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Finding spider woman: the past and present role of women in arachnology

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Abstract

As with many scientific disciplines, arachnology has long been male dominated. This gender bias has been changing gradually over the years, with some prominent early pioneers playing influential roles. Starting with Eliza Staveley in the mid-1800s, women pursued arachnology in a somewhat clandestine manner. The frequency with which women became involved in the study of arachnology increased considerably in the early and mid-1900s, although women were still expected to focus their responsibilities on family before any scientific pursuit, and only very rarely held any kind of academic position. Towards the latter part of the 1900s, there was a tremendous growth in certain areas of biology—notably behavioural ecology and biological control, both fields in which spiders are extremely amenable to study. With this growth came a new generation of independent women arachnologists. As the presence of women has grown in arachnology, so too has their ability to serve as mentors and role models to a younger generation of students from identities underrepresented in arachnology. Indeed, recent years have seen the student composition of meeting presenters reach close to a balanced gender composition. However, there is still considerable male gender bias in more senior positions in arachnology, including not only academic positions, but also first-authored papers, and oral presentations at meetings. Through examination of science and other STEM fields, we can better understand the barriers women face in academia. We conclude that, while we still have a way to go to achieve gender equity in arachnology, there are multiple avenues towards progress, including utilizing technology to better connect with students on a wider scale, improving our science communication, assessing hiring practices and tenure review, and increasing support, recognition and guidance given to early-career arachnologists.

Keywords: Araneae • arachnology • DEI • gender equity • women in STEM

Introduction

The link between women and spiders can be traced through the legends of many people. The Diné, or the Navajo people, believed in Na'ashjéii Asdzáá, the spider woman, who was the weaver of the universe. With her web weaving capabilities, she bestowed the wisdom of weaving on Diné ancestors, forming an important traditional practice (Reichard 1997). Hopi mythology tells another tale about Kókyangwúti, grandmother spider. Shaped by the god of creation, Kókyangwúti constructed all living creatures on Earth and guided humans to the fourth world, where they would reside (Mullett 1979). Greek mythology has its own tale of Arachne, a talented weaver, who offended Athena and was formed into a spider to weave for eternity, both as a punishment and as an acknowledgment of her weaving skills (Roman & Roman 2010).

Today, the link between women and spiders has changed. Female black widows and other examples of female spiders consuming male counterparts have instead created a darker association between women and spiders. A cultural example of this is the song *Black Widow* by Iggy Azalea: "I'm going to love you until you hate me, like a black widow" (Kelly 2014). Spiders and other arachnids have in general lost the respect once held by human societies. When the negative perception of arachnids and other arthropods is combined with the barriers for women entering STEM, we find a field that has been yet to reach gender equality, though similar biases exist in other zoological disciplines (Isbell, Young & Harcourt 2012; Sardelis & Drew 2016; Walker 2018; Perry *et al*. 2020; Warnock *et al*. 2020; Lerman *et al*. 2021). In the last few decades, many women have risen in arachnology, and the field has begun to welcome a much more diverse set of scientists. However, like most biological sciences, arachnology has more progress to be made. In this paper, we will discuss the history of arachnology from the perspective of gender equality and investigate the current state of the global arachnological community.

The first female arachnologists: 19th and early 20th century

Arachnological studies began to advance in parallel with other entomological pursuits, with perhaps the earliest monograph being on the spiders of Sweden by Swedish arachnologist and entomologist Carl Alexander Clerck (Clerck 1757). However, almost all early arachnologists were males (Beron 2018). Women were not publicly involved in the early works of scientific fields like arachnology during this period. However, as arachnology started to grow in the 1800s, some women became involved in the work, though often, as was common during this time (Easley 2004) removed their first names from publications, obscuring any gender. This necessity to mask gender has likely resulted in lost stories of early female arachnologists.

One of the earliest female arachnologists was Eliza Fanny Staveley (1831–1903) who published thorough and engaging compilations on British spiders and insects (Staveley 1866, 1871), the latter recognized by Alfred Russel Wallace in a book review for Nature (Wallace 1871). She published under the title E. F. Staveley, obscuring any indication of gender. However, although Staveley's identity as a female arachnologist was obscured in her major publications, she did publish short notes under 'Miss Staveley', 'On the presence of teeth on the maxillae of spiders' (Staveley 1865), and 'Observations on the Neuration of the Hind Wings of Rymenopterous Insects, and on the Hooks which join the Fore and Hind Wings together in flight' (Staveley 1860); the work itself was communicated to the Linnean and Zoological societies by John Edward Gray. As the Linnean society did not accept women fellows until 1904, presentation by a female author may have not been supported.

