Who are ASM Journals? A Gender-based Analysis

Running title: A gender-based analysis of ASM journals

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Abstract

Despite 50% of biology Ph.D. graduates being women, the number of women that advance in academia decreases at each level (e.g. from graduate to post-doctorate to tenure-track). 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 the 15 journals published by the American Society for Microbiology (ASM), we describe the representation of women at ASM journals and the outcomes of their manuscripts. Senior women authors at ASM journals were 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, and by the institution for US-based authors. Nonetheless, the pattern for women corresponding authors to receive more negative outcomes on their submitted manuscripts indicated a pattern of gender-influenced editorial decisions. We conclude with suggestions to improve the representation of and decrease bias against women.

Importance

Barriers in science and academia have prevented women from becoming researchers and experts that are viewed equivalent to their colleagues who are men. We evaluated the participation and success of women researchers at ASM journals to better understand their success in the field of microbiology. We found that women are underrepresented as expert 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). There have been many proposed reasons for these disparities, 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 (1–7). These issues do not act independent of one another, instead they accumulate for both individuals and the community, much as advantages do (8, 9). 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 forums 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 (10). 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 (11), a factor influenced by the gender of the editor (12). Several studies have concluded that there is no significant bias against papers authored by women (12–17). Recent reports of manuscript outcomes at publishers for ecology and evolution, physics, and chemistry journals have found that women-authored papers are less likely to have positive peer reviews and outcomes (18–21).

The representation of women scientists and gender attitudes differ by scientific field and no studies to-date 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 25,818 original research papers across 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* (JVI), *mBio*, *Microbiology and Molecular Biology Reviews* (MMBR), *Genome Announcements* (GA, now *Microbiology Resource Annoucements*), *Molecular and Cellular Biology* (MCB), *mSphere*, and *mSystems*. Two journals, EC and CVI, were retired during the period under study and three journals, GA/MRA, MMBR, and CMR, were excluded from the analysis due to their relatively low number of submissions. The goal of this research study was to describe the population of ASM journals through the gender-based representation of authors, reviewers, and editors and the associated peer review outcomes.

Results

Over 100,000 manuscript records were obtained for the period between January 2012 and August 2018 (Fig. 1). Each of these were evaluated by editors and/or reviewers, leading to multiple possible outcomes. AT ASM journals, manuscripts may be immediately rejected by editors instead of being sent to peer review, often due to issues of scope or quality. These were defined as editorial rejections and identified as manuscripts rejected without review. Alternately, editors send a majority of manuscripts out for review by two or more experts in the field from a list of potential reviewers suggested by the authors and/or editors. Reviewers give feedback to the authors and editor, who decides whether the manuscript in question should be accepted, rejected, or sent back for revision. Manuscripts with suggested revisions that are expected to take more than 30 days to address are rejected, but generally encouraged to resubmit. If resubmitted, the authors are asked to note the previous 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 manuscripts and linking records for resubmitted manuscripts, there were 79,189 unique manuscripts processed (Fig. 1).

We inferred genders of both peer review gatekeepers (e.g., editor-in-chief, editors, reviewers) and authors on the manuscripts evaluated during this time period using a social media-informed classification algorithm with stringent criteria and validation process (Supp Text). 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 based on first names (and appearance for editors), as this information is what reviewers and editors also have available. Among the individuals inferred to be either men or women, the sensitivity and specificity of our method were 0.97 when validated against a curated set of authors and editors (Supp Text). In addition to identifying journal participants as men or women, this method of gender inference resulted in a category of individuals whose gender could not be reliably inferred (i.e., unknown). We included those individuals whose names did not allow a high degree of confidence for gender inference in the "unknown" category of our analysis, which is shown in many of the plots depicting representation of the population. These individuals were not included in the comparison of manuscript outcomes.

Men dominated as gatekeepers and senior authors. We first evaluated the representation of men and women who were gatekeepers 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, in turn, handle the peer review process. There were 17 EICs, 17.6% of which were women. Four years before retirement, the EIC of CVI transferred from a man 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 1015, 28.8% of which were women.

Over 40% of both men and women editors were from US-based R1 institutions, defined as doctoral-granting universities with very high research activity. Non-US institutions and U.S. medical schools or research institutions supplyed the next largest proportions of editors (Fig. 2A)(22). Since 2012, there was a slow trend toward equivalent gender representation among editors (Fig. 2B). The trends for each journal varied considerably, though most had 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 was the only journal with an increasing parity gap.

Altogether, 30439 reviewers submitted reviews and 24.6% were inferred to be women. The greatest proportion of reviewers (over 50% of all groups) came from non-US institutions, while R1 institutions supplied the next largest cohort of reviewers (Fig. 2C). The proportions of each gender were steady among reviewers at ASM journals (Fig. 2D) and representative of both the suggested reviewers at all journals combined, and the actual reviewer proportions at most journals (Fig. S2).

Editorial workloads were not proportionate. Across all journals combined, men handled a slightly greater proportion of manuscripts than women, relative to their respective editorial representations (Fig. 3A). This trend was present at most individual journals with varying degrees of difference between workload and representation (Fig. S1). For instance, at *mSphere*, both workload and proportions were identical; however, CVI, *mBio*, and JVI each had periods at which the workload for women editors was 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, decreasing the gap in editorial workload. However, representation and relative workloads for men and women editors at JVI held steady over time, while the proportionate workload for women at *mBio* has increased.

The median number of manuscripts reviewed by men, women, and unknown individuals was 2, for each group. Half of those in the men, women, or unknown gender groups reviewed between one and 5, 4, or 3 manuscripts each, respectively (Fig. 3B). Conversely, 44.6% of men, 40.1% of women, and 48.6% of unknown gendered reviewers reviewed only one manuscript, suggesting that women were more likely than other groups to review multiple manuscripts. Reviewers of all genders accepted fewer requests to review from women editors (average of 47.8%) than from men (average of 53.3%; Fig. 3C). Reviewers were also less likely to respond to women editors than men (no response rate averages of 25.1 and 19.9%, respectively). Editors of both genders contacted reviewers from all three gender groups in similar proportions, with women editors contacting 76.4% of suggested reviewers and men contacting 74.1% (median of the percent contacted from each gender group).

Women were underrepresented as authors. Globally, microbiology researchers are 60% men and 40% women (23). In September 2018, 38.4% of ASM 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 manuscripts and published papers. We began by describing author institutions by gender. Over 60% of submitting senior authors (last or corresponding) were from non-US institutions, followed by about 20% from R1 institutions (Fig. 4A). The proportions of all men and women authors at ASM decreased over time at equivalent rates, as the proportion of unknown gendered authors increased; the ratio of men to women authors was 4 to 3 (i.e., 57% men; Fig. 4B).

In the field of microbiology, order of authorship on manuscripts signals the type and magnitude of contributions to the finished product. First and last authorships are the most prestigious. First authors are generally trainees (e.g., students or post-docs) or early career researchers responsible for the bulk of the project, while last authors are lead investigators that supply 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 manuscripts submitted with men and women as first authors remained constant at 29.1 and 30.7%, respectively (Fig. 4C, dashed). The proportions of their published papers were nearly identical at 33.1% for men and 33.8% for women. The proportion of submitted manuscripts with men corresponding authors remained steady at an average of 41.6% and the proportion with women corresponding authors was at 23.4% (Fig. 4D, dashed); the proportion for unknown gendered authors declined. Both men and women corresponding authors had a greater proportion of papers published than manuscripts submitted. Accordingly, manuscripts with corresponding authors of unknown gender were rejected at a higher rate than their submission. The difference between submitted manuscripts and published papers was 8.2% when men were corresponding authors, but only 0.9% when women were corresponding authors. This trend was similar for middle and last authors (Fig. S3).

Of 38594 multi-author manuscripts submitted by men corresponding authors, 23.5% had zero women authors. In contrast, 7253 (36.3%) of manuscripts submitted by women corresponding authors had a majority of the authors as women, exceeding those submitted by men corresponding authors in both the number (3247) and percent (8.4) of submissions. Additionally, the proportion of women authors decreased as the number of authors increased (Fig. S4). Men submitted 225 single-authored manuscripts while women submitted 69 single-authored manuscripts.

We hypothesized that we would be able to predict the inferred gender of the corresponding author. We trained a logistic regression model to predict the inferred gender of the corresponding author using the following variables: whether the corresponding author's institution was in the U.S., the total number of authors, the proportion of authors that were women, whether the paper was published, the gender of senior editors and editors, the number of revisions, and whether the manuscript was editorially rejected at any point. We measured the model's performance using the area under the receiver operating characteristic curve (AUROC). The AUROC value is a predictive performance metric that ranges from 0.0, where the model's predictions are completely wrong, to 1.0, where the model perfectly distinguishes between outcomes. A value of 0.5 indicates the model did not perform better than random. The median AUROC value of our model to predict the corresponding author's inferred 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 was capable of predicting the inferred gender of the corresponding author, but that prediction was primarily driven by the percentage of authors that were inferred to be women.

As described above, first authors were slightly more likely to be women (30.7%W vs 29.1%M), but corresponding authors were significantly more likely to be men (23.44%W vs 41.59%M). A concern is that if authors are not retained to transition from junior to senior status, they are also left out of the gatekeeping roles. Since authorship conventions indicate that last and corresponding authors are typically senior authors, we combined both first and middle authors into the "junior" author role and tracked individuals through the possible roles at ASM journals. There were 75451 women who participated as junior authors (first/middle) at ASM journals. Of those junior authors who were women, 8.2% also participated as senior authors (last/corresponding), 8.9% were potential reviewers and 5.4% participated as reviewers. 0.2% of women junior authors were also editors at ASM journals. For men, there were a total of 83727 junior authors, where 13.6% also participated as senior authors, 16.7% were potential reviewers, and 11.1% actually reviewed. 0.7% of men junior authors were also editors at ASM journals. Overall, women were half as likely to move to senior author or reviewer roles, and 30% as likely to be an editor than men.

Manuscripts 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 equivalent rates for men and women (a 0 percentage point difference across all journals). However, manuscripts with senior women authors were rejected more frequently than those authored by men with -1.6 and -0.9 percentage point differences for corresponding and last authors, respectively (Fig. 5A, vertical line). The overall trend of overperformance by men was most pronounced at JB, *mSystems*, *mBio*, and *mSphere*. The greatest differences were 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 review points, initial review by the editor and the first round of peer review. Manuscripts authored by women were editorially rejected by as much as 12 percentage points more often than those authored by men (Fig. 5B). The difference at all ASM journals combined was -3.8 percentage points (vertical line). MCB and *mBio* had the most extreme percentage point differences. Manuscripts 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 (left panel) more often while men-authored papers were more often given revision (center panel) decisions. The differences for rejection and revision decisions after review were -5.6 and 5.6 percentage points, respectively (Fig. 5C, vertical lines). JB, AAC, and MCB had the most extreme differences for rejection and revision decisions. Percentage point differences were not correlated with journal prestige as measured by 2018 impact factors (R^2 = -0.022, P = 0.787).

In addition to manuscript decisions, other disparate outcomes may occur during the peer review process (24). 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. Manuscripts authored by women took slightly longer (from submission to ready for publication) than those by men at some journals (*mSphere*, *mBio*, *mSystems*, CVI, JB, JCM, AEM) despite spending similar amounts of time in the ASM journal peer review system (Fig. S5), and having the same median number of revisions prior to acceptance (Median = 2, IQR = 0).

