Article:

Sjöberg, Y. orcid.org/0000-0002-4292-5808, Bouchard, F. orcid.org/0000-0001-9687-3356, Gartler, S. orcid.org/0000-0002-7411-8701 et al. (2 more authors) (2023) Focus on Arctic change: transdisciplinary research and communication. Environmental Research Letters, 18. 010201-010201. ISSN 1748-9326

https://doi.org/10.1088/1748-9326/acabd7

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ENVIRONMENTAL RESEARCH
LETTERS

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OPEN ACCESS

RECEIVED
12 December 2022

ACCEPTED FOR PUBLICATION
15 December 2022

PUBLISHED
4 January 2023

EDITORIAL

Focus on Arctic change: transdisciplinary research and communication

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Keywords: Arctic change, research communication, permafrost, coastal communities, transdisciplinary research

1. Introduction

The Arctic is a vast and diverse region, spanning eight countries on two continents, the longest coastlines in the world, tundra and forest ecosystems, glaciers, and the homelands of numerous Indigenous Peoples. It is a region undergoing rapid changes, most notably the climatic warming, which was recently estimated to be four times faster than the global average (Rantanen *et al* 2022). These changes and their impacts have been the focus of several reviews and reports in recent years (e.g. AMAP 2017, Constable *et al* 2022). In the latest IPCC report it is concluded that the ongoing climate changes in the Arctic motivate swift response to reduce risks to social and ecological systems (Constable *et al* 2022). This issue of ERL collects ten papers focusing on the rapid changes across the Arctic and how transdisciplinary research and communication can be used to tackle some of the socioecological challenges that follow.

2. Rapidly changing Arctic

As described in the papers in this focus issue, the rapid warming in the Arctic region results in observable changes in sea ice cover, snow, permafrost, precipitation patterns and timing (rain vs. snow), habitat distributions, and mid-latitude weather patterns. Cascading effects from changes in one part of the ecosystem to another are also expected. Overland *et al* (2021) describe changes cascading through atmospheric circulation, sea-ice loss, warming atmospheric and sea temperatures, to impacts on ecosystems. They further show how such changes to the atmospheric circulation reach beyond the Arctic to mid-latitude regions. Li *et al* (2022) report on an extreme loss of ice during a single year (2010–2011), triggering a positive ice-albedo amplifying feedback that accelerated ice extent reduction in the following years, by focusing on Arctic sea ice dynamics (its extent but especially its thickness) over the last decades as shown by satellite imagery. Such results clearly show the vulnerability of Arctic environments to climate-induced non-linear (i.e. threshold) disturbances. Serreze *et al* (2021) summarize the cumulative and cascading impacts of 'rain-on-snow' (ROS) events, not only on terrestrial ecosystems and the animal populations that depend on them, but also on marine and coastal environments, freshwater ecosystems, and local communities. Clearly, ROS events are likely to become more prevalent in a warming Arctic, with profound impacts on snow and ice cover properties.

The focus issue also includes studies of thawing permafrost, and its cascading effects on the water cycle, erosion, and the spreading of pathogens. More than half of settlements located currently on permafrost in the coastal zone will experience impacts of thaw by 2050 (Bartsch *et al* 2021). Guimond *et al* (2022) explore how warming and associated thawing of permafrost and changes in sea level impact the magnitude and salinity of groundwater discharge to coastal waters. Their results indicate that increases in discharge may be expected in coastal areas experiencing permafrost thaw but limited sea level rise, while in areas where sea level rise is greater groundwater discharge may decrease. In terrestrial ecosystems, permafrost degradation can result in a northward expansion of diseases traditionally affecting southern areas (Waits *et al* 2018). Stella *et al* (2021) identify environmental conditions and geographical areas at risk for outbreaks of anthrax using georeferenced data for e.g. reindeer herding and permafrost thaw in the form of active layer thickening. In addition to increases in active layer, Ward Jones *et al* (2019) show that abrupt thaw features, such as thermo-erosion gullies and retrogressive thaw slumps have become more frequent and spatially distributed in recent years in comparably cold High Arctic island regions, where permafrost is still continuous. Local topographic conditions, ground-ice content, and soil type appear to have a significant impact on the development of these thaw features, in addition to regional climate dynamics.

