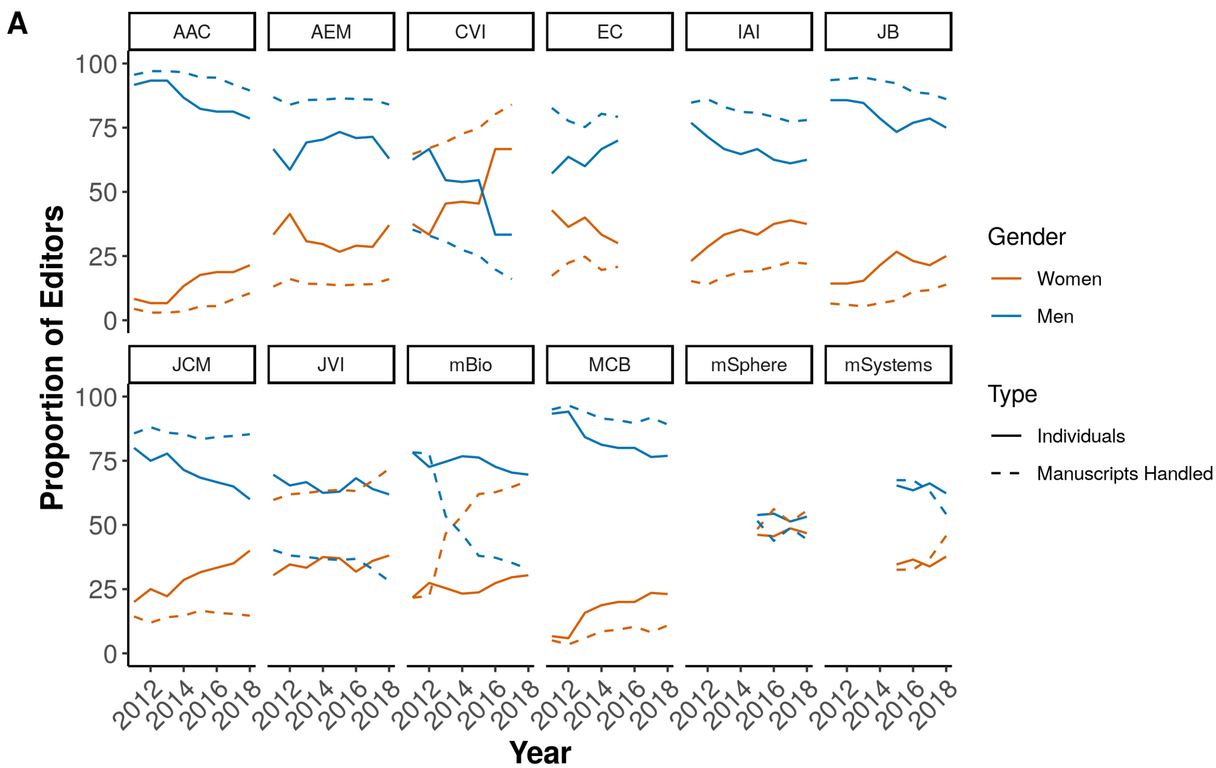


Figure S1. The proportion of editors (solid line) and their workloads (dashed line) at each ASM journal from 2012 to 2018.

