Women are underrepresented and receive differential outcomes at ASM journals: A six-year retrospective analysis

Running title: A six-year retrospective analysis of ASM journal outcomes

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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 and evaluation of women in their peer review processes; however, representation and attitudes differ by scientific field and no studies to-date 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 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 type of institution for US-based authors. Nonetheless, the pattern for women corresponding authors to receive more negative outcomes on their submitted manuscripts held. We conclude with suggestions to improve the representation of and decrease structural penalties against women.

Importance

Barriers in science and academia have prevented women from becoming researchers and experts that are viewed as 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, in part, due to a combination of both low submissions from senior women authors and more negative outcomes on submitted manuscripts 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 (1–8). These issues do not act independent of one another, instead they accumulate for both individuals and the community, much as advantages do (9–11). 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 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 (12). 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 (13), a factor that is reported to be influenced by the gender of the editor (14). Several studies have concluded that there is no significant bias against papers authored by women (14–19). 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 (20–23).

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. A recent statement notes that “A diverse ASM enhances the microbial sciences, increases innovation, strengthens the community and sustains the profession” and pledges to “address all members’ needs through development and assessment of programs and services” that aims to ensure “equitable access and accountability through transparent procedures and communication” (24). One of the ASM’s 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 Announcements*), *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 our research study was to describe the population of the ASM journals both 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 some by reviewers, leading to multiple possible outcomes. At the 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 selected 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, we identified 79,189 unique manuscripts (Fig. 1).

We inferred gender for both the peer review participants (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, Fig. S1). 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. The sensitivity, specificity, and accuracy of our method were 0.97 (maximum of 1.0) when validated against a curated set of authors (Table S1). The accuracy was 0.99 when applied to the list of editors, whose inferred genders were validated by hand using Google (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. Finally, we refer to editors and peer reviewers collectively as gatekeepers, which describes and recognizes their essential role in maintaining the scientific quality of manuscripts accepted (or rejected) at peer reviewed journals (25, 26).

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 (27). Non-US institutions and U.S. medical schools or research institutions supplied the next largest proportions of editors (Fig. 2A)(27). Since 2012, there was a slow trend toward equivalent gender representation among editors (Fig. 2B). Individual journal trends varied considerably, though most had slow trends toward parity (Fig. 2C). CVI and *mSphere* were the only ASM journals to have accomplished equivalent representation of men and women, 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 (using our algorithm with 0.97-0.99 accuracy). 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. 2D). The proportions of each gender group were consistent over time among reviewers at the ASM journals (Fig. 2E) and were 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. To evaluate the editorial workload for each gender, we calculated the proportion of manuscripts handled by editors of each gender (excluding editorial rejections), relative to their representation. If the workload is proportionate, then the workload for each gender will be equivalent to the gender's representation at that journal. Across all of the 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 journals with varying degrees of difference between workload and representation (Fig. 2C). For instance, at *mSphere*, both workload and representation 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 proportional workload for women at *mBio* has increased.

The median number of manuscripts reviewed by men, women, and unknown gendered 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 gender groups 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). Both men and women editors 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 (28). In September 2018, 38.4% of ASM members who reported their gender were women. We wanted to determine if these proportions were similar for senior authors at the journals and to understand the distribution of each gender group among submitted manuscripts and published papers. We began by describing senior author (last/corresponding author) institutions by gender group. Over 60% of submitting senior authors were from non-US institutions, followed by about 20% from R1 institutions. The proportion of manuscripts submitted from US institutions by women senior authors was 31% versus 36% from women who were senior authors at non-US institutions. Women senior authors were more highly represented at low research universities and federal research institutions than at any other US-based institution (Fig. 4A). The proportions of all men and women (senior and co-) authors at the ASM journals decreased over time at equivalent rates, while 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 a manuscript signals the type and magnitude of contributions to the finished product. First and last authorship are the most prestigious. First authors are generally trainees (e.g., students or post-docs) or early career researchers responsible for performing the bulk of the project, while last authors are generally lead investigators that supplied 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), of which there can be multiple.

The proportion of manuscripts submitted with men or women as first authors remained constant at 29.1 and 30.7%, respectively (Fig. 4C, dashed). The proportions of first author published papers were nearly identical at 33.1% for men and 33.8% for women (Fig. 4C, solid). 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 23.4% (Fig. 4D, dashed); the proportion of published unknown gender 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 the percent of submitted manuscripts and published papers was 8.2% when men were corresponding authors, but only 0.9% when women were corresponding authors, making the submitted to published difference near equal (Fig. 4C, solid). This trend was similar for middle and last authors (Fig. S3).

Of the 38594 multi-author manuscripts submitted by men corresponding authors, 23.5% had zero authors inferred to be women. In contrast, 7253 (36.3%) of the manuscripts submitted by women corresponding authors had more than half of the authors inferred 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, such 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% (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 using a logistic regression model trained on 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 distinguishes perfectly between outcomes. A value of 0.5 indicates that the model did not perform better than a random assignment. The median AUROC value of our model to predict the corresponding author's inferred gender was 0.7 (Fig. S5A, panel A). The variable with the largest absolute weight (i.e., the most predictive value), in our model was the proportion of women authors (Fig. S5C). These results indicate that manuscript submission data was capable of predicting the inferred gender of the corresponding author, but that the 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 will be 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 the ASM journals. There were 75451 women who participated as junior authors (first/middle) at the 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 became editors at the ASM journals over the 6 year period studied. 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 became editors at the ASM journals. Overall, women who participated at the ASM journals as junior authors were half as likely to move to senior author or reviewer roles, and 30% as likely to be an editor than men at the ASM journals.

Manuscripts submitted by women have more negative outcomes than those submitted by men. To further investigate the difference in percents of 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). To more easily visualize and understand the differences in outcomes according to author gender, we calculated the outcome rate for each gender then subtracted the rate for women from men to generate the percentage point difference. To correct for the disparity in participation by women compared to men, all percentage point comparisons were made relative to the gender and population in question. Where men received an outcome more often than women, the value is positive (blue) while a negative value (orange) indicates that women outperformed men in the given metric. For the following analyses, only manuscripts authored by an individual inferred to be a man or woman were included. Finally, these analyses were conducted on all available manuscripts, not a statistical sampling. As a result, statistical tests were only required for correlative analyses.

Middle authors were rejected at equivalent rates for men and women (a 0.23 percentage point difference across all journals). However, manuscripts with senior women authors were rejected more frequently than those authored by men with -6.7 and -6.0 percentage point differences for corresponding and last authors, respectively (Fig. 5A, vertical lines). The overall trend of increased rejection for women was most pronounced at MCB, JB, IAI and AAC. 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 editor review 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 of the 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 (29). 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 between submission and being ready for publication to those authored by men. Manuscripts authored by women took slightly longer (from submission to ready for publication) to complete 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. S6), and having the same median number of revisions prior to acceptance (Median = 2, IQR = 0).

To understand how a gatekeeper's (editor/reviewer) gender interacted with decision types (e.g., Fig. 5C), we grouped editor decisions and reviewer suggestions according to the gatekeeper's inferred gender (unknowns excluded). Both men and women editors rejected proportionally more women-authored papers, however the percentage point 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 and 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 frequently for men-authored manuscripts than women did (Fig. 6C).

To evaluate if inferred 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 (Fig. S5B). The median AUROC value was 0.61 (Fig. S5A, panel B), which indicated that editorial decisions were not random, however, the relatively low AUROC value indicated that there are factors not included in our model that influence editorial decisions.

Multiple factors contribute to the overperformance of men. The association between inferred gender and manuscript decision could be attributed to implicit gender bias by journal gatekeepers, however, there are other types of bias that may contribute to, or obscure, 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 (20). Other studies have documented prestige bias, where men are over-represented in more prestigious (i.e., more respected and selective) programs (30). 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 from 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 using the Carnegie Classification of Institutions of Higher Education (TM) (27). We used the same strategy as described above. When only considering US-based authors, the percentage point difference for editorial rejections increased from -3.8 to -1.4 percentage points (Fig. 7A). The trend of percentage point 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 differences in outcomes by inferred gender, 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 the Carnegie classification) and re-evaluated the differences for men and women (27). 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. S7A). This percentage point difference in the editorial rejections of corresponding authors from medical schools or institutes was spread across most of the ASM journals, while the editorial rejection of papers submitted from women at R2 institutions was driven primarily by submissions to JCM (Fig. S7A). Evaluating the percentage point difference in acceptance rates by institution and inferred gender mirrored that of editorial rejections for some journals, where submissions from men recieved better outcomes than submissions from women (Fig. 7CD and S7BC). For instance, manuscripts submitted by men from medical schools or institutes were accepted up to 10 percentage points more often than those submitted by women (Fig. 7C).

