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INFORMING DECISION-MAKING WITH INDIGENOUS AND LOCAL KNOWLEDGE AND SCIENCE

Research Article

The need for transformative changes in the use of Indigenous knowledge along with science for environmental decision-making in the Arctic

Helen C. Wheeler[1] | Finn Danielsen[2] | Maryann Fidel[3] | Vera Hausner[4] | Tim Horstkotte[5] | Noor Johnson[6] | Olivia Lee[7] | Nibedita Mukherjee[8] | Amy Amos[9] | Heather Ashthorn[10] | Øystein Ballari[11] | Carolina Behe[12] | Kaitlin Breton-Honeyman[13,14] | Gunn-Britt Retter[15] | Victoria Buschman[16] | Pâviârak Jakobsen[17] | Frank Johnson[18] | Bjarne Lyberth[19,20] | Jennifer A. Parrott[21] | Mikhail Pogodaev[22] | Rodion Sulyandziga[23] | Nikita Vronski[23]

[1]School of Life Sciences, Anglia Ruskin University, Cambridge, UK; [2]Nordic Foundation for Development and Ecology (NORDECO), Copenhagen, Denmark; [3]Yukon River Inter-Tribal Watershed Council, Anchorage, AK, USA; [4]Department of Arctic and Marine Biology, UiT, The Arctic University, Tromso, Norway; [5]Swedish University of Agricultural Sciences, Umeaa, Sweden; [6]National Snow and Ice Data Center, University of Colorado, Boulder, CO, USA; [7]International Arctic Research Center, University of Alaska, Fairbanks, AK, USA; [8]Department of Zoology, University of Cambridge, Cambridge, UK; [9]Gwich'in Renewable Resource Board, Inuvik, Canada; [10]Arctic Borderlands Ecological Knowledge Society, Whitehorse, Canada; [11]Office of the County Governor of Troms/Finnmark County, Department of Reindeer Herding, Tromso, Norway; [12]Inuit Circumpolar Council Alaska, Anchorage, AK, USA; [13]Nunavik Marine Region Wildlife Board, Inukjuak, Canada; [14]Polynya Consulting Group, Peterborough, Canada; [15]Arctic and Environment Unit, Saami Council, Karasjok, Norway; [16]School of Environmental and Forest Sciences, University of Washington, Seattle, WA, USA; [17]Piniakkanik Sumiiffinni Nalunaarsuineq (PISUNA), Aasiaat, Greenland; [18]Bering Straits Regional Housing Authority, Nome, AK, USA; [19]Association of Fishers and Hunters in Greenland, Nuuk, Greenland; [20]Ministry of Environment and Nature, Government of Greenland, Nuuk, Greenland; [21]Inuvialuit Regional Corporation, Inuvik, Canada; [22]Arctic Development and Indigenous Peoples Issues of Sakha Republic, Yakutia, Russia and [23]Center for Support of Indigenous Peoples of the North, Moscow, Russia

Correspondence
Helen C. Wheeler
Email: helen.wheeler@anglia.ac.uk

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Abstract

1. Recent attention to the role of Indigenous knowledge (IK) in environmental monitoring, research and decision-making is likely to attract new people to this field of work.
2. Advancing the bringing together of IK and science in a way that is desirable to IK holders can lead to successful and inclusive research and decision-making.
3. We used the Delphi technique with 18 expert participants who were IK holders or working closely with IK from across the Arctic to examine the drivers of progress and limitations to the use of IK along with science to inform decision-making related to wildlife, reindeer herding and the environment. We also used this technique to identify participants' experiences of scientists' misconceptions concerning IK.
4. Participants had a strong focus on transformative change relating to the structure of institutions, politics, rights, involvement, power and agency over technical issues advancing or limiting progress (e.g. new technologies and language barriers).

5. Participants identified two modes of desirable research: coproducing knowledge with scientists and autonomous Indigenous-led research. They highlighted the need for more collaborative and coproduction projects to allow further refinement of approaches and more funding to support autonomous, Indigenous-led research.
6. Most misconceptions held by scientists concerning IK that were identified by participants related to the spatial, temporal and conceptual scope of IK, and the perceived need to validate IK using Western science.
7. Our research highlights some of the issues that need to be addressed by all participants in research and decision-making involving IK and science. While exact approaches will need to be tailored to specific social-ecological contexts, consideration of these broader concerns revealed by our analysis are likely to be central to effective partnerships.

KEYWORDS

Arctic, community-based, coproduction, decision-making, Indigenous knowledge, leverage points, participatory, policy, research, wildlife

1 | INTRODUCTION

There is growing recognition of the need to engage with and utilize Indigenous knowledge (IK) in a more comprehensive and meaningful way when conducting assessments of environmental change and making environmental decisions from local to global scales (Ford, Cameron, et al., 2016; Ford, Maillet, et al., 2016; Gustafsson, Berg, Lidskog, & Löfmarck, 2019; Obermeister, 2019). Policy-makers situated outside Indigenous communities are increasingly acknowledging the importance of IK for understanding and adapting to environmental change (Armitage, Berkes, Dale, Kocho-Schellenberg, & Patton, 2011; Raymond-Yakoubian & Daniel, 2018). Indigenous peoples inhabit over 25% of earth's land surface (Garnett et al., 2018), and the rights to use and manage their lands sustainably are increasingly acknowledged by international environmental organizations, including the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Tengö et al., 2017). Likewise, there is expanding interest within the scientific community in working with IK holders to inform decision-making. With this growing interest, there is a need for all scientific disciplines to work with IK holders to advance common goals, as opposed to only those within the social sciences (Agrawal, 1995; Behe & Daniel, 2018).

