PLOS CLIMATE

REVIEW

Polar fieldwork in the 21st century: Early Career Researchers considerations regarding safety and sustainability

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Abstract

Conducting fieldwork in polar regions presents a multifaceted challenge not only because of the remoteness of the environment, but also potential geopolitical disputes, language barriers, divergent national policies, and disparities in emergency healthcare access. This review addresses the climate crisis and reevaluates the ethical considerations of polar fieldwork in alignment with broader social responsibilities, with particular emphasis on the challenges faced by Early Career Researchers (ECRs). Ongoing climate change and its associated impacts and effects (e.g., reduced snow and ice cover, thawing permafrost, intensified fires, and increased wildlife interactions) will undoubtedly compound the aforementioned challenges. ECRs, often with a heightened awareness for contending with issues pertaining to environmental conservation and sustainability, face greater career stakes than tenured researchers, which can lead to innovation in addressing safety concerns regarding polar fieldwork. This review summarizes current challenges faced by ECRs in polar fieldwork, elaborates on how these may change during this century, and presents possible solutions. To address the aforementioned challenges, we propose a comprehensive set of recommendations, including innovative data collection methods using improved technology and emphasizing meaningful remote local collaborations to minimize the travel and environmental impact and risk of disease contagion. We advocate for reducing the redundancy among research groups by promoting data sharing. Additionally, we suggest enhancing cooperation by integrating (traditional) Indigenous knowledge while respecting the rights of Arctic communities. Such recommendations highlight the intricate dynamics of polar fieldwork safety and logistics in a changing climate, emphasizing the need for adaptability, sustainability, and inclusivity in research practices. A call for action towards revising current practices is clear, emphasizing that ECRs can be key agents in forging and establishing responsible, comprehensive, and adaptive protocols toward enhancing safe and successful fieldwork in the polar sciences.

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1. Introduction

The current climate crisis has instigated a need for the polar research community to reevaluate fieldwork practices to align with broader social considerations and responsibilities, specifically focusing on the challenges arising from the safety, sustainability, and logistical aspects of polar fieldwork [e.g., 1–3]. In this endeavor, important contributions have been made by Early Career Researchers (ECRs): e.g., leading gender-marginalized individuals to outdoor and scientific experiences in the 'Inspiring Girls*' initiative, organizing across the Arctic or in bodies like UArctic or the Association of Polar Early Career Scientists (APECS), and instilling new and mutually beneficial research practices, despite their vulnerability and lack of authority [4–6].

In this article, we will refer to an ECR as a researcher in the stages R1-"First Stage Researcher" and R2-"Recognised Researcher" of the European Commission framework [7] based on competencies; Early Stage Researcher (ESR) or Early Career Scientist (ECS) can be considered as synonyms of ECR. Moreover, we will refer to "fieldwork" as any form of data collection conducted by human collating efforts and/or the actions of semi- or fully autonomous instruments installed by humans.

Similar to fieldwork in other remote environments, working in polar regions above the Arctic Circle at approximately 66˚N or below the Antarctic Circle at 66˚S poses challenges for researchers, including ECRs (Fig 1). These include working in the harsh polar climate types, [8] regions where the monthly average temperature does not rise above 10˚C in the warmest month of summer [8, 9]. This climate type covers the whole of the Antarctic continent in the polar South, most of the Arctic, and North American and Scandinavian areas a few latitudinal degrees south of the Arctic circle, and high-altitude mountain areas such as the Tibetan plateau [9]. In those areas, the field researcher may also have to contend with strong winds [10], and plan for low human population density (according to the Arctic Human Development report [11], the entire Arctic region had a declining population of just above 4 million people in 2013) as well as limited access to infrastructure for logistics and in case of emergencies [12]. Additionally, due to Earth's tilted axis and the subsequent soliterraneous dynamics, polar regions have substantial seasonal variations in climate and light availability (e.g., including 24-hour sunlight and 24-hour darkness, depending on the time of year [13]), which sets them apart from the otherwise comparable high-altitude regions. Most importantly for the purpose of this review, the rate of change observed in polar regions is higher than any other comparable remote areas, with the Arctic warming at up to four times the global rate [14], and the loss of the Antarctic ice shelf accelerating [15, 16]. Changing temperatures impact other environmental variables such as precipitation patterns [17], sea ice distribution [18], and landscape stability [e.g. 19, 20]. The speed with which conditions for field work are changing makes the environment more unpredictable, resulting in planning successful and safe campaigns more challenging. As current ECRs face these challenges throughout their careers in the 21st century, the predicted changes in polar regions are larger than the global average predicted changes [16]; e.g., High arctic Greenland facing 6–8˚C average temperature increases by 2100 [21] and up to 40% of Antarctic Sea ice loss [22]. The polar landscapes in which ECRs plan their field campaigns may therefore experience rapid and potentially unpredictable responses [16].

ECRs, being uniquely positioned to innovate and adapt to these ensuing changes [1, 2, 6], may hold the key to devising and implementing feasible solutions for navigating polar regions sustainably. This review first summarizes the challenges faced by ECRs in planning and conducting fieldwork in polar regions today (Fig 2, left panel): i) physical, ii) social, iii) political, and iv) environmental. We then discuss the potential solutions (Fig 2, right panel), offering actionable insights for the research community to effectively address and overcome these challenges. We provide specific examples where these solutions have already been successfully

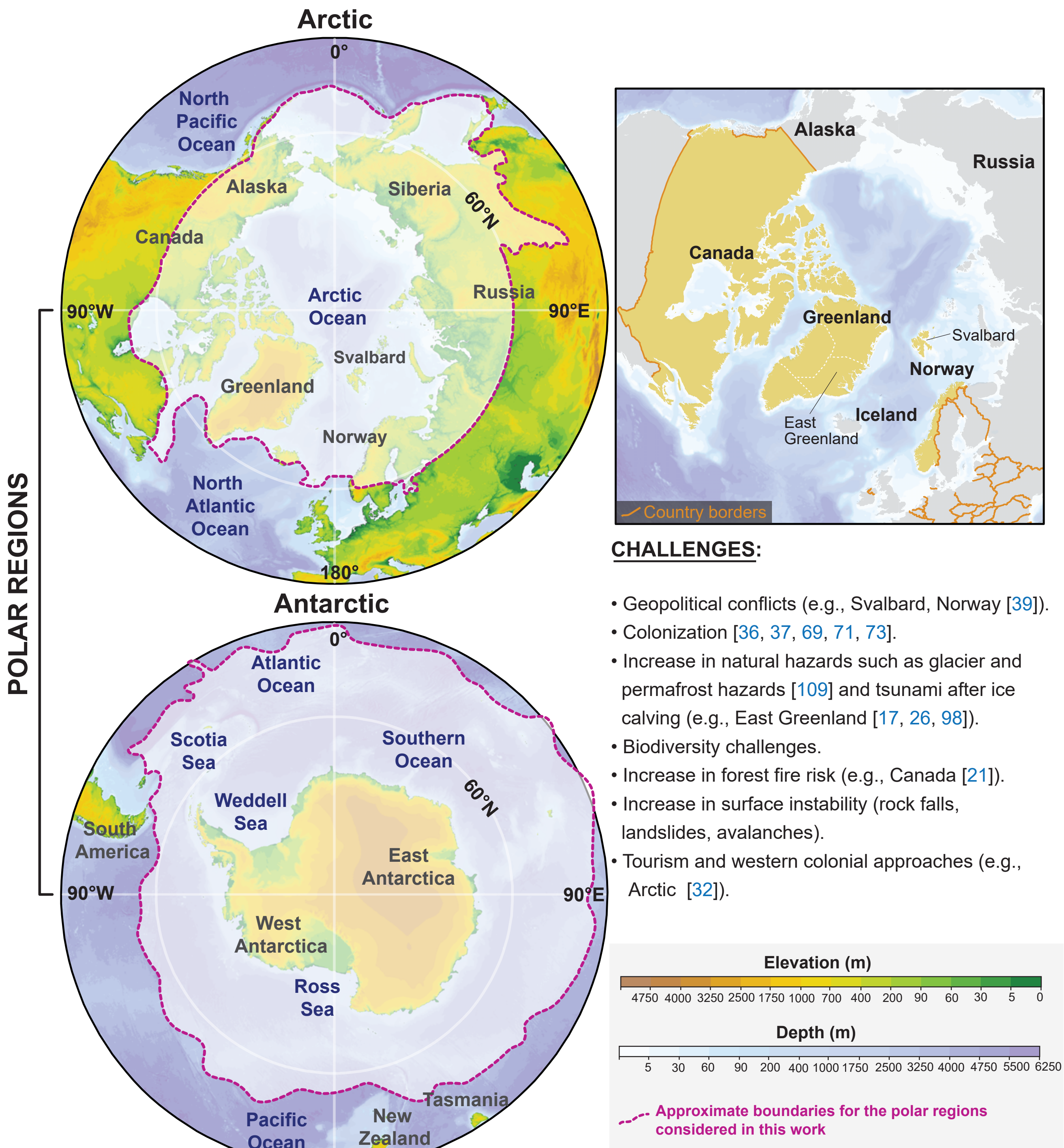

Fig 1. Left panel: approximate geographic extent of the polar regions, marked by the dashed pink line. Right panel: examples of the challenges identified in this and previous studies, with the border to the countries/regions affected by such challenges marked in brown together with relevant references. Some challenges were exemplified in specific regions (e.g., geopolitical conflicts in Svalbard, Norway, [63]), whereas many others were presented as ubiquitous in previous studies (e.g., tourism and western colonial approaches in the Arctic, [54]). Bathymetric map (depth and elevation) extracted from the 15 arc-second GEBCO 2020 bathymetric grid [109].

