

REVIEW

Fewer than three percent of land plant species named by women: Author gender over 260 years

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Abstract How has women's contribution to science developed over multiple generations? We present the first quantitative analysis of the role played by women in publishing botanical species names, and the first complete analysis of women's contribution to a field of science with a timeframe of more than 260 years. The International Plant Names Index and The Plant List were used to analyse the contribution of female authors to the publication of land plant species names. Authors of land plant species were automatically assigned as male or female using Wikipedia articles and manual research. Female authors make up 12.20% of the total number of authors, and they published 2.82% of names. Half of the female authors published 1.5 or more names, while half the male authors published 3 or more names. Female contribution has accounted for more than 1% of new species names since 1900, and now stands at 11.97%. The difference in productivity between male and female authors has declined over time, and female authors are now 80% as productive as their male counterparts. In spite of botany's traditional image as a feminine pursuit, women's contribution was not significantly reflected in species authorship until the twentieth century, around the same time as in other branches of science.

Keywords biodiversity inventory; botany; history of science; new species; nomenclature; women in science

Supplementary Material The Electronic Supplement (Tables S1–S2; Fig. S1; Appendices S1–S4) is available in the Supplementary Data section of the online version of this article at <http://www.ingentaconnect.com/iapt/tax>

■ INTRODUCTION

Women are less likely than men to become scientists (UNESCO, 2007) and female scientists publish less than their male counterparts (Lariviere & al., 2013). Gender representation in science is a debated issue (e.g., Ceci & Williams, 2010; Moss-Racusin & al., 2012; Shen, 2013) but recent research has focused on the last 50 years, covering only one or two generations of scientists (e.g., Jagsi & al., 2006; Kaufman & Chevan, 2011; Duch & al., 2012). How has female contribution to science developed over multiple generations? Could the study of change over multiple generations help predict future dynamics and inform policy setting? Botany and the naming of land plant species offer a longer-term picture, particularly since botany has been a traditionally acceptable female pursuit (Shteir, 1996; Horwood, 2010). We quantify the gender gap in the authorship of species names since the middle of the eighteenth century using extraordinarily comprehensive records of all land plant name publications and their authors over the last 260 years, the International Plant Names Index (IPNI, 2015) and The Plant List (The Plant List, 2013). This is the first exploration of gender differences in global biodiversity inventory and the first study documenting female

participation in a branch of science with a timeframe of more than 260 years.

Biodiversity inventory is an ongoing process as botanical exploration continues, and some 2000 new plant species are described every year (Prance, 2001; Bebbler & al., 2010). Binomial species names have been in use since Linnaeus's *Species plantarum* (Linnaeus, 1753; Jarvis, 2007). Botanical nomenclature is reliant on accurate historic records, which have been kept from 1753 to the present day, and is governed by a set of nomenclatural rules which have remained largely unchanged over this period (Knapp & al., 2004; Brummitt, 2006; Rivera & al., 2014). Under the *International Code of Nomenclature for algae, fungi, and plants* the earliest name published for any species is the one that must be used, except in a few very specific circumstances (McNeill & al., 2012; Turland, 2013), maintaining a continuous requirement for the indexing of historical literature. The accurate record keeping in this discipline and the relatively little change in species naming rules makes it an excellent model system in which to study trends in scientific publication across a large span of time.

The International Plant Names Index is a globally comprehensive dataset of seed plant, fern, and lycophyte names published from 1753 onwards and all botanical name authors,

