Title: Gender Equity in Oceanography

PREPRINT SUBMITTED TO EARTHARXIV

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Gender Equity in Oceanography: PREPRINT SUBMITTED TO EARTHARXIV

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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 about 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 1st-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; re-examining selection and evaluation procedures; and removing structural inequities.

Contents

1. INTRODUCTION

What is gender equity? Drawing on the definition from the World Health Organization `https://www.who.int/health-topics/gender#tab=tab_1`, gender refers to 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 the focus in this review is 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 all genders, assuming 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 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**. This review benefits from some of the global preparation for the ongoing United Nations Decade of Ocean Science for Sustainable Development, including the Empowering Women for the Ocean Decade Programme (Black 2020). Many specific aspects of gender equity within oceanography have been assessed in the last decade, often focusing on just one metric (for example, number of PhDs, American Geosciences Institute (2013)), just one activity (for example, the MPOWIR mentoring program, Clem et al. (2014)), or just one country (for example, Brazil, Marins & da Costa (2015)). Here we aim to synthesize these different studies, including world-wide comparisons where possible, and offer a comparison of different metrics. However, we acknowledge a bias toward USA-centric information owing to the lead-author's status as a USA 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 nonbinary genders are largely omitted from the statistics. Better self-identified gender collection is needed to address this gap (Strauss et al. 2020) (see sidebar).

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 the superscipt $^{GDS[N]}$, where $[N] = 1, 2, 3, 4, 5$.

Gender Data Source 1 (GDS1): legal database

In a few cases, gender has been determined from a legal database (e.g. for Brazilian researchers). Often such data-bases 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 including nonbinary options

Sometimes gender is self-identified, e.g. for the UKRI. As emphasized in Strauss et al. (2020), reliable gender data can only be obtained through self-identification, which must include non-binary options and sufficient anonymity to ensure respondents feel safe answering accurately. Other methods erase nonbinary people in particular.

Gender Data Source 4 (GDS4): given name algorithm

There are many studies where gender is determined by the study author, often using an algorithm based on given-names. This is problematic: given-name data-bases 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 such as used 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 1-to-1 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.

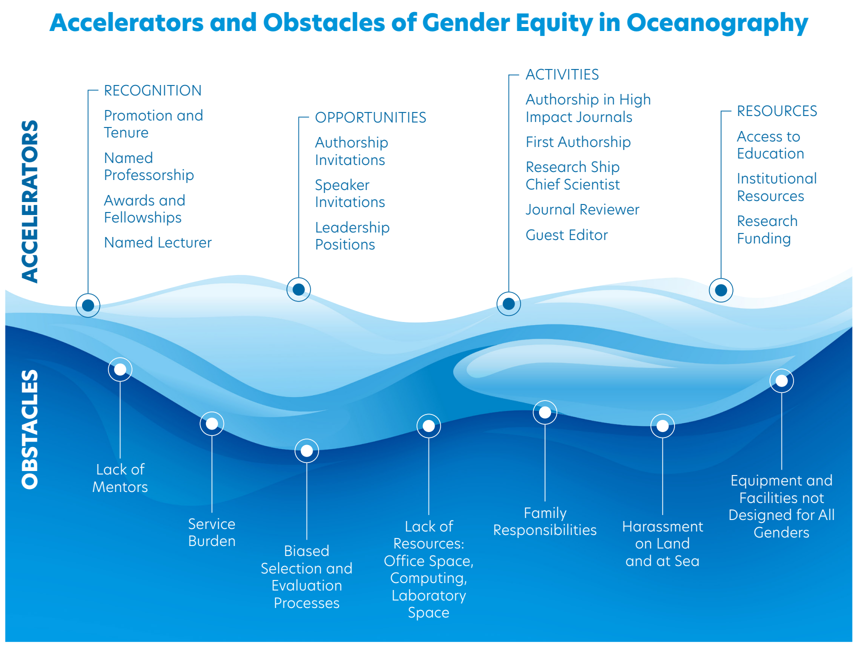

Figure 1

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

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, socio-economic class, national origin, and sexuality. Full gender equity will not be achieved until all women and nonbinary people can fully participate in our community.