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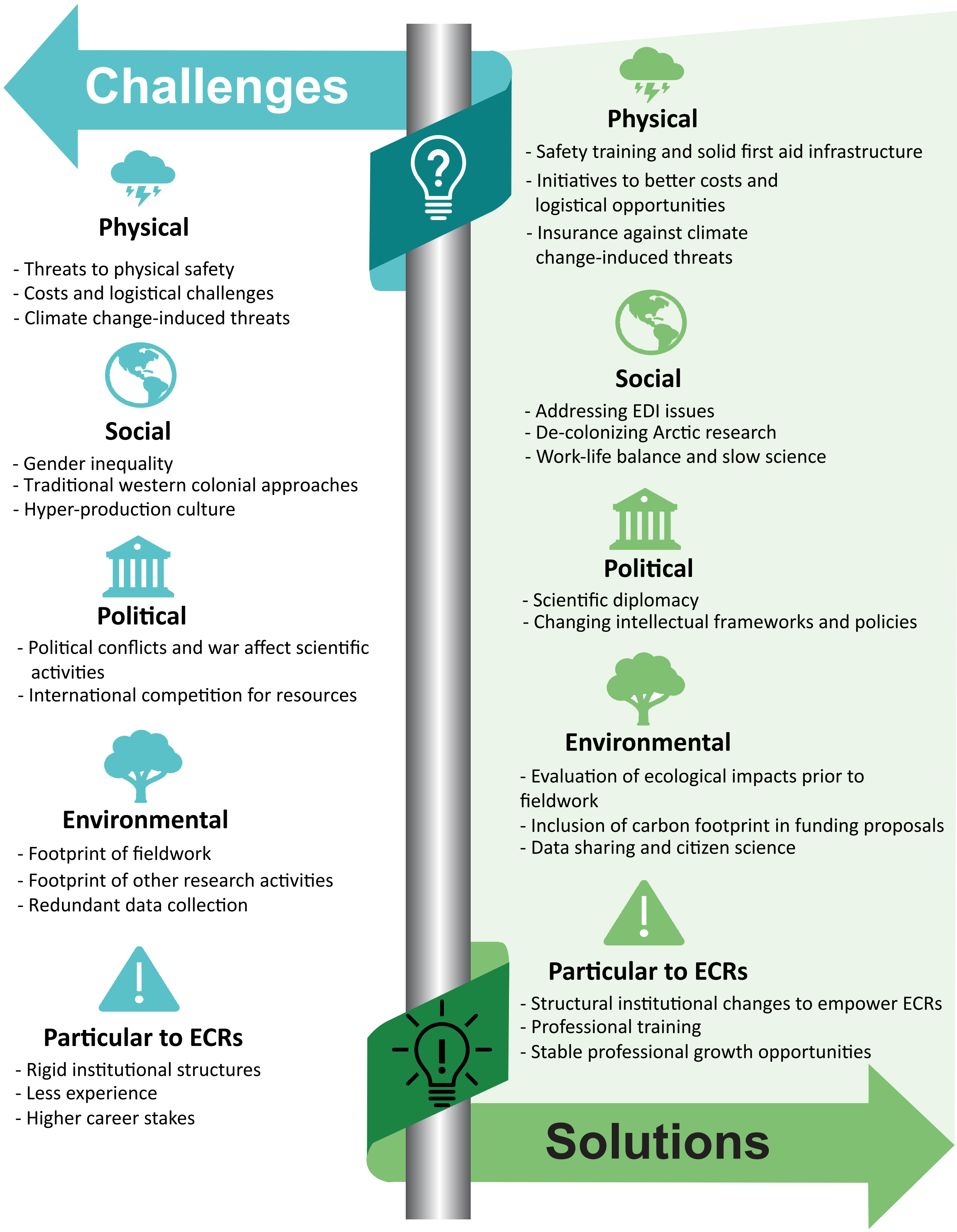
Challenges
Physical
- Threats to physical safety
- Costs and logistical challenges
- Climate change-induced threats
Social
- Gender inequality
- Traditional western colonial approaches
- Hyper-production culture
Political
- Political conflicts and war affect scientific activities
- International competition for resources
Environmental
- Footprint of fieldwork
- Footprint of other research activities
- Redundant data collection
Particular to ECRs
- Rigid institutional structures
- Less experience
- Higher career stakes
Physical
- Safety training and solid first aid infrastructure
- Initiatives to better costs and logistical opportunities
- Insurance against climate change-induced threats
Social
- Addressing EDI issues
- De-colonizing Arctic research
- Work-life balance and slow science
Political
- Scientific diplomacy
- Changing intellectual frameworks and policies
Environmental
- Evaluation of ecological impacts prior to fieldwork
- Inclusion of carbon footprint in funding proposals
- Data sharing and citizen science
Particular to ECRs
- Structural institutional changes to empower ECRs
- Professional training
- Stable professional growth opportunities
Solutions

Fig 2. Main challenges (left) outlined in this review alongside the corresponding proposed solutions (right). Challenges are categorized into physical, social, political, environmental, or a combination of these categories. Additionally, early career researchers (ECRs) confront these challenges with heightened urgency due to the inherent constraints associated with their career stage.

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implemented and highlight potential pitfalls. It is important to note that the authors acknowledge that the challenges described in this manuscript are based on their collective experiences and observations, as well as a review of relevant literature. Experiences and reactions of different researchers to these challenges may vary, and the manuscript does not claim to provide a comprehensive or universally applicable account of polar fieldwork. Instead, the intention here is to raise awareness of potential difficulties that researchers may face and to contribute to ongoing discussions about best practices and support mechanisms for polar fieldwork in the context of global climate change.

2. Physical challenges

Before even setting out into the field, one prevailing challenge arises from the preconception that polar fieldwork is inherently dangerous, a view which is largely rooted in a historical fascination and trepidation toward polar regions as dangerous terrains of exploration [23]. This perception can bias the narrative and expectations surrounding polar fieldwork, potentially impacting ECRs as they navigate their first field seasons.

2.1. Costs and logistical challenges

Planning and executing fieldwork in polar regions involves complex logistics, including securing permits, arranging transportation, and ensuring the availability of necessary supplies and safety training. Specific transportation–i.e., land (e.g., snowmobiles), air (e.g., airplanes, helicopters), and sea (e.g., boats, zodiacs)–is needed for fieldwork, which requires significant investments in maintenance (especially fuel), storage, and proper training for users, and/or in renting equipment, hiring drivers/pilots, etc. Collected research samples may require specific permits and specialized storage conditions during collation and transport, which can increase costs, complicate logistics, and possibly heighten risks. Thorough information guides focusing on research planning in the polar environment have only recently been compiled but are useful resources underscoring the need for extensive planning, strong international cooperation, and long-term, high-budget allocation [1, 2, 24, 25].

Despite detailed fieldwork planning, researchers may encounter disruptions due to unpredictable weather, which can affect schedules and necessitate mental and logistical flexibility. This means that successful fieldwork in the polar regions can be longer and ten times as expensive as the same fieldwork in less challenging environments [24].

Medical care in polar fieldwork shares similarities with space missions, characterized by isolation, confinement, and extreme conditions [26]; the harsh working conditions, characterized by rapid weather changes coupled with the relative remoteness and lack of easy access to assistance in emergencies makes polar fieldwork inherently dangerous, especially for those not adequately trained [26, 27]. Recent upgrades in satellite telecommunications, such as Starlink in the High Arctic, provide improvements in remote support for research, emergency assistance, and real-time data transfer [28]. However, obtaining proper and adequate insurance coverage remains an administrative challenge [29]. Institutions may be hesitant to cover insurance for polar fieldwork due to high costs associated with the unique risks and challenges of working in these extreme environments. These costs can include expensive emergency evacuations, medical treatment in remote locations, and the potential for costly delays or cancellations due to weather or other unforeseen circumstances. To address this issue, researchers purchase individual insurance policies or rely on the insurance coverage provided by their funding agencies. As these alternatives may not always provide comprehensive coverage, researchers, particularly ECRs with limited funding and who cannot afford the prohibitive cost of individual insurance policies, are potentially exposed to financial risk in the event of an emergency. Some may even forgo securing such insurance policies due to lack of funding, which may compromise research planning and protocols.

Researchers work in (small) teams for extended periods when engaging in polar fieldwork, relying on this close-knit group as their main safety net in all respects. Interpersonal tension and conflict, a significant stressor in Antarctic overwintering research missions, can lead to psychological challenges such as fatigue, depression, and emotional instability [26, 30]. The extreme variation in daylight, ranging from continuous sunlight to complete darkness, can impact researchers' circadian rhythms and sleep cycles; the physiological ramifications are concomitant with associated cognitive and emotional consequences and must also be taken into consideration during fieldwork preparation [31–34].

2.2. Climate change-induced threats

Polar fieldwork is adapting to the rapid warming of polar regions [14]. The resulting environmental changes introduce new hazards and challenges for researchers (Fig 3A–3F). In mountainous polar regions, traditional hazards such as glacier lake outburst floods, snow avalanches, and debris flows are escalating due to rising temperatures and permafrost degradation [35]. Permafrost thaw, a primary factor in increased rockfalls in mountainous regions [36, 37], will expand throughout polar areas as climate change progresses. Changes in regional surficial materials, including ice, snow, and permafrost-affected terrain, threaten fieldwork activities and instrumentation, with the potential for destabilization or collapse. Extreme weather events, like prolonged summer droughts leading to increased wildfires [16], as witnessed in the recent 2023 summer wildfires in Canada, will add a new dimension to polar fieldwork planning in the years to come [38].

Polar regions support diverse wildlife, including apex predators such as polar bears (*Ursus maritimus*) and brown bears in the Arctic (*U. arctos*), and leopard seals in the Antarctic (*Hydrurga leptonyx*) [39]. These regions are also important feeding and breeding grounds for many migratory species. Managing safety and ethical considerations such as minimizing disturbance with respect to wildlife interactions is critical for fieldwork planning in such settings [40]. With key polar habitats, such as Arctic Sea ice, decreasing spatially and temporally, alongside increased anthropogenic activity (e.g., shipping [41]), encounters between humans and potentially dangerous and/or sensitive wildlife are likely to become more frequent [42].