underpinning all botanical biodiversity informatics (e.g., WCSP, 2015; Roskov & al., 2015), and The Plant List (comprising 1,296,662 scientific plant names in version 1.1, published in 2013) is a compilation of databases representing the best currently available list of all vascular plant and bryophyte species (The Plant List, 2013). A predecessor to IPNI, *Index Kewensis*, was personally commissioned by Charles Darwin who left a provision in his will that “£250 annually be left for 4 or 5 years” in order to compile a list of all known plants (Allan, 1967; Meikle, 1971). IPNI has been compiled and maintained at the Royal Botanic Gardens, Kew with collaborators at Harvard University and the Australian National Herbarium to the same high standards since and was converted to a CD-ROM in 1993, then to an online format in December 1999 (Croft & al., 1999; Nic Lughadha, 2004; IPNI, 2015). IPNI coverage included 42,887 individual authors in August, 2013. The authors of every plant name are documented and every author has a unique standard form (e.g., “L.M.Gardiner” for Lauren Maria Gardiner 1981– and “Voronts.” for Maria Sergeevna Vorontsova 1979–; McNeill & al., 2012). As the number of authors increased, updated reference lists were published (Meikle & al., 1980; Brummitt & Powell, 1992), maintained by IPNI, which is now the de facto international standard for botanical nomenclature authorship. IPNI and The Plant List are unparalleled and complete resources, enabling us to trace the numbers of male and female authors and the numbers of plant species names they published over more than 260 years of biodiversity inventory (1753–2013).

■ MATERIALS AND METHODS

We compiled a list of binomial species names that were published with the intention of describing land plant species new to science. We therefore document the publication of new plant species names as understood by taxonomists at the time, including names now considered to be synonyms. A total of 1,064,035 plant species name publication records were downloaded from The Plant List database version 1.1 published in

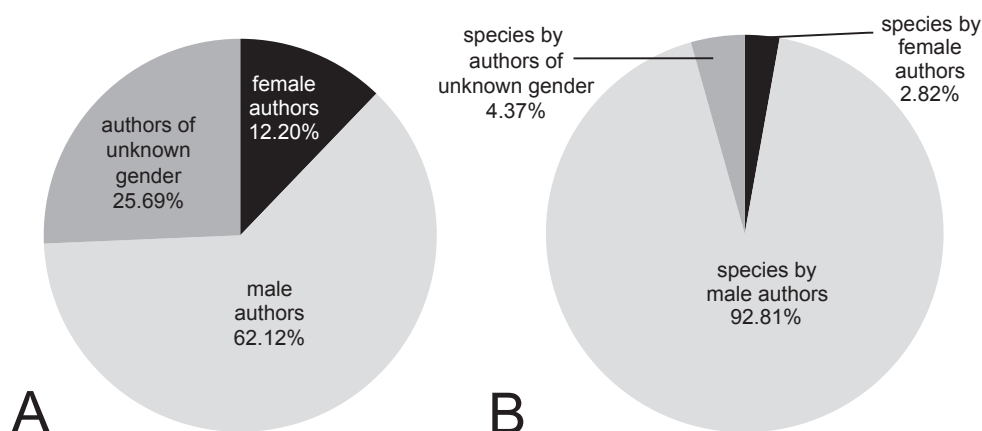
Table 1. Number of male and female authors of plant species names (1753–2013).

	Number of authors	Percentage of authors
Male authors	9,693	62.12%
Female authors	1,903	12.20%
Gender unknown	4,008 (including 1,684 with no record of first name)	25.69%
Total	15,604	

2013 (Electr. Suppl.: Table S1) including currently accepted species, synonyms, and unassessed (not marked as accepted or synonym) species names for flowering plants, ferns and bryophytes. In order to include newly published plant species only (e.g., not including the names published when a known species is moved to a different genus—known as “new combinations” or “replacement names”), we omitted species names marked as such and species names with parentheses in the author string. The list of species names was de-duplicated based on species name and year, eliminating duplicate species names while keeping homonyms. Author strings were cleaned to eliminate author names before “ex” and after “in”. Author strings with multiple authors were split and proportional contribution per author was assigned, e.g., for plant species names with three authors each author was assigned a score of 0.33.

