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Gender and Arctic climate change science in Canada

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ABSTRACT There is growing recognition that gender diversity within research organizations can result in innovative research outcomes. It has also been recognized that gender homogeneity can undermine the quality and breadth of the research and may allow some to cast doubt on the legitimacy of scientific findings. In this paper, we present the results of a gender-based analysis of Canada's ArcticNet Networks Centers of Excellence. Representing Canada's single largest commitment to climate change science, ArcticNet has involved 761 researchers who have published >2400 peer-reviewed publications on the impacts of climate change in the Canadian Arctic. Our results indicate that, despite outnumbering their male peers at the graduate levels, the representation of women within ArcticNet exhibits a marked decline to only 21% ($N = 51$) of all ArcticNet investigators ($N = 246$). In addition to being numerically under-represented, female investigators in ArcticNet have fewer research collaborators and are generally less integrated into the network as compared to their male colleagues. Male investigators tend to form homophilious ties—publishing predominately with other males, whereas female investigators have heterophilious collaborations, with fewer peer-reviewed journal articles. Given the complexities of climate change research, particularly in the Arctic where the impacts of climate change are projected to be most extreme, the equitable inclusion of female scientists and other under-represented groups is crucial if sustainable solutions are to be found.

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Introduction

"Women have made outstanding contributions to polar research in recent decades, though full engagement may be hindered by persistent inequities" (Starkweather et al., 2018).

It is safe to say that in 2020 there are more young women pursuing careers in Arctic research than ever before (Moon, 2018). In the past 50 years alone, women have gone from being barred from Arctic field sites, to leading international research expeditions, directing national and international research organizations, and serving as mentors to the next generation of Arctic researchers. According to Seag (2019), the history of women in Arctic research is a story of exclusion to inclusion that has been "led by inspiring women who broke one ice ceiling after another". Yet if the gains women have made in Arctic sciences are to continue, they will require the necessary institutional support to advance their research careers (Carey et al., 2016; Moon, 2018). Unfortunately, there are indications that this support—and the opportunities it can offer to women in Arctic sciences—are far from being fully realized.

During the Polar 2018 Open Science Conference in Davos, Switzerland, over 300 attendees participated in a session entitled *From Entering the Field to Taking the Helm: Perspectives of Women in Polar Research*. During this session, panelists, and participants shared experiences of professional exclusion, harassment, and in some cases, workplace violence. These conditions were attributed in part to a research culture firmly rooted in masculine norms of behavior (Seag, 2019) where the exclusionary legacies of the early twentieth century remain deeply entrenched in the conduct of Arctic science today (Starkweather et al., 2018). While acknowledging that progress has been made —in the field, the laboratories, and administration— the full entry of women into Arctic sciences has yet to be achieved (Hoogensen, 2017). Rather, women continue to encounter formidable obstacles to their career development and are challenged to gain the same professional opportunities (Moon, 2018) and recognitions (Gazni and Didegah, 2011) as their male peers.

In this paper, we present the results of a gender-based analysis of the ArcticNet Networks Centers of Excellence (NCE) (hereafter ArcticNet). Established in 2004, ArcticNet represents Canada's single largest commitment to Arctic climate change science to date. The principal objective of ArcticNet is to study the impacts of climate change in the Canadian Arctic by consolidating national and international research expertise. To this end, ArcticNet has engaged over 1000 researchers, including investigators, graduate students, post-doctoral fellows, and other specialists from 34 Canadian universities and 20 federal and provincial laboratories and agencies (http://www.arcticnet.ulaval.ca). To determine the extent to which women have gained entry into this national research network, we assessed how the gender of ArcticNet researchers influences professional collaborations and research output. Our results lend quantitative support to the testimonials of female researchers who have felt excluded and marginalized in the conduct of Arctic climate change science in Canada.

ArcticNet centers of excellence

Nations throughout the world are contributing considerable amounts of public funding to research on climate change. It is estimated that between 2003 and 2016, \$14.6 Bn (USD) in research funding was directed globally to climate change research (Hook et al., 2017). In the Arctic, where the impacts of global warming are expected to be most pronounced (AMAP, 2012), an estimated \$1.5 Bn (USD) has been provided to universities and research centers to examine the social and bio-physical impacts stemming from a warming Arctic environment (Hook et al., 2017). While each of the Arctic states has made major financial investments into their climate change research portfolios, Canada's largest commitment to date has been through the establishment of ArcticNet, which has received over \$363 million (CAD) in government funding (2004–2018).