To understand how a gatekeeper's (editor/reviewer) gender influenced decisions (e.g., Fig. 5C), we grouped editor decisions and reviewer suggestions according to the gatekeeper's gender. Both men and women editors rejected proportionally more women-authored papers, however the difference in decisions were slightly larger for men-edited manuscripts (Fig. 6A). Reviewers were more likely to suggest rejection for women-authored manuscripts as compared to men, although a minimal difference in revise recommendations was observed (Fig. 6B). Both men and women reviewers recommended rejection more often for women-authored manuscripts although men recommended acceptance and revision more often for men-authored manuscripts than women did (Fig. 6C).

To evaluate if gender played a role in manuscript editorial decisions, we trained a logistic regression model to predict whether a manuscript was reviewed (i.e. editorially rejected or not).

We used the inferred genders of the 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 0.61, which indicated that editorial decisions were not random, however, the AUROC value was relatively low indicating that there are factors other than those included in our model that influence editorial decisions.

Multiple factors contribute to the overperformance of men. The association between gender and manuscript decision 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 preference for research submitted by authors from a gatekeeper's own country or region (18). Other studies have documented prestige bias, where men are over-represented in more prestigious (i.e., more respected and selective) programs (25). 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., the highest rate of submissions from women were at low research institutions, 37%; Fig. 4A).

To quantify how these factors affected manuscript decisions, we next looked at the outcome of manuscripts submitted only by corresponding authors at US institutions, because these institutions represented the majority of manuscripts and could be classified by the Carnegie Foundation (22). For reference, the proportion of manuscripts submitted from US institutions by women was 31% versus 36% from women at non-US institutions. When only considering US-based authors, the difference for editorial rejections increased from -3.8 to -1.4 percentage points (Fig. 7A). The difference in decisions after review for US-based authors mirrored those seen for all corresponding authors at the journal level (Fig. 7B). The over-representation of women in rejection decisions increased from -5.6 to -4.4 percentage points, and the over-representation of men in revise only decisions decreased from 5.6 to 4.2 (Fig. 7B). The difference in the rate of accept decisions changed from -1.4 to 0.2 percentage points after restricting the analysis to US-based authors. These results suggest that the country of origin (i.e., US versus not) accounted for some of the observed gender bias, particularly for editorial rejections.

To address institution-based prestige bias, we split the US-based corresponding authors according to the type of institution they were affiliated with (based on Carnegie classification) and re-evaluated the differences for men and women (22). Editorial rejections occurred most often for women from medical schools or institutes, followed by those from R2 institutions: 32% and 28% of manuscripts from each institution were submitted by women, respectively (Fig. 7C, Fig. S6A). This difference in the editorial rejections of corresponding authors from medical schools or institutes was spread across most ASM journals, while the editorial rejection of papers submitted from women at R2 institutions was driven primarily by submissions to JCM. Evaluating the difference in acceptance rates by institution and gender mirrored that of editorial rejections for some journals, where submissions from men outperformed submissions from women. For instance, manuscripts submitted by men from medical schools or institutes were accepted up to 20 percentage points more often than those submitted by women (Fig. S6B).

To evaluate if these factors affect manuscript decisions, we trained a logisitic regression model to predict whether a manuscript was editorially rejected, using the variables: origin (US vs non), institution (US institution type), number of authors, proportion of authors that were women, and the inferred genders of both gatekeepers and corresponding authors. The model had a median AUROC value of 0.67, which indicated a non-random interaction between these factors and editorial decisions. Manuscripts from authors at U.S. “other” institutions, men EICs, men that were corresponding authors from “other” U.S. institutions, and women from medical schools and institutes were more associated with editorial rejections (Fig. S6C). Conversely, manuscripts from R1 institutions, authors from the U.S., EICs that were women, and the number of authors were more likely to be associated with review (Fig. S6C). These results confirm that the country of origin and class of institutions impact decisions in a non-random manner, though not as much as gender.

A final factor we considered was whether the type of research pursued by men as opposed to women may impact manuscript outcomes. Black women philosophers and physicists have described the devaluation of non-traditional sub-disciplines in their fields (26–28). While originally focused on bias against Black women—the intersection of two historically marginalized identities—the concept that researchers in an established core field might be skeptical of less established, or non-traditional, sub-field research likely applies elsewhere. A bias against sub-fields in a gendered context has recently been observed in the biomedical sciences, where NIH proposals focusing on women's reproductive health were the least likely to be funded (29). To explore the phenomenon in ASM journals, we looked at the editorial rejection rates of all manuscripts (regardless of origin or institution) for each research category at the five largest ASM journals: AAC, AEM, IAI, JVI, and JCM. Together, these journals account for 47% of the manuscripts analyzed in this study across 55 categories.

The number of submissions in each category ranged from 1 (FDA Approval at AAC) to 2952 (Bacteriology at JCM) while the acceptance rates varied from 29.4% (Chemistry:Biosynthesis at AAC) to 71.3% (Structure and Assembly at JVI) (Table 1). We argued that the number of submissions to each category could help indicate core versus periphery subfields, (i.e., core subfields would have more submissions than periphery subfields) and based on the literature to-date, we expected that periphery subfields might have a higher participation of women. Women submitted on average 35.3% of the manuscripts to each category, ranging from 20% to 86% (Table 1). There was not a correlation between the proportion of women authors and the number of submissions (R^2 = -0.0177, P = 0.779) to each category. Nor was there a correlation between the proportion of women authors and the category acceptance rate (R^2 = 0.041, P = 0.078). These data suggest that there was not a relationship between the participation of women and either the number of submissions or the acceptance rate of categories in our dataset.

We next looked at the differences of performance for men and women in each category at two decision points: editorial rejection and rejection after the first review. Each journal focuses on a different facet of microbiology or immunology, making the results difficult to compare directly. However, the pattern of increased rejection rates for women over men was maintained across most categories with some categories displaying major differences in gendered performance (Fig. S7). For instance, the Biologic Response Modifier (e.g., immunotherapy) sub-category at AAC, had extreme differences for both editorial rejections and rejections after review, about -30 and -40 percentage points, respectively. While that category had a relatively low number of submissions (N = 44), 43% were from women (Fig. S7A). One category, Mycology, was represented at two journals, AEM and JCM. At both journals, men overperformed relative to women in this category.

At AEM, there were 73 Mycology submissions, 44% from women authors that had a difference of almost -20 for editorial rejection outcomes and -10 for rejections after review (Fig. S7B). JCM had 587 Mycology submissions with a submission rate of 39% from women authors (Fig. S7D). Differences between outcomes were almost -10 for editorial rejections and -12 for rejections after review at JCM.

Because of these extreme percentage point differences in categories with high women authorship, we next asked if the number of women participating in a particular category was related to manuscript outcomes. There was no correlation between the difference in editorial rejection by category and the percent of women that were either authors (R^2 = -0.003, P = 0.363) or editors (R^2 = -0.018, P = 0.765). The percent of women authors and percent of women editors in journal categories did not correlate either (R^2 = -0.007, P = 0.682), which is likely related to the underrepresentation of women editors in categories dominated by women authors (e.g., Epidemiology). These data suggest the possibility of persistent (e.g., by editors and reviewers) bias against women in particular fields (e.g., Mycology), though it does not seem to relate to either the number of submissions or participation of women in those subfields.

Discussion

We described the representation of men and women at ASM journals between January 2012 and August 2018 and compared editorial outcomes according to the authors' gender. Women were consistently under-represented (30% or less in all levels of the peer review process) excluding first authors, where women represented about 50% of authors where we could infer a gender (Figs. 2 and 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 gender varied according to the journal (Figs. 3 and S1). Additionally, manuscripts submitted by corresponding authors that were women received more negative outcomes (e.g., editorial rejections) than those submitted by men (Figs. 5 and 6). These negative outcomes were somewhat mediated by whether the corresponding author was based in the US, the type of institution for US-based authors, and the research category (Figs. 7 and S7). However, the trend for women corresponding authors to receive more negative outcomes held, indicating a pattern of gender-influenced editorial decisions regardless of journal prestige (as determined by impact factor). Together, these data indicate a persistent bias against senior women microbiologists who participate in ASM journals.

The proportion of women as first authors is higher than data obtained globally and from self-reported ASM membership data, which 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 trends 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 (junior) to investigator (senior) (30). These data indicate that microbiology (as represented by ASM journals) is not exempt from the issues that limit the retention of women through academic ranks.

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). We argue that the goal should depend on the workload and visibility of the position. 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 (31–33). Conversely, lower visibility positions (e.g., reviewers) require effort from 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 20-25% 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 (34).

In contrast to institutional service, the editing workload at ASM journals seems to be predominantly borne by men. A possible explanation for the difference in gatekeeper representation and editor workloads is that women are more likely to study non-traditional sub-disciplines (26–28). Their separation from the traditional center of a field decreases their perceived competency, which could result in research typecasting and lower manuscript handling responsibilities. However, our data could not confirm this phenomenon at ASM journals. Another possibility is the increased proportion of potential reviewers that either did not accept, or did 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, thus making them seem less efficient (i.e., less capable) than men editors. Three journals, *mBio*, CVI, and JVI were 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. The tendency for reviewers to reject requests to review from editors that are women, may also extend to editors that are men; this could result in men editors being more likely to reject 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 (12), but supports findings that women editors contact more reviewers than men (35).

Our data also revealed some disturbing patterns in gendered authorship that have implications for the retention of women microbiologists. Previous research suggests that women who collaborate with other women receive less credit for these publications than when they collaborate with men (36), and that women are more likely to yield corresponding authorship to colleagues that are men (19). 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 (37). This observation was supported by the positive correlation between citations and author count (Fig. S6). It was concerning that when the number of authors exceeded 30 on a manuscript (N=59), the proportion of individuals inferred to be women was always below 51%, despite equivalent numbers of trainees in the biological sciences (Fig. S4). Additionally, while women corresponding authors submitted fewer manuscripts, more of them (both numerically and proportionally), had a majority of women co-authors, compared to those submitted by men corresponding authors, which supports previous findings that women are more likely to collaborate with other women (21, 38–40). This gender-based segregation of collaborations at ASM journals likely has had consequences in pay and promotion for women and could be a factor in the decreased retention of senior women. It would likely be aggravated by the under representation of women as corresponding authors, which may also have negative consequences for their careers and microbiology, since senior authorships impact status in the field. Buckley et al., suggested that being selected as a reviewer increases the visibility of a researcher, which has a direct and significant impact on salary (16). Therefore, the under representation of women as senior authors and reviewers likely 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 (16, 41). The retention of women 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.

