Distinct patterns of bioscience doctoral publication disparities by gender and race/ethnicity

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Abstract

The ability to address the lack of diversity in the Science, Technology, Engineering and Math workforce depends on inclusive and equitable training of doctoral students to succeed in the profession. An important metric used to assess equitable training in bioscience doctoral programs is the number of publications that result from a student's research. The purpose of this study was to investigate whether there are demographic differences in publication rates among all students in a cohort of bioscience Ph.D. programs at the University of California Los Angeles who graduated between 2011 and 2019. Using institutional data and publication database queries, we determined the number of doctoral publications parsed by authorship position, and the timing of the first publication for each student. The resulting dataset was then analyzed for the relationships between publication categories and student gender, race/ethnicity, and citizenship status. We find that female students published significantly fewer total and co-author papers compared to male students, but had the same number of first-author publications. In contrast, students from underrepresented racial/ethnic groups had fewer first-author papers compared to students from well-represented groups, but similar numbers of total and co-author publications. Publication of the first doctoral paper occurred later for female versus male, and underrepresented versus well-represented students. These results provide evidence for distinct patterns of doctoral publication disparities by gender and race/ethnicity, offering insights into a key metric of bioscience student success and informing potential strategies to achieve equitable outcomes in bioscience doctoral education.

Introduction

Scientific career success is defined by a variety of metrics, including productivity, the type of independent researcher position obtained, academic impact, length of career, and the ability to attract collaboration [1]. These markers of success develop over the course of years, so they can be less accessible in early career stages. At the doctoral level, productivity, as gauged by publication count and authorship position, is used as an impactful metric during the Ph.D. and for future success. However, a number of studies have uncovered disparities in publication rates linked to gender and racial-ethnic differences at the doctoral level and onwards, with some variation by field [2–15]. As such, ensuring equal access to academic research careers demands more equitable early career publication rates.

In response to these studies and a commitment to addressing hidden academic disparities, Graduate Programs in Bioscience (GPB) at the University of California Los Angeles (UCLA) initiated an examination of publication rate outcomes of graduating students. GPB is a consortium of seven Ph.D. programs with over 500 students in the David Geffen School of Medicine and the College Division of Life Sciences. One mission of GPB is to provide professional development for students and faculty across the consortium, which complements the in-depth research training provided by member programs. As part of this mission, in 2015 GPB began launching various initiatives focused on recruiting and retaining individuals from underrepresented groups (URG) in the biosciences. These initiatives included efforts to enhance culturally inclusive, evidence-based mentorship practices for both faculty and trainees, along with programming aimed at fostering trainee research independence, self-efficacy,

leadership skills, and career development. To help guide these efforts, we sought to establish a dataset on publications and time to degree across the GPB programs.

This cohort study investigates potential gender, racial/ethnic, and citizenship differences in doctoral publication numbers and timing of first publication among all GPB graduates from 2011 to 2019. The time period encompasses students who graduated prior to and during the initial implementation phase of GPB initiatives, ending in 2019 to avoid confounding effects of the SARS CoV-2 pandemic. We utilized institutional data and publication database queries with the aim of avoiding potential survey pitfalls such as biased response rates and self-reporting. Here we report doctoral publication number and timing disparities by gender and race/ethnicity, with unexpectedly distinct patterns that differ by authorship position between the two demographic categories.

Methods

Study Population

This study was authorized by the UCLA Institutional Review Board, protocol #20-002132. All students who graduated from GPB member programs with a PhD between the years 2011 and 2019 were included in the study. The seven GPB member Ph.D. programs are: Bioinformatics; Human Genetics; Molecular Biology; Molecular, Cellular, & Integrative Physiology; Molecular & Medical Pharmacology; Neuroscience; and Physics & Biology in Medicine. The data span a change in the umbrella program organization in which admissions into four previous programs (Biological Chemistry; Molecular Cell and Developmental Biology; Microbiology, Immunology, and Molecular Genetics; and Cell and Molecular Pathology) were subsumed by the Molecular Biology

PhD program. Admissions into all these programs have been grouped under Molecular Biology.

The UCLA Division of Graduate Education (DGE) provided Ph.D. program application data that covered the period from 2002 to 2016 and included demographic and academic information. Gender and ethnicity were self-reported. Because students in the dataset applied to Ph.D. programs during a time when the UCLA application only asked for applicant sex, not yet accommodating non-binary gender affiliations, only self-reported binary designations are available. For this study, we use the term “gender” when referring to these self-reported binary designations for male and female. Based on 2022 application data, in which 2% of applicants identified as non-binary, some students are likely misclassified. For ethnicity, Black, Latine, Native American, Alaskan Native, and Pacific Islander students are categorized as Underrepresented Groups (URG) while White and Asian students are categorized as Overrepresented Groups (ORG). Students who declined to state their ethnicity or who stated their ethnicity as “other” were omitted from the ethnicity aspects of this study. Admission data included citizenship information that was used to define students as international or domestic (U.S. citizen or permanent resident). Academic information included Ph.D. program of study, whether the student was concurrently pursuing an M.D., the doctoral committee chair name, co-chair name if applicable, and matriculation and graduation years. Because of our focus on the early career, we excluded students who had previously obtained an M.D., but retained students who were receiving a concurrent M.D. through the Medical Scientist Training Program program.

Doctoral Publication Counts

Using the list of student names from the applications submitted to UCLA DGE by all students meeting the study criteria described above, we generated queries to identify publications by the students during the time period of interest. If students had changed their names during the course of their graduate education, this was documented in the record of each name registered by the DGE. Papers published by students were identified by querying PubMed using the R package RISmed [16]. Queries were constructed using student names and the names of the chair of their doctoral committees, including co-chairs if available. For Ph.D. students in the programs we studied, the doctoral committee chair is almost always the student's faculty research advisor and they generally are included as an author in published doctoral work. To determine the timeframe of doctoral studies, we used matriculation and graduation dates. UCLA operates on a quarter system, with most students starting their Ph.D. programs in October, which is the fall quarter. Due to limitations in PubMed indexing, we were only able to access the calendar year of the publications. Thus, we limited our search to start the calendar year after matriculation and end one calendar year past their graduation year. Any publications during the time frame between matriculation, generally in October, and December of the matriculation year were presumed to be from work done prior to entering the program. We chose one-year post-graduation to capture papers that were submitted or close to completion at graduation. Because there is sometimes a discrepancy between the doctoral committee chair (mentor) of record and the faculty members that a student publishes with, the query was constructed to require either the mentor as an author on the paper or an UCLA affiliation. For example,

"BRUIN J[Author] AND (MENTOR D[Author] OR UCLA[Affiliation] OR University of California Los Angeles[Affiliation]) AND 2009[EDAT]: 2017[EDAT]".

