A global survey on the perceptions and impacts of gender inequality in the Earth and space sciences

Andrea L. Popp[1,2,+,*], Stefanie R. Lutz[3,§,+,*], Sina Khatami[4], Tim H.M. van Emmerik[5], Wouter J.M. Knoben[6]

[1]Department of Water Resources and Drinking Water, Eawag, 8600 Dübendorf, Switzerland

[2]Department of Environmental Systems Science, ETH, 8006 Zürich, Switzerland

[3]Department of Catchment Hydrology, UFZ Helmholtz Centre for Environmental Research, 06120 Halle (Saale), Germany

[§]now at Department of Hydrogeology, UFZ Helmholtz Centre for Environmental Research, 04318 Leipzig, Germany

[4]Department of Infrastructure Engineering, University of Melbourne, Parkville, Victoria, 3010, Australia

[5]Department of Hydrology and Quantitative Water Management, Wageningen University, 6708 PB Wageningen, The Netherlands

[6]Faculty of Engineering, University of Bristol, Bristol BS8 1TH, UK

[+]these authors contributed equally to this work

[*]corresponding authors: andrea.popp@eawag.ch & stefanie.lutz@ufz.de

Key Points:

- Both genders view male geoscientists as substantially more gender-biased than female scientists.
- Women perceive negative gender biases twice as often as their male colleagues.
- Potential measures to combat the leaky pipeline in the geosciences are more supported by women than men.

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1029/2019EA000706

Corresponding author: Andrea L. Popp & Stefanie R. Lutz , `andrea.popp@eawag.ch` & `stefanie.lutz@ufz.de`

Abstract

The *leaky pipeline* phenomenon refers to the disproportionate decline of female scientists at higher academic career levels and is a major problem in the natural sciences. Identifying the underlying causes is challenging, and thus solving the problem remains difficult. To better understand the reasons for the leaky pipeline, we assess the perceptions and impacts of gender bias and imbalance—two major drivers of the leakage—at different academic career levels with an anonymous survey in geoscience academia (n=1220). The survey results show that both genders view male geoscientists as substantially more gender-biased than female scientists. Moreover, female geoscientists are more than twice as likely to experience negative gender bias at their workplaces and scientific organizations compared to male geoscientists. There are also pronounced gender differences regarding (i) the relevance of role models, (ii) family-friendly working conditions and (iii) the approval of gender quotas for academic positions. Given the male dominance in senior career levels, our results emphasize that those feeling less impacted by the negative consequences of gender bias and imbalance are the ones in position to tackle the problem. We thus call for actions to better address gender biases and to ensure a balanced gender representation at decision-making levels to ultimately retain more women in geoscience academia.

Plain Language Summary

Despite a fairly equal gender representation among PhD students in the Earth and space sciences, there is a disproportionate dropout of women at higher academic career levels. Resolving the underlying causes of this problem requires a comprehensive understanding of the perceptions and impacts of gender inequality. In a survey among 1220 geoscientists, women report negative gender bias twice as often as their male colleagues and appear particularly affected by the impacts of gender imbalance such as the lack of same-gender role models. In contrast, male geoscientists are less aware of gender inequality and less supportive of intervention measures such as gender quota.

Hence, our results suggest the need for reconciling the views of those most affected by gender inequality (i.e., primarily non-tenured female geoscientists) with those in the position to reduce gender inequality through policy and decision-making (i.e., primarily male tenured geoscientists).

1 Introduction

The disproportional decline of female scientists with increasing academic rank—called the leaky pipeline—has been a continuing issue ever since the term was first introduced in the early 1990s (Alper, 1993). The most pronounced loss of women in academia occurs at the transition from the PhD to higher career levels (Newton, 2012). The geosciences are among the least diverse scientific disciplines regarding gender and underrepresented minorities (Holmes et al., 2008; Nature Geoscience Editorial, 2016; Dutt et al., 2016). This is despite various calls for more workforce diversity, which is known to boost innovation and productivity (Medin & Lee, 2012; Nature Editorial, 2018). The poor retention of women does not only impede a large and diverse talent pool, it is also a moral and ethical issue contrary to the principle of granting equal opportunities to everyone (Nature Geoscience Editorial, 2016). Within the U.S. geosciences, for example, women accounted for 40% of BSc students but only 14% of full professors in 2015 (Fig. 1). Likewise, women are underrepresented in major geoscience organizations (i.e., professional societies) such as the European Geosciences Union (EGU) and the American Geophysical Union (AGU). Within the EGU, women represented 43% of student members (including PhD candidates), 35% of the total membership and 18% of Emeritus members (older than 60 and retired) in 2018 (personal communication with the EGU Executive Office, April 2018). Within the AGU, women accounted for 44% of student members, 27% of mid-career members, 15% of experienced members, and 7% of retired members in 2018 (personal communication with the AGU Membership Office, December 2018). However, there has been some progress in closing the gender gap in recent years (Bernard & Cooperdock, 2018):

within the U.S. geoscience workforce, the proportion of female PhD recipients increased from 23% to 40%, and the proportion of female full professors increased from 5% to 14% between 1996 and 2015 (Fig. 1). Nonetheless, the geosciences continue to leak women as academic level increases (Holmes et al., 2015) and gender balance at the faculty level is yet to be achieved (Bernard & Cooperdock, 2018).