The destabilization of ice sheets, glaciers, and sea ice can alter river paths, disrupting water sources necessary for fieldwork [35]. Events like tsunamis following ice calving into fjords and lakes, exemplified by the Ella Island incident in East Greenland in August 2023, underscore the need for constant vigilance [43]. Researchers face risks like sudden ice movement, glacier calving events, falling into hidden crevasses, thin ice breakage, severe storms/blizzards, and avalanches, especially when working on steep slopes or near alpine glaciers [35, 44]. Ice pressure on ships navigating polar waters is a continuous threat, potentially leading to vessel damage and accidents [45]. Navigating the dynamic landscape of polar fieldwork in the future requires careful consideration of the cryosphere being in a state of rapid flux and the associated hazards, highlighting the need for continuously revised safety plans that address both the increasing unpredictability of the polar regions and interactions with native wildlife.

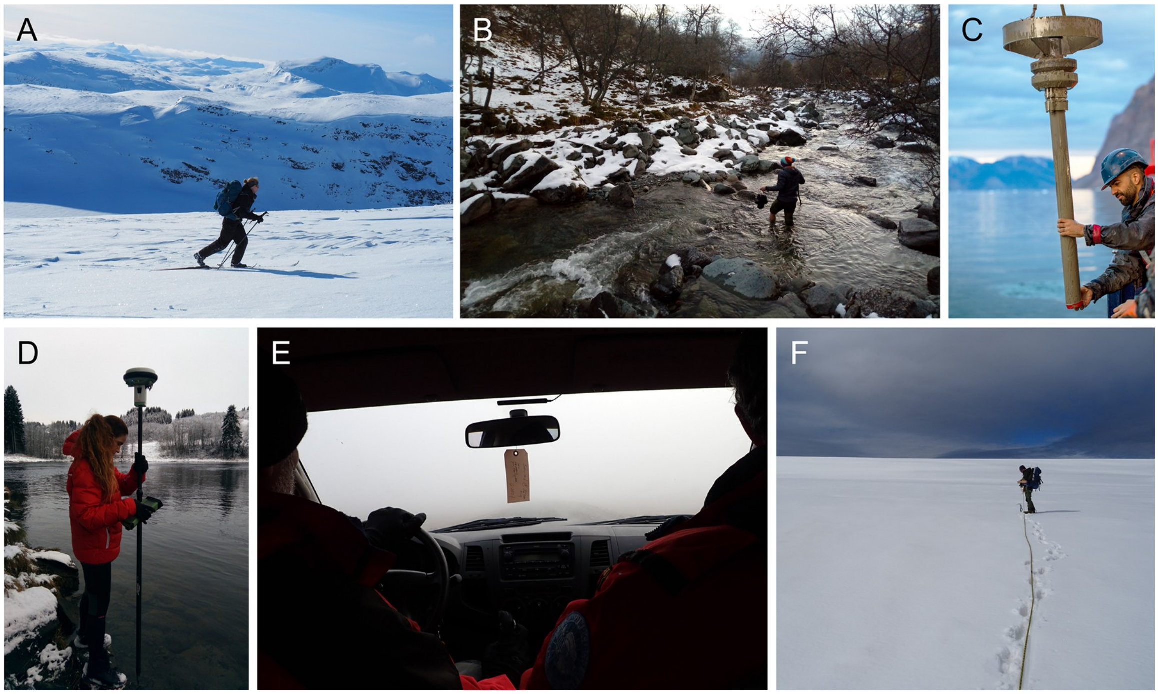

Fig 3. Examples of fieldwork challenges encountered by the authors (a-f). A) Navigating terrain between snow and soil data loggers poses challenges, requiring rugged transportation modes (e.g., skis; photo credit: Ulrika Ervander). Climate change introduces variability, altering avalanche risks and transportation routines. B) UAV battery failure due to low temperatures during aerial surveying of a Norwegian river led to an early career researcher (ECR) crossing the cold, slippery river barefoot for data retrieval (photo credit: ©Adina Moraru). ECRs risk personal safety in unpredictable conditions due to their higher career stakes. C) Extracting marine sediment cores in East Greenland (MSM110 Expedition—ECOTIP Project; photo credit: ©Olivia Rempel/GRID-Arendal). ECRs collecting data on marine research vessels face risks in unpredictable marine weather conditions (e.g., strong winds, large waves). D) Surveying hydraulic parameters in a Norwegian river (photo credit: ©Ana Juárez). Limited accessibility motivates ECRs to take risks, like working on unstable floodplains and climbing steep terrain with heavy equipment. E) Greenland's rapidly evolving weather conditions, such as high wind speeds and whiteout conditions, especially in the absence of closed vehicles, increase the risk of getting lost or accidental vehicle damage (photo credit: ©Filippo Calì Quaglia). F) Glacier ice fieldwork involves acknowledging risks associated with working around crevasses; shorter snow seasons may increase bridge instability, increasing the risks for researchers, while a more extended snow-free season may improve crevasse visibility, facilitating safer navigation (photo credit: ©Laura Helene Rasmussen).

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3. Social challenges

3.1. Gender equality, inclusion, and interpersonal dynamics

An important aspect of group dynamics and interpersonal relationships among researchers in polar environments is gender equality and the dynamics among people of all self-identified genders in the field. With 25–50% of polar researchers identifying as female, the gender distribution has become more balanced among ECRs in developed countries, but it has nonetheless grown in parity relatively slowly in recent years [6, 46]. Despite the significant contributions of women to polar research, there are still persistent gender disparities in the field, manifesting in alarming rates of workplace harassment in remote polar settings [47–49]. Women of color and those identifying as LGBTQ+ are disproportionately affected by harassment compared to other women; in general, women and people of color are overrepresented in precarious positions [46, 50]. A comprehensive analysis of historical, current, and future barriers faced by women at different career stages in polar research was conducted [51] and revealed persistent challenges faced by women, specifically incidents of sexual harassment with assault being the most common – e.g., field trips to Antarctica depicted in the documentary "Picture a Scientist" in 2020; [52]. For Antarctic overwintering crews, the largest source of stress is interpersonal conflicts, with women often relegated to more roles that are designated or at least perceived as being more nurturing and less authoritative and experiencing stress stemming from male-dominated team dynamics [26, 30]. Not recognizing the diversity of human experiences in polar regions, including Indigenous peoples, women, and other marginalized groups, and the impact of intersectionality (i.e., unique challenges faced by individuals with multiple marginalized identities) and the underrepresentation and marginalization of such groups in various scientific fields and decision-making spaces, can lead to the exclusion of valuable perspectives [50, 53] that can enrich research efforts.

3.2. Traditional western colonial approaches in Arctic research

As we explore the transformative potential of citizen science in bridging traditional ecological and scientific knowledge systems in the Arctic, our focus shifts to the colonial attitudes in Arctic research and the challenges they bring to both Indigenous Peoples and ECRs working in these territories. Historically, colonial research practices have often marginalized Indigenous Peoples, excluding them from research processes due to established foreign organizational power and racism. Colonial research aligned with the dominant Western scientific group [54, 55], primarily serves the interests of foreign researchers and institutions. Unfortunately, this neglect of power imbalances and privilege has led to mistrust and strained relationships with Indigenous communities [56–58], affecting subsequent processes like cooperation in policy development [59].

ECRs working in polar regions face additional challenges. Some ECRs may lack familiarity with long-established local socio-political dynamics, hindering their ability to fully acknowledge and respect the rights, contributions, and sovereignty of Indigenous communities. However, ECRs can demonstrate a willingness to continuously reflect and adapt their research practices based on community needs while being guided by principles that emphasize co-learning, co-creation, and addressing historical injustices [60].

It is customary to compensate individuals responsible for data sampling in citizen science projects, particularly knowledge keepers and elders. Such compensation serves to recognize their valuable contributions, ensures equitable collaboration, and addresses the emerging concern of "research fatigue" within small Arctic communities [61]. These communities increasingly rely on volunteer time from local and Indigenous individuals. Additionally, compensation establishes a benchmark for the quality of work agreed to be performed.

4. Political challenges

As illustrated in issues pertaining to gender inequality, polar fieldwork is conducted in the context that integrates scientific research, geopolitics, and resource interests, and requires that ECRs navigate this arena with nuanced approaches (in regard to sensitivities and reflexivity of different political agendas) to maintain international cooperation and mutually address the global climate crisis.

Historically, the practice of 'Arctic exceptionalism' fostered international cooperation of states and major powers in Arctic scientific research, even amidst broader geopolitical conflicts, facilitating knowledge exchange in the region [62]. However, the geopolitical landscape and associated fieldwork logistics and safety issues, has been altered along with climate change, so that more actors and nation-states, including non-Arctic powers, invest in research infrastructures in sensitive polar regions like Svalbard (Norway) to advance scientific knowledge, but potentially also to gain governance power in the Arctic [63]. This geopolitical shift is not limited to the Arctic; scientific endeavors in Antarctica can also be driven by geopolitical aims, especially concerning potential resource extraction in the future. Some argue that conducting scientific research is a diplomatically advantageous way for some nations to establish a foothold in these regions, which is another example of indirect colonization efforts [64].

With Russia's invasion of Ukraine on February 24, 2022, the geopolitical landscape of polar sciences shifted dramatically, marking the end of an era [65]. The conflict in Ukraine is disrupting research partnerships across various scientific domains, significantly impacting Arctic climate science [66]. This disruption particularly affects ECRs as they often have limited resources and professional networks. Consequently, ECRs may struggle to secure alternative field sites and establish new research partnerships. Given the substantial area of the Arctic within Russian territory, critical climate change-related phenomena necessitate continuous monitoring and study, making this disruption particularly detrimental [67]. Concerns arise regarding the discontinuation of cooperation with Russia in the Arctic Council and its potential impact on Arctic climate science by hindering fieldwork in the Russian Arctic [66, 68, 69].

5. Environmental challenges

As scientists observe rapid environmental changes happening in the fragile polar ecosystems, reducing the impact of fieldwork (see [3]) and observing the recommendations by the European Polar Board [70], becomes increasingly important for ECRs. However, decreasing the ecological footprint of research stations will be challenging, particularly in Antarctica, with its unique logistical challenges (see above). Geoscientific research infrastructures, including satellite launches and ground-based observatories, significantly contribute to the carbon footprint of research. [71] estimates that active astronomical research infrastructures worldwide have an equivalent carbon footprint of 20.3±3.3 $MtCO_2$, emitting 1,169±249 $ktCO_2e\ yr^{-1}$ annually. They emphasize that, in comparison to other research activities like travel or material purchases, research infrastructures contribute the most to an experimental researcher's carbon footprint. Research station managers from various countries, with the involvement of ECRs and the whole scientific community, need to sensibly decrease the environmental impact of research–e.g., reducing inessential services that cannot be provided in such remote locations and repurposing existing field stations [72].