The initial queries identified nearly 10,000 papers, but this number was inflated by false positives arising from students with common names and from papers with large numbers of authors which included those who shared names with the student and their mentor or other UCLA faculty members. Although we searched PubMed using last name and first initial, we curated the article list by requiring a full match for first and last name. If the journal only reported author initials, we required a last name and first initial match, as well as a per-author UCLA affiliation. We eliminated papers that only reported author initials and did not include per-author information on affiliations. We also excluded papers where the student author was listed at a position greater than the 50th author, as in the process of manual checking, we found that these were almost always not the student in question and likely not an important contribution even if a true association. We excluded articles that began with "Correction:" or included the words "withdrawn", "erratum", or "corrigendum". Every student with no articles identified by the query was manually checked to verify the lack of publications. We also manually checked every student with more than 20 articles to verify that there were no false attributions.

One issue with identifying publications by name queries is that accurate publication attribution can be more challenging for women and people of color [17–19]. For students who had changed their names during the course of their doctoral program, we conducted queries using all names provided. Names composed of multiple words can be separated by either spaces or hyphens, but the separating character is not

always the same between journals. To address possible complications from hyphenated or multiple-word names, we searched all permutations of multiple-word names to ensure no papers were lost in the query. Some students publish with shortened versions of their first name such that their initials match (e.g. Rob instead of Robert), but the requirement for a full name match missed the variation of the name used in the publication. When students had papers identified by initials but fewer papers identified by a full name match, we verified the name the student used on publications. After all filtering and checking, the search yielded 2924 papers.

Paper counts were calculated by summing the number of all papers identified per student. First-author publications were counted if the student was first in the list of authors. We did not check for co-first author designations when the student is listed second or third with a note that they made an equal contribution to the paper as the first author, because sensitivity analysis showed this was not common in our dataset. Co-author publications were defined as the student having a second or greater position in the author list and were calculated by subtracting the number of first-author publications from the total number of publications.

Modeling

We modeled three different kinds of outcomes by total publications and by authorship position: the count of papers published by each student, whether or not a student published, or the time to publication or graduation without publication. For count data, we considered the counts to follow a negative binomial distribution. We used both a classic fixed-effects negative binomial regression [20] and a mixed-effects negative

binomial regression [21]. Because there are differences in publication rates by scientific field of study, we used the doctoral program of the student as a proxy for their scientific field and fit the program as a random intercept in the model. For the binary outcome of whether a student published or not, we fit a logistic regression [20]. Finally, for the time-to-event data, we used the Kaplan-Meier estimator [22] to model the differences in time to publication and considered students censored if they graduated without publishing. We excluded four students who graduated after 8 years as outliers in this analysis. Figures were made using the R packages ggplot2 and survminer [23,24]. For all statistical tests, p-values are reported and results were considered significant if $p < 0.05$, but results with $p < 0.1$ are discussed as notable.

Results

The seven UCLA bioscience Ph.D. programs listed in Table 1 were selected for analysis based on their membership in a centrally-supported umbrella consortium. These programs provide training across a wide spectrum of bioscience fields. To establish baseline data for the assessment of programmatic initiatives introduced by the consortium, publication rates were determined for 614 students in the member programs who obtained their Ph.D. between 2011 and 2019 (matriculated 2002-2016). Of the students included in the analysis, 10% received their Ph.D. as part of the doctoral training phase of the M.D./Ph.D. program. Table 1 presents the population characteristics by gender, race/ethnicity, citizenship, Ph.D. program, and degree track. The median time to degree for the whole population in the dataset was 5.5 years. There were no differences in time to degree by gender or citizenship status. However, a

195 significant difference was observed by race/ethnicity, with URG students taking longer

196 to graduate (Table 2).

197 **Table 1. Demographics of study population.**

Characteristic		N=614
Gender	Female	302 (49%)
	Male	312 (51%)
Race/Ethnicity	Underrepresented group	66 (10.7%)
	Overrepresented group	489 (79.7%)
	Unknown or other*	59 (9.6%)
Citizenship	International	128 (21%)
	Domestic	486 (79%)
Program	Bioinformatics	25 (4.1%)
	Human Genetics	24 (3.9%)
	Molecular Biology	252 (41%)
	Molecular, Cellular, & Integrative Physiology	72 (12%)
	Molecular & Medical Pharmacology	84 (14%)

	Neuroscience	106 (17%)
	Physics & Biology in Medicine	51 (8.3%)
Degree	MD/PhD	62 (10%)
	PhD	552 (90%)

198 *9 people declined to state their race and ethnicity but did indicate their gender

199 **Table 2. Disparity in time to degree by race/ethnicity, but not gender or**

200 **citizenship status.**

		Median (years)	**IQR**	**P-value**
Gender	Female	5.50	(4.75, 6.25)	0.3
	Male	5.75	(4.75, 6.25)	
Race/Ethnicity Group	URG	5.75	(5.25, 6.75)	0.005
	ORG	5.50	(4.75, 6.25)	
Citizenship Status	International	5.38	(4.75, 6.25)	0.7
	Domestic	5.75	(4.75, 6.25)	
Total		5.50	(4.75, 6.25)	

201 IQR: interquartile range; URG: underrepresented group; ORG: overrepresented group;

202 Domestic: U.S. citizen or permanent resident. P-value determined by the Wilcoxon rank sum

203 test.

204 To determine the number of doctoral publications for each student we queried

205 the NIH PubMed database for publications between the beginning of the student's

206 second year in the program and one year after graduation. The query results were then

207 curated to eliminate false attributions, resulting in 2924 papers from 614 students (see
208 Methods). The resulting dataset was analyzed with a focus on comparing the number of
209 publications according to gender, race/ethnicity, and citizenship status. Given the
210 importance of publications as indicators of scholarly productivity in bioscience fields, we
211 first examined whether there were demographic disparities in the percentage of
212 students who failed to publish (Table 3). No significant differences were observed
213 between female and male students (Chi-square test p=0.2), between students in
214 racial/ethnic groups traditionally underrepresented in bioscience (URG: Black, Latine,
215 Native American, Alaskan Native, Native Pacific Islander) and those in groups
216 traditionally overrepresented in bioscience (ORG: White, Asian) (Chi-square test p>0.5),
217 or between international and domestic students (Chi-square test p>0.5).