A myriad of reasons have been proposed to explain the leaky pipeline for women in STEM (science, technology, engineering and mathematics) fields, including women's career and family choices, low recruitment and retention, post-tenure burnout, gender bias, and a lack of role models, mentors and networks (Ceci & Williams, 2011; Hill et al., 2010; Newton, 2012; Reuben et al., 2014; Holmes et al., 2015). Holmes et al. (2015) categorized the reasons into three overlapping groups of individual, interactional, and institutional barriers, with the lack of role models and implicit (unconscious) gender bias lying at the heart of their overlap. Gender bias manifests itself in unequal opportunities in research funding (van der Lee & Ellemers, 2015) and collaborations (National Research Council, 2006), underrepresentation in prestigious scientific roles (e.g., journal editorial board members) (Vila-Concejo et al., 2018), men-exclusive networks (Massen et al., 2017), unequal pay and less prospects of research positions (Moss-Racusin et al., 2012), lower acceptance and citation rates for research papers (Fox & Paine, 2019), fewer invitations to review manuscripts (Lerback & Hanson, 2017) and write commentaries or commissioned articles (Editorial, 2012; Conley & Stadmark, 2012), fewer opportunities to speak at conferences and colloquiums (Nittrouer et al., 2018; Ford et al., 2018; King et al., 2018), weaker recommendation letters (Dutt et al., 2016), and fewer research grants and academic prizes (Lincoln et al., 2012; Tamblyn et al., 2018). These examples indicate that gender bias is widespread and potentially impacts a woman's professional trajectory in academia. But how do female and male geoscientists actually perceive gender bias? And does gender inequality (in this study referring to gender bias and imbalance) impact geoscientists, e.g., at scientific meetings or in their institutions? To address these questions, we conducted an anonymous online survey, with 1220 participants working across the Earth and space sciences. The aim of this study is to provide a global picture of the perceptions and impacts of gender inequality in the geosciences. A thorough understanding of this is vital to design measures that are both widely accepted within the community and effective in sealing the geosciences leaky pipeline.

2 Methods

2.1 Conceptual Design and Distribution of the Online Survey

The survey “Survey on gender equality in Earth and space sciences” was conducted from March 25 to April 11, 2018 using Google Surveys. The link to the survey was distributed by the authors via email (e.g., young scientists network of the German Hydrological Society, DHG; 500 Women Scientists Zurich; individual scientists working in Earth and space sciences; and institutional and departmental mailing lists) as well as social media (Twitter and Facebook). Among the 1415 participants, we analyzed the responses of those who identified as either female or male (leaving out seven non-binary respondents due to the small sample size), and currently work in academia (i.e., universities or research institutes, including emeritus and adjunct professors, research support staff, and research assistants). We thereby retained 1220 respondents with a gender distribution of 67.0% female to 33.0% male survey participants. All of these respondents associated themselves with scientific fields related to the Earth and space sciences. Analyses on career stages were performed using a subset of 1080 participants who identified either as BSc and MSc students, PhD candidates, postdoctoral researchers, assistant or associate professors, or full professors.

2.2 Background of Survey Participants

Participants were mainly based in Europe (53.4%) and North America (36.9%), and worked in hydrology (24.0%), geomorphology (8.9%), geochemistry, mineralogy, petrology and volcanology (8.6%), and various other geoscience disciplines. Participants consisted of 35.0% PhD candidates, 19.0% postdoctoral researchers, 17.3% assistant or associate professors, 9.7% non-tenured scientists, 9.7% BSc and MSc students, and 7.5% full professors.

2.3 Statistical Data Analysis

For the statistical analyses, we used the programming language and software environment R (R Core Team, 2018). We applied Pearson's chi-squared (χ^2) tests to all results to analyze differences between female and male participants (unless stated otherwise), using post-hoc tests with Benjamini-Hochberg correction (Benjamini & Hochberg, 1995) for responses with more than two categories. This allows identifying individual categories with significant differences between female and male participants (i.e., adjusted p-value<1.0e-2) and permits statistical assertions on gender differences despite the overrepresentation of women in the survey population relative to their representation in the geosciences (Holmes et al., 2008; Wilson, 2016) . Test-statistics of the chi-squared tests are reported as follows: χ^2(degrees of freedom, sample size)=χ^2-value, p-value or adjusted p-value after Benjamini-Hochberg correction for all categories where degrees of freedom>1. We report the maximum p among all categories with significant p (i.e., adjusted p<1.0e-2) and give the exact p-value for all categories with non-significant p. In the text, variables on a scale from 1 to 5 (Figs. 2c, 2d & 2h) are aggregated as follows: values 1 and 2 as *"not at all or little"*, 3 as *"neutral"*, and 4 and 5 as *"somewhat to very"*. When discussing categorical variables, we indicate in the text whether we refer to aggregated categories. The *"Don't know"* option for categorical variables was kept unless noted otherwise, as it accounted for more than 5% among female or male respondents in most cases (Figs. 2a, e-g).

3 Results and Discussion

3.1 Perceptions of Gender Imbalance

Given that the geoscience workforce is generally male-dominated (Holmes et al., 2008)—with 19% female and 81% male geoscientists in faculty positions at U.S. universities in 2015 (Wilson, 2016)—the gender distribution of our respondents suggests that female geoscientists generally feel more affected by the survey topic than their male peers. The greater interest in the topic by women is also reflected in their awareness of the leaky pipeline concept: although the majority of respondents have heard of the leaky pipeline, a lower percentage of men (61.4%) than women (72.7%) are familiar with the term ($\chi 2(1, 1220)$=15.6, p<1.0e-4). Moreover, BSc and MSc students as well as PhD students are less aware of the term (41.5% and 58.5%, respectively) than postdocs (78.4%), assistant or associate professors (88.2%) and full professors (79.3%; Fig. S1). Both female (85.7%) and male (73.6%) participants predominantly believe that male tenured scientists outnumber female counterparts in their scientific institutions (i.e., departments, Fig. 2a). However, a greater percentage of men (13.9%) than women (6.8%) perceive the gender distribution as balanced (Fig. 2a, $\chi 2(3, 1220)$=32.2, p<1.2e-3 except for p (*"Don't know"*)=4.7e-1). The vast majority of participants (83.4%) consider an equal gender distribution in a research group important, or to some extent important, for creating a healthy work environment (*"Don't know"* accounting for 1.1% discarded). This view is largely independent of the participants' career level, with more than 80% in each career level considering gender balance important. Yet a greater percentage of women (87.6%) than men (74.9%) express this view (Fig. 2b, $\chi 2(1, 1206)$=30.4, p<1.0e-4), whereas a considerably greater percentage of men (25.1%) than women (12.4%) dismiss gender balance in research groups as not really or not at all important. The latter is disproportionately common among male postdocs, who account for the highest percentage among those dismissing gender balance as rather unimportant (30.3% vs. 13.2% of female postdocs; Fig. S2). These results show how gender representation alone can be perceived differently between genders. Moreover, we show that gender balance in research teams is more important to female than to male geoscientists.