Whether academic research journals support women has been the topic of many papers, which note the lack of women authors publishing relative to men in high impact journals (42–48). However, submissions data is required to determine if the lack of representation is due to low submissions or bias during peer review. Using such data, 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 (Fig. 4). When examining manuscript outcomes, we found a consistent trend favoring positive outcomes for manuscripts submitted by corresponding authors that were men (Fig. 5). Manuscripts submitted by corresponding authors who were women were editorially rejected at greater rates and gatekeepers of both genders favored rejection for manuscripts authored by women. Neither geographic (i.e., US or not), institution type, nor sub-discipline could fully account for the observed gender-based bias (Fig. 6, Fig. 7, Fig. S6, Fig. S7). Instead, the presence of bias favoring men over women from U.S. R1 institutions and medical schools and institutes suggests that the bias persists, even in environments with generally excellent resources and infrastructure for research. Science and the peer review system select for decisions that are often based on the assumption that scientists are objective, impartial experts. As a result, scientists who believe themselves immune to bias are making decisions that inherently rely on biases to speed the process. The types of biases at play and their potential roles in peer review are well documented (49, 50). For instance, previous studies show 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) (6, 51, 52). These and similar biases might train women to be more conservative in their manuscript submissions, making our observed bias even more concerning.

Even if a gatekeeper does not know the corresponding author or their gender, there remain 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 (24, 53). 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, but women are often at a disadvantage for these resources due to the cumulative affects of bias (8, 9). As a result, corresponding authors that are women may be spending their resources in research fields where competition impacts are mitigated and/or on topics that are historically understudied. This has the disadvantage of further decreasing perceived competency of these women scientists compared to those studying core research field(s) (26–28). Alternatively, non-traditional research may be seen as less impactful, leading to poorer peer review outcomes (29). These possibilities are reflected in our data, since while the number of revisions before publication is identical for both men and women, manuscripts authored by women have increased rejection rates and time spent on revision. This suggests that manuscripts submitted by women receive more involved critiques (i.e., work) from reviewers and/or their competency to complete revisions within the prescribed 30 days is doubted, compared to men. Women may also feel that they need to do more to meet reviewer expectations, thus leading to longer periods between a decision and resubmission. Finally, our data show a penalty for women researching mycology (Fig. S7). Despite being among the most deadly communicable diseases in 2016 (along with tuberculosis and diarrheal diseases), mycology is an underserved, and underfunded, field in microbiology that has historically been considered unimportant (54–56). Microbiology would benefit from a more nuanced evaluation of sub-fields to better understand how they interact with gender and peer review outcomes.

A limitation to our methodology is the use of an algorithm to infer gender from first names. This method left us with a category of unknown gendered individuals and the gender of an individual may be interpreted differently according to the reader (e.g., Kim is predominately a woman's name in the U.S., but likely a man's name in other cultures). 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 poor quality papers from Asia. Our method had low performance on non-gendered languages from this region (Supp Text) resulting in exclusion of many Asia-submitted manuscripts from the decision outcome analyses, which increased our confidence that the trends observed were gender-based. Another concern might be the small effect size observed in many analyses. 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 in peer review at our journals.

All parties have an opportunity and obligation to advance underrepresented groups in science (57). We suggest that journals develop a visible mission, vision, or other statement that commis to equity and inclusion and 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 response to, instances of discrimination and harassment. Second, society journals should begin collecting additional data from authors and gatekeepers such as race, ethnicity, gender identity, and disabilities. This data should not be readily available to journal gatekeepers, but instead kept in a dis-aggregated manner that allows for public presentation and tracking the success of inclusive measures to maintain accountability. Third, society journals can implement mechanisms to explicitly provide support for women and other minority groups, reward inclusive behavior by gatekeepers, nominate more women to leadership positions, and recruit manuscripts from sub-fields that are more likely to attract women and other minorities (29). Gatekeepers and authors can help advance women (and other marginalized 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 (58), while reviewers can agree to review for women editors more often. Editors can rely more on manuscript reference lists and data base searches than personal knowledge to recruit reviewers (59), and journals can improve the interactivity and functionality of the reviewer selection software. Given the propensity for journals to recruit editors and EiCs from within their already biased reviewer pools, opening searches to include more scientists in their reviewer pool and/or editors from outside the journal while enacting more transparent processes could be a major component of improving representation. Growing evidence suggests that representation problems in STEM are due to retention rather than recruitment. We need to align journal practices to foster the retention of women and other minority groups.

Most approaches to overcoming bias 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 (60, 61). Since bias (gender, geographic, prestige, or otherwise) is partially the result of accumulated disadvantages and actions resulting from implicit biases, a structural, system-wide approach is required. 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 with rubrics. When implemented correctly, rubrics can reduce bias during evaluation and enhance the evaluation process for both the evaluator and the evaluatee (62–65). We argue that rubrics could be implemented in the peer review process to 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 (66, 67). This might also change the overall negative attitude toward replicatitive research and negative results, thus bolstering the field through reproduciblity. We also argue that reconsidering journal scope and expanding honorary editorial boards might help address structural barriers of bias against women (and other minorities) 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 and underserved research fields (the case at *mSphere* with an increased pool of editors). Implementing these steps to decrease bias—review rubrics, increased focus on solid research, expansion of journal scopes and editorial boards—will also standardize competency principles for researchers at ASM journals and improve microbiology as a whole.

This report demonstrates that although the level of bias at many ASM journals is small, it is present. Peer review at ASM journals is not immune to the accumulated disadvantages against women in microbiology. However, the adaptation of women (and other marginalized groups) to bias (e.g., area of research and communication styles), make it impossible to address at the individual level. Instead, we must commit to changing the fundamental structure and goals of peer review to minimize bias. We encourage ASM journals, as well as other societies, to institute more fair and transparent procedures and approaches of peer review. The self-correcting nature of science is a badge that scientists wear proudly, but no single report or action can correct the inertia of a millenniums-old instiution. Instead, it requires the long-standing and steady actions of many. Our findings reflect many similar reports, and suggest concrete actions to correct the inertia of peer review at all levels. The next step is commitment and implimentation.

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. 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., 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. To help protect the confidentiality of peer review, names were removed from all records, and identifying data (e.g., manuscript numbers, days of date), were replaced with randomized values.

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) (22). 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 typically 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 were a category on their own.

Gender inference. The genderize.io API was used to infer an individual's gender based on their given name and country where possible. The genderize.io platform uses data gathered from social media to infer gender based on given names with the option to include an associated language or country to enhance the probability of successful inference. Since all manuscripts were submitted in English, which precludes 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, all unique given names associated with an accepted country were submitted to the genderize.io API and any names returned without an inferred value of either male or female were resubmitted without an associated country. The data returned include the name, inferred gender (as "male", "female", "unknown"), the probability of correct gender inference (ranging from 0.5 to 1.0), and the number of instances the name and gender were associated together (1 or greater). The inferred 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 infer genders (man/woman) of the individuals in our data set (Supp Text). The presenting gender (man/woman) of editors and senior editors in our data set was inferred by hand using Google where possible, and the algorithm was validated using both editor and published data (Supp Text)(5).

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 were made relative to the gender and population in question. For instance, the percentage point difference in acceptance rates was the acceptance rate for men minus the acceptance rate for women. A positive value indicated that men received the outcome more often than women, whereas a negative value indicated that women outperformed men in the given metric.

Logistic regression models. For the L2-regularized logistic regression models, we established modeling pipelines for a binary prediction task (68). 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).

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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Table 1. Analysis of sub-discipline participation by women corresponding authors at five ASM journals.

Journal	Category	N	% Accepted	% Women Editors	% Women Authors
AAC	Analytical Procedures	135	43.0	14	29
AAC	Antiviral Agents	836	56.5	6	33
AAC	Biologic Response Modifiers	44	40.9	12	43
AAC	Chemistry; Biosynthesis	109	29.4	10	32
AAC	Clinical Therapeutics	1060	48.9	13	31
AAC	Epidemiology and Surveillance	765	52.3	14	40
AAC	Experimental Therapeutics	1329	57.4	13	28
AAC	FDA Approvals	1	NA	NA	NA
AAC	Mechanisms of Action: Physiological Effects	597	51.8	14	30
AAC	Mechanisms of Resistance	1783	60.0	14	36
AAC	Pharmacology	878	66.6	13	29
AAC	Susceptibility	1051	46.8	12	39
AEM	Biodegradation	302	38.4	35	26
AEM	Biotechnology	802	37.9	30	27
AEM	Environmental Microbiology	2395	30.3	35	42
AEM	Enzymology and Protein Engineering	340	46.5	28	24
AEM	Evolutionary and Genomic Microbiology	279	48.4	32	30
AEM	Food Microbiology	1216	38.2	33	39
AEM	Genetics and Molecular Biology	587	51.8	32	36
AEM	Geomicrobiology	151	44.4	34	37
AEM	Invertebrate Microbiology	317	45.7	29	37
AEM	Methods	529	39.7	30	29
AEM	Microbial Ecology	1121	35.8	29	37
AEM	Mycology	73	47.9	33	44

Journal	Category	N	% Accepted	% Women Editors	% Women Authors
AEM	Physiology	356	50.3	32	31
AEM	Plant Microbiology	346	36.4	29	39
AEM	Public and Environmental Health Microbiology	893	34.0	32	45
IAI	Bacterial Infections	716	58.4	35	36
IAI	Cellular Microbiology: Pathogen-Host Cell Molecular Interactions	685	55.2	35	37
IAI	Fungal and Parasitic Infections	353	59.5	33	33
IAI	Host Response and Inflammation	763	50.2	35	40
IAI	Host-Associated Microbial Communities	7	57.1	43	86
IAI	Microbial Immunity and Vaccines	342	56.4	35	32
IAI	Molecular Genomics	33	60.6	37	33
IAI	Molecular Pathogenesis	617	68.4	35	31
JCM	Bacteriology	2952	33.2	27	41
JCM	Chlamydiology and Rickettsiology	80	32.5	25	41
JCM	Clinical Veterinary Microbiology	364	32.7	29	40
JCM	Epidemiology	854	29.7	30	45
JCM	Fast-Track Communications	5	40.0	33	40
JCM	Immunoassays	139	36.0	31	41
JCM	Mycobacteriology and Aerobic Actinomycetes	510	42.9	32	41
JCM	Mycology	587	37.3	19	39
JCM	Parasitology	337	33.2	27	34
JCM	Virology	1140	37.5	29	41
JVI	Cellular Response to Infection	604	51.2	36	32
JVI	Gene Delivery	98	41.8	32	20
JVI	Genetic Diversity and Evolution	883	51.1	39	27

Journal	Category	N	% Accepted	% Women Editors	% Women Authors
JVI	Genome Replication and Regulation of Viral Gene Expression	813	64.6	39	23
JVI	Pathogenesis and Immunity	1622	60.4	35	33
JVI	Prions	92	69.6	56	22
JVI	Structure and Assembly	725	71.3	39	29
JVI	Transformation and Oncogenesis	154	59.1	39	36
JVI	Vaccines and Antiviral Agents	1149	59.2	36	28
JVI	Virus-Cell Interactions	2414	63.6	40	30