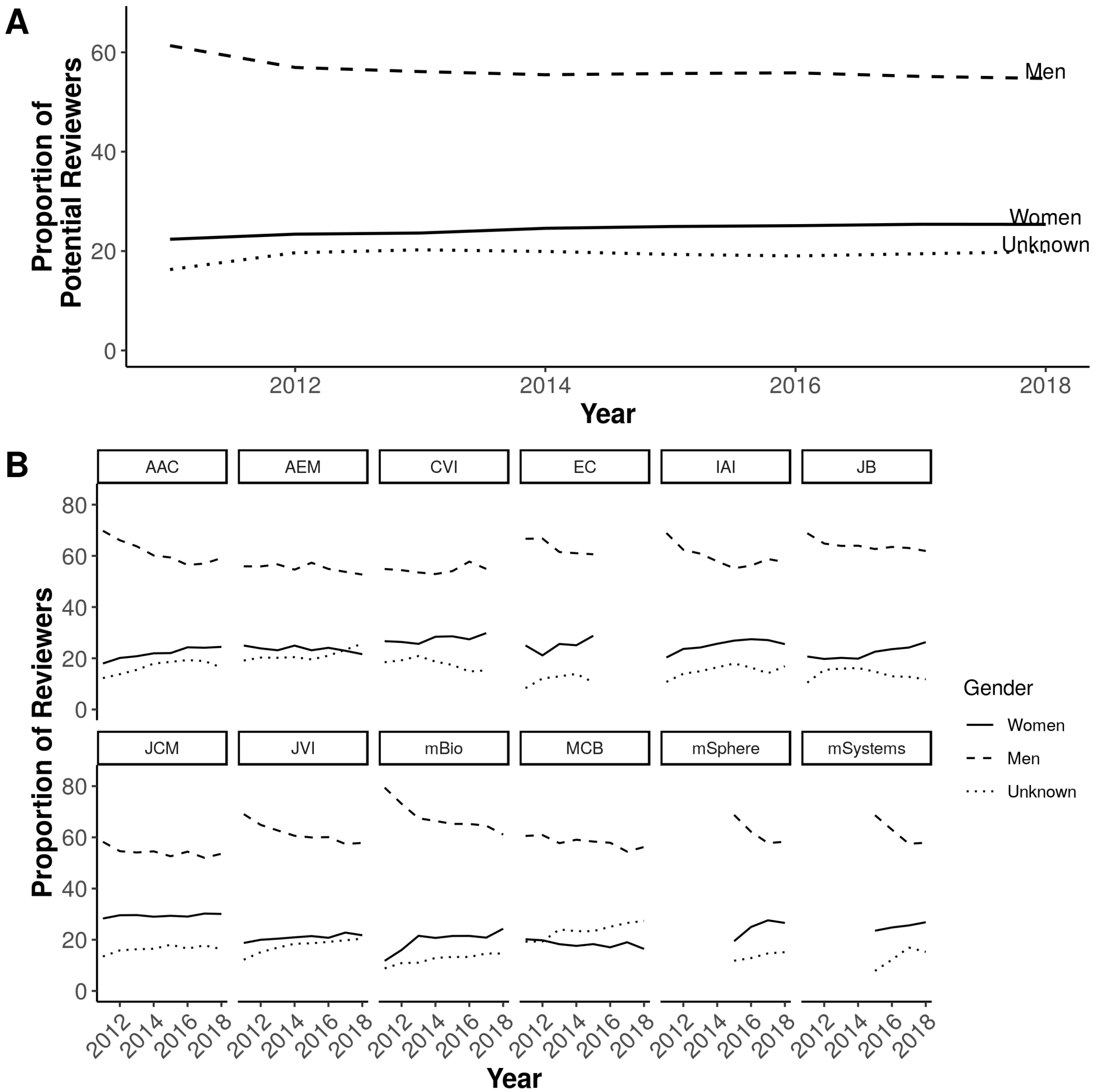