3.2 Perceptions of Gender Bias

In addition to differences in the perceptions of gender imbalance, female and male scientists experience gender-bias of colleagues at their institutions differently. The majority of male respondents consider their female and male colleagues (69.2% and 58.0%, respectively) as little to not gender-biased (Figs. 2c & 2d). Moreover, only a small percentage of male respondents view their female and male colleagues (12.2% and 17.7%, respectively) as somewhat to strongly gender-biased. In contrast to men, female respondents perceive gender-bias of their female and male colleagues differently: while a majority of female respondents (58.3%) see their female colleagues as little to not biased, a minority of them (33.1%) perceive their male colleagues as little to not biased. Similar to male respondents, 12.6% of women consider their female colleagues as somewhat to strongly biased. However, 33.3% of female respondents consider their male colleagues as somewhat to strongly biased (Figs. 2c & 2d). This perception is more pronounced among women at higher career levels, with 48.9% of female professors considering male scientists as biased, as opposed to around 27% of both undergraduate and graduate students (Fig. S3). Among male geoscientists, the relationship between respondents perceiving male scientists as gender-biased and their career stage is less distinct (Fig. S3): 21.3% of the full professors consider male scientists as biased, compared to between 14.5% and 19.5% for the remaining career stages. In summary, although both genders consistently regard male scientists as more gender-biased, female respondents perceive male scientists as gender-biased by a considerably larger proportion (33.3% female vs. 17.7% male respondents, $\chi 2(2, 1220)$=71.1, p<1.3e-3). Interestingly, these gender differences do not occur in the perception of female scientists' gender bias (12.6% female vs. 12.2% male respondents, $\chi 2(2, 1220)$=16.6, p<4.8e-

4 except for p(*"Somewhat to strongly biased"*)=0.91). Possible explanations for these findings include that (1) men are less aware of gender bias and its implications at workplaces (Flood & Russell, 2017) and more critical of scientific studies depicting gender bias in STEM disciplines (Handley et al., 2015), and (2) women are more prone to experience gender bias (e.g., Williams & Ceci, 2015). Notwithstanding the emphasis on gender-biased male scientists, research has also reported same-gender bias among women faculty (Moss-Racusin et al., 2012) and examples of female faculty being more critical of women than men (i.e., *the queen bee syndrome*) (Ellemers et al., 2004, 2012).

3.3 Impacts of Gender Inequality

Our data show the prevalence of gender inequality in scientific institutions (i.e., workplaces), organizations (i.e., professional societies such as the EGU) and meetings (e.g., conferences). Beyond everyday work, scientific organizations and conferences play an important role in supporting researchers as they provide scientific journals and grants, are gateways to academic careers and show where and how scientists participate in the geoscience community (Ford et al., 2018; Biggs et al., 2018; Potvin et al., 2018; King et al., 2018).

Experiences with gender bias (negative, positive or both) in scientific institutions (e.g., in terms of supervision style, pay gap, recruitment, promotion, and support by mentors) are reported more often by women (55.7%) than men (29.4%), resulting in an average of 47.0% among all respondents (Fig. 2e). Whereas male participants experience *"mostly positive"* and *"mostly negative"* biases at equal rates (9.5%), female respondents experience negative bias at a considerably higher rate (25.8%) than positive bias (3.1%, Fig. 2e, $\chi 2(4, 1220)$=126.5, p<1.0e-4 except for p(*"Don't know"*)=1.6e-2). While a quarter of the female participants has been exposed to negative biases, about the same fraction has reported experiences with both positive and negative biases (Fig. 2e). In contrast, the percentage of men who have experienced gender bias at their workplace is only about 10% for both positive and negative biases.

Considering that 37.8% of female full professors have experienced negative gender bias, but only around 20% of female undergraduate and graduate students (Fig. S4), the impact of gender inequality on women seems to intensify with increasing academic rank. Another, more preferable explanation of this difference could be a recent shift towards a more gender-inclusive climate in science, which exposes fewer young women to biased behaviour than at the time today's senior women scientists started their career. Among male geoscientists, on the contrary, postdocs account for the highest percentage of experiences with negative bias (14.3%, compared to 8.5% of full professors; Fig. S4). One explanation for this might be that male postdocs feel negatively affected by measures and policies promoting women at earlier career stages with whom they are in direct competition for tenured positions. Moreover, female participants who report an underrepresentation of either female or male tenured scientists in their departments (Fig. 2a) experience negative biases in their institutions more often (28.2%) than those from gender-balanced workplaces (16.4%, Fig. S5, $\chi 2(1, 746)$=3.0, p=8.2e-2, *"Don't know"* accounting for 8.8% discarded). These findings are in line with earlier reported negative impacts of male-dominated academic institutions on women such as sexual harassment and unequal pay (Elsevier, 2017; Funk & Parker, 2018).

Gender bias appears to be less pronounced in scientific organizations (e.g., in terms of selection for oral presentations, representatives, awards and panel members) compared to scientific institutions, with 28.4% of the respondents having experienced bias in scientific organizations in some way (negative, positive, or both). Nevertheless, a greater percentage of women (32.9%) than men (19.2%) have experienced some kind of bias in scientific organizations, and negative biases are almost twice as frequent for females (16.0%) as for males (8.2%) (Fig. S6, $\chi 2(4, 1220)$=37.1, p<8.5e-4 except for p(*"Yes, mostly positive"*)=0.61 and p(*"Don't know"*)=0.61). The prevalence of biases perceived by women is also in line with the findings of Ford et al. (2018) who reported unequal speaking opportunities for women at the AGU Fall Meeting.