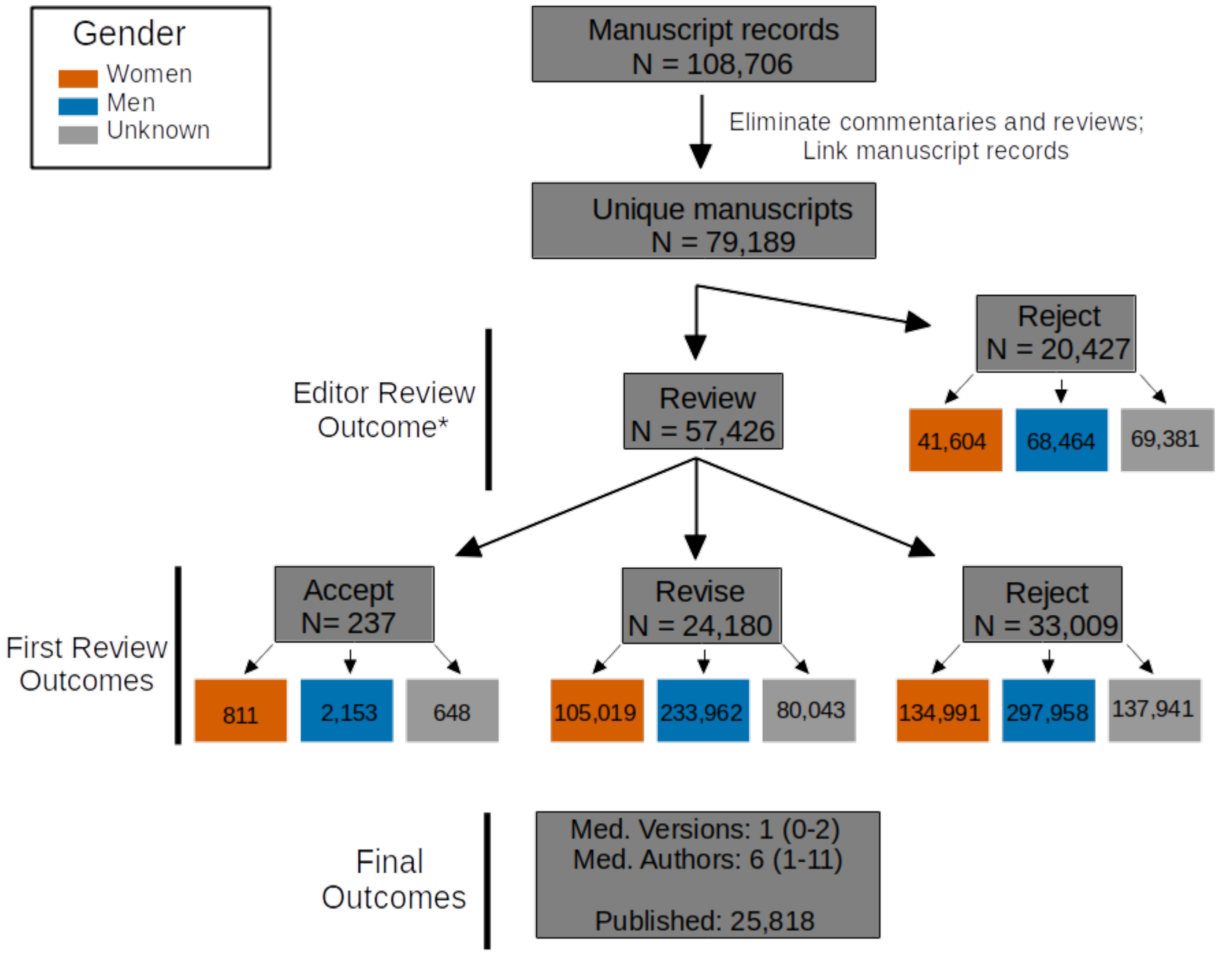


Figure 1. Overview of manuscript outcomes. 108,706 manuscript records were obtained for the period between January 2012 and August 2018. After eliminating non-primary research manuscripts and linking records for resubmitted manuscripts, we processed 79,189 unique manuscripts. The median number of versions was 1 (IQR=0-2) with a median of 6 (IQR=1-11) authors per manuscript. As of August 2018, 34,196 of these were published at ASM journals. Revisions were requested for 24,016 manuscripts and 53,436 manuscripts were rejected at their first submission. The number of individuals (e.g., author, editor, reviewer) involved in each category of manuscript decision are indicated in the colored boxes: women (orange), men (blue), and unknown (gray). *A small number were given revise (242) or acceptance (1094) decisions without review.

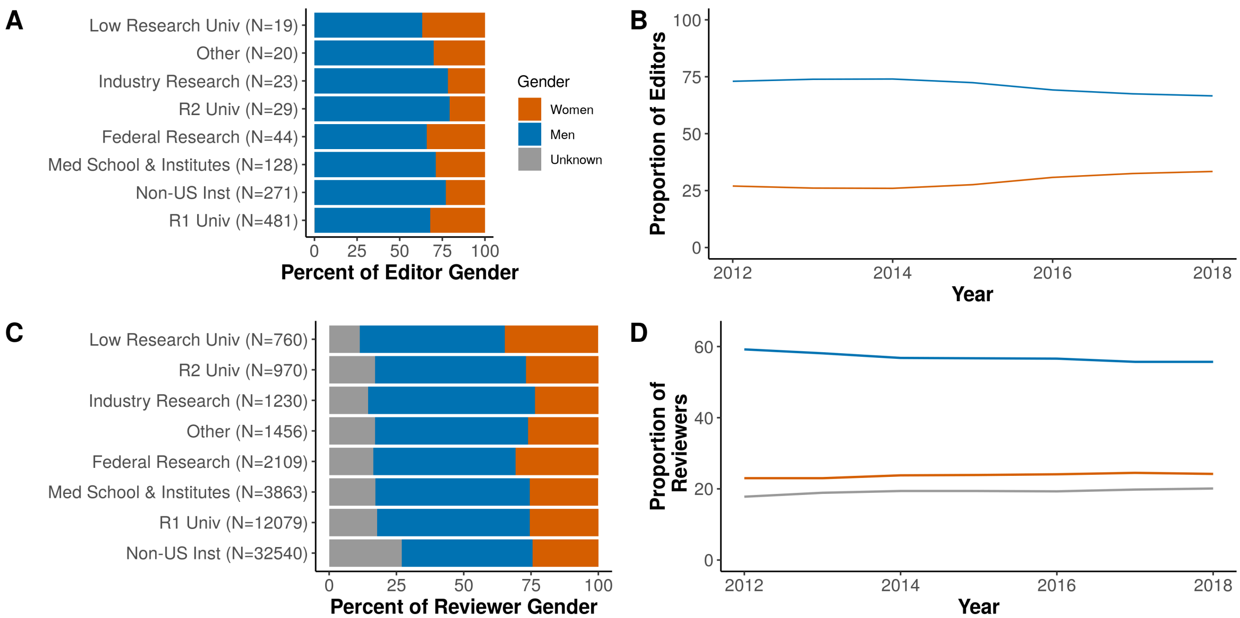


Figure 2. Gendered representation among gatekeepers. Proportion of editors from (A) institution types and (B) over time. Editors and senior editors are pooled together. Proportion of reviewers from (C) institution types and (D) over time. (A,C) Each gender equals 100% when all institutions are summed.(B,D)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

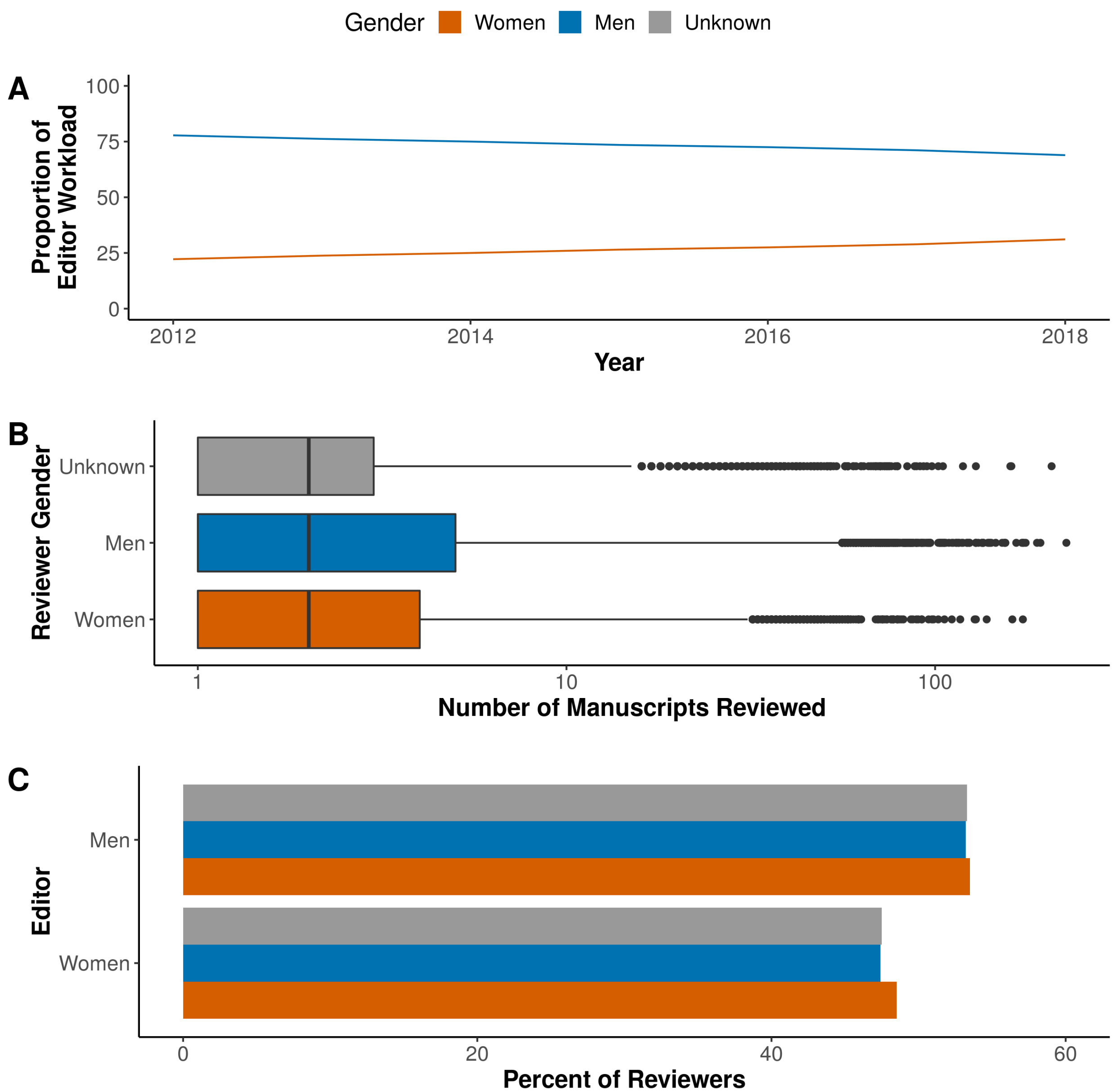
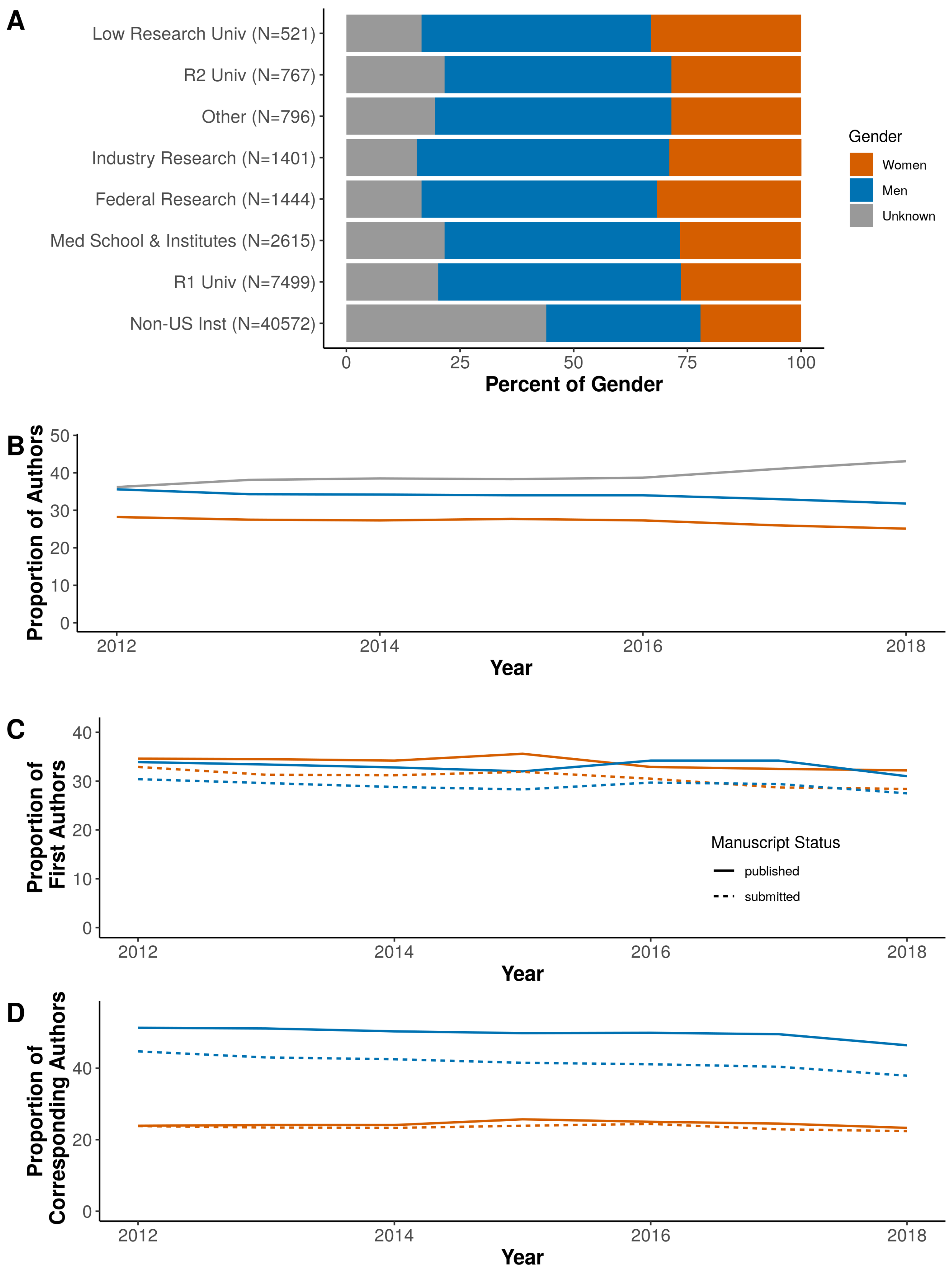


