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Inequalities of ice loss: a framework for addressing sociocryospheric change

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Abstract

Cryospheric change occurs in unequal spaces. Societies living near ice are divided by race, class, gender, geography, politics and other factors. Consequently, impacts of ice loss are not shared equally, and everyone experiences cryospheric changes differently. Responsibility for recent ice loss is also driven by a relatively small portion of humanity: those who emit the most greenhouse gases. Additionally, people who study the cryosphere come from institutions and societies where inequality is often systemic, making research on ice and snow a symptom of and contributor to social inequality. To better understand unequal effects of cryospheric change within and across diverse communities, including research communities, this paper focuses on three areas, drawing primarily from glacier-related work: (1) the social context of cryospheric changes; (2) attribution and responsibility for cryospheric changes and (3) imbalances in knowledge about the cryosphere. Addressing these dimensions of ice loss requires transdisciplinary approaches that connect research to societies and link glaciology and other cryospheric sciences with social sciences and humanities. These concepts, cases and suggestions to help address inequalities also reveal that no singular conceptualization of sustainability exists. Different societies, residents and researchers possess distinct understandings of and goals for 'ice in a sustainable society'.

Introduction

Not everyone experiences ice loss the same. Even in communities adjacent to shrinking glaciers, the effects are spread unevenly because societies are divided by factors like race, poverty, gender, geography, age, access to health care, jobs, water rights and education (Cruikshank, 2005; Nüsser and Baghel, 2014; Bravo, 2017; Hastrup, 2018; Sherry and others, 2018; Dodds, 2019). Variation also exists across global scales: generally the people who live in glacierized mountains or the Arctic have contributed the least but experience the worst of human-caused climate change and cryospheric impacts, such as glacial lake outburst floods (GLOFs), diminished glacier runoff, thinning sea ice, thawing permafrost or rising sea levels that will submerge those with the least capacity to relocate or adapt (Marino, 2015; Nuttall, 2019; Huggel and others, 2020a). In the future, marginalized populations living downstream from mountain glaciers will likely suffer the harshest consequences of hydrologic variability and water insecurity, while coastal residents who lack insurance and the means to relocate – or Indigenous communities who choose not to leave their coastal homelands – will face inundations from sea-level rise.

Beyond the impacts of ice loss, there are also inequalities in cryospheric knowledge. Knowledge in the Global North is produced in institutions where Black, Indigenous and People of Color (BIPOC) researchers are few, where men usually outnumber women and non-binary people, and where systems and cultures of inequality exclude certain groups of researchers and knowledge types while elevating others (Hulbe and others, 2010; Nash and others, 2019; Seag and others, 2019). In international scientific bodies, women and Indigenous authors remain poorly represented (Ford and others, 2016; Gay-Antaki and Liverman, 2018), while countries from the Global South are often excluded from research in Antarctica (Howkins, 2016; O'Reilly, 2017) and research in Greenland has historically been tied to geopolitical strategizing (Doel and others, 2016; Bruun, 2020). Despite increasing awareness about historical injustices and colonialism, local and Indigenous knowledge about icy landscapes is thus often neglected or excluded from research, assessment reports and policymaking (Cruikshank, 2005; Williams and Golovnev, 2015; Eerkes-Medrano and Huntington, 2021). The framing of the climate crisis and glacier shrinking usually does not address unequal social landscapes. Instead, it frames climate as 'anthropogenic warming' or 'human-caused climate change', incorrectly implying that all people contribute equally to greenhouse gas emissions (Setzer and Benjamin, 2020; Stuart-Smith and others, 2021a).

These points about the inequality of ice loss might seem obvious, or perhaps too complex to consider addressing without specialized training in social sciences, community-based work or environmental justice. We suggest, however, that the inequality of ice is essential for everyone to recognize and help resolve – including glaciologists, climate scientists, non-governmental organizations (NGOs) and government agencies – and not just social science and humanities researchers or activists from civil society. If a goal of cryospheric research is to assess the relevance of glaciers and glaciology to sustainability, which was an objective of both the 2022 International Glaciological Society conference in Bilbao and this special journal

issue, then it is crucial to first understand how societies and research communities are organized, divided and related – and how the very notion of sustainability is diverse and often contested within and across societies.

We contend that beneath abstract calls for environmental justice are concrete ways that cryospheric researchers can address or reckon with inequalities of ice no matter how technical their work may be. Exposing inequalities also shows who is most (and least) vulnerable to cryospheric changes, and why. Ultimately, drivers of social inequality (consumption, colonialism, commodification, capitalist economies) are inseparable from sustainability and the drivers of anthropogenic climate change, the topic that explicitly or implicitly drives much cryospheric research. Inequalities of ice loss are thus fundamental to all glacier, snow, ice and permafrost research and work. This paper explores three aspects of inequalities of ice loss that bridge scientific research, cultural and societal research and people who are affected by inequalities: (1) the social context of cryospheric changes, (2) attribution and responsibility for cryospheric changes and (3) the imbalances in knowledge about ice and snow. This paper has implications for all cryospheric research and topics (and we hope other fields), though our examples focus primarily on the inequalities related to glaciers and glacier-related research.