According to our survey data, gender imbalance at scientific meetings (e.g., in terms of raising questions, speaking up, received responses by colleagues) has a significant impact on the overall experience and behavior of scientists and women in particular: the majority of female respondents (58.1% female vs. 24.9% male) feel at least to some extent affected by gender imbalance at scientific meetings (Fig. 2f, $\chi2(2, 1220)$=145.3, p<1.0e-4 except for p(*"Don't know"*)=8.1-e2). In contrast, men are more than twice as likely as women (69.2% and 32.9%, respectively) to feel not at all or not really affected by gender imbalance at scientific meetings. These results align well with recent findings reported by King et al. (2018) who observed at two Canadian geoscience meetings that only 20% of questions were asked by women and women were more likely to ask questions in female-dominated sessions. Our findings further demonstrate the possibility of an exclusionary and sexist climate for women at geoscience conferences—a phenomenon that has been reported for other scientific disciplines before (Settles & O'Connor, 2014). Overall, these results highlight that female geoscientists experience negative impacts of gender inequality at their workplaces, organizations and conferences substantially more often than their male colleagues.

3.4 How Important are Role Models?

Role models can encourage students and early career scientists to pursue a career in academia as they show career possibilities and reduce stereotypes about scientists (Canetto et al., 2012; Young et al., 2013; Dasgupta & Stout, 2014). Accordingly, Vila-Concejo et al. (2018) showed that a lack of role models is perceived to be a key obstacle for gender equity. Hence, providing same-gender role models is now one of the most promising retention strategies for female scientists in the geosciences (Hernandez et al., 2018). To the majority of respondents (76.6%), role models are somewhat to very important for their career choices. However, there is a significant gender difference (Fig. 2g, $\chi2(2, 1220)$=69.7, p<8.4e-4) between those who consider role models as rather important (*"somewhat important"* or *"very important"*) and rather unimportant (*"not* *very important"* or *"not important"*). A great majority of female participants (83.6% females vs. 62.2% males) fall into the first category, whereas 32.1% of male respondents (vs. 14.4% females) fall into the second category (*"Don't know"* accounting for difference to 100%). Gender differences become also apparent when looking at different career stages (Fig. S7): while role models are most important for women right before the most leaky part of the pipeline, i.e., the PhD level (87.9%, compared to 79.1% of female BSc and MSc students and 80% of women professors), they matter the most to men at the postdoc and assistant or associate professor levels (67.5% and 69.7%, respectively, compared to 55.6% of male undergraduates and 51.1% of male professors). Moreover, 36.7% females (vs. 7.5% males) prefer same-gender role models, compared to only 1.8% (vs. 3.7% males) preferring other-gender role models and 57.1% (vs. 76.6% males) indicating no gender preference (Fig. S8, $\chi 2(3, 1220)$=128.6, p<1.0e-4 except for p(*"Other gender"*)=7.0e-2). Furthermore, women from gender-imbalanced departments (Fig. 2a) are more likely to consider role models as important (86.5%) compared to those from gender-balanced departments (73.6%; Fig. S9, $\chi 2(1, 758)$=5.7, p=1.7e-2, *"Don't know"* accounting for 7.3% discarded). These results underline that role models—particularly female role models—are more desirable and more crucial for female than male geoscientists, especially in institutions where these role models might not be available due to the scarcity of women senior scientists.

3.5 How Important are Family-Friendly Working Conditions?

A recent study found that "parenthood is an important driver of gender imbalance in STEM" (Cech & Blair-Loy, 2019). That is because family obligations are still mostly seen as female responsibilities and women take on a disproportionate amount of domestic work including parenting (Editorial, 2012; Rosen, 2017). Moreover, in many countries, childcare is expensive and/or scarce (Newton, 2012). Balancing the demands of family responsibilities and being a young scientist striving for tenure is perceived as one of the biggest barriers for young women in academia (National Research Council, 2006; Newton, 2012; Gay-Antaki & Liverman, 2018). Additionally, hiring biases still persist against young female scientists who might interrupt their career to start a family, as this will impact their scientific output (National Research Council, 2006; Raymond, 2013; Vila-Concejo et al., 2018). The combination of these obstacles most likely plays a role in the smaller number of female scientists (on tenure-track) having children compared to their male peers (Holmes et al., 2008). Our data show that family-related working conditions (e.g., the option to work part-time, daycare facilities for children) are important (*"at the moment"* or *"in the future"*) to the vast majority (76.1%) of survey participants (82.8% females and 73.9% of males; Fig. S10; $\chi 2(1, 1162)$=12.0, p=5.4e-4, *"Don't know"* accounting for 4.8% discarded). Family-friendly working conditions are important "in the future" especially for younger researchers at the BSc and MSc level (54.2%), PhD level (71%) and postdoc level (50.4%). Accordingly, they are particularly important "at the moment" for the more advanced career levels, with male full professors showing the highest percentage among all career levels and both genders (63.8%; compared to 53.3% of female professors; Fig. S11). In contrast, only 17.2% of female and 26.1% of male geoscientists (overall 19.2%) consider family-related working conditions as not (very) important. These findings emphasize that the compatibility between work and family is highly relevant for most geoscientists, and women in particular. To facilitate a healthy balance between family and work in academia, institutions need to foster affordable daycare, support the return from parental leave and grant flexible working hours (Vila-Concejo et al., 2018). Progress in this regard would not only benefit female scientists, but also encourage the increasing number of male scientists with egalitarian role attitudes to reconcile family responsibilities with academic careers (Damaske et al., 2014; Flood & Russell, 2017).