2. HISTORICAL OBSTRUCTIONS TO GENDER EQUITY IN OCEANOGRAPHY

Historically, there have been numerous obstacles impeding 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 which emphasize the apprentice model, affinity bias (Wolfinger et al. 2008, Patton et al. 2017, Sheltzer & Smith 2014). Here we focus primarily on barriers specific to oceanography.

2.1. Bans on women's involvement in sea-going oceanography

Women's involvement in early sea-going oceanography was suppressed by superstition-based restrictions preventing them from serving on ships, either as crew or scientists, in Western Europe and North America (Hendry et al. 2020, Bonatti & Crane 2012). 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 1st half of the 20th century, small numbers of women participated in sea-going oceanography in both Britain (Hendry et al. 2020) and USA (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, Lewandowski 2018, Kalemeneva & Lajus 2018) owing to strong support for participation of women in oceanography from the head of the State Oceanographic Institute (Kalemeneva & Lajus 2018). In the USA, women's access to sea-going 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 take 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 "larger and more commodious ship[s]" (L.V. Worthington, quoted in Bonatti & Crane (2012)) 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), 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 USA, changes to institutional policies preventing women from participating in sea-going 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 Woods Hole (WHOI scientist 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 for Oceanography to join a sea-going 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 in 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 which 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 UK in the early 1900s (Hendry et al. 2020), Easter Ellen Cupp was the first woman to receive a PhD from Scripps 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 Svedrup most likely because she was a woman (Day 1999). Anti-nepotism 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 sea-going resources.

Even though women could obtain higher education in oceanography throughout the 20th century, their success depended on the willingness of male faculty to advise them; some male faculty at Scripps were open about never taking women students Day (1999). Silver (2005) describes 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, our male colleagues".

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 USA oceanography from shore, including June Pattullo (the first USA 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 their male colleagues and counterparts. Oreskes (1996, 2000) hypothesizes that the work of these women oceanographers was considered routine, boring, and most importantly "un-herioc" because it did not involve the adventure of going to sea. This focus on geoscientists as adventurer-explorers has not only excluded white women who were not permitted to join these expeditions, but also excluded people of color and people with physical disabilities (Pico 2021, Marshall & Thatcher 2019, Marin-Spiotta et al. 2020).

2.4. Harassment at sea

A continuing barrier to women's participation in sea-going oceanography is gender-based harassment, which encompasses everything from demeaning remarks and unwanted attention, to bullying and sexual assault (National Academies of Sciences, Engineering, and Medicine 2018, O'Hern 2015). The restricted space at sea makes it difficult for women to avoid their harasser, who may be far from institutional oversight (Consortium for Ocean Leadership and California State University Desert Studies 2021). Hendry et al. (2020) note that as the numbers of women on UK ships increased in the 1990s, so too did the incidence of harassment. More recently behavioral guidelines and reporting structures have been developed (`https://mpowir.org/women-scientists-at-sea/`, `https://www.unols.org/shipboard-civility`), although there is still much work to do to ensure everyone can be safe at sea. Harassment is also a problem in other oceanographic work places, and harassment continues to push women and other marginalized groups out of oceanography (National Academies of Sciences, Engineering, and Medicine 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 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 tracks the numbers of women in the global oceanographic workforce, with 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, about 10% higher than for natural science as a whole. There are large differences between different countries, with Croatia showing the greatest proportion of women ocean science researchers at 63% and Japan showing the lowest proportion at 12%. The proportion of ocean science researchers who are women for some of the nations discussed elsewhere in this report are USA: 35% (all ocean science personnel, 2013 value), UK: 43%, Germany: 40% (one institution only), Spain: 43%, Brazil: 50%, South Africa: 33%. Data are not provided for China or India. Of the respondents to the latest survey, women make up 50% or more of the oceanographic researchers in Angola, Croatia, Brazil, Bulgaria, 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 which 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 to show that women made up 42% of the oceanographic researchers in Brazil at that time. A later analysis by Marins & da Costa (2015)^{GDS1} shows 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 between different sectors or stages of employment. One useful metric for gender equity at the entry level of oceanographic research is PhD completion data. The USA National Science Foundation tracks PhD completion in different science fields with associated demographic data including gender (the Survey of Earned Doctorates `https://www.nsf.gov/statistics/srvydoctorates/`^{GDS2}), and the American Geosciences Institute frequently examines the trends in this data. The survey has historically included only binary gender, so may not include accurate responses from nonbinary and trans students, (DeHority et al. 2021). The percentage of USA oceanography PhDs who are women has been at or around 50% since around 2007 (American Geosciences Institute 2013, Ranganathan et al. 2021, Ocean Science Educators' Retreat 2020). 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 USA this gender parity has been achieved from a level of about 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 (Ranganathan et al. 2021, American Geosciences Institute 2013, O'Connell 2014). Improvements in gender parity in oceanography PhDs in the USA has largely benefited white women (Bernard & Cooperdock 2018), and there has been little improvement in inclusion of women of color in USA oceanography doctoral education (Ocean Science Educators' Retreat 2020, American Geosciences Institute 2020).