Inequalities in glacier contexts

Glacier shrinkage produces uneven impacts both across and within societies. For one, people in the Global South broadly and in mountain regions specifically have contributed relatively little to anthropogenic climate change but suffer some of the worst consequences, including from glacier hazards. Two types of glacier hazards are particularly devastating (Haeberli and Whiteman, 2021). First, glacier landslides, debris flows and rock–ice slides are usually a mixture of ice and rock, which race down mountains at dangerously high speeds. Second, GLOFs occur when glacial lakes overtop their natural or artificial dams, or when moraine dams fail, sending a concoction of water, rocks, sediment and debris down river channels and frequently into human communities and infrastructure. Harrison and others (2018) identified 165 GLOF events since the early 19th century, with the most (55) occurring in the Hindu Kush Himalaya (HKH) and the second most in the South American Andes (40). Worse, glacier disasters tend to be more deadly and destructive in the Global South, not in wealthy countries in the Global North. Outburst floods and slope failures obviously occur in wealthier nations, but fewer people die from these events. As Carrivick and Tweed (2016) explain for GLOF disasters, 'Peru, Nepal and India have experienced fewer floods yet higher levels of damage'. Other studies similarly report that South America and Central Asia have experienced the world's most deadly glacier-related disasters, especially the Cordillera Blanca glacier disasters in Peru (1941, 1962 and 1970) that killed ~10 000 people and the 2013 Kedarnath outburst flood from Lake Chorabari in India that has an official death toll of under 7000 people, but with estimates as high as 30 000 casualties (Ziegler and others, 2014; Allen and others, 2015; Evans and others, 2021).

While there is a significant global imbalance in glacier-related deaths and destruction, there is also variability in human impacts at the local scale, with changes occurring over both time and space. For example, the deadly glacier disasters in Peru's Cordillera Blanca between 1941 and 1970 frequently damaged the region's urban areas built adjacent to rivers and on alluvial fans. These towns had wealthier populations compared to rural communities, where Quechua-speaking people frequently built homes farther above rivers in order to access land for farming, grazing and other rural sources of livelihoods, as well as for cultural reasons (Figueiredo and others, 2019). This example reveals that, on a global scale, Peruvian victims were poorer than inhabitants of western Europe or North America. Yet on a local Andean scale, the wealthier populations suffered most, at least prior to 1970. In recent decades, however, vulnerability has shifted over time and space. Urbanization has brought many rural residents into cities, such as Huaraz, below the Cordillera Blanca. These new residents – often poorer than previously established urban families – are exposed to high GLOF risk in the city of Huaraz because they have built homes in the Nueva Florida district along the Quillcay River, whose source is unstable glacial Lake Palcacocha and other now-artificially-dammed glacial lakes (Huggel and others, 2020a).

Another temporal shift in vulnerability stems from the tremendous success Peruvian engineers have had in monitoring, damming and partially draining 35 of the most unstable Cordillera Blanca glacial lakes (Carey, 2010). As a result, regional GLOF risk has declined over time due in part to engineering projects that were conceived of and executed by Peruvians. Yet on a national scale, the Cordillera Blanca region (Ancash) lacks budgetary resources, stable local governance and national government support compared to coastal areas like Lima, thereby creating uneven risks across Peruvian space (Lynch, 2013; Moulton and others, 2021). When the national government went through neoliberal reforms in the 1990s and regionalization after 2003, disaster risk prevention and glacial lake engineering projects shifted from the national government to the regional government, which has less capacity and demonstrates minimal commitment to preventing glacier hazards (Carey, 2010; Huggel and others, 2020a).

As this Andean case shows, the social landscape of vulnerability to glacier hazards consists of imbalance and inequality. These unequal categorizations are not static: they change markedly across space (on global, national and local scales) and time, making it crucial to avoid broad classifications or generalizations about homogeneous communities or vulnerable people grappling with glacier retreat. Instead, vulnerability and exposure must be investigated in each place-specific context. Funding agencies and academic institutions seeking 'broader impacts' often encourage researchers to offer these generalizable – but sometimes inaccurate – claims about glacier hazard impacts on vulnerable societies, without the nuance needed to fully understand social, economic and political systems and their capacity to adapt to ice loss. In many cases residents worry more about issues outside of glacier hazards, such as food security, housing, jobs, cultural traditions, natural resource depletion by foreign companies, corruption, eroding political authority or limited infrastructure. Climate change and glacier hazards that may not occur for decades are not always urgent for people living their daily lives and weighing dozens of other risks (Huntington and others, 2019; Haverkamp, 2021; Moulton and others, 2021).

