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Gender Equity in Oceanography

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Abstract

Gender equity, providing for full participation of people of all genders in the oceanographic workforce, is an important goal for the continued success of the oceanographic enterprise. Here, we describe historical obstructions to gender equity; assess recent progress and the current status of gender equity in oceanography by examining quantitative measures of participation, achievement, and recognition; and review activities to improve gender equity. We find that women receive approximately half the oceanography PhDs in many parts of the world and are increasing in parity in earlier levels of academic employment. However, continued progress toward gender parity is needed, as reflected by metrics such as first-authored publications, funded grants, honors, and conference speaker invitations. Finally we make recommendations for the whole oceanographic community to continue to work together to create a culture where oceanographers of all genders can thrive, including eliminating harassment, reexamining selection and evaluation procedures, and removing structural inequities.

1. INTRODUCTION

What is gender equity? Drawing on an overview by the World Health Organization (WHO 2022), we can define gender as the social and cultural roles and behaviors of girls, boys, women, men, and gender minorities. Gender differs from sex, which refers to the differing biological and physiological characteristics of females, males, and intersex people. Because this review focuses on gender—the socially constructed differentiation between men and women—we use the terms women and men throughout, rather than male and female. We also acknowledge that gender is not binary, and we use the term nonbinary gender to refer to those who identify outside or across the categories of men and women.

We focus on gender equity rather than gender equality. Gender equity aims for fairness between genders, recognizing that some genders start from a place of disadvantage, with imbalances that must be addressed. Gender equality, by contrast, means providing the same to people of all genders, assuming that people of different genders experience the same advantages and disadvantages (Black 2020, Craig & Bhatt 2021).

Equity across all axes, including gender, as a societal goal is simply the right thing to do. Equity will ensure that all members of society experience the same rights, privileges, and opportunities (Haacker et al. 2022). From a scientific perspective, gender equity ensures that people of all genders can contribute to the scientific enterprise in ways that also support their identity. In addition, the oceanographic enterprise as a whole will benefit by including all genders, for example, by broadening perspectives addressing societally relevant changes in the ocean (Gissi et al. 2018).

This review of the current status of gender equity in oceanography provides an assessment of progress in the past few decades and gives perspective on the work that is still needed, summarized visually in **Figure 1**. It benefits from some of the global preparation for the ongoing United

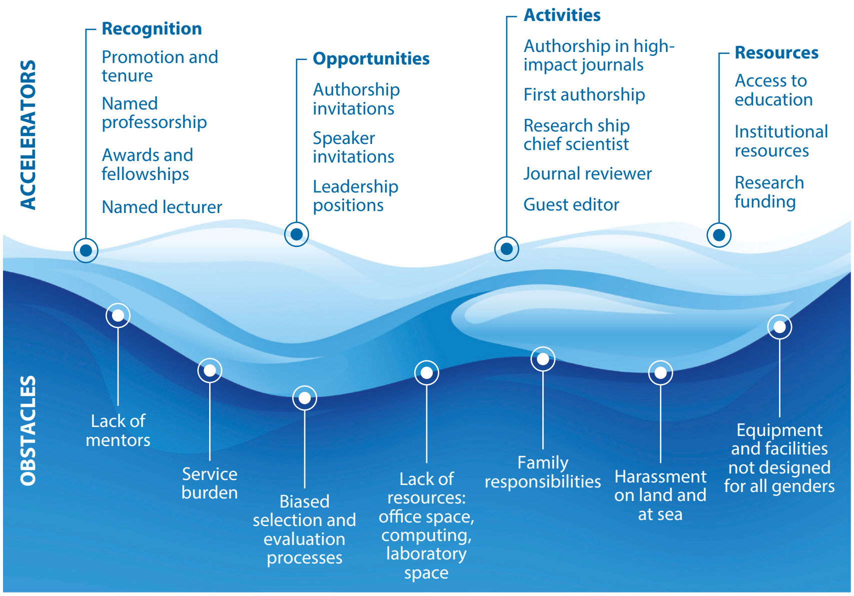

Figure 1

A graphical summary of some of the accelerators that together contribute to advancement in an oceanographic career (grouped under the categories of recognition, opportunities, activities, and resources) and a selection of the obstacles that hinder advancement, particularly for women and gender minorities. Many of these accelerators and obstacles, as well as the gender equity indicated by their available metrics, are examined in further detail in this review.

Nations Decade of Ocean Science for Sustainable Development, including the Empowering Women for the United Nations Decade of Ocean Science for Sustainable Development program (Black 2020). Many specific aspects of gender equity within oceanography have been assessed in the last decade, often focusing on just one metric (e.g., number of PhDs; Wilson 2013), just one activity [e.g., the Mentoring Physical Oceanography Women to Increase Retention (MPOWIR) program; Clem et al. 2014], or just one country (e.g., Brazil; Marins & da Costa 2015). Here, we aim to synthesize these different studies, including worldwide comparisons where possible, and offer a comparison of different metrics. However, we acknowledge a bias toward US-centric information owing to the lead author's status as a US resident and limited knowledge about unpublished sources of information elsewhere.

We acknowledge that many publications use only a gender binary (a construct imposed and propagated around the world through European colonialism, erasing Indigenous gender identities and roles; Picq & Tikuna 2019) and that nonbinary genders are largely omitted from the statistics. Better self-identified gender collection is needed to address this gap (Strauss et al. 2020) (see the sidebar titled Gender Data).

While this review focuses only on gender equity, we acknowledge that there are many intersectional equity issues experienced by women and nonbinary people who also belong to other marginalized groups, including those defined by race and ethnicity, socioeconomic class, national origin, and sexuality. Full gender equity will not be achieved until all women and nonbinary people can fully participate in our community.

GENDER DATA

The sources of gender data vary widely in the publications reviewed here. Below, we list the methods of determining gender, along with the issues associated with each method. Throughout this review, we attempt to identify the method used to identify gender with a superscript $^{\mathrm{GDS}[N]}$, where $[N] = 1, 2, 3, 4$, or 5:

- Gender data source 1 (GDS1): a legal database. In a few cases, gender has been determined from a legal database (e.g., for Brazilian researchers). Often, such databases only recognize a gender binary and may misgender transgender people.
- Gender data source 2 (GDS2): self-identification with only binary gender options.
- Gender data source 3 (GDS3): self-identification with nonbinary gender options. Sometimes gender is self-identified (e.g., for UK Research and Innovation). As emphasized by Strauss et al. (2020), reliable gender data can only be obtained through self-identification, which must include nonbinary options and sufficient anonymity to ensure that respondents feel safe answering accurately. Other methods erase nonbinary people in particular.
- Gender data source 4 (GDS4): a given-name algorithm. In many studies, gender is determined by the study author, often using an algorithm based on given names. This is problematic because given-name databases are often culture specific, some names are gender neutral, and an individual need not follow the gender conventions associated with their name.
- Gender data source 5 (GDS5): web search for pronouns and other gender identification. A more careful assessment of gender (e.g., as done in Ranganathan et al. 2021) requires an internet search for each individual until information on their gender can be located (e.g., pronouns). However, pronouns are not equivalent to gender, both because they do not map one to one and because a person's choice of pronouns can vary across different aspects of their life. People's genders can change over time, and an individual's openness about their gender can also change.

2. HISTORICAL OBSTRUCTIONS TO GENDER EQUITY IN OCEANOGRAPHY

Historically, numerous obstacles have impeded women's involvement in oceanography. Some of them are common to other professional and scientific fields, such as barriers to combining work and family, advancement structures that emphasize the apprentice model, and affinity bias (Patton et al. 2017, Sheltzer & Smith 2014, Wolfinger et al. 2008). Here, we focus primarily on barriers specific to oceanography.