Several factors underlie the benefits of including IK in natural resource management. These include a strong link between cultural and biological diversity inherent within IK systems, the timescales and temporal grain over which these knowledge systems operate and their holistic view of systems and the opportunity to address social justice issues through the inclusion of IK in research and decision-making (Bohensky & Maru, 2011; Gavin et al., 2015). The strong link between cultural and biological diversity inherent within IK is congruent with a biocultural perspective to conservation (Ens et al., 2015). Many Indigenous cultures have very strong ties to nature, which are reflected in values, knowledge, perceptions and practices (Inuit Circumpolar Council-Alaska, 2015; Pilgrim et al., 2009). Biocultural approaches to natural resource management and conservation highlight the threats to both cultural and biological diversity and the fact that these are interlinked through a process of co-evolution. Biocultural approaches may thereby provide frameworks for integrating IK and science (Mackey & Claudie, 2015). This approach claims that by working within the relevant local system of values and cultural context, more favourable outcomes for biological systems that address community needs can be achieved (Davidson-Hunt et al., 2012).

IK can operate over time-scales and temporal grains often unachievable through scientific study (Ferguson, Williamson, & Messier, 1998; Leonard, Parsons, Olawsky, & Kofod, 2013). The year-round associations of IK holders with a given place can generate knowledge that tracks change across seasons (Inuit Circumpolar Council, 2016; Riedlinger & Berkes, 2001). IK holders also tend to have longer-term associations with their local environment than scientists. Culturally transmitted information may have been transferred through multiple generations. Knowledge can be accumulated that is both high in temporal resolution and extends over long time-scales. IK systems often have less linear systems of causation and address systems in a more holistic manner than the conventional viewpoint of western science. This aligns with the development of systems-focussed approaches to natural resource management and conservation. Greater use of IK to inform decision-making therefore has the potential to enrich knowledge and improve systems understanding.

Finally, from a social justice perspective, power relationships can define who benefits from decision-making (Berbés-Blázquez, González, & Pascual, 2016). Both the content of information included in the evidence base as well as the process for its inclusion will affect the decisions that it ultimately informs (Wheeler et al., 2019). Participatory approaches that equitably involve IK

holders from initial planning, through evidence gathering and interpretation to decision-making can help improve the balance of power relations (such as equity between partners) where IK holders are under-represented (Gavin et al., 2015; Inuit Circumpolar Council Alaska, 2018a).

Creating opportunities for a more equitable and substantive role of IK in building an evidence and knowledge base for research and decision-making can create benefits for Indigenous communities, scientists and decision-makers. However, these initiatives need to find meaningful ways to engage with IK holders who are compatible with their expectations and needs. Despite increasing recognition of its value, further progress is required to more fully include IK in research and decision-making (Manrique, Corral, & Guimarães Pereira, 2018). With increasing interest from the science community in engaging with IK holders, there are both opportunities and risks (Mistry & Berardi, 2016). Finding appropriate ways to work with Indigenous and scientific knowledge is key to the success of knowledge partnerships (Watson, 2013).

The urge to include IK in environmental decision-making is not new. It has been a part of the sustainable development policies of international funding agencies for a long time (Agrawal, 1995), and multiple scholars have argued for the potential of IK to enrich our understanding of environmental change through assessment and monitoring (Berkes, 2009) and knowledge exchange and coproduction (Tengö, Brondizio, Elmqvist, Malmer, & Spierenburg, 2014). While there has been longstanding discussion of how to work with IK in environmental management (Agrawal, 1995; Berkes, Colding, & Folke, 2000; Bohensky & Maru, 2011; Gadgil, Berkes, & Folke, 1993; Huntington, 2000), there is currently increased interest in IK within a wider section of the scientific community (Bohensky, Butler, & Davies, 2013; Tengö et al., 2017). This brings increased risks of well-intentioned attempts to work with IK holders, without understanding how to meet their needs and expectations. This can ultimately reduce trust between parties and increase the challenges for ongoing collaboration (Watson, 2013).

As a region experiencing the fastest rate of warming globally there is a need to maximize adaptive capacity and resilience of social-ecological systems (Chapin III, Sommerkorn, Robards, & Hillmer-Pegram, 2015) through fair and well-informed decision-making. The Arctic is experiencing rapid biophysical and socio-economic change. Biophysical drivers of change such as climate-driven changes in ice and snow can simultaneously affect multiple aspects of culture, society, industry, economy and ecology and have implications for the interdependencies between these components (Hovelsrud, Poppel, van Oort, & Reist, 2011). For example, changes in ice and snow alter accessibility of different regions of the Arctic, providing new economic opportunities where access is increased, while affecting commercial activities, transport, infrastructure and local livelihoods where access becomes less reliable (Stephenson, Smith, & Agnew, 2011). Wildlife can concurrently be affected by direct effects of climate, and those mediated through biophysical and socio-economic change, which can in turn affect food security and sovereignty (Berteaux et al., 2016; Inuit Circumpolar Council Alaska, 2018b, 2019; Prowse & Furgal, 2009). Decision-making occurs at international, national, regional and local levels, from the pan-arctic scale through international organizations such as the Arctic Council, to national environmental policy, to more regional and local levels through territorial and regional government and wildlife management boards and councils. In this context of rapid and complex change spanning socio-economic and biophysical systems, natural resource-related decision-making at any of these scales can have far-reaching consequences. Addressing power relations and inclusivity in these relationships at each of these scales becomes increasingly important under rapid social-ecological change.

Our goals here are to identify, (a) what drives progress and (b) what limits advancements in the use of IK along with science to inform environmental decision-making. We also address key misconceptions of scientists towards IK from the perspective of participants. We hope this knowledge will help scientists who plan to engage with IK to do so in ways that are better aligned with the needs and expectations of IK holders. This effort to gain a better understanding of progress and limitations will hopefully lead to better science and more informed decision-making based on multiple ways of knowing.