Inequalities of ice can also manifest outside of the glacier hazard space. In Greenland, for example, ice loss largely attributed to anthropogenic warming driven by the Global North is affecting everything from food security to mental health (McDougall, 2019; Timlin and others, 2021). Scientists arrive in Greenland each year to study sea-ice changes, melting glaciers, shifting fjord dynamics and the changing ocean–ice interface. Despite the fact that local communities are increasingly considered, there are variable amounts of research being conducted in West versus East Greenland due to global geopolitics, infrastructural access, grant funding, historical cultural narratives that divide the island and du jour topics of scientific research (Hastrup, 2019; Nuttall, 2019; Christensen and others, 2020). Additionally, funding for societal research that includes the effects of ice loss on community health and welfare, especially for

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Indigenous Greenlanders, is lacking. Overall, scientific research is still focused predominantly on the physical changes to glaciers rather than issues like employment, mental health, migration, changes in navigation, shifting relationships with glacial landscapes and access to healthy and culturally appropriate food as climate change shifts foodways.

Diverse social relations, living conditions and impacts of ice loss – from declining glacier runoff to cataclysmic rock–ice slope failures – mean that sweeping references to local communities or affected populations are likely to be inaccurate, making it crucial to avoid assertions about homogeneous or static populations in cryospheric research. The IPCC (2019) *Special Report on the Ocean and Cryosphere*, for example, recognizes 680 million low-lying coastal residents and 670 million mountain residents subject to impacts of sea-level rise and mountain glacier loss. While the report does quantify the percentage of Arctic and alpine populations that are Indigenous, it rarely explains how gender, class, age, education levels, religion, political affiliation and livelihoods also create divergent levels of vulnerability to ice loss and cryospheric changes. The report and most literature on the Arctic cryosphere also fail to capture Indigenous and local perspectives of hope, happiness or success, because studies tend to portray Indigenous inhabitants only as victims of loss (Eerkes-Medrano and Huntington, 2021). By establishing the social context of inequalities of ice on multiple scales, researchers and practitioners can better understand the cultural and social dynamics of the regions where they work (Huntington and others, 2019). This contextual work establishes a baseline for building trust with local communities in order to conduct ice research that aligns with local norms, values and needs (Holm and others, 2011). The approach also builds toward what Whyte (2020) has identified as crucial components of research with Indigenous communities – including consent, trust, accountability and reciprocity – that can apply to research with local communities more generally.

Ice loss accountability and authority

It is important to recognize that not everyone is equally responsible for causing climate change and the ensuing ice loss and glacier hazards – despite the framing of 'anthropogenic warming' that blurs humanity together as equally culpable. This framing of 'human-caused' climate change is inaccurate (Chakrabarty, 2009; Provant and Carey, 2022). After all, a relatively small portion of companies and consumers emit most greenhouse gases (Starr, 2016) and emission reductions, green technologies and carbon offsets often put pressure on countries that have historically emitted the least, while developed nations continue business as usual. This inequity is reflected in the Paris Agreement and nationally determined contributions, where there are gaps between developing nations requesting financial support to lower their emissions and developed nations that submit emission reduction plans that they do not intend to meet (Pauw and others, 2020). Sustainability scientist Nicholas (2021) directs culpability to the world's wealthiest consumers, the 'carbon elite', who emit greenhouse gases at disproportionately high levels. Developed nations, high-emitting corporations and the carbon elite have thus far failed to assume a proportional amount of responsibility for the emissions that have melted ice globally. For example, Switzerland is paying to install green technologies in households in Ghana – including more efficient lighting and clean-burning stoves. In exchange, Switzerland would receive credit for reducing its national emissions without needing to take action within its own borders (Tabuchi, 2022). This raises questions about who holds the responsibility for reducing emissions that melt glaciers and thaw permafrost, especially given that Switzerland is a wealthy nation currently experiencing a high degree of glacier melt, while Ghana has no glaciers and is significantly less wealthy (World Bank, 2021).

Attribution scientists calculating the influence of human-caused climate change on glacier change can play a role in understanding and addressing the inequalities of ice. Some researchers have even started to attribute ice loss on specific glaciers to anthropogenic warming (e.g. Vargo and others, 2020; Roe and others, 2022). In one case, climate and glacier scientists have calculated that increased GLOF risk at Peru's Lake Palcacocha stems from anthropogenic warming (Stuart-Smith and others, 2021b). This attribution science could increase specificity around the inequality of ice loss if it can pinpoint precisely who is responsible for melting glaciers and increasing risks from glacier hazards, especially if that research can help hold them accountable for loss and damage (Huggel and others, 2020a). Interestingly, though, most glacier research – as well as glacier news, public media and policymaking – focuses on *impacts* of cryospheric change. Rarely do news stories or research articles mention those responsible for anthropogenic climate change, ice loss or glacier hazards because, as Emmer and others (2022) note, attribution research remains limited.