It is challenging for ECRs, who may have limited resources and experience in polar regions, to have a complete understanding of the potential environmental impact of their fieldwork in highly sensitive polar ecosystems. Antarctica, in contrast to the Arctic, is under the auspices of the legal framework of the Antarctic Treaty system, which promotes and sets policies to reduce the environmental impact of fieldwork [73] and references therein]. While Antarctica benefits from a ratified legal framework, the Arctic presents a more fragmented scenario, which is geopolitically divided among several countries, each with different laws and political agendas. The Arctic Monitoring and Assessment Programme (AMAP, https://www.amap.no/) provides valuable and up-to-date information on pollution and human health in the Arctic, albeit with a global rather than regional focus.

6. Challenges specific to ECRs carrying out fieldwork in polar regions

For many ECRs, conducting fieldwork in polar regions presents a distinct set of challenges that set it apart from other fieldwork in remote conditions. Whilst fieldwork in other challenging environments may also involve political instability, limited resources, and access, these environments may not necessarily require the same level of international collaboration and shared logistics, specialized equipment, long-term planning and a limited field season as polar research. Furthermore, the harsh and unpredictable environmental conditions in polar regions pose unique safety risks that may not be present in other fieldwork settings. Funding expensive research by partnering with tourist vessels or being immersed in fieldwork in conflict regions, the challenges are not only scientific and professional but also deeply personal. Their research endeavors become embroiled in paradox as the urgency of their research on climate change can sometimes fail to align with the practicalities of fieldwork [74]. Idiosyncrasies of being an ECR in polar field research often include a combination of: 1) Relatively less (or lack of) experience in the field; 2) Less access to secure funding; 3) Higher dependency on the outcome of fieldwork in order to achieve research objectives to satisfy granting agencies and secure tenure at their home institutions; and 4) Maintaining flexibility to change plans (e.g., duration of field season), which in turn can produce more instability and difficulties in achieving work-life balance. These challenges make ECRs particularly vulnerable to the harsh realities of fieldwork safety and logistics–e.g., missing field seasons due to political conflicts such as the Russian invasion of Ukraine or a global pandemic (COVID-19), which disrupted Antarctic fieldwork and disproportionately affected ECRs [64]). The loss of opportunities to collate research data can be a significant setback for ECRs, negatively impacting their academic progress, which can have broad professional and personal consequences [see 75].

Physical safety in the field may be compromised by limited budgets and lack of adherence to safety training due to lack of experience and higher career stakes (e.g., the fatal accident of Drs. Malcolm A. Ramsay and Stuart Innes in the Canadian High Arctic in 2000; [6, 76]). ECRs are often expected to demonstrate intrepid bravery without possibly being adequately informed about the potential risks they may encounter [40, 77]. ECRs in conflict regions face unique challenges, including physical access, engaging with reluctant participants, and maintaining confidentiality in sensitive research contexts [78]. Finally, for those ECRs who are starting families, balancing fieldwork with equitable childcare responsibilities and striving to maintain a healthy work-life balance is a significant challenge, leading to delays and relative disparities in career advancement [79]. Altogether, these aforementioned challenges emphasize the need for ongoing dialogue, support, and pertinent changes to policies to facilitate the professional growth and safety of ECRs in the field.

7. Discussion and proposed solutions to challenges

To empower ECRs to overcome the challenges highlighted, we propose the following solutions: data sharing and training, citizen science engagement, governance and structural changes, alternative solutions to bridge the gap in fieldwork research, equality improvements, and decolonized polar research.

7.1. Promoting data sharing and collaboration

A practice which could mitigate safety risks and reduce environmental impact is promoting the collection of earth observation data, and increasing data sharing among researchers and institutions because it would discourage redundancy in data collection. Earth observation and remote monitoring at different times of the year would address challenges such as having a resource-constrained budget, safety, and sustainability (Fig 4). This field monitoring strategy optimizes fieldwork planning, reduces costs and ecological impact, as well as improves the safety for ECRs, e.g. remote data collection on fluvial processes minimized exposure to risks in areas affected by the summer 2023 storm Hans (Fig 4A–4C). While this method promotes safety, challenges such as deep snow coverage present limitations for fluvial flood risk studies, necessitating different logistical considerations (Fig 4D). Nevertheless, remote monitoring supplements weather forecasts, which is particularly crucial in regions with limited monitoring or distinctive and unpredictable local climates (e.g., valleys in polar regions).

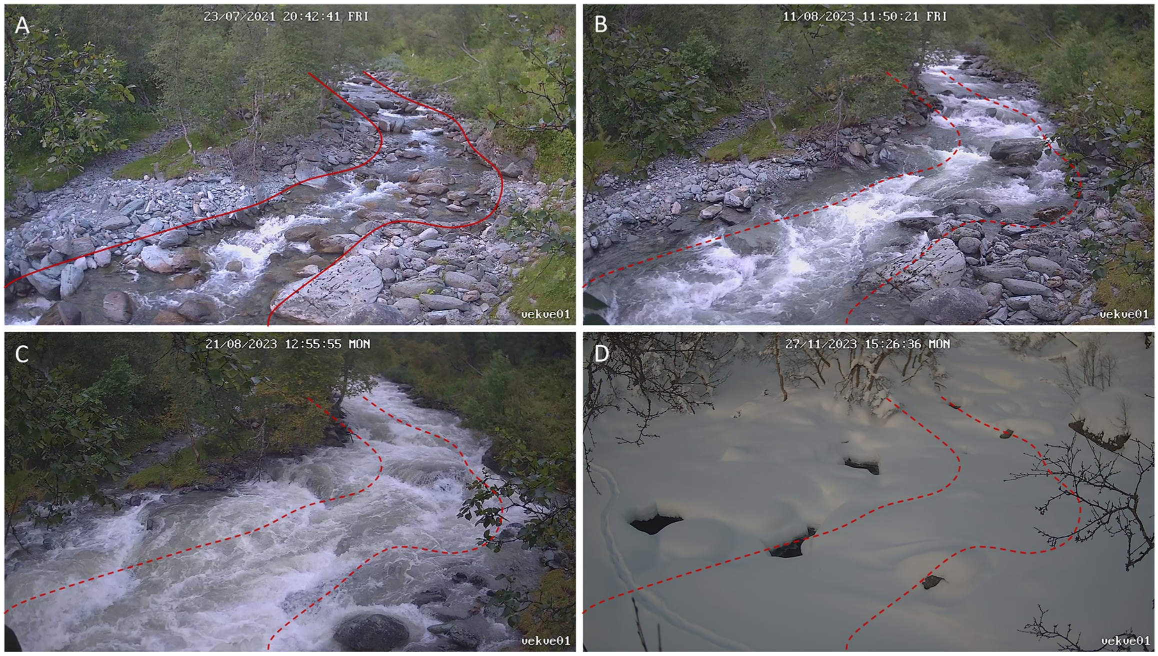

Fig 4. Illustration of proposed solutions addressing physical and environmental challenges, highlighting the importance of field monitoring strategies to optimize fieldwork planning, reduce costs and ecological impact, and improve safety for early career researchers (ECRs). ECRs can remotely collect data on fluvial processes (a-c), minimizing exposure to risks in areas affected by the summer 2023 storm Hans. However, deep snow coverage (d) is suboptimal for fluvial flood risk studies, necessitating different logistical considerations. Remote monitoring also supplements weather forecasts, crucial in regions with limited monitoring or distinctive and unpredictable local climates (e.g., mountain valleys). Photo credit: Adina Moraru.

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Access to shared observatory data is particularly advantageous for resource-constrained ECRs (e.g., [6, 80]). Open-access datasets remove financial barriers, enabling scientific explorations without incurring significant expenses. This inclusivity can extend opportunities to individuals with limited access to funding, instrumentation, and fieldwork, as well as decrease the environmental impact of polar fieldwork. Some initiatives in polar data sharing have been made and should be encouraged. E.g., in the terrestrial polar research disciplines, a long-standing success is the Circumpolar Active Layer Monitoring (CALM) project [81], which has recorded the thickness of seasonally unfrozen ground in the polar regions since 1991 and facilitated increased understanding of climate change impact on active layer depths [82–84]. More recent projects, which encompass a diverse range of data types, such as INTERACT Data Portal, Sustaining Arctic Observation Networks Data sharing, and Arctic PASSION are promising as infrastructure for data sharing going forward, however, have limited participation so far and hence limited data availability [85–87]. The ECR-driven approach to analyzing storm events in the Mid-Atlantic Bight using data from the Ocean Observatories Initiative Pioneer Array is one of many real-world examples of collaborative projects led by ECRs within the field of polar oceanography [80], a field that has advanced more significantly in collaborative and interdisciplinary working practices, emphasize the need for a solid foundation supporting inclusive and collaborative scientific practices in addressing critical environmental issues.

Traditionally, the study of ocean-atmosphere interactions and biogeochemical cycles relied on limited ship-based point measurements, constrained by factors like data collection duration and instrument availability. Sensor-equipped ocean-observing systems with multi-year capabilities now offer continuous, long-term sampling, fostering interdisciplinary research.

The wealth of observational data in oceanography presents interdisciplinary challenges, effectively addressed through collaborative efforts. Open-source community tools offer innovative solutions for analyzing complex datasets, which support a systems-based approach that harnesses the diverse skills of interdisciplinary research teams, expanding the scope of oceanographic research.

In the planning phase of fieldwork, initiatives like the Greenlandic Infrastructure Isaaffik [88] is an example of a platform in which researchers, among others, can declare and disclose their field plans and resources so that other projects can reach out for prospective collaboration and sharing in logistics management. More initiatives like the Greenland Infrastructure Issaffik could improve resource utilization via sharing and allocation and reduce the environmental impact of fieldwork in polar regions. Moreover, investment in the training and collaborative involvement of ECRs is essential for the continued success of observatory data collation and study; without such support, future generations of polar researchers would decline in number. Such investment in highly qualified personnel (HQPs) facilitates maintaining a robust scientific community, elevating the scientific profile and impact, and promoting inclusivity. By supporting ECRs in utilizing observatory data through interdisciplinary collaboration and advanced data analyses, we can advance our understanding of climate change and address environmental challenges even more effectively.