3. Impacts of Arctic changes

The above described changes pose challenges for local Arctic societies but also for people living beyond the Arctic. At the local scale, these changes have negative impacts on traditional livelihoods and food sources. Coastal ecosystems constitute the basis for food sources for many Arctic communities. Galappaththi *et al* (2022) note that climatic changes impact fish harvesting practices, such as the loss of access to certain fishing sites due to thawing permafrost, changing sea ice conditions, and changes in marine fish migration and distribution. Similarly, Hauser *et al* (2021), describe how a dramatic decrease in the length of the sea ice season has limited the hunting period for bearded seal, which is a critical marine resource for an indigenous coastal community in Alaska. Changes in coastal groundwater systems, projected by Guimond *et al* (2022), may have additional implications for the health and functioning of coastal ecosystems (Taniguchi *et al* 2019).

Impacts on large herbivores such as reindeer/caribou and muskox which constitute an important part of livelihood for many Arctic Indigenous Peoples, are summarized by Stella *et al* (2021) and Serreze *et al* (2021). Increased incidence of diseases such as anthrax spreading at a higher rate due to the thawing of permafrost uncovering carcasses, which host the disease, can result in the loss of important food sources for local communities. For example, a recent anthrax outbreak in the Yamalo-Nenets peninsula in Russia resulted in the loss of thousands of reindeer, hospitalization, and even death, of local community members (Stella *et al* 2021). This adds to impacts on ungulate populations through weather extremes such as ROS. Serreze *et al* (2021) report on the multifaceted societal impacts of ROS events, especially when they occur in early winter. Generally associated with short-lived (hours to days) warm spells followed by rapid drops in temperature, ROS events result in the formation of hard, several centimeter-thick ice crusts within or at the base of the snow cover. These ice layers create barriers that prohibit foraging for large herbivores and can lead to massive die-offs and related socio-economic impacts on local communities, specifically reindeer herders (e.g. food security, transportation, cultural vitality).

Changes to Arctic ecosystems not only impact local traditional Indigenous livelihoods. Land use across the Arctic has been expanding continuously specifically related to the oil and gas industry and mining during the last two decades (Bartsch *et al* 2021). One fifth of all settlements installed on permafrost across the Arctic, i.e. one million people, are located in coastal areas (Ramage *et al* 2021) and 15% of all human impacted areas within a 100 km buffer from the Arctic permafrost affected coastline are new (Bartsch *et al* 2021). This not only impacts the local natural environment but also increases the amount of infrastructure potentially at risk due to permafrost thaw. Additionally, some changes have impacts beyond the Arctic. For example, the effects of extended weather events which impact sea ice and marine life locally may also reach and impact people in temperate regions in the form of cold spells, as shown by Overland *et al* (2021).

4. A need for communication in Arctic science

Motivated by the need to understand these changes and the challenges they pose to societies, Arctic scientific production has increased over the past couple of decades. For instance, scientific literature about permafrost and the so-called 'permafrost carbon feedback' has seen an exponential growth since the late 20th century, with more than 90% of publications released after 2005, and 80% released during the last decade (Sjöberg *et al* 2020, Schuur *et al* 2022). With such growth in scientific output arises a need to communicate our current understanding of complex physical processes and feedbacks beyond the scientific community, to enable societies to respond to the associated challenges. Non-traditional communication strategies, such as cartoons describing several aspects of Arctic research, for example, have provided notable outreach impacts on school students and teachers by explaining the role of Arctic ecosystems for local communities and as a part of the global climate system (e.g. Nääs *et al* 2017, Bouchard *et al* 2018).

In this focus issue, Overland *et al* (2021) discuss how the connections between Arctic and mid-latitude weather systems have been challenging to explain to non-experts because they are typically intermittent and controlled by several interacting processes, which has led to difficulties in communicating the current state of knowledge. They demonstrate how specific examples from observed weather events in North America and eastern Asia can be used to illustrate such connections and further highlight how these events have impacted ecosystems and people in and beyond the Arctic.

The contributions to this focus issue show how many of the challenges facing Arctic societies today can benefit from closer collaboration across disciplines and between scientists, Arctic residents and institutions. One such example is how the lack of reliable georeferenced data poses a major challenge for identifying the risks to animals and humans from thawing permafrost (Bartsch *et al* 2021, Stella *et al* 2021). Observations by Arctic residents, including Indigenous communities, about ROS events are key to enhancing understanding and anticipating such phenomena, in conjunction with other observation tools and instruments (e.g. satellite imagery, meteorological stations) (Serezze *et al* 2021). The potential benefits of such collaborations have also previously been acknowledged by early career scientists working in the Arctic, but lack of sufficient funding, networking opportunities, and time has limited such collaborations (Sjöberg *et al* 2018).