2.1. Bans on Women's Involvement in Seagoing Oceanography

Women's involvement in early seagoing oceanography was suppressed by superstition-based restrictions that prevented them from serving on ships, as either crew members or scientists, in western Europe and North America (Bonatti & Crane 2012, Hendry et al. 2020). Despite these restrictions, botanist Jeanne Baret joined a French expedition in 1676–1679 disguised as a man, but no women joined the 1872–1876 *Challenger* expedition, often considered the founding expedition of western ocean science (Bonatti & Crane 2012).

In the first half of the twentieth century, small numbers of women participated in seagoing oceanography in both Britain (Hendry et al. 2020) and the United States (Day 1999), mostly for short coastal expeditions. By contrast, in the Soviet Union, marine geologist Maria Klenova was leading oceanographic research expeditions in the Arctic in the 1920s (Beniest 2020, Kalemeneva & Lajus 2018, Lewandowski 2018) owing to strong support for the participation of women in oceanography from the head of the State Oceanographic Institute (Kalemeneva & Lajus 2018). In the United States, women's access to seagoing oceanography became more restricted during and after World War II, with policy changes such as a formal ban on women on ships at Scripps Oceanographic Institution attributed by Day (1999) and Oreskes (2000) to the increased relationship between Scripps and the US Navy, with similar restrictions at Lamont Geological Observatory and Woods Hole Oceanographic Institution (WHOI) (Bonatti & Crane 2012). In the 1950s, WHOI graduate student Roberta Eike argued that it was important for her career for her to make her own observations. However, while many of the senior male oceanographers at WHOI seemed to be willing to allow women to go to sea, they indicated that "larger and more commodious ship[s]" (L.V. Worthington, quoted in Bonatti & Crane 2012, p. 36) were needed. In 1956, Eike tired of waiting for the necessary changes to happen and stowed away on a research ship, leading to her unfair dismissal from WHOI (Freiburger 2020) and ending her oceanography career (Bonatti & Crane 2012). During the same time period, women were similarly prevented from sailing on the open-ocean ship RRS *Discovery II* in Britain (Hendry et al. 2020) and on German research ships (Bonatti & Crane 2012). The reason often given was "lack of facilities" (e.g., separate bathrooms and cabins; Sullivan 1998), which in retrospect could easily have been remedied with sufficient will (and may still need to be addressed for nonbinary oceanographers). As pointed out by Kathy Sullivan, oceanographer turned astronaut, "'facilities' were not a problem in anybody's mind aboard space shuttles, despite infinitely more crowded spaces and less privacy" (Sullivan 1998).

In the United States, changes to institutional policies preventing women from participating in seagoing research were precipitated by the 1963 Scripps expedition on the R/V *Argo*, joined by two Soviet scientists, one of whom was a woman, geophysicist Elena Lubimova (Bonatti & Crane 2012). Scripps allowed women to go to sea from then on, as did WHOI [Elizabeth (Betty) Bunce was chief scientist on several WHOI cruises in the 1960s and 1970s; Lewandowski 2018], and Lamont permitted women on ships for the first time in 1965 (Bell et al. 2005). In Britain, microbiologist Betty Kirtley was the first woman from the National Institute of Oceanography to join a seagoing expedition, on the *Discovery III* in 1963 (Hendry et al. 2020), and women oceanographers in (West) Germany were finally allowed at sea in 1974 (Bonatti & Crane 2012).

The end of formal bans on going to sea did not, however, mean the end to obstacles for women going to sea. As described by Hendry et al. (2020), basic amenities for women (e.g., waste disposal bins for sanitary products) were still lacking on British ships into the 1990s, despite the increasing number of women going to sea. Even in recent years, many ships do not stock protective clothing in sizes suitable for women (Hendry et al. 2020), an unnecessary oversight that puts women in danger (Glüder 2020).

2.2. Restrictions on Women's Education and Employment in Oceanography

Women have been able to pursue an education in oceanography for longer than they have been able to go to sea: Statistician Rosa Lee was employed at the Marine Biological Association in the United Kingdom in the early 1900s (Hendry et al. 2020); Easter Ellen Cupp, the first woman to receive a PhD from Scripps, was awarded her degree in 1934 (Day 1999); and Mary Sears received her PhD from Radcliffe College in 1933 (Lewandowski 2018). However, their employment was often impeded by gender-biased rules; for example, Rosa Lee's civil service employment was terminated upon marriage (Hendry et al. 2020), and Ellen Cupp was dismissed from employment at Scripps by director Harald Sverdrup, most likely because she was a woman (Day 1999). Antinepotism rules also prevented women married to other oceanographers from being employed at the same institution. For example, Laura Clark Hubbs worked unpaid with her husband Carl Hubbs for 35 years (Day 1999)—a particular problem in a field where employment opportunities were historically confined to a small number of institutions with seagoing resources.

Even though women could obtain higher education in oceanography throughout the twentieth century, their success depended on the willingness of male faculty to advise them, and some male faculty at Scripps were open about never taking women students (Day 1999). Silver (2005) described discussions at Scripps in the 1960s about whether women should be excluded from the PhD program because their failure rate was too high and women were "taking the place of people who needed to be there more, that is, [their] male colleagues" (p. 59).

2.3. Downgrading of Women's Oceanographic Contributions

Despite these obstacles to women's participation in oceanography, particularly at sea, several women did make important contributions to US oceanography from shore, including June Pattullo, the first US woman to receive a PhD in physical oceanography, followed by Mary Robinson, who led the bathythermograph unit at Scripps (Oreskes 2000); biological oceanographer and Oceanographer of the Navy Mary Sears; and cartographer Marie Tharpe at Lamont, who produced the first ocean bathymetry maps showing the rift valley of the Mid-Atlantic Ridge (Lewandowski 2018). However, the work of these women was often undervalued compared with that of their male colleagues and counterparts. Oreskes (1996, 2000) hypothesized that the work of these women oceanographers was considered routine, boring, and, most importantly, not "heroic" (Oreskes 1996, p. 100) because it did not involve the adventure of going to sea. This focus on geoscientists as adventurer–explorers has excluded not only white women who were not permitted to join these expeditions, but also people of color and people with physical disabilities (Marin-Spiotta et al. 2020, Marshall & Thatcher 2019, Pico 2021).

2.4. Harassment at Sea

A continuing barrier to women's participation in seagoing oceanography is gender-based harassment, which encompasses everything from demeaning remarks and unwanted attention to bullying and sexual assault (Natl. Acad. Sci. Eng. Med. 2018, O'Hern 2015). The restricted space at sea makes it difficult for women to avoid a harasser, who may be far from institutional oversight (Consort. Ocean Leadersh. & Calif. State Univ. Desert Stud. 2021). Hendry et al. (2020) noted that as the numbers of women on UK ships increased in the 1990s, so too did the incidents of harassment. More recently, behavioral guidelines and reporting structures have been developed (Beal 2016, UNOLS 2022b), although there is still much work to do to ensure everyone can be safe at sea. Harassment is also a problem in other oceanographic workplaces, and harassment continues to push women and other marginalized groups out of oceanography (Natl. Acad. Sci. Eng. Med. 2018).

3. PROGRESS AND CURRENT STATUS OF GENDER EQUITY

Given that formal restrictions on women's participation in oceanography (i.e., those that prevented women from going to sea, obtaining a PhD, or gaining employment) were eliminated decades ago, we now assess the current status of gender equity in oceanography by examining a variety of metrics, many of which are associated with the accelerators listed in **Figure 1**.