Figs. 1–22: Women pioneers in arachnology, in order as cited in the text. **1** Elizabeth Maria Gifford Peckham (1854–1940), from Wikidata (2021); **2** Elizabeth Bangs Bryant (1875–1953), from Shea (2021), courtesy Museum of Comparative Zoology, Harvard; **3** Harriet Exline (1909–1968), from Peck (1969); **4** Rita Schiapelli (1906–1976; left) and Berta Gerschman de Pikelín (1905–1977; right), courtesy Danni Sherwood, BMNH; see also Brescovit *et al*. (2017); **5** Tamara Mkheidze (1915–2007), from Marusik and Otto (2008); **6** María Rambla Castells (1918–2016), from Barrientos Alfagame *et al*. (2014), photo G. Giribet; **7** Jadwiga Łuczak (1920–2007), from Dąbrowska-Prot and Kajak (2007); **8** Valerie Todd Davies (1920–2012) from Davies and Monteith (2013); **9** Lyn Forster (1925–2009) from Vink *et al*. (2009); **10** Frances Murphy (1926–1995), from Arzuza Buelvas (2018), photo by Rowley Snazell; **11** María Elena Galiano (1928–2000), from Brescovit et al. (2017), MACN; **12** Lorna Levi (1928–2014) from Maddison (2014); **13** Barbara York Main (1929–2019) from Harvey (2019), photo John Banister; **14** Beatrice Vogel (1930–2018) from Writer (2018); **15** Christa L. Deeleman-Reinhold (b. 1930) from ESA (2022); **16** Jacqueline Kovoor (b. 1931), from Legendre & Emerit (1973); **17** Ansie Dippenaar-Schoeman (b. 1948) from ARC website (2022); **18** Chiyoko Okuma (1931–1996), from Kayashima (1997); **19** Susan Riechert (b. 1945), from Derryberry (2022); **20** Yael Lubin (b. 1945), from the Greifswald website (2018); **21** Ruth Buskirk (b. 1947), from Frankliin (2014); **22** Jacqueline Heurtault (1936–2000), from Legendre & Emerit (1973).

Research collaboration with a male counterpart was often a necessity for women in the 1800s and into the 1900s. Elizabeth Maria Gifford Peckham (1854–1940; Fig. 1) was another early arachnologist, who worked closely with her husband George W. Peckham (1845–1914). Elizabeth Peckham began her academic pursuits prior to meeting George W. Peckham, graduating from Vassar College in 1888 with a master's degree (Bonta 1995). Later in life, she went on to receive a PhD from Cornell University in 1916. Cornell was one of the first Ivy League institutions to accept women, beginning in 1858, with numbers increasing yearly hereafter; in fact, in 1857 a woman was promoted to a professorship and provided equal pay at Cornell, making it the first institution to do this (Rexroat 2021). Other institutions were slower to open their doors to female scholars. Elizabeth and George Peckham were inextricably connected in their work, studying behaviour and taxonomy of salticid spiders and publishing together; despite Elizabeth holding a graduate degree, George Peckham was identified as the main contributor to the research publications as was common for spousal research times in this era. However, in her husband's obituary following his passing in 1914, Elizabeth was publicly recognized as a key contributor. Following her husband's passing, Elizabeth continued her research career and was included in American Men of Science in 1926. Her involvement in women's suffrage may have given her confidence to stand resolute in her identity as a woman during a time when women were not widely recognized in the sciences.

Another way in which women became involved in arachnology was through volunteer work or secretary duties for societies. Elizabeth Bangs Bryant (1875–1953; Fig. 2) is one such example (Deichmann 1958). Bryant attended Radcliffe where she met the men in the Boston Natural History Museum and the Museum of Comparative Zoology (Louis Agassiz Museum of Comparative Zoology, MCZ), and started volunteering to take care of the small spider division in the latter in 1898 (Gochberg 2021). Here, through maintaining the collection and conducting extensive fieldwork, she became interested in taxonomy. Her attentiveness and knowledge of the collection was clearly recognized, though it was only after 30 years that she was promoted to the assistant curator and paid a small salary. During her tenure at the MCZ, she contributed multiple new specimens and species descriptions, initially focusing on New England (Bryant 1908), though later conducting extensive work in the Caribbean (Deichmann 1958). However, her name was rarely featured on official museum publications and she declined to be listed in the American Men of Science as she felt that such would be an intrusion into positions superior to her own (Deichmann 1958). Bryant is just one example of many women who worked as assistants at the museum and were integral to maintenance of the collection and taxonomic progress (Harvard Museums of Science & Culture 2021).

Growth in stature of women in arachnology: early/mid-20th century

It was in the 20th century that we saw a greater increase in women in arachnology globally. During this period, women were more involved in the sciences in general, pursuing and receiving PhDs, publishing widely, and becoming faculty members at universities or receiving curatorial positions at museums. Harriet Exline (1909–1968; Fig. 3) was one of the pioneers in the US. She began her career early, entering Reed College at 16 and studying spider taxonomy for her undergraduate thesis (Peck 1969). She continued on to a graduate degree at University of Washington, receiving her PhD in 1936 (Exline 1937). Following graduation, she was the first woman to receive a Sterning Fellowship for postdoctoral work at Yale with Alexander Petrunkevitch, where her arachnology research continued. After marrying Don Frizzell, she took a position as guest researcher in spiders in the Department of Zoology at the University of Texas and then moved to the University of Missouri in 1948; she also held appointments at the California Academy of Sciences and at the University of Arkansas. Exline largely worked independently from her home laboratory. She amassed a large collection of spiders and an extensive publication record and served as a collaborator and mentor to many other members of the growing arachnological community. However, she always considered her primary role to be a wife and a homemaker, with her research playing a secondary role (Peck 1969).