3.6 Gender Quotas: a Divisive Matter

There is a contested debate on possible benefits and harms of gender quotas as a major policy tool to mitigate gender imbalance in academia, particularly at the highest career levels (e.g., Vernos, 2013; Wallon et al., 2015). Proponents argue that the belief in meritocracy itself is biased (Christensen & Muhr, 2018), and that a quota system accelerates the achievement of gender parity by ensuring the presence of role models for female scientists, particularly early in their careers (Nature Editorial, 2013; Pyke & White, 2018). Opponents question the efficacy of quotas in addressing the underlying discrimination, advocate instead for a purely merit-based system and point out the potential stigma associated with individuals hired via a quota system (Vernos, 2013; Wallon et al., 2015). This ambivalence is also evident in our survey, showing that both positions are almost equally strong: 39.3% of the respondents are in favor of gender quotas, while 33.2% are against them. However, opinions on gender quotas in academia are strongly gendered (Fig. 2h, $\chi 2(2, 1220)$=56.2, p<1.0e-4 except for the neutral position with p=1.9e-1): while nearly half of women (44.9%) are in favor of quotas, the same holds for less than a third of men only (27.9%). On the other end of the spectrum, around half of the male respondents (47.0%) but only about a quarter of female respondents (26.3%) are against quotas. The remainder (28.9% female and 25.1% male) have a neutral position. Being at a critical moment in their scientific career, female postdocs show the highest approval rate of gender quotas (56.1%), followed by female BSc and MSc students (50.5%; Fig. S12) In contrast, the approval of gender quotas by male respondents is highest among professors (34.%; Fig. S12) and lowest among geoscientists potentially striving for tenure (22.1% among male postdocs and 25.0% among male assistant and associate professors), which possibly reflects fears of being disadvantaged by quotas in favour of female colleagues during a critical stage on tenure-track. Among those who acknowledge the importance of gender balance for a healthy research group (Fig. 2b), 44.8% (49.0% of women and 34.9% of men) support gender quotas for academic positions, compared to only 12.0% (17% of women and 7% of men) among those who dismiss gender balance as (rather) unimportant (Fig. S13, *"Don't know"* accounting for 1.1% discarded, $\chi 2(2, 1206)$=124.0, p<1.0e-4 except for the neutral position with p=9.8e-2). These results clearly indicate the polarizing nature of quotas as an adequate tool to combat the leaky pipeline, especially in view of the considerable opposition among female respondents who would actually benefit from a quota system. Instead of mandatory gender quotas, softer measures to reduce gender bias in the hiring process, such as anonymous applications (Åslund & Skans, 2012) and formalized interviewing procedures (Holmes et al., 2015), might be met with more approval from the geoscience community.

4 Summary: Insights Into the Perceptions and Impacts of Gender Inequality

Almost 30 years after its first recognition, the persistence of the leaky pipeline for female scientists still poses a great challenge to the geosciences community. The insights revealed by this survey underscore the gendered perceptions and impacts of gender inequality within geoscience academia:

- Although most geoscientists are well aware of the leaky pipeline and value gender-balanced research teams, men appear less receptive to this matter.
- Male scientists perceive their female and male colleagues as equally (un)biased, while female scientists perceive their male colleagues as more biased than their female colleagues.
- Female scientists report negative gender biases at their workplaces and scientific organizations about twice as often as male respondents, and a majority of female respondents feel affected by gender imbalance at scientific meetings.
- The impact of gender inequality on women becomes more severe higher up the career ladder.
- Having same-gender role models and family-friendly working conditions is more important to female scientists.
- Gender quotas in academia are a divisive matter; while gender quotas have a greater approval by women than men, they are not endorsed by the majority

of geoscientists surveyed. Male mid-career geoscientists who might be directly affected by gender quotas are particularly opposed to gender quotas.

In light of the above, we show that male geoscientists generally feel less impacted by gender inequality, which suggests that they are also less aware of its negative impacts on female geoscientists. However, no true progress can be made as long as the problem of gender inequality and the resulting female under-representation in geoscience faculty is not fully acknowledged by both genders (Raymond, 2013; Vila-Concejo et al., 2018). Men should also be invited and encouraged to join the discussion about gender equality, which is often a topic solely addressed to and by women. Gender inequality, however, is not only a female issue; it affects both women and men (Flood & Russell, 2017).

Based on the outcomes of this survey, recent literature on this topic as well as personal discussions with colleagues and institutional diversity officers, we stress the following strategies as the most promising approaches to retain more female scientists in geoscience academia: 1) mandatory gender bias training to combat unconscious biases, 2) transparent candidate selection criteria of institutions and funders for hiring processes and funding opportunities, respectively, 3) better promotion and representation of female scientists by selecting them for prestigious decision making roles in scientific organizations and institutions, 4) inviting more men to an open discussion about gender equality and 5) granting more rights, flexibility and support for parents to share parental responsibilities and to transform academia into a more family-friendly workplace. We believe that these strategies are feasible endeavors for individual scientists, scientific institutions, organizations and funders. The successful implementation of these measures will promote fair and inclusive opportunities for career progression by women as they climb up the career ladder and thus foster gender equality in the Earth and space sciences.

Acknowledgments

All data used in this study are available online (http://doi.org/10.5281/zenodo.2596561). We are thankful for the feedback and comments provided by Suzanne O'Connell and one anonymous reviewer who helped improve this manuscript. We also thank Mary Anne Holmes, Wouter R. Berghuijs, Jendrik Seipp, Amir AghaKouchak, Erfan Haghighi, Gi-Mick Wu, Ines Thronicker, Sebastian Gnann, Lina Stein, Enayat A. Moallemi, and Claudia Jesus-Rydin for valuable comments on this manuscript. Moreover, we thank Natalie Lerch-Pieper, Max Ramgraber, Wouter R. Berghuijs and Ines Thronicker for their feedback on the survey questions. Finally, we would like to thank all who participated in the survey. The authors declare no competing interests. This work did not receive any funding.

Figure Captions

Fig. 1: Relative decline of female geoscientists in the U.S. with increasing academic rank between 1996 and 2015 (data from the American Geosciences Institute (Wilson, 2016) and Holmes et al. (2008)).

Fig. 2: Gender distribution of replies to key questions of the survey. Answers by female (f) and male (m) respondents are relative to total number of answers per gender (n=818 for female and n=402 for male respondents). Asterisks next to percentages indicate statistical significance according to χ^2-tests (* for p<5.0e-2 and ** for p<1.0e-2).

References

Alper, J. (1993). The Pipeline Is Leaking Women All the Way Along. *Science*, *260*(5106), 409–411. doi: 10.1126/science.260.5106.409

Åslund, O., & Skans, O. N. (2012). Do Anonymous Job Application Procedures Level the Playing Field? *ILR Rev.*, *65*(1), 82–107. doi: 10.1177/001979391206500105

Benjamini, Y., & Hochberg, Y. (1995). Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing. *J. R. Stat. Soc. Ser. B*, *57*, 289–300.