Authors of plant species names were automatically scored as male, female, or unassigned, using a database compiled from Wikipedia articles on first names (Appendices S1–S4). Every unassigned author name with full first name information was visually examined and scored manually, as far as possible. Manual checks with additional literature research were carried out for all authors identified as female, all authors who have published more than 10 names, and the 500 most productive authors identified as male. Corrections were made, for example, all authors with the first name “Jean” were automatically marked as female and had to be checked and reassigned

Fig. 1. Total numbers of authors and new plant species names published (1753–2013). **A**, Percentage of male and female authors of land plant species names; **B**, percentage of species names published by male and female authors.



manually, e.g., Jean Marie Bosser 1922–2013. The final dataset of 15,604 plant species name authors who contributed to publishing species in The Plant List includes 9693 male authors, 1903 female authors, and 4008 unassigned authors (Table 1; Fig. 1A; Electr. Suppl.: Table S2). Of the unassigned authors 1684 have no full first name recorded (e.g., initials or only a surname).

The greatest number of unassigned authors are those with Chinese names. We researched manual name assignment by foreign language specialists and consulted Dr. Tiangang Gao (Institute of Botany, the Chinese Academy of Sciences). Names of Chinese botanists cannot be unambiguously scored as male or female and assignment can only be carried out by workers with access to relevant personnel records. We concluded that full gender assignment of all foreign language names would be better suited to a larger international collaborative project. Authors of unknown gender account for only 4.37% of land plant species names so completion of this task would not significantly alter our conclusions.

Every plant name author since 1753 has a unique author standard form (Meikle & al., 1980; Brummitt & Powell, 1992; IPNI, 2015). The high quality of these data enabled us to match authors to species unambiguously: e.g., 68 authors with the surname Smith are recorded in The Plant List. Forty-nine Smiths are known to be or have been male and have published 7196 species; four Smiths are female and have described 91 species. Records lacking publication year were included in the analysis of the overall number of plant species names but not included in the chronological analysis (Electr. Suppl.: Table S1).

Data quality has placed some limitation on the accuracy of this analysis. IPNI has invested resources into the cleaning and standardisation of author abbreviations: in 2006 approximately 64% of all author names had been standardised, increasing to 90% to 2014. Since the most prolific author names were standardised by IPNI first, the remaining 10% of non-standardised author names are linked to fewer than 10% of taxon names (IPNI, 2015). Paper volumes of Index Kewensis were digitised in the 1970s using early optical character recognition,

misreading ca. 1% of all characters (Royal Botanic Gardens Kew, 1997) and some of these remain undiscovered (IPNI, 2015). Manual scoring of unassigned names could have introduced additional bias as male historic author names are more familiar to us than female historic author names, hence the latter were less likely to be recognised.

■ RESULTS

Female authors of plant species names make up 12.20% of the total number of authors (Table 1; Fig. 1A). Female authors have published 2.82% of plant species names between 1753 and 2013 (Table 2; Fig. 1B). The relationship between the number of plant species names published by each author and the frequency of authors follows a power law distribution repeating previously published results (Electr. Suppl.: Fig. S1; Bebbier & al., 2014). The ten most productive male and female authors are listed in Table 3. The influential Swiss botanist and natural scientist Augustin Pyramus de Candolle published the highest number of plant species names in the late nineteenth century: 10,222. The most prolific female author was South African Harriet Margaret Louisa Bolus, great niece of the influential botanist and philanthropist Harry Bolus, publishing 1494 plant species in the early twentieth century. Of the 500 most productive plant name authors, 8 are female.

Table 2. Number of plant species names published by male and female authors (1753–2013).

	Number of species published	Percentage of species published
Male authors	579,757	92.81%
Female authors	17,604	2.82%
Gender unknown	27,321	4.37%
Total	624,682	

Table 3. The most productive male and female authors of land plant species names (1753–2013). Names and dates appear as published in IPNI.