Figure 3. Gatekeeper workload and response to requests to review. (A) Proportion of manuscript workloads by men and women editors, editorial rejections excluded. (B) Box plot comparison of all manuscripts, by reviewer gender. (C) The percent of reviewers by gender that accepted the opportunity to review, split according to the editor's gender.



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813 **Figure 4. Author representation by gender.** The proportion of (A) men and women senior

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 manuscripts (dashed line) and published papers (solid line).

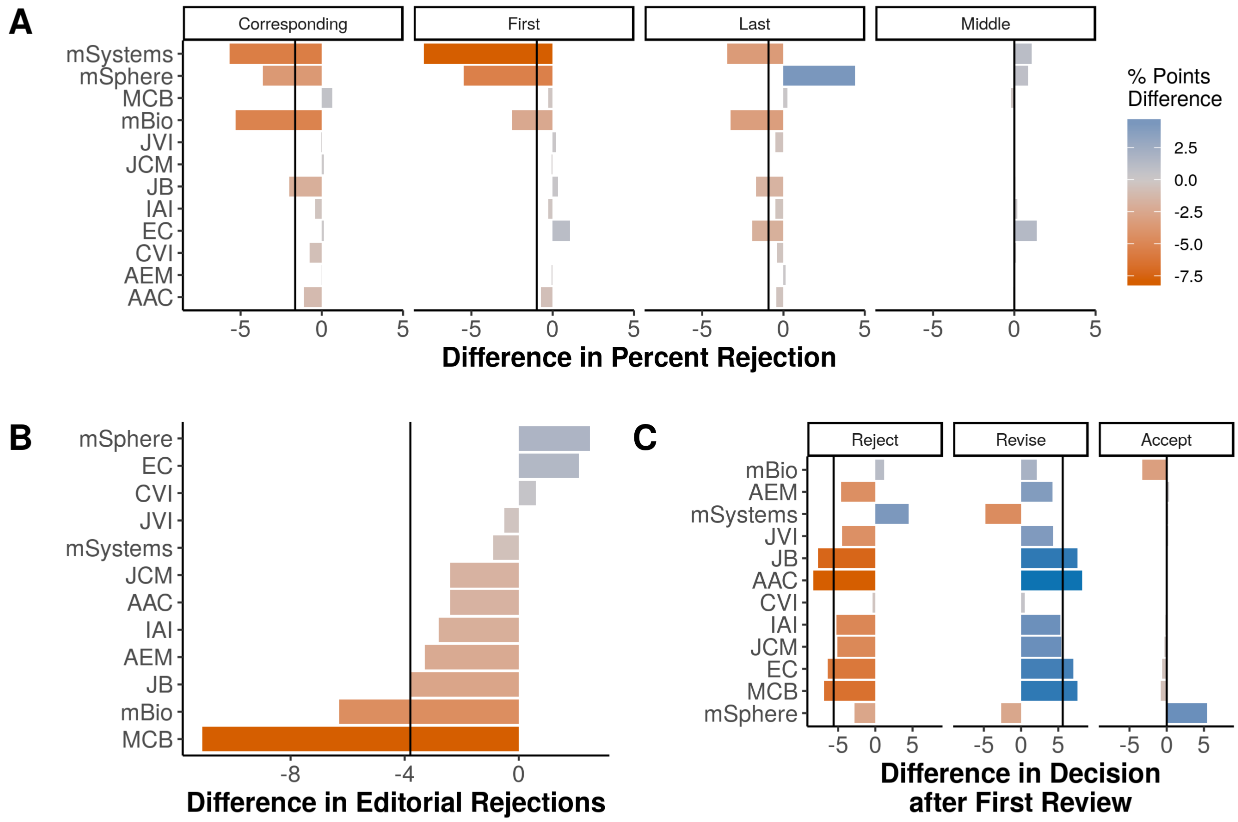


Figure 5. Difference in manuscript outcomes by author gender. (A) The percent of manuscripts rejected by author gender and type (e.g., corresponding, first, last, middle) at any stage across all journals where 0 indicates equal rates of rejection. (B) The difference in percent editorial rejection rates for corresponding authors at each journal. (C) 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 no difference, or parity.

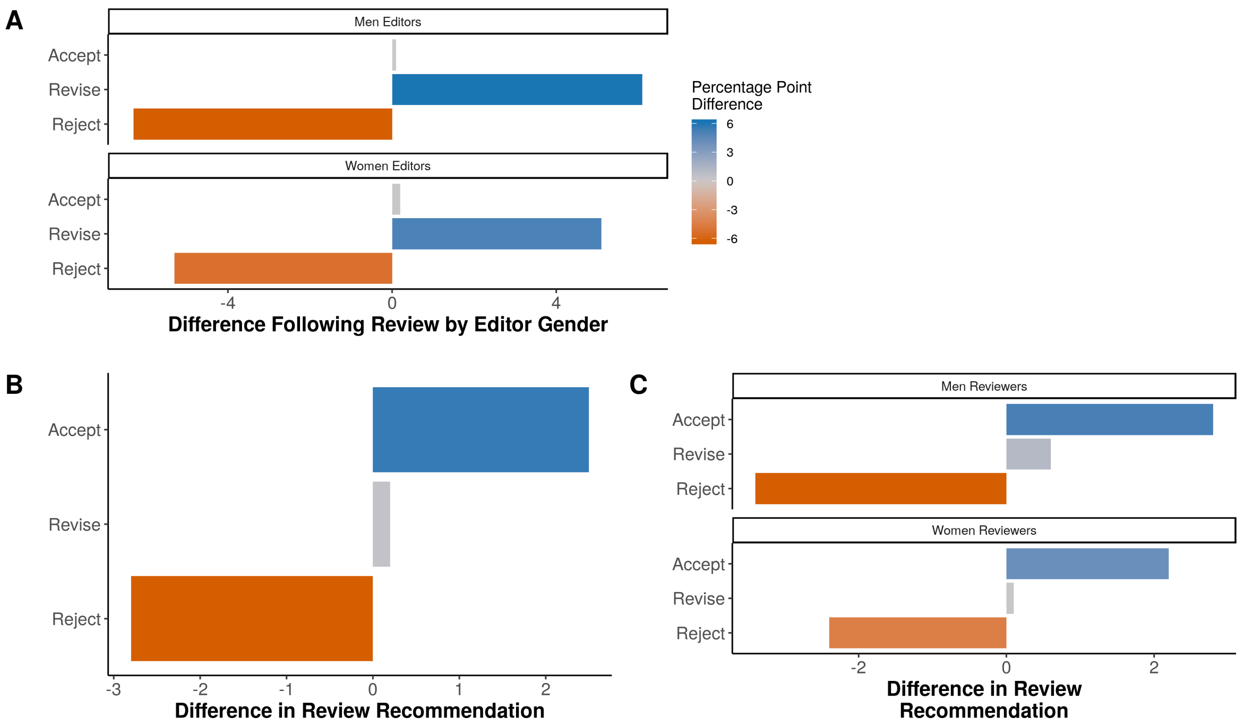


Figure 6. Difference in decisions or recomendations according to the gatekeeper gender. (A) Effect of editor gender on the difference in decisions following review. (B) Difference in percentage points for review recommendations and (C) how that is affected by reviewer gender. (A-C) All journals combined.