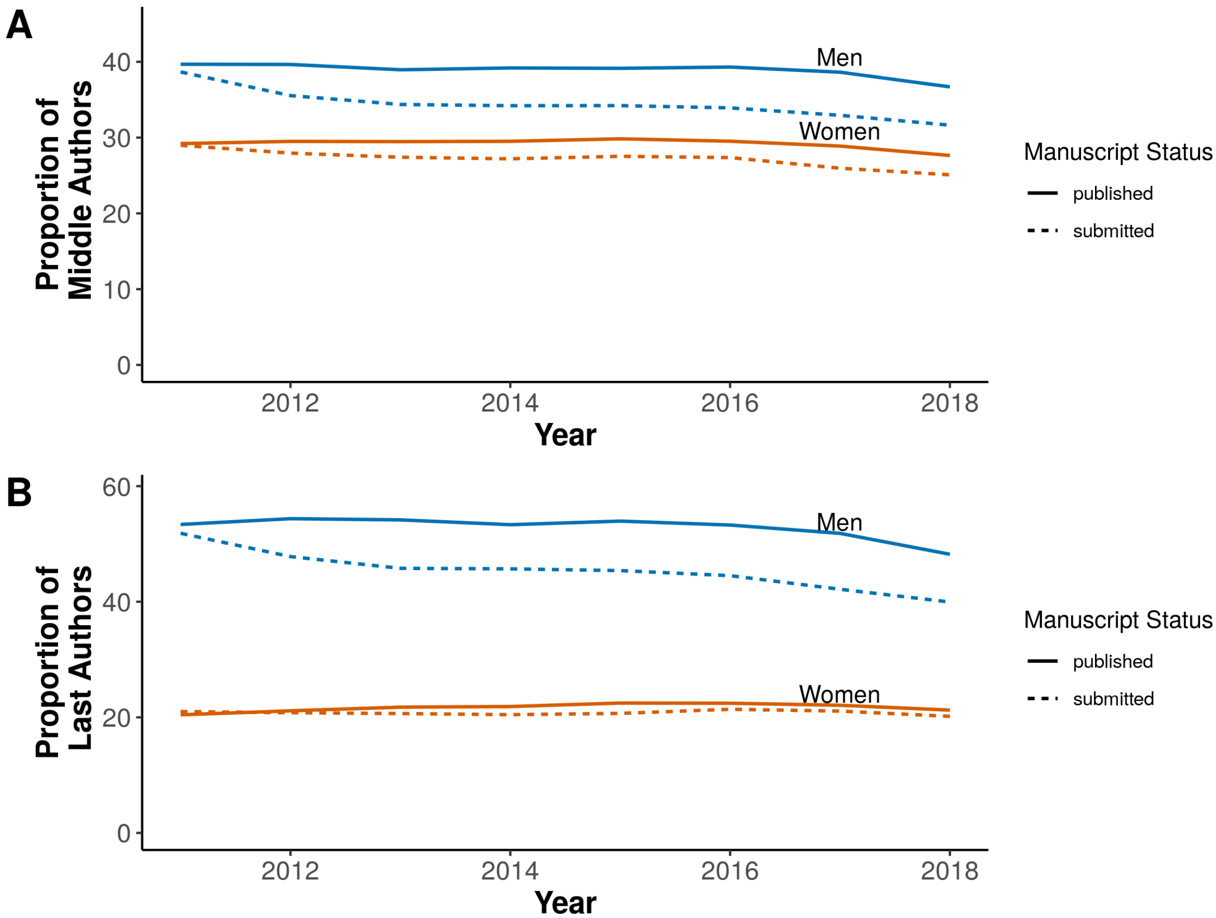