Bernard, R. E., & Cooperdock, E. H. (2018). No progress on diversity in 40 years. *Nat. Geosci.*, *11*(5), 292–295. doi: 10.1038/s41561-018-0116-6

Biggs, J., Hawley, P. H., & Biernat, M. (2018). The Academic Conference as a Chilly Climate for Women: Effects of Gender Representation on Experiences of Sexism, Coping Responses, and Career Intentions. *Sex Roles*, *78*(5-6), 394–408. doi: 10.1007/s11199-017-0800-9

Canetto, S. S., Trott, C. D., Thomas, J. J., & Wynstra, C. A. (2012). Making Sense of the Atmospheric Science Gender Gap: Do Female and Male Graduate Students Have Different Career Motives, Goals, and Challenges? *J. Geosci. Educ.*, *60*(4), 408–416. doi: 10.5408/12-296.1

Cech, E. A., & Blair-Loy, M. (2019). The changing career trajectories of new parents in STEM. *Proc. Natl. Acad. Sci.*, 201810862. doi: 10.1073/pnas.1810862116

Ceci, S. J., & Williams, W. M. (2011). Understanding current causes of women's underrepresentation in science. *PNAS*, *108*(8), 3157–3162. doi: 10.1073/pnas.1014871108

Christensen, J. F., & Muhr, S. L. (2018). Fear of gender quotas is irrational. *ScienceNordic*.

Conley, D., & Stadmark, J. (2012). A call to commission more women writers. *Nature*, *488*(7413), 590. doi: 10.1038/488590a

Damaske, S., Ecklund, E. H., Lincoln, A. E., & White, V. J. (2014). Male Scientists' Competing Devotions to Work and Family: Changing Norms in a Male-Dominated Profession. *Work Occup.*, *41*(4), 477–507. doi: 10.1177/0730888414539171

Dasgupta, N., & Stout, J. G. (2014). Girls and Women in Science, Technology, Engineering, and Mathematics. *Policy Insights from Behav. Brain Sci.*, *1*(1), 21–

29. doi: 10.1177/2372732214549471

Dutt, K., Pfaff, D. L., Bernstein, A. F., Dillard, J. S., & Block, C. J. (2016). Gender differences in recommendation letters for postdoctoral fellowships in geoscience. *Nat. Geosci.*, *9*(11), 805–808. doi: 10.1038/ngeo2819

Editorial, N. (2012). Nature's sexism. *Nature*, *491*(7425), 495–495. doi: 10.1038/491495a

Ellemers, N., Heuvel, H., Gilder, D., Maass, A., & Bonvini, A. (2004). The underrepresentation of women in science: Differential commitment or the queen bee syndrome? *Br. J. Soc. Psychol.*, *43*(3), 315–338. doi: 10.1348/0144666042037999

Ellemers, N., Rink, F., Derks, B., & Ryan, M. K. (2012). Women in high places: When and why promoting women into top positions can harm them individually or as a group (and how to prevent this). *Res. Organ. Behav.*, *32*, 163–187. doi: 10.1016/j.riob.2012.10.003

Elsevier. (2017). Gender in the Global Research Landscape. *Elsevier*.

Flood, M., & Russell, G. (2017). *Men Make a Difference: How to Engage Men on Gender Equality* (Tech. Rep.). Sidney, Australia: Diversity Council Australia.

Ford, H. L., Brick, C., Blaufuss, K., & Dekens, P. S. (2018). Gender inequity in speaking opportunities at the American Geophysical Union Fall Meeting. *Nat. Commun.*, *9*(1), 1358. doi: 10.1038/s41467-018-03809-5

Fox, C. W., & Paine, C. E. T. (2019). Gender differences in peer review outcomes and manuscript impact at six journals of ecology and evolution. *Ecol. Evol.*(January), 3599–3619. doi: 10.1002/ece3.4993

Funk, C., & Parker, K. (2018). Women and men in STEM often at odds over workplace equity. *Pew Res. Cent.*(January), 1–157. doi: 202.419.4372

Gay-Antaki, M., & Liverman, D. (2018). Climate for women in climate science: Women scientists and the Intergovernmental Panel on Climate Change. *Proc. Natl. Acad. Sci.*, *115*(9), 2060–2065. doi: 10.1073/pnas.1710271115

Handley, I. M., Brown, E. R., Moss-Racusin, C. A., & Smith, J. L. (2015). Quality of evidence revealing subtle gender biases in science is in the eye of the beholder. *Proc. Natl. Acad. Sci.*, *112*(43), 13201–13206. doi: 10.1073/pnas.1510649112

Hernandez, P. R., Bloodhart, B., Adams, A. S., Barnes, R. T., Burt, M., Clinton, S. M., ... Fischer, E. V. (2018). Role modeling is a viable retention strategy for undergraduate women in the geosciences. *Geosphere*, *14*(6), 1–9. doi: 10.1130/GES01659.1

Hill, C., Corbett, C., & St. Rose, A. (2010). *Why So Few ? Women in Science, Technology, Engineering, and Mathematics.* AAUW.

Holmes, M. A., O'Connell, S., & Dutt, K. (2015). *Women in the Geosciences — Practical, Positive Practices Toward Parity.* John Wiley & Sons, Inc., Hoboken, New Jersey.

Holmes, M. A., O'Connell, S., Frey, C., & Ongley, L. (2008). Gender imbalance in US geoscience academia. *Nat. Geosci.*, *1*(2), 79–82. doi: 10.1038/ngeo113

King, L., MacKenzie, L., Tadaki, M., Cannon, S., McFarlane, K., Reid, D., & Koppes, M. (2018). Diversity in geoscience: Participation, behaviour, and the division of scientific labour at a Canadian geoscience conference. *FACETS*, *3*(1), 415–440. doi: 10.1139/facets-2017-0111

Lerback, J., & Hanson, B. (2017). Journals invite too few women to referee. *Nature*, *541*, 455–457.