The research program of ArcticNet is organized around four integrated regional impact studies (IRIS). The IRIS correspond to the main political, physiographic, and oceanographic regions of the Canadian Arctic: Western and Central Arctic; Hudson Bay; Eastern Arctic; and Eastern Sub-Arctic (Fig. 1).

In each IRIS, ArcticNet researchers carry out studies in one of four thematic areas: Marine Systems; Terrestrial Systems; Inuit Health, Education and Adaptation; and Northern Policy Development and Knowledge Transformation. The marine research of ArcticNet is conducted in large part on the Canadian Coast Guard Ship *Amundsen*, a state-of-the-art research vessel that has served as the primary platform for ArcticNet's marine investigations. Terrestrial research has focused on the changes occurring in coastal environments, including changes in wildlife ecology and population shifts. These studies have also included the traditional ecological knowledge of Inuit land users to add to western scientific observations, leading to the co-production of new knowledge. Inuit health, education, and adaptation research has involved collaborations with Inuit communities to address the dynamics between climatic change and Inuit health and well-being. Last, northern policy development and knowledge transformation focuses on the dissemination and integration of research results, leading to the formulation of adaptive strategies to future climate scenarios (http://www.arcticnet.ulaval.ca/aboutus/rationale.php).

The projects conducted by ArcticNet researchers are selected through an annual call for proposals, which includes a pre-screening of Letters of Intent from any eligible Canadian researcher. ArcticNet does not accept proposals from individual researchers or laboratories, but rather requires team submissions involving academic, government, and Indigenous community collaborators. ArcticNet's evaluation process is also guided by the NCE Equity Policy that is committed to furthering diversity and inclusion of all applicants in order to mobilize the best possible research and most impactful results (http://www.nce-rce.gc.ca/About-APropos/EDI-EDI_eng.asp).

Methodology

Data collection. Data collection and preparation involved several iterative stages. Descriptive statistics were compiled from on-line ArcticNet Annual Research Reports and Compendiums (2004–2018) http://www.arcticnet.ulaval.ca/media/annualreport.php. From these on-line sources a list of ArcticNet researchers was tabulated. The list of researchers included graduate students (MA and Ph.D), post-doctoral fellows, investigators, project leads, and IRIS leads. ArcticNet publications (http://www.arcticnet.ulaval.ca/media/publications.php) were accessed through the Arctic Science and Technology Information System (ASTIS), which houses an ArcticNet Publications Database. From on-line and bibliographic databases two data sets were created—one containing all ArcticNet researchers (2004–2018) and one containing all peer-reviewed ArcticNet publications (2004–2018). After merging, cleaning and manual verification, the final dataset contained 761 ArcticNet researchers and 2416 peer-reviewed publications.

Gender inference. The gender of ArcticNet researchers was determined through the use of NamSor Applied Onomastics