Figure S2. The proportion of (A) potential reviewers at all ASM journals combined, (B) reviewers at each ASM journal.



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604 Figure S3. The proportion of all submitting (dashed line) and publishing (solid line) (A) middle and
605 (B) last authors by gender at each ASM journal.

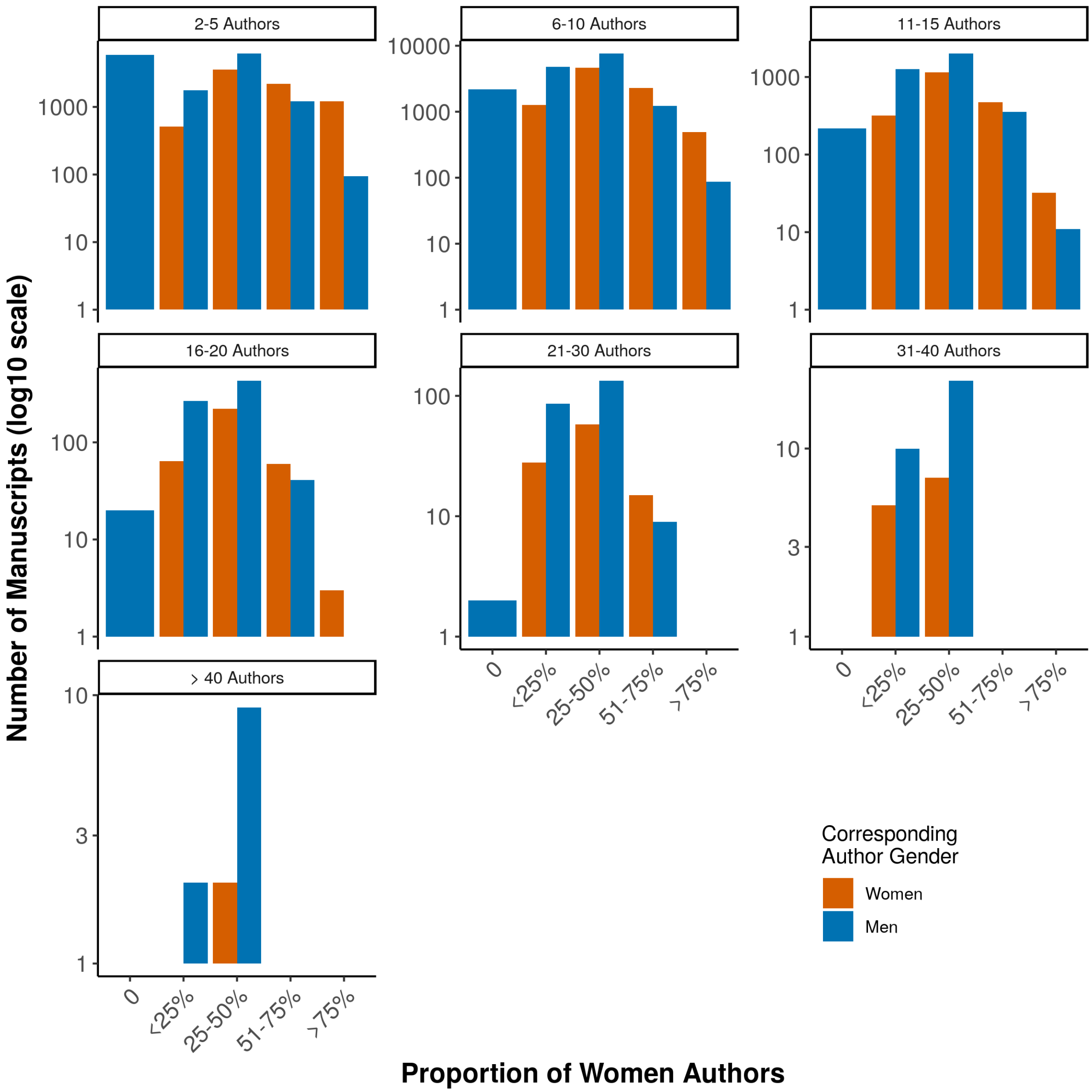

Figure S4. The proportion of women authors on submitted manuscripts according to the number of authors and the gender of the corresponding author.