As climate litigation cases increase internationally, attribution research related to glaciers may play an increasing role, even if major companies and governments often challenge attribution studies and work to keep the science out of the courtroom (Schiermeier, 2021; Stuart-Smith and others, 2021a). One of these climate lawsuits focuses on Peru's Palcaraju Glacier and glacial Lake Palcacocha, which threatens to generate a GLOF that could inundate tens of thousands of downstream residents who have barely contributed to greenhouse gas emissions (Walker-Crawford, 2023). The ongoing case began in 2015, when a Peruvian farmer named Saúl Luciano Lliuya sued the RWE energy company, one of Europe's largest emitters of greenhouse gases (Frank and others, 2019). The plaintiff contends that RWE is partially responsible for the greenhouse gas emissions that melted the glacier and created the GLOF threat; therefore, RWE should pay the proportional cost of an engineering project to stabilize Lake Palcacocha. Early in the case, the German judge, Rolf Meyer, put the inequality issue clearly, remarking: 'But in the places in the world where money is scarce, can we leave these people on their own even when we are causing the problem over here? Is that just?' (quoted in Walker-Crawford, 2023, p. 77). While scientists, attorneys and the German courts work through the attribution science to determine risk and responsibility, the case offers several broader lessons about the inequality of ice loss: (1) the way people living close to glaciers face the highest risks of climate change, despite emitting little compared to the world's wealthiest companies and consumers; (2) the way attribution science can play a role in environmental justice movements and litigation, by calculating responsibility and accountability for climate change and glacier hazards and (3) the way global power disparities and persistent legacies of colonialism continue to shape legal and political landscapes – so that a Peruvian farmer has to seek justice and pursue his human rights in a court in western Europe, not his own community.

Legal pathways to establish accountability and justice are sometimes messy and complex, especially when considering ice inequities that may affect scientists and people in power as well as local people. The Argentine glaciologist Ricardo Villalba – along with three local environment ministers – were indicted in 2017 for 'abuse of authority' under a 2010 glacier law that was meant to preserve glacierized areas and water sources in Argentina. Villalba, who led the National Institute of Snow, Ice, and Environmental Research (IANIGLA), was accused of favoring mining companies in his map of Argentina's ice inventory. Since

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the ice around the Veladero mine was smaller than a hectare, the mine was allowed to continue operations, which led a local grassroots group to file a lawsuit after cyanide was spilled in the watershed. Villalba had used a standard scientific minimum glacier size measurement, but the protestors went after those deemed to have political authority, in this case a glaciologist.

Argentines who challenged the mine and the glacier inventory conceptualized accountability and authority in very different ways than the Saul v. RWE case, which hold the Global North accountable for emissions that melt glaciers in the Global South. Instead, Argentina's glacier law and those who support it target mining companies that damage glaciers and pollute glacial watersheds, holding the national government – and its agencies like IANIGLA – responsible for ice mapping to counter mining companies (Fraser, 2017). Many of Villalba's supporters connected the indictment to a lack of trust in science. However, it also illustrates a politics of glaciers and ice (Taillant, 2015), where some groups use sometimes inappropriate mechanisms of justice to hold people in authority accountable for ice and water inequities (Haslam, 2018). Overall, the case of Villalba and the country's glacier law more broadly demonstrate a shifting scale of governance and meaning over glaciers, which has crucial implications for equity and authority (Höglund Hellgren, 2022). It also raises questions about whether authorities and scientists should be held personally accountable for inequalities of ice, or whether private mining companies or energy companies should bear all or part of the blame. In either case, and as with climate litigation worldwide, the question arises: what are the global legal channels for accountability when it comes to shrinking glaciers? This question directly involves natural scientists who study the cryosphere because it asks researchers and practitioners to contend with important, albeit difficult, questions of authority in matters of ice, as well as thinking about baselines and standards for glacier and environmental knowledge (Barandiarán, 2020).

Finally, accountability to local communities and to research that involves humans does not often extend to physical science work, since local communities are considered external to the physical system being studied. In 2019, residents of the Andean town of Musho drove ice core researchers off a glacier on nearby Mount Huascarán (Ohio State News, 2019). Residents became frustrated in part because the scientists had not first sought permission from local authorities. The scientists had received approval to extract the ice cores from the national government, including the Peruvian president, but not at the local level. Given longstanding local distrust of the national government, which is common in many countries and particularly among Indigenous communities who assert political and legal authority over their land, community members had many reasons to believe the ice corers should have asked them for access permission. Most natural science researchers, however, are not required to engage local communities or seek their permission to do work in the region, as scholars working with humans are required to do through the human subjects review process overseen by a university-based Institutional Review Board in the USA (Holm and others, 2011). Ice core research, whether in Greenland or Peru, is often considered to be exempt from the type of contextual work and the permissions that are required of anthropologists and human geographers, for example. Yet when both the glacier context and ice loss authority are considered, it becomes clear that addressing societal inequality is vital even for ice corers doing their work above 6000 m. As glaciologist Lonnie Thompson, who led the Huascarán ice core team, reflected after he met with Musho community members to help deescalate residents' animosity: 'If you're working in a remote area, and an area where indigenous people have lived for thousands of years, you are the outsider. And you don't judge what they believe or don't believe'. In short, local politics, community consent and trust, and relationships with people are essential for good science.