Disciplinary and fundamental science can further benefit from co-production of knowledge and transdisciplinary research approaches for understanding changes in ecological and social systems. Such approaches involve scientists from different disciplines as well as non-academics throughout the research process and a focus on addressing real-world problems (Serrao-Neumann *et al* 2015). Galappaththi *et al* (2022) pick up this theme by pursuing two objectives: First, to describe how the concept of resilience is used in marine and anadromous Northern fisheries management and beyond; and second, to determine ways of implementing resilience-fostering, adaptive co-management. The authors argue that guidelines for adaptive co-management need improvement in the face of rapid environmental change, the emergence of novel guidelines for evaluating and building resilience and calls for reconciliation through research and management. They propose five revisited resilience-based steps to implement adaptive co-management: (a) discussion forums, (b) place-based social-ecological participatory research, (c) design of resilience-building management actions, (d) collaborative monitoring, and (e) joint process evaluation. Implementing similar ideas, Hauser *et al* (2021) apply a transdisciplinary approach to investigate the effects of sea ice loss on seal hunting in an indigenous community in Alaska. The authors stress the importance of centering Indigenous Knowledge as a driving force in hypothesis-based science and shifting the power dynamics from the team of multidisciplinary scientists to the local sovereign Tribal government. They argue that this transdisciplinary approach can lead to more sustainable and inclusive research outcomes and opportunities for policy-making led by Indigenous Peoples.

While Arctic research is increasingly inspired by Indigenous and collaborative approaches, Doering *et al* (2022) address the role of funding to meet the needs of Indigenous Peoples and Organizations as well as their non-Indigenous research allies. They develop a set of comprehensive recommendations that address all stages, from the pre-funding call stage to a responsibility and reflections stage at the end of each project. Thus, for example, regardless of their size, projects should be funded for at least five years to allow for mutual relationship building, community empowerment and true co-creation based upon equality of all partners involved—also as a means of addressing colonial legacies of unequal power sharing. The authors conclude that not only should the expertise of knowledge holders and landusers, marginalized for a long time, be rightfully acknowledged, but also should other-than-human relationships, spiritualities and accountabilities be brought into research design and outcomes.

5. Directions for future research and communication on Arctic change

Future research needs to capture the full range of impacts from climate change, including feedbacks and cascading effects. Livelihood and food sources, infrastructure, health and wellbeing, water resources, and transportation and supply are key affected areas, as well as the global climate. Research needs exist within and between disciplines and require communication and collaboration with local stakeholders. For example, Serreze *et al* (2021) strongly recommends combining information from meteorological station records, local and Indigenous knowledge holders (e.g. reindeer herders), satellite remote sensing (e.g. radar records) and atmospheric reanalyses as a way of moving forward in better understanding ROS events and their environmental and societal impacts.

Transdisciplinary approaches and co-creation of knowledge may provide effective means to adapt and respond to challenges resulting from rapidly changing climate. More transdisciplinary research and co-production of knowledge can strengthen Indigenous and local research capacity in the Arctic and thereby better benefit both local societies and the scientific community (Doering *et al* 2022). It may also be fundamental for resilience-building, for example by focusing on understanding drivers of change that shape social-ecological systems (Galappaththi *et al* 2022). This is acknowledged in the most recent IPCC report chapter on the polar regions, which concludes that the inclusion of Indigenous Knowledge in research and resource management not only supports climate resilience but can also contribute to overcoming colonialism in the Arctic (Constable *et al* 2022). However, such research may require new funding structures and mechanisms, which allow for long-term mutual relationship and capacity building as well as empowerment of Arctic communities (Doering *et al* 2022).

The rapidly changing Arctic, home to a high number and great variety of Indigenous Peoples with typically close ties to the natural environment, may offer unique opportunities for transdisciplinary science despite its colonial history. Contributions to this focus issue specifically illustrate how communities dependent on coastal ecosystems are experiencing cascading changes related to sea ice, permafrost, water quality and land use, for which transdisciplinary approaches provide effective means to address the impacts on local sociocultural-ecological systems.

Acknowledgments

Susanna Gartler and Annett Bartsch received funding from Nunataryuk, a project of the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 773421. Annett Bartsch also received funding from the H2020 project CHARTER (No. 869471) and ESA CCI+ Permafrost.

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