2 | METHODS

We used a structured expert elicitation process (the Delphi technique) to explore perspectives of IK holders and those closely involved in the use of knowledge in environmental contexts on the drivers of progress and limitations to the better use of IK for environmental decision-making. The Delphi technique is an iterative, anonymous survey with controlled feedback (Mukherjee et al., 2015). We used this expert-based technique as it is appropriate to explore viewpoints on contentious, value laden issues. The anonymous nature of the technique seeks to elucidate the true viewpoints of the participants and aims to minimize dominance effects in group settings. In addition, the opportunities for remote participation embedded within the technique allowed us to collect responses from remote areas in a cost-effective manner and explore the degree of consensus among participants. The feedback process allowed each participant to view the group response and allowed modification to individual responses if needed. This is not usually possible in interviews or stand-alone surveys (Mukherjee et al., 2018).

We used purposive sampling to select participants. We contacted IK holders, those who work to improve the understanding of IK outside Indigenous communities and those who work with IK in research, monitoring or decision-making (Figure 1). We aimed to represent different Arctic countries and peoples working at different spatial scales, from international to regional (Figure 2). Reflecting both our aim to include known experts in the use of IK and challenges in recruiting participants with no pre-existing relationship to

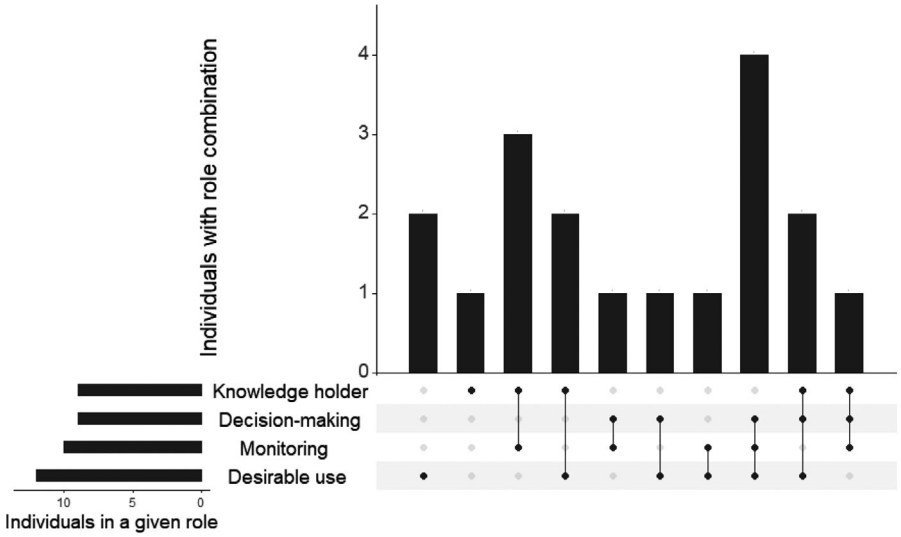

FIGURE 1 Summary of the relationship of our participants to Indigenous knowledge (IK). The horizontal bar graph to the left shows the number of individuals who were either IK holders (knowledge holder), contributing to environmental decision-making organizations which involve IK (decision-making), working in monitoring programs that involve IK (monitoring) and working to support the use of IK (desirable use). Combinations of roles held by participants are denoted by connected dots. The left vertical bar chart highlights the number of participants having each combination of relationships to IK

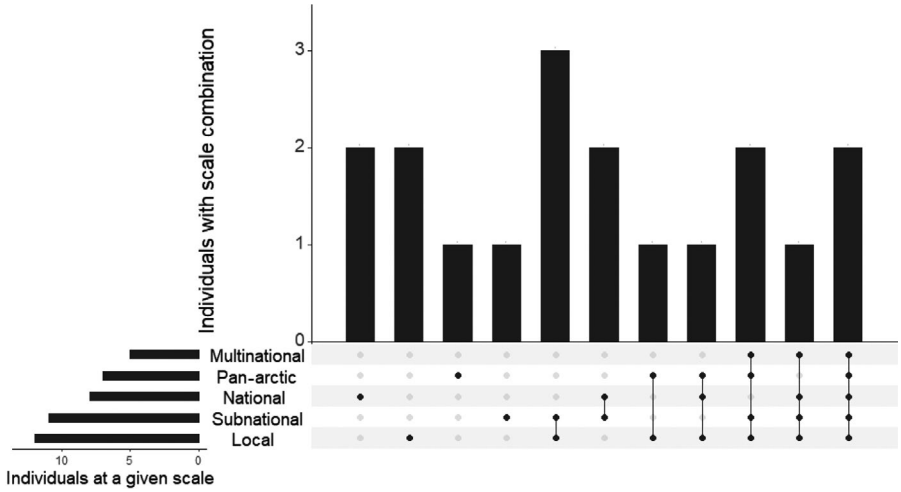

FIGURE 2 Summary of the scales at which participants engage with issues related to Indigenous knowledge. The total number of individuals engaged at a given scale is seen on the left horizontal bar chart, combinations of scale at which individuals work are denoted by connected dots and the number of individuals engaged at each combination of scales is shown in the right vertical bar chart

those instigating the research, participants were generally known to at least one non-participant co-author (those involved in conducting the research but not as interview participants). Although they were not always contacted directly by this co-author, this contact was normally referred to directly in correspondence. All non-participant co-authors have engaged in previous research activities related to IK, thus participants were likely to have been aware that they had an interest in the use of IK in decision-making.

Our approach consisted of an initial survey of participants where we posed open-ended questions to determine, (a) the drivers of progress and (b) the limitations in the use of IK along with science to inform environmental decision-making and (c) participants' perceived misconceptions of scientists concerning IK. The second round of our survey then allowed participants to rank the gathered ideas for each question in order of their importance, elaborate on these themes and add any missing ideas. Each iteration of the survey was translated into Russian, Norwegian and Swedish and participants were informed that they could provide comments in these languages or Danish. The subsequent manuscript draft was also translated as needed.