Another nearby example of scientists, managers and NGO representatives interacting with local communities offers other relevant points for researchers working on glacier hazards. In 2016, residents living near Carhuaz, Peru dismantled a GLOF early-warning system at Lake 513 in the Cordillera Blanca. Project leaders had collaborated for years with residents on the early-warning system, but others attacked the installation. One local justification for dismantling the early-warning system was cultural, with some believing the high-tech equipment installed on the mountain caused the region's extreme drought. Another explanation was that GLOF prevention efforts overshadowed their more pressing priority of water for irrigation and drinking rather than flood risk. And still another explanation was political, with suggestions that the GLOF prevention prioritized the urban area of Carhuaz rather than rural regions, where the GLOF threat was minimal but water insecurity was increasing and where rural residents felt their authority slipping. Huggel and others (2020b) captured the lessons learned about the Lake 513 early-warning system, concluding that 'the acquisition of a profound understanding of the social, political and cultural conditions, particularly in terms of power dynamics, is a prerequisite for early warning as well as more generally for climate adaptation service development'. Their conclusions suggest that researchers, policymakers and planners need to maintain systems and processes of accountability to local people – and that local people are not homogeneous and do not hold the same goals or agendas. The case also shows the need to develop an understanding of the local context before engaging in glacier research or climate adaptation. Although this is not the norm in glaciology, it may help alleviate community concerns and reduce inequalities.

Inequalities of knowledge about icy areas

Inequalities of ice loss also manifest through the production of glacier knowledge. Growing awareness about gender imbalance in the field of glaciology – and other disciplines from physics to philosophy – has led to quantitative improvements in gender balance and representation (Hulbe and others, 2010). Yet at more advanced career stages (e.g. full professors, project managers and directors), women and non-binary researchers still make up a smaller portion of glaciologists and other professionals. What's more, these quantitative measurements that count men versus women, for instance, fail to tackle deeper power imbalances beyond the gender binary, which stem from embedded cultures and systems of inequality that cannot simply be overcome by adding more women scientists (Marín-Spiotta and others, 2020; Demery and Pipkin, 2021). Nash and others (2019) identify five key gendered barriers in Antarctic research: '(1) Physical barriers, (2) Caring responsibilities/unpaid work, (3) Cultural sexism/gender bias, (4) Lack of opportunities/recognition, and (5) Unwanted male attention/sexual harassment'. Seag and others (2019) also recognize that inclusivity and diversity in Polar research are shaped not just by gender but also by intersecting and overlapping variables, such as ethnicity, nationality, religion, language, sexuality, age, appearance and physical abilities.

In the field of glaciology, certain values and celebrated traits imbue research with gendered or racial connotations that reinforce inequalities within ice research (Bloom, 1993; Hulbe and others, 2010; Carey and others, 2016; Nash and others, 2019). The image of the macho mountaineer overcoming both pain and logistics, for example, still sells news stories and magazine features. This public thirst for adventure stories with heroic, individual and often masculine scientists makes it more challenging for researchers whose glacier work is lab based, collaborative

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or rejects conquests and data extraction from 'remote' environments, where photographs of rugged scientists at work in the field can help sell public-facing articles. Militaristic metaphors to describe research also help promote certain relationships and expectations about unobstructed access and even ownership over icy landscapes, as well as more extractive science. For example, magazine articles commonly portray glaciology as an assault on the glacier, where researchers battled harsh weather and were armed with high-tech instruments to penetrate the ice and map the lay of the land. These militaristic and masculinist metaphors can provide foundations for inequality. In other cases, such as apartheid South Africa, the research community and policymakers imagined Antarctica as a white continent for men, both because of the snow and ice but also because of the gendered and racial dynamics present in South Africa (van der Watt and Swart, 2016). Knowledge production, in other words, is shaped not just by intellectual questions and scientific inquiry but also by societal forces and cultural preferences that reinforce gendered and masculinist stereotypes of ice researchers and other scientists (Oreskes, 1996, 2022; Roberts and others, 2016; Bloom, 2022). In this cultural space, certain individuals or groups carry more prestige because their research attracts more visibility in public media, news outlets, lectures, university communication teams and even in peer-reviewed articles and grant funding.