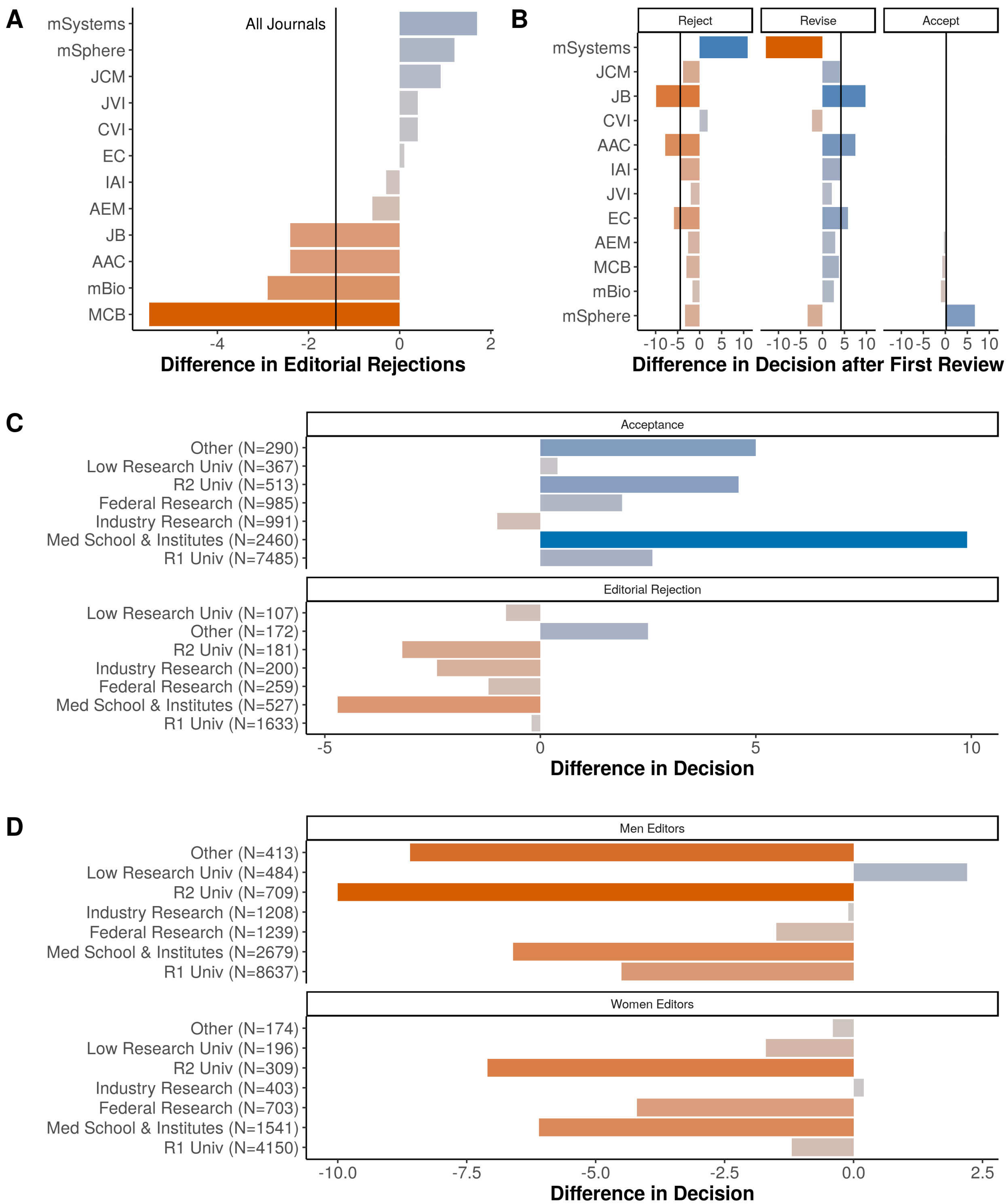


Figure 7. Impact of origin and U.S. institution type on manuscript decisions by gender. Difference in percentage points for (A) editorial rejections and (B) following first review of manuscripts submitted by US-based corresponding authors. Vertical line indicates value for

all ASM journals combined. (C) Difference in percentage points for acceptance and editorial rejections according to institution types and (D) acceptance decisions by editor gender and institution type.

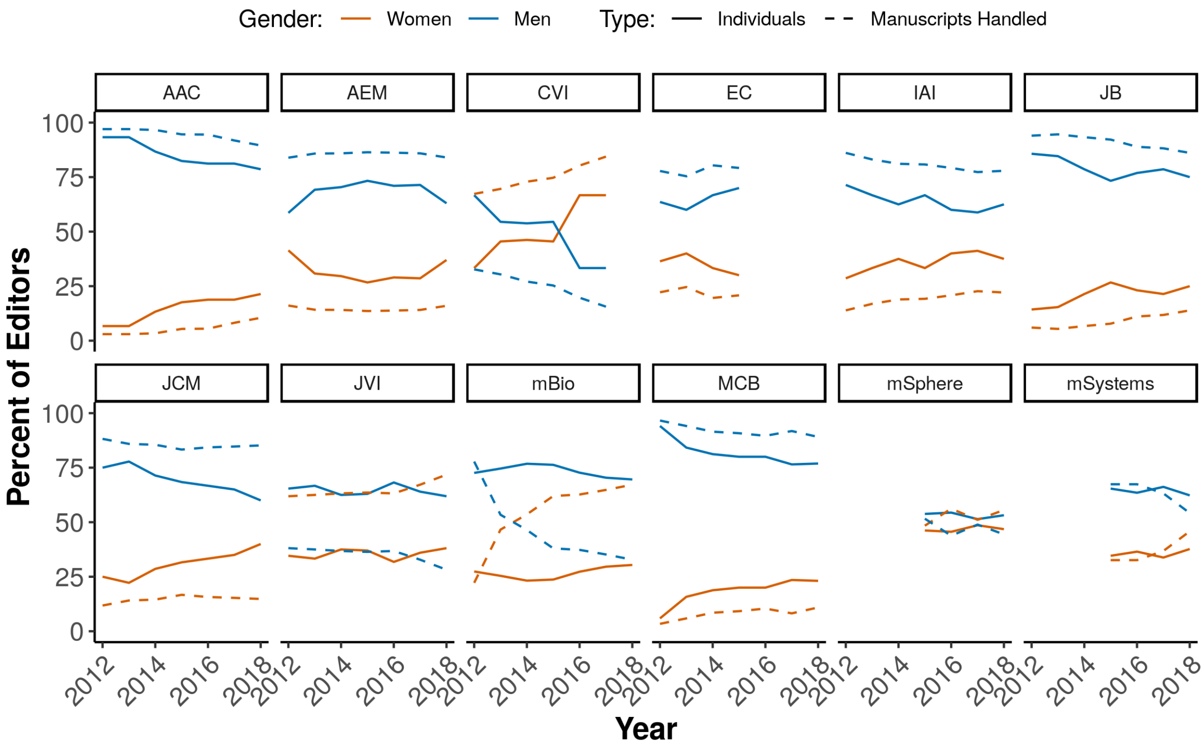


Figure S1. The proportion of editors (solid line) and their workloads (dashed line) at each ASM journal from 2012 to 2018.

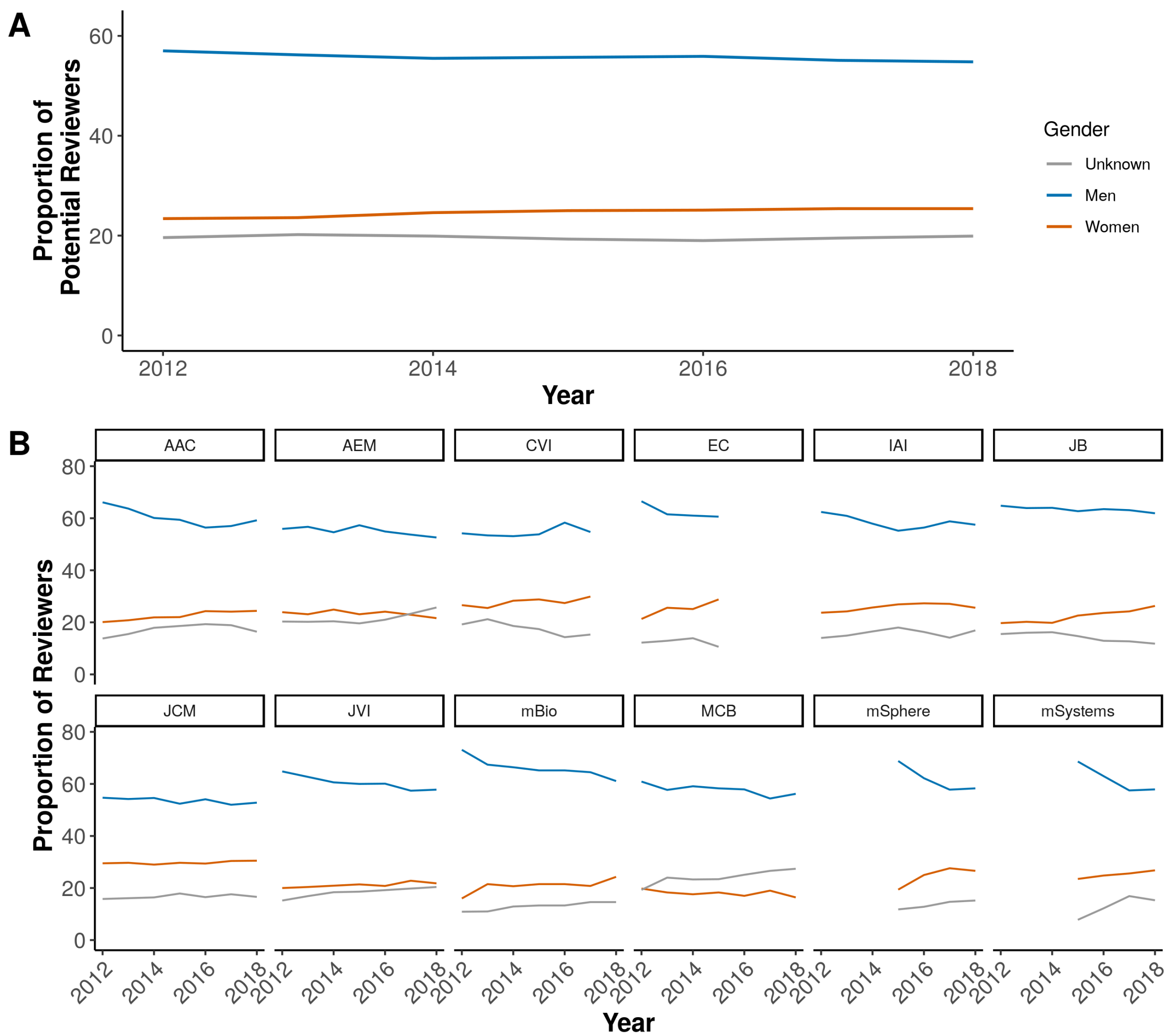


Figure S2. The proportion of (A) potential reviewers at all ASM journals combined, (B) reviewers at each ASM journal.