We used initial (round one) surveys to ask three key open-ended questions to which the participants were asked to respond with text:

1. What are the key drivers of progress in the use of IK with science to inform decision-making relating to wildlife, reindeer herding and the environment?
2. What are the key things limiting progress in the use of IK with science to inform decision-making relating to wildlife, reindeer herding and the environment?
3. What are the most common misconceptions of IK that you have observed within scientific communities?

In addition, we asked participants to identify any key omissions they perceived in our questions on this theme:

4. Other than the questions above, are there other questions you think we should be asking to better support the use of IK with science to inform decision-making relating to wildlife, reindeer herding and the environment?

We used Google forms to send our surveys to most participants. In some cases where an online form was not practical for the participant, they were given electronic documents to complete offline or filled out a printed document by hand. For each key question, we identified themes within participant's responses using content analysis (Vaismoradi, Turunen, & Bondas, 2013). Once themes were identified in round one of the Delphi process, we re-reviewed themes to ensure that they were non-overlapping and distinct. We also combined themes where ideas were closely aligned to produce a set of less than ten ideas for each question. Themes were coded from participants' original text using NVivo 12 Pro (NVivo qualitative data analysis software; QSR International Pty Ltd. Version 12, 2018).

In round two, we provided these condensed themes to participants and asked them to rank them in order of importance. Each set of themes was distinct for each question, i.e. participants ranked the themes for each question separately. Participants were also given the opportunity to elaborate on their understanding of the theme or explain their ranking by providing additional text. At the end of each question, participants were also asked to add any ideas that they believed to be missing from the set of themes. Although we had initially envisaged that participants would rank all the themes individually, we received responses from some participants that this was challenging because a number of the themes were highly interdependent, therefore we allowed participants to rank with ties. We then transformed ranks such that the total sum of ranks was identical for each participant. This meant that all participants had equal influence in the weighting of the relative importance of different themes.

We received responses from 16 of our 18 original participants. Each participant was given at least three reminders if they had not responded, to ensure all those who we initially contacted had equal opportunity to respond. Although participants were included in writing the manuscript discussion and invited to be co-authors on the paper, reflecting their contribution to the article, participants were not involved in conceiving questions, selecting participants or coding themes. We allowed participants to influence the ranking procedure so that we could adapt our methods to better reflect their conceptions of the systems of drivers of progress, limitations and misconceptions. Graphical representations of findings were produced using R Statistical computing language (version 3.3.4) and package GGPLOT and UPSETR. As our aim was to best reflect participant's views on these subjects, we subsequently asked for feedback on the manuscript and used participant explanations in the surveys to substantially inform the results and discussion.

Participant identity was confidential until they confirmed their desire to be a co-author of the manuscript on receipt of a draft. Research was approved by Anglia Ruskin University Institutional research ethics board. All participants gave informed consent for their participation prior to the study on receipt of a document detailing the purpose and approach of the study and arrangements regarding confidentiality.

3 | RESULTS

3.1 | Characteristics of participants

We received responses from 18 participants in this first stage of the Delphi process. All other people contacted (39 additional people, i.e. response rate of 32%) did not respond to initial contacts (one contact and two follow-ups) with the exception of one person who declined to engage due to previous poor experience with the Delphi process in another project and another who did not relate sufficiently strongly to the questions. Our participants were IK holders (50% of participants), those working to support the use of IK (67%), those contributing to environmental decision-making organizations which involve IK (50%) and those working in monitoring programs that involve IK (56%). Most of our participants self-identified as meeting more than one criterion (Figure 1). Of those who did not identify themselves as IK holders, 78% had more than ten years of experience working with IK. Our participants were 44% female, 50% male and 6% preferred not to share their gender. Our participants work at a number of geographic extents, most engaged with Indigenous issues at multiple spatial scales (Figure 2). Four participants were from Norway, one from Sweden, two from Greenland, three from Russia, four from Canada and four from USA.

3.2 | The need for transformative changes in the use of IK with science

Our analysis identified the value placed on creating opportunities for coproduction and collaboration between IK holders and scientists. It also highlighted that building capacity for research within Indigenous institutions was a high priority. In particular, addressing issues of equity in the power and agency of IK holders and institutions in the whole process that leads to informed decision-making was seen as important to our participants (Figure 3). Many issues that reach far further than environmental decision-making alone, such as the impact of cultural assimilation and colonialism, were seen to limit progress (Figure 4). Participants tended to rank issues relating to institutions, culture and values as more important than technological sources of progress and limitations. While new technologies were identified as a driver of progress, this was ranked lowest relative to all other drivers. Similarly, although language barriers were recognized as a limitation, these were also ranked lowest relative to other limitations. While ranks suggest the relative importance of themes across our participant group, all themes were identified as important by at least one participant and more commonly more.

3.3 | Drivers of progress

The two most highly ranked sources of progress in advancing the use of IK along with science highlighted the role of increased work involving IK both through collaborations and coproduction with science