3.1. The Oceanographic Workforce

The International Oceanographic Commission (IOC) tracks the numbers of women in the global oceanographic workforce (with the latest figures documented in IOC-UNESCO 2020). These data are self-reported by one point of contact per country and are frequently incomplete. Globally, women make up 37% of the ocean science workforce and almost 39% of oceanographic researchers, approximately 10% higher than the proportion for natural science as a whole. There are large differences among different countries, with Croatia showing the greatest proportion of women ocean science researchers (at 63%) and Japan showing the lowest (at 12%). The proportions of ocean science researchers who are women for some of the nations discussed elsewhere in this report are 35% in the United States (all ocean science personnel, 2013 value), 43% in the United Kingdom, 40% in Germany (one institution only), 43% in Spain, 50% in Brazil, and 33% in South Africa. Data are not available for India or the People's Republic of China. Of the respondents to the latest survey, women make up 50% or more of the oceanographic researchers in Angola, Brazil, Bulgaria, Croatia, the Dominican Republic, El Salvador, Mauritius, Poland, and Suriname. The overall global proportion of women ocean scientists has increased only slightly from 38% in the 2013 IOC survey (IOC-UNESCO 2017).

More accurate than these survey answers reported by individual country representatives are analyses of researcher databases, particularly those that include gender, such as that maintained by the Brazilian government. Leta & Lewison (2003)[GDS1] examined information from this researcher database for the period 1997–2001 and found that women made up 42% of the oceanographic researchers in Brazil at that time. A later analysis by Marins & da Costa (2015)[GDS1] showed that the percentage of women at all levels (including students) in oceanographic research groups listed in the Brazilian government database increased from 54% in 2000 to 58% in 2010.

3.2. Oceanography PhDs

These national gender ratios provide information at only the most general level and do not distinguish among different sectors or stages of employment. One useful metric for gender equity at the entry level of oceanographic research is PhD completion data. The US National Science Foundation (NSF) tracks PhD completion in different science fields along with associated demographic data, including gender, in its Survey of Earned Doctorates (NSF 2021)[GDS2], and the American

Geosciences Institute frequently examines the trends in these data. The survey has historically included only binary gender and so may not include accurate responses from nonbinary and trans students (DeHority et al. 2021). The percentage of US oceanography PhDs who are women has been at or around 50% since around 2007 (Consort. Ocean Leadersh. 2020, Ranganathan et al. 2021, Wilson 2013). Similar gender parity is seen in Brazil (Marins & da Costa 2015)[GDS1], where women have made up 50% or more of oceanography PhDs since 2004. In the United States, this gender parity has been achieved from a level of approximately 30% women PhD students in 1988 (Nowell & Hollister 1988) and 40% in 2000 (O'Connell & Holmes 2005, Orcutt & Cetinić 2014), and the proportion of women earning PhDs in oceanography exceeds that in other geosciences (O'Connell 2014, Ranganathan et al. 2021, Wilson 2013). Improvements in gender parity in oceanography PhDs in the United States have largely benefited white women (Bernard & Cooperdock 2018), and there has been little improvement in the inclusion of women of color in US oceanography doctoral education (Consort. Ocean Leadersh. 2020, Gonzales & Keane 2020).

Oceanography PhD gender ratios are more difficult to determine for countries where this data collection is not routine, and national-level data tend to be grouped under very broad categories (e.g., natural sciences; Eur. Comm. Dir.-Gen. Res. Innov. 2021). We have examined the genders of recipients of PhDs and master's degrees from four different universities in the People's Republic of China from 2019 to 2021, using publicly available data[GDS1], and found that the proportion of women varies from 38% to 65% at the master's level and from 40% to 60% at PhD level—that is, approximately equal or in some cases higher proportions of women. Near gender parity in the beginning levels of oceanography education is seen in several other countries; for example, women make up more than 50% of marine science graduates at the University of the South Pacific (Michalena et al. 2020).

3.3. Academic Employment

PhDs in oceanography are only the first stage in an oceanography research career. For women to fully contribute to oceanography, their expertise needs to be retained and rewarded. In US oceanography academia, several studies over the past few decades have examined career progression differentiated by gender (Consort. Ocean Leadersh. 2020, Nowell & Hollister 1988, O'Connell 2014, O'Connell & Holmes 2005, Orcutt & Cetinić 2014, Ranganathan et al. 2021, Thompson et al. 2011), with the current status summarized in **Figure 2**. A common conclusion is that the proportion of women in oceanography faculty positions has historically been less than would be expected from the proportion of women graduating with oceanography PhDs. For example, in a study that examined 26 different US institutions, Orcutt & Cetinić (2014)[GDS5] found an average of 40% women faculty at the assistant professor level, 30% at the associate professor level, and 15% at the full professor level; in the same year, O'Connell (2014)[GDS5], examining 6 oceanographic institutions, found 35%, 33%, and 20% women at the assistant, associate, and full professor levels, respectively. Both of these studies showed (slow) improvements from the 10% proportion of women noted by Nowell & Hollister (1988).

Ranganathan et al. (2021)[GDS5] examined whether the declining proportion of women at advanced career levels can be attributed to lower numbers of women PhDs entering the academic career path in the past (the pipeline explanation), by means of a fractionation factor—the ratio between the gender ratio at one rank (i.e., associate professor) and the gender ratio at the previous rank (i.e., assistant professor) at an earlier time. Using this metric, they showed that up until about 2015, women were less likely than men to advance from one career stage to the next (i.e., the pipeline hypothesis is incorrect). In recent years, this tendency has been reduced, and for ocean sciences, the gender ratio of assistant professors in 2020 matches that of PhDs (i.e., close to 50%

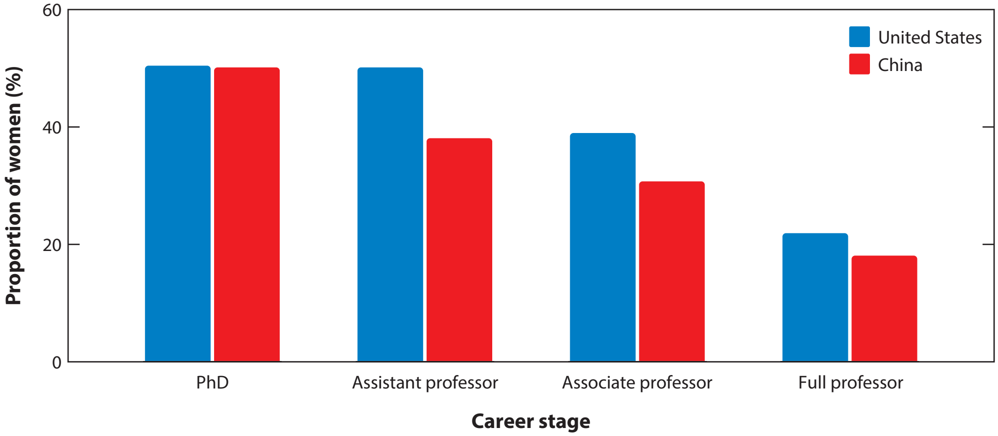

Figure 2

The percentage of women at each stage of an oceanographic academic career in the United States and the People's Republic of China, shown as a snapshot around 2020–2021. US PhD data are for 2020 from the National Science Foundation Survey of Earned Doctorates, Ocean and Marine Sciences (NSF 2021); US faculty data are for 2020 from Ranganathan et al. (2021); Chinese PhD data are an average for 4 universities for 2019–2021; and Chinese faculty data are an average for 15 universities for 2021.

women). However, in 2020, only 39% of associate professors in oceanography were women, giving a fractionation factor of 0.78 (i.e., women are only 0.78 as likely as men to be promoted from assistant to associate professor). Only 22% of full professors of oceanography were women in 2020, reflecting the impact of historical attrition. Ranganathan et al. (2021) also discussed differences among different oceanography subdisciplines: Whereas overall oceanography faculty were 31% women, for physical oceanography, this percentage was only 21%.