218 **Table 3. Students with no publications are evenly distributed within gender,**
219 **race/ethnicity, and citizenship status groups.**

		Total number of students	**Number with no publications (%)**	**P-value**
Gender	Female	302	13 (4.3%)	0.2
	Male	312	< 10	
Race/Ethnicity Group	URG	66	< 10	>0.5
	ORG	489	16 (3.3%)	
Citizenship Status	International	128	< 10	>0.5
	Domestic	486	17 (3.5%)	

URG: underrepresented group; ORG: overrepresented group; Domestic: U.S. citizen or permanent resident. P-value determined by Pearson's Chi-squared test.

We applied the non-parametric unadjusted Wilcoxon Rank Sum Test to compare total publications by student gender or race/ethnicity. Consistent with other reports, female students published significantly less than male students ($p<0.001$, Table 4A Total paper count, Fig. 1A, Fig. S1A) [9–14]. To probe this disparity in more detail, we compared publication numbers based on the student's position in the order of authors in each publication. Traditionally in the fields represented in this study, the first author position denotes a more significant contribution than other positions, except for the last position, which is often reserved for the principal investigator who directed the project [25]. Based on this convention, we determined the number of first-author papers for each student and the number of papers where the student was not first-author (co-author papers). Strikingly, there was not a significant difference in the number of first-author publications by female and male students ($p=0.13$, Table 4A, Fig. 1A, Fig. S1A), but there were significantly fewer co-author publications by female students ($p<0.001$; Table 4A, Fig. 1A, Fig. S1A). These results suggest that a gender-based difference in co-authorships is a major contributor to the disparity in total publications between female and male students. In contrast to the gender-based results, no significant differences were observed between ORG and URG in total, first-author, or co-author publications (Table 4B, Fig. 1B, Fig. S1B). By citizenship status, there were no significant differences in total and co-author publications, but a reduced number of first-author papers by international students was noted ($p=0.063$, Table S1).

243 **Table 4. Disparity in unadjusted co-author and total paper counts by gender, but**

244 **not race/ethnicity.**

A

		F N=302	M N=312	P-value
First-author papers	Mean (SD)	1.53 (1.46)	1.67 (1.47)	0.13
	Median (IQR)	1 (1, 2)	1 (1, 2)	
	Total number	462	522	
Co-author papers	Mean (SD)	2.6 (2.8)	3.7 (3.6)	< 0.001
	Median (IQR)	2 (1, 4)	3 (1, 5)	
	Total number	797	1143	
Total paper count (first + co-author papers)	Mean (SD)	4.2 (3.5)	5.3 (4.4)	< 0.001
	Median (IQR)	3 (2, 6)	4 (2, 7)	
	Total number	1259	1665	

B

		URG N=66	ORG N=489	P-value
First-author papers	Mean (SD)	1.30 (1.08)	1.64 (1.52)	0.4
	Median (IQR)	1 (0, 2)	1 (1, 2)	
	Total number	86	801	
Co-author papers	Mean (SD)	3.0 (2.9)	3.2 (3.3)	0.3
	Median (IQR)	2 (1, 4)	2 (1, 5)	
	Total number	198	1570	
Total paper count	Mean (SD)	4.3 (3.5)	4.8 (4.0)	0.3
	Median (IQR)	3.5 (2, 6)	4 (2, 6)	
	Total number	284	2371	

(first + co-author papers)				

SD: standard deviation; IQR: interquartile range. P-value determined by the Wilcoxon rank sum test.

Figure 1. Disparities in unadjusted publications by gender but not race/ethnicity. Distribution of the unadjusted number of doctoral publications by: (A) gender and author position (F: female; M: male); and (B) race/ethnicity and author position (ORG: overrepresented group; URG: underrepresented group). The value for 'all papers' is calculated as the sum of the values for first-author papers and co-author papers. The heavy line indicates the median and the boxes indicate the interquartile range. Wilcoxon rank sum test is used to calculate significance. NS: Not significant, $P \geq 0.05$; ***: $P < 0.001$

To account for the fact that paper counts cannot be below zero or include fractional values, the data were fit to a negative binomial regression model to predict the number of publications by gender, URG, and international status. Furthermore, to factor in possible differences in publication rates between fields of study, we used mixed effects negative binomial regression models that allow for a random effect of Ph.D. program, while fitting gender, URG, and international status as fixed effects. We fit three models predicting numbers of first-author, co-author, and total publications (Table 5). The results of this approach also provide evidence for gender-based disparities in total and co-author publications: the total publication incidence rate ratio (IRR) for female

264 versus male students was 0.82 (p=0.002), co-author IRR was 0.75 (p<0.001), first
265 author IRR was 0.96 (p=0.6). That is, as an example, the data predict that for every ten
266 papers published by a male student, a female student publishes only 8 papers. In
267 contrast, we observed that URG status was significantly associated with a negative
268 effect on first-author publications (IRR 0.78, p=0.046), but not on co-author (IRR 1.01,
269 p>0.9) or total (IRR 0.93, p=0.4) publications. These findings reveal a race/ethnicity-
270 based disparity in first-author publications. There were no observed differences
271 between international and domestic students for any of the publication categories.
272 Similar results for each demographic category were obtained using fixed effects
273 negative binomial regression models without accounting for possible publication
274 differences by field (Table S2).

275 **Table 5. Negative binomial mixed-effects regression: gender- and ethnicity/race-**
276 **based disparities in number of publications**

	First Author Papers			**Co-Author Papers**			**Total Papers**		
Characteristic	**IRR**	**95% CI**	**P**	**IRR**	**95% CI**	**P**	**IRR**	**95% CI**	**P**
Female	0.96	0.83, 1.11	0.6	0.75	0.64, 0.88	<0.001	0.82	0.72, 0.93	0.002
URG	0.78	0.61, 1.0	0.046	1.01	0.79, 1.30	>0.9	0.93	0.76, 1.13	0.4
International	0.91	0.75, 1.10	0.3	1.09	0.90, 1.33	0.4	1.02	0.87, 1.2	0.8

277 Coefficients from negative binomial mixed effects regression, incorporating fixed effects of
278 gender (male as reference), race/ethnicity (ORG: overrepresented group as reference), and
279 international status (domestic as reference) and a random effect of doctoral program. URG:
280 underrepresented group. IRR = Incidence Rate Ratio, CI = Confidence Interval, P = p-value
281

The negative binomial regression analyses uncovered distinct patterns of publication number disparities between gender and race/ethnicity categories. In light of these findings, we explored if there were differences in whether students publish at all by logistic regression, accounting for the effects of gender, race/ethnicity, and citizenship status on whether a student had no publications in any of the authorship categories (Table 6). Although the patterns of female/male- or URG/ORG-based differences across authorship categories by logistic regression parallel those in the negative binomial analyses, only the gender disparity in co-author papers was significant, with female students having virtually half the odds of publishing any co-author paper compared to male students. Based on this analysis, URG students had notably lower odds of any first-author publications compared to ORG students. International students were no more or less likely to publish overall compared to domestic students but had decreased odds of any first-author papers (OR = 0.59; p = 0.026) yet increased odds of any co-author papers (OR = 1.83; p = 0.06).