Oceanography PhD gender ratios are more difficult to determine for countries where this data collection is not routine, and national level data tends to be grouped under very broad categories (e.g. Natural sciences (European Commission and Directorate-General for Research and Innovation 2021)). We have examined gender of recipients of PhDs and Masters degrees from 4 different universities in the People's Republic of China from 2019-2021, using publicly available data^{GDS1}, and find that the proportion of women varies from 38-65% at masters level, and from 40-60% at PhD level, i.e. approximately equal or in some cases higher numbers of women. Near gender parity in the beginning levels of oceanography education is seen in several other countries: women make up more than 50% of marine science graduates at the University of the South Pacific (Michalena et al. 2020).

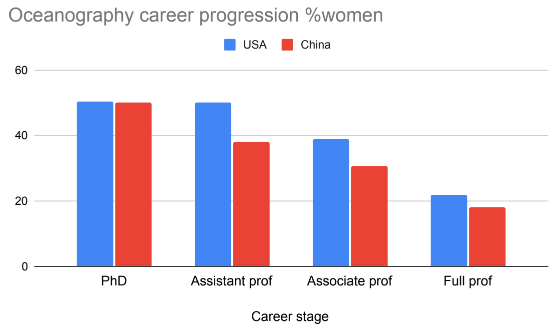

Figure 2

The percentage of women at each stage of an oceanographic academc career in USA and China, shown as a snapshot around 2020/2021. USA PhD data is for 2020 from the NSF survey of earned doctorates, Ocean and Marine Sciences; USA faculty data is for 2020 from Ranganathan et al. (2021); China PhD data is an average of 4 universities for 2019-2021; China faculty data is an average of 15 universities for 2021.

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 USA oceanography academia, career progression differentiated by gender has been examined in several studies over the past few decades (Nowell & Hollister 1988, O'Connell & Holmes 2005, O'Connell 2014, Orcutt & Cetinić. 2014, Thompson et al. 2011, Ocean Science Educators' Retreat 2020, Ranganathan et al. 2021), 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, Orcutt & Cetinić. (2014)^{GDS5} found in 2014, for 26 different USA institutions, an average of 40% women faculty at the assistant professor level, 30% at the associate professor level and 15% at the full professor level; also in 2014, O'Connell (2014)^{GDS5}, examining 6 oceanographic institutions, found gender ratios of 35%, 33% and 20% for assistant, associate and full professor levels, both (slow) improvements of the faculty gender ratio from about 10% noted in Nowell & Hollister (1988).

Ranganathan et al. (2021)^{GDS5} examine 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 show 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 (ie. close to 50%). However, only 39% of associate professors in oceanography are women in 2020, 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. For full professors in oceanography only 22% are women in 2020, reflecting the impact of historical attrition. Ranganathan et al. (2021) also discuss differences between different oceanography subdisciplines: whereas overall oceanography faculty are 31% women, for physical oceanography this ratio is only 21%.

Decreasing numbers of women at higher career levels are noted elsewhere: in Europe for all natural sciences, in 2016 women made up nearly 40% of PhD graduates, but only 15% of professors (European Commission and Directorate-General for Research and Innovation 2021); data from the French CNRS, Italian Academia and Spanish CSIC in 2021 all show a decline in women's representation from about 50% at PhD level, to around 25% at the highest academic levels (Giakoumi et al. 2021)[GDS1,GDS5]; in the Baltic gender consortium group of European marine science institutions (Baltic Gender 2019) the percentage of women declines from around 30-60% at postdoc level to around 25% at full professor level. In Spain in 2001, women made up 63% of undergraduates in oceanography, but only 42% of oceanography researchers (Liquete 2005), and whereas about 50% of Spanish men oceanography researchers were in permanent (i.e. the highest career level) positions, only 22% of women oceanography researchers were in permanent positions.