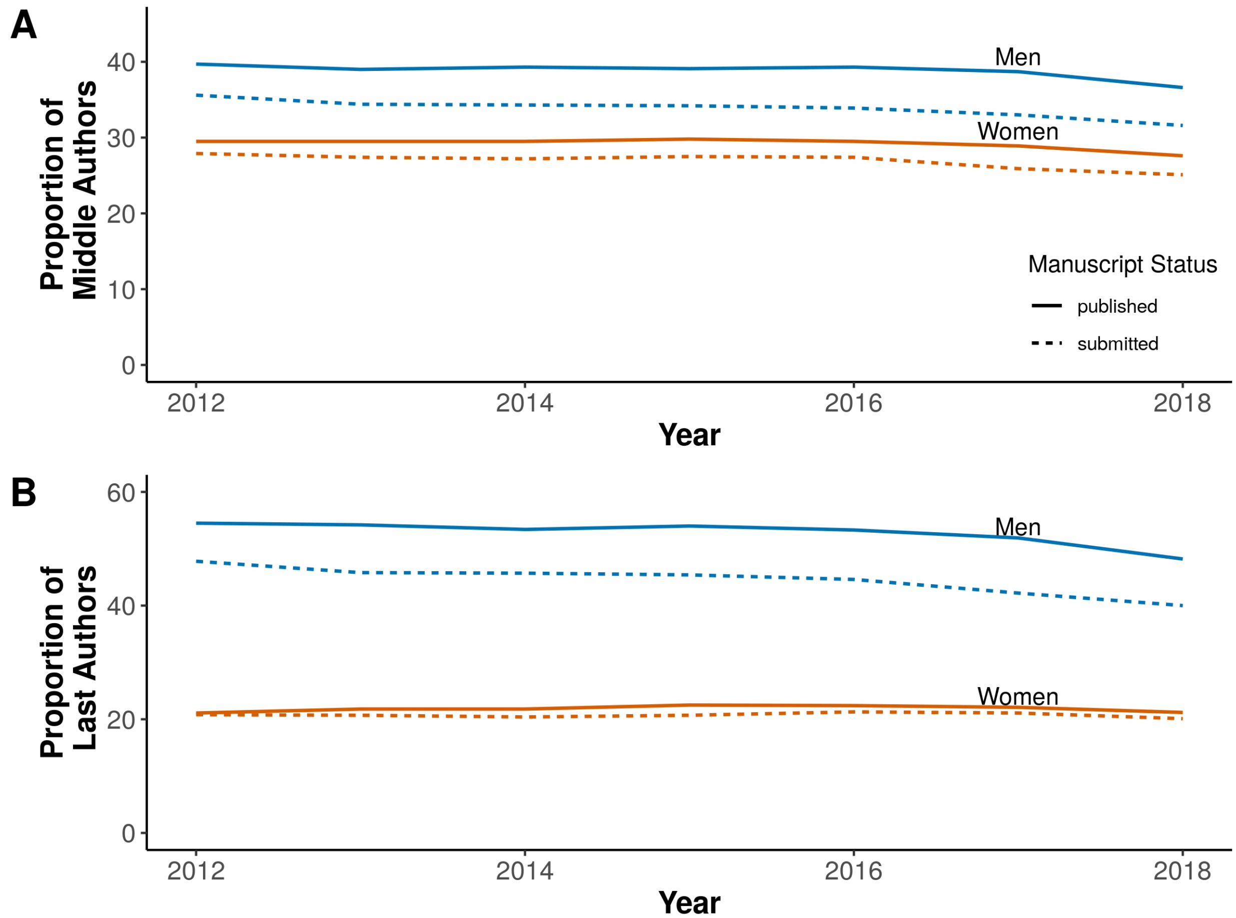


Figure S3. The proportion of all submitted (dashed line) and published (solid line) (A) middle and (B) last authors by gender at each ASM journal.

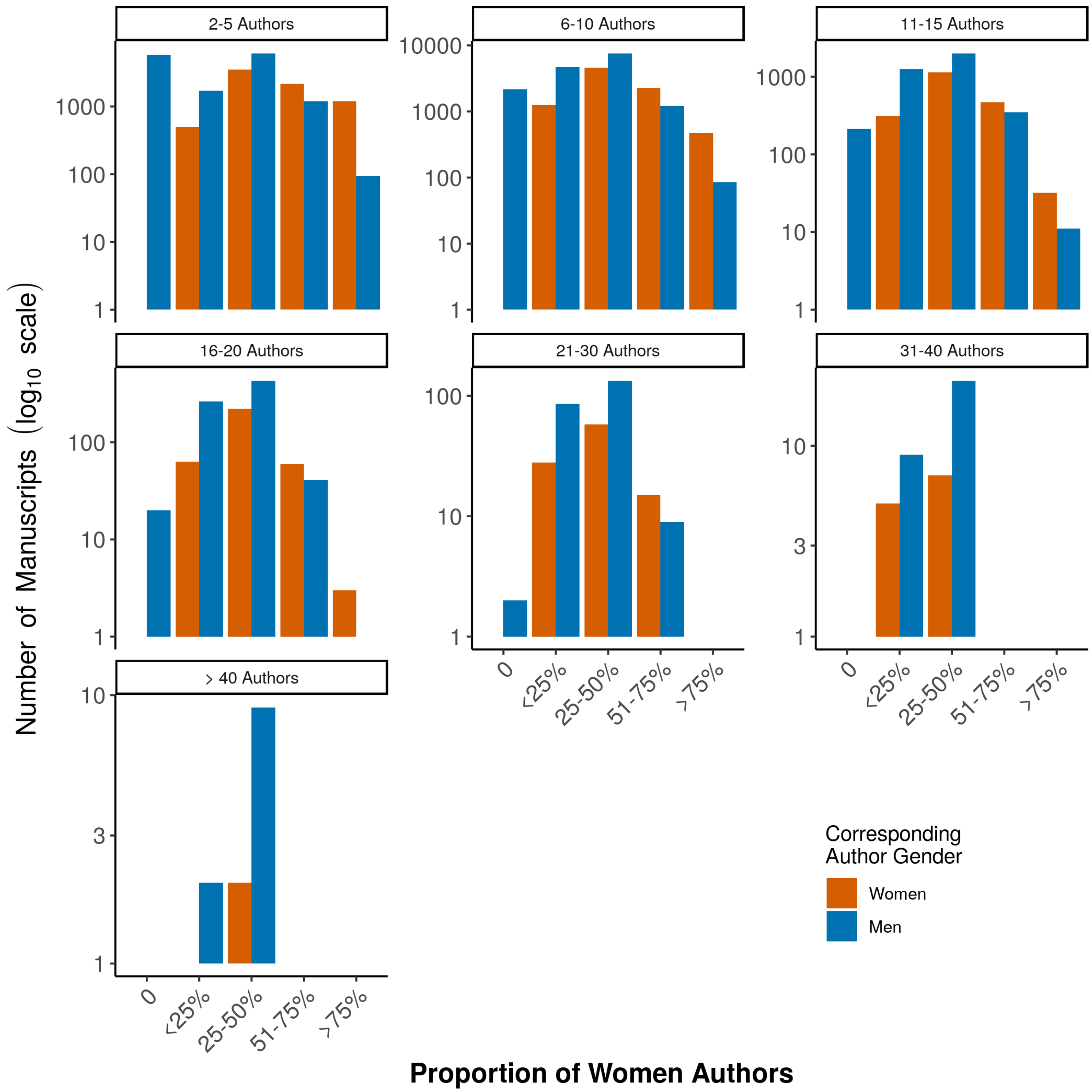


Figure S4. The proportion of women authors on submitted manuscripts according to the number of authors and the gender of the corresponding author. Y axis indicates the total number of manuscripts on a $\log_{10}$ scale.

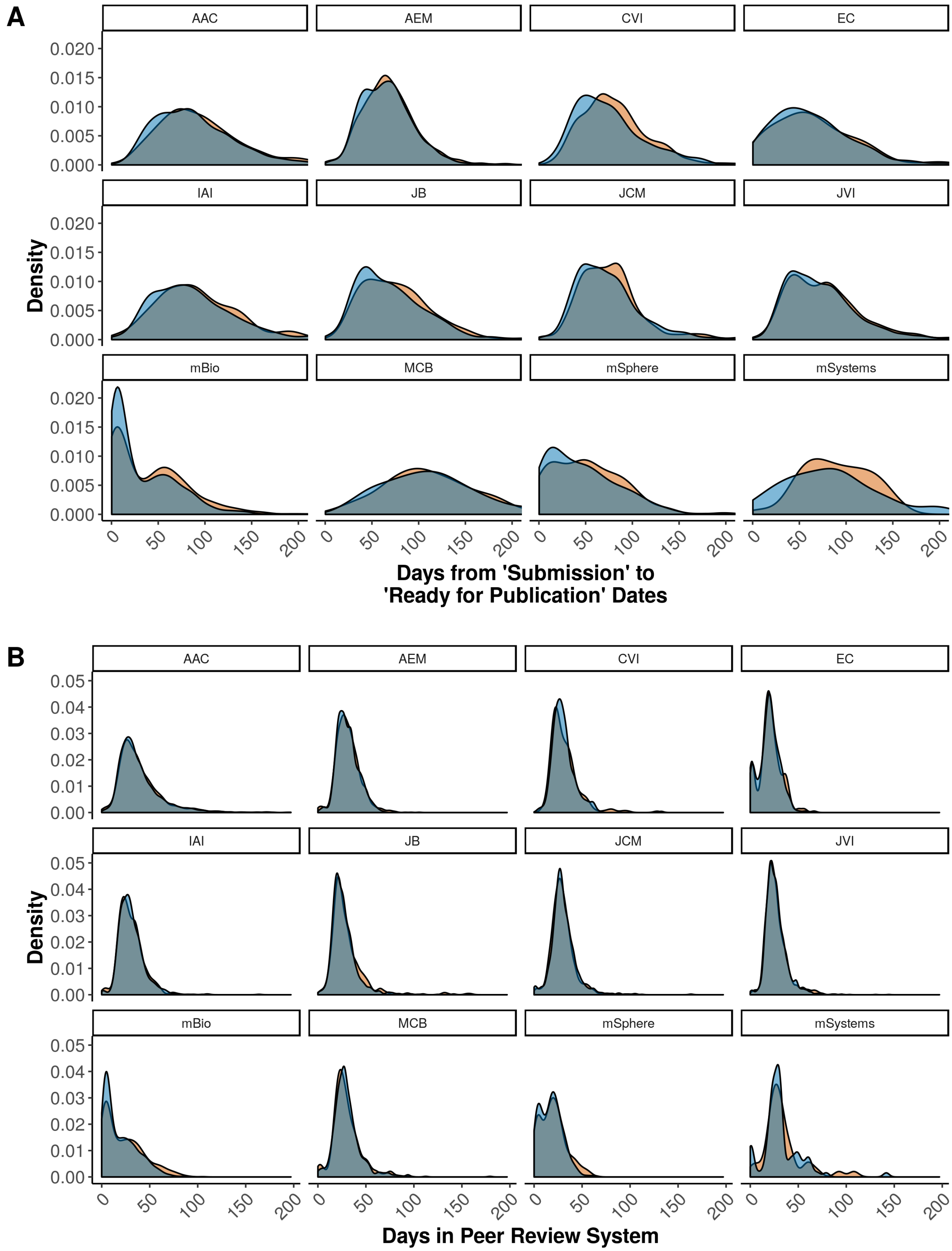


Figure S5. Comparison of time to final decision and impact by gender. The number of days (A) between when a manuscript is initially submitted and finally published or (B) that a manuscript spends in the ASM peer review system.