Argentina saw several women pioneers in arachnology. Rita Schiapelli (1906–1976) and Berta Gerschman de Pikelín (1905–1977) (Fig. 4) were appointed to positions at the Argentine Museum of Natural Sciences (MACN) in Buenos Aires in 1929, with Schiapelli being responsible for the arachnid collection and subsequently (1952) becoming head of the arachnology section (Brescovit *et al*. 2017). Schiapelli and Gerschman de Pikelín together created the National Collection of Arachnology and published on the systematics of mygalomorphs (Schiapelli & Gerschman de Pikelín 1970, 1973), Ctenidae (Schiapelli & Gerschman de Pikelín 1973) and others (Schiapelli & Gerschman de Pikelín 1971). They were joined at the MACN by María Elena Galiano (1928–2000; Fig. 11) who was appointed relatively early in her career in 1951 (Scioscia *et al*. 2001); she focused on neotropical spiders, primarily Salticidae, studying the mode of inheritance of colour polymorphism in *Phiale* (Salticidae) and showing that colour patterns in these highly polymorphic species are inherited as simple Mendelian alleles (Galiano 1981, 1994). Europe also had pioneers, including María Rambla Castells in Spain (1918–2016; Fig. 6), who led the way on early work on opilionids (Barrientos Alfagame *et al*. 2014). These women were very active in arachnology and played a lasting role in the field.

At the same time, in Poland, Jadwiga Łuczak (1920–2007; Fig. 7) studied at the University of Warsaw, where she was appointed to the faculty in 1962, and then joined the Institute of Ecology of the Polish Academy of

Sciences in 1979 (Dąbrowska-Prot & Kajak 2007). Her primary focus was on the ecology of spiders (Łuczak 1963) and their role in agroecosytems (Łuczak 1993), and extended her work to look at the effects of industrial pollution on arthropod communities. She published extensively with Eliza Dąbrowska-Prot (b. 1930), working together on predator-prey interactions between spiders and mosquitoes (Dąbrowska-Prot & Łuczak 1968, Dąbrowska-Prot, Łuczak & Tarwid 1966, 1968).

However, the difficulty for women to become established in independent careers was very apparent during these years. Several women managed to move forward through working closely with their spouses. In New Zealand, Lyn Forster (1925–2009; Fig. 9) was enrolled at Victoria University College in Wellington, but met and married Ray Forster and moved to Christchurch in 1948 without completing her degree. Like others at the time, she dedicated herself to her family and only resumed studies in the late 1960s, with a PhD on New Zealand jumping spiders in 1979 from the University of Otago (Vink, Sirvid & Hall 2009). She continued her work on jumping spiders in particular, after her PhD, and invariably served as a source of encouragement for budding arachnologists. In the US, Lorna Levi (1928–2014; Fig. 12) served as a pillar of support for the work of her husband, Herbert Levi (Leibensperger 2016), and frequently published with him, with the well-known *Golden Guide* being one of the best known joint contributions (Levi & Levi 2001). And, of course, in the UK, Frances Mary Murphy (1926–1995; Fig. 10) worked closely with her husband John, and they published prolifically together. Frances was one of the founding members of the British Arachnological Society and a member of 12 other arachnological groups and natural history societies and was relentless in her encouragement of young arachnologists through field study courses and surveys, mainly in the south of England (O'Neill 1995).

In Australia, two luminaries were Valerie Todd Davies (1920–2012; Fig. 8) and Barbara York Main (1929–2019; Fig. 13). Davies, after receiving a PhD in Zoology at Somerville College in Oxford, returned to New Zealand to marry her husband George in 1948. She spent the next 24 years focused on raising her family and entertaining colleagues of her husband before being appointed curator of arachnids at the Queensland Museum in 1972 focusing on often obscure spiders of the leaf litter and describing >150 new species (Davies & Monteith 2013). Main was the first female to receive a PhD in Zoology at the University of Western Australia in 1952. She focused largely on mygalomorphs (Mason, Wardell-Johnson & Main 2018; Cooper *et al*. 2011), though published broadly on spiders (Main 1964, 2001; Rix *et al*. 2017). For her work, she was awarded the Order of Australia in 2011 and the Royal Society of Western Australia Medal in 2018 (Harvey 2019). However, while her husband was eventually employed at UWA, York Main was never even considered for a formal position and never received a salary from the university (Jones 2019), though she was a source of encouragement and inspiration for many younger women struggling to balance work and home life and to establish themselves in scientific careers.