To evaluate if these factors affect manuscript decisions, we trained a logistic 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 (Fig. S5A, panel C), 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 all more associated with editorial rejections (Fig. S7D). Conversely, manuscripts from R1 institutions, authors from the U.S., EICs that were women, and the number of authors were all more likely to be associated with review (Fig. S7D). These results confirm that the country of origin and class of institution 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 (31–33). This concept originally described bias against Black women—the intersection of two historically marginalized identities. However, the idea that researchers in an established core field might be skeptical of less established, or non-traditional, sub-field research likely applies elsewhere. The disparate outcomes of sub-fields in a gendered context has recently been observed in the biomedical sciences, where NIH proposals focusing on womens’ reproductive health were the least likely to be funded (34). To explore this phenomenon in the ASM journals, we looked at the editorial rejection rates of 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 and comprise 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 (31–33). 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 percentage point differences in 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 was maintained across most categories with some displaying major differences in gendered performance (Fig. S8). 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. S8A). "Mycology", was a category at two journals, AEM and JCM. At both journals, men received favorable outcomes relative to women in this category. At AEM, there were 73 "Mycology" submissions, 44% from women authors with a percentage point difference of almost -20 for editorial rejection outcomes and -10 for rejections after review (Fig. S8B). JCM had 587 "Mycology" submissions with a submission rate of 39% from women authors (Fig. S8D). 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 negative outcomes 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 inferred men and women participating in the submission and peer review process at the ASM journals between January 2012 and August 2018 and compared editorial outcomes according to the authors' inferred 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 of the ASM journals combined, but those workloads were disproportionate at the journal level and the overburdened gender varied by journal (Figs. 2 and 3). Additionally, manuscripts submitted by women corresponding authors 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 S8). However, the trend for women corresponding authors to receive more negative outcomes held across all analyses, indicating a pattern of gender-influenced editorial decisions regardless of journal prestige (as determined by impact factor). Together, these data indicate a persistent penalty for senior women microbiologists who participate at the ASM journals.

The proportion of women as first authors was higher than data obtained globally and from self-reported ASM membership data, which was higher than the proportion of senior women authors at the ASM journals. Only half as many women who were junior authors at the ASM journals were also senior authors when compared to men. The representation of women decreased as the prestige (e.g., reviewer, editor) increased. These trends are consistent with the representation of senior women in academic biological sciences, the observation that women are more likely to leave academia during the transition from postdoc (junior) to investigator (senior), and mentorship bias (35, 36). These data indicate that microbiology (as represented by the 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 (37–39). 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 at the 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 (40).

In contrast to institutional service, the editing workload at the ASM journals seems to be predominantly borne by men (Fig. S1). A possible explanation for the difference in gatekeeper representation and editor workloads is that women are more likely to study non-traditional sub-disciplines (31–33). Their separation from the traditional center of a field decreases their perceived competency, which could result in research typecasting and lower manuscript handling responsibilities (6, 31–33). However, our data could not confirm this phenomenon at the 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 (Fig. 3C). 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 (Fig. S1). At these journals, the editorial workloads of women exceeded 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 women editors, may also extend to editors; men editors may be more likely to reject requests to handle manuscripts from women EICs. 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 (14), but supports findings that women editors contact more reviewers than men (41).

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 (42), and that women are more likely to yield corresponding authorship to colleagues that are men (21). 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 (43). This observation was supported by the positive correlation between citations and author count (Fig. S7). Thus it concerns us 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). And while women corresponding authors submitted fewer manuscripts, more of them (both numerically and proportionally), had a majority of co-authors inferred to be women, compared to those submitted by men corresponding authors. These data support previous findings that women are more likely to collaborate with other women (23, 44–46). Additionally, the proportion of women authors was the greatest predictor of corresponding author gender. This gender-based segregation of collaborations at the ASM journals likely has had consequences in pay and promotion for women microbiologists and could be a factor in the decreased retention of senior women. We predict that the low retention is aggravated by the under representation of women as corresponding authors, which also has negative consequences for both their careers and microbiology. Since senior authorships impact status, visibility, and salary, the under representation of women as senior authors and reviewers likely hampers their career progression and desire to progress (18, 47). The retention of women (and other marginalized groups) 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 (48–54). However, submissions data are 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 the ASM journals (Fig. 4). When examining manuscript outcomes, we found a consistent trend of positive outcomes for manuscripts submitted by men corresponding authors (Fig. 5). Manuscripts submitted by women corresponding authors were editorially rejected at greater rates and recommended for rejection more often by gatekeepers of both genders. Neither geographic (i.e., US or not), institution type, nor sub-discipline could fully account for the observed gender-based outcomes (Fig. 6, 7, S7, and S8). Instead, the presence of outcomes that favor men over women from U.S. R1 institutions and medical schools and institutes suggests that the penalty for women persists, even in environments with generally excellent resources and infrastructure for research. Science and the peer review system select for decisions based on the assumption that scientists are objective, impartial experts. But scientists who believe themselves immune to bias are making decisions that inherently rely on cognitive biases to speed the process, some of which have negative impacts (55–57). For instance, previous studies show that a greater burden of proof is required for women to achieve similar competency as men (6, 58, 59). This and similar implicit biases might train women to be more conservative in their manuscript submissions, which makes our observed difference in outcomes 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 (29, 60). Additionally, women are often at a disadvantage for the resources required for highly competitive fields due to cumulative penalties (9–11). 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, thus these are cues to gender and perceived competency (31–33). Alternatively, non-traditional research may be seen as less impactful, leading to poorer peer review outcomes

(34). 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. S8). Despite being among the most deadly infectious diseases in 2016 (along with tuberculosis and diarrheal diseases), mycology is an underserved, and underfunded, field in microbiology that has historically been considered unimportant (61–64). 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. While we report a high accuracy (0.97-0.99) where gender was inferred, this method left us with a category of unknown gendered individuals. Additionally, 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 the ASM journals from Asian countries, particularly China. Anecdotally, most editorial rejections are poor quality papers from Asia, and our method had low performance on non-gendered languages from this region (Supp Text, Fig. S1), thus excluding many Asia-submitted manuscripts and increasing our confidence that the trends observed were gender-based. For corresponding authors, manuscript submissions are the end product of several other prior decisions such as a mentor's implicit bias(es), postdoctoral fellowships, faculty applications, start-up funding negotiations, and grant proposals. These prior factors, which cannot be accounted for in our analysis, along with the small effect size observed in some analyses, limit quantifying the role of gatekeeper decisions in the disparate gender-influenced outcomes. However, the consistency of decisions to benefit men corresponding authors over women across all of the 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 marginalized groups in science (65). We suggest that journals develop a visible mission, vision, or other statement that commits to equity, justice, and inclusion and includes a non-discrimination clause regarding decisions made by editors and editors-in-chief. This non-discrimination clause should 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. These data should not be available to journal gatekeepers but instead kept in a dis-aggregated manner that allows for public presentation, tracking the success of inclusive measures, and to maintain accountability. Third, society journals can implement mechanisms to explicitly provide support for women and other marginalized 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 marginalized groups (34). We can all help advance women (and other marginalized groups) within the peer review system by changing how we select experts in our field. For instance, authors can suggest more women as reviewers using "Diversify" resources (66), 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 (67), 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 skewed 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 marginalized groups.

Most approaches to disparate outcomes focus on choices made by individuals, such as double-blinded reviews and implicit bias training. These cannot fully remedy the effects of implicit bias and may even worsen outcomes (68, 69). Since disparate outcomes (by gender, geographic, prestige, or otherwise) are partially the result of accumulated disadvantages and actions resulting from implicit biases and systemic "-isms", 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 implicit bias during evaluation and enhance the evaluation process for both the evaluator and the evaluatee (70–73). 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 (74, 75). This might also change the overall negative attitude toward replicative research and negative results, thus bolstering the field through reproducibility. We also argue that reconsidering journal scope and the membership of honorary editorial boards might help address structural penalties resulting from implicit bias against women (and other marginalized groups) 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 implicit bias and structural penalties—review rubrics, increased focus on solid research, expansion of journal scopes and editorial boards—will also standardize competency principles for researchers at the ASM journals and improve microbiology as a whole.

Although the level of bias at many of the ASM journals is small, it is present. Peer review at the ASM journals is not immune to the accumulated disadvantages against women in microbiology. However, the adaptation of women and other marginalized groups to implicit 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 the impact of such bias. We encourage the 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 centuries-old institution. 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 implementation.

Data and Methods

Data. All manuscripts handled by the 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 the 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. Since reviews and commentaries are often commissioned, only original, research-based manuscripts were included in this analysis, 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 the 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) (27). 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 their own groups. The "Other" category represents uncategorized US institutions. Non-US institutions were their own category.

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 the 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 (76). 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. Data and code for all analysis steps, logistic regression pipeline, and an Rmarkdown version of this manuscript, are 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
AEM	Physiology	356	50.3	32	31

Journal	Category	N	% Accepted	% Women Editors	% Women Authors
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