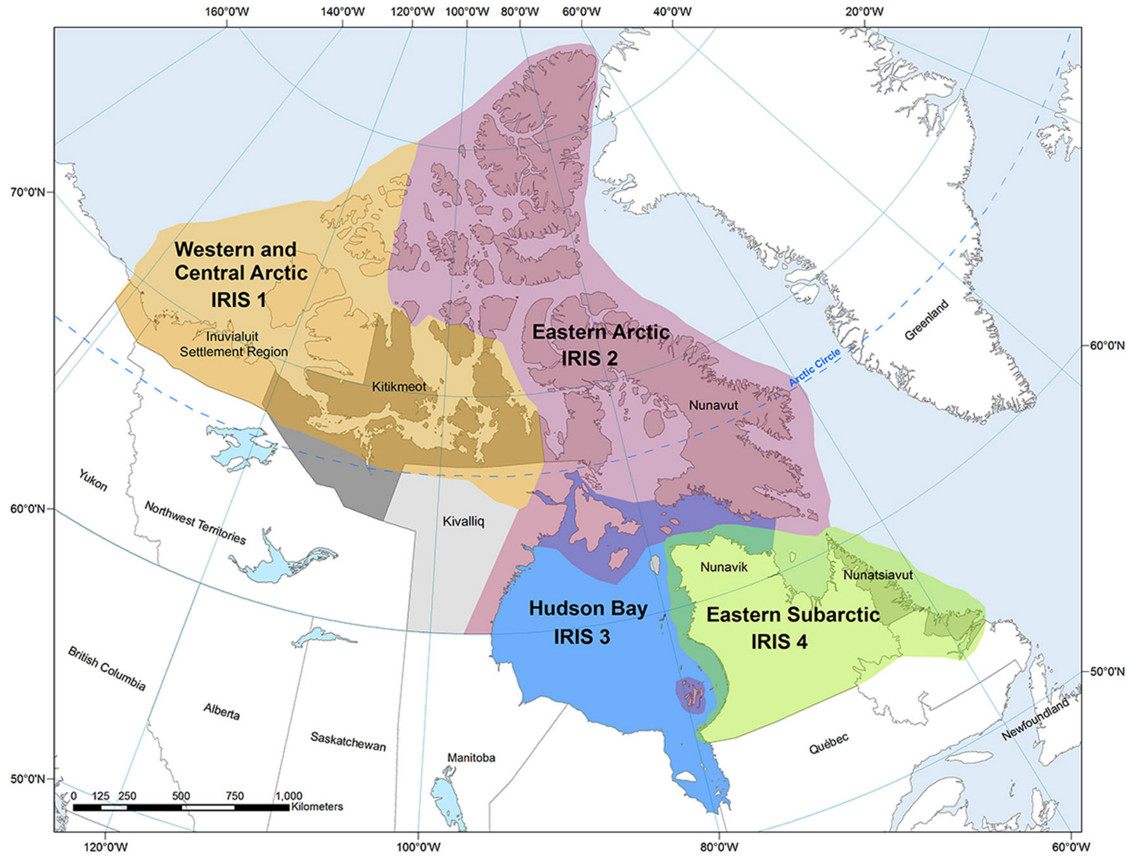

Fig. 1 ArcticNet integrated regional impact studies areas (http://www.arcticnet.ulaval.ca/research/irises.php).

software (NamSor Gender API, 2019). NamSor is a name recognition software and a machine learning algorithm, which predicts the gender of a personal name on a -1 to $+1$ scale, male and female, respectively, and it has an extensive name coverage database that it draws from (US, European, Indian, African, Chinese, Hebrew, Russian, Slavic, Cyrillic, Arabic). To maximize accuracy, the software uses two algorithms (i) a global name sociolinguistics algorithm, which recognizes the origin of the first and last name and infers whether the name sounds male or female in that particular culture; (ii) a query in a large database (800,000 names), which contains statistical information regarding baby names across the globe (NamSor Gender API, 2019). Mattauch et al. (2018) references several analyses, which provide evidence for the reliability of NamSor's classification algorithm (Vichnevskaia, 2015). In generating the gender variable for all the researchers in ArcticNet, NamSor classified 98% of the researchers as either female or male, only 2% were classified as unknown, which we manually processed. We expanded the manual checking to the cases located within the -0.5 to 0.5 accuracy estimations to ensure robust results.

Statistical analysis. Our focus in this study was on female and male ArcticNet investigators. This group is more established in terms of career development, are the most stable in ArcticNet membership, and are responsible for the greatest amount of ArcticNet's research output. Furthermore, we were interested in testing whether our focus on ArcticNet investigators is consistent with the findings of similar gender-based analyses. Brass (1985) looking at interaction patterns among employees of an organization, found that influential women had similar network structures to those of men, but women were less central in male interaction networks. In addition, Ibarra (1992, 1997) found that men frequently form homophilous ties with other men to enhance their career development opportunities, while women must adapt to status differences and form instrumental ties with men.

Statistical analysis was carried out to test the following hypothesis: the gender of investigators—male or female—affects the extent of their engagement in the ArcticNet. Engagement is defined as total degree centrality and represents the number of direct connections an ArcticNet investigator has with others in the network. Degree centrality is indicative of a researchers' level of activity or engagement within the network. To test this hypothesis, the average degree of male and female ArcticNet investigators were compared. A two-sample t-test was used to determine if the mean degree centrality of female investigators was lower than the mean degree centrality of male investigators. The standard t-test used to compare the means of two groups uses a permutation test to generate the significance level so that standard assumptions of independence and random sampling are not required (10,000 permutations were used).