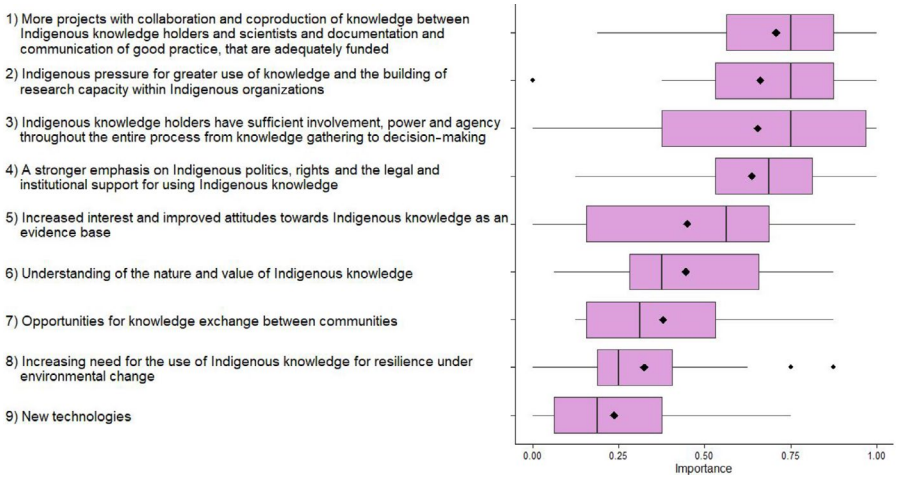

FIGURE 3 Summary of the key drivers of progress in the use of Indigenous knowledge (IK) with science to inform decision-making relating to wildlife, reindeer herding and the environment as identified by a group of experts on IK. Rankings are scales between 0 and 1, with 1 being the most important theme and 0 being the least important theme. Median and interquartile ranges are denoted on the box plots and the diamond symbol denotes the mean rank

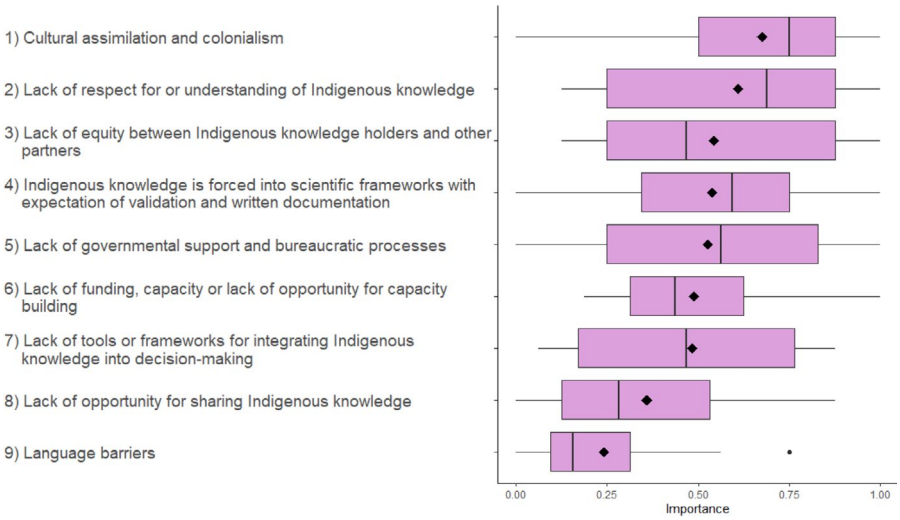

FIGURE 4 Summary of the key things limiting progress in the use of Indigenous knowledge (IK) with science to inform decision-making relating to wildlife, reindeer herding and the environment as identified by a group of experts on IK. Rankings are scales between 0 and 1, with 1 being the most important theme and 0 being the least important theme. Median and interquartile range are denoted on the box plots and the diamond symbol denotes the mean rank

(theme 1, Figure 3) and through increased capacity of Indigenous organizations to do their own research (theme 2, Figure 3). In particular, one participant highlighted that there are now several funding mechanisms that ask applicants to reflect on how IK is utilized or encourage research consortiums to partner with IK holders. Similarly, the success of calls from Indigenous Peoples' organizations to have stronger recognition of IK in international fora was highlighted, with recognition in the Convention on Biological Diversity, the Intergovernmental Panel of Biodiversity and Ecosystem services, United Nations Framework Convention on Climate Change, European Union and Arctic Council. These were mentioned in addition to national law and arctic science or research organizations such as the International Arctic Social Sciences Association, International Arctic Science Council, Sustaining Arctic Observing Networks and Arctic Council working groups.

Two modes of contributions of IK to decision-making were identified in these first two themes. While theme one focussed on collaboration and coproduction with science, theme two focussed on research by Indigenous organizations that was more independent and autonomous from science. The benefits of increasing capacity within Indigenous organizations was also emphasized under theme two as this allows Indigenous organizations to house research projects at their own institutions, allowing local communities to more effectively shape the body of research to include questions and methodologies of their own design. One participant stated that IK should be reviewed by other IK holders, not by scientists who most likely do not understand the setting surrounding the IK. Another participant highlighted that there were wider concerns with IK being evaluated by those who were not experts in that knowledge system. This aim for autonomous Indigenous research was also reflected in the view that increased knowledge exchange between communities was another driver of progress (theme 7, Figure 3).

While many participants considered collaboration and coproduction of knowledge with scientists as desirable, they also identified drawbacks. Firstly, collaboration or coproduction was generally seen to result in research results, but these often did not translate to an impact on or involvement in decision-making. Secondly, there was a concern that collaboration could divert resources from other priorities including autonomous Indigenous research.

The challenge of balancing investment of resources between collaborative research and autonomous Indigenous research was highlighted by several participants. It was emphasized that

increased interest and improved attitudes towards IK as an evidence base (theme 5, Figure 3) has led to more requests for Indigenous organizations and Indigenous people to participate in scientific research projects. These organizations rapidly become overloaded and then face diverting time away from work more directly relevant to the Indigenous organizations' own priorities, such as leading more independent and autonomous research. Beyond being overloaded, many processes for funding calls and research activities work on a different time-scale than Indigenous organizations are able, due to the competing demands on their time such as supporting community activities and existing priorities. Another participant expanded on this to highlight that when requests for collaboration are made, they are often not accompanied by efforts to increase capacity either through training or funding, and further support might alleviate the problem of overloading. These all place pressures on indigenous organizations which make balancing investment in resources between collaborative and autonomous research more challenging. A further concern was that where organizations are not sufficiently funded to conduct their own research, they feel pressured to agree to requests for collaboration in order to attain some influence in decision-making, even when these collaborations are tokenistic and do not meet the needs of Indigenous communities or organizations.