Elsewhere, the proportion of women decreases at higher career levels: In Europe in 2016, for all natural sciences, women made up nearly 40% of PhD graduates but only 15% of professors (Eur. Comm. Dir.-Gen. Res. Innov. 2021); 2021 data from the French Centre National de la Recherche Scientifique (CNRS), Italian academia, and the Spanish Consejo Superior de Investigaciones Científicas (CSIC) all showed a decline in women's representation from approximately 50% at the PhD level to approximately 25% at the highest academic levels (Giakoumi et al. 2021)[GDS1, GDS5]; and in the institutions participating in the Baltic Consortium on Promoting Gender Equality in Marine Research Organisations (Baltic Gender), the percentage of women declines from approximately 30–60% at the postdoctoral level to approximately 25% at the full professor level (Baltic Gend. 2019). In Spain in 2001, women made up 63% of undergraduates in oceanography but only 42% of oceanography researchers (Liquete 2005), and whereas approximately 50% of Spanish men oceanography researchers were in permanent positions (i.e., the highest career level), only 22% of women oceanography researchers were in such positions.

Similar trends are seen in the People's Republic of China, where we surveyed faculty numbers in oceanographic departments at 15 different universities in early 2022[GDS1] using publicly available data (summarized in **Figure 2**). Combining all oceanographic subdisciplines, women made up 38.1% of lecturers (the equivalent of assistant professor), 30.7% of associate professors, and 18.2% of professors, a declining percentage at each successive career stage. The proportion of women at the lecturer level is less than the proportion of women receiving PhDs at four of these institutions, indicating that women have been less likely to advance from PhD to entry-level faculty. The gender disparities at the professor level vary considerably among subdisciplines: Whereas only 12% of professors in physical oceanography are women, 23.2% of those in marine biology are women. At the lecturer level, women exceed men in marine ecology (61.4% women) and are close to parity in physical oceanography (46.2% women) but still make up only a small proportion in marine geology (29.5%).

For Brazil, while neither Leta & Lewison (2003) nor Marins & da Costa (2015) gave data for gender ratios of faculty in oceanography, Marins & da Costa (2015) noted that 47% of research groups at a 2013 national meeting were coordinated by women (with differences among disciplines, biological oceanography groups having 50% women leadership compared with 43% for chemical and physical oceanography). This is a substantial proportion compared with those in many other parts of the world but less than the percentage of women who receive PhDs.

Women remain very underrepresented in leadership levels of employment, with only 24% of French CNRS marine laboratories led by women in 2019 and only 33% of the directors of the Spanish Institute of Marine Sciences over an 80-year period being women (Giakoumi et al. 2021). Marins & da Costa (2015) noted that only 1 of the 7 marine science National Institutes of Science and Technology in Brazil is led by a woman, and only 3 of the 18 senior researchers in the National Institute of Oceanic and Waterways Research are women. However, progress was noted by O'Connell (2014) in the appointment by 2014 of women directors at 3 of the 6 US oceanographic institutions featured in an earlier study (O'Connell & Holmes 2005).

An alternative method to track women's career progression is to focus on cohorts of PhD students, determining their current employment through internet searches. Thompson et al. (2011)[GDS5] used this method to compare career trajectories of men and women PhDs in physical oceanography originating at 6 US institutions. The student cohorts were separated into those who graduated between 1980 and 1995 and those who graduated between 1996 and 2009, and the analysis excluded those still in postdoctoral positions as of 2009. For both cohorts, approximately a quarter of the men PhDs obtain tenure-track faculty positions; however, for the women PhDs in the 1996–2009 cohort, the likelihood of obtaining a tenure-track position decreased to 8% from the 23% likelihood in the earlier period. A greater fraction of women in the later period were employed as research faculty and staff.

We have attempted to repeat this analysis for the recent decade 2010–2019, using the same employment categories, again eliminating those who are still in postdoctoral positions from the analysis and examining only physical oceanography PhDs. Our analysis is restricted to only 3 of the original 6 schools examined by Thompson et al. (2011)—the Massachusetts Institute of Technology (MIT)–WHOI, the University of Washington, and the University of Rhode Island—due to data availability. For this recent cohort, men and women PhDs obtained tenure-track faculty positions at a similar rate (30% and 29%, respectively). The most noticeable difference between men's and women's employment is now in the private sector, which employs 33% of men PhDs in contrast to only 23% of women (more of whom are research faculty). This analysis confirms that men and women in physical oceanography are now equally likely to obtain faculty positions, in agreement with the analysis of Ranganathan et al. (2021) for US oceanography in general, that there is finally, in 2021, no greater attrition of women compared with men in the transition from student to assistant professor.

Promotion along the career ladder is not the only measure of employment equity in oceanography careers, and lack of advancement may be a consequence of other underlying inequities. Prompted by the MIT gender report (MIT 1999), WHOI conducted a gender equity review (WHOI 2000). This review demonstrated gender inequities in the salaries of scientific staff that diverged between men and women after employment (there being little difference in the initial salaries for starting entry-level men and women scientists) and in the allocation of space, with men tenured scientists having approximately 50% more space than women tenured scientists.

3.4. Research Funding

Access to research funding is an important component of success in oceanography, where many academic scientists are funded through research grants. The competitive process to obtain research funding in most countries needs to be examined to ensure it does not favor one particular demographic. In the United States, much basic research is funded by the NSF, which publishes annual summaries of the merit review process and conducts periodic external evaluations. The 2009 report from the Committee of Visitors for the NSF Division of Ocean Sciences (OCE) within the Geosciences directorate (Fine et al. 2010) noted that the OCE success rate for proposals with women principal investigators (PIs) increased from 23% in 2006 to 27% in 2008, but it did not give the comparable figures for proposals led by men PIs. However, the most recent merit review process digest for 2019 (Natl. Sci. Board 2020) showed that the overall NSF funding rate (i.e., the percentage of submitted proposals that are successful in receiving funding) for women PIs has consistently, since 2009, been approximately 1–2 percentage points higher than the funding rate for men PIs (table 8 in Natl. Sci. Board 2020[GDS2]), and the percentage of proposals submitted by women has increased slightly, from approximately 23% in 2009 to 29% in 2019. In the Geosciences directorate specifically, in 2019 26% of proposals had women PIs and 56% had men PIs (the gender of 17% of PIs was not known), and 40% of proposals submitted by women PIs were funded, compared with 37% of proposals submitted by men PIs. Statistics on the relative resubmission rates for proposals with women and men PIs are not available, which could be a factor influencing success rates. Another factor contributing to gender equity in funding rates may be the gender balance in NSF program managers: For the entire NSF, the proportion of women program managers has increased from 36% in 2006 (Natl. Sci. Board 2007) to 47% in 2019 (Natl. Sci. Board 2020). Deliberate policies at the NSF designed to ensure equitable outcomes are another possible factor. We are not aware of similar reviews for other US oceanographic funding agencies (e.g., the Office of Naval Research), which have very different structures for proposal evaluation.

Lima & Rheuban (2021)[GDS4] have conducted a thorough analysis of publicly available NSF data (which do not include declined proposals) specific to OCE, finding that the proportion of funded proposals with women PIs has increased from 10% in 1987 to 30% in 2019. These authors argued that since this gender ratio for OCE women PIs slightly exceeds that of the earth, atmospheric, and oceanic sciences workforce, there is no gender bias in NSF OCE funding, a conclusion supported by the similarity of the Geosciences directorate funding rates for male and female PIs given above. Examining the different programs within OCE reveals significant differences by subdiscipline: Women's participation (i.e., as PIs and co-PIs) is much higher in education programs in particular, as well as in biological oceanography, and much lower in programs associated with instrumentation and ship operations, and also relatively low in physical oceanography.