Similar trends are seen in the People's Republic of China, where we have surveyed faculty numbers in oceanographic departments at 15 different universities for the current time (early 2022)[GDS1], from publicly available data, summarized in **Figure 2**. Combining all oceanographic subdisciplines, women make 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 between 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 only make up a small proportion in marine geology (29.5%).

For Brazil, while neither Marins & da Costa (2015) nor Leta & Lewison (2003) give data for gender ratios of faculty in oceanography, Marins & da Costa (2015) notes 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 to 43% for chemical and physical oceanography), a substantial proportion compared to many other parts of the world, but less than the percentage of women who receive PhDs.

Women remain very under-represented 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 Science over an 80 year period being women (Giakoumi et al. 2021). Marins & da Costa (2015) note that only 1 of the 7 marine science National Institutes of Science and Technology in Brazil is led by a woman, and only 3 out of 18 of the senior researchers in the National Institute of Oceanic and Waterways Research is a woman. However, progress is noted by (O'Connell 2014) in the appointment by 2014 of women directors at 3 of the 6 USA 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 search. Thompson et al. (2011)[GDS5] used this method to compare career trajectories of men and women PhDs in physical oceanography, originating at 6 USA institutions. The student cohorts were separated into those who graduated between 1980-1995 and 1996-2009, and the analysis excluded those still in postdoctoral positions as of 2009. For both cohorts, about 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 was reduced 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 of Thompson et al. (2011), namely MIT-WHOI, University of Washington, and 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 with 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 USA oceanography in general, that there is finally, in 2021, no greater attrition of women compared to 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 (Massachusetts Institute of Technology 1999), Woods Hole Oceanographic Institution conducted a gender equity review (Woods Hole Oceanographic Institution 2000). This review demonstrated gender inequities in the salaries of scientific staff which 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 about 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 USA, much basic research is funded by the National Science Foundation, 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 oceanography division 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 did not give the comparable figures for proposals led by men PIs. However, the most recent Merit Review Process digest for 2019 (National Science Board 2019) shows that the funding rate (i.e. the percentage of submitted proposals which are successful in receiving funding) for all of NSF for women PIs has consistently, since 2009, been about 1 or 2 percentage points higher than the funding rate for men PIs (Table 8 in National Science Board (2019)[GDS2]), and the percentage of proposals submitted by women has increased slightly from about 23% in 2009 to 29% in 2019. In the GEO 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 to 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 gender balance in NSF program managers: over the whole of NSF, the proportion of women program managers has increased from 36% in 2006 (National Science Board 2006) to 47% in 2019 National Science Board (2019). Deliberate policies at NSF designed to ensure equitable outcomes are another possible factor. We are not aware of similar reviews for other USA oceanographic funding agencies (e.g. ONR) which have very different structures for proposal evaluation.

Lima & Rheuban (2021)^{GDS4} have conducted a thorough analysis of publicly available NSF data (which does not include declined proposals) specific to the Division of Ocean Sciences, finding that the proportion of funded proposals with women PIs has increased from 10% in 1987 to 30% in 2019. These authors argue 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 GEO directorate funding rates for male and female PIs quoted 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 biological oceanography, and much lower in programs associated with instrumentation and ship operations, and also relatively low in physical oceanography.

In Europe, by contrast with NSF, European Commission and Directorate-General for Research and Innovation (2021) shows that women's research funding proposals are 2.5 percentage points less likely to be funded than men's in natural sciences, but no further breakdown is available by scientific field. By contrast Giakoumi et al. (2021) shows that for European Research council grants (in the Ecology, Evolution, and Environmental Biology section for the period 2013-2018), the success rate for proposals lead by women was slightly higher than for 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 is available via a dashboard `https://www.ukri.org/our-work/supporting-healthy-research-and-innovation-culture/equality-diversity-and-inclusion/diversity-data/`, and summarized in annual reports, the most recent being UK Research and Innovation (2021)^{GDS3}. For principal investigators, 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 PIs had an award rate of 28% compared to an award rate of 24% for women. This overall parity masks large differences between research councils. In particular NERC (the Natural Environment Research Council, which is largely responsible for oceanography funding) consistently has a funding rate for women PIs about 5% lower than for men PIs. By contrast NERC fellowships have had a higher funding rate for women than men over the period 2015-2019, and close to parity in 2019-2020. Over the period 2015-2020 women PIs made up 22% to 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 CNPq fellowships, 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) shows good gender parity in national research scholarships in oceanography for both international and domestic research for the period 2001-2013. However, for the highest-level "scientific productivity" awards, only about 30% of these awards went to women during that period, despite the significant proportion of oceanography PhDs going to women. Both authors conclude 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 contribution to research.