A second statistical analysis was performed to test whether the gender of the investigator affects the centrality of the actor in terms of influence in ArcticNet. Here, influence is defined as total betweenness centrality in the collaboration network—i.e., the number of times a researcher acts as a bridge along the shortest path between two other ArcticNet investigators. If an investigator is located on the shortest path between two other investigators, this affords her or him certain advantages in potential collaborations (Freeman, 1979). For instance, the more people depend on an investigator to make connections to others, the more influence that investigator has, and more opportunities to collaborate and publish (Brass, 1984; Burt, 2005). Collaborations with other scholars become crucial in increasing efficiency—by sharing resources, bringing together diverse skillset (Bammer, 2008; Hauptman, 2005; Söderbaum, 2001) and enhancing an investigator's productivity and impact (Gazni and Didegah, 2011; Katz and Martin, 1997; Lee and Bozeman, 2005; Sooryamoorthy, 2009). Betweenness centrality is often seen as an important variable to measure influence (Brass, 1984). A two-sample *t*-test was used to determine if the mean betweenness centrality of female investigators is lower than the mean betweenness centrality of male investigators. Again, a permutation test was used.

Co-authorship networks. Gender homophily was measured by using the EI-Index and the Yules Q (odds ratio). Homophily is the tendency to relate or interact with others with similar characteristics (Lazarsfeld and Merton, 1954a, 1954b), in this case gender. The standard measure of association is EI (inverse index of homophily), and varies from −1 to +1. A score of −1 means that investigators only have ties with others in the same category as themselves—perfect homophily. A score of +1 means that investigators only have ties to others in different categories showing perfect heterophily.

Results

Descriptive statistics. Between 2004 and 2018, 761 researchers were involved in 119 ArcticNet research projects. This includes 420 graduate students, 95 post-doctoral fellows, and 246 investigators.[1] At their earliest stage of career (Masters), women ($N=146$) outnumbered men ($N=90$) by 24%. This percentage declined at the doctoral level, but women ($N=100$) continued to outnumber their male peers ($N=84$) by 8% in total representation. However, between the doctoral and post-doctoral levels, the representation of women and men inverted, with men ($N=54$) surpassing women ($N=41$) by 11%. Although we did not track the aggregate attrition rates of female researchers, this distributive decline is consistent with the 'leaky pipeline' common in other Science, Technology, Engineering and Mathematics (STEM) fields and academia more broadly, where women experience a high prevalence of early career exits and other obstacles that impede their progression into and through academic and research careers (Ceci and Williams, 2011; Nielsen et al., 2017; Pearson et al., 2015; Ysseldyk et al., 2019). In the case of ArcticNet, this downward trajectory is amplified at the investigator level ($N=246$), where the representation of women is only 21% ($N=51$) of all ArcticNet investigators (Fig. 2).

Among the 51 female investigators, 14 (15%) served as Project Leads or co-Leads. Project leads are defined as principal investigators who provide intellectual and administrative oversight for the conduct of the research. The project lead(s) are the primary individuals responsible for the preparation, conduct, and administration of the research. Although representing 15% (14/95) of all ArcticNet project leads, in no single year between 2004 and 2018 did women exceed 10% of project leadership (Fig. 3), nor have women served as IRIS leads.

Of the 14 female project leads, nine (64%) directed research in the area of Inuit Health, Education and Adaptation. The projects conducted in this theme focused on the human dimensions of climate change and involved research teams with a higher proportion of social scientists. Of the remaining five female project leads, four were in Terrestrial Systems and one was in Policy and Knowledge Transformation. There were no female project leads for the 29 Marine Systems projects conducted between 2004 and 2018 (Fig. 4).

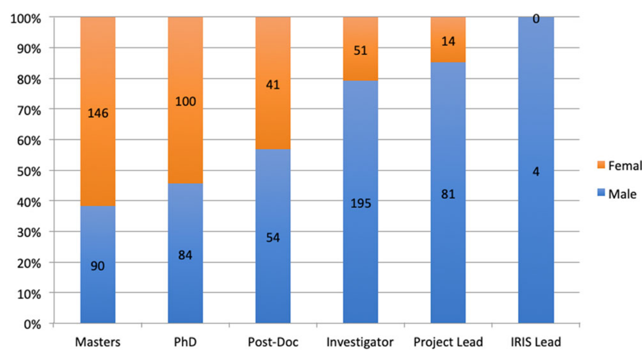

Fig. 2 Male and female representation of ArcticNet researchers (2004–2018).