In Europe, in contrast to the NSF, women's research funding proposals are 2.5 percentage points less likely to be funded than men's in natural sciences (Eur. Comm. Dir.-Gen. Res. Innov. 2021), but no further breakdown is available by scientific field. By contrast, Giakoumi et al. (2021) showed that for European Research Council grants (in the Ecology, Evolution, and Environmental Biology section for the period 2013–2018), the success rate for proposals led by women was slightly higher than that for proposals led by men, but the proportion of applicants who were women was significantly less (38% women, 62% men) for starting grants, and substantially less (13% women, 87% men) for advanced grants. For the United Kingdom, UK Research and Innovation demographic data are available via a dashboard (UK Res. Innov. 2021a) and are summarized in annual reports (the most recent being UK Res. Innov. 2021b[GDS3]). For PIs, the overall award rate (over all research councils) for men and women PIs reached parity (for the first time) at 29% in 2019–2020, whereas in 2015–2016, men and women PIs had award rates of 28% and 24%, respectively. This overall parity masks large differences among research councils. In particular, the UK Natural Environment Research Council (NERC), which is largely responsible for oceanography funding, consistently has a funding rate for women PIs that is approximately 5 percentage points lower than that for men PIs. By contrast, NERC fellowships have had a higher funding rate for women than men over the period 2015–2019 and rates close to parity in 2019–2020. Over the period 2015–2020, women PIs made up 22–25% of the applicants for NERC research funding. For studentships, NERC funding is much closer to parity, with close to 50% of awardees being women over the 2015–2019 time period.

In Brazil, Leta & Lewison (2003) examined researcher funding data from 2000 and concluded that whereas 42% of the men oceanographers in the database were recipients of fellowships from the National Council for Scientific and Technological Development, the same applied to only 24% of the women oceanographers. This contrasted with the similar proportions of men and women oceanographers who were leaders of research groups—65% of men and 57% of women. Marins & da Costa (2015) showed good gender parity in national research scholarships in oceanography for both international and domestic research for the period 2001–2013. However, only approximately 30% of the highest-level scientific productivity awards went to women during that period, despite the significant proportion of oceanography PhDs going to women. Both studies concluded that despite the strong representation of women in Brazilian oceanography, they are not being rewarded at the highest ranks at a level commensurate with their contributions to research.

3.5. Chief Scientists

An important leadership position in oceanography is that of chief scientist or principal scientific officer (PSO) on a research ship. The proportion of chief scientists who are women has increased from 10% in the early 2000s to 20% in the early 2010s on University-National Oceanographic Laboratory System (UNOLS) ships and from 15% to 30% on the German *Polarstern* research vessel (Orcutt & Cetinić 2014), proportions that are similar to those for associate and senior faculty and women PIs of US proposals at that time. The proportion of PSOs on UK ships has also increased over the past two decades (Hendry et al. 2020). The Deep Sea Drilling Project (1968–1983) and Ocean Drilling Program (1985–2003) showed an increase in women's participation from less than 10% of the scientific party in the 1970s to more than 25% in the early 2000s (O'Connell & Holmes 2005). Whereas only 4 women served as co-chief scientists in the Deep Sea Drilling Project, women were co-chief scientists on 16 Ocean Drilling Program expeditions. For the multiplatform Integrated Ocean Drilling Program, over the period 2004–2013, women averaged 30% of the scientific party but only 12% of co-chief scientists (O'Connell 2014). O'Connell (2014) noted that the International Ocean Drilling Program had a requirement for a certain proportion of co-chief scientists from each country whose government contributed funding, and although Japan was a substantial contributor, there were no Japanese women co-chief scientists, contributing to the low overall proportion of women co-chief scientists (e.g., compared with the proportion for UNOLS ships). More recently, during the International Ocean Discovery Program (2014–present), gender balance has improved: Women were 32% of co-chief scientists between 2014 and 2018 (Koppers et al. 2019). Data from German research ships show that, for 255 scientific cruises in 2018 and 2019, 24% of the chief scientists were women.

3.6. Research Publications

Oceanographers record and communicate scientific advances through peer-reviewed publications, which also contribute to evaluations and assessments of a scientist's career. Obstacles to submission and publication in the peer-reviewed literature can therefore have a wide impact on other measures of gender equity (e.g., promotion, leadership, and awards). Giakoumi et al. (2021) examined the gender of first and last authors from European Union–affiliated institutions for publications in journals corresponding to four different marine science themes from 2009 to 2019. For all types of journals, the last author (often the head of the group) is much less likely to be a woman (approximately 25%). By contrast, the first author is equally likely to be a man or woman for journals ranked in the bottom two quartiles, while for journals ranked in the top two quartiles, more than 75% of first authors are men and fewer than 25% are women.

Leta & Lewison (2003) found that 43% of papers by Brazilian oceanographers from 1996 to 2000 included women authors or coauthors, similar to the proportion of women in the field in Brazil at that time (42%). Both men and women published predominantly in lower-impact domestic journals.

When there is a gender imbalance in the authorship of published papers, does that imbalance result from differences in submission rates or from bias within the review process? Data on submissions, reviewers, and final publications are needed to answer this question. In the American Geophysical Union (AGU) journal *Journal of Geophysical Research: Oceans* (*JGR Oceans*) for the period 2016–2021, for those corresponding authors whose gender can be determined[GDS4], the proportion of corresponding authors who are women has increased from 21% in 2016 to 25% in 2021, being roughly constant over the period 2018–2021, with a small decrease in 2020–2021 compared with 2019 [perhaps due to COVID-19, although for AGU journals as a whole, Wooden & Hanson (2022) found no change in gender ratio for submissions]. The improvement in corresponding author gender ratio for this journal is more marked than that for other AGU journals, where the average proportion of women corresponding authors in 2016 was similar to that for *JGR Oceans* (at 21.4%) but had increased only very slightly by 2021 (to 22.4%).

Is this difference between *JGR Oceans* corresponding author gender ratio and the gender ratio in other journals due to changing membership demographics in the AGU Ocean Sciences Section? In fact, the self-reported gender demographics of AGU members shows that the proportion of women in this section has increased slightly, from 29.3% in 2015 to 33.2% in 2021, while the proportion of women in the rest of the AGU membership has increased slightly faster, from 28.8% in 2015 to 33.0% in 2021. For both the Ocean Sciences Section and the rest of the AGU, the proportion of women in the membership is greater than the proportion of women corresponding authors, likely because membership growth has been in the earlier-career cohort, who are less likely to be prolific authors.

Unless rejected by the journal editor, each submitted manuscript must be reviewed by multiple topical experts selected by the journal editors. For *JGR Oceans*, the proportion of women among the reviewers invited by the editors has increased steadily, from 19% in 2016 to 26% in 2021. This is similar to the gender ratio of reviewer invitations at other AGU journals, and this proportion has increased faster than the proportion of corresponding authors who are women in *JGR Oceans*. However, invited reviewers have the option to decline the invitation, and whereas in 2016 the rate at which invited reviewers agreed to do the review was approximately equal for men and women (agree rate of 45–46%), in 2020–2021 (during the COVID-19 pandemic), the agree rate for women declined to 35–37%, while that for men declined less, to 41–42%. As a result of the lower invitation rate combined with the lower acceptance rate for women, the proportion of reviewers who are women for *JGR Oceans* manuscripts has been low, ranging from 18.6% in 2016 to 22.8% in 2021, both of which are lower than the proportion of submitting authors who are women.

Finally, at *JGR Oceans*, the percentage of submitted papers that were ultimately accepted varied from 69% to 65% for women first authors over the period 2017–2020 and from 64% to 54% for men first authors. The acceptance rate in all years is a few percentage points higher for women authors than for men authors. This is also true at other AGU journals.

In contrast to journals such as *JGR Oceans*, where manuscript submission is open to all, other journals consist of invited contributions, where a guest editorial board decides on the list of invitees for each issue; an example is special issues of *Oceanography*, the magazine published by The Oceanography Society (TOS). Kappel & Thompson (2014)[GDS4] examined the proportion of women first authors for *Oceanography* special issues for the period 2004–2014 and found that 22% of the contributions were first-authored by women. This study included the 2005 special issue on women in oceanography, where all of the authors were women, as well as eight special issues (20% of the total) where no women were first authors. Only two issues had more than 50% women first authors, and most had fewer than 40%. Of those eight special issues with no women first authors, six had no women guest editors (approximately 50% of the special issues had no women guest editors). For the period 2015–2021, women first-authored 37% of the articles, there were no issues with no women first authors, approximately 30% of the issues had 50% or more women first authors, and approximately 30% of issues had no women guest editors. Hence, by all metrics, the participation of women in *Oceanography* special issues has improved in the 2015–2021 period compared with the 2004–2014 period, and in fact surpasses the participation of women in the open submission journal *JGR Oceans*.