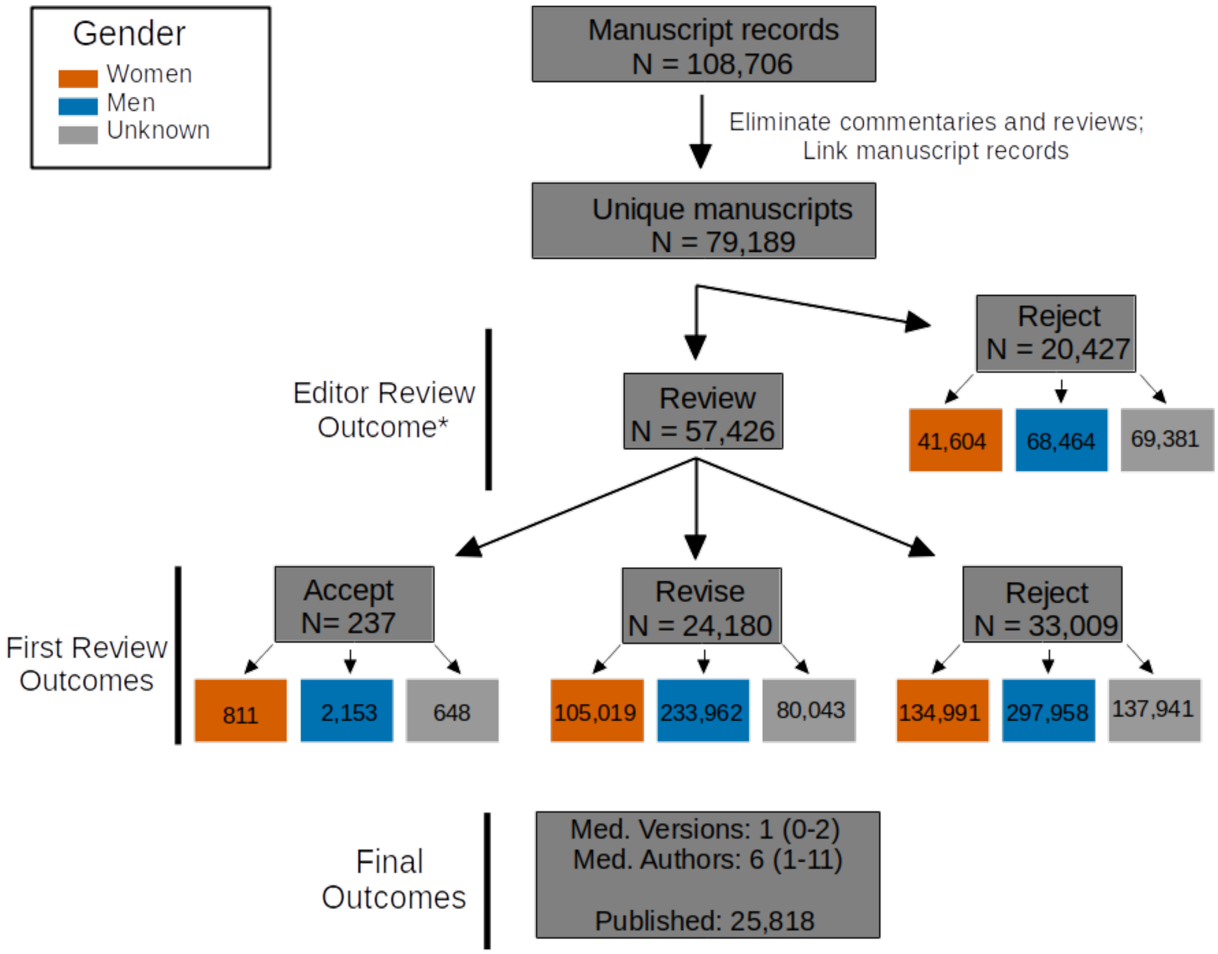


Figure 1. Overview of manuscript outcomes. 108,706 manuscript records were obtained for the period between January 2012 and August 2018. After eliminating non-primary research manuscripts and linking records for resubmitted manuscripts, we processed 79,189 unique manuscripts. The median number of versions 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 the 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.

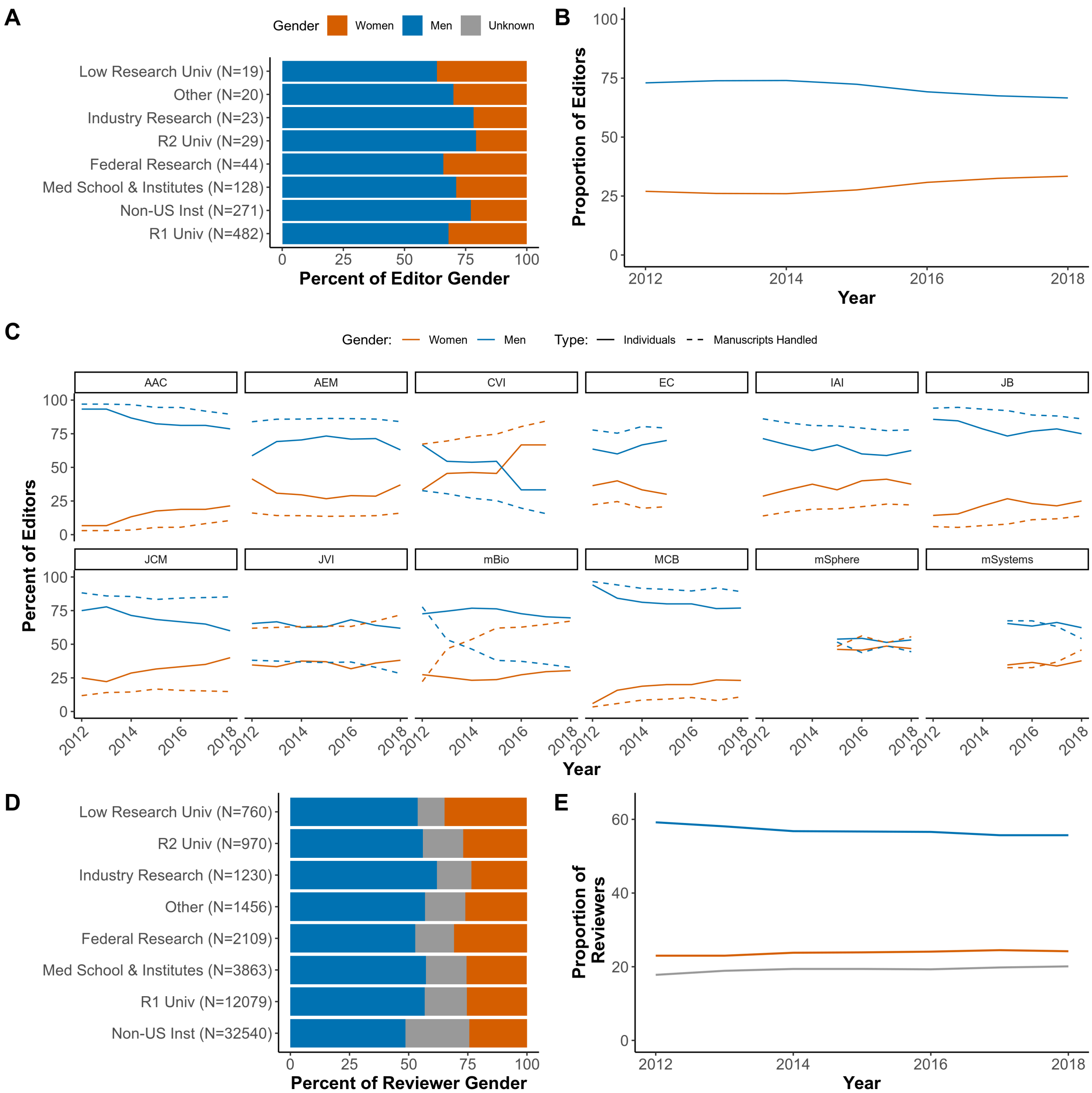


Figure 2. Gendered representation among gatekeepers. Proportion of editors from (A) institution types and (B) over time. Editors and senior editors are pooled together. (C) The proportion of editors (solid line) and their workloads (dashed line) at each of the ASM journals from 2012 to 2018. Proportion of reviewers from (D) institution types and (E) over time. (A,D) Each gender equals 100% when all institutions are summed.(B,E) Each individual was counted once per calendar year, proportions of each gender add to 100% per year.