Network analysis. Social network analysis was performed to determine the relative position that male and female investigators occupy within ArcticNet. Our dataset contained only ArcticNet investigators ($N=246$), which included 195 men (79%) and 51 women (21%). Figure 5 below shows the collaborative network between male (blue) and female (orange) investigators. Only a small percentage of investigators (9%) had no collaborations with other investigators—five (2%) women and 18 (7%) men—whereas the majority of the investigators collaborated with at least one other investigator (Fig. 5).

Male investigators account for the highest proportion of collaborations within ArcticNet. Among the top 10 investigators with the highest number of collaborations, and therefore the most influence (measured by degree centrality), are all men. Further, among the top 25 most central investigators, 21 were men. The most central investigator was male who had ties to 44 other investigators (Fig. 6).

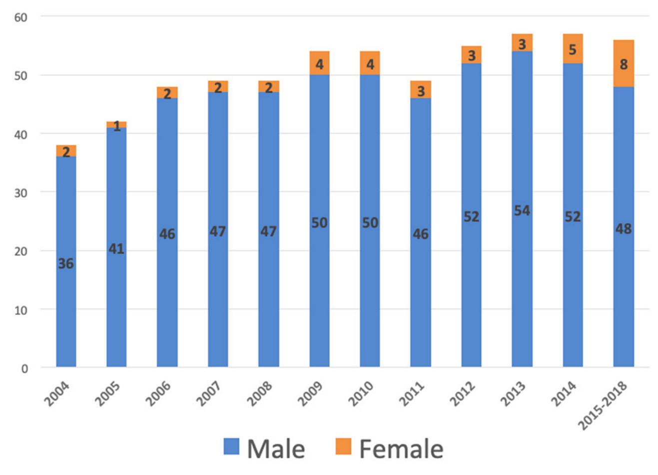

Fig. 3 ArcticNet project leads and co-leads by gender.

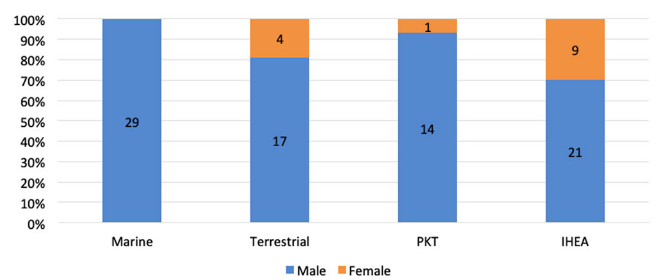

Fig. 4 ArcticNet project leads by research theme.

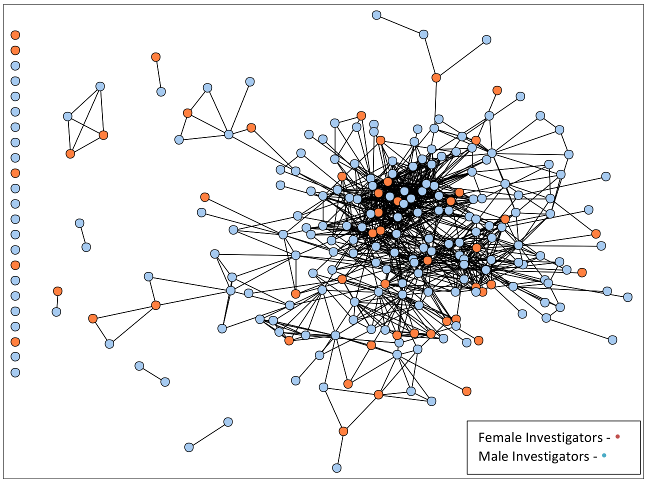

Fig. 5 Collaboration map of ArcticNet investigators by gender ($N = 246$).