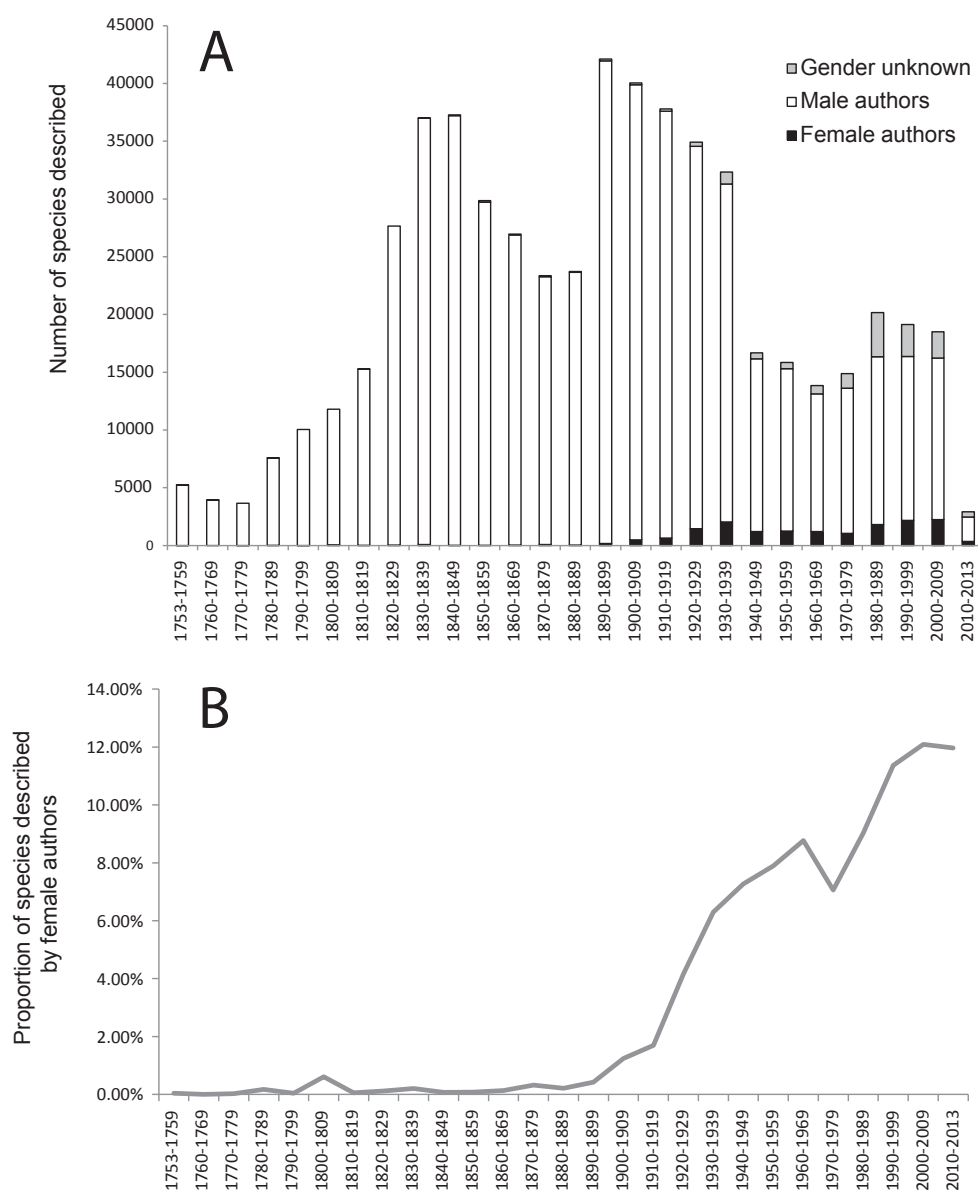
Most productive male authors		Most productive female authors	
Name and dates	Number of species published	Name and dates	Number of species published
1 Augustin Pyramus de Candolle, 1778–1841	10,222	Harriet Margaret Louisa Bolus, 1877–1970	1,494
2 Carl Ernst Otto Kuntze, 1843–1907	8,503	Aimée Antoinette Camus, 1879–1965	677
3 George Bentham, 1800–1884	8,202	Lily May Perry, 1895–1992	414
4 Carl Linnaeus, 1707–1778	7,272	Alice Eastwood, 1859–1953	395
5 Ernst Gottlieb von Steudel, 1783–1856	6,988	Olive Mary Hilliard, 1926–	372
6 Friedrich Richard Rudolf Schlechter, 1872–1925	6,695	Käthe Hoffmann, 1883–?	354
7 Pierre Edmond Boissier, 1810–1885	5,832	Charlotte Morley Taylor, 1955–	278
8 John Gilbert Baker, 1834–1920	5,724	Antonina Ivanovna Pojarkova, 1897–1980	230
9 Friedrich Anton Wilhelm Miquel, 1811–1871	4,651	Antonina Georgievna Borissova, 1903–1970	195
10 Joseph Dalton Hooker, 1817–1911	4,558	Janet Russell Perkins, 1853–1933	191