Responses highlighted that the capacity or indeed existence of Indigenous institutions varies substantially across the Arctic. While one participant highlighted the crucial role of Indigenous organizations in wildlife management and conservation management in Canada, supported by law, financing and public opinion, another stated that Indigenous peoples are still limited in their ability to initiate and conduct research projects, with no financial support from states, foundations and scientific and educational institutions. Among Canadian participants, there was also variation in the extent to which they perceived sufficient institutional support for IK, with one participant acknowledging that Indigenous organizations need to be able to apply for and receive funding to drive research.

Participants also ranked highly the sufficient involvement, power and agency of IK holders throughout the entire process from knowledge gathering to decision-making as a driver of progress (Figure 3, theme 3), although there was more variation in participants' rankings of this theme. Part of the variation in ranking reflected the degree to which participants felt this theme is a current driver of progress. In some cases, the theme received a low ranking because participants stated that there was insufficient power and agency. In particular, one participant stated that more resources are urgently needed to build and strengthen existing institutions so that Indigenous organizations can document knowledge for themselves. Involving IK holders, community members and representative organizations and governments throughout all stages of a research or implementation project (from knowledge production through evaluation and reporting) was identified as a critical way to support greater power and agency of IK holders when collaborating with scientists. This process should be mediated jointly by the involved parties with terms, conditions and expectations established early in the process.

3.4 | Limitations in the use of IK with science

Participants identified cultural assimilation and colonialism, values, inequities and dominant frameworks for the use of knowledge as some of the key issues limiting the use of IK with science (Figure 4). There was less distinction between the rankings of themes relating to limitations to the use of IK with science than for drivers of progress. Many limitations covered similar themes to drivers of progress (e.g. theme 6, Figure 3 and theme 2, Figure 4), reflecting that even where progress was identified it was still deemed that further progress is needed.

Cultural assimilation and colonialism had the highest mean rank but also was associated with a high degree of variation in the ranks assigned by participants (theme 1, Figure 4). Participants highlighted that policies resulting in cultural assimilation and colonialism continue today, reflected in the risk to Indigenous lands through encroachment of industry, resulting in land use change, land degradation and fragmentation. Also ranked highly were a lack of respect or understanding of IK (theme 2), lack of equity between IK holders and other partners (theme 3) and the forcing of IK into scientific frameworks with the expectation of validation and written documentation (theme 4). Participants stated that IK is sometimes added to primarily scientific research in a manner that was not meaningful, such as being decoration or anecdotes, or added in bits and pieces. With respect to a lack of equity, one concern was that arctic natural science funding appeared to be increasing, while this was not happening for IK research, increasing inequities between the two knowledge systems. There were divergent views on the impact of a lack of frameworks for integrating IK into decision-making. Some participants described this as a limitation, while others observed that frameworks do exist and have been proposed by Indigenous organizations, but those frameworks have often been ignored.

3.5 | Misconceptions of IK by scientists

Many of the participants' assessments of misconceptions of IK by scientists referred to an underestimation of its spatial (theme 1, Figure 5), thematic (theme 3) or temporal (theme 6) scope. Participants experienced that IK was perceived as being more localized, limited to traditional activities and considered static by scientists, compared to what our expert group observed. In addition, the misconception that IK is not logical or verifiable due to its nonlinear nature was ranked highly by participants (theme 2). There was divergence as to whether IK was deemed to have scientific qualities across participants, with some focussing on commonalities with attributes of rigour associated with science, such as that knowledge is tested, and others focussing on the differences and that IK is a distinct knowledge system. There was more consensus on the misconception of scientists that IK needed to be validated or verified by science. This raised the concern that IK was valued to a lesser extent than science.

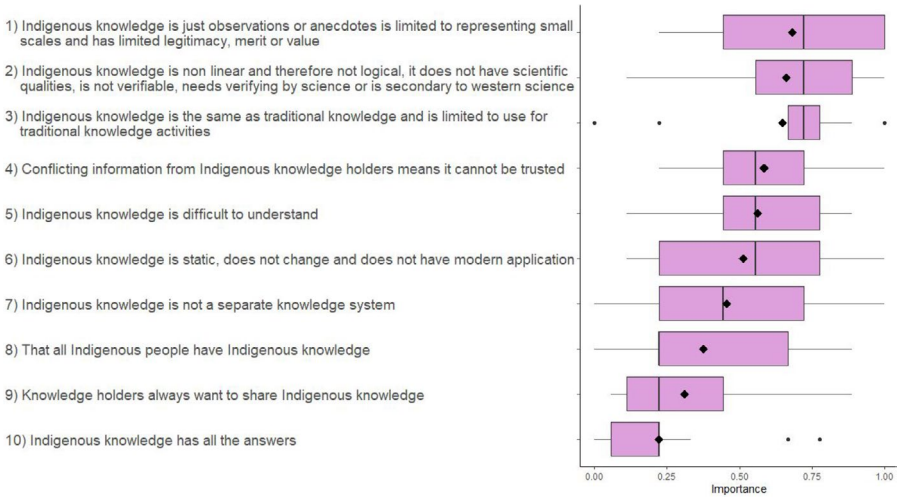

FIGURE 5 Summary of the most common misconceptions of Indigenous knowledge (IK) within scientific communities as identified by a group of experts on IK. Rankings are scales between 0 and 1, with 1 being the most important theme and 0 being the least important theme. Median and interquartile range are denoted on the box plots and the diamond symbol denotes the mean rank

One additional misconception identified subsequent to ranking was the idea that Indigenous participants in research always wished to remain anonymous. It was highlighted that for some IK holders, removing their name is the equivalent of removing a citation as it may strip away the information's credibility and diminish the associated community's right and access to that collective knowledge. This was deemed to be particularly challenging as there are sometimes funder requirements for anonymity even when a participant wishes to be identified.