7.2. Citizen science and public engagement

Another approach to minimizing the environmental impact of polar fieldwork is employing citizen science initiatives, particularly in the context of Arctic research, which has established human communities year-round. Citizen science, a collaborative approach that involves layman individuals in assisting in scientific research projects (e.g., data collection efforts and analyses) presents an efficient, cost-effective, and sustainable means to document rapid ecological changes in expansive and remote Arctic regions [89–91]). Citizen scientists can contribute their observations (data) and personal expertise to assist professional scientists in addressing even complex and extensive research questions, which can reduce the number of costly field campaigns and thus incurred ecological impacts on the part of the ECR.

However, various challenges persist in the Arctic's unique socio-cultural landscape which can impede engagement, access, and truth and reconciliation efforts initiated and conducted by Western research in (nascent) scientific collaborations–e.g., low community involvement due to limited project awareness, language barriers, competing subsistence activities [92], harsh working conditions, and cultural differences [93]. To address these challenges, we propose to incorporate specialized training modules and workshops, with collaborative and cross-cultural approaches, tailored for ECRs working in polar regions [e.g. UArctic platform, Sharing Circle in ArcticPassion; 87, 94]. Moreover, we recognize the importance of direct communication with Indigenous partners, as each community may have unique priorities and needs. Citizen science methods can be implemented more successfully with full disclosure of research objectives and planning (e.g., timelines, projected environmental impacts, local/regional community benefits), careful planning and coordination in community involvement, and cultural awareness and training programs in participatory research processes led by Indigenous communities themselves [87, 94, 95]. This approach ensures that the training content is relevant, respectful, and tailored to the specific cultural context of the polar regions. It also contributes to capacity building and empowerment within Indigenous communities.

We believe that collaborative implementation of citizen science projects has much potential in facilitating the bridging of traditional local and scientific knowledge systems in the Arctic when the focus shifts from solely prioritizing Western science research objectives to more symmetric interactions and making more activities community-centric that can benefit local/regional communities [87]. To implement citizen science at a larger scale, researchers must plan meticulously to effectively integrate the aforementioned inclusive strategies into their long-term study objectives. Another example could include integrating citizen science data from expedition cruises into Arctic observation networks, which would offer a valuable means to enhance Arctic change monitoring and passenger engagement [54, 55]. While financial compensation can effectively enhance participation rates, it also introduces potential challenges [61]. External incentives, such as monetary payments, may inadvertently displace intrinsic motivations, including personal gratification and social acceptance. Once intrinsic motivations are compromised, reconciling such a shift in competing motivations can complicate matters related to commitment and compensation. Consequently, project organizers must carefully assess the impact of compensation on both the quality of contributions and the autonomy of the participants.

7.3. Changing intellectual frameworks and policies

The climate and ecological crisis pose a significant threat to human civilization, including academic research and education. Although universities have the potential to lead transformational change, recent studies posit that they are currently falling short (e.g., [96]). Urgent and radical action at all societal levels is necessary to establish a thriving scientific community capable of effectively addressing the climate crisis; universities can help achieve this goal by informing policy and educating future generations to become scientifically and environmentally literate. Emphasizing the importance of ecological sustainability and social justice should be at the core of these pedagogical efforts.

It is also essential to recognize that ECRs operate within institutional environments (e.g., universities, research institutes, funding agencies, etc.) characterized by rigid intellectual infrastructure that can be slow to change due to historical legacies [6]. Progressive ECRs, who adopt a proactive stance and open mind to explore new approaches and may be more adaptable and motivated to challenge the status quo, may encounter resistance within such traditional organizational structures. To address this challenge, we propose that institutions develop and maintain ECR network and knowledge exchange platforms, inspired by successful models like APECS. By adopting and promoting APECS-like practices, institutions can facilitate the exchange of best practices and knowledge among ECRs, enabling them to collectively negotiate and work within prospective institutional barriers. Furthermore, it is just as important for ECRs not to adopt an overly exclusive/close-minded stance. Instead, they should be prepared to share their discoveries and innovative ideas widely with the broader research community, society, and organizations. This openness fosters a culture of collaboration and facilitates development of novel approaches and solutions to addressing the complex challenges posed by the climate crisis. Building on the reported best practices by the European Polar Board [70], the solutions proposed herein are based on personal experiences and tailored to empower peer ECRs and foster environmental sustainability. Although ECRs are well-positioned to lead initiatives, the solutions proposed are not solely reliant on ECRs but require a collective effort from researchers at all career stages.

To promote a more sustainable research culture, institutions should encourage and support ECRs and researchers at all career stages to prioritize ecological considerations in their work, including minimizing travel-related emissions. A collaborative research culture within institutions can lead to more efficient use of resources and minimize the need for travel. By facilitating data sharing, joint projects, and interdisciplinary collaboration, institutions can create an environment where researchers can achieve their objectives without the need for excessive travel, consequently reducing their carbon footprints. For example, one key initial step is to raise awareness of carbon footprints associated with research by calculating and incorporating those costs into funding proposals [97]. Furthermore, cutting down on business travel, where feasible, by substituting aerial travel with railway or efficient road travel, especially for national fieldwork and working more remotely (e.g., virtual meetings/conferences, remote monitoring of study sites), could contribute to emissions reduction and push towards more responsible and sustainable standard operating procedures. This not only reduces carbon emissions but also encourages more inclusive participation, as it can eliminate barriers related to travel costs and accessibility.

Another strategy to promote ecological sustainability is prolonging the lifespan of laboratory materials, such as opting for glass over plastic, minimizing purchases of consumables via collaboration and/or exchange with other laboratories and research groups, and properly maintaining electronic equipment and instrumentation; these alongside other activities can be promising avenues for reducing waste and the ecological footprints of researchers. Altogether, adopting these practical solutions can collectively lead to a ~60% reduction in greenhouse gas emissions of a research group [98]. Furthermore, institutions can support sustainable research practices by investing in green technologies and infrastructure, such as energy-efficient buildings and renewable energy sources. They can also implement policies that encourage telecommuting and virtual collaboration, further reducing the need for travel. Such practices would reflect polar scientists adopting a more environmentally sustainable and responsible *modus operandi*, bolstering their profile and image in the public eye.

7.4. Enhancing scientific diplomacy

In response to disruptions in Arctic research partnerships, scientists outside of Russia are exploring alternative approaches to data collection. Remote-sensing techniques can partially address information needs, but limitations exist, e.g., in monitoring methane emissions in the Arctic [42]. The anticipated French-German MERLIN mission, designed to bolster such monitoring capabilities, is not expected to launch until at least 2027. Alternatively, some researchers maintain personal collaborations with their Russian counterparts, navigating the challenges of disrupted geopolitical relations [67]. Science diplomacy emerges as a potential solution, involving international and interdisciplinary efforts that employ scientific and technical exchanges to achieve objectives beyond scientific discovery [99] to consider and reconcile other priorities and needs. As polar regions become not only scientific frontiers but also geopolitical arenas, ECRs must learn to navigate a spectrum of challenges that can extend beyond the scientific domain, traditional power structures and organizational frameworks.

A pending critical challenge for polar regions is the lack of accurate demographic projections under conditions of global warming with concrete statistical links to climate change and future environmental demands. Currently, the focus tends to be on migration and adaptation of human settlements. However, we propose considering population projections as a potential avenue for future research as human residential communities have a significant impact on the landscape with respect to environmental footprint and modification.

7.5. Addressing EDI issues

While mixed-gender (as opposed to all-men) Antarctic overwintering has revealed omnipresent incidents of sexual harassment, it has also shown improved overall crew well-being [100]. This accentuates the importance of achieving objectives outlined in equality, diversity, and inclusivity (EDI) initiatives which are fundamental for promoting and enhancing the well-being of researchers in the advancement of polar science. Further research and data collection on intersectionality in polar research, incorporating resources and literature from non-English speaking countries, increasing the visibility of inequality statistics, and creating an open dialogue on intersectionality and gender issues during polar meetings could foster equality and create safe, respectful work environments in polar fieldwork [50, 51]. Polar science organizations are urged to continue initiatives that support leadership roles in promoting equitable workplace culture and addressing gender disparities within the field – e.g., APECS, Inspiring Girls* initiative [20]. Additionally, it is important to ensure that all members of the polar research community feel welcomed, supported, and equipped to contribute. To achieve equality and inclusion, we must invest in the training and collaborative involvement of ECRs and HQPs, including implementing intersectional approaches to leadership, mentorship, and team-building, and addressing the systemic challenges faced by underrepresented groups [6, 46, 50].

7.6. De-colonizing Arctic research

Decolonial research can be done by supporting research with, by, and for Indigenous Peoples. Such research is a broad, inclusive process, creating space for diverse ways of knowing and establishing mutually agreed-upon motivations, goals, and outcomes [59, 101]. Furthermore, it promotes self-determination and the return of knowledge ownership to Indigenous communities, fostering meaningful, long-lasting partnerships among prospective research partners. This is achieved through the co-production of research outputs [102, 103] and the development of institutional capacity that fosters and supports these endeavors [104].

In academic research, adherence to the CARE Principles for Indigenous Data Governance is crucial [105]. These principles, in addition to the FAIR principles [105], focus on people and purpose, underscoring the role of data in advancing Indigenous innovation and self-determination. Decolonial research calls for reshaping the approach to climate change in both policy and research contexts. This means prioritizing the concerns and perspectives of Indigenous communities, along with climate science, to ensure that their voices and the issues they raise receive the attention they deserve [106]. This approach aligns with the practical guidance provided in the "Roadmap to Decolonial Arctic Research" and by the Sharing Circle initiative, encouraging researchers to go beyond formal requirements and familiarize themselves with ethical standards outlined by Indigenous peoples [87, 107].