3.5. Chief Scientists

An important leadership position in oceanography is that of Chief Scientist or Principal Scientific Officer 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 UNOLS ships and from 15% to 30% on the German Polarstern research vessel (Orcutt & Cetinić. 2014), ratios which are similar to the gender ratio of associate and senior faculty and women PIs of USA proposals at that time. The proportion of Principal Scientific Officers on UK ships has also increased over the past 2 decades (Hendry et al. 2020). The Deep Sea Drilling Project (1968-1983) and Ocean Drilling Program (1985-2003) show an increase in women's participation from less than 10% of the scientific party in 1970s to over 25% in the early 2000s (O'Connell & Holmes 2005). Whereas only 4 women served as co-chief scientists in DSDP, women were co-chief scientists on 16 ODP expeditions. For the multiplatform Integrated Ocean Drilling Program, over the period 2004-2013, (O'Connell 2014), women average 30% of the scientific party, but only 12% of co-chief scientists. O'Connell (2014) note that IODP 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 to UNOLS). More recently during the International Ocean Discovery Program (2014-present) gender balance has improved: women were 32% of co-chief scientists between 2014-2018 (Koppers et al. 2019). Data from German research ships show that, out of the 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, awards). Giakoumi et al. (2021) examines the gender of first- and last-authors from EU-affiliated institutions for publications in journals corresponding to 4 different marine-science themes from 2009-2019. For all types of journals, the last author (often the head of the group) is much less likely to be a woman (around 25%). In contrast, the first author is equally likely to be a man or woman for journals ranked in the bottom 2 quartiles, while for journals ranked in the top 2 quartiles, more than 75% of first authors are men and fewer than 25% are women.

For Brazilian oceanographers, Leta & Lewison (2003) found that 43% of papers by

Brazilian oceanographers from 1996-2000 included women authors or co-authors, similar to the proportion of women in the field in Brazil at that time (42%), and both men and women publish predominantly in "lower impact" domestic journals.

When there is gender imbalance in authorship of published manuscript, 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. For the AGU journal Journal of Geophysical Research: Oceans (JGR:Oceans) for the period 2016-2021, for those corresponding authors where 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 to 2019 (perhaps due to covid-19, although for AGU journals as a whole no change in gender ratio for submissions was noted in Wooden & Hanson (2022)). The improvement in corresponding author gender ratio for this journal is more marked than for other AGU journals, where the average gender ratio in 2016 was similar to JGR oceans (at 21.4%), but has only increased very slightly to 22.4% by 2021. Is this difference between JGR ocean corresponding author gender ratio and the gender ratio in other journals due to changing membership demographics in the ocean section of AGU? In fact the self-reported gender demographics of AGU members shows that the proportion of women in the ocean 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 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 has to 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 at 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 37-35%, while that for men declined less, to 41-42%. As a result of lower invitation rate, combined with lower acceptance rate for women, the proportion of reviewers who are women for JGR oceans manuscripts is low, ranging from 18.6% in 2016 to 22.8% in 2021, both lower than the proportion of submitting authors who are women.

Finally, at JGR-Oceans, the percentage of submitted papers which are ultimately accepted varies from 69%-65% for women first authors, over the period 2017-2020, and from 64%-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 like 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, such as special issues of Oceanography Magazine, the publication of the Oceanography Society. 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 included the

2005 special issue on Women in Oceanography where 100% of the authors were women, as well as 8 special issues (20% of the total) with zero women first authors. Only 2 issues had more than 50% women first authors, most had less than 40%. Of those 8 special issues with no women 1st authors, 6 had no women guest editors (about 50% of the special issues had no women guest editors). Repeating this analysis for the period 2015-2021, women 1st-authored 37% of the articles, there were no issues with no women first authors, about 30% of issues had 50% or more women 1st-authors, and about 30% of issues had no women guest editors. Hence, by all metrics, the participation of women in Oceanography magazine special issues has improved in the 2015-2021 period compared to 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 Annual Reviews of Marine Science. From 2009-2022, women have made up 28% of the first authors[GDS5]. This has varied considerably from year to year, as low as 9.5% in 2011 and as high as 40% in 2019, and back down to 21% in 2022 (perhaps impacted by the covid-19 pandemic).

