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Gender bias in ecosystem restoration: from science to practice

Running head: Gender bias in ecosystem restoration

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ABSTRACT

The declaration of the United Nations Decade on Ecosystem Restoration 2020-2030 has established the need to focus on human rights in restoration initiatives, including gender equality. Although this goal raises a need to monitor gender biases on ecosystem restoration, we still lack basic gender information and evaluations on the current situation. The main purpose of this study is to analyze gender bias in ecosystem restoration covering three dimensions: research, outreach, and practice. We used scientific publications from the Restoration Ecology journal, mentions of these articles in Altmetric Explorer and Twitter, and projects from the Society for Ecological Restoration's database. First, we study gender bias among people leading ecosystem restoration initiatives in the three dimensions. Second, we assessed factors that could influence gender bias, including year, target ecosystem and socioeconomic country development. Third, we analyzed whether the impact of scientific knowledge in society depends on the gender of the scientific team. Our results indicate that men were primary leaders in research, outreach, and practice initiatives in ecosystem restoration. There seems to be a trend over time towards equality in research, but gender inequality is still present in most types of ecosystems, with women leading more projects in more developed countries. The impact of scientific knowledge is independent of the author's gender, but research of male senior authors seems to reach society more easily. This broad perspective of inequality in the three dimensions can evolve towards gender equality, by applying gender approaches in restoration policies and initiatives.

KEY WORDS

gender bias; equality; gender gap; leadership; leaky pipeline; women in science

IMPLICATIONS FOR PRACTICE

- Gender inequality persists within research, outreach and practice in ecosystem restoration, mainly in senior positions. These results can serve as a baseline for the design of equal restoration initiatives triggered by the UN Decade on Ecosystem Restoration.
- Active efforts are needed to develop initiatives and policies in ecosystem restoration to achieve equal opportunities in reaching senior research positions, equal transfer of scientific knowledge and equal participation and benefit sharing in projects, putting global efforts in countries with lower resources.
- Reaching gender equality within these restoration dimensions requires incorporating gender aspects in research teams and practices, including women in decision-making and evaluation processes, assuring gender balance hiring, equal pay and funding opportunities, and recognizing women's achievements.

INTRODUCTION

The declaration of the United Nations Decade on Ecosystem Restoration aims to create a new trajectory for the relationships between societies and nature. Along with scientific, economic and social aspects, it stresses the importance of human rights (with a focus on gender equality, youth, local communities, indigenous people, and future generations), becoming central to restoration initiatives. To address gender equality, the declaration advises considering the benefits of restoration efforts for women, including women in decision making, monitoring gender indicators on restoration success and incorporating women's needs and perceptions in restoration communication (UNEP & FAO 2020). However, to adequately implement these initiatives, we need to improve our base knowledge about women's role in ecosystem restoration.

Ecosystem restoration is not gender neutral and can intersect with gender in different dimensions (Broeckhoven and Cliquet 2015). Gender equality can be part of every restoration-related initiative (policies, plans, international agreements, research, communication, education programs, project design and implementation) both as an *outcome* and as an *intrinsic feature* (de Siqueira et al. 2021). Considering gender equality as an *outcome* implies setting up related goals, that then should be monitored, informed, and analyzed to detect baselines and tendencies. Considering gender equality as an *intrinsic feature* may be a driver of success and promote democratic values and social justice (de Siqueira et al. 2021). For example, a restoration project can be designed with the goal (i.e. desirable *outcome*) that the natural (e. g. clean water) and social benefits (e. g. capabilities acquired), and negative offsets are assured equally to all genders. Also, as an *intrinsic feature*, it may consider equal working teams at all levels (implementation, management, decision-making). Here, we focus on the gender features of teams performing restoration initiatives, specifically the team leaders that steer restoration initiatives in research, communication, and practice.

Ecosystem restoration is intimately related to ecological research, where gender inequality has been observed (Bradshaw & Courchamp 2018). The proportion of women in most scientific authorship roles has increased over the last years (Huang et al. 2020). However, gender differences in research are a universal phenomenon persisting in every STEM discipline –Science, Technology, Engineering, and Mathematics– (Fox et al. 2018; Holman et al. 2018; Salerno et al. 2019), in many geographic regions –notably in wealthier countries such as Japan, Germany, and Switzerland (Holman et al. 2018)–, and dependent on the gender of the coauthors (Bradshaw & Courchamp 2018; Fox et al. 2018; Salerno et al. 2019). In ecosystem restoration in particular, little is known about those patterns and gender issues

have been described as being largely ignored in the specialized literature, according to Broeckhoven and Cliquet (2015).

In relation to the impact of research, most of the authors, peer reviewers and editors in scientific journals are men, despite the increasing proportion of scientific women (Lundine et al. 2018). Male authors receive 30% more citations for their publications than women (Huang et al. 2020), allowing them to reach a greater audience. Total impact –an indicator based on the number of citations and articles– shifts from slightly more impact for women in the 1950s to a 34% gap favoring male authors in the 2000s (Huang et al. 2020). However, it is unknown if this higher popularity of men's research extends beyond academia.

Studies addressing how gender influences science communication to the general public are crucial for three reasons. First, from several perspectives, communicators identifying with different genders have been reported to adopt different communicative styles (Ecklund et al. 2012; Johnson et al. 2014). Second, the manner in which scientific results are communicated determines how much they are considered in practice (Fabian et al. 2019). Third, communication outside of academia can disseminate ideas rapidly and increase the scope of audiences (Bombaci et al. 2016). If scientific production of both genders is not equally communicated, gender bias could be aggravated through science to society. In ecosystem restoration, improving gender equality in communication is essential, given the general lack of effective communication outside academia which usually ignores the pressing needs of practitioners (Rodríguez-Uña et al. 2020).