Table 6. Logistic regression: disparities in odds of publishing by gender and international status

	First Author Papers			**Co-Author Papers**			**Total Papers**		
Characteristic	**OR**	**95% CI**	**P**	**OR**	**95% CI**	**P**	**OR**	**95% CI**	**P**
Female	0.91	0.60, 1.37	0.6	0.47	0.29, 0.77	0.003	0.53	0.19, 1.36	0.2
URG	0.59	0.33, 1.07	0.074	1.11	0.56, 2.44	0.8	0.80	0.25, 3.54	0.7
International	0.59	0.37, 0.95	0.026	1.83	0.99, 3.62	0.066	1.64	0.52, 7.24	0.4

OR = Odds Ratio, CI = Confidence Interval, P = p-value; Male as reference for gender, ORG as reference for race/ethnicity, domestic as reference for international.

The timing of a student's initial doctoral publication in any category of authorship has the potential to impact both the total number of graduate publications and other factors that can contribute to student success during their graduate studies (and onward in their career). For example, publications are commonly used as metrics for graduate fellowships, appointments to federally-funded predoctoral training programs, funding for travel and registration to attend conferences, and other types of awards and distinctions. Accordingly, we used the Kaplan-Meier method to compare the timing of the initial graduate publication by female versus male students [26]. As presented in Fig. 2A, the probability of not having published a paper declined for female students more slowly than male students ($p=0.05$), with a gap becoming evident by the end of year 2 and dissipating by the end of year 6. Thus, there was a notable delay in the time to first graduate school publication for female students compared to male students. When the timing of initial publication was analyzed by authorship position, the data revealed that students generally published their initial first-author paper later than a co-author paper (Figures 2B and 2C). Notably, the timing of the initial first-author paper was not significantly different between female and male students ($p=0.39$; Figure 2B), whereas a significant delay was evident in the timing of the initial co-author publication by female compared to male students ($p=0.0047$; Figure 2C). These findings provide evidence of a gender-based disparity in the timing of a student's initial publication in graduate school, which can be largely attributed to a difference in the timing of the initial co-author publication. A significant delay in the timing of initial publication by URG compared to ORG was also apparent by Kaplan-Meier analysis (Figure 3A). When

analyzed by authorship position, differences in the timing of initial publication were not significant, likely due to the small number of URG students (Figure 3B-C).

Figure 2. Disparity in time to first graduate co-author publication by gender.

Time to first publication by author position represented by Kaplan-Meier curves. The probability that a student remains in the program without a publication is presented as a function of time spent in the program, with the shaded area representing the 95% confidence interval. Students who graduated with no publications of a given authorship type are considered to be censored in the dataset, which is represented by a + symbol. Four students who graduated after 8 years were excluded as outliers. (A) Probability that a student has not published as a function of years spent in their graduate program. (B) Probability that a student has not published a first-author paper as a function of years spent in their graduate program. (C) Probability that a student has not published a co-authored paper as a function of years spent in their graduate program.

Figure 3. Disparity in time to first graduate publication by race/ethnicity.

Time to first publication by author position represented by Kaplan-Meier curves. The probability that a student remains in the program without a publication is presented as a function of the time spent in the program, with the shaded area representing the 95% confidence interval. Students who graduated with no publications of a given authorship type are considered to be censored in the dataset, which is represented by a + symbol. Four students who graduated after 8 years were excluded as outliers. (A) Probability that a student has not published as a function of years spent in their graduate program. (B) Probability that a student has not published a first-author paper as a function of years spent in their graduate program. (C) Probability that a student has not published a co-authored paper as a function of years spent in their graduate program.

Discussion

Publications serve as important indicators of research potential during Science, Technology, Engineering, and Math (STEM) education and are broadly used as measures of success in STEM careers. Consequently, inequities that arise at early stages of training can have long-range impacts. In this study, we assembled a dataset of doctoral publications by students in a consortium of bioscience Ph.D. programs and analyzed the dataset for publication number and timing disparities across different demographic categories. The results provide evidence for distinct patterns of disparities by gender and race/ethnicity, distinguished by authorship position. These findings offer insights that can inform strategies to reduce inequities that arise during doctoral research training and extend into later stages of academic careers [27,28].

Our analyses by gender extend existing documentation that women publish less than men in STEM fields [3–7,15], and demonstrate that this difference is already apparent at the Ph.D. level in a cohort of bioscience students, consistent with other reports that publication disparities arise at this early career stage [9–14]. Notably, our findings also highlight underappreciated aspects of publication gender bias. By including authorship position in our studies, the data reveal that the diminished number of total publications by female students is driven by fewer co-authored publications. Furthermore, we find that female students publish their initial doctoral paper later than male students, and the initial paper for both genders is more likely to be a co-authorship. Together, these results suggest that co-authorship may be a key early determinant of gender-based disparities in STEM careers.

A slower time for women to publish their initial doctoral paper, regardless of authorship position, may have potentially significant negative implications for their graduate education. The absence of a doctoral publication can impact not only tangible outcomes like fellowships and prizes but also less tangible aspects of professional development such as self-efficacy. Self-efficacy, an individual's belief in their capacity to perform specific tasks [29], is associated with higher research productivity, in addition to increased measures of personal satisfaction and resilience [30–32]. As such, self-efficacy is an important psychosocial component of doctoral student professional development. Considering that publications are a significant metric of success, the initial doctoral paper serves as a strong indicator of performance accomplishments, and a key source of self-efficacy [33]. By this reasoning, the gender disparity in the time to initial publication disadvantages female students by delaying a substantial boost in self-efficacy and associated benefits.

In the bioscience fields represented in this study, co-authorship (i.e. author position between first and last authors) can be interpreted as an indicator of collaboration in a project, based on the academic convention of assigning first and last authorship to the project leaders. From the perspective of collaboration, a number of factors may contribute to co-authorship gender disparity. For example, there may be a bias toward women in conferring authorship for collaborative contributions, as reported by Ross et al. [34]. Other possibilities include ineffective mentorship and/or fewer or delayed opportunities for women to participate in collaborations [35].

An intervention to address gender-based disparities in co-authored publications and time to initial paper would be to increase awareness among mentors and mentees.