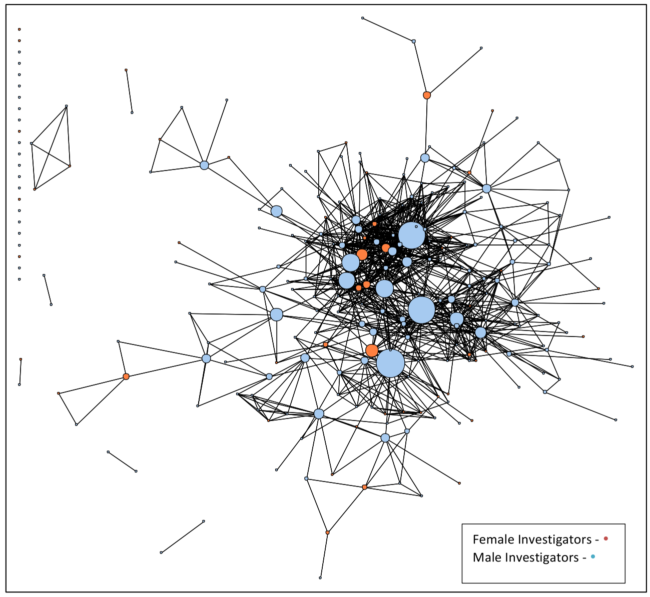

Fig. 7 Collaboration map of investigators within ArcticNet by gender and betweenness centrality (size of each node is proportional to its centrality).

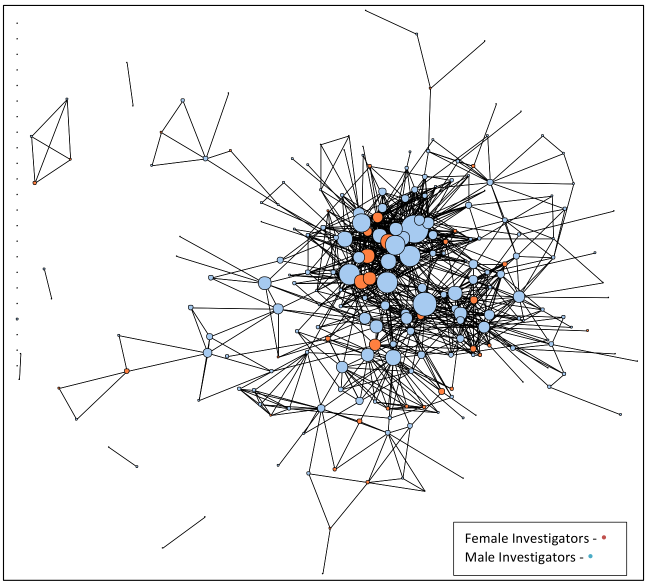

Fig. 6 Collaboration map of ArcticNet investigators by gender and freeman degree centrality (size of each node is proportional to its centrality).

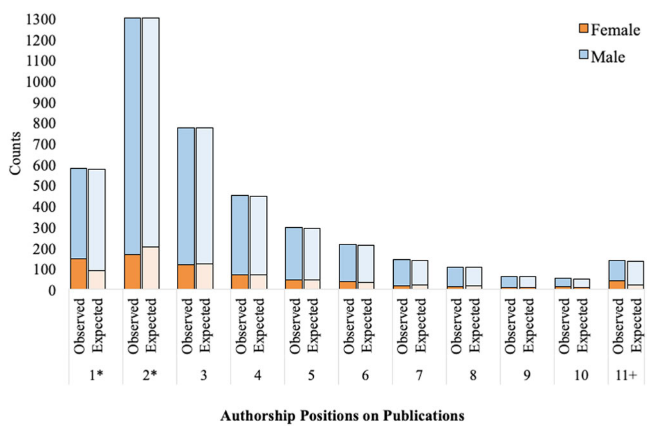

Fig. 8 Observed and expected place of authorship among ArcticNet investigators.

Betweenness centrality of investigators was calculated by quantifying the number of times an investigator acts as a bridge along the shortest path between two other ArcticNet investigators. If an investigator is located on the shortest path between two researchers, this affords her or him certain advantages in potential collaborations (Freeman, 1979). For instance, the more people depend on an investigator to make connections to others, the more influence that investigator has, and the more opportunities to collaborate (Brass, 1984; Burt, 2005). In this way, investigators with high betweenness centrality link investigators across the network. The top ten investigators who serve as network brokers were all men, as were 21 (84%) of the top 25 investigators. The average betweenness centrality of male investigators was 3.5 times higher than the female average, indicating that men occupy statistically more significant brokering positions within the network (Fig. 7).