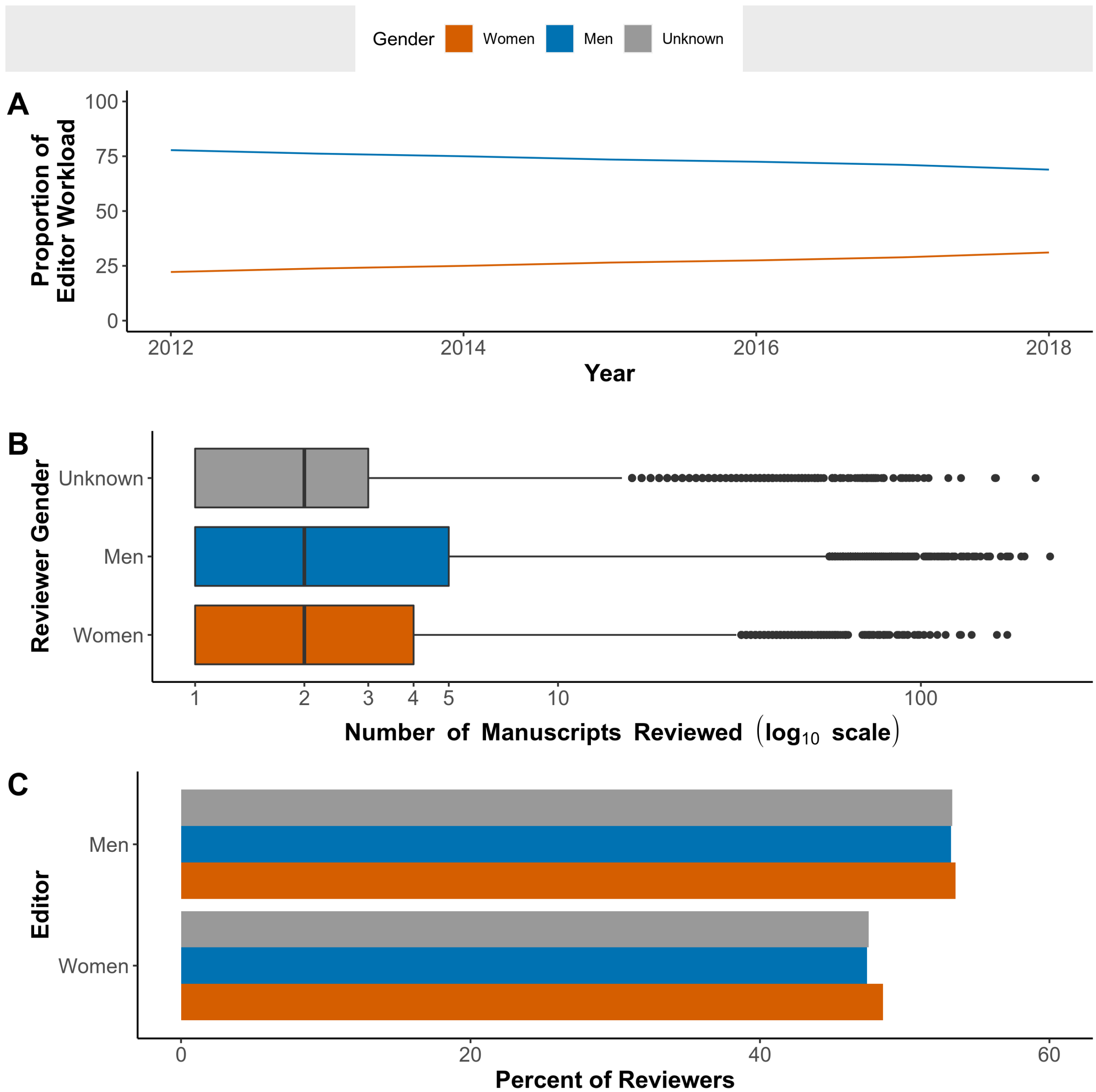


Figure 3. Gatekeeper workload and response to requests to review. (A) Proportion of manuscript workload handled by men and women editors, editorial rejections excluded. (B) Box plot comparison of all manuscripts by reviewer gender on a $\log_{10}$ scale. (C) The percent of reviewers by gender that accepted the opportunity to review, split according to the editor's gender.

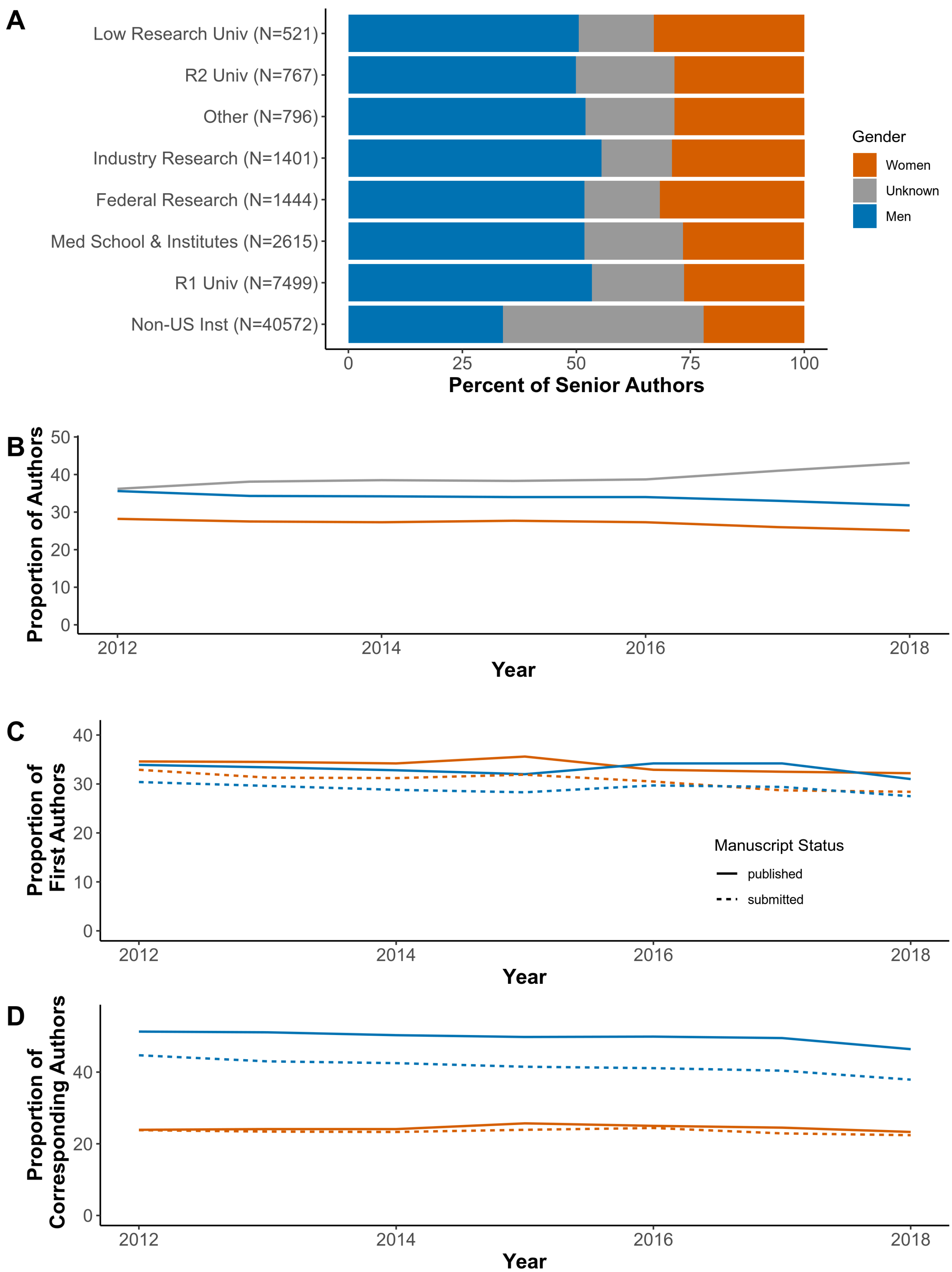


Figure 4. Author representation by gender. The proportion of (A) men, women, and unknown

gender senior authors from each institution type, (B) men, women, and unknown (senior and co-) 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).

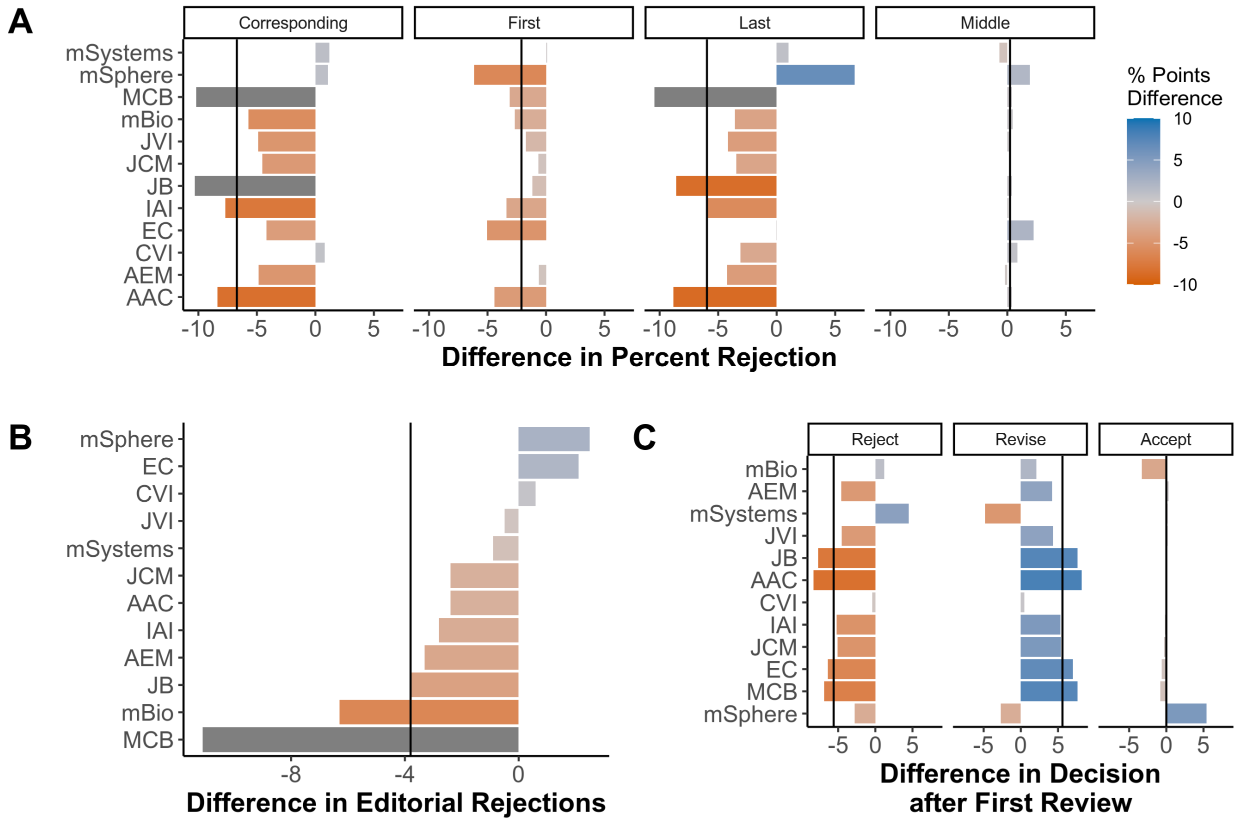


Figure 5. Difference in manuscript outcomes by author gender. The difference in the percent of manuscript outcomes was calculated by subtracting the percent of women who received the outcome, from the percent of men. A negative value (orange) indicates women received the outcome more often, 0 (or no bar) indicates equal rates of the outcome, and positive (blue) indicates that men received the outcome more frequently. Vertical lines indicate the difference value for all journals combined. (A) The difference in percent rejections by author gender and type (e.g., corresponding, first, last, middle) at any stage across all journals. (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.