392 Such conversations could be introduced into mentorship training and development
393 activities for faculty and trainees, as well as in other forums aimed at promoting trainee
394 success. Raising awareness could be coupled with concerted encouragement of
395 mentors to create early opportunities for collaboration, increasing the chances for co-
396 authorship and thereby shortening the time to initial publication. Collaboration could
397 also present students with experiences that are known to be sources of self-efficacy in
398 addition to mastery of skills, for example: the ability to vicariously learn, receive positive
399 feedback that fosters growth, and experience excitement through contributing to a larger
400 project [33,36,37]. Optimally, access to teamwork and collaborations that lead to co-
401 authorship would be an integral part of doctoral training in the biosciences, with
402 attention to delegating opportunities equitably.

403 Our regression analyses revealed a pattern of disparity by race/ethnicity that is
404 distinct from that of the gender-based disparities. In the case of publication numbers,
405 when compared to ORG students, URG students had fewer first-author papers but
406 similar numbers of co-author and total papers. In the case of time to initial publication,
407 there was a delay for URG students which mirrored that observed between the genders.

408 Even without a significant difference in total publications, the race/ethnicity
409 disparity in the number of first-author publications has the potential to be especially
410 impactful in academic settings, given that the first-author position normally reflects
411 leadership of a project and often is considered a more important indicator of
412 independent scholarship than co-authorship. A possible example from our data
413 consistent with this view is an effect on time to degree. We observed that the first-
414 author publication disparity was associated with a slower time to doctoral degree for

URG students. In contrast, there was no difference in time to degree by gender, where women had the same number of first-author publications as men, although experiencing a disparity in time to initial publication comparable to that of URG students.

It is worth noting that the race/ethnicity results were more nuanced than those from the gender analysis: the race/ethnicity disparity in the number of first-author publications was apparent only in regression models, not in unadjusted analysis, and it was not possible to extend the difference in timing of initial publication to authorship position. We attribute these limitations to effects on the statistical power of our analyses that stem from the small number of underrepresented students in the cohort. This is likely to be less of an issue in follow-up studies because the diversity across the cohort programs has more than doubled in recent years.

We propose the mentoring relationship between student and faculty research adviser as a target to address the race/ethnicity-based publication disparities. Effective mentorship plays a crucial role in the ability of mentees to persist and succeed in research careers, profoundly influencing their research productivity, self-efficacy, and ultimate career fulfillment [38]. However, race/ethnicity is a factor that can impede effective mentorship: racial/ethnic disparities in access to high-quality mentorship have been suggested as barriers to publishing and funding [39,40]. Moreover, issues arising from cultural diversity, such as race and ethnicity, can hinder the continued engagement of URG mentees with their mentors [41]. These findings suggest that efforts to reduce the race/ethnicity-based publication inequities would benefit from an early mentorship intervention that supports cultural awareness and responsiveness. An example would be Culturally Aware Mentorship (CAM), an evidence-based training curriculum designed

438 to facilitate mentors' understanding of their intrapersonal views on race and ethnicity
439 and how those views may then influence interpersonal interactions, ultimately bringing
440 awareness of how their biases and privileges may play out in their mentoring
441 relationships [42–45]. As part of CAM, mentors could be made aware of publication
442 disparities and encouraged to consider the potential impact of their biases on student
443 project and authorship decisions. Supplemental interventions could include providing
444 professional development venues for trainees to obtain secondary mentorship or access
445 to broader networks of support that aim to address disparities in doctoral training and
446 later career stages.

447 The patterns of publication disparities defined in our study derive from an
448 analysis of a subset of Bioscience Ph.D. programs in the UCLA School of Medicine and
449 Division of Life Sciences. This subset covers a wide spectrum of biomedical and life
450 science areas, from Medical Informatics to Molecular Biology, suggesting that the
451 results are broadly applicable. However, additional studies are needed to assess the
452 full scope of these types of doctoral publication inequities across STEM programs both
453 within and beyond UCLA.

454 With the specific demographic disparities uncovered in this baseline study, it will
455 be important to monitor the effects of consortium initiatives aimed at reducing inequity in
456 subsequent student cohorts. Follow-up research on student publications should be
457 coupled with surveys to probe student experiences in domains that include mentorship,
458 program structure, and psychosocial development [46]. Ultimately, the goal is to inform
459 evidence-based interventions that lead to fully inclusive doctoral programs and career
460 outcomes in STEM.

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Works Cited

1. Lee D. Exploring the determinants of research performance for early-career researchers: a literature review. Scientometrics. 2023;129: 181–235.

2. West JD, Jacquet J, King MM, Correll SJ, Bergstrom CT. The role of gender in scholarly authorship. PLoS One. 2013;8: e66212.

3. Duch J, Zeng XHT, Sales-Pardo M, Radicchi F, Otis S, Woodruff TK, et al. The possible role of resource requirements and academic career-choice risk on gender differences in publication rate and impact. PLoS One. 2012;7: e51332.

4. Poodry CA, Asai DJ. Questioning Assumptions. CBE Life Sci Educ. 2018;17: es7.

5. Sá C, Cowley S, Shahrin B, Stevenson C, Su A. Disciplinary gender balance, research productivity, and recognition of men and women in academia. PLoS One. 2023;18: e0293080.

6. Mihaljević-Brandt H, Santamaría L, Tullney M. The Effect of Gender in the Publication Patterns in Mathematics. PLoS One. 2016;11: e0165367.

7. Hemming J, Eide K, Harwood E, Ali R, Zhu Z, Cutler J, et al. Exploring Professional Development for New Investigators Underrepresented in the Federally Funded Biomedical Research Workforce. Ethn Dis. 2019;29: 123–128.

8. Larivière V, Ni C, Gingras Y, Cronin B, Sugimoto CR. Bibliometrics: Global gender disparities in science. In: Nature Publishing Group UK [Internet]. 11 Dec 2013 [cited 6 Sep 2024]. doi:10.1038/504211a

9. Mendoza-Denton R, Patt C, Fisher A, Eppig A, Young I, Smith A, et al. Differences in STEM doctoral publication by ethnicity, gender and academic field at a large public research university. PLoS One. 2017;12: e0174296.

10. Pezzoni M, Mairesse J, Stephan P, Lane J. Gender and the Publication Output of Graduate Students: A Case Study. PLoS One. 2016;11: e0145146.

11. Fisher M, Nyabaro V, Mendum R, Osiru M. Making it to the PhD: Gender and student performance in sub-Saharan Africa. PLoS One. 2020;15: e0241915.

12. Lindahl J, Colliander C, Danell R. Early career performance and its correlation with gender and publication output during doctoral education. Scientometrics. 2020;122: 309–330.