Despite the challenges associated with establishing research careers, women continued to succeed in the field of arachnology at a global scale. The first Georgian arachnologist, Tamara Mkheidze (1915–2007; Fig. 5) attended Stalin University, Tbilisi (now lvane Javakhishvili University) where she subsequently worked, first as a laboratory assistant, and then taught invertebrate and entomological zoology. She published extensively on the arachnids of Georgia, describing more than 40 new species (Marusik & Otto 2008). The Dutch arachnologist Christa L. Deeleman-Reinhold (b. 1930; Fig. 15) received her PhD from Leiden University in 1978 where she was based. Her research focuses on the spiders of Southeast Asia (van Dorp 2020); through this work, she developed the largest collection of Southeast Asian spiders, currently housed at Naturalis Biodiversity Centre in Leiden (Deeleman-Reinhold 2001). In France, Jacqueline Kovoor (b. 1931; Fig. 16) and Jacqueline Heurtault (1936–2000; Fig. 22) both held positions at the Museum national d'Histoire naturelle (MNHN). Kovoor worked on silk ultrastructure and microanatomy (Kovoor & Zylberberg 1982; Kovoor 1987; Kovoor, Cuevas & Escobar 1993). Heurtault, after receiving her PhD at the at MNHN in 1972 held appointments as lecturer and professor. She worked extensively on pseudoscorpions – anatomy, ecology, systematics, sexual behaviour and the interaction of different species (Heurtault & Rebière 1983). In Japan, Chiyoko Okuma (1931–1996; Fig. 18) was the first woman arachnologist with a PhD and the first woman at Kyushu University. Her main work was on *Tetragnatha* and other spiders associated with agroecosystems (Okuma 1968, 1987; Okuma, Lee & Hokyo 1978). However, women were still very much pioneers and oddities, as reflected in the statement in Okuma's obituary that she was only interested in spiders and was not even interested in marriage (Kayashima 1997). Gaining positions was not straightforward. Beatrice Vogel (1930–2018; Fig. 14) graduated from Stanford (mathematics) in 1952 and, despite receiving a PhD from Yale in 1968 with extensive communication with Willis Gertsch and Harriet Exline, she struggled to survive in the field. However, she did serve as the first president of the American Arachnological Society and published considerably on the taxonomy of *Pardosa* (Vogel 2004), although several of these papers were self publications (Vogel 1971, 1972) as there was little support for submitting papers for peer review (P. Cushing pers. comm.).

Rise of independent women in arachnology: mid/late 20th century

The 1970s saw a tremendous growth in the fields of behaviour and ecology and, in particular, the intersection of these disciplines. Based on the premise that behaviours will evolve to maximize fitness, there was an emphasis on quantifying behaviours, and using variation in behaviours to test hypotheses of adaptation. The focus on the ability to quan-

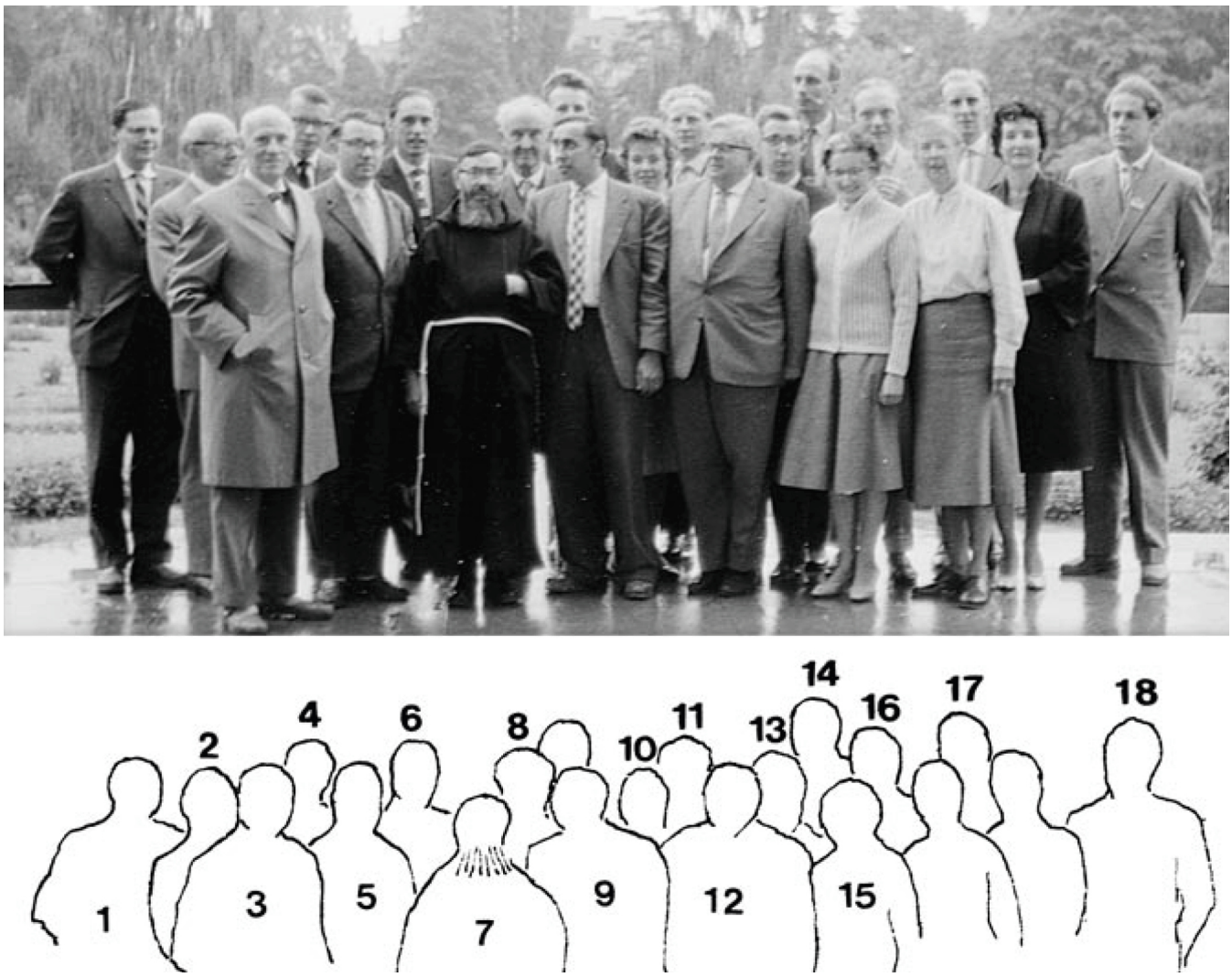
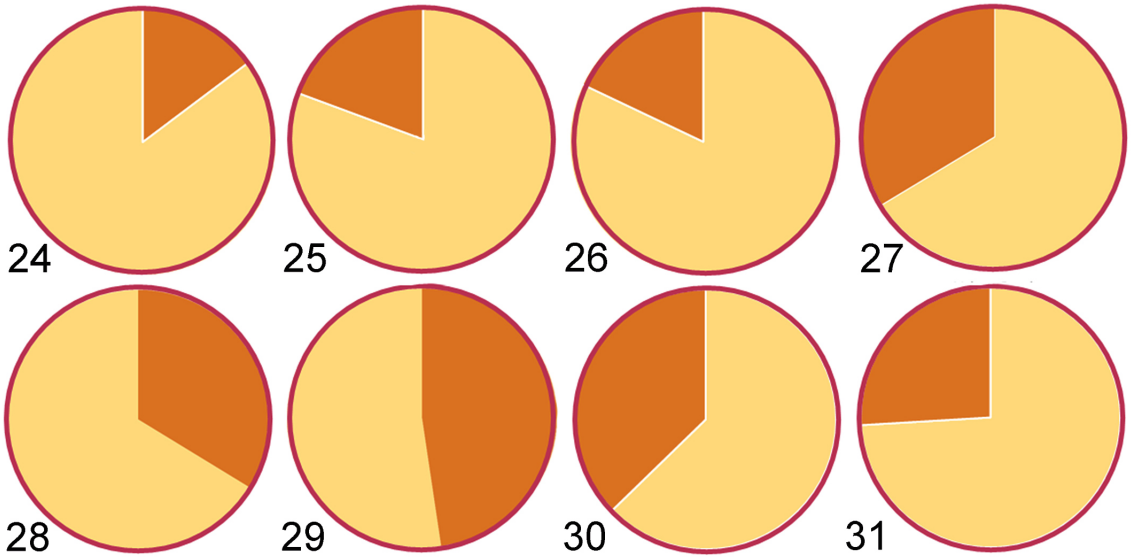