The diverse network of stakeholders that plays an important role in carrying out restoration projects –including state agencies, NGOs, civil society organizations and the private sector– makes it difficult to evaluate gender equality in restoration practice. First, a limited number of restoration projects address aspects of the gender dimension, and when they do, the projects simply mention women as participants (Broeckhoven and Cliquet, 2015). Second, little is known about restoration professionals (from project design to implementation), including their gender (Wainwright et al. 2017). The project actors, with their perspectives, values and environmental knowledge, shape the narratives, the objectives and the outcomes (Broeckhoven & Cliquet 2015). Female practitioners often have more precarious employment (Padrosa et al. 2022), and are often lower in the power hierarchy, and therefore their voices are less likely to shape projects. However, including women's perspectives and expertise in restoration projects is crucial so that the restoration resources and benefits are more equally distributed in the communities (Elias et al. 2021).

Each type of ecosystem has its own ecological and social characteristics, as well as specific

historical contexts, which affect its recovery (Jones et al. 2018). For example, arid ecosystems are generally affected by extreme environmental limitations that may hinder their recovery, requiring a particular set of skills and knowledge to restore them. However, different ecosystem types are not equally studied in restoration science (Wainwright et al. 2017), creating a mismatch between what is studied and what is needed by society. For instance, grasslands are the most studied ecosystem in applied restoration studies (Wainwright et al. 2017), but wetlands are the most degraded (IPBES 2018). This fact may be aggravated by gender inequalities in science, and can also be affected if there is a gender mismatch between researchers and practitioners, or inequality in communication, because gender knowledge regarding ecosystems might be different and complementary (e.g. in forests, Elias et al. 2017).

Given the crucial role of gender equality in reaching the goals of the UN Decade on Ecosystem Restoration, we aim to evaluate gender bias in the field of ecosystem restoration by addressing three specific questions. First, is gender bias present among people leading ecosystem restoration initiatives in research, outreach and practice? Considering the gender inequality present in other scientific disciplines (Fox et al. 2018; Holman et al. 2018; Salerno et al. 2019), we expect gender bias to be present in the three dimensions. Second, what are the factors that could influence these patterns of gender bias in ecosystem restoration? Based on results for other related disciplines, we predict a decrease in gender inequality over time and with women as coauthors. Also, we explore other potentially influential factors such as the target ecosystem of study and countries' human developed index. ~~We expect few differences among countries, since countries where women's rights are especially flouted are underrepresented in ecological restoration articles and practical cases. We also expect that ecosystems with a long tradition in restoration, such as forests and grasslands, may be led by men.~~ And third, does the impact of scientific knowledge on society depend on the gender of the scientific team? Given the higher impact of men in academic circles (Huang et al. 2020), we hypothesize that scientific publications led by male authors will be more cited and communicated outside research. The results could broaden our knowledge on women's role in ecosystem restoration to enhance equality actions in this discipline.

METHODS

Data sources

To study gender bias in ecosystem restoration we used five different data sources (**Table S1**): Web of Science, Altmetric Explorer, Twitter, the Society for Ecological Restoration's (SER)

project repository, and the SER's directory for the Certified Ecological Restoration Practitioner Program (CERP) and CERP in Training Program (CERPIT). First, we extracted the metadata from all the articles published between January 1st 1995 and December 31st 2020 in the Restoration Ecology journal from Web of Science. This journal was selected because it focuses specifically on ecosystem restoration and it is available for a wide time range (i.e. 1995 to present). Moreover, it includes the largest number of complete first names and affiliations of the authors in their metadata, in comparison to other specialized journals in ecosystem restoration. We excluded review papers, editorials, corrections, and other publications not considered standard research papers. The metadata extracted included DOI (Digital Object Identifier), complete author names and affiliations, publication year and number of citations. From the 2,386 subsetted research articles (**Table S1**), 24.4% included only author initials and needed to be searched manually. We considered the first and last author of scientific publications as the researcher leading the paper and the senior researcher (i.e., head of laboratory), respectively (Duffy 2017).

Using the DOIs of this set of scientific publications, we extracted the Altmetric Attention Score (AAS), and its components from the Altmetric Explorer database sourced from Almetric.com. This index is derived from an automated algorithm that is determined by (1) quantity of posts mentioning the research output and (2) quality of each post based on the potential impact considering the disseminator source profile. The AAS tracks direct online mentions to a research article –i.e. a link to the DOI URL, the journal article URL, the PubMed version of the article, the article on arXiv or the article in an institutional repository, etc.–, in different dissemination channels: (1) Scientific platforms (e.g. Mendeley), (2) outreach channels such as social networks (e.g. Twitter), blogs, news and mainstream media or Wikipedia, and (3) policy documents or patents (**Figure S1; Figure S2**). For more information on AAS, consult the Altmetric web (AAS 2022). Outreach outputs were obtained for 1,345 scientific publications, but only publications between 2014 and 2020 were used in further analysis (747 cases). This period was selected because it ensured that more than 50% of the research articles were tracked.

To study who communicates ecosystem restoration on social media, we focused on Twitter, since it includes most of the online mentions tracked by Altmetric Explorer (**Figure S2**). Twitter is one of the most popular social media platforms and is used by researchers as a collaborative channel to develop their professional circles, launch new research projects and get feedback from the community. We downloaded the tweet id (i.e. the unique identifier for each message posted in Twitter) of all the tweets that mentioned the studied DOIs from Altmetric Explorer. We used *twitterR* package (Gentry 2015) to download username, name and profile description for each tweet id. We obtained a total of 7,832 tweet ids, from which 4,815 had available

information in the Twitter database and were posted in 2,681 Twitter accounts. These were classified as institutional and personal accounts (20.9% and 76.2%, respectively; **Table S1**).