13. ST Miller EK Saclarides ES L. Sex Differences in Doctoral Student Publication Rates. Sage Journals. 2018;47: 76–81.

14. Feldon DF, Peugh J, Maher MA, Roksa J, Tofel-Grehl C. Time-to-Credit Gender

Inequities of First-Year PhD Students in the Biological Sciences. CBE—Life Sciences Education. 2017 [cited 6 Sep 2024]. doi:10.1187/cbe.16-08-0237

15. Symonds MRE, Gemmell NJ, Braisher TL, Gorringe KL, Elgar MA. Gender differences in publication output: towards an unbiased metric of research performance. PLoS One. 2006;1: e127.

16. Kovalchik S. RISmed. 2021. Available: https://CRAN.R-project.org/package=RISmed

17. Pellack LJ, Kappmeyer LO. The ripple effect of women's name changes in indexing, citation, and authority control. J Am Soc Inf Sci Technol. 2011. doi:10.1002/asi.21469

18. Cheng TO. Chinese personal name variation in medical publications: implications for information retrieval. Int J Cardiol. 2010;139: 211–212.

19. Ruiz-Pérez R, Delgado López-Cózar E, Jiménez-Contreras E. Spanish personal name variations in national and international biomedical databases: implications for information retrieval and bibliometric studies. J Med Libr Assoc. 2002;90: 411–430.

20. Venables WN, Ripley BD. Modern Applied Statistics with S. Springer Science & Business Media; 2003.

21. Bates D, Mächler M, Bolker B, Walker S. Fitting linear mixed-effects models Usinglme4. J Stat Softw. 2015;67. doi:10.18637/jss.v067.i01

22. Therneau TM, Grambsch PM. Modeling Survival Data: Extending the Cox Model. Springer Science & Business Media; 2000.

23. Wickham H. ggplot2: Elegant Graphics for Data Analysis. Springer Science & Business Media; 2009.

24. Alboukadel Kassambara MKAPB. survminer: Drawing Survival Curves using "ggplot2." 2021. Available: https://CRAN.R-project.org/package=survminer

25. Authorship. In: COPE: Committee on Publication Ethics [Internet]. [cited 18 Jan 2024]. Available: https://publicationethics.org/resources/discussion-documents/what-constitutes-authorship-english-june-2014

26. Kaplan EL, Meier P. Nonparametric Estimation from Incomplete Observations. J Am Stat Assoc. 1958 [cited 6 Sep 2024]. Available: https://www.tandfonline.com/doi/abs/10.1080/01621459.1958.10501452

27. von Bartheld CS, Houmanfar R, Candido A. Prediction of junior faculty success in biomedical research: comparison of metrics and effects of mentoring programs. PeerJ. 2015;3: e1262.

535 28. Ginther DK, Basner J, Jensen U, Schnell J, Kington R, Schaffer WT. Publications
536 as predictors of racial and ethnic differences in NIH research awards. PLoS One.
537 2018;13: e0205929.

538 29. Bandura A. Social Foundations of Thought and Action: A Social Cognitive Theory.
539 Prentice Hall; 1986.

540 30. Etherton K, Steele-Johnson D, Salvano K, Kovacs N. Resilience effects on student
541 performance and well-being: the role of self-efficacy, self-set goals, and anxiety. J
542 Gen Psychol. 2022;149: 279–298.

543 31. Komarraju M, Swanson J, Nadler D. Increased Career Self-Efficacy Predicts
544 College Students' Motivation, and Course and Major Satisfaction. Journal of Career
545 Assessment. 2013 [cited 17 Sep 2024]. doi:10.1177/1069072713498484

546 32. Savi Çakar F. The relationship between the self-efficacy and life satisfaction of
547 young adults. Int Educ Stud. 2012;5.

548 33. Byars-Winston A, Diestelmann J, Savoy JN, Hoyt WT. Unique effects and
549 moderators of effects of sources on self-efficacy: A model-based meta-analysis. J
550 Couns Psychol. 2017;64: 645–658.

551 34. Ross MB, Glennon BM, Murciano-Goroff R, Berkes EG, Weinberg BA, Lane JI.
552 Women are credited less in science than men. Nature. 2022;608: 135–145.

553 35. Martin S, Rhodes AC, Brill CD, Sandoz EK. Diversity-related Factors in Research
554 Mentorship and Publishing in the ACBS Community and the Journal of Contextual
555 Behavioral Science. J Contextual Behav Sci. 2022;26: 56–62.

556 36. Aikens ML, Kulacki AR. Identifying Group Work Experiences That Increase
557 Students' Self-Efficacy for Quantitative Biology Tasks. CBE Life Sci Educ. 2023;22:
558 ar19.

559 37. Butz AR, Usher EL. Salient sources of early adolescents' self-efficacy in two
560 domains. Contemp Educ Psychol. 2015;42: 49–61.

561 38. National Academies of Sciences, Engineering, and Medicine; Policy and Global
562 Affairs; Board on Higher Education and Workforce; Committee on Effective
563 Mentoring in STEMM. The Science of Effective Mentorship in STEMM. Dahlberg
564 ML, Byars-Winston A, editors. Washington (DC): National Academies Press (US);
565 2019.

566 39. Ginther DK, Schaffer WT, Schnell J, Masimore B, Liu F, Haak LL, et al. Race,
567 ethnicity, and NIH research awards. Science. 2011;333: 1015–1019.

568 40. Gutiérrez Á, Guerrero LR, McCreath HE, Wallace SP. Mentoring Experiences and
569 Publication Productivity among Early Career Biomedical Investigators and
570 Trainees. Ethn Dis. 2021;31: 273–282.

41. National Research Council, Policy and Global Affairs, Board on Higher Education and Workforce, Committee to Study the National Needs for Biomedical, Behavioral, and Clinical Research Personnel. Research Training in the Biomedical, Behavioral, and Clinical Research Sciences. National Academies Press; 2011.

42. Womack VY, Wood CV, House SC, Quinn SC, Thomas SB, McGee R, et al. Culturally aware mentorship: Lasting impacts of a novel intervention on academic administrators and faculty. PLoS One. 2020;15: e0236983.

43. Byars-Winston A, Womack VY, Butz AR, McGee R, Quinn SC, Utzerath E, et al. Pilot Study of an Intervention to Increase Cultural Awareness in Research Mentoring: Implications for Diversifying the Scientific Workforce. J Clin Transl Sci. 2018;2: 86–94.

44. Pfund C, Sancheznieto F, Byars-Winston A, Zárate S, Black S, Birren B, et al. Evaluation of a Culturally Responsive Mentorship Education Program for the Advisers of Howard Hughes Medical Institute Gilliam Program Graduate Students. CBE Life Sci Educ. 2022;21: ar50.