Figure 6. Difference in decisions or recommendations according to the gatekeeper gender. The difference in the percent of manuscript outcomes was calculated by subtracting the percent of women who received the outcome, from the percent of men. A negative value (orange) indicates women received the outcome more often, 0 (or no bar) indicates equal rates of the outcome, and positive (blue) indicates that men received the outcome more frequently. (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.

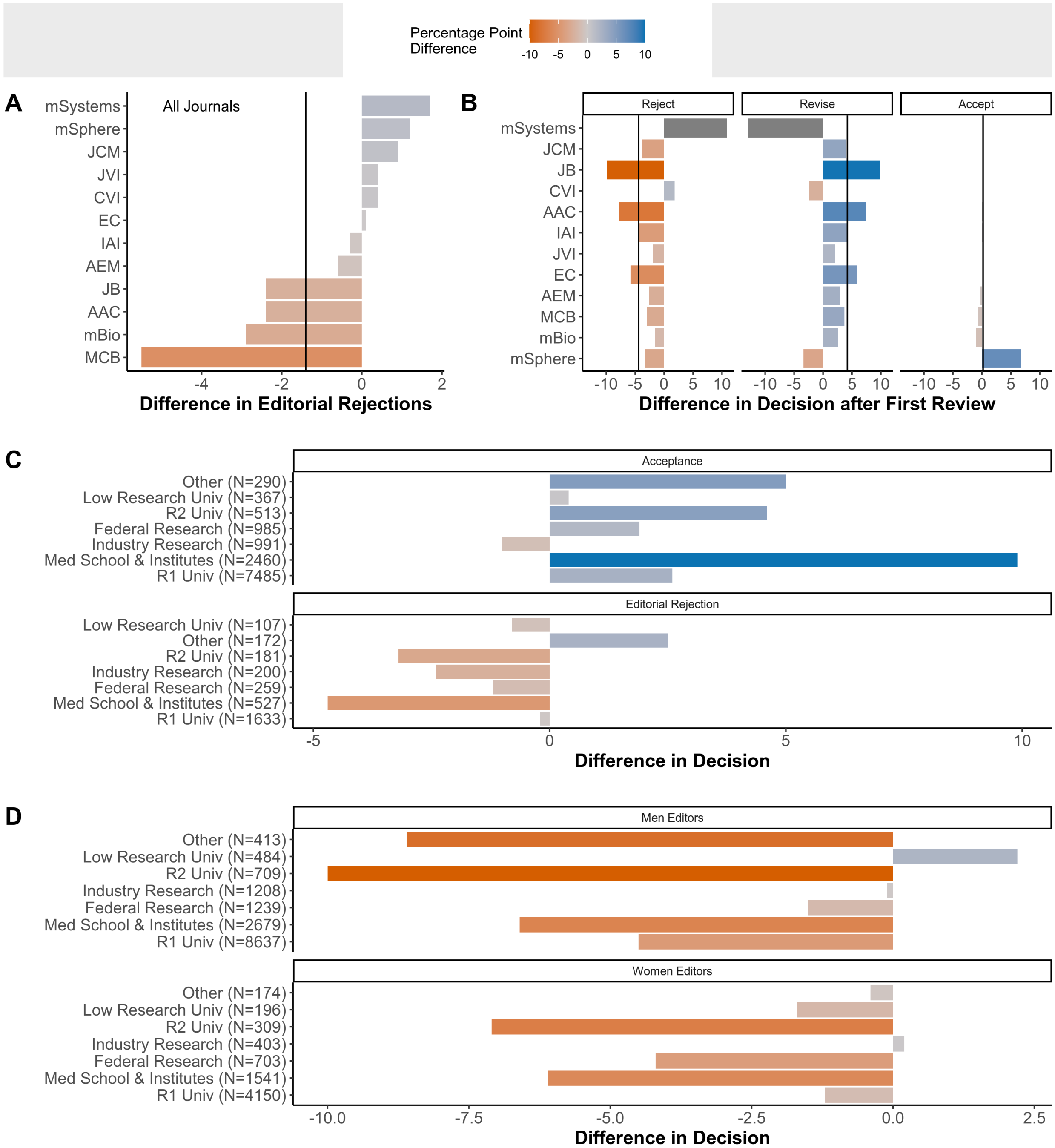


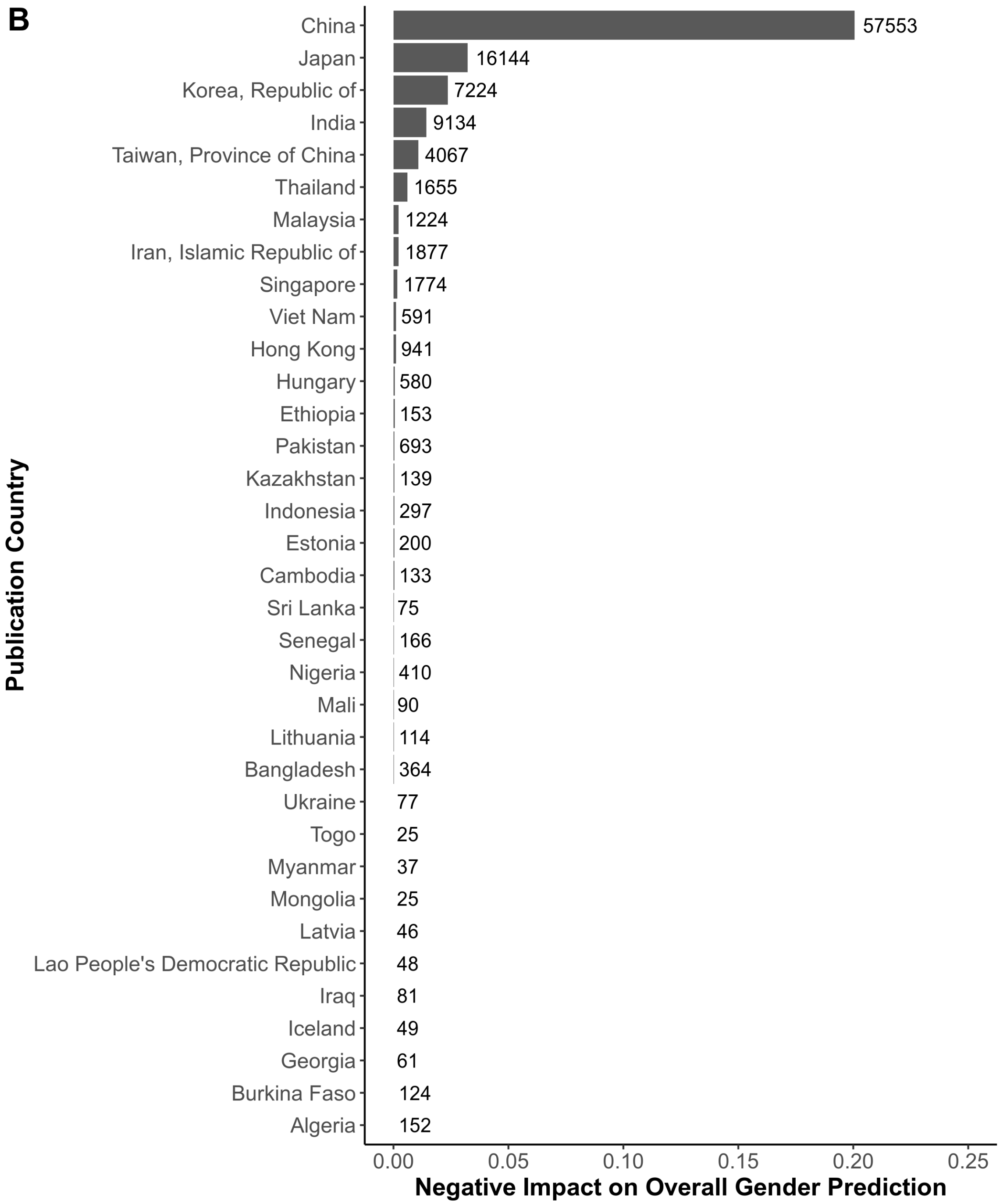
Figure 7. Impact of origin and U.S. institution type on manuscript decisions by gender. The difference in the percent of manuscript outcomes was calculated by subtracting the percent of women who received the outcome, from the percent of men. A negative value (orange) indicates women received the outcome more often, 0 (or no bar) indicates equal rates of the outcome, and positive (blue) indicates that men received the outcome more frequently. Vertical lines indicate the difference value for all of the ASM journals combined. 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 of the 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.

A

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

B



889 Figure

S1. (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.