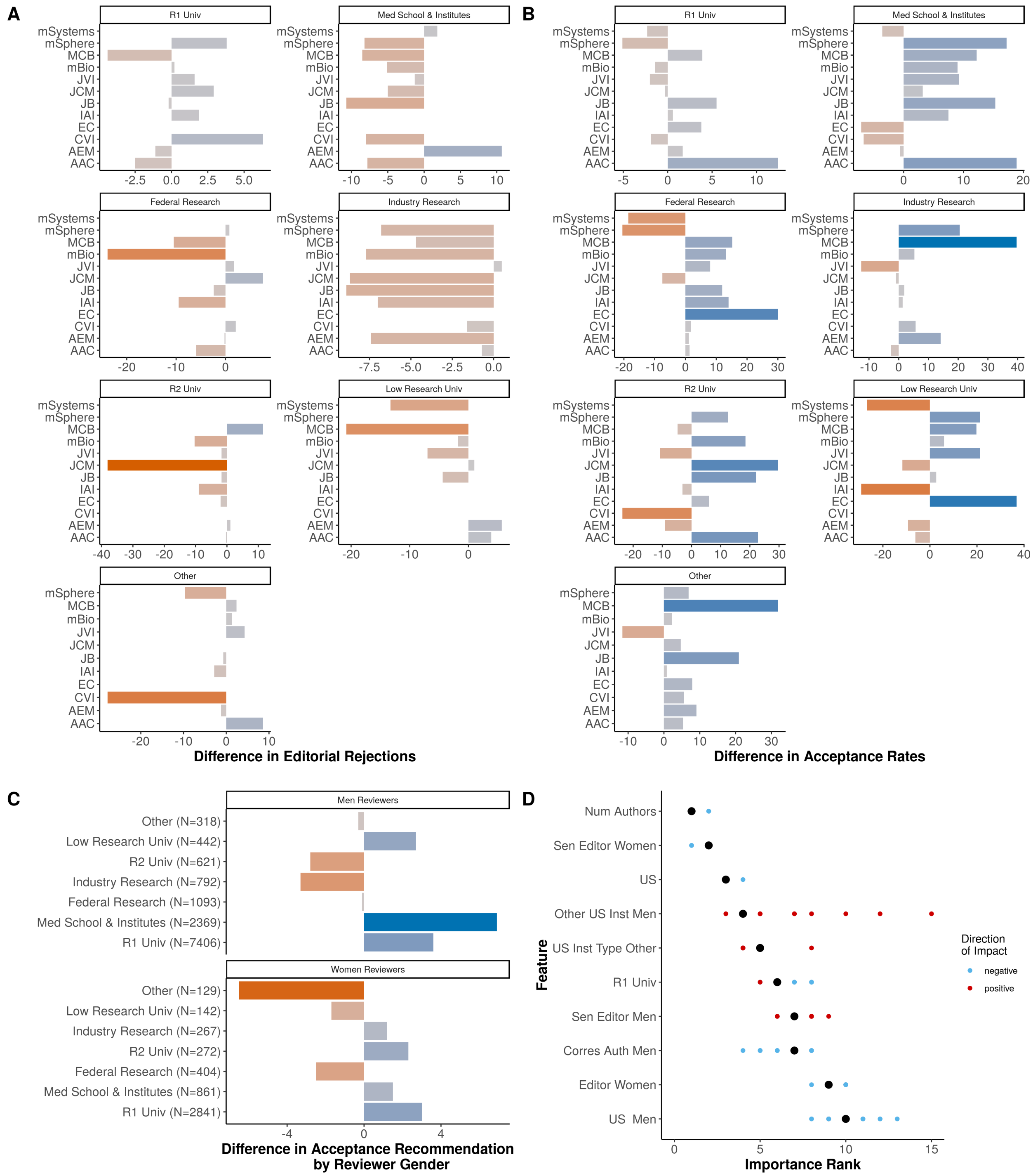


Figure S6. Difference in A) editorial rejection and B) acceptance rates by journal and institution type. C) Difference in review recommendations by reviewer gender and author institution type. D) Median importance (black dot) of features affecting editorial rejections, and their range. Color of smaller dots (N=25) indicate the direction of the impact.

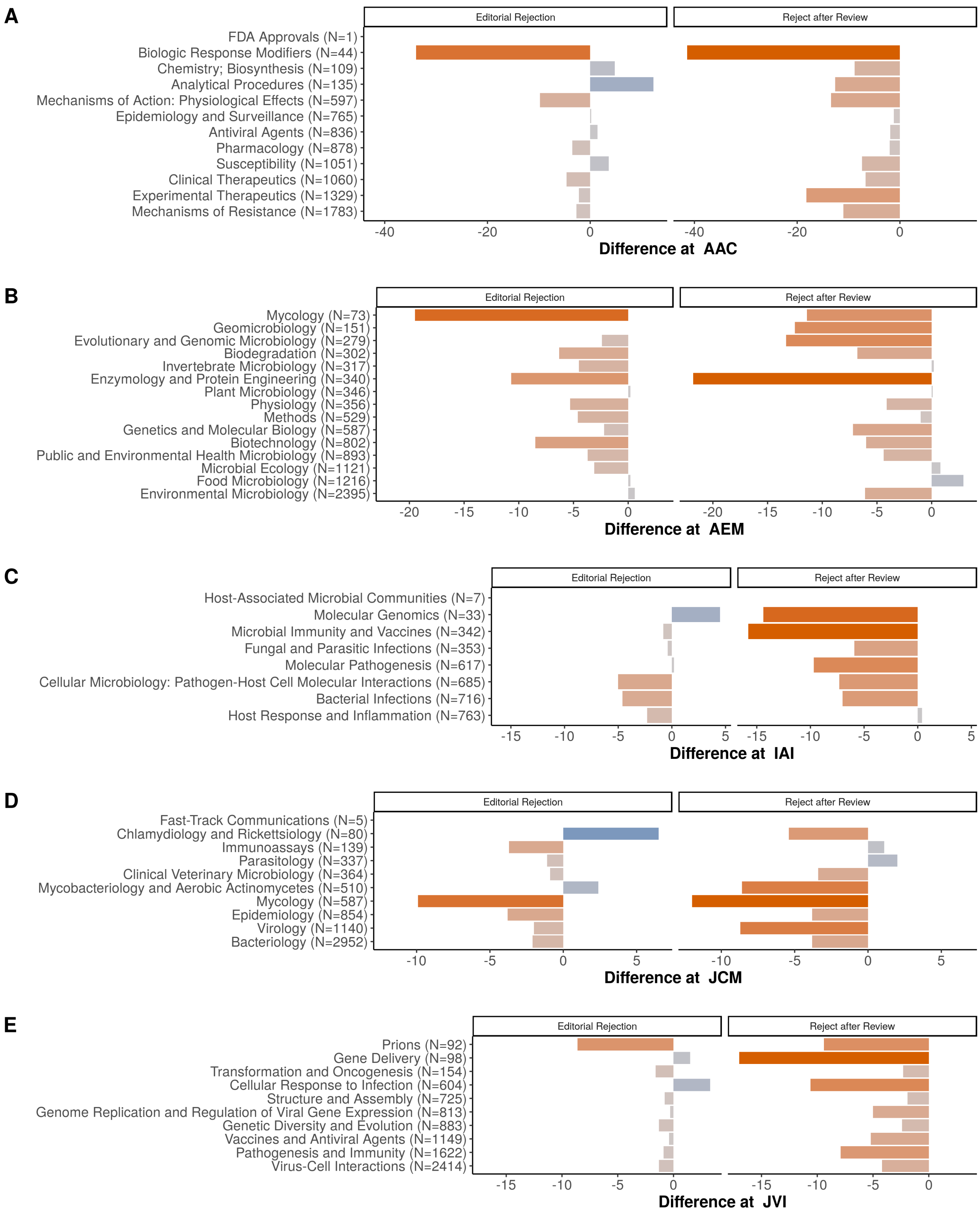
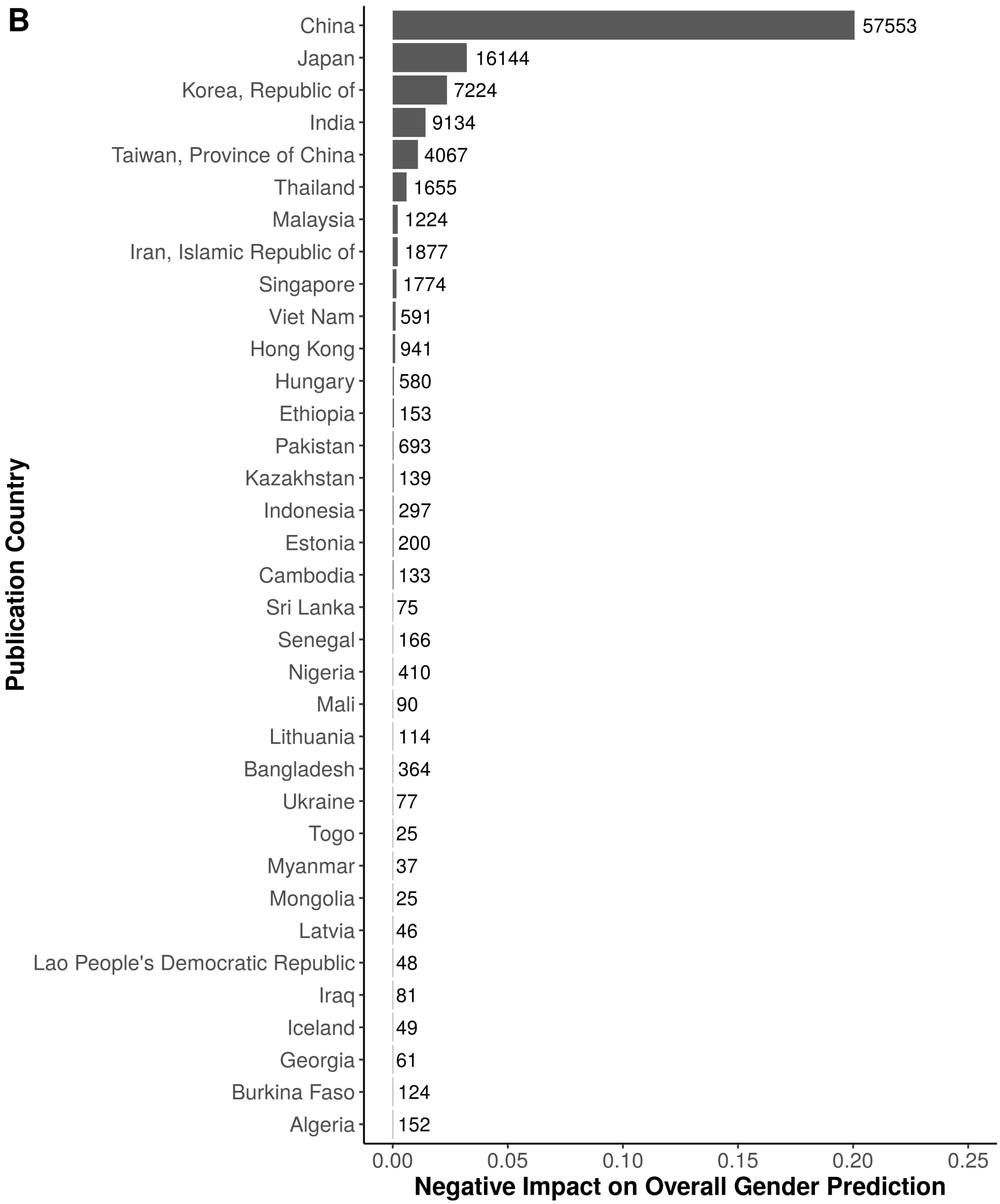


Figure S7. Difference in editorial rejections and rejections after review by corresponding author gender and manuscript category at (A) AAC, (B) AEM, (C) IAI, (D) JCM, and (E) JVI. In parentheses: N = the number of manuscripts submitted.

A

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

B



Figure

S8. (A) Equation for calculating negative bias by genderize algorithm. C indicates a country. (B) The negative impact of each country on the overall gender inference of the full data-set. Number to the right of each column is the total number of names associated with that country.