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. IOC-UNESCO (2020) examined participant lists[GDS4] from 37 international ocean conferences held from 2015-2018, and found that 43% of the participants are women, but this proportion varies by topic (e.g. >50% of participants at ocean health conferences were women, about 50% at marine ecosystem conferences, and only about 30% at ocean crust and marine geohazards conferences) as well as 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). The proportion of women participants increased slightly over the period from 2012-2018.

Not all conference roles are equally prestigious. IOC-UNESCO (2020)[GDS4] shows that for the conferences they examine, women make up on average only 29% of featured speakers, considerably less than their average participation level. 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 Fall AGU format, the Gordon Research conferences consist of a small number (around 25) of invited speakers, and about 9 discussion leaders. Each GRC is focused on a particular topic, and each topic holds a meeting about every 2 years, enabling 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, e.g. for chemical oceanography the proportion of women speakers increased from less than 20% in 1995 to around 30% in 2007-2013. Extending this analysis^{GDS5}, the two most recent Chemical oceanography GRCs in 2017 and 2019 had 50% or more women speakers. Coastal Ocean Modeling (now Coastal Ocean Dynamics) has increased from around 10% women speakers in 2001, to around 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 around 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

Table 1 Professional society oceanography awards, data compiled from society websites^{GDS5}. Shown are the oceanography awards of American Geophysical Union (AGU), American Meteorological Society (AMS), European Geophysical Union (EGU), International Association for Physical Sciences of the Ocean (IAPSO), Association for the Sciences of Limnology and Oceanography (ASLO), and The Oceanography Society (TOS).

Professional society	Award name	period examined	Awards to women/total awards	% of awards to women
AGU	Ewing Medal	2007-2021	4/14	29%
AGU	Revelle Medal	2004-2021	6/17	35%
AGU	Ocean Sciences Award	2002-2021	1/11	9%
AGU	Ocean sciences early career award	2002-2021	5/12	42%
AGU	Ocean sciences voyager award	2014-2020	2/4	50%
AGU	Emiliani Lecture	2005-2021	9/21	33%
AGU	Svedrup Lecture	2000-2021	12/22	54%
AMS	Stommel Research Medal	2011-2022	2/12	16%
AMS	Svedrup Medal	2011-2022	2/12	16%
AMS	Fofonoff award	2011-2022	5/12	42%
EGU	Nansen medal	2011-2022	3/12	25%
EGU	Ocean div. early career award	2011-2022	3/8	38%
IAPSO	Prince Albert medal	2000-2021	2/11	18%
IAPSO	Eugene LaFond medal	2003-2019	5/9	55%
IAPSO	early career scientist medal	2019-2021	2/4	50%
ASLO	Lindemann Award	2000-2021	10/22	45%
ASLO	Hutchinson Award	2010-2021	3/12	25%
ASLO	Redfield lifetime achievement award	2015-2021	3/8	38%
ASLO	Yentsch-Schindler early career award	2013-2022	4/10	40%
TOS	Munk Medal	1993-2017	1/13	8%
TOS	Jerlov award	2000-2020	1/11	9%

[a]Table footnote; [b]second table footnote.

Awards, usually made by professional and academic societies, are an important recognition of achievement for scientists. As noted in O'Connell (2014), women oceanographers were largely absent from these honor rolls until the 21st century. Table 1 shows professional society oceanography awards made to women, concentrating on the 21st century, for the American Geophysical Union (AGU), American Meteorological Society (AMS), European Geophysical Union (EGU), International Association for Physical Sciences of the Ocean (IAPSO), Association for the Sciences of Limnology and Oceanography (ASLO), and The Oceanography Society (TOS). Progress toward gender equity is evident particularly in the early career awards (AGU ocean sciences early career award, AMS Fofonoff award, EGU Ocean division early career award, IAPSO Eugene LaFond and early career scientist medals, ASLO Lindemann and Yentsch-Schindler awards) which have gone to women 38-55% over the past decade. Women have been 50% of the recipients of the AGU Ocean sciences voyager (mid-career) award and the AGU oceanographic honorific lectures (Emiliani and Svedrup lectures) have increasingly been awarded to women. However, in the past decade, women make up only 25% of the ASLO Hutchinson (mid-career) award.