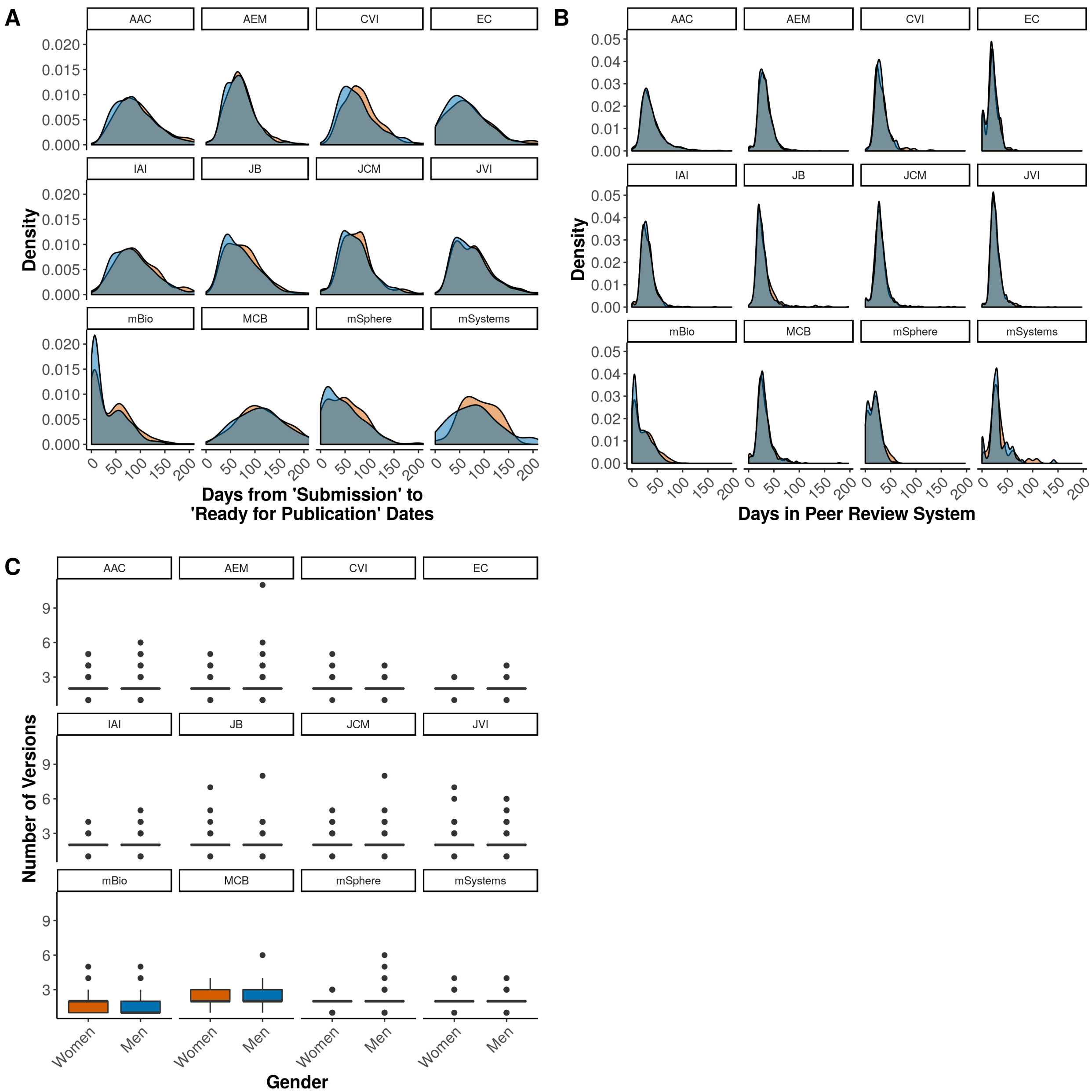

Figure S5. Comparison of time to final decision and impact by gender. The number days (A) between when a manuscript is initially submitted then finally published and (B) that a manuscript spends in the ASM peer review system. How the impact of papers published by men (blue) versus women (orange) vary according to (C) cites and (D) total reads. Citation data includes articles published between 36 and 48 months prior to August 2018. Total reads includes both HTML and PDF online views for articles published between 12 and 24 months prior to August 2018. Impact data are divided by the number of months published.