Lincoln, A. E., Pincus, S., Koster, J. B., & Leboy, P. S. (2012). The Matilda Effect in science: Awards and prizes in the US, 1990s and 2000s. *Soc. Stud. Sci.*, *42*(2), 307–320. doi: 10.1177/0306312711435830

Massen, J. J., Bauer, L., Spurny, B., Bugnyar, T., & Kret, M. E. (2017). Sharing of science is most likely among male scientists. *Sci. Rep.*, *7*(1), 1–5. doi: 10.1038/s41598-017-13491-0

Medin, D. L., & Lee, C. D. (2012). Diversity Makes Better Science. *Assoc. Psychol.*

Sci..

Moss-Racusin, C. A., Dovidio, J. F., Brescoll, V. L., Graham, M. J., & Handelsman, J. (2012). Science faculty's subtle gender biases favor male students. *Proc. Natl. Acad. Sci.*, *109*(41), 16474–16479. doi: 10.1073/pnas.1211286109

National Research Council. (2006). *To Recruit and Advance: Women Students and Faculty in Science and Engineering.* The National Academies Press, Washington, D.C. doi: 10.17226/11624

Nature Editorial. (2013). Science for all. *Nature*, *495*(7439), 5. doi: 10.1038/495005a

Nature Editorial. (2018). Science benefits from diversity. *Nature*, *558*.

Nature Geoscience Editorial. (2016). Of rocks and social justice. *Nat. Geosci.*, *9*(11), 797. doi: 10.1038/ngeo2836

Newton, A. (2012). Plugging the leaks. *Nat. Geosci.*, *5*(8), 522–522. doi: 10.1038/ngeo1542

Nittrouer, C. L., Hebl, M. R., Ashburn-Nardo, L., Trump-Steele, R. C. E., Lane, D. M., & Valian, V. (2018). Gender disparities in colloquium speakers at top universities. *Proc. Natl. Acad. Sci.*, *115*(1), 104–108. doi: 10.1073/pnas.1708414115

Potvin, D. A., Burdfield-Steel, E., Potvin, J. M., & Heap, S. M. (2018). Diversity begets diversity: A global perspective on gender equality in scientific society leadership. *PLoS One*, *13*(5), 1–14. doi: 10.1371/journal.pone.0197280

Pyke, J., & White, K. (2018). Gender quotas and targets would speed up progress on gender equity in academia. *The Conversation*.

R Core Team. (2018). *A language and environment for statistical computing. R Foundation for Statistical Computing.* Vienna.

Raymond, J. (2013). Most of us are biased. *Nature*, *495*, 33–34.

Reuben, E., Sapienza, P., & Zingales, L. (2014). How stereotypes impair women's careers in science. *PNAS*, *111*(12), 4403–4408. doi: 10.1073/pnas.1314788111

Rosen, J. (2017). Data Illuminate a Mountain of Molehills Facing Women Scientists. *Eos, Trans. Am. Geophys. Union*, 89.

Settles, I. H., & O'Connor, R. C. (2014). Incivility at Academic Conferences: Gender Differences and the Mediating Role of Climate. *Sex Roles*, *71*(1-2), 71–82. doi: 10.1007/s11199-014-0355-y

Tamblyn, R., Girard, N., Qian, C. J., & Hanley, J. (2018). Assessment of potential bias in research grant peer review in Canada. *CMAJ*, *190*(16), E489–E499. doi: 10.1503/cmaj.170901

van der Lee, R., & Ellemers, N. (2015). Gender contributes to personal research funding success in The Netherlands. *PNAS*, *112*(40), 12349–12353. doi: https://doi.org/10.1073/pnas.1510159112

Vernos, I. (2013). Quotas are questionable. *Nature*, *495*(39).

Vila-Concejo, A., Gallop, S. L., Hamylton, S. M., Esteves, L. S., Bryan, K. R., Delgado-Fernandez, I., ... Splinter, K. (2018). Steps to improve gender diversity in coastal geoscience and engineering. *Palgrave Commun.*, *4*(1), 103. doi: 10.1057/s41599-018-0154-0

Wallon, G., Bendiscioli, S., & Garfinkel, M. S. (2015). Exploring quotas in academia. *EMBO*.

Williams, W. M., & Ceci, S. J. (2015). National hiring experiments reveal 2:1 faculty preference for women on STEM tenure track. *PNAS*, *112*(17), 5360–5365. doi: 10.1073/pnas.1418878112

Wilson, C. (2016). *Status of the Geoscience Workforce 2016.* AGI.

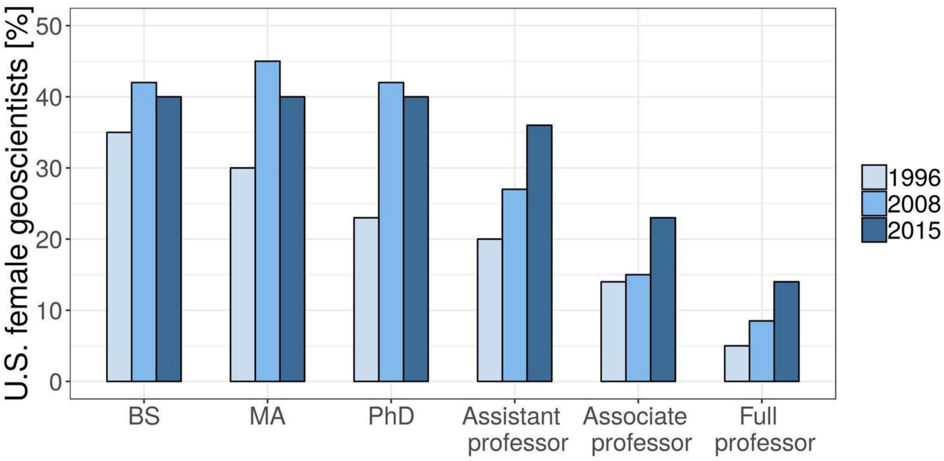
Young, D. M., Rudman, L. A., Buettner, H. M., & McLean, M. C. (2013). The Influence of Female Role Models on Women's Implicit Science Cognitions. *Psychol. Women Q.*, *37*(3), 283–292. doi: 10.1177/0361684313482109

Figure 1.