Finally, to determine gender bias in restoration practice, we used two SER databases. We scraped the data using the *rvest* package (Wickham 2021). First, we downloaded the data from the SER's Project Database (SER Project Database 2021). From 263 available projects, the database included the name and affiliation (including the country) of 44 project leaders. For the rest of the projects, we manually searched for this information in reports, publications, etc., obtaining a database of 225 projects. Second, we used the directory of the SER's CERP and CERPIT programs (SER 2021), with 471 practitioners certified between 2017 and 2020 (349 and 122, respectively; **Table S1**).

Gender identification

"Gender" describes the socially-constructed characteristics typically associated with male and female identities. In this article we inferred people's gender based on names, pictures and other information accepting the traditional binarism (i.e. female or male). We are aware of the limits of this procedure regarding important gender aspects such as inferring the gender of a person from a single attribute or ignoring other realities as non-binary or trans identities (Mihaljević et al. 2019). However, lack of specific information regarding gender identity hindered us from performing more complex approaches to address this aspect.

For first and last authors of scientific publications, project leaders and certified practitioners, gender was identified using the first name and the online database https://genderize.io through the *GenderGuesser* package (Caddigan 2021). This database includes a list of over 250,000 distinct names and provides a probability which indicates the certainty of the assigned gender for these names. We used the genders that had at least 75% accuracy. For the rest, we manually determined the gender, based on the information available online (e.g. Google Scholar or ResearchGate profiles). For Twitter profiles, which did not have a regular structure (i.e. first name + family name) or omitted real names, we determined the gender based on the information provided in the account and further internet search when required.

We obtained genders of 2,277 first authors (99.8%) and 2,070 last authors (99.5%). We also obtained the gender of Twitter users associated with 3,426 tweets (97.6% of personal tweets), 225 project leaders (85.5%) and 471 certified practitioners (100%). We were only able to discern non-binary gender in the case of Twitter users when it was specified in the account profiles (1.7% from the total obtained genders), and these were excluded from the analysis (see **Figure S3** for more details).

Target ecosystem and socioeconomic development

To evaluate if gender bias depended on the ecosystem of study, we manually classified the type of restored ecosystem in articles and projects (hereafter "target ecosystem"). The established nine target ecosystem classes were based on a simplified classification of the IUCN's Habitats Classification Scheme (IUCN 2022): arid, coastal, forest, freshwater, grassland, marine, urban and other, when the target ecosystem did not fall into any of the previous general categories. We assigned "mixed" when several ecosystems were addressed. For each scientific publication, we identified the target ecosystem from the abstract and methods sections. 249 (10.9%) articles were not directly related to the restoration of any specific ecosystem. Similarly, we classified the target ecosystem for the practice dimension by reviewing the ecosystem classification provided by the SER Project Database.

To assess the influence of social and economic aspects on gender bias, we extracted the affiliation country of the first and the last author of publications, Twitter users and project leaders. Location of Twitter users was not available for 539 accounts (20.4%). We then calculated the Human Development Index adjusted for Inequalities (henceforth IHDI) (Hicks 1997) as a proxy of the level of socioeconomic development of the country. For authors with multiple institutional affiliations located in different countries, we selected the first affiliation country assuming to be the main affiliation (Hottenrott et al. 2021).

Statistical analysis

To calculate gender bias among people leading ecosystem restoration initiatives (first research question), we used Pearson's chi-squared tests to individually identify if there was a different proportion of men and women as first authors, last authors, Twitter users, project leaders, and practitioners who obtained a CERP or CERPIT. Papers with a single author (8.8%) were analyzed separately.

To evaluate the ~~main~~ factors that can be associated with gender bias in ecosystem restoration (second research question), we fitted generalized linear models (GLMs) with a binomial distribution and a logit link function for each dimension of the study. In doing so, we tested whether the probability of being a woman of (a) first authors (b) last authors, (c) single authors, (d) Twitter users and (e) and of project leaders varied over time and depended on the gender of the coauthor (for a and b), on the target ecosystem (for a-e) and on the IHDI (for a-e). We discarded information of 431 tweets previous to 2014, four projects without a starting year and 10 projects between 1960 and 1983 that made the temporal distribution of the projects unbalanced. Also, for the models, we only used data of target ecosystems where both genders

were represented. Multicollinearity was evaluated using the variance inflation factor (VIF), which was lower than 2, confirming no redundancy of the explanatory variables (Dormann et al. 2013). Goodness of fit was evaluated with McFadden D^2 (McFadden 1973). Pearson's chi-squared tests were applied for each target ecosystem individually to identify differences in the proportion of men and women as first authors, last authors, single authors, Twitter users and project leaders.

To assess the effect of author gender on the impact of scientific knowledge on society (third research question), we fitted generalized linear mixed-effects models (GLMMs) to the number of scientific citations per article, the AAS, the number of tweets per article, and the proportion of tweets made by women and men per article. Genders of the first and last authors were included as fixed factors, and the year of publication as a random intercept, to account for the nonlinear accumulation of citations and mentions through time and the increased popularity of Twitter in more recent years (Liu et al. 2014). For the GLMMs on citations, AAS and number of tweets, we used a negative binomial distribution, after checking for overdispersion. For the proportions of tweets made by male and female users, we used the beta distribution with logit link function after applying the transformation proposed by Smithson and Verkuilen (2006) to the data. Fit of GLMMs was evaluated by the linear relationship between observed and predicted values.