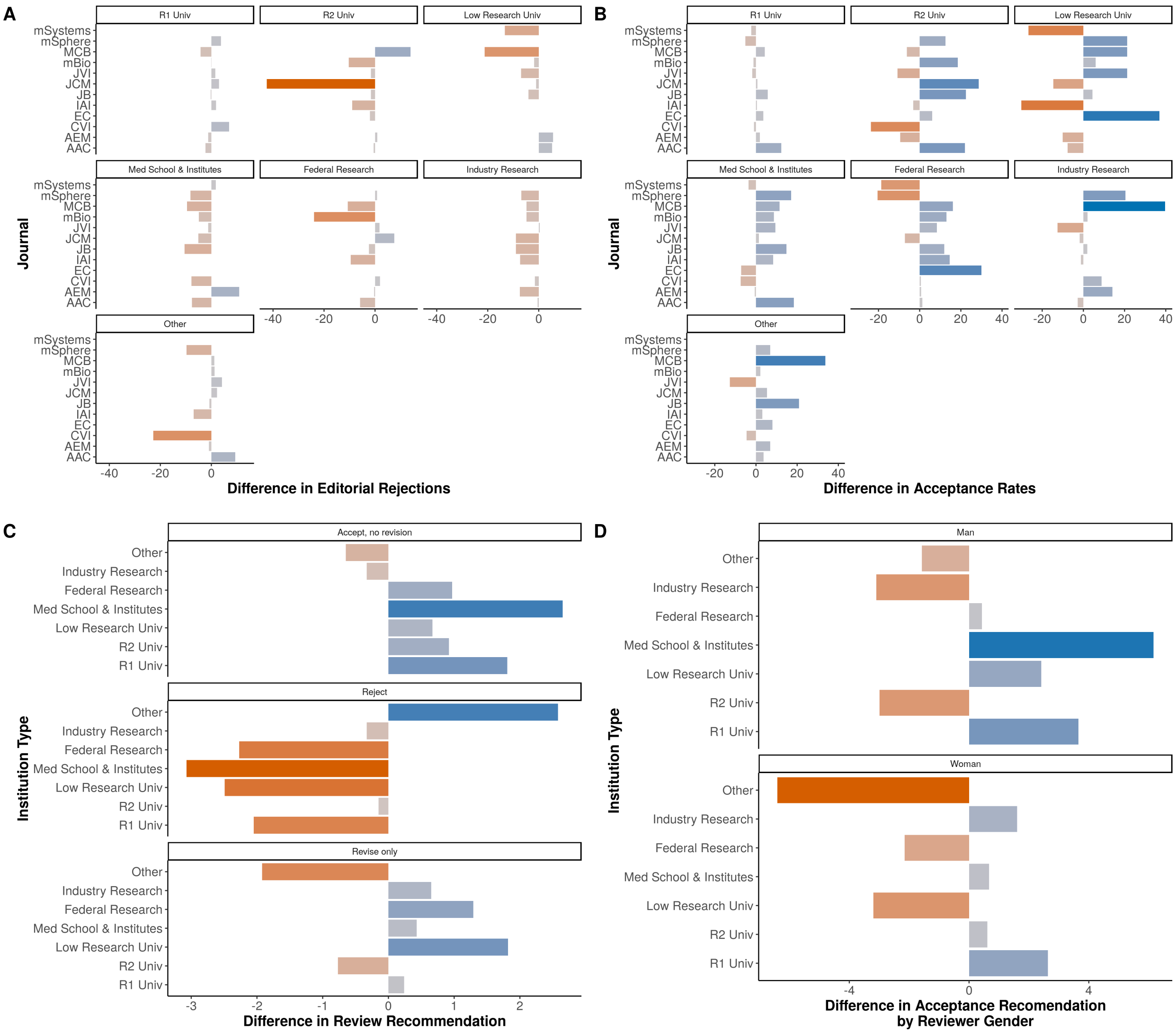

Figure S6. Difference in acceptance and rejections by institution type.

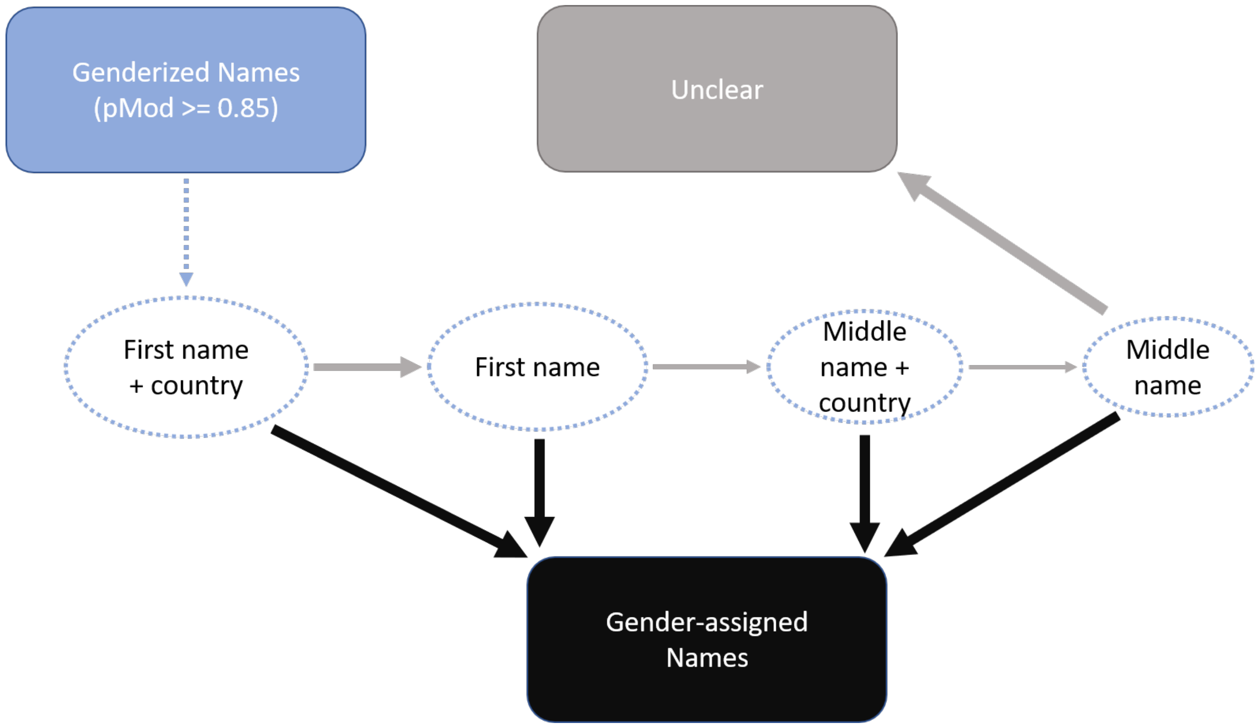

Figure S7. Schematic of gender prediction and assignment.