4 | DISCUSSION

Our research highlights a range of factors that external parties need to be cognizant of when working with IK to inform decision-making. Although some drivers and limitations of progress, such as equity in participation, can be addressed directly by scientists in their practice, others pertain to the political, legal and institutional settings under which IK can inform decision-making and point to a need for deeper systemic change. While these may require changes beyond the scope of scientists as individuals, an awareness of the setting and historical legacies under which research and decision-making is occurring (e.g. Cameron, 2012; Held, 2019; Simpson, 2004) can still be used to direct activities to mitigate some of the undesirable situations and outcomes associated with them.

Issues related to institutions, culture and values were generally considered of greater importance to participants in driving or limiting the better use of IK with science to inform decision-making. In contrast, more technical challenges and solutions such as language barriers and use of new technologies were less critical factors affecting IK use with science. This highlights a need to focus on transformative change by addressing difficult structural interventions, referred to as 'deep leverage points' related to design or intent of the current systems of research and decision-making (Fischer & Riechers, 2019). Such issues include cultural assimilation policies and colonialism, politics, rights and legal and institutional support, the involvement, power and agency of Indigenous organizations and people within the full process of research and decision-making and forcing of IK into scientific frameworks (Spak, 2005; White, 2006). Addressing these issues related to institutions, equity and worldviews appears to have particularly high importance within our set of drivers and limitations.

Having more equitable collaborative and coproduction projects that receive adequate funding and support can allow practice within these settings to be refined based on experience. Our participants place high priority on the opportunity for more research with collaboration and coproduction between IK holders and scientists. Collaborative and coproduced research and decision-making is occurring in a number of regions and at a range of spatial scales (Alessa et al., 2016; Johnson et al., 2015). However, a recent review of arctic research projects during the period 1965–2010 highlighted an only slight increase in the prevalence and proportion of participatory projects with local people (Brunet, Hickey, & Humphries, 2014). More recently, while there has been a growth in literature on coproduction, much of this is focussed on community-based research and community-based adaptation (Ford, Stephenson, et al., 2016; Kouril, Furgal, & Whillans, 2015). Ensuring that good practices are documented and shared will accelerate this learning process about how to successfully implement coproduction projects. Literature must be critical and highlight the challenges as well as the successes of programs to promote more effective learning from collective experience. This will increase all parties' capacities to coproduce research in ways that are desirable to IK holders.

Authors have also highlighted that having funding for a sufficiently long and consistent time is essential for building trust between participants in coproduction and is critical to success (Robards et al., 2018). Another consideration is creating funding mechanisms which allow co-definition of problems, given many research funding bodies require clear research objectives from the outset. Creating funding mechanisms for iteratively co-defining problems prior to more formal research would support increased power and agency for IK holders throughout the entire process from knowledge gathering to decision-making. Examples of progress in implementing such funding mechanisms can be seen from the Arctic Funders Initiative, a consortium of philanthropic

organizations, but also from mission-driven governmental agencies that recognize the importance of including IK holders as partners in all stages of research from planning through implementation (Kendall Jr. et al., 2017).

Although, collaboration and coproduction was rated as very important, participants also emphasized the need for Indigenous organizations to conduct independent research and knowledge exchange between communities. This highlights dual aims for coproduction with scientists and independent Indigenous research. With limited resources, a necessary consideration is that engagement in research coproduction might divert capacity from more autonomous Indigenous research. Ensuring research coproduction addresses Indigenous priorities by initiating research with processes for co-defining problems is important for ensuring these collaborative and coproduction projects are a worthwhile investment of limited time and resources (Robards et al., 2018).

The most highly ranked limitation to the use of IK with science for decision-making was cultural assimilation and colonialism. This highlights the need to be aware of power imbalances between IK systems and western scientific knowledge, with vastly greater resources and infrastructural support offered to western science compared to IK. It also requires an awareness of how historical legacies of past colonial actions can impact processes of knowledge coproduction today (Castleden, Morgan, & Lamb, 2012). Marginalization and exclusion of Indigenous people from their traditional lands and waters, as well as forced assimilation into Western style education, have reinforced the dominance of western cultures and ways of knowing. The dominance of western scientific lenses through which knowledge is assembled, evaluated and applied to decision-making can limit the degree to which IK informs environmental decision-making. IK is more than simply an information product and encompasses thought, experience and action (McGregor, 2004). The processes of documentation and translation can reframe IK to fit communication and analytical methods of western scientific worldviews. It has been suggested that this separates IK from its meaning (McGregor, 2004; Simpson, 2004). Mechanisms to involve IK holders in environmental decision-making may be based on western scientific decision-making frameworks (Natcher, 2001; White, 2006). This can limit IK holders' power to use IK to inform environmental decision-making due to the mismatch between knowledge systems underlying knowledge production and those used for decision-making. This situation is particularly challenging as the lack of documentation of IK has been cited as a key limitation to the use of IK in decision-making (Breton-Honeyman, Furgal, & Hammill, 2016). Finding appropriate approaches to navigate these tensions and address some of the structural inequalities that underlie them is a challenge for Indigenous organizations, scientists and decision-makers alike.

Protecting Indigenous land and waters, supporting self-determination and allowing transmission of knowledge between generations in culturally meaningful ways has been highlighted as important to reducing colonial impacts (Simpson, 2004) and will provide deeper rooted support to the use of IK in environmental decision-making both through coproduction with scientists and Indigenous independent research. Involving Indigenous people as self-determining nations and working with their associated governance structures rather working with Indigenous people as one of many stakeholders in natural resource management can also support greater and more meaningful use of IK with science in decision-making (von der Porten, de Loë, & Plummer, 2015).