The marginalization of other types of knowledge – such as Indigenous knowledge or social science and humanities research – represents another area of inequality related to ice. Researchers have shown how climate science generally and the Intergovernmental Panel on Climate Change (IPCC) specifically have historically neglected Indigenous voices (Ford and others, 2016), women (Gay-Antaki, 2021) and social sciences and humanities (Carey and others, 2014b). Yet these are not simply issues of counting authors by sex, race or discipline. As Borie and others (2021) explain, the IPCC as well as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services promote certain 'institutional epistemologies' that are not actually diverse but rather restricted to the perspectives of powerful actors within the organizational apparatus. In South America, by contrast, Indigenous leaders emphasize the interconnectedness of glacial landscapes with coastal and jungle ecosystems, criticizing the separation of ecosystems that scientific synthesis reports like the IPCC tend toward (ONAMIAP, 2022). Yet this Indigenous knowledge and conceptions of interconnected ecosystems have yet to meaningfully drive research, policies or climate adaptation projects in the Andes or elsewhere.

Illustrating other challenges to more equitable research relationships and knowledge production, through an example from the USA, is the National Science Foundation's Navigating the New Arctic (NNA) initiative, which was established to diversify knowledge and empower Arctic communities. In 2020, Tribes and Tribal Organizations representing many Western Alaska and Bering Sea communities reported that funded research projects 'do not and will not fulfill any of those [NNA] claims' (Kawerak Inc. and others, 2020). Communities reported that true collaboration with Arctic communities had not occurred, and the NNA requirement to form networks with locals created time-consuming burdens on Arctic communities (Stone, 2020). The NNA program is working to overcome these deficiencies and has set up required trainings and an annual workshop for funded research teams, in addition to 'community offices' at several universities in Alaska that act as hubs for Indigenous engagement (Early, 2021). But this takes time and requires that research be both funded and supported in ways that prioritize trust and relationship-building to truly achieve more equitable research practices in icy places. The publishing model for researchers at most universities worldwide – with quantitative metrics, dollar-driven grant prestige, restrictions on funding for community members and citation-hungry publication decisions among many researchers – directly contradicts long-term relationship building, a crucial pillar at the heart of equity and anti-colonialism.

In Arctic research, some successful efforts have been made to diversify knowledge through the co-production of studies, such as the Siku-Inuit-Hila Project, which included publication of the award-winning book, *The Meaning of Ice*, among many other positive outcomes for the participating communities in Greenland, Nunavut and Alaska (Gearheard and others, 2013). Other efforts are underway to build partnerships and center community agendas, such as the Arctic Indigenous Scholars Program, a collaboration between the Arctic Research Consortium of the US and the Inuit Circumpolar Council, that aims to 'create space for Indigenous scholars to educate and inform policy and decisionmakers engaged in Arctic issues' (Arctic Research Consortium of the United States (ARCUS), 2022), and the U.S. Interagency Arctic Research Policy Committee (IARPC) (2018) 'Principles for Conducting Research in the Arctic' that underscore accountability, communication, respect, relationships and environmental stewardship as guiding principles for all researchers (these are elaborated on the Alaska Native Knowledge Network at https://www.uaf.edu/ankn/indigenous-knowledge-syst/principles-for-the-conduc/). Indigenous philosopher Whyte (2020) also explains that consent, trust, accountability and reciprocity should be part of research and knowledge collaborations, while Arctic scholars such as Holm and others (2011) writing from Greenland assert the importance of research protocols, ethics and permission practices that should guide research in the Arctic.

In communities where researchers study ice, it is important to recognize both that local people usually have different priorities than scientists and that specific histories shape their views of outsiders. Longstanding contexts of marginalization, histories of racism, poor treatment by governments, mistrust of outsiders and limited sovereignty over land and resources all influence the way people interact with cryospheric researchers who appear in their communities, from Peru and Nepal to Norway and Canada (Jurt and others, 2015; Carey and others, 2016). Glacier research also has military and geopolitical legacies that still play out, such as the Cold War power struggles that drove the early boon in Soviet and US glacier research (Doel and others, 2016; Bruun, 2020). The first ice core drilled to bedrock in Greenland came from Camp Century, a nuclear-powered US military base in the ice sheet, while Soviet drillers soon after began drilling at Vostok in Antarctica. The US military abandoned Camp Century in the mid-1960s but left behind a toxic dump of ice-entombed chemicals such as Polychlorinated Biphenyls (PCBs) that have, ever since, been sliding toward downslope fjords and food chains (Colgan and others, 2016). Greenlanders were not consulted or asked to approve Camp Century military activity, or ice coring; the governments of Denmark and the USA made those decisions. In other contexts and world regions, ice exists in the homelands of Indigenous peoples, from Argentina and Bolivia to Russia and Finland. In Canada and the USA, many glacierized peaks that scientists access as laboratories, often without seeking formal permission from adjacent communities, still have the names of military generals, foreign diplomats and explorers or other non-local names that illustrate continuing colonial legacies on ice (Smith, 2020).