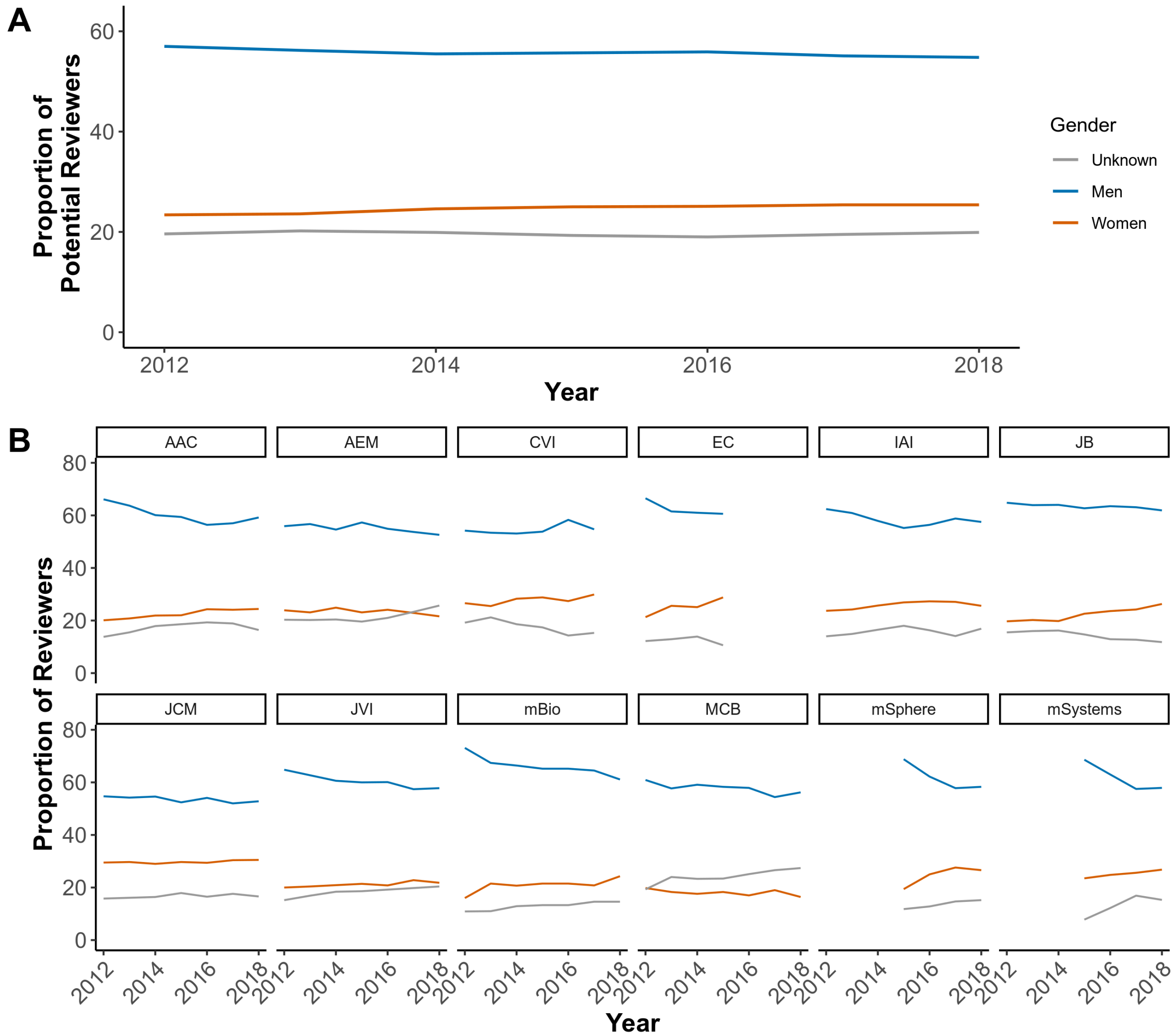


Figure S2. The proportion of (A) potential reviewers at all of the ASM journals combined, (B) reviewers at each ASM journal.

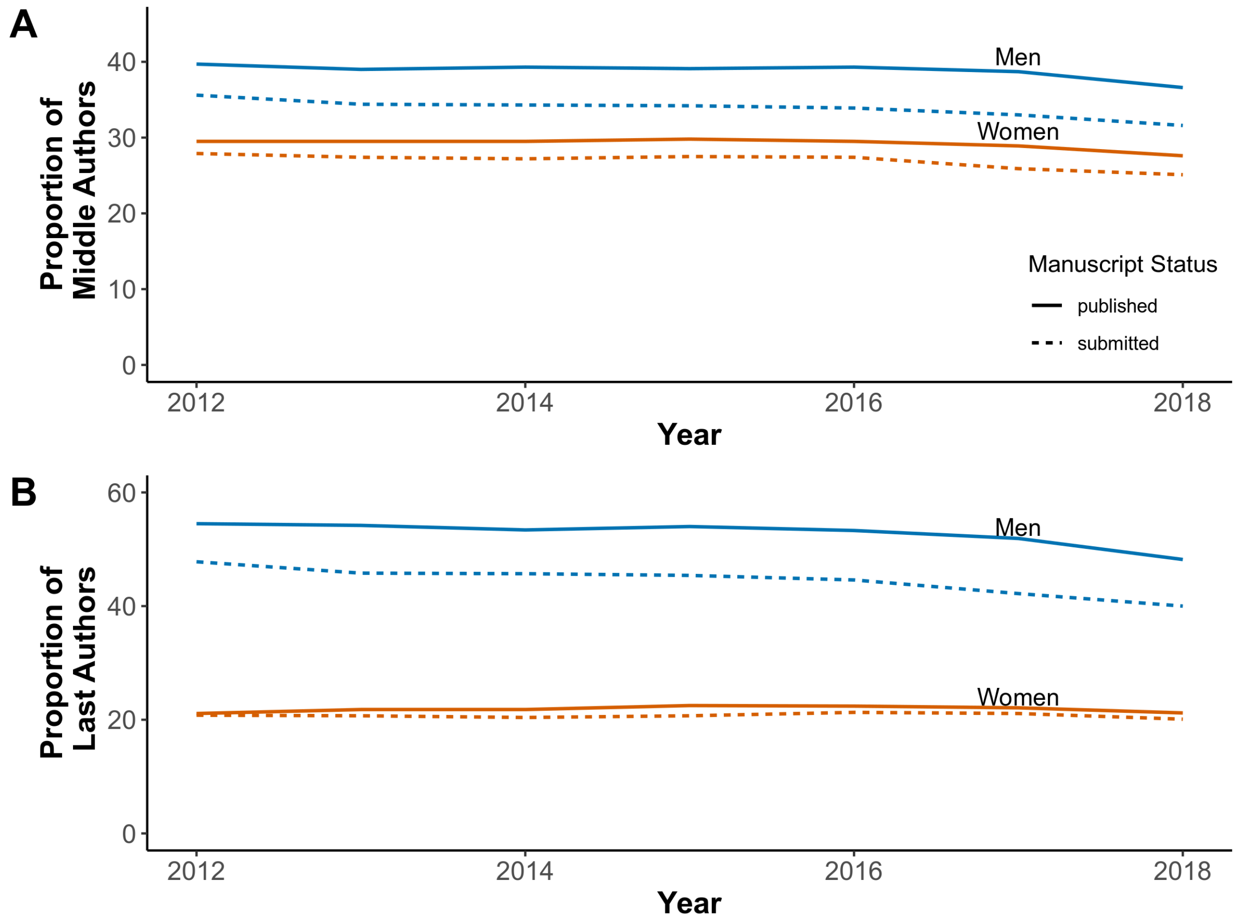


Figure S3. The proportion of all submitted (dashed line) and published (solid line) (A) middle and (B) last authors by gender at each ASM journal.