For senior awards, the gender ratio is variable. While the AGU Maurice Ewing and Roger Revelle awards have improved their gender ratios since O'Connell (2014), the AGU Ocean Sciences Award, rewarding a senior oceanographer's service to the community, has only gone to one woman since 2000. The ASLO Redfield lifetime achievement award has gone to women 3 out of 8 awards since 2015. The senior oceanography awards of AMS (Stommel and Svedrup) and IAPSO (Prince Albert Medal) have rarely gone to women, and the two TOS senior awards with a longer term history (Munk Medal and the Nils Gunnar Jerlov Award) have each gone to women only once.

In contrast to the improvement in gender equity for awards, the AGU ocean sciences section fellows have shown little improvement since 2014, when as documented in Kappel & Thompson (2014) women made up about 22% of fellows. Since 2015, women have made up 10 out 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 2015-2021 being women. The Oceanography Society (TOS) has a small fellows program, with women making up 6/17 TOS fellows up to 2014 (Kappel & Thompson 2014), and 8/27 from 2015-2021 - a decreasing proportion.

3.9. Leadership roles: committees, boards, 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 about 30% of the membership of these organizations, and encouragingly also about the same proportion of the steering committees of these societies. However organizing committees for international conferences in coastal geosciences and engineering between 2013-2016 were only 22% women.

By contrast, at the World Climate Research Program CLIVAR (climate variability and prediction) project, which focuses on the ocean's role in climate, women currently make up 44% of its panelists (as indicated on the CLIVAR website http://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 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. The Oceanography Society had only 2/10 women presidents from 1989-2010, while from 2010-2022, 2/6 of the presidents have been women (`https://tos.org/tos-council`). The Ocean Sciences section of the AGU first had a woman president in 1988, and from 1990-2022 has had 6/15 women presidents, with 3/5 women presidents since 2010 (`https://connect.agu.org/oceansciences/about/leadership/past-leaders`). ASLO first had a woman president in 1988, and from 1990-2022 has had 6/16 women presidents, including 3/6 since 2010. Finally, IAPSO has had only 2 women presidents (both in the 21st century) in its entire history since 1919 (with 23 presidents in total).

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, e.g. race, socio-economic 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 UN 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. The Baltic Consortium on Promoting Gender Equality in Marine Research Organisations (Baltic Gender), a 2016-2020 project partnering 8 institutions from 5 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. These indicators (available at `http://www.baltic-gender.edu/outcomes`) include several described in the previous section, e.g. proportions of men and women at different career stages on the academic track, a glass ceiling index similar to the "fractionation index" of Ranganathan et al. (2021) by comparing 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 on boards and committees, the proportion of women and men job applicants, interviewees, and new hires. They also suggest 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.

Mentoring Physical Oceanography Women to Increase Retention (MPOWIR) is a long-running mentoring program, initiated in the early 2000s by senior women in physical oceanography in USA and described in Lozier (2005), Clem et al. (2014), Mouw et al. (2018). The core program focuses on early career women from the late stages of the 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 retrospective analysis of the participants indicates that about 80% are still in academia or government or nonprofit research 5 years after PhD.

via:mento_ocean (`https://www.mentoringocean.uni-kiel.de/en/via-mento_ocean`) is a similar mentoring program, but restricted to women doctoral and postdoctoral researchers at Kiel Marine Sciences. The program was of limited duration from 2012-2018, with 3 2-year cycles of about 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 Gender 2019).

Baltic Gender instituted a similar mentoring program (`http://oceanrep.geomar.de/50254/1/BG_D5-2_Synthesis_Report_on_Mentoring_Program.pdf`), for two cycles of 8 and 10 mentees each, from 2017-2020. The mentees were required to be affiliated with the Baltic Gender institutions, and in the second round, less 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 has ended with the end of the Baltic Gender program.

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, now run as a charitable organization with a global reach. SWMS began one-to-one and small-group mentoring programs in 2018, where SWMS matches the mentors and mentees, and provides guidance and oversight. Mentors may be based anywhere in the world, and at any career stage from high-school and above (for mentees) and from post-undergraduate and above (for mentors).