Fig. 23: First CIDA meeting in Bonn, Germany, 1965 (Kraus 1999). Legend: 1 = G. Schmidt, 2 = H. Casemir, 3 = H. Homann, 4 = B. von Broen, 5 = H. Nemens, 6 = R. Braun, 7 = Father Chrysanthus, 8 = H. Wiehle, 9 = E. Kullmann, 10 = Mrs Kullmann, 11= H. Hiebsch, 12 = R. Lehmensick, 13 = M. Grasshoff, 14 = W. Engelhardt, 15 = Mrs Crome, 16 = W. Crome, 17 = O. Kraus, 18 = B. Heydemann.

tify and test behaviours in an ecological context led to a massive growth in the field (Owens 2006). Spiders, with their clearly measurable behaviours and ecological associations, were ideal candidates for this kind of work. At the same time, there was an awareness of damaging effects of pesticides, with spiders highlighted as playing a critical role in agroecosystems (Riechert 1974). This period saw the arrival of Susan Riechert (b. 1945; Fig. 19). After receiving her PhD in 1973 at the University of Wisconsin, Madison, she immediately took a position on the faculty at the University of Tennessee Knoxville, where she played a central role in the development of the field (Riechert 1978, 1979). Yael Lubin (b. 1945; Fig. 20) studied Zoology at The Hebrew University of Jerusalem in Israel, and Columbia University and the University of Florida in the USA, before starting work on tropical spiders, initially with the Smithsonian Tropical Research Institute (Lubin 1978). It was during this time that she started working on social spiders (Lubin 1974; Lubin & Robinson 1982) and, after returning to Israel in 1984 and joining the Desert Research Institute at Ben-Gurion University of the Negev, she continued to develop this work (Whitehouse & Lubin 1999; Crouch & Lubin 2000). Ruth Buskirk (b. 1947; Fig. 21) was another early player in the field of spider behaviour: After her PhD at the University of California at Davis in 1972, she continued her work at the University of Texas (Buskirk 1975, 1981). Ansie Dippenaar-Schoeman (b. 1948; Fig. 17) made progress outside of behaviour, with an emphasis on agricultural research. She began her career studying the systematics of crab spiders (Araneae: Thomisidae: Misumeninae) for her PhD, with early work focused on the impacts of pesticides on spider diversity and the role of spiders in agroecosystems as biological control agents (Dippenaar-Schoeman & Van den Berg 1999). She went on to become a Specialist Scientist and Unit Manager of the South African Arachnology Unit of the Biosystematics Division, ARC – Plant Protection Research Institute in 2003.