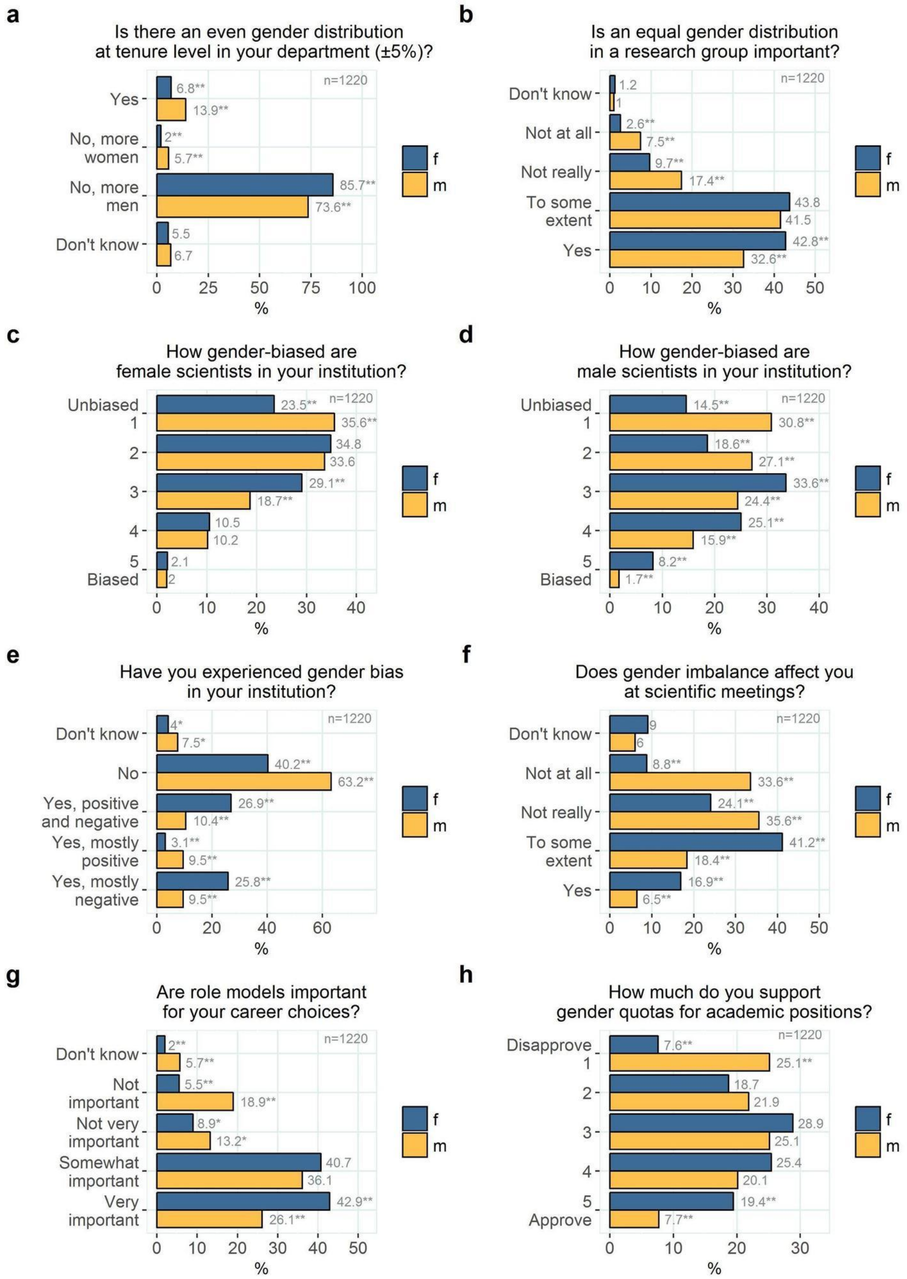

U.S. female geoscientists [%]
0
10
20
30
40
50
BS
MA
PhD
Assistant professor
Associate professor
Full professor
1996
2008
2015

Figure 2.


a
Is there an even gender distribution at tenure level in your department (±5%)?
n=1220
Yes
6.8**
13.9**
No, more women
2**
5.7**
No, more men
85.7**
73.6**
Don't know
5.5
6.7
0
25
50
75
100
%
f
m
b
Is an equal gender distribution in a research group important?
n=1220
Don't know
1.2
1
Not at all
2.6**
7.5**
Not really
9.7**
17.4**
To some extent
43.8
41.5
Yes
42.8**
32.6**
0
10
20
30
40
50
%
f
m
c
How gender-biased are female scientists in your institution?
n=1220
Unbiased 1
23.5**
35.6**
2
34.8
33.6
3
29.1**
18.7**
4
10.5
10.2
5 Biased
2.1
2
0
10
20
30
40
%
f
m
d
How gender-biased are male scientists in your institution?
n=1220
Unbiased 1
14.5**
30.8**
2
18.6**
27.1**
3
33.6**
24.4**
4
25.1**
15.9**
5 Biased
8.2**
1.7**
0
10
20
30
40
%
f
m
e
Have you experienced gender bias in your institution?
n=1220
Don't know
4*
7.5*
No
40.2**
63.2**
Yes, positive and negative
26.9**
10.4**
Yes, mostly positive
3.1**
9.5**
Yes, mostly negative
25.8**
9.5**
0
20
40
60
%
f
m
f
Does gender imbalance affect you at scientific meetings?
n=1220
Don't know
9
6
Not at all
8.8**
33.6**
Not really
24.1**
35.6**
To some extent
41.2**
18.4**
Yes
16.9**
6.5**
0
10
20
30
40
50
%
f
m
g
Are role models important for your career choices?
n=1220
Don't know
2**
5.7**
Not important
5.5**
18.9**
Not very important
8.9*
13.2*
Somewhat important
40.7
36.1
Very important
42.9**
26.1**
0
10
20
30
40
50
%
f
m
h
How much do you support gender quotas for academic positions?
n=1220
Disapprove 1
7.6**
25.1**
2
18.7
21.9
3
28.9
25.1
4
25.4
20.1
5 Approve
19.4**
7.7**
0
10
20
30
%
f
m



2019EA000706-f01-z-.jpg



2019EA000706-f02-z-.jpg