Another example of an invitation-only journal is the *Annual Review of Marine Science*. From 2009 to 2022, women have made up 28% of the first authors[GDS5] (although for this journal, the first author is not necessarily the invited author). This proportion has varied considerably from year to year, from as low as 9.5% in 2011 to as high as 40% in 2019, and back down to 21% in 2022 (perhaps impacted by the COVID-19 pandemic). For the present 2023 volume, 48% of first authors (and invited authors) are women.

3.7. Scientific Conferences

In addition to educational attainment, employment, and publications, another method of tracking the contributions of women to oceanography is through their participation in scientific conferences. An IOC report examined participant lists from 37 international ocean conferences held from 2015 to 2018 and found that 43% of the participants were women, but this proportion varies by topic (e.g., women made up more than 50% of participants at ocean health conferences, approximately 50% at marine ecosystem conferences, and only approximately 30% at ocean crust and marine geohazards conferences) as well as by regional focus and country of origin (with women making up more than 50% of the participants from Russia, Italy, Brazil, and Portugal and less than 20% of the participants from Japan) (IOC-UNESCO 2020)[GDS4]. The proportion of women participants increased slightly over the period from 2012 to 2018.

Not all conference roles are equally prestigious. The same IOC report showed that for the conferences examined, women made up on average only 29% of featured speakers, considerably less than their average participation level (IOC-UNESCO 2020)[GDS4]. Examination of select conferences showed a positive correlation between the proportion of women conference organizers and the proportion of women invited speakers.

One possible explanation for the low numbers of women as invited speakers is the tendency for women participants in conferences to be at earlier career levels than the men participants (IOC-UNESCO 2020). Indeed, examining the AGU Fall Meeting database, where participants self-report demographic information and date of PhD, Ford et al. (2018)[GDS3] found that while women are less likely to be invited and assigned oral presentations, this disparity disappears when controlling for career stage. However, if the data are further examined for race and ethnicity, women from certain groups (Hispanic/Latino, African American, Native American, and Pacific Islander) are the least likely to be given speaking opportunities at this conference (Ford et al.

2019)[GDS3]. The Ocean Sciences meeting, held every two years, would be an ideal large conference to examine the same demographic statistics in an oceanographic setting; however, the same self-reported data are not available.

As a contrast to the large AGU Fall Meeting format, the Gordon Research Conferences (GRCs) consist of small numbers of invited speakers (approximately 25) and discussion leaders (approximately 9). Each GRC focuses on a particular topic, and each topic holds a meeting approximately every two years, enabling an examination of trends. As described by Kappel & Thompson (2014)[GDS4], the GRCs related to oceanography (Ocean and Human Health, Polar Marine Science, Chemical Oceanography, and Coastal Ocean Modeling) have shown some improvement in the percentage of women speakers and discussion leaders over time; for example, for the Chemical Oceanography GRC, the proportion of women speakers increased from less than 20% in 1995 to approximately 30% in 2007–2013. Extending this analysis[GDS5] shows that the two most recent Chemical Oceanography GRCs, in 2017 and 2019, had 50% or more women speakers. The Coastal Ocean Modeling (now Coastal Ocean Dynamics) GRC has increased from approximately 10% women speakers in 2001 to approximately 30% women speakers in 2017–2019. The newest GRC, Ocean Mixing, had 25% women speakers in 2018, a lower proportion than most of the others. For all the GRCs, the proportion of women discussion leaders (a less prestigious role, often awarded to earlier-career scientists) is greater than the proportion of women speakers, averaging approximately 50% in recent years for many of the GRCs and 60% for the 2018 Ocean Mixing GRC, with large fluctuations from year to year but an increasing trend over the 2000–2014 period (Kappel & Thompson 2014).

3.8. Awards and Honors

Awards, usually made by professional and academic societies, are an important recognition of achievement for scientists. As noted by O'Connell (2014), women oceanographers were largely absent from these honor rolls until the twenty-first century. **Table 1** shows professional society oceanography awards made to women, concentrating on the twenty-first century, for the AGU, the American Meteorological Society (AMS), the Association for the Sciences of Limnology and Oceanography (ASLO), the European Geophysical Union (EGU), the International Association for the Physical Sciences of the Ocean (IAPSO), and TOS. Progress toward gender equity is evident particularly in the early-career awards (the AGU Ocean Sciences Early Career Award, the AMS Fofonoff Award, the ASLO Lindeman Award and Yentsch–Schindler Early Career Award, the EGU Division of Ocean Sciences Outstanding Early Career Scientist Award, and the IAPSO LaFond Medal and Early Career Scientist Medal), which have gone to women 38–55% of the time over the past decade. Women have been 50% of the recipients of the AGU Ocean Sciences Voyager Award (for mid-career scientists) and the AGU oceanographic honorific lectures (the Emiliani and Sverdrup Lectures) have increasingly been awarded to women. However, in the past decade, women have made up only 25% of the recipients of the ASLO Hutchinson Award (for mid-career scientists).

For senior awards, the gender ratio is variable. While the AGU Ewing Medal and Revelle Medal have improved their gender ratios since the study by O'Connell (2014), the AGU Ocean Sciences Award, which rewards a senior oceanographer's service to the community, has gone to only one woman since 2000. The ASLO Redfield Lifetime Achievement Award has gone to women three out of eight times since 2015. The senior oceanography awards of AMS (the Stommel Research Medal and the Sverdrup Gold Medal) and IAPSO (the Prince Albert I Medal) have rarely gone to women, and the two TOS senior awards with a longer-term history (the Munk Medal and the Jerlov Award) have each gone to women only once.

Table 1 Professional society oceanography awards

Professional society	Award name	Period examined	Awards to women/total awards	Proportion of awards to women
AGU	Ewing Medal	2007–2021	4/14	29%
	Revelle Medal	2004–2021	6/17	35%
	Ocean Sciences Award	2002–2021	1/11	9%
	Ocean Sciences Early Career Award	2002–2021	5/12	42%
	Ocean Sciences Voyager Award	2014–2020	2/4	50%
	Emiliani Lecture	2005–2021	9/21	43%
	Sverdrup Lecture	2000–2021	12/22	55%
AMS	Stommel Research Medal	2011–2022	2/12	17%
	Sverdrup Gold Medal	2011–2022	2/12	17%
	Fofonoff Award	2011–2022	5/12	42%
ASLO	Lindeman Award	2000–2021	10/22	45%
	Hutchinson Award	2010–2021	3/12	25%
	Redfield Lifetime Achievement Award	2015–2021	3/8	38%
	Yentsch–Schindler Early Career Award	2013–2022	4/10	40%
EGU	Nansen Medal	2011–2022	3/12	25%
	Division of Ocean Sciences Outstanding Early Career Scientist Award	2011–2022	3/8	38%
IAPSO	Prince Albert I Medal	2000–2021	2/11	18%
	LaFond Medal	2003–2019	5/9	56%
	Early Career Scientist Medal	2019–2021	2/4	50%
TOS	Munk Medal	1993–2017	1/13	8%
	Jerlov Award	2000–2020	1/11	9%

Data compiled from the society websites[GDS5]. Abbreviations: AGU, American Geophysical Union; AMS, American Meteorological Society; ASLO, Association for the Sciences of Limnology and Oceanography; EGU, European Geophysical Union; IAPSO, International Association for the Physical Sciences of the Ocean; TOS, The Oceanography Society.