We emphasize the continued efforts in decolonizing and dismantling previous disreputable practices in the Arctic to recognize Indigenous land rights and self-governance and foster new and equitable partnerships with Indigenous Peoples [54, 55]. For instance, we call for two-eyed seeing methods that combine Indigenous and Western knowledge systems, which are crucial for promoting mutual collaboration, co-learning, and respect in addressing the environmental crises currently impacting the Arctic [108].

8. Conclusion and outlook

As discussed in this review, the challenges outlined in polar fieldwork for ECRs, reflect the dynamic landscape of the changing polar regions. These challenges encompass physical, social, political, and environmental issues and underscore the urgency of reevaluating the ethical considerations of fieldwork in the face of the current climate crisis. The proposed solutions in this review highlight that many, if not all, of these issues are interrelated, and addressing them is vital for the sustainability of academic research in polar regions. Indeed, the principles outlined provide a comprehensive framework for the social foundation of academia [96]. They emphasize the importance of fostering academic freedom, promoting long-term contemplation of sustainability, and encouraging innovative research, which are especially pertinent for

ECRs navigating the complexities of polar fieldwork. The need for secure positions and careers that offer recognition and personal gratification aligns with the precarious nature of fieldwork, where ECRs face challenges ranging from uncertain climate change complexities to adapting to unforeseen events like the COVID-19 pandemic. Fostering a strong sense of community [96] resonates deeply with the collaborative spirit needed to contribute to healthy, supportive, and collegial academic environments. The commitment to issues pertaining to EDI is not only ethically imperative but also aligns with the interdisciplinary nature of polar research, encouraging and supporting the integration of diverse perspectives to address multifaceted challenges.

In the specific context of polar fieldwork, ECRs encounter challenges not only related to their scientific pursuits but also to their well-being and professional growth. Growing safety concerns, data-sharing challenges, and the need for increased scientific collaboration and diplomacy with communities underscore the need for devising and implementing supportive policies, continuous dialogue, and equitable collaborations. The polar regions, with their harsh climates and logistical complexities, serve as an arena where these broader principles are put to the test, accentuating the interconnectedness of shifting academic values and the practical challenges faced by ECRs.

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References

1. Rasch M., Arndal M. F., Fugmann G., Hansen F. S., Topp-Jøorgensen E. (2019). INTERACT practical field guide. International Network for Terrestrial Research and Monitoring in the Arctic, 74pp. ISBN: 978-8793-1291-4-6.

2. Schneider A., Rasch M., Topp-Jørgensen E., Arndal M. F., Hansen C., Moreno Ibáñez M., et al. (2021). INTERACT Communication and Navigation guidebook. Zenodo, 84pp. https://doi.org/10.5281/ZENODO.4692556

3. Frendrup L. L., Rasch M., Topp-Jørgensen E., Arndal M. F. (2021). INTERACT Reducing the Environmental Impacts of Arctic Fieldwork. Zenodo, 48pp. https://doi.org/10.5281/ZENODO.5139698

4. Young J., Clement S., Pettit E. (2023). Removing Barriers to Science and the Outdoors for Teenage Youth and Early Career Professionals in the US Arctic and Beyond: An Expedition-Based Model. Sibirica: The Journal of Siberian Studies 22, 33–55. https://doi.org/10.3167/sib.2023.220103.

5. Ulunnguaq Markussen U. (2017). Towards an Arctic Awakening: Neocolonalism, Sustainable Development, Emancipatory Research, Collective Action, and Arctic Regional Policymaking. Springer International Publishing. https://doi.org/10.1007/978-3-319-57532-2_31

6. Moraru A., Calì Quaglia F., Kim M., López-Quirós A., Huynh H. M. (2024). Empowering early career polar researchers in a changing climate: challenges and solutions. PLOS Climate, 3(1), e0000332. https://doi.org/10.1371/journal.pclm.0000332

7. European Commission Directorate General for Research and Innovation. Available at: https://euraxess.ec.europa.eu/sites/default/files/policy_library/towards_a_european_framework_for_research_careers_final.pdf [last accessed: 12 March 2024].

8. Köppen W. (1936). Das geographische System der Klimate, 1–44. Gebrüder Borntraeger: Berlin, Germany.

9. Cui D., Liang S., Wang D. (2021). Observed and projected changes in global climate zones based on Köppen climate classification. Wiley Interdisciplinary Reviews. Climate Change, 12(3), e701-n/a. https://doi.org/10.1002/wcc.701

10. Dong X., Wang Y., Hou S., Ding M., Yin B., Zhang Y. (2020). Robustness of the Recent Global Atmospheric Reanalyses for Antarctic Near-Surface Wind Speed Climatology. Journal of Climate 33, 4027–4043. https://doi.org/10.1175/JCLI-D-19-0648.1

11. Nymand Larsen J., Fondahl G., (eds.) (2014). Arctic Human Development Report II: Regional Processes and Global Linkages. Copenhagen: Nordic Council of Ministers. http://norden.diva-portal.org/smash/get/diva2:788965/FULLTEXT03.pdf

12. Fedotov D. M., Zubov L. A., Nazarov A. A. (2011). Vozdeystvie izmeneniy klimata na traditionnyy uklad zhizni korennogo naseleniya i usloviya okazaniya meditsinskoy pomoshchi v Nenetskom Avtonomnom okruge [The impact of climate change on the Arctic Human Development Report 343 Traditional way of life of the Indigenous population and the conditions of the provision of medical care in Nenets autonomous okrug]. Proceedings of All-Russian Science and-Practice Conference with international participation "Circumpolar Medicine: Impact of Environmental Factors on Human Health Formation", 27th–29th June 2011, pp. 294–297. Arkhangelsk, Russian Federation.

13. French H. M. (2018). The periglacial environment. Wiley Blackwell, Hoboken, New Jersey, fourth edition. ISBN: 978-1-119-13281-3.

14. Rantanen M., Karpechko A. Y., Lipponen A., Nordling K., Hyvärinen O., Ruosteenoja K., et al. (2022). The Arctic has warmed nearly four times faster than the globe since 1979. Communications Earth & Environment, 3, 168. https://doi.org/10.1038/s43247-022-00498-3

15. Seo K.-W., Wilson C. R., Scambos T., Kim B.-M., Waliser D. E., Tian B., et al. (2015). Surface mass balance contributions to acceleration of Antarctic ice mass loss during 2003–2013: Antarctic ice mass loss acceleration. Journal of Geophysical Research. Solid Earth, 120, 3617–3627. https://doi.org/10.1002/2014jb011755

16. Meredith M., Sommerkorn M., Cassotta S., Derksen C., Ekaykin A., Hollowed A., et al. (2019). Polar Regions. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [Pörtner H.-O et al. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 203–320. https://doi.org/10.1017/9781009157964.005

17. Nicola L., Notz D., Winkelmann R. (2023). Revisiting temperature sensitivity: how does Antarctic precipitation change with temperature? The Cryosphere, 17, 2563–2583. https://doi.org/10.5194/tc-17-2563-2023

18. Mokhov I. I., Parfenova M. R. (2021). Relationship of the Extent of Antarctic and Arctic Ice with Temperature Changes, 1979–2020. Doklady Earth Sciences, 496, 66–71. https://doi.org/10.1134/S1028334X21010153

19. Chen Y., Liu A., Cheng X. (2022). Detection of thermokarst lake drainage events in the northern Alaska permafrost region. The Science of the Total Environment 807, 150828–150828. https://doi.org/10.1016/j.scitotenv.2021.150828 PMID: 34627883

20. Luetzow N., Veh G., Korup O. (2023). A global database of historic glacier lake outburst floods. Earth System Science Data 15, 2983–3000. https://doi.org/10.5194/essd-15-2983-2023

21. Rasmussen L. H., Zhang W., Hollesen J., Cable S., Christiansen H. H., Jansson P.-E., et al. (2018). Modelling present and future permafrost thermal regimes in Northeast Greenland. Cold Regions Science and Technology 146, 199–213. https://doi.org/10.1016/j.coldregions.2017.10.011

22. Holmes C. R., Bracegirdle T. J., Holland P. R. (2022). Antarctic Sea Ice Projections Constrained by Historical Ice Cover and Future Global Temperature Change. Geophysical Research Letters, 49(10). https://doi.org/10.1029/2021GL097413

23. Lewis-Jones H. (2017). Imagining the Arctic: heroism, spectacle and polar exploration. London: Bloomsbury Publishing, ISBN: 978-1786-7324-6-0, 448pp.

24. Mallory M. L., Gilchrist H. G., Janssen M., Major H. L., Merkel F., Provencher J. F., et al. (2018). Financial costs of conducting science in the Arctic: examples from seabird research. Arctic Science 4, 624–633. https://doi.org/10.1139/as-2017-0019

25. Figuerola B., Valiente N., Barbosa A., Brasier M. J., Colominas-Ciuró R., Convey P., et al. (2021). Shifting Perspectives in Polar Research: Global Lessons on the Barriers and Drivers for Securing Academic Careers in Natural Sciences. Frontiers in Ecology and Evolution, 9, 777009. https://doi.org/10.3389/fevo.2021.777009

26. Sandal G. M., Leon G. R., Palinkas L. (2006). Human challenges in polar and space environments. Reviews in Environmental Science and Biotechnology, 5, 281–296.