All statistical analyses were performed using the R statistical software version 4.0.5 (R Core Team 2021). We fitted GLMs and GLMMs using *lme4* (Bates et al. 2015) and *glmmTMB* packages (Brooks et al. 2017). The p-values for models fitted with *lme4* were calculated with *lmerTest* package (Kuznetsova et al. 2017). Model predictions were calculated with *ggeffects* (Lüdecke 2018). Data manipulation and plotting was mostly done with *tidyverse* (Wickham et al. 2019) and *patchwork* (Pedersen 2020), and we used *googledrive* package to facilitate the workflow during the analysis (McGowan & Bryan 2020).

RESULTS

Restoration leaders and gender bias

Men were the primary leaders in research, outreach and practice initiatives in ecosystem restoration (**Figure 1**). This leadership was greater in more advanced career stages, such as last authors in the research dimension, and project leader or CERP in the practice dimension.

Factors influencing the gender of restoration leaders

Gender differences were affected by different factors in each dimension (**Figure 2; Table S2**). The probability of being a female researcher increased over time (**Figure 2a**), although it was not enough to reach equality (i.e. probability = 0.5). The significant trend over time was noticeable only for first authors of scientific articles (**Table S2**). Gender equality in research was independent of the coauthor gender for both first and last authors (**Figure 2a**; **Table S2**). In outreach and practice, the increase of gender equality over time was not significant when looking at the gender of Twitter users and project leaders (**Figure 2a**; **Table S2**). Projects tended to be led by women more frequently in more developed countries, as indicated by the increasing probability of finding a female project leader with higher IHDI (**Figure 2b,** fourth panel; **Table S2**). However, inequality in science was independent of IHDI (**Figure 2b,** first and second panels; **Table S2**) and gender bias persisted in restoration science and practice in all countries.

Men dominated the three dimensions for most target ecosystems (**Table S2**, **Figure 3**). When considering confounding factors such as year, gender of coauthors and IHDI, the level of dominance of men was similar for every target ecosystem (**Table S2**). Analyzing by target ecosystem, we observed that forest and freshwater ecosystem articles, tweets and projects were significantly less lead by women. Additionally, the proportion of women as last authors was significantly lesser in all ecosystem types except for urban. A lower proportion of women was also found in coastal ecosystems, for first and single scientific authors, and in grassland ecosystems, for single authors and Twitter users (**Figure 3; Table S3**).

Impact of publications on the scientific community and transference to society

Authors' gender did not affect the scientific impact of the articles (i.e. number of citations), but when the last author was a male researcher, articles had higher AAS (**Figure 4b; Table S4**). In general, male authors of scientific papers received more mentions in dissemination channels than female authors (**Figure S2**). Regarding Twitter, where mentions were further analyzed considering the year, mentions did not depend on the gender of the researchers (**Table S4**). Institutions mentioned both genders equally on Twitter, but male Twitter users tended to mention articles authored by men, and female Twitter users tended to mention articles authored by women. Specifically, the proportion of tweets made by women was higher for female last authors (**Figure 4d**), and the proportion of tweets made by men was higher for male first authors (**Figure 4; Table S4**).

DISCUSSION

Our study shows that gender inequality persists in each dimension of ecosystem restoration –research, outreach and practice–, especially in more advanced career stages. However, the number of female research leaders has increased over the last few years and a similar increment has been observed in projects carried out in more developed countries. Men dominated research, outreach and practice in most target ecosystems. Results also suggest that the scientific impact of knowledge gained was independent of the author's gender, but senior male researchers seem to reach broader society more easily. On Twitter, each gender tended to share articles authored by people of the same gender.

Gender bias persists in restoration leadership

Our analyses uncover a higher proportion of male restoration leaders in all the restoration dimensions studied. The underrepresentation of female researchers, especially as last and single authors, has been previously observed (West et al. 2013). Gender inequality may hinder ecosystem restoration success (Ota et al. 2020) and women's inclusion in restoration research is crucial to include equally the perspectives of both genders in order to provide comprehensive solutions for present restoration challenges (Nielsen et al. 2017). Our results showed that the probability of being a woman as first author did not vary as a function of the gender of the senior author on a manuscript (last author). This contrasts with previous studies which found a higher proportion of women when the senior author was also a woman across the ecological literature (Fox et al. 2016, 2018). One of the reasons may be that ecosystem restoration is a relatively young discipline in comparison with more traditional research areas or subfields of ecology (Matzek et al. 2017), so gender might not be as decisive in creating a research team.

Gender-biased communication practices occur in mass media and they affect society's informational and educational processes (Iranzo-Cabrera & Gozálvez Pérez 2021). In general, women are underrepresented and represented in a stereotypical way in traditional media (D'Heer et al. 2020). Our results indicated that male scientific authors tend to receive more mentions in dissemination channels than women. Communication of scientific results determines their consideration for practical application (Fabian et al. 2019), and gender differences between the person responsible for producing the results and the person communicating them might affect restoration outcomes. Thus, communication gender bias could diminish the transfer of women's scientific research.

Inequality exists at all levels of authority in the labor market (Smith 2012), in terms of participation, employment, professional conditions and remuneration, independently from the educational level achieved by women (Castellano & Rocca 2019). Our results regarding restoration practitioners mirror this reality, showing that further efforts are needed to truly conquer equality among ecosystem restoration professionals. Women are crucial stakeholders in rural areas, where many restoration practices take place (Ceccon et al. 2020; Wells et al. 2021), and this role is significantly important in developing countries (Mbile et al. 2019). Thus, they should be included in the implementation of restoration initiatives that truly satisfy society's needs (de Siqueira et al. 2021).