The differences between male and female investigators are also reflected in the number of authored publications. Male investigators authored or co-authored an average of 18 papers, compared to an average of 12 papers for female investigators. However, within the investigators' group, this difference is not statistically significant ($p > 0.05$). These results indicate that within this group, the productivity gap between female and male researchers diminishes. Even if present, a productivity gap can be in part explained by the position that investigators occupy on publications. While female investigators tend to be either first or second authors, their male counterparts occupy more commonly second and third authorship positions—56% of the time. For these two authorship positions, the differences between male and female ArcticNet investigators are statistically significant (χ^2 (10) $= 69.68$, $p < 0.01$). Both the observed and expected publication counts are shown in Fig. 8, with the asterisk demarcating author positions for which the differences are statistically significant.

Female and male investigators in ArcticNet also show different patterns in terms of tendencies of association in co-authoring publications. Males tend to form homophilious ties—publishing

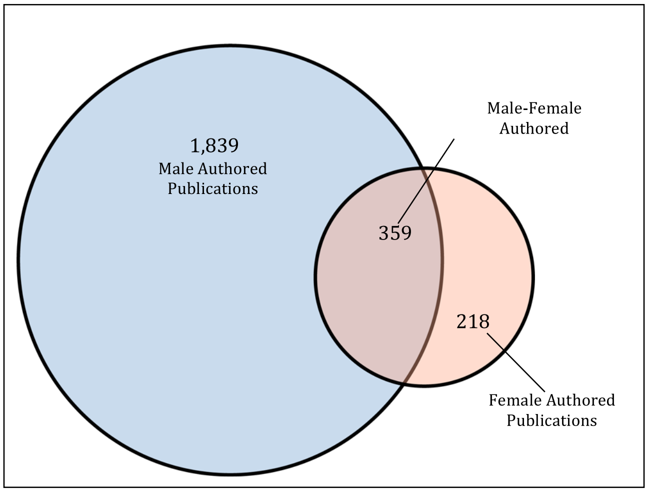

Fig. 9 Publications authored by ArcticNet investigators.

predominately with other males, whereas female investigators have heterophilious collaborations. This tendency is reflected by the statistically significant difference ($p < 0.01$) in the averages of EI and Yule's Q indicators among the two groups of researchers (for reference please methodology). The average EI score for female researchers is 0.26, whereas the males' average was −0.26, and −0.18 and 0.18, respectively, for Yule's Q. This tendency is clearly reflected in the authorship of ArcticNet publications, where 76% ($N = 1839$) of all published papers had exclusively male authorship, 9% ($N = 218$) had only female authors, and 15% ($N = 359$) were co-authored by male and female investigators (Fig. 9).

Discussion

There is growing recognition that diversity within research organizations influences the tone, conduct, and content of the science produced (Gay-Antaki and Liverman, 2018). Diversity, whether in terms of gender or the inclusion of under-represented populations, can result in innovative research dividends where new questions, interpretations, and discoveries can be made (Liao, 2011; Nielsen et al., 2017). However, the opposite is also true, where the lack of gender heterogeneity within scientific organizations can undermine the quality and breadth of the research conducted and may allow some to cast doubt on the legitimacy of scientific findings.

In this study, we focused on the participation of women in the ArcticNet Centers of Excellence. Established in 2004, ArcticNet represents Canada's most significant investment in climate change science. The scientific contributions of ArcticNet to climate change research are indubitable. Over the past 15 years, ArcticNet has harnessed the talents of 761 researchers who have published more than 2400 peer-reviewed papers on the causes and consequences of Arctic climate change. The research conducted by ArcticNet has yielded important new insights on the complex interplay between climate and marine, terrestrial, and human systems in the Canadian Arctic. In the conduct of this research, ArcticNet has provided unique training opportunities to over 400 graduate students—Canada's next generation of climate change scientists. The considerable achievements of ArcticNet have led Canada's Federal Government to renew its commitment to ArcticNet through 2025, with an additional $35 million in research funding.