45. Byars-Winston A, Rogers JG, Thayer-Hart N, Black S, Branchaw J, Pfund C. A randomized controlled trial of an intervention to increase cultural diversity awareness of research mentors of undergraduate students. Sci Adv. 2023;9: eadf9705.

46. Fisher AJ, Mendoza-Denton R, Patt C, Young I, Eppig A, Garrell RL, et al. Structure and belonging: Pathways to success for underrepresented minority and women PhD students in STEM fields. PLoS One. 2019;14: e0209279.

Supporting Information

S1 Figure: Distribution of paper counts by gender and race/ethnicity

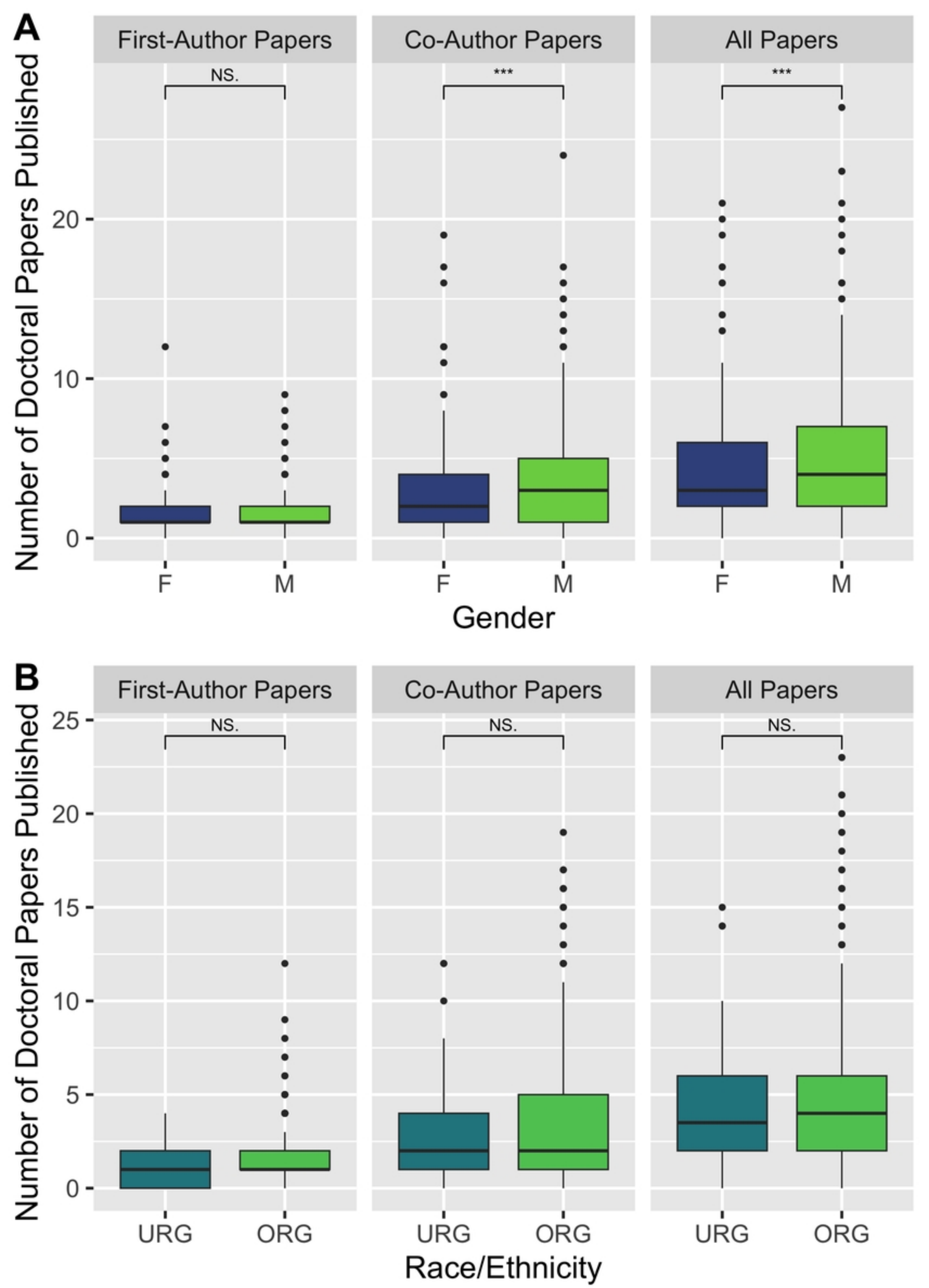
Distribution of the percentage of students by publication count (A) by student gender (B) by student race/ethnicity. Six students who had more than 20 papers were removed for the purposes of legibility.

S1 Table: No significant disparity in total and authorship position paper counts by citizenship.

SD: standard deviation; IQR: interquartile range, Domestic: U.S. citizen or permanent resident. p-value determined by the Wilcoxon rank sum test

S2 Table: Negative binomial regression fixed effects model is similar to the mixed effects model

Coefficients from negative binomial regression incorporating the effects of gender (male as reference), race/ethnicity (overrepresented group as reference) and international status (domestic as reference). URG: underrepresented group. IRR = Incidence Rate Ratio, CI = Confidence Interval, P = p-value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Co-Author Papers
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URG
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Race/Ethnicity