27. Cassano J. J., Maslanik J. A., Zappa C. J., Gordon A. L., Cullather R. I., Knuth S. L. (2010). Observations of Antarctic Polynya With Unmanned Aircraft Systems Active Source Seismic Experiment Peers Under Soufrière Hills Volcano. Eos, 91(28), 245–252. https://doi.org/10.1029/2010EO280001

28. Casoni M., Grazia C. A., Klapez M., Patriciello N., Amditis A., Sdongos E. (2015). Integration of satellite and LTE for disaster recovery. IEEE Communications Magazine, 53(3), 47–53. https://doi.org/10.1109/MCOM.2015.7060481

29. Harrington A. (2020). Insurance as Governance for Outer Space Activities. Astropolitics, 18(2), 99–121. https://doi.org/10.1080/14777622.2020.1786300

30. Stuster J., Bachelard C., Suedfeld P. (2000). The relative importance of behavioral issues during long duration ICE missions. Aviation, Space, and Environmental Medicine, 71(9, Sect2, Suppl.), A17–A25. PMID: 10993304

31. Paul M. A., Love R. J., Hawton A., Brett K., McCreary D. R., Arendt J. (2015). Sleep deficits in the High Arctic summer in relation to light exposure and behaviour: use of melatonin as a countermeasure. Sleep Medicine, 16(3), 406–413. https://doi.org/10.1016/j.sleep.2014.12.012 PMID: 25747331

32. Lubas M. M., Szklo-Coxe M. (2018). Exploring the Associations Between Sleep Hygiene, Sunlight Exposure, and Sleep Outcomes During an Arctic Summer. Sleep, 41 (suppl_1), A64. https://doi.org/10.1093/sleep/zsy061.163

33. Bhargava R., Mukerji S., Sachdeva U. (2000). Psychological impact of the Antarctic winter on Indian expeditioners. Environmental Behavior 32, 111–127. https://doi.org/10.1177/00139160021972450 PMID: 11542940

34. Palinkas L. A., Glogower F. G., Dembert M., Hansen K., Smullen R. (2004). Incidence of psychiatric disorders after extended residence in Antarctica. International Journal of Circumpolar Health, 63(2), 157–168. https://doi.org/10.3402/ijch.v63i2.17702 PMID: 15253482

35. Haeberli W., Whiteman C. (2021). Chapter 1—Snow and ice-related hazards, risks, and disasters: Facing challenges of rapid change and long-term commitments. In: Hazards and Disasters Series, Snow and Ice-Related Hazards, Risks, and Disasters (Second Edition), Haeberli W and Whiteman C (Eds.), Elsevier, 1–33, ISBN: 9780128171295, https://doi.org/10.1016/B978-0-12-817129-5.00014-7

36. Haeberli W., Schaub Y., Huggel C. (2017). Increasing risks related to landslides from degrading permafrost into new lakes in de-glaciating mountain ranges. Geomorphology, 293 (Part B), 405–417. https://doi.org/10.1016/j.geomorph.2016.02.009

37. Hendrickx H., Le Roy G., Helmstetter A., Pointner E., Larose E., Braillard L., et al. (2022). Timing, volume and precursory indicators of rock- and cliff fall on a permafrost mountain ridge (Mattertal, Switzerland). Earth Surface Processes and Landforms, 47(6), 1532–1549. https://doi.org/10.1002/esp.5333

38. Hu F. S., Higuera P. E., Duffy P., Chipman M. L., Rocha A. V., Young A. M., et al. (2015). Arctic tundra fires: natural variability and responses to climate change. Frontiers in Ecology and the Environment 13, 369–377. https://doi.org/10.1890/150063

39. Robinson S. A. (2022). Climate change and extreme events are changing the biology of Polar Regions. Global Change Biology, 28(20), 5861–5864. https://doi.org/10.1111/gcb.16309 PMID: 35821589

40. Hilhorst D., Hodgson L., Jansen B. J., Mena R. (2016). Security guidelines for field research in complex, remote and hazardous places. ISS-EUR, The Hague, 51pp. Available at: https://www.iss.nl/en/research/research-projects/when-disaster-meets-conflict/training

41. Gross M. (2018). Arctic shipping threatens wildlife. Current Biology, 28(15), R803–R805. https://doi.org/10.1016/j.cub.2018.07.053

42. Callaghan T. V., Johansson M. (2021). Chapter 5—Snow, ice, and the biosphere. In: Haeberli and Whiteman (eds.): Hazards and Disasters Series, Snow and Ice-Related Hazards, Risks, and Disasters (Second Edition), Elsevier, 137–164, ISBN: 9780128171295.

43. Wenger M. (2023). Mysterious tsunami hits station in East Greenland. Polar Journal, https://polarjournal.ch/en/2023/09/22/mysterious-tsunami-hits-station-in-east-greenland/ [last accessed: 18 March 2024].

44. National Oceanic and Atmospheric Administration (NOAA). Office of Oceanic and Atmospheric Research; Global Ocean Monitoring and Observing (GOMO) Program (2021). Glacier and Permafrost Hazards. Series: NOAA Technical Report OAR ARC; 21–13. https://doi.org/10.25923/v40r-0956

45. Jackson M. (2022). Snow and Ice-Related Hazards, Risks, and Disasters. In: Hazards and Disasters Series, Snow and Ice-Related Hazards, Risks, and Disasters (Second Edition), Haeberli W and Whiteman C (Eds.), Elsevier, Amsterdam, the Netherlands. ISBN: 978-0-128-17129-5 and Mountain Research and Development, 42(2), M1. https://doi.org/10.1659/mrd.mm272.1

46. Davis C., De Cock A., Ibrahimllari A., Odud L., Radilova S. (2024). Women in water: how to support everyone's contribution. IWA Publishing, London, 70pp. https://doi.org/10.2166/9781789064070

47. Sharp G., Kremer E. (2006). The safety dance: Confronting harassment, intimidation, and violence in the field. Sociological Methodology, 36(1), 317–327. https://doi.org/10.1111/j.1467-9531.2006.00183.x

48. Clancy K. B. H., Nelson R. G., Rutherford J. N., Hinde K. (2014). Survey of Academic Field Experiences (SAFE): Trainees report harassment and assault. PLoS ONE, 9(7), e102172. https://doi.org/10.1371/journal.pone.0102172 PMID: 25028932

49. Rinkus M. A., Kelly J. R., Wright W., Medina L., Dobson T. (2018). Gendered Considerations for Safety in Conservation Fieldwork. Society and Natural Resources, 31(12), 1419–1426. https://doi.org/10.1080/08941920.2018.1471177

50. Seag M., Badhe R., Choudhry I. (2020). Intersectionality and international polar research. Polar Record, 56, e14. https://doi.org/10.1017/S0032247419000585

51. Starkweather S., Seag M., Lee O., Pope A. (2018). Revisiting perceptions and evolving culture: a community dialogue on women in polar research. Polar Research, 37(1), 1529529–4. https://doi.org/10.1080/17518369.2018.1529529

52. Taylor L. S. (2022). Review of the Picture a Scientist documentary. Molecular Pharmaceutics, 19(2), 359–360. https://doi.org/10.1021/acs.molpharmaceut.2c00018 PMID: 35124967

53. Ferguson J., Abdel-Fattah D., Friedrich D., Lee O., Nikolaeva S. (2023). The spectrum of intersectionality in the Arctic. Sibirica, 22(1), 1–4. https://doi.org/10.3167/sib.2023.220101

54. Taylor A. R., Barðadóttir ., Auffret S., Bombosch A., Cusick A. L., Falk E., et al. (2020). Arctic expedition cruise tourism and citizen science: A vision for the future of polar tourism. Journal of Tourism Futures, 6, 102–111. https://doi.org/10.1108/JTF-06-2019-0051

55. Meyer A. N., Lutz B., Bergmann M. (2023). Where does Arctic beach debris come from? Analyzing debris composition and provenance on Svalbard aided by citizen scientists. Frontiers in Marine Science, 10, 1092939. https://doi.org/10.3389/fmars.2023.1092939

56. Nadasdy P. (2003). Hunters and bureaucrats: power, knowledge, and aboriginal-state relations in the southwest Yukon. UBC press, 328pp. ISBN: 978-0774-8098-4-9.

57. Smith L. T. (2013). Social justice, transformation and indigenous methodologies. In: Ethnographic worldviews: Transformations and social justice (Rinehart R., Barbour K., Pope C., Eds.). Springer, Dordrecht, the Netherlands, (pp. 15–20). https://doi.org/10.1007/978-94-007-6916-8_2

58. Smith L. T. (2021). Decolonizing methodologies: Research and indigenous peoples. Bloomsbury Publishing, 220pp. ISBN 978-1786-9981-2-5.

59. Zanotti L., Carothers C., Apok C. A., Huang S., Coleman J., Ambrozek C. (2020). Political ecology and decolonial research: co-production with the Iñupiat in Utqiaġvik. Journal of Political Ecology, 27, 43–66. https://doi.org/10.2458/v27i1.23335

60. Lafferty A., Gonet J., Wasilik T., Thompson L., Ertman S., Bandara S. (2023). Navigating the Shifting Landscape of Engagement in Northern Research: Perspectives from Early Career Researchers. Northern Review, (54), 5–31. https://thenorthernreview.ca/index.php/nr/article/view/973/1087

61. Walker D. W., Smigaj M., Tani M. (2021). The benefits and negative impacts of citizen science applications to water as experienced by participants and communities. WIREs Water, 8(1), e1488. https://doi.org/10.1002/wat2.1488

62. Exner-Pirot H., Murray R. W. (2017). Regional order in the Arctic: Negotiated exceptionalism. Politik, 20, 47–64. https://doi.org/10.7146/politik.v20i3.97153

63. Pedersen T. (2021). The politics of research presence in Svalbard. The Polar Journal, 11(2), 413–426. https://doi.org/10.1080/2154896X.2021.1883900

64. Convey P. (2023). What is the place of science in Antarctica? Antarctic Science, 35, 1–3. https://doi.org/10.1017/S095410202300007X

65. Koivurova T., Shibata A. (2023). After Russia's invasion of Ukraine in 2022: Can we still cooperate with Russia in the Arctic? Polar Record 59, e12. https://doi.org/10.1017/S0032247423000049

66. Mortensgaard L.A. (2023). Arctic climate science is caught in the middle of geopolitical tension. Danish Institute for International Studies. Policy Brief. https://www.diis.dk/en/research/arctic-climate-science-is-caught-in-the-middle-of-geopolitical-tension [Last accessed: 29 November 2023].