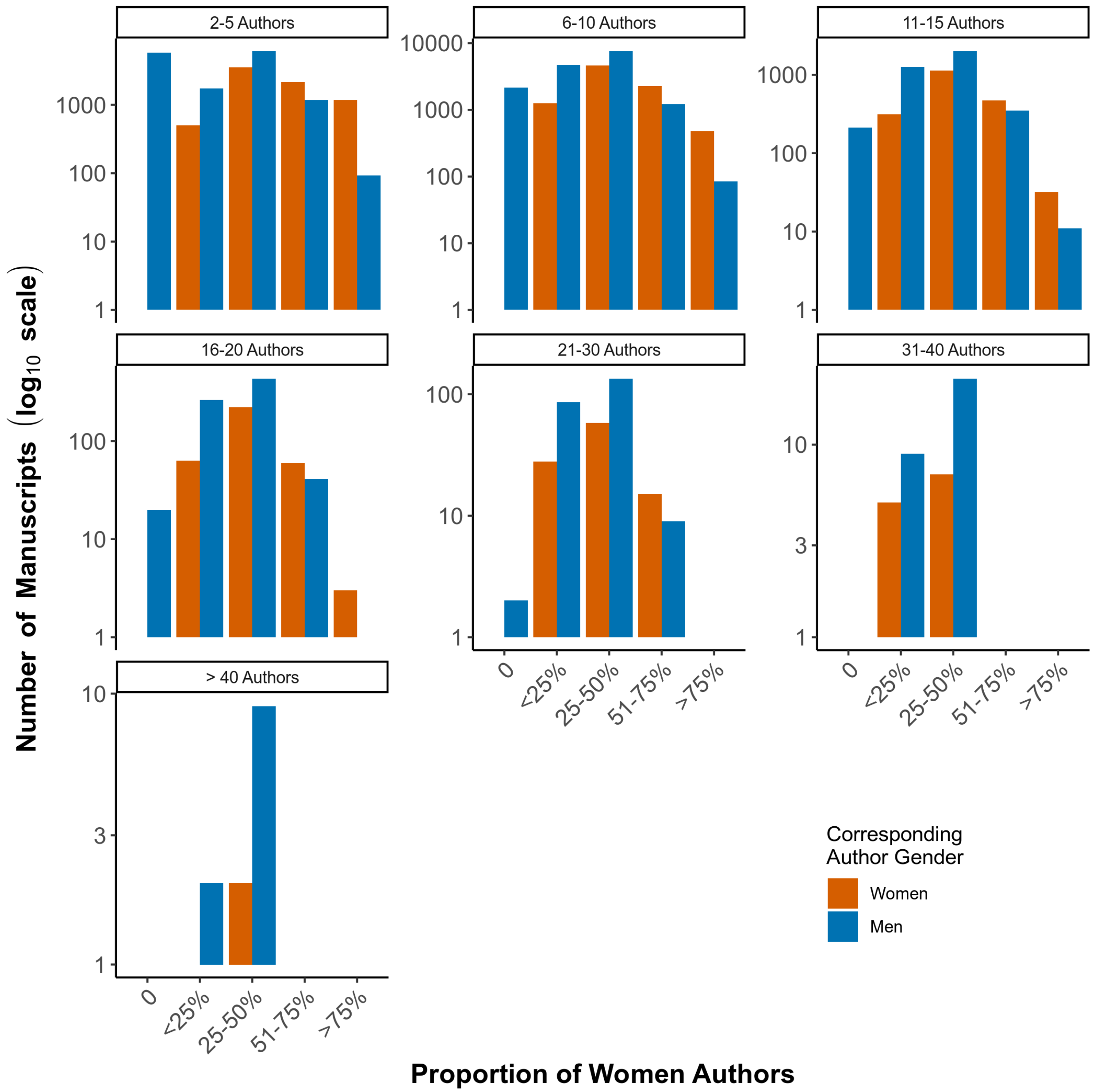


Figure S4. The proportion of women authors (x-axis) on submitted manuscripts (y axis, $\log_{10}$ scale) according to the number of co-authors (individual plot) and the gender of the corresponding author (orange/blue). Single author papers were eliminated and the manuscripts grouped according to the number of co-authors: groups of 5 authors up to 20, groups of 10 authors up to 40, and a single group of manuscripts with 40+ authors. The manuscripts were then split according to the proportion of co-authors that were inferred to be women: 0, up to 24%, 25-50%, 51-75%, and more than 75%. The manuscripts were then further split according to the inferred gender of the corresponding author. Regardless of the number of co-authors, women corresponding authors (orange) submitted more manuscripts with a majority (>50%) of women co-authors than men corresponding authors. Men corresponding authors submitted more manuscripts with less than 50% women co-authors than women corresponding authors did, and the trend of this gap increased with the number of co-authors.

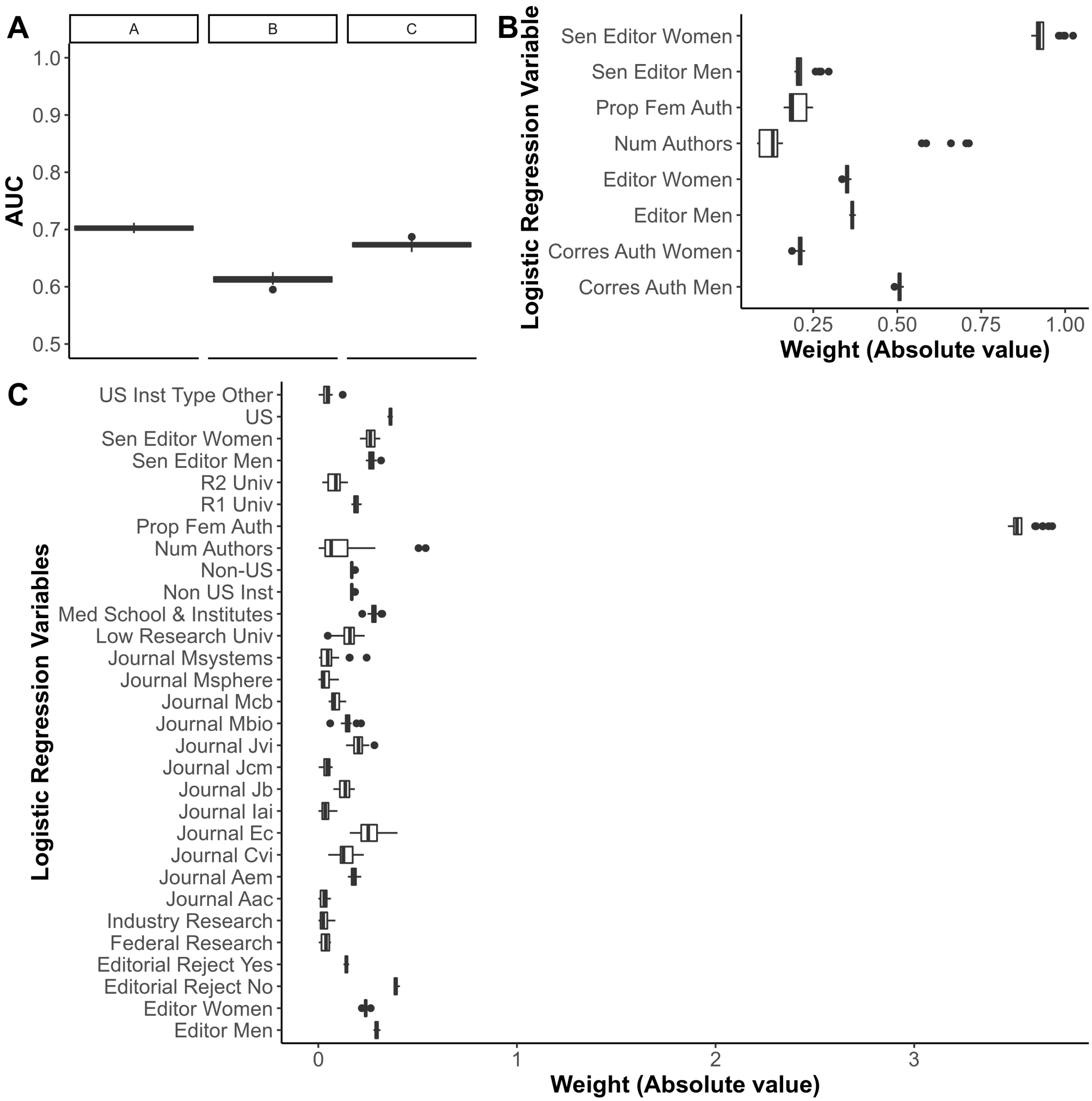


Figure S5. Boxplots of linear regression results from 25 data-splits. A) AUC values, each panel represents a different prediction model: A - Corresponding author's gender; B - Author gender on editorial decisions; C - Institution on editorial decisions. B,C) Effect of variables on the logistic regression model represented as the absolute values of the variable weight. B) Author gender from editorial decisions. C) Corresponding author's gender.

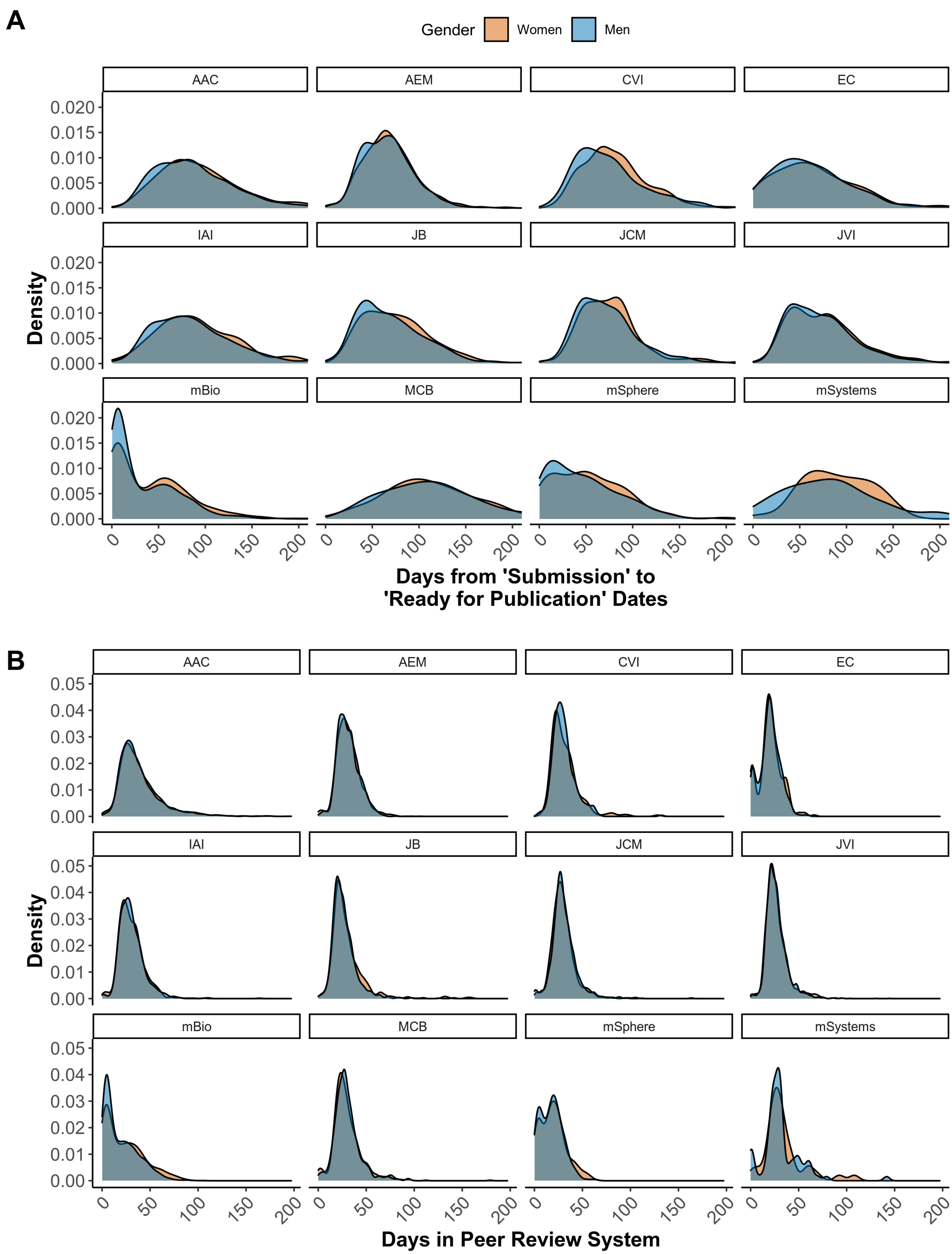


Figure S6. Comparison of time to final decision and impact by gender. The number of days (A) between when a manuscript is initially submitted and finally published or (B) that a manuscript spends in the ASM peer review system.