The majority of plant species name publication took place in the nineteenth and early twentieth century when access to biodiversity-rich tropical areas had been established for the first time (Fig. 2A). The first plant species published by a female author was a wild ginger, *Amomum verum* Blackw., published by the Scottish artist and businesswoman Elizabeth Blackwell in 1757 (Blackwell, 1757: tabula 371). The first volume of her herbal of 500 prints (Blackwell, 1737) was so successful it was re-published in Germany (Tjaden, 1972; Evenden, 2004) four years after the formal start of the Linnaean naming system for plants. This species name is still in use today (Lamxay & Newman, 2012). The next plant species published by a female author was not until the 1780s. Only in the twentieth century did female authored plant species names account for more than 1% of all newly published plants (Fig. 2B). Female authorship slowly rose throughout the twentieth century, with some

fluctuations, until the proportion of plant species names published by women exceeded 10% in the 1990s, and has remained more or less constant since. The percentage of plant species names described by female authors has never risen above 12%.

The number of plant species names published per author is consistently lower for women (Fig. 3). The most common number of names for an author to publish regardless of gender is one (Electr. Suppl.: Fig. S1). The mean number of names published by female authors is 9.3 while the mean number published by male authors is 59.7 (Fig. 3A). The median number of plant names published by female authors is 1.5 species each, while the median for male authors is 3 (Fig. 3A). The difference in productivity between the genders has declined over time (Fig. 3B, C) and over the last two decades of this study (between 1990–1999 and 2000–2009) female authors have on average published 80% of the number published by their male counterparts

Fig. 2. Number of land plant species published 1753–2013. **A**, Total number of species names published by male and female authors in every decade from 1753 to 2013; **B**, percentage of species published by female authors in every decade from 1753 to 2013. The 1753–1759 category includes species published over just seven years, reflecting the start of Linnaean nomenclature in 1753. The 2010–2013 category includes only some of the species published over the three years as not all the literature from 2012 and 2013 was fully indexed at the time of this study.



Who are the historically significant female plant species authors? Many seem to have been brought into that role through family circumstances. Elizabeth Blackwell published her botanical art to release her husband from a debtors' prison (Evenden, 2004). Harriet Margaret Louisa Bolus assisted her great-uncle, and her employment at the Bolus herbarium was a condition of his bequest to the University of Cape Town (Cape Argus, 1911; Gunn & Codd, 1981). Aimée Camus grew up assisting her botanist father from a young age and continued his work on the family Poaceae after his death (Leandri, 1966). In contrast Alice Eastwood, the fourth most productive female author, was a teacher who taught herself botany and became Curator of Botany Emeritus at the California Academy of Sciences and the honorary president of the Seventh International Botanical Congress (Howell, 1954). Lily May Perry and Janet Perkins were also teachers (Howard, 1992; Singer, 2003). The

Neotropical Rubiaceae specialist Charlotte M. Taylor at the Missouri Botanical Garden is the only one of the ten most productive female botanists who continues work today.