In contrast to the improvement in gender equity for awards, the AGU Ocean Sciences Section Fellows program has shown little improvement since 2014, when, as documented by Kappel & Thompson (2014), women made up approximately 22% of fellows. Since 2015, women have made up 10 of 45 new fellows over this period, an average of 22% women. The ASLO Fellows program has better gender balance than that of AGU, with 34% of both sustaining fellows and regular fellows between 2015 and 2021 being women. TOS has a small fellows program, with women making up 6 of 17 TOS fellows up to 2014 (Kappel & Thompson 2014) and 8 of 27 from 2015 to 2021—a decreasing proportion.

3.9. Leadership Roles: Committees, Boards, and Panels

An additional indicator of women's inclusion and recognition by the oceanographic community is their representation in community leadership positions, such as boards, committees, and panels. Vila-Concejo et al. (2018) conducted a survey of professional organizations in coastal geosciences and engineering and found that women make up approximately 30% of the membership of these organizations and, encouragingly, also approximately the same proportion of the steering committees of these societies. However, the organizing committees for international conferences in coastal geosciences and engineering between 2013 and 2016 were only 22% women.

By contrast, at the World Climate Research Programme CLIVAR (Climate Variability and Predictability) project, which focuses on the ocean's role in climate, women currently make up 44% of its panelists [as indicated on the CLIVAR website (**https://www.clivar.org**) in January 2021[GDS5]). This high proportion of women is especially notable since it also intersects with geographical diversity, including women from all of the inhabited continents of the globe. CLIVAR actively encourages self-nominations from early-career scientists for these leadership positions.

The presidents of oceanographic professional societies are examples of leadership positions at the highest level. From 1989 to 2010, only 2 of 10 TOS presidents were women, while from 2010 to 2022, 2 of 6 presidents have been women (TOS 2022). The AGU Ocean Sciences Section first had a woman president in 1988, and from 1990 to 2022, 6 of 15 presidents have been women, including 3 of 5 since 2010 (AGU 2022). ASLO first had a woman president in 1988, and from 1990 to 2022, 6 of 16 presidents have been women, including 3 of 6 since 2010. Finally, in IAPSO's entire history since 1919, only 2 of 23 presidents have been women, both in the twenty-first century.

4. MEASURES TO IMPROVE EQUITY

In the past two decades, numerous initiatives have been implemented to address inequalities in gender representation in oceanography. Here, we examine a cross section of these different interventions and their impacts. Many of these interventions can also be employed to address other axes of inequity, such as race and socioeconomic class (Behl et al. 2021).

4.1. Data Collection

A first step in many intervention programs is the establishment of assessments to determine the current status of women's participation in the field. Without complete gender-disaggregated data for all participants in oceanographic activities, the gendered barriers to participation cannot be precisely identified. The Empowering Women for the United Nations Decade of Ocean Science for Sustainable Development program has begun an effort to achieve gender equity in ocean science by collecting baseline gender-disaggregated data from selected international organizations and national institutions. Baltic Gender, a 2016–2020 project partnering eight institutions from five countries in the Baltic Sea region, developed a set of 13 gender-sensitive indicators to assess the status of gender equity at each institution and monitor its evolution over time (Baltic Gend. 2022). These indicators include several described in the previous section, such as proportions of men and women at different career stages on the academic track and a glass ceiling index that is similar to the fractionation index described by Ranganathan et al. (2021), which compares the proportion of women at one career level to that of the level above. Other quantitative indicators used by Baltic Gender include the gender pay gap, a part-time employment index, the proportion of women and men chief scientists on research cruises, the proportion of women and men on boards and committees, and the proportion of women and men job applicants, interviewees, and new hires. Baltic Gender also suggested qualitative indicators for flexible work arrangements and child care services, gender analysis and gender equality plans in research project design and implementation, and gender-sensitive language and teaching methods.

4.2. Mentoring

The routine collection of data is important, but initiatives to improve gender equity in oceanography can be pursued even in the absence of complete quantitative data. One widely embraced mechanism to address gender inequity is through mentoring programs, with the aim of addressing imbalances in access to mentoring.

MPOWIR is a long-running mentoring program that was initiated in the early 2000s by senior women in physical oceanography in the United States (described in Clem et al. 2014, Lozier 2005, Mouw et al. 2018). The core program focuses on early-career women from the late stages of a PhD into the early years of a longer-term position, with a variety of group mentoring activities. It is notable that all applicants who fit the eligibility criteria are accommodated. More than 200 early-career scientists have participated, and a retrospective analysis of the participants indicates that five years after completing a PhD, approximately 80% are still in academia or government or nonprofit research.

The via:mento_ocean program (**https://www.mentoringocean.uni-kiel.de/en/via-mento_ocean**) is a similar mentoring initiative, but restricted to women doctoral and postdoctoral researchers at Kiel Marine Science. The program was of limited duration, lasting from 2012 to 2018, with three two-year cycles of approximately 10–20 mentees. In addition to matching mentors and mentees, the program also provided professional development training, networking events, and travel expenses to allow the mentor–mentee pairs to meet in person. This program was recognized as a best practice by the German Research Foundation and by Baltic Gender (Baltic Gend. 2019).

Baltic Gender instituted a similar mentoring program (Baltic Gend. 2020), for two cycles of 8 and 10 mentees each, from 2017 to 2020. The mentees were required to be affiliated with the Baltic Gender institutions, and in the second round, fewer than half of the 22 applicants were selected. The program matched the mentees with senior mentors based around the world and provided professional development training and travel funds for meetings with mentors and career development activities. This mentoring program ended when the Baltic Gender program concluded.

The Society for Women in Marine Science (**https://swmsmarinescience.com**) is a peer support and networking organization founded by early-career women scientists in 2014 and now run as a charitable organization with a global reach. It began with one-to-one and small-group mentoring programs in 2018, matching mentors and mentees, and provides guidance and oversight. Mentees can be at any career stage from high school onward, and mentors can be based anywhere in the world and can be at any career stage from post-undergraduate onward.

The Ocean Womxn program (Commonw. Blue Chart. 2021), based at the University of Cape Town, South Africa, was launched in 2019 to address the underrepresentation of Black women in the university's Department of Oceanography: In 2018, only 12 of 73 postgraduate students were Black women in this majority Black country, and there were no Black women on the faculty. To address the lack of Black women role models in the department, the program hosts regular mentoring sessions for program fellows with Black women leaders in other STEM fields.

Mentoring programs can be developed to train women for specific leadership roles, addressing inequities in informal advisor-based training. For example, Marine Scotland Science has developed a scheme for training PSOs, open to all genders, in which a co-PSO is appointed on each expedition (Hendry et al. 2020), contributing to the development of a gender-balanced pool of trained PSOs.

4.3. Institutional Change Initiatives

The targeted mentoring programs described above can provide both the support and access to information to allow women to thrive in oceanographic careers. However, these programs guide minoritized groups to negotiate barriers to success without directly addressing the institutional and structural issues that create these barriers. In effect, mentoring programs can leave in place the exclusionary environments at the institutions where those mentees are expected to succeed (Berhe et al. 2022, Marin-Spiotta et al. 2020). As such, mentoring is not a substitute for institutional change.

Several initiatives have been developed to promote institutional change, with the goal of reaching gender equity at the faculty/PI level in both academic and scientific institutions. Examples include the NSF ADVANCE program in the United States and the Athena Scientific Women's Academic Network (SWAN) program in the United Kingdom. The Earth Institute at Columbia University was the recipient of an NSF ADVANCE award in 2004 (Bell et al. 2005) and implemented programs to create and codify strategies to recruit and retain more women faculty and provide the tools that will enable these women to succeed, while also institutionalizing accountability. Hendry et al. (2020) credited the Athena SWAN charter, launched in 2005, with promoting policy changes such as the creation of a gender-balanced pool of PSOs by Marine Scotland Science. And, as described by Black (2020), the government of Canada has created and implemented Gender-Based Analysis Plus (GBA+), a framework for analyzing how policies and programs affect different identities, including gender.