A

$$\boldsymbol{Impact_C} = \left| \frac{(\%\,\boldsymbol{Unpredicted_C} - \%\,\boldsymbol{Unpredicted_{Total}})\ \boldsymbol{x}\ \left(\dfrac{\boldsymbol{Observations_C}}{\boldsymbol{Observations_{Total}}}\right)}{\%\,\boldsymbol{Unpredicted_{Total}}} \right|$$

B

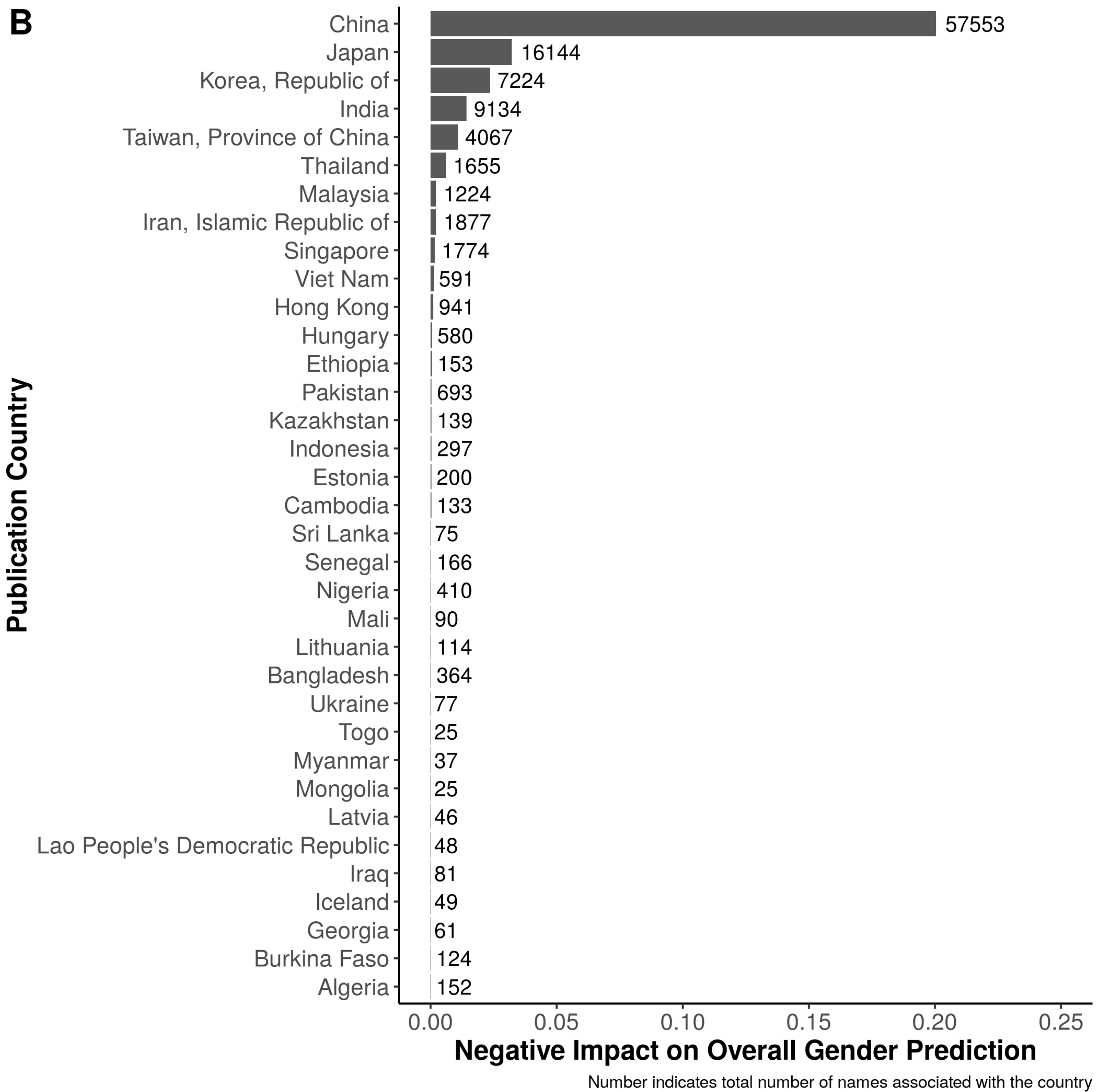

Figure S8. (A) Equation for calculating negative bias by genderize. C indicates a country. (B) The negative impact of each country on the overall gender prediction of the full data-set. Number is the total n of names associated with each country.

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