Geographer and anticolonial scientist Max Liboiron says that geoscientists need to ask key questions about research methodologies: 'How do our disciplines, pedagogical norms and research methods benefit from access to Indigenous land, life and knowledge? Who has done the research on Indigenous land and where are they from? What are the permission processes for field trips

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and research sites, including seemingly landless datasets? What open-access data management policies are in place and how might they increase access to Indigenous land, rather than respect it?' (Liboiron, 2021a). These questions ask that researchers not only investigate these topics but also conduct research differently. Doing research that is community led and informed by local priorities, not just research that involves communities through time-bound participation in workshops, for example, is another way to help work toward 'glacier justice' (Carey and others, 2020).

Future research directions and practices

The last decade or so has seen substantial growth in research on the human dimensions of ice, including work that exposes inequalities (e.g. Orlove and others, 2008; Gagné and others, 2014; Huggel and others, 2015; Doel and others, 2016; Radin and Kowal, 2017; Ruiz and others, 2019; Dodds and Sörlin, 2022). Yet research gaps still prevent solid understandings of how people perceive, experience, respond to, understand and study glacier change – many of which can and should be reflected in both natural and social science research programs. Next steps for future research could start by recognizing that communities near glaciers are not simply homogeneous 'affected communities', as if everyone downslope and downstream from a glacier is the same, with equal vulnerabilities, equal priorities for their futures or equal abilities or goals for adaptation. Too often, research simplistically categorizes societies into two groups: victims who live nearby glaciers and saviors who work to resolve the climate crisis through knowledge or adaptation programs. This problematic, simplistic conception of ice-related issues influences the questions that natural hazard researchers and managers ask while limiting the solutions that they ultimately propose. The fact that communities living in icy areas are both diverse and multifaceted also suggests that 'ice in a sustainable society' has many meanings, depending on who defines the very concepts of ice, society and sustainability. Just as societies are not homogeneous, the definitions and goals for 'sustainability' are varied, and frequently contested.

Glacier hazard research could be more precise if it investigated how societies near glaciers are organized and divided, such as by race, class, gender, territory, livelihoods, religion and political affiliation. Asking who has the power to make decisions (and who doesn't) is fundamental yet often overlooked. It leads to a better understanding of who can adapt, find new jobs, migrate, retain water rights, continue cultural traditions or protect knowledge. Studies that start from community perspectives and agendas, rather than starting with researcher perspectives, are necessary but so far limited, as Emmer and others (2022) recognized in a recent analysis of research on glacier hazards. Researchers may also ask who is the most and least vulnerable, what vulnerability even means to different social groups, what

Figure 1. Questions for equitable field research. Researchers should ask and answer these questions before starting fieldwork.

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factors influence vulnerability and how different families and communities navigate glacier change now and for the future. Some may see ice loss and potential glacier hazards as a dire threat; others may not be so worried about ice loss, instead identifying other risks or even opportunities, that may not have been considered by researchers. Additional research in attribution science could also help expose the inequalities of glacier hazards – from pinpointing responsibility to providing evidence for loss and damage claims and climate litigation. This area of accountability has developed in some areas of climate research more than for the cryosphere, thus revealing a knowledge gap.

Research on glacier runoff is another area needing more development in order to address ice inequalities. It should consider both water availability as well as water allocation, demand and quality, which are usually unequal, inconsistent and variable across different regions and periods (Carey and others, 2014a, 2017). More specifically, research lacks answers to a host of questions that remain unexplored in most claims about ice loss implications, such as with the common conclusion that HKH glaciers provide water for 1–2 billion people. To be sure, glaciers are vital water towers worldwide. But a billion people do not have equal access to that snowpack and glacier runoff. The claims equating ice loss with water loss that are common in research and news about HKH, Andean, alps and other mountain glaciers requires more refined analysis to understand who is and is not affected by those water towers (Molden and others, 2022). Research, for example, needs to analyze downstream water rights, water sources and water distribution policies and practices just as much – if not more – than research on the ice itself. Also, water use and hydrologic needs are shaped by many factors, not just the amount of glacier runoff. These include crop choice, construction of infrastructure, industrial development, urbanization, energy needs and sources (hydropower versus fossil fuels), wars, transborder water conflicts and religion. The point is that when water leaves HKH glaciers it flows, not to a billion equal residents, but into complex, diverse and unequal societies. This means that laws and policies, social relations and customs, economies and public utilities, energy regimes and infrastructure investments determine who gets water, where it comes from, and how much it costs. Claims about ice loss generating water shortages have so far largely failed to consider these questions of coupled ice and hydrologic inequalities.