Further studies should explore if gender bias in ecosystem restoration research also occurs in journals with different impact factors (Holman et al 2018) and whether it depends on the number of co-authors (Bendels et al. 2018). Also, future studies should assess whether the outreach of research articles reflects the proportion of female and male researchers, or whether the *symbolic annihilation* of women in outreach (i.e. ignoring women or portraying them in stereotypical roles; Tuchman 2000) persists when a broader community is considered. It would also be desirable to address the effects of gender bias on the success of restoration practices in further studies.

Need for restoring the leaky pipeline

The number of scientific articles in ecological restoration led by female authors has increased over the last few years, as has been previously observed in ecology (West et al. 2013) and other fields (Helmer et al. 2017; Huang et al. 2020). The significant trend over time towards equality in our study was noticeable only for first authors of scientific articles, but not for last and single authors and practitioners, highlighting the difficulty that women face in reaching leadership positions. This idea is in consonance with other results of this study that suggested a larger presence of male last authors, project leaders and CERP practitioners, i.e., more advanced career stage positions. Other studies obtained similar results when studying authorship roles usually associated with seniority (Duffy 2017; Holman et al. 2018; Fox et al. 2018; Kwiek & Roszka 2022). The difficulty for women to reach leadership positions has also been largely described in other sectors outside academia (Cotter et al. 2001). In research, this process is depicted with the "leaky pipeline" metaphor (Pell 1996; Huyer 2015; Resmini 2016), in reference to the way women are lost ("leaked") when the academic career ("pipeline") progresses.

Women find more obstacles than men to stabilize their careers and reach senior positions as ecosystem restoration leaders. These difficulties include the *maternal wall* (i.e., the lower

performance during maternity leave), higher scrutiny of women's performance or the lack of recognition and support for leadership (Williams 2013; Huyer 2015). The prevalence of male senior leaders (Morley 2013) is a result of the efforts women need to make to break the "glass ceiling", i.e., the gender barriers hindering the attainment of high-status positions (Heinrichs et al. 2022). The leaky pipeline effect is aggravated by the "sticky floor" –a discriminatory pattern that increases the risk of women staying in lower ranks and/or abandoning their careers (Ciminelli et al. 2021). For example, women are more likely to receive lower salaries and leave their jobs as they still have higher childcare and housework responsibilities (McGuire et al. 2012).

Global projections for gender equality estimate that the overall gender gap (i.e. an index composed of economic participation and opportunity, educational attainment, health and survival, and political empowerment) is projected to close in 135.6 years (World Economic Forum 2021). The short time periods considered in outreach and the low and unbalanced number of projects in our analysis may hinder the detection of any significant trend over time. Nevertheless, these results call for action in the implementation of measures to speed up gender equality in ecosystem restoration, especially considering that some social perturbations, such as the COVID-19 pandemic (Collins et al. 2021; World Economic Forum 2021), negatively affect the gender gap and reverse the advances acquired over decades.

Socioeconomic and ecological factors affect gender equality

While no significant differences were found in the number of female research leaders among the major regions of the world, projects tend to be led by women more frequently in more developed countries, where women's rights and opportunities are likely to be more equal (World Economic Forum 2021). On the contrary, the independence of gender bias from the IHDI in restoration research and communication might indicate that cultural or other societal aspects are still highly rooted in more developed countries. For example, Holman (2018) found that countries in which children of both genders attend school longer have more female authors, while countries with higher *per capita* income have fewer female authors. Also, the shortage of data in less developed countries, and the imbalance among the number of articles per country, may not allow us to analyze the complete gradient of development and inequalities and thus, prevent us from seeing any stronger tendency.

Gender inequality was present in most target ecosystems for the three dimensions. Male leaders were dominant in those ecosystems with longer tradition in restoration initiatives, such as forests, freshwater and grasslands. In restoration practice, the number of male leaders was higher in all target ecosystems and it is likely we did not find significant differences in some

ecosystems due to the low sample sizes. Since gender equality may be related to successful restorations (Ota et al. 2020), special effort should be made to reach equality for those ecosystems that are of extremely valuable but are highly threatened (e.g. wetlands; IPBES 2018). Active measures should be especially applied to include women in regions where they have fewer opportunities, given that many of the most valuable ecosystems are located in less-developed countries (Williams 2013).

Other variables not considered in this study may interact with socioeconomic and ecological factors to explain gender bias, such as the cultural constructions that deter women from participating in STEM disciplines, the type of organization implementing restoration projects (NGOs, public sector or private sector), the country where the studies or projects are carried out (often different from the origin country of the leader), the freedom of expression of each country, or the presence of proactive measures towards equity of the institutions involved in restoration.

The scientific impact outside academia depends on the authors' gender

Our results indicate that the first and last authors' gender may not determine the scientific impact of the published articles (measured as the number of citations). This observation is consistent with other studies in the field of ecology (Borsuk et al. 2009; Cameron et al. 2016), but contrasts with others (Fox et al. 2018; Bendels et al. 2018). Different outcomes can be obtained if various scientific journals, differing in their impact factor, are included in the analysis. An article published in a higher impact journal might likely have more citations, and a lower proportion of female first and last authors in these highly-competitive journals may exist (Bendels et al. 2018; Lundine et al. 2018).