Methods

To review the structure of the field, both past and present, we compiled data from society websites and articles, notably the International Society of Arachnology, formerly



Figs. 24–31: Changes in gender composition at different international meetings. **24** Warrensburg (American) in 1975 (95 total, 14 women); **25** Panama 1983 (62 total, 12 women); **26** Australia (Queensland) 1993 (116 total, 12 women); **27** New Zealand 2019 (163 total, 55 women); **28** gender composition of presentations at the International Congress of Arachnology, Christchurch, New Zealand, in 2019, of all oral presentations, 55 of 163 presenters were women; **29** same meeting, of the student oral presentations, 21 of 44 presenters were females; **30** current gender composition within the American Arachnological Society, of the US members totalling 314, 117 are females; **31** same society, of the non-US members, totalling 185, 48 are females.

Centre International de Documentation Arachnologique (CIDA) (Kraus 1999), the American Arachnological Society (Peck 1980; Vogel 2011), the Japanese Arachnological Society (Yaginuma 1961; ASJ 2021), the Australasian Arachnological Society (AAS 2021) and other papers that described the history of arachnology in different regions (Cokendolpher, Zamani & Snegovaya 2019). To compile information on gender, we used membership, conference presentations, and publications in arachnological journals. Membership from the International Society of Arachnology was taken from the Members A–Z page on the society website on 22 November 2022. The History page on the website was used to assess early involvement and representation of women in the field. The abstract book from the 21st International Congress of Arachnology and the 2020 American Arachnological Society meeting were used to determine gender composition of presenters. Proceedings were used to determine the composition of congresses in Panama 1983 (Eberhard, Lubin & Robinson 1986) and Queensland 1993 (Raven 1993). Issues of the *Journal of Arachnology* from four years (1974, 1990, 2010, 2020) were downloaded and assessed for author composition, focusing on first authorship. To determine gender, we used any publicly available data on suffixes and pronouns as well as most common gender associated with first name. Through this process, we made assumptions about gender identities of people within the arachnological community; we recognize the gender associated with a first name may not align with the gender identity of an individual. While this is a preliminary look at the gender composition of the field today, we acknowledge that there is a more diverse composition in our community than we were able to summarize here.

Results and Discussion

Women in arachnological societies in the 1900s

By the mid-1900s, there was an increasing number of women arachnologists involved in diverse disciplines expanding beyond taxonomy. Despite this increase, arachnological societies did not reflect the growing number of women. The first CIDA (Centre International de Documentation Arachnologique, later the International Society of Arachnology) meeting in 1965 featured few women. A telling photo from the meeting (Fig. 23) shows four women among a larger group of men; the caption identifies two of the four women, both labelled as ‘Mrs’ while the men lack any prefix. While all men were identified, the remaining two women lacked identification in the caption. Despite this poor presentation of women, Jacqueline Heurtault served as the Secrétaire Général until 1983. However, the more public role of president for CIDA was exclusively male from 1963 until 2004, when Ansie Dippenaar-Shoeman became the first female president of the society. Membership and leadership in smaller societies was similar; the charter membership of the American Arachnological Society in 1973 had 12 women of 116 members and the Warrensburg International meeting of 1975 had 14 women involved of 95 attendees. Changes in gender composition at international meetings through the years has changed incrementally (Figs. 24–27). However, representation of women in the field has gradually increased the number of available mentors and allowed more women to enter arachnology, with a concomitant gradual increase in numbers overall.

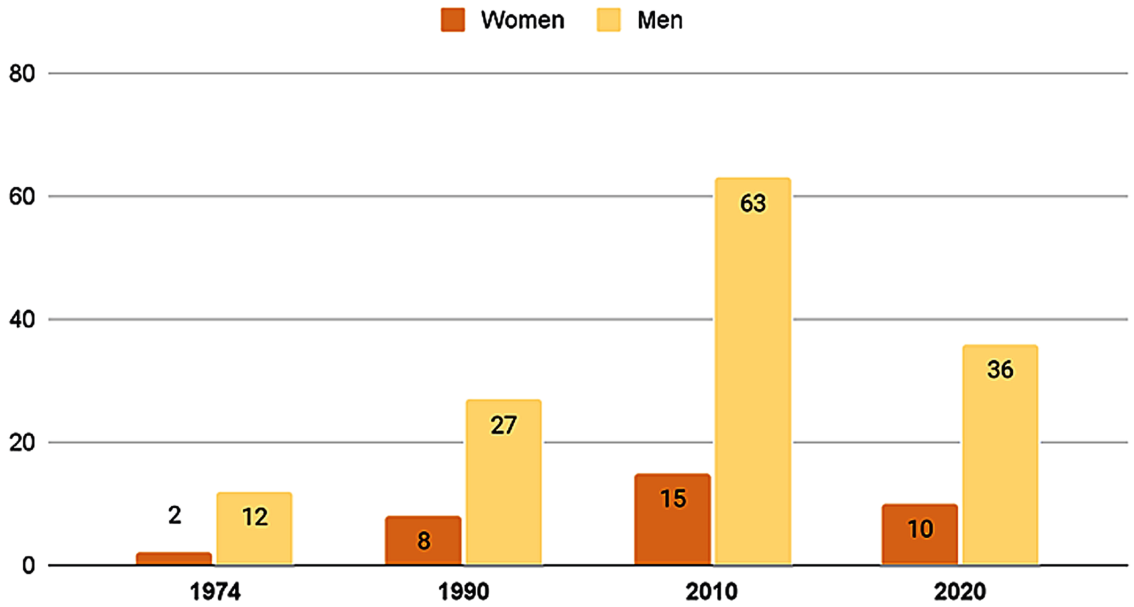


Fig. 32: Number of male versus female first authored publications in *Journal of Arachnology* in issues published in 1974, 1990, 2010, and 2020.