Notwithstanding the significant scientific accomplishments of ArcticNet, female scientists within the network are under-represented compared to their male colleagues. At the earliest stages of their career, women outnumber their male peers 276 to 174. However, at the post-doctoral level, the representation of women exhibits a marked decline that is consistent with the leaky pipeline found in academic and STEM disciplines in particular (Pearson et al., 2015). While the causes for the aggregate attrition of female researchers in ArcticNet were beyond the scope of this study, this decline may indicate that women are choosing to leave or postpone research careers for personal reasons, for instance family responsibilities (Bee et al., 1998), or may indicate more systemic or structural reasons for their exit, such as a lack of female role models (Maddrell et al., 2016), professional isolation (Dutt et al., 2016), masculinist work environments (Seag, 2019), or harassment (Alaimo, 2009). The downward trajectory that is observable at the post-doctoral level is then extended to ArcticNet investigators. At this level, male investigators outnumber their female colleagues by nearly 4 to 1 (194:51), account for 85% of project lead positions (81 out of 95), and represent 100% of IRIS leads (4 out of 4). The under-representation of women may have profound implications for the quality and breadth of ArcticNet research projects, since diversity among investigators themselves has been linked to more innovative science (Gay-Antaki and Liverman, 2018; Nielsen et al., 2017). These conditions may also prove detrimental to the research careers of women, as resources and opportunities needed for promotion and career development are often located within the domain of male dominated networks (Beck et al., 2014). For example, ArcticNet's requirement that funded research projects consist of multi-institutional team submissions may actually advantage male investigators at the expense of female researchers owing to the relative size of their respective networks.

In addition to being numerically under-represented, female investigators in ArcticNet have fewer research collaborators and are generally less integrated into the network as compared to their male colleagues (measured by centrality and betweenness). This is most pronounced among the STEM disciplines, such as those encompassed within the Marine Systems thematic area. As ArcticNet is organized by team-based research collaborations, the extent of one's collaboration is a strong predictor of productivity, as measured by peer-reviewed publications (Misra et al., 2017). In this case, female investigators in ArcticNet have smaller research networks (e.g., co-authors), which results in fewer peer-reviewed journal articles. Campbell et al. (2013) found that peer-reviewed publications with gender-heterogeneous authorship received 34% more citations than publications with gender-uniform authorship. This may suggest that publications with gender-heterogeneous authorship are of higher quality and have greater impact than publications with gender-uniform authorship (Campbell et al., 2013).

Conclusion

Given the complexities of climate change, particularly in the Arctic where its impacts are projected to be most extreme (Trainor et al., 2007), the inclusion of female scientists and other under-represented groups is crucial if sustainable solutions are to be found. By harnessing diverse and collective abilities of the entire scientific community, ArcticNet and other research organizations will be better placed to address the societal challenges associated with climate change in the future (Beck et al., 2014). Therefore, promoting diversity within research organizations is not only a matter of equity but also leads to higher quality science (Nielsen et al., 2017).

The objective to produce the highest quality of science possible is clearly reflected in Canada's NCE Program and its Statement on Equity, Diversity and Inclusion, which commits to supporting all qualified individuals, inclusive of members of under-represented groups, in order to mobilize Canada's best research. By extension, the NCE Secretariat expects all NCE-funded research organizations (e.g., ArcticNet) to be equally committed to those principles. Yet expectations alone are insufficient in creating representational equity. The results from this analysis indicate that the challenges women once faced in gaining entry into Arctic sciences are not yet resolved, and persistent inequalities continue to hamper the career opportunities of female scientists. What is therefore required is to move beyond statements on equity, diversity, and inclusion to actual policies that ensure principals of inclusion are not only respected but actually implemented. In other words, policies that move from being unconsciously exclusive to consciously inclusive of gender equality (Kuo, 2017). By increasing the representation of women in Arctic sciences, particularly in climate change research where conclusions remain contentious (Gay-Antaki and Liverman, 2018), will lend to greater scientific credibility and improved public acceptability of research findings.

Data availability

The data sets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Notes

1 Not included in our analysis are the public and private collaborators and technicians who may have played a role in the research but may not have been supported directly by ArcticNet funding.

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DN, KS, and AL designed the study with the help of AMB. AMB conducted the social network analysis. DN led the writing of the manuscript with substantial assistance from all co-authors.

Competing interests
The authors declare no competing interests.

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