67. Witze A. (2022). Russia's war in Ukraine forces Arctic climate projects to pivot. Nature, 607, 432. https://doi.org/10.1038/d41586-022-01868-9 PMID: 35817867

68. Andreeva S. (2023). Science at Stake–Russia and the Arctic Council. Arctic Review on Law and Politics 14, 112–131. https://doi.org/10.23865/arctic.v14.5455

69. López-Blanco E., Topp-Jørgensen E., Christensen T.R., Rasch M., Skov H., Arndal M.F., et al. (2024). Towards an increasingly biased view on Arctic change. Nature Climate Change, 14, 152–155. https://doi.org/10.1038/s41558-023-01903-1

70. Elshout P., Chappellaz J., Gibéryen T., Hansen C., Jania J., Jones-Williams K., et al.(2023). Synthesis Report on the Environmental Impacts of Polar Research and Logistics in the Polar Regions. Zenodo, 52pp. https://doi.org/10.5281/ZENODO.7907235

71. Knödlseder J., Brau-Nogué S., Coriat M., Garnier P., Hughes A., Martin P., et al. (2022). Estimate of the carbon footprint of astronomical research infrastructures. Nature Astronomy, 6, 503–513. https://doi.org/10.1038/s41550-022-01612-3

72. Fryirs K., Snape I., Babicka N. (2013). The type and spatial distribution of past waste at the abandoned Wilkes Station, East Antarctica. Polar Record, 49, 328–347. https://doi.org/10.1017/S0032247412000721

73. Stark J. S., Johnstone G. J., King C., Raymond T., Rutter A., Stark S. C., et al. (2023). Contamination of the marine environment by Antarctic research stations: Monitoring marine pollution at Casey station from 1997 to 2015. PLOS ONE, 18, e0288485. https://doi.org/10.1371/journal.pone.0288485 PMID: 37556440

74. van Soest M. (2023). An Arctic expedition: a supposedly useful thing I'll never do again. Polar Research, 42, 1–6. https://doi.org/10.33265/polar.v42.9070

75. Inouye D. W., Underwood N., Inouye B. D., Irwin R. E. (2020). Support early-career field researchers. Science, 368, 724–725. https://doi.org/10.1126/science.abc1261 PMID: 32409467

76. Messier F. (2000). Obituary of Dr. Malcolm Alexander Ramsay. Arctic, 53(3), 332–333.

77. Roguski M., Tauri J. M. (2013). Key issues effecting field researcher safety: A reflexive commentary. New Zealand Sociology, 28, 18–35.

78. Browne B., Moffett L. (2014). Finding Your Feet in the Field: Critical Reflections of Early Career Researchers on Field Research in Transitional Societies. Journal of Human Rights Practice, 6(2), 223–237. https://doi.org/10.1093/jhuman/huu010

79. Lininger K. B., Rowan A. V., Livers B., Kramer N., Ruiz-Villanueva V., Sendrowski A., et al. (2021). Perspectives on being a field-based geomorphologist during pregnancy and early motherhood. Earth Surface Processes and Landforms, 46, 2767–2772. https://doi.org/10.1002/esp.5238

80. Levine R. M., Fogaren K. E., Rudzin J. E., Russoniello C. J., Soule D. C., Whitaker J. M. (2020). Open Data, Collaborative Working Platforms, and Interdisciplinary Collaboration: Building an Early Career Scientist Community of Practice to Leverage Ocean Observatories Initiative Data to Address Critical Questions in Marine Science. Frontiers in Marine Science, 7. https://doi.org/10.3389/fmars.2020.593512

81. CALM (Circumpolar Active Layer Monitoring program). Available at: https://www2.gwu.edu/~calm/ [last accessed: 12 March 2024].

82. Hrbáček F., Vieira G., Oliva M., Balks M., Guglielmin M., de Pablo M. Á., et al. (2021). Active layer monitoring in Antarctica: an overview of results from 2006 to 2015. Polar Geography 44, 217–231. https://doi.org/10.1080/1088937X.2017.1420105

83. Nyland K. E., Shiklomanov N. I., Streletskiy D. A., Nelson F. E., Klene A. E., Kholodov A. L. (2021). Long-term Circumpolar Active Layer Monitoring (CALM) program observations in Northern Alaskan tundra. Polar Geography (1995), 44(3), 167–185. https://doi.org/10.1080/1088937X.2021.1988000

84. Kaverin D., Malkova G., Zamolodchikov D., Shiklomanov N., Pastukhov A., Novakovskiy A., et al. (2021). Long-term active layer monitoring at CALM sites in the Russian European North. Polar Geography (1995), 44(3), 203–216. https://doi.org/10.1080/1088937X.2021.1981476

85. INTERACT—The Network of Terrestrial Research and Monitoring in the Arctic. Virtual Access Single Entry Point. Available at: https://dataportal.eu-interact.org/ [last accessed: 12 March 2024].
86. SAON (Sustaining Arctic Observing Networks) Data Portal. Available at: https://data.arcticobserving.org/ [last accessed: 12 March 2024].
87. Arctic Passion pan-Arctic Observation and Monitoring Action and Share Circle. Available at: https://arcticpassion.eu/data/ [last accessed: 12 March 2024].
88. ISAAFFIK Arctic Gateway. Logistics search engine. Available at: https://isaaffik.org/logistics [last accessed: 12 March 2024].
89. Gofman V. (2010). Community based monitoring handbook: Lessons from the Arctic. CAFF CBMP Report No.21, August 2010, CAFF International Secretariat, Akureyri, Iceland. ISBN: 978-9979-9778-4-1.
90. Dickinson J. L., Bonter D., Bonney R., Crain R.L., Martin J., Phillips T., et al. (2012). The current state of citizen science as a tool for ecological research and public engagement. Front. Ecol. Environ. 10, 291–297. https://doi.org/10.1890/110236
91. Dunmall K. M., Reist J. D. (2018). Developing a citizen science framework for the Arctic using the 'Arctic Salmon' initiative. Impacts of a Changing Environment on the Dynamics of High-latitude Fish and Fisheries. Alaska Sea Grant, University of Alaska Fairbanks, 31–47. https://doi.org/10.4027/icedhlff.2018.02
92. Parlee B., Huntington H., Berkes F., Lantz T., Andrew L., Tsannie J., et al. (2021). One-Size Does Not Fit All—A Networked Approach to Community-Based Monitoring in Large River Basins. Sustainability, 13(13), 7400. https://doi.org/10.3390/su13137400
93. Hervé C., Laneuville P., Lapointe L. (2023). Participatory action research with Inuit societies: A scoping review. Polar Record, 59, E22. https://doi.org/10.1017/S0032247423000128
94. UArctic workshop for ECRs in polar regions "A week of exchange: ethics and methods in Arctic transformative research". 3–6 October 2023, Oulu, Finland. Available at: https://members.uarctic.org/media/y4bl0rbc/230629_2023-wema-davgi_invite.pdf [last accessed: 15 March 2024].
95. Lauter O. (2023). Challenges in combining Indigenous and scientific knowledge in the Arctic.Polar Geography, 46(1), 62–74. https://doi.org/10.1080/1088937X.2023.2233578
96. Urai A. E., Kelly C. (2023). Rethinking academia in a time of climate crisis. ELife, 12, e84991. https://doi.org/10.7554/eLife.84991 PMID: 36748915
97. Lannelongue L., Greatley J., Inouye M. (2021). Green Algorithms: Quantifying the Carbon Footprint of Computation. Advanced Science, 8(12), 2100707. https://doi.org/10.1002/advs.202100707 PMID: 34194954
98. Gratiot N., Klein J., Challet M., Dangles O., Janicot S., Candelas M., et al. (2023). A transition support system to build decarbonization scenarios in the academic community. PLOS Sustainability and Transformation, 2, e0000049. https://doi.org/10.1371/journal.pstr.0000049
99. Devyatkin P. (2022). Environmental Détente: U.S.-Russia Arctic science diplomacy through political tensions. The Polar Journal, 12(2), 322–342. https://doi.org/10.1080/2154896X.2022.2137091
100. Rosnet E., Jurion S., Cazes G., Bachelard C. (2004). Mixed-gender groups: coping strategies and factors of psychological adaptation in a Polar environment. Aviation, Space, and Environmental Medicine, 75(7 Suppl), c10–c30. PMID: 15267070
101. Mulrennan M. E., Mark R., Scott C. H. (2012). Revamping community-based conservation through participatory research. The Canadian Geographer/Le Géographe canadien, 56, 243–259. https://doi.org/10.1111/j.1541-0064.2012.00415.x
102. Wilkens J., Datchoua-Tirvaudey A. R. (2022). Researching climate justice: a decolonial approach to global climate governance. International Affairs, 98(1), 125–143. https://doi.org/10.1093/ia/iiab209
103. Yua E., Raymond-Yakoubian J., Daniel R. A., Behe C. (2022). A framework for co-production of knowledge in the context of Arctic research. Ecology and Society, 27(1), 24 pp. https://doi.org/10.5751/ES-12960-270134
104. Schulz K. A. (2017). Decolonizing political ecology: ontology, technology and 'critical' enchantment. Journal of Political Ecology, 24, 125–143. https://doi.org/10.2458/v24i1.20789
105. Carroll S. R., Herczog E., Hudson M., Russell K., Stall S. (2021). Operationalizing the CARE and FAIR Principles for Indigenous data futures. Scientific Data, 8, 108. https://doi.org/10.1038/s41597-021-00892-0 PMID: 33863927
106. Huntington H. P., Carey M., Apok C., Forbes B. C., Fox S., Holm L. K., et al. (2019). Climate change in context: putting people first in the Arctic. Reg Environ Change 19, 1217–1223. https://doi.org/10.1007/s10113-019-01478-8

107. Herrmann T. M., Brunner Alfani F., Chahine A., Doering N., Dudeck S., Elster J., et al. (2023). Comprehensive Policy-Brief to the EU Commission: Roadmap to Decolonial Arctic Research. University of Oulu, Helmholtz-Centre for Environmental ResearchUFZ, The Indigenous Voices (IVO) research group– Álgoálbmogii jienat, Arctic University of Norway UiT, Saami Council. Áltá –Kárášjohka–Leipzig–Oulu, 30pp. https://doi.org/10.25365/phaidra.400

108. Aikenhead G., Michell H. (2011). Bridging cultures; indigenous and scientific ways of knowing nature. Pearson Canada Inc, Toronto, 208pp. ISBN: 978-0132-1055-7-6.

109. GEBCO Compilation Group (2020). The General Bathymetric Chart of the Oceans (GEBCO) 2020 Grid. https://doi.org/10.5285/a29c5465-b138-234d-e053-6c86abc040b9