DISCUSSION

We present the first analysis of the role played by women in publishing plant species names and the first complete analysis of women's contribution to any branch of science with a timeframe of 260 years. Female authors published very few species until 1990, and are currently contributing ca. 12% of new plant species names (Fig. 2). The only comparable modern study is that of the 1.5 million paper corpus of scholarly literature, 1665 to the present day, held by JSTOR (West & al., 2013) which was not able to fully account for pre-1990 article

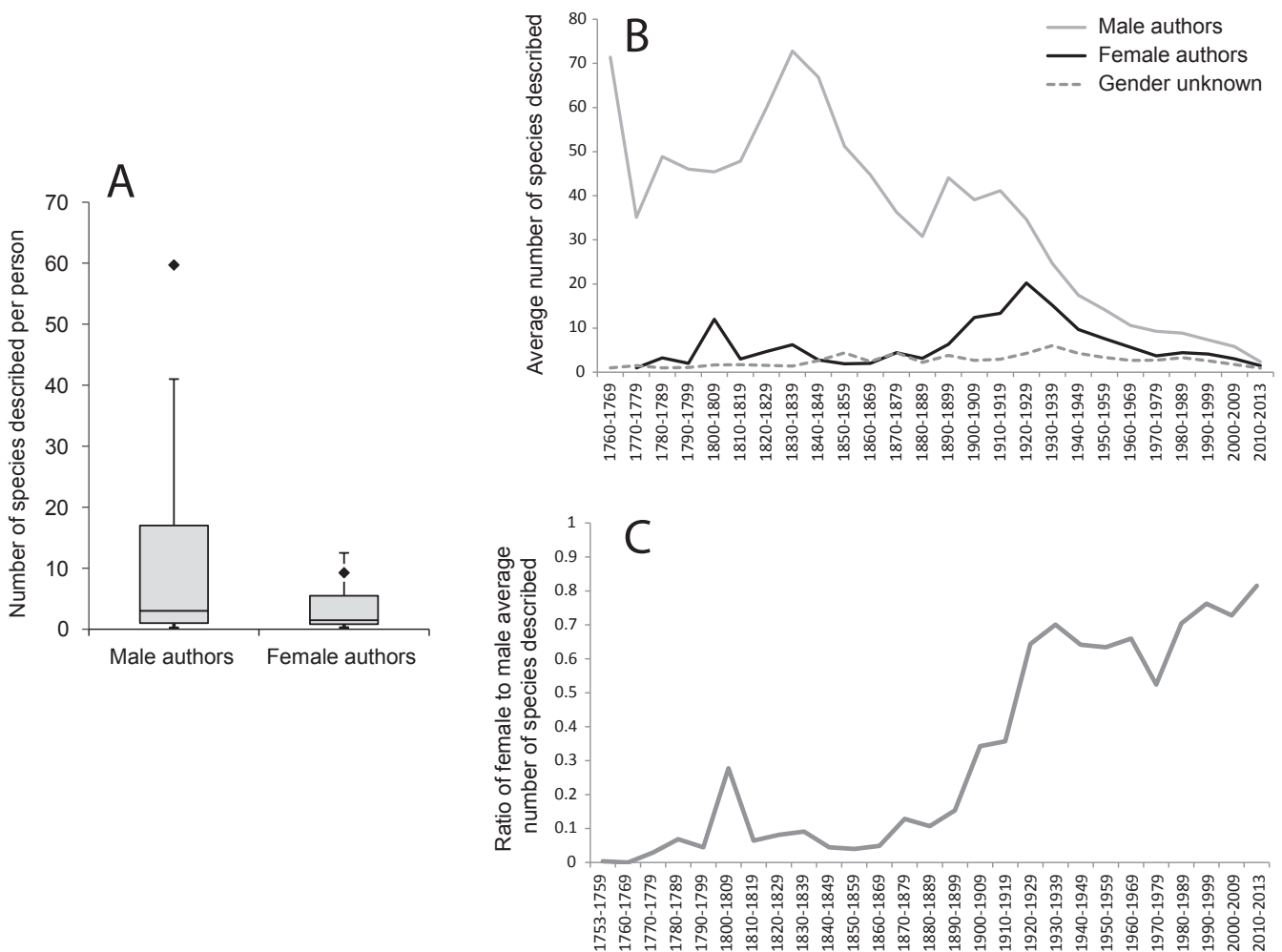


Fig. 3. Productivity of male and female authors, 1753–2013. **A**, Number of species names per author, published by all male and female authors, visualised using Tukey boxplots. Lines within boxes represent median values, boxes represent interquartile ranges, bars represent 1.5 of the lower and upper quartiles, black diamonds represent the mean number of plant species names published per author. **B**, Productivity in every decade from 1753 to 2013. **C**, The ratio of female to male author productivity in every decade from 1753 to 2013. The 1753–1759 category includes species published over just seven years, reflecting the start of Linnaean nomenclature in 1753. The 2010–2013 category includes only some of the species published over the three years as not all the literature from 2012 and 2013 was fully indexed at the time of this study.

authorship. The consistent quality of historic and modern day records in IPNI and The Plant List, and our use of Wikipedia and manual assignment of author names to gender (instead of the U.S. Social Security Administration records, limited to first names, and popularly used in the U.S.A.) have allowed us to compare data across the full 260 year time period. The overall number of women involved in naming plant species is lower than in the JSTOR records: female authors represent 20.8% of all scholarly authors and 22.76% of authors in ecology and evolution (West & al., 2013), compared to 12.20% of female plant species name authors in our study.

We present the first known study of a long-term reduction and gradual closing of a gender gap in productivity (Fig. 3). The recurrent theme in other studies, of lower productivity for female academic authors, as measured by fewer publications per person and per career and lower impact of these publications (e.g., Kaufman & Chevan, 2011; Duch & al., 2012), is in agreement with our results. Just 12% of pre-1990 single author articles are written by women (West & al., 2013) yet female authors have published a negligibly small proportion of pre-1900 plant species (Fig. 2). Approximately 20% of scholarly authors between 1900 and 2000 were female and