The gender of an author and the gendered stereotypes established in their research area could impact the perceived scientific quality of their work (Knobloch-Westerwick et al. 2013). This perception may be important in ecosystem restoration considering that we found a higher dissemination of men's scientific production when they were last authors, but no differences in the number of citations between female and male authors. Traditionally, there has been a higher proportion of men as heads of labs (Lerchenmueller & Sorenson 2018), with the opportunity to develop their conceptual ideas in articles where they appear as last authors. Some of their publications, or even themselves, can become references in their respective study fields, with a high social impact and dissemination in social media, news, etc. For example, those researchers with more followers on Twitter are mostly men (You 2014).

Twitter users are prone to mention articles with authors of their same gender. This result may be related to the inequality in social networks among men and women (Lin 2000) that have been demonstrated to impact education (Raabe et al. 2019) and work (Collischon & Eberl 2021). The patterns observed in Twitter could sustain gender bias and stereotypes hindering the equality of ecosystem restoration. Although the Twitter environment has been described as mainly stereotype-free and includes positive discourses about gender disparity in STEM (Stella 2020), patterns of male professionals being more proactive in gaining recognition from their male peers in Twitter has also been described (Maares et al. 2021). Our results show this homophilic behavior for both genders. Nevertheless, this pattern may also be affected by a common practice among certain Twitter users to write tweets about their own articles.

Towards gender equality in ecological restoration

Identifying where gender gaps persist is essential to increase awareness and improve the representations of diverse genders. Tulloch (2020) raises the importance of creating good practice guides to incorporate gender information, which can be sensitive in many contexts, but could help to address inequality if they are applied to ecosystem restoration. For example, the collection of data in conferences relative to gender of attendees, speakers, scientific committee, and organization staff can reveal barriers to women in academia (Lupon et al. 2021) since conscious or unconsciousness of gender bias is responsible for women's underrepresentation in science (Skov 2020). In practice, gender equality should be included and evaluated as a critical determinant for the success of any restoration initiative (Broeckhoven & Cliquet 2015).

In the following paragraphs, we have compiled some actions that could be considered to promote female participation in the three dimensions in ecological restoration ~~(**Table S5**)~~. In research, gender equity should be considered in work teams and advisory groups. Also, organizational structures in departments could detect problems, priorities, and strategies to enhance female participation in science. Efforts from investigation departments or institutions should promote the same opportunities in funding, travel, research stays and conferences and assure equal pay (Huyer 2015; Grogan 2019). Peer-review gender bias should be monitored to ensure a merit-based system that depends on the value of the scientific contribution (Helmer et al. 2017; Holman et al. 2018). Lastly, recognition of women's achievements by society should be renowned. This recognition may help women themselves to recognize and self-promote the value of their work which has been proved to be underestimated among female researchers, with a higher risk of reducing the impact of their publications (Lerchenmueller et al. 2019).

Regarding outreach, equality policies should be incorporated in conferences (congresses, workshops, symposia, discussion panels) that contribute to having a representative gender ratio (Holman et al., 2018). Including gender topics in congresses can help to account and speak about gender imbalances in ecosystem restoration and to raise awareness in inclusiveness (Lupon et al. 2021). Additionally, in order to achieve inclusive science communication, it would be necessary to critically analyze language regarding intentionality on gender identities, reciprocity in the recognition of various forms of expertise in research and practice and reflexivity on the communicators' and audiences' personal identities, practices, and outcomes (Canfield & Menezes 2020). In addition, more dissemination of women's contributions to ecosystem restoration towards society (specially to young generations) is needed (Damschen et al. 2005).

In practice, transparent evaluations during hiring and promotion processes should be ensured for leadership and decision-making positions, to mitigate unconscious selection biases (Grogan 2019). Implementation of gender policies in the workplace that address the acceptance and disadvantages of needed work-life balance is essential (Huyer 2015). The elimination of the pay gap is a fundamental first step. Also, it is important to start with the attenuation of biased cultural beliefs, such as the inappropriateness of women pursuing higher roles (Sterling et al. 2020) or physically demanding tasks, through education in equality and awareness-raising campaigns, the promotion of public debates regarding feminist issues, supporting diverse representation and empowerment, and by developing and strengthening legal regulations. As a conclusion, women should be included in the entire cycle of restoration projects, from the inclusion of gender in project design and monitoring, to the consideration of women as equal stakeholders in the decision-making process (Lau 2020; de Siqueira et al. 2021).

Our results showed that gender gaps are present in research, outreach and practice in ecosystem restoration. There is a need to address the barriers that are affecting this inequality globally, that ensure the recruitment and retention of women in restoration, by implementing actions and effective policies. The United Nations is clear in this sense, including gender equality and empowerment of women and girls as one of its Sustainable Development Goals. This need is directly allocated to the field of ecosystem restoration by the declaration of the Decade on Ecosystem Restoration, and specifically the promotion of women in science has been claimed by UNESCO for decades (Huyer 2015; UNEP & FAO 2020). Ecological restoration societies must encourage gender equality to overthrow structural barriers from science to practice.

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FIGURE CAPTIONS

Figure 1. Percentage of female and male researchers, communicators and practitioners from total people classified by gender in each category. The dotted line marks 50%, that is, gender equality.

Figure 2. Probability of being a female first and last research author, Twitter user and project leader as a function of (a) year, and (b) the Human Development Index Corrected by Inequalities. Shaded areas represent the 95% confidence interval of the prediction. The dotted line marks 0.5 of probability, that is, gender equality.

Figure 3. Proportion of researchers (first authors), Twitter users and practitioners leading restoration initiatives by gender and target ecosystem. Numbers represent the number of publications, tweets or projects by target ecosystem. The white dots represent the proportion of female last authors and blue triangles the proportion of female single authors. The dotted line marks a proportion of 0.5, that is, gender equality.