As part of Baltic Gender, programs from the participating institutions were promoted as best practices, including Gender Equality Plans, gender-sensitive teaching practices, quotas for boards, transparent hiring schemes for postdocs, a "come back to research" program for researchers who had been out of the workforce, gender-indicator-based funding, and the use of institutional codes of conduct. At one of the participating institutions, GEOMAR in Kiel, the Women's Executive Board represents women in leadership to ensure that women's needs are included in decision-making. One outcome of Baltic Gender was the development of GenderWave (Valve 2020), a digital tool that allows researchers to examine gender links in the planning of marine science projects and make improvements to promote gender equity at the outset.

Too Big to Ignore (TBTI), a global network of researchers working with communities to support sustainable fisheries, explicitly considers gender throughout its work and created a research cluster in 2014 to specifically focus on women and gender in fisheries (Black 2020). Finally, the Ocean Womxn program (Commonw. Blue Chart. 2021) combines its mentoring efforts with institutional change, including staff and students in discussions to change departmental culture.

4.4. Support Networks

Outside of academic and research institutions, discipline-based community groups provide networking, support, and advocacy for gender-based issues, as well as issues associated with multiple intersecting marginalized identities. Examples include the Earth Science Women's Network (**https://eswnonline.org**), the Society for Women in Marine Science, Women in Coastal Geoscience and Engineering (**https://womenincoastal.org**), Women for One Ocean (based in Japan) (**https://womenforoneocean.com**), and Black in Marine Science (**https://www.blackinmarinescience.org**).

4.5. Addressing Harassment

None of these initiatives to remove barriers and promote the success of women in oceanographic careers will achieve the goal of equity if the presence of sexual harassment is not addressed in both land-based and shipboard working environments. Sexual harassment in STEM fields has been the focus of much recent attention (Natl. Acad. Sci. Eng. Med. 2018), but addressing the problem requires institutional change, not just punishment of individual perpetrators after the fact. The recent Workshop to Promote Safety in Field Sciences (Consort. Ocean Leadersh. & Calif. State Univ. Desert Stud. 2021) provided a long list of recommendations, including culture change, accountability, policy development, and reporting, emphasizing the importance of accommodating the cross-institutional nature of ocean fieldwork, as well as the urgency of dealing with harassment at sea. Since 2019, UNOLS has a standing Maintaining an Environment of Respect Aboard Ships (MERAS) committee (UNOLS 2022a). An interview with Kent Sheasley, captain of the R/V *Neil Armstrong* (Beal 2016), emphasized the important role of the captain and chief scientist in promoting a safe environment on board ships. Baltic Gender included the development of measures to prevent sexual harassment at sea, promoting codes of conduct and guidelines for reporting.

5. SUMMARY AND RECOMMENDATIONS

Our survey of data related to gender in oceanography from around the globe reveals that women are close to parity in undergraduate and graduate education in oceanography in many countries, and are increasing in parity in earlier levels of academic oceanographic employment. There is therefore no lack of interest in oceanography among women. While the proportion of women first authors and PIs does not yet match the proportion of women PhDs in oceanography, in some funding programs, proposals from women PIs are as likely to be funded as those from men PIs. Improvements in gender ratios of awards vary enormously among different organizations, as does women's representation on panels and committees. The differences between different organizations (e.g., NSF versus NERC for funding, or TOS versus the AGU Ocean Sciences Section for awards) may reflect different processes for selection, some of which may be more susceptible to both structural and cognitive bias, motivating reexamination of current processes to develop more equitable frameworks. There continue to be differences in gender parity among subdisciplines of oceanography, with physical oceanography having less participation from women than biological oceanography.

These improvements in gender equity at the broadest levels, however, mask continuing inequities for certain groups of women. True gender equity in oceanography must include the participation of women at all life stages; socioeconomic backgrounds; races, ethnicities, and nationalities; sexualities; and physical abilities. Furthermore, gender equity must include people of nonbinary genders, who continue to be erased in numerous gender data collection methods (Strauss et al. 2020) and experience disrespectful remarks in the geoscience workplace at higher rates than binary women (Diaz-Vallejo et al. 2021). Gender equity must also include trans people of all genders, who face gender discrimination and harassment as well as institutional obstacles, for example, in recognizing an individual's name changes (Gaskins & McClain 2021).

While the trend toward gender parity at early-career levels is encouraging, effort needs to continue to remove barriers to equal participation throughout all levels of an oceanographic career path, such as those listed in **Figure 1**. Removing the obstacles that women and other minoritized groups face will reduce the attrition of talented scientists from oceanographic careers and ensure that all groups are able to contribute.

Based on this review of current data and publications on gender in oceanography, we have several umbrella recommendations, drawing on specific ideas given by Black (2020), Hendry et al. (2020), Marcus (2005), Orcutt & Cetinić (2014), and Vila-Concejo et al. (2018). Notably, we do not advocate for "strategies for women to succeed in science," which were recommended to address gender disparities a decade or two ago (e.g., O'Connell & Holmes 2005); rather, we focus on measures to change the system to fully include women and other people with minoritized genders and to cease obstructing their career advancement. Our recommendations are as follows:

1. Routinely collect gender-disaggregated data: Adequate data are needed to determine the extent and specific details of gender inequity. Gender data should be self-identified, include nonbinary options, and recognize that trans women are women. All organizations, including academic institutions, funding agencies, professional societies, journals, workshops, and

conferences, should collect gender-disaggregated data (as well as other self-identified data, e.g., on race and sexuality) for applicants and selections and should review the statistics frequently to evaluate gender equity. Oceanographers should engage with social scientists and gender studies experts in this work.

2. Eliminate all forms of harassment: Numerous guidelines for eliminating harassment in science and academia, including field sciences, have been produced in recent years. Institutions must act on these, stop protecting harassers, and ensure that participation—particularly at sea—is safe for all.
3. Reexamine all selection, evaluation, promotion, and nomination procedures to remove gender disparities: The decision-making processes that govern others' advancement in a scientific career need to be examined and reconsidered if there are gender disparities in outcomes. This applies to everything from admissions to graduate school, PhD completion, entry-level hiring, tenure, promotion to professor, awards, panel and invited speaker selection, and funding allocation. A gender ratio that does not reflect that of the available pool of scientists is an indicator of bias, whether structural or cognitive, which needs to be addressed, both in the interests of fairness and to achieve the advancement of the science endeavor. Removal of gender inequities will take continued deliberate effort to interrupt bias and structural barriers in the decision-making process.
4. Remove structural inequities: Structural issues that disproportionately impact women and nonbinary people (e.g., the availability of child care, accommodation of dual careers, and access to appropriate bathrooms) must be addressed to remove barriers to participation in science. A current and urgent example of inequity in science is the disproportionate impact of the COVID-19 pandemic on women's careers (Natl. Acad. Sci. Eng. Med. 2021), due in part to the disproportionate burden of child and elder care placed on women.
5. Address unequal access to resources and unequal demands: The resources needed for success in science must be accessible to all, including mentorship, funding, space, technical support, advocacy. Similarly, one group should not be unfairly burdened with tasks that may limit their advancement, such as committee duties and administrative tasks.
6. Encourage all members of the community to work for equity: The burden of producing a more equitable community must not fall on those who are most affected by the inequity. While those at leadership levels are the most able to effect structural change and must continue to engage in this work, at every career level we have the ability to choose our collaborators, whom we nominate for awards, and whom we invite to speak. As described by Drake (2019), there are many ways for all oceanographers to get involved—we should work together to create an oceanographic community where everyone is able to contribute and thrive.

DISCLOSURE STATEMENT

S.L. was a co-PI for MPOWIR from 2014 to 2022, is the current cochair of the Scientific Steering Group of the World Climate Research Programme CLIVAR project, and is a current co–vice chair for the Ocean Mixing GRC. E.K. is the editor of *Oceanography*, published by TOS, and was previously a manager for the International Ocean Drilling Program. Several of the authors are members of some of the scientific societies examined in this review.

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