yet female authors account for 5% of the new plant species names published during that time period. The productivity gap as measured by the average annual number of publications per author has remained roughly constant between 1960–2010 in the fields of engineering, chemistry, molecular biology, and psychology (Duch & al., 2012). Our results show male and female plant species publication productivity steadily decreasing but also converging between 1753 and 2013, with women describing on average 80% as many species as men from 1980 onwards.

What is behind the long-term trends in overall contribution and productivity, and is this pattern unique to naming plants? The study of plants was considered to be a feminine pursuit and was popular among British ladies from before 1753, including Queen Charlotte who began to study botany seriously in the 1770s and ensured her daughters studied it, too (Shteir, 1996). In spite of the extensive research being carried out by women, their contribution to the formal naming of plant species before 1900 seems to have remained largely undocumented, as exemplified by Jane Colden, the daughter of a keen botanist and New York's surveyor-general, who described over 400 species of plants during the 1750s but was not successful at getting her manuscript published in spite of her father's efforts (Shteir, 1996). The mycologist and writer Beatrix Potter had her work rejected by the then Director of the Royal Botanic Gardens, Kew, William Thiselton-Dyer in 1896, and was barred from presenting a paper at the Linnean Society in 1897 (Horwood, 2010). Female contribution to formal species publication is lower than female participation in the botanical community: 8%–18% of the U.K. Botanical Exchange Club members 1856–1932 were female (Groom & al., 2014). Significant occurrence of female authorship in plant species naming did not begin until after 1900, roughly the same time as for the other sciences (West & al., 2013). Unlike the other sciences, the rate of publication of new plant species names has decreased since the nineteenth and early twentieth century, and the lack

of mainstream scientific interest in the field could have made it more accessible to modern women.

The assessment of women's contribution to land plant species naming has shown patterns previously undetected in other sciences. The gap in productivity between male and female authors has become smaller and has almost been closed. The total female contribution to the naming of plant species has nevertheless risen only to 12%. Multiple generations of women, participating in a scientific discipline traditionally considered to be suitable for women, have not yet closed the gap.

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