Figure 4. Predicted values of the (a) Altmetric Attention Score, and of the proportion of tweets made by (b) female users and (c) male users considering the gender of last or first authors of the scientific publications, respectively. Line ranges represent the 95% confidence interval of the prediction.

FIGURES

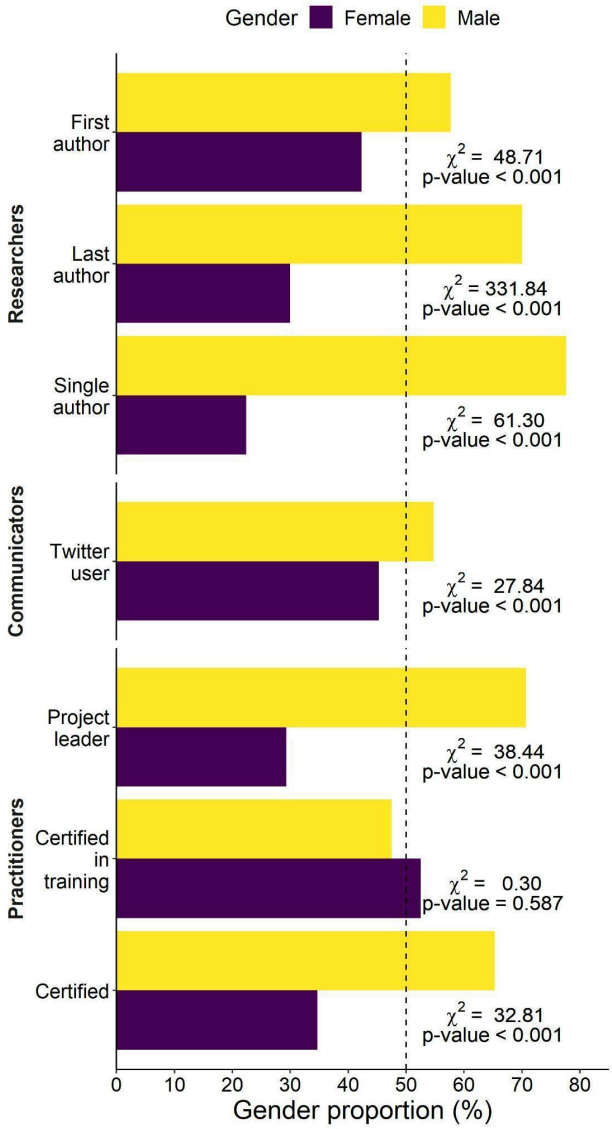
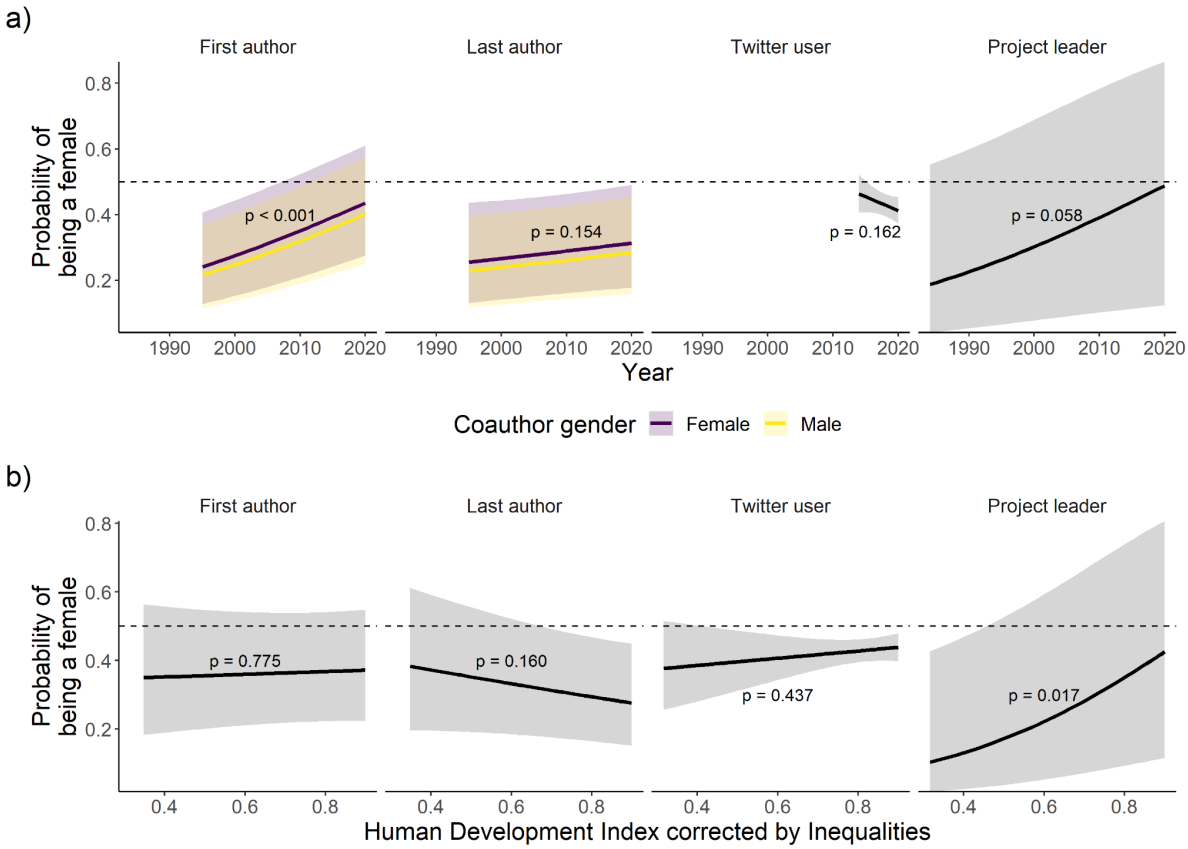