Figure 1

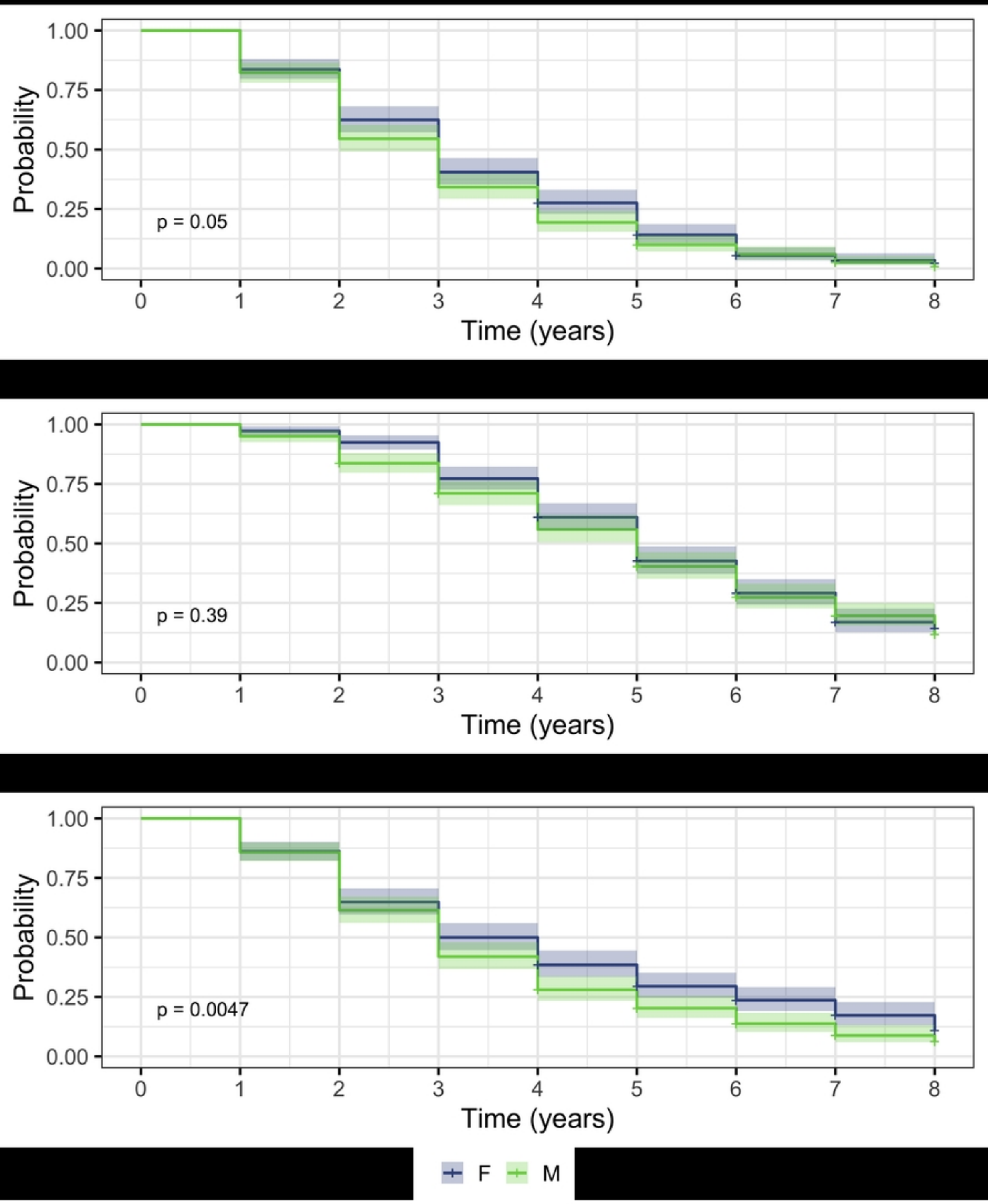
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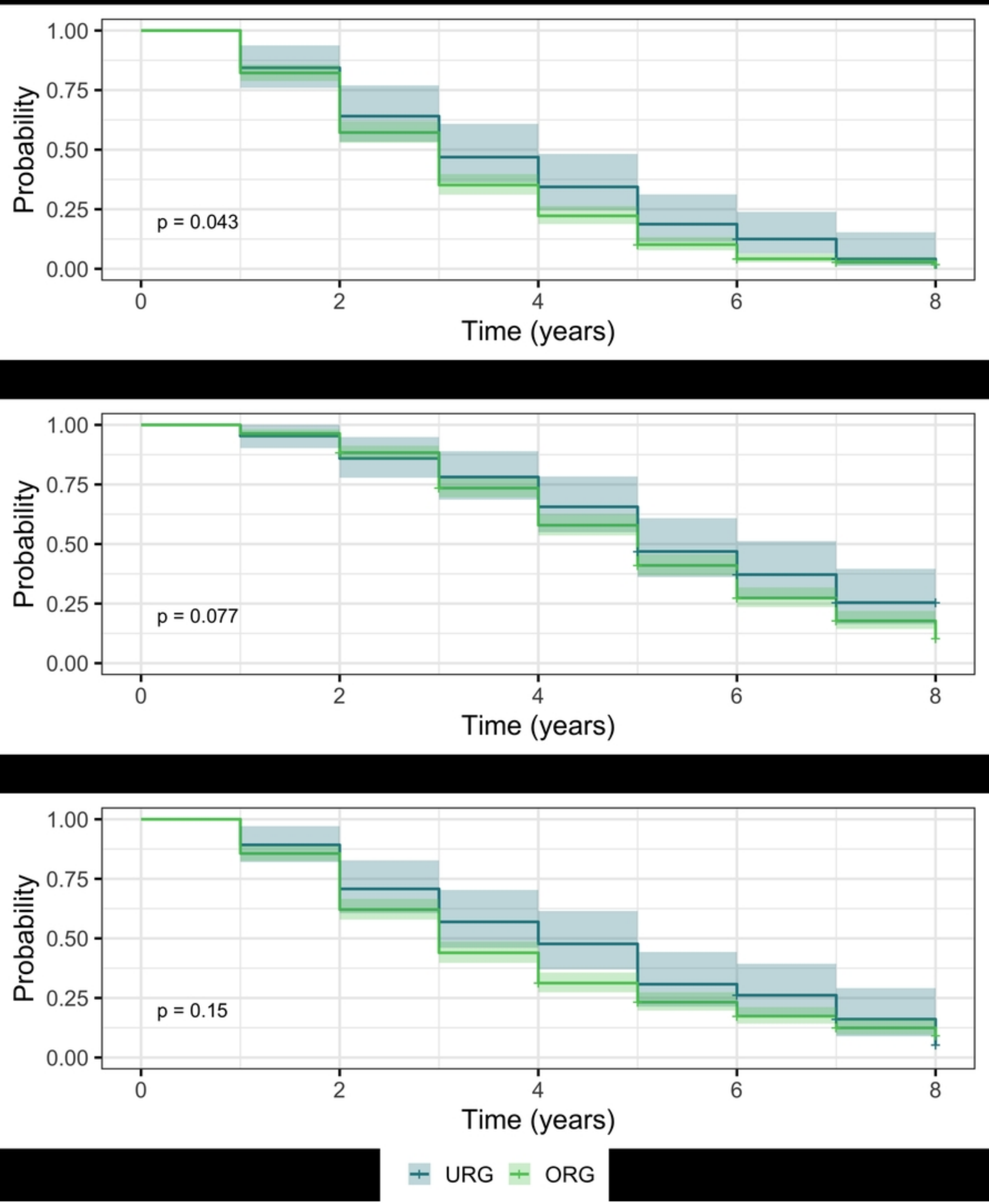
Figure 2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Time (years)
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Figure 3