While our research highlights some commonalities in the drivers of progress and limitations to better use of IK with science, it also revealed some variation in priorities. The details of the best approach are likely to be specific to different contexts (Forbes & Stammler, 2009). While the Delphi method can highlight priorities and helps move toward consensus, both the use of this method and our sample size does not allow for a detailed exploration of geographic variation in drivers of progress and limitations to the better use of IK with science. Further detailed contextual research is needed to understand the geographic variation in priorities. Although the literature surrounding collaboration and coproduction has grown, its presence varies geographically, with greater focus on North America as compared to other Indigenous groups in the Arctic (Kouril et al., 2015). In the European and Russian Arctic, the land has been co-occupied with other ethnic groups for centuries. In some cases building institutions for bridging knowledge among a diversity of local inhabitants have proved challenging (Broderstad, Hausner, Josefsen, & Søreng, 2020), but there are also promising examples of coproduction of knowledge in diverse ethnic settings, such as in Greenland (Danielsen et al., 2014) and Yakutia (Enghoff, Vronski, Shadrin, Sulyandziga, & Danielsen, 2019). This reinforces both the need for coproduction to occur from the inception of a project, such that approaches fit the local political, social and ecological context. Iteratively co-defining problems has been suggested as a critical component of successful coproduction (Robards et al., 2018). Current geographic variation in these projects also emphasizes the need to support collaboration and coproduction more widely across the Arctic to build experience and capacity where it is more limited.

Our results suggest that there are some continued misconceptions of IK by members of the scientific community, although responses suggested that experiences of these misconceptions vary between individuals. The most strongly identified misconceptions were associated with the ideas that IK is limited in spatial, temporal or conceptual scope, or needs verifying by western science to be useful. IK is increasingly being gathered by networks of communities and scientists to understand processes at large scales through community-based observation networks and community observation forums (Alessa et al., 2016; Griffith, Alessa, & Kliskey, 2018). The long temporal horizon of IK is reflected in the fact that this knowledge can be intergenerational, often transmitted orally and through practice (Herman-Mercer et al., 2016; Mustonen & Lehtinen, 2013). The misunderstanding concerning the limited temporal scope of IK more likely relates to a perception that the scope is limited to traditional activities of Indigenous peoples and perhaps less relevant to the current context of rapid social-ecological change. While there have been suggestions that predictions are more challenging under rapid change, the flexibility of IK to adapt to current conditions has

been seen as important to resilience and adaptation (Pearce, Ford, Willox, & Smit, 2015).

Finally, the misconception that IK needs to be verified by science is also highlighted as a limitation to progress in the equitable utilization of IK along with science. There has been much discussion concerning the relationship between IK and science, whether these knowledge systems should be compared, whether there are key characteristic differences between these knowledge systems and whether the frameworks to which often we apply IK undermine its richness and meaning, when those frameworks are strongly aligned with Western knowledge systems (Mustonen, 2018). Some argue that viewing IK as an adaptive process of understanding, interpreting and responding to observations and experiences rather reducing it to content, such as observations to fit within scientific frameworks, is critical and helps lead to a focus on partnership rather than integration of knowledge systems (Berkes, 2009). Others have further stressed that IK holds its own methodologies, validation and evaluation processes (Inuit Circumpolar Council, 2013). It is important to recognize that often IK and science are asking different questions. The issue that scientists try to verify IK with scientific information also reflects the theme of equity and power; if science is evaluated by its own peer reviewers internal to that knowledge system, it seems under an equitable system IK would be evaluated by knowledge holders from that knowledge system (Tengö et al., 2017). Furthermore, the lack of training for natural scientists on how to avoid bias from misunderstanding IK use in the peer review process continues to hamper progress in more widespread inclusion of IK published in the scientific literature (O. Lee, pers. observ.). Providing more training for scientists to overcome misconceptions of IK is particularly important as the number of researchers drawn to future collaborations with Indigenous communities increases.

Understanding the drivers of progress and limitations to better and more acceptable use of IK to inform decision-making is central to improved partnerships between IK holders, decision-makers and scientists. The need to address systemic barriers to progress is highlighted by the focus of our experts on deep leverage points (including identified issues from cultural assimilation, colonialism and politics). Developing more collaborative and coproduction work to continuously improve and define approaches will be key to the ongoing expansion in this area (Danielsen et al., 2020). Ensuring that values, laws, institutions, funding and mechanisms of support create desirable power relations between collaborators in this work is also key to progress toward the better use of IK with science.

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CONFLICTS OF INTEREST

Nibedita Mukherjee is an Associate Editor for *People and Nature*, and Helen Wheeler is a Guest Editor for the 'Informing decision-making with Indigenous and local knowledge and science' Special Feature, but neither were involved in the peer review and decision-making process for this manuscript.

AUTHORS' CONTRIBUTIONS

H.C.W. conceived the original idea for the project, H.C.W. and N.M. designed the Delphi and conducted preliminary research for the project with support from F.D., M.F., V.H., T.H., N.J. and O.L.; H.C.W., F.D., T.H. and O.L. contacted participants and V.H. provided recommendations and contact details; A.A., H.A., Ø.B., C.B., K.B.-H., G.-B.R., V.B., P.J., F.J., B.L., J.A.P., M.P., R.S. and N.V. participated in the full Delphi process and hence provided the data for this project; H.C.W. analysed the data and wrote the first draft of the manuscript and managed subsequent edits; F.D., M.F., V.H., T.H., N.J., O.L., N.M., H.A., C.B., K.B.-H., V.B. and G.-B.R. provided text, comments and edits to the manuscript.

DATA AVAILABILITY STATEMENT

Due to the confidentiality of the Delphi technique process, the summarized data are available in the manuscript, but the full data sets cannot be publicly archived.

ORCID

Helen C. Wheeler https://orcid.org/0000-0002-9820-5818
Vera Hausner https://orcid.org/0000-0001-9825-0419
Nibedita Mukherjee https://orcid.org/0000-0002-2970-1498

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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