Researchers can contribute to the efforts to address these inequalities, even if their work is primarily lab-based, by assembling research teams intentionally, adjusting lab group operations, collaborating with interdisciplinary colleagues and local communities and disseminating research in equitable and accessible ways. Notably, funding that supports glacier and ice research teams often starts with researchers at institutions and only includes

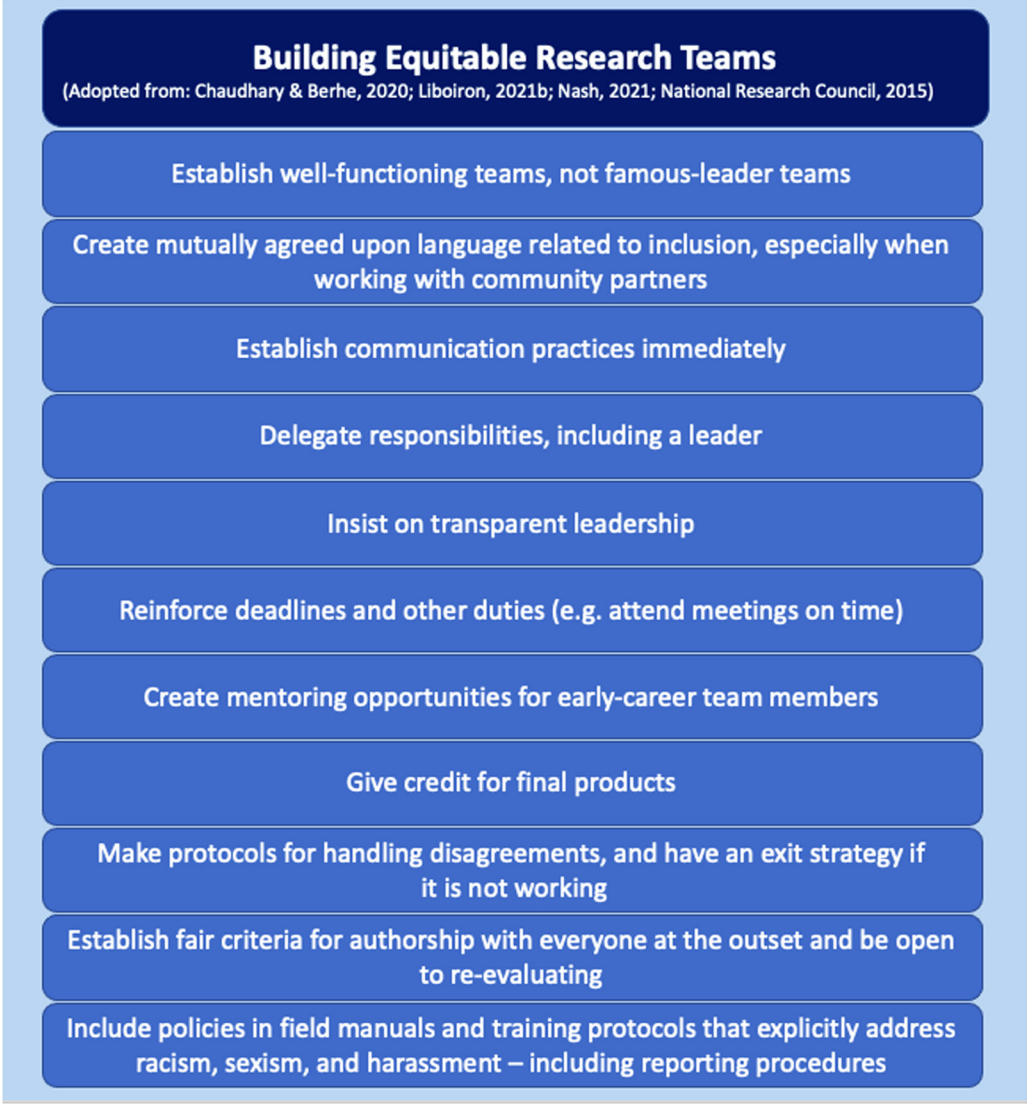

Figure 2. Building equitable research teams. Suggested guidelines for addressing inequalities in any research team.

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local people after the project is nearly fully conceived. This can be addressed by directing funding to local collaborators or investing in capacity-building to allow local partners to establish their own projects and apply for grant funding independently in the future. Figures 1 and 2 offer more specific points of guidance for researchers to address the inequalities of ice loss. They are built on sources cited above and our own work on collaborative teams. They can help researchers who work on any dimensions of cryospheric change and from any discipline, from glaciology and climate science to anthropology and environmental humanities. Additionally, they can assist researchers who contribute applied work, such as water management engineering and climate change adaptation planning for global cities affected by ice loss.

Figure 1 poses questions intended to help researchers address inequality and harm in field research, particularly in ways that facilitate collaborations, communication and dissemination of research results among members of research teams and with local communities (Holm and others, 2011; Huntington and others, 2019; Kawerak Inc. and others, 2020; Liboiron, 2021b). Figure 2 focuses on ways to make research teams themselves more equitable and just, as well as more effective (National Research Council, 2015; Chaudhary and Berhe, 2020; Nash, 2021; Liboiron, 2021b). This includes recommendations drawn from existing literature that address leadership, that promote mentoring and authorship opportunities and that establish policies for addressing and reporting racism as well as sexual and gender harassment. These tools ask that researchers conduct their work with a greater focus on inequality, even when studying urgent biophysical processes like glacier disasters, hydrologic changes and ice loss more broadly.

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