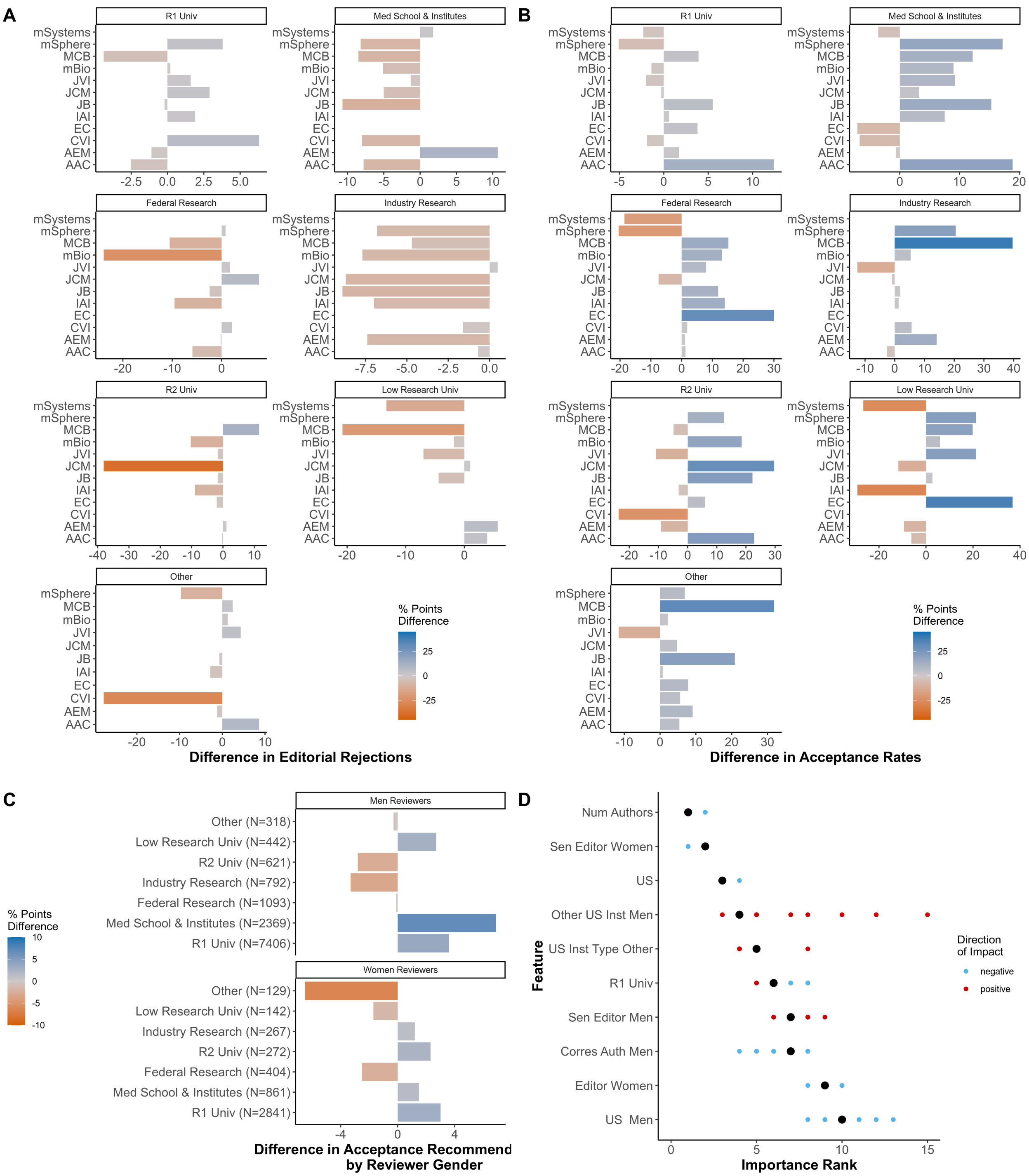


Figure S7. Difference in A) editorial rejection and B) acceptance rates by journal and institution type. C) Difference in review recommendations by reviewer gender and author institution type. D) Median importance (black dot) of features affecting editorial rejections, and their range. Color of smaller dots (N=25) indicate the direction of the impact.

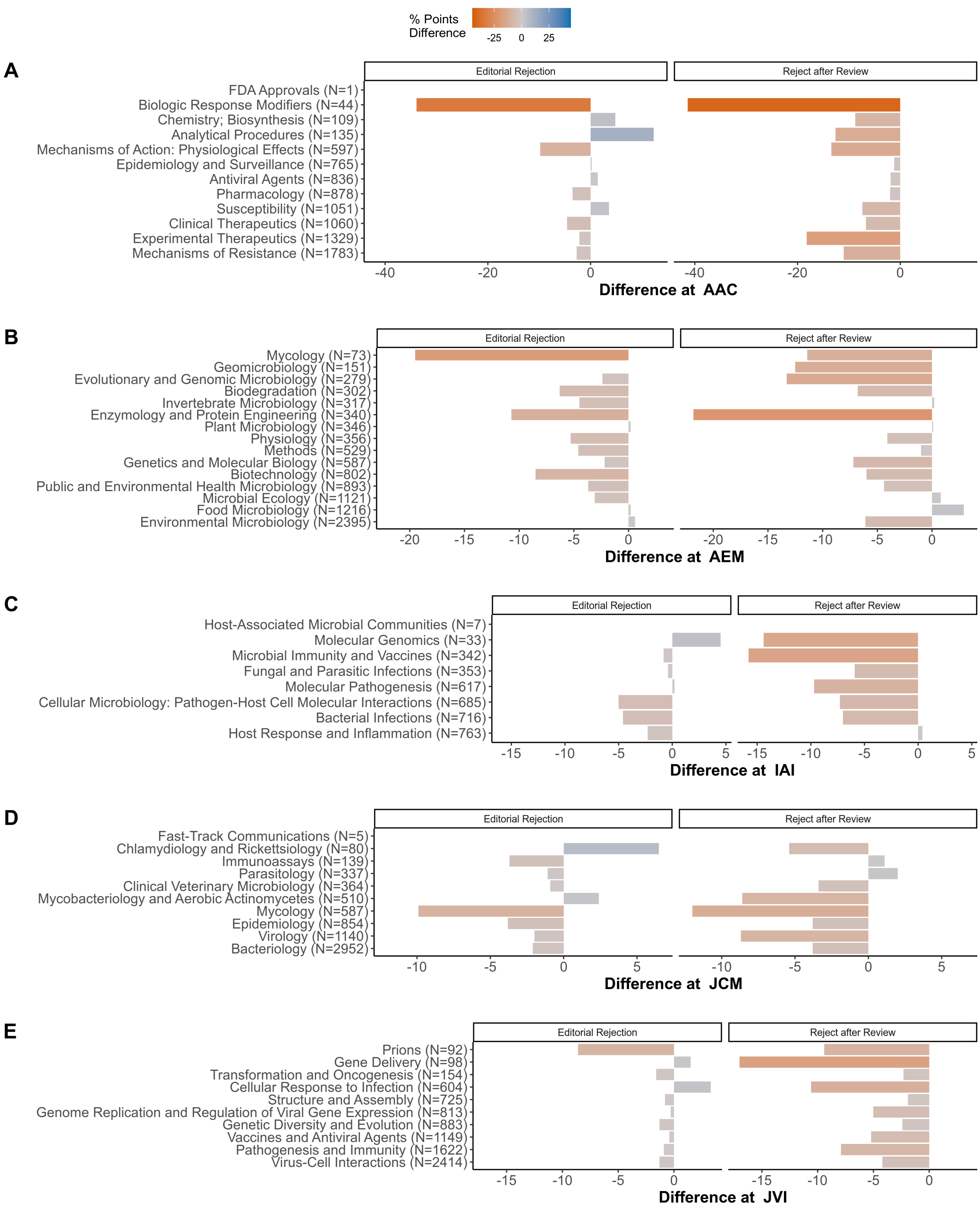


Figure S8. Difference in editorial rejections and rejections after review by corresponding author gender and manuscript category at (A) AAC, (B) AEM, (C) IAI, (D) JCM, and (E) JVI. In parentheses:

N = the number of manuscripts submitted.