Figure 1



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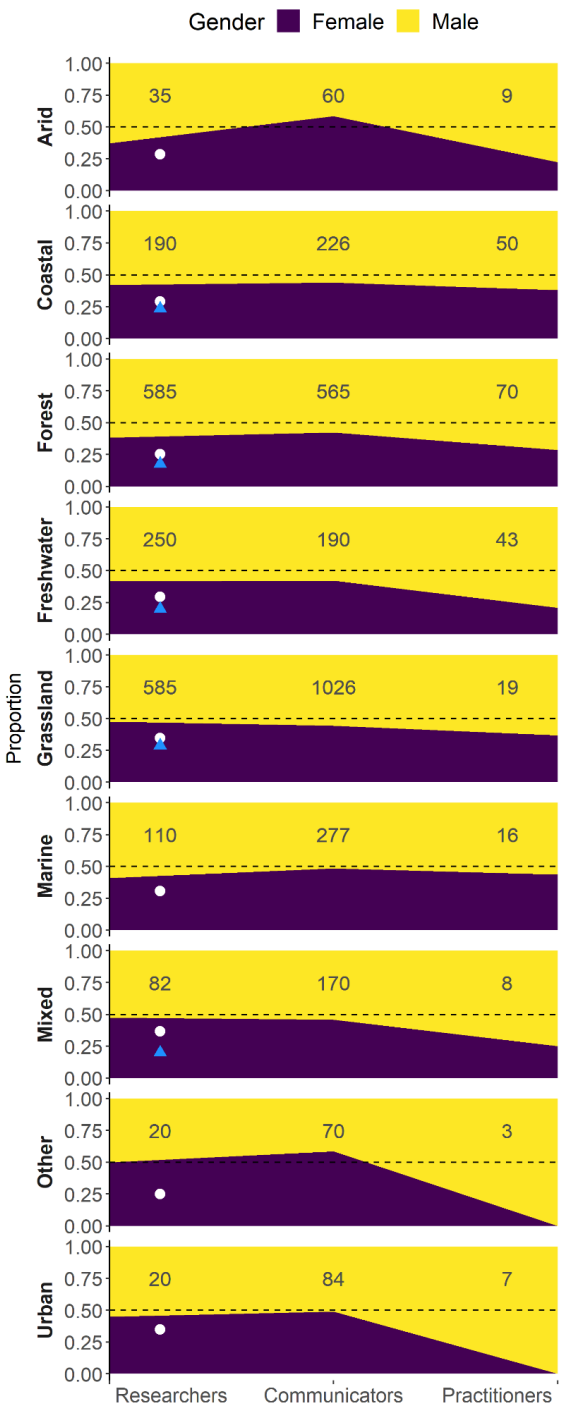

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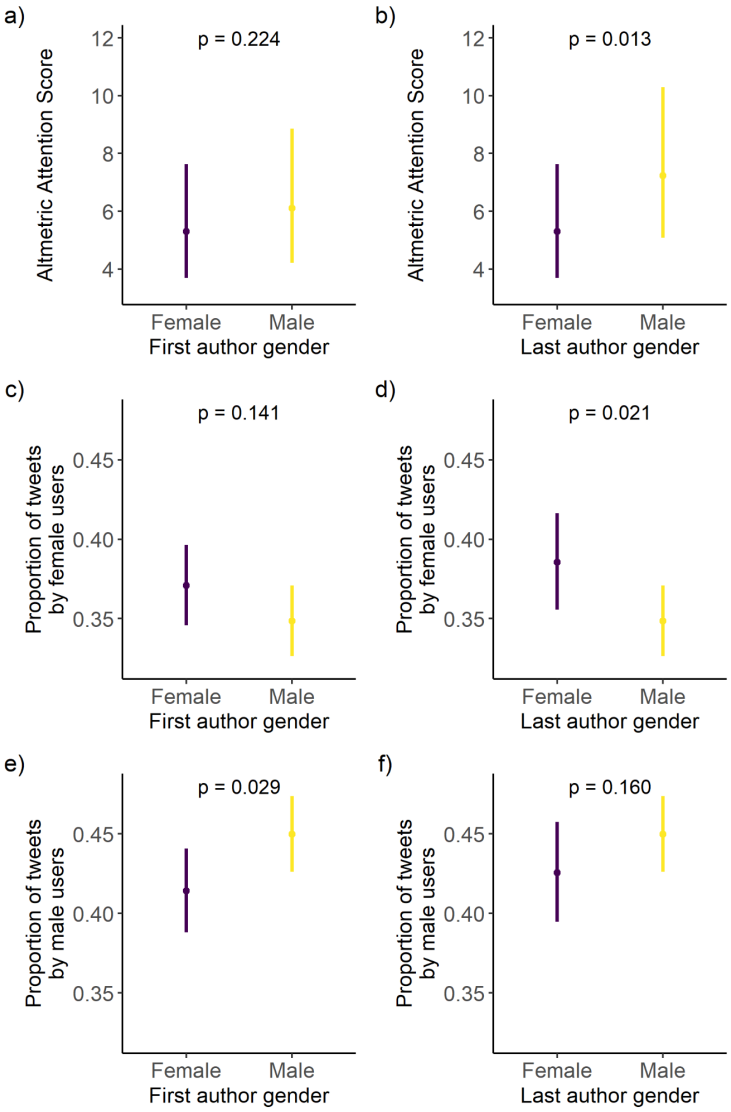

Figure 4.