An analysis of arachnology in the 21st century

The International Society of Arachnology (ISA) contains the largest membership and provides an international perspective on the arachnological community. Of the 814 active members in November 2021, only 15% (122) were women. The most recent (2019) ISA congress in Canterbury, New Zealand (ICA XXI 2019) showed better representation, with 34% (55) of oral presentations given by women (Fig. 27). The invited talks showed a similar composition; of the 10 invited speakers, 3 were given by women. This is an improvement from previous years in Panama 1983 and Queensland 1993 (Figs. 24–26). Importantly, among student oral presentations, 21 of 44 presenters were female - much more balanced compared to only 55 women presenters among the total of 163 oral presentations (Figs. 28–29). This highlights the increasing number of junior women entering the field,

In certain regional arachnological societies, we see a larger percentage of women; the American Arachnological Society consists of 117 women out of 314 members among the US members, though only 48 out of 185 non-US members (Figs. 30–31). In other countries, the gender balance remains highly skewed towards men (e.g. ASJ 2021). Moreover, when looking at arguably the most important metric of success in academia, publications, we see little improvement. Using four representative years (1974, 1990, 2010, 2020) we assessed female first authorship in the *Journal of Arachnology*. For every year examined, percent of female first authors was below 25% (Fig. 32). Despite seeing an overall increase in female first authorship across STEM fields in the 21st century, 2010 and 2020 in the *Journal of Arachnology* do not reflect this trend. In 2010, 19% (15) of publications were authored by women; 2020 saw fewer publications overall, but similarly showed low female first authorship, with 22% (10) of publications authored by women. While society membership may seem like a poor measure of equality, the role of societies, leadership, awards, and associated journals contributes to the gendered nature of the sciences.

As many arachnologists are publishing in a breadth of journals that are not arachnology specific, these numbers do not entirely reflect gender divides in the field. Today, there are multiple world-renowned female arachnologists who are conducting ground-breaking research with impacts stretching beyond arachnology. These women are providing crucial mentorship; aspiring arachnologists can now find advisorship from faculty and curators who look like them and who are capable of providing support for identity-specific struggles. In the student population, we are seeing progress towards an equal gender divide. At ISA's most recent International Congress (ICA XXI 2019), there were 21 women and 23 men involved in the student competition. Essential, then, is retention of early-career arachnologists. By examining STEM fields broadly, we can learn more about the ways in which we lose women from sciences and, through this, better understand how we can support a diverse arachnological community.

Lessons across STEM fields

While little is known about the barriers to inclusion in arthropod-related fields specifically, there is a growing body of literature addressing lack of equality in STEM fields in general. Rejection of STEM fields begins early for women, with cultural messages about who belongs in science and engineering influencing decisions about a career path. Representation of women in science and engineering has increased in media, often with female characters occupying high-level positions. However, accompanying these women are often gendered stereotypes, discrimination and judgment by male colleagues, emphasis on appearance, and romance-oriented plot lines (Steinke 2017). Such media

messaging shapes construction of gender schemas in children and adolescents (Bem 1981); many young girls associate science with masculinity and therefore avoid the field in order to be gender-role-consistent (Levy, Sadovsky & Troseth 2000; Carli *et al*. 2016). Relationships with teachers, family, and friends are additionally crucial in shaping ideas about STEM fields and associated gender alignment. Without encouragement from trusted adults and peers, the chance of entry into a STEM field will be greatly reduced (Dasgupta & Stout 2014). However, growing use of social media is widening the reach of positive messaging around women in STEM. For example, communication about women in STEM on the platform Twitter is highly positive, with tweets associating women in STEM with adjectives such as 'great', 'inspirational', 'amazing', and many users promoting themselves as strong representations of women in science (Alkhammash 2019). Access to positive media messaging may greatly benefit the next generation of female scientists by combating stereotypes and presenting real life examples of successful women in science while giving an avenue for direct communication with these role models.

Changing aspects of society, including the increased representation in media and dedicated programs encouraging women to join STEM fields, have increased the number of women entering the biological sciences during their undergraduate and graduate years (Hill, Corbett & St Rose 2010). However, women proceed to switch fields or leave academia altogether at a higher rate. Some of the same issues outlined above influence a woman's success in her chosen STEM field. Despite performing at the same level or higher than men in academic success metrics, women in STEM majors may feel inadequate or incapable because of learned gender roles (Bloodhart *et al*. 2020). This lack of confidence, despite clear demonstration of capabilities, is linked to exiting STEM (Robnett & Thoman 2017). Alongside individual doubts about one's capabilities, women may experience harassment, discrimination and lack of support during their college experience. A negative culture on campus can strongly affect a woman's trajectory in STEM. Not only does this lead to disengagement, it also negatively impacts self-esteem and identity (Casad, Petzel & Ingallis 2019). Classroom environments are a part of this, where professors' beliefs and interactions alter a woman's understanding of her success (Moss-Racusin *et al*. 2012); inadequate support from both professors and institutions are partially responsible for women exiting STEM (Seymour 1995). Through more emphasis on community building, support from professors and academic advisors, and improvements in campus culture, we can increase the number of women successfully completing STEM degrees.