The Ocean Womxn program (Commonwealth Blue Charter 2021), based at the University of Cape Town, South Africa, was launched in 2019 to address the under-representation of Black women in the Department of Oceanography: in 2018 only 12 out 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 Principal Scientific Officers (PSO), 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 leading to gender equity at the faculty/principal investigator level in both academic and scientific institutions. Examples include the NSF ADVANCE program in the USA and the Athena SWAN program in the UK. 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, provide the tools that will enable these women to succeed while also institutionalizing accountability. Hendry et al. (2020) credits the Athena SWAN charter, launched in 2005, with promoting policy changes such as the creation of a gender-balanced pool of Principal Scientific Officers by Marine Science Scotland. As described in 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. An outcome of Baltic Gender was the development of Gender Wave (Valve 2020), a digital tool to allow researchers to examine gender links in the planning of marine science projects and make improvements to promote gender equity at the outset. The Too Big To Ignore (TBTI) global network of researchers working with communities to support sustainable fisheries explicitly considers gender throughout their work, as well as creating a research cluster in 2014 to specifically focus on Women and Gender in Fisheries (Black 2020). The Ocean Womxn program (Commonwealth Blue Charter 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 (`http://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 ship-board working environments. Sexual harassment in STEM has been the focus of much recent attention National Academies of Sciences, Engineering, and Medicine (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 (Consortium for Ocean Leadership and California State University Desert Studies 2021), provides a long list of recommendations, including culture change, accountability, policy development, and reporting, emphasizing the importance of accommodating the cross-institutional nature of ocean field work, as well as the urgency of dealing with harassment at sea. Since 2019, UNOLS has a standing committee on Maintaining an Environment of Respect Aboard Ships (`https://www.unols.org/committee/maintaining-environment-respect-aboard-ships-meras`). An interview with Kent Sheasley, Captain of the R/V Neil Armstrong (`https://mpowir.org/women-scientists-at-sea/`) 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 1st 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 between different organizations, as does women's representation on panels and committees. The differences between different organizations (e.g. NSF v. NERC for funding, or the Oceanography Society v. AGU Ocean Sciences for awards) may reflect different processes for selection, some of which may be more susceptible to both structural and cognitive bias, motivating re-examination 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, socio-economic backgrounds, races/ethnicities/nationalities, sexualities, and physical abilities. Furthermore, gender equity must include 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, e.g. 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**. By removing the obstacles that women and other minoritized groups face, we 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 suggest the following umbrella recommendations, drawing on specific ideas listed in Hendry et al. (2020), Black (2020), Vila-Concejo et al. (2018), Marcus (2005), Orcutt & Cetinić. (2014). 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)), but rather focus on measures to change the system to fully include women and other people with minoritized genders, and cease obstructing their career advancement.

1. Routinely collect gender dis-aggregated 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 dis-aggregated data (as well as other self-identified data, e.g. on race and sexuality) for applicants and selections, and 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 participation particularly at sea is safe for all.

3. Re-examine all selection, evaluation, promotion, and nomination procedures to remove gender disparities.

The decision-making processes which 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 admission to graduate school, PhD completion, entry-level hiring, tenure, promotion to professor, awards, panel and invited speaker selection, and funding allocation. A gender ratio which 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 childcare, accommodation of dual careers, 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 (National Academies of Sciences & Medicine 2021), due in part to the disproportionate burden of child and elder care placed on women.

5. Address unequal access to resources, 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 which may limit their advancement, e.g. committee duties, administrative tasks.

6. All members of the community need 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, who we nominate for awards and who we invite to speak. As described in Drake (2019) there are many ways for all oceanographers to get involved - let's work together to create an oceanographic community where everyone is able to contribute and thrive!

DISCLOSURE STATEMENT

Sonya Legg has been a co-Principal Investigator for Mentoring Women in Physical Oceanography to Increase Retention (MPOWIR) from 2014-2022, is the current co-chair of the Scientific Steering Group of the World Climate Research Program CLIVAR project, and is a current co-vice chair for the Ocean Mixing Gordon Research Conference. Ellen Kappel is editor of Oceanography magazine, published by The Oceanography Society, 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. Apart from those affiliations, the authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

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