While the number of women in PhD STEM programs are equitable, even occasionally higher than men, this does not translate to degree completion or progress to tenure (Miller & Wai 2015). At the doctoral level, personal perceptions are influential in a woman's success. When a woman enters a graduate program feeling less adequate and prepared, she is less likely to publish and, therefore, she is less competitive than male colleagues following degree completion (Fisher *et al*. 2019). Because of experiences throughout primary and secondary education as well as undergraduate years, the feeling of inadequacy and imposter syndrome are likely more prevalent in women, resulting in lagging success. This is compounded by department structure and advisorship; women receiving clear guidance and expectations throughout their degree experience less distress and publish at a comparable rate to other students, while women in programs lacking adequate structure publish less (Fisher *et al*. 2019). Challenging perceptions of self and feelings of inadequacy may be compounded with more explicit discrimination and harassment. In a field setting, women experience high rates of sexual harassment and assault (Clancy *et al*. 2014). Even more concerning is that this harassment or assault largely comes from colleagues senior to them. Because of the power dynamics, such mistreatment often goes unreported, and the consequences impact only the victim who may face psychological distress and/or reductions in career enjoyment and productivity (Clancy *et al*. 2014). This is yet another factor which leads to retention issues. A strong departmental support system and avenues for safely reporting advisorship issues and harassment/assault, paired with clear guidance through a dissertation program will better support women progressing through their degree.

Today, the biological sciences do support higher numbers of women through undergraduate and graduate degrees; however, this falls significantly when examining tenured faculty. Women in nontenured positions are much higher than those in tenured positions in the biological sciences, representing a barrier that exists along the path to tenure (Fiegener 2010; Hill, Corbett & St Rose 2010). This trend can also be seen in article authorship. While publications featuring women as first authors have increased through time, we see a clear lag in female sole authors and last authors in the biological sciences (Fox, Ritchey & Paine 2018; Holman, Stuart-Fox & Hauser 2018). A less competitive resumé due to experiences faced by women throughout her education combined with hiring practices, biased tenure review, authorship disagreements, and lack of recognition through awards and grants are key factors resulting in a reduction in women holding tenured positions (Hill, Corbett & St Rose 2010; James, Chisnall & Plank 2019; Ni *et al*. 2021).

While these barriers may force some women to leave academia, many women instead choose to leave. Not only is academia perceived as challenging, but it is logistically challenging; Issues including lack of affordable childcare or supportive maternity leave packages can require women to make a choice between children and a career. Compounded with a male-dominated environment that may be accompanied by microaggressions or inappropriate commentary associated with gender, staying in academia becomes a heavy burden for some women. Similar conclusions have been drawn for other zoological fields: In mammalogy, data from the American Society of Mammalogists indicate a comparable pattern in which women are well represented at earlier career stages, but with strong attrition that might be

attributed to family constraints, obstacles to opportunity, unconscious bias, and limited access to role models (Isbell, Young & Harcourt 2012). Suggestions have been made to increase retention and hence balance the gender biases well known in entomology (Walker 2018), ornithology (Lerman *et al*. 2021), ichthyology and herpetology (Sardelis & Drew 2016, Perry *et al*. 2020), and paleontology (Warnock *et al*. 2020), including the need to provide on-campus childcare, flexibility in working hours, increased emphasis on work-life balance and a support network removed from faculty themselves. As more women stay in academia, even more women will feel they belong and find community and support around shared experiences. The challenges to increasing women in tenured positions are daunting and require a rounded approach, where each step in the career pathway is improved. Through continued commitment, we will move closer to equity in the sciences and in arachnology.

Conclusion

Starting from legends and transitioning into powerful scientists, we see women hold an essential place in arachnology. Our review hopes to capture the incredible accomplishments of female arachnologists throughout history and highlight the barriers they faced in their careers. Remembering this history is integral to continued progress as the field grows and welcomes new members. This history is mostly one of female arachnologists from Europe, the United States, and Australia, stories that we can find. There are certainly women outside of these areas that were involved in arachnology but whose stories are now lost. We recognize the many individuals of diverse backgrounds who have built the field into what it is today.

Reflecting on STEM teaches us many lessons which can be applied to arachnology. Taking advantage of ever-growing social media platforms as a tool for science communication, arachnology can be spread more widely. Highlighting stories about women in arachnology and building a more robust online database about female arachnologists on Wikipedia or other platforms will further allow women to see themselves represented in the field. By disseminating knowledge on the fascinating world of arachnids, cultural perceptions around arachnids can begin to shift and, in turn, increase excitement across multiple age groups. More emphasis can be placed on providing positive support, recognition and guidance through our labs and campus departments, which will then increase retention. While serving on review panels and hiring committees, we can remind ourselves of our unconscious biases and assess our judgments more closely to ensure fair treatment. By increasing the diversity of faculty studying arachnology, we can create more role models to support students of all identities. We can be vocal in the face of discrimination and harassment, and we can listen to women and other groups when they speak about their experiences. Open dialogue around the barriers women and other underrepresented groups face in our field will only encourage growth and expand scientific progress, allowing the arachnological community to be as diverse as the order itself.

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