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INFORMING DECISION-MAKING WITH INDIGENOUS AND LOCAL KNOWLEDGE AND SCIENCE

Editorial

Informing decision-making with Indigenous and local knowledge and science

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There is an increased focus on the role of Indigenous and local people and organizations in knowledge gathering, knowledge synthesis and decision-making. This is occurring at a range of scales from international policy formation to local and regional management and decision-making (Hausner, Engen, Brattland, & Fauchald, 2020; McElwee et al., 2020; Rayne et al., 2020; Tengö et al., 2017, all this feature). There have been calls for both more and deeper partnerships between Indigenous knowledge holders and scientists (see Box 1), to address the multifaceted issues facing conserved areas and those experiencing environmental change (Mistry & Berardi, 2016). In creating and strengthening these partnerships, it may be possible to address biological conservation issues alongside ensuring sustainable livelihoods and use of resources, culture, governance and economic development (Berkes, 2009a). As scientists working in areas where Indigenous or local knowledge have an important role, we are increasingly aware of the need to learn how best to contribute to inclusive and equitable research and decision-making and how collaboration between multiple knowledge systems can lead to a richer, more effective knowledge base to inform decision-making.

There are many reasons for Indigenous and local knowledge holders and scientists to work together and it should, in theory, be an enriching win–win situation from multiple perspectives. To get to this point, however, we need to develop appropriate methodological toolboxes to gain insights from multiple knowledge systems and create situations that maximize the chances that those insights are used appropriately to inform management and decision-making. Emerging methods demonstrate new perspectives on why interdisciplinarity is needed across these difficult knowledge differences and differences in worldviews, as well as how to do it. We hope through this Special Feature, we can continue to learn from the breadth of approaches that are have been applied and are emerging for Indigenous and local knowledge holders and scientists working together, and identify some of the needs and expectations of Indigenous and local knowledge holders when collaborating with scientists to develop research methods and to inform decision-making. As a framing to the Special Feature, here we address the following questions:

- What are the needs and benefits of Indigenous and local knowledge-science partnerships?
- What are the challenges and tensions that can occur within these partnerships?
- What are important attributes of knowledge and information when conducting research for informed management decision-making
- How well do existing modes of synthesis and collaboration between knowledge systems support the equitable inclusion of Indigenous and local knowledge in research for informed management and decision-making and how do we measure success in this process?

1 | THE NEEDS AND BENEFITS OF RESEARCH PARTNERSHIPS BETWEEN INDIGENOUS AND LOCAL KNOWLEDGE AND SCIENCE

An important reason to find methods for working with Indigenous and local knowledge is pursuit of the best information to inform decision-making. Ecological science, like all science relying on a strict epistemological method and aiming to produce general and universal knowledge, has not had the time or opportunity to sufficiently detail the operations of nature across spatial scales. Filling these knowledge gaps can provide key opportunities either to confirm existing models, generate new hypotheses, or even make new discoveries.

BOX 1 Summary of key terms and concepts

Indigenous people

People who have a multigenerational long-term association with a given place, Indigenous people are often defined as those who are descended from people who have been present in a location prior to colonization by another ethnic group. The United Nations considers self-identification as Indigenous as key to being Indigenous and Indigenous people will often be communities with their own customs, traditions and laws (Hill et al., 2020).

Local people

People who currently live in an area and often have multigenerational association with a given place but are not necessarily defined as Indigenous. They are connected to a given place by their livelihoods, cultural identities and knowledge (Hill et al., 2020), but do not necessarily self-identify as Indigenous, are not necessarily the earliest inhabitants of an area or inhabitants prior to a colonization by another ethnic group.

Indigenous and local knowledge

There are many Peoples and communities with different cultures and understandings of natural systems, which may be profoundly different from each other. Therefore, there is not one unified definition for Indigenous and local knowledge beyond it being the knowledge of Indigenous and local people which often pertains to social–ecological systems. Despite the diversity within Indigenous and local knowledge systems among peoples and cultures, there are some common characteristics such as that knowledge emerges from a close association with the land, is passed down through generations and often integrates culture, practice and beliefs (Gadgil, Berkes, & Folke, 1993). Note that people can also engage in multiple knowledge systems, such as in the case of Indigenous scientists, who are both scientists and Indigenous knowledge holders.

Governance

The way in which a system is managed, or resources are allocated, and the processes of influencing, steering, controlling or managing the actions of different parts of society to achieve management goals. This process occurs at multiple spatial scales involving multiple actors for example, governments, agencies, NGOs and households and multiple and sometimes sets of conflicting goals (Muñoz-Erickson et al., 2016).

Epistemology

The nature of knowledge, the way in which knowledge is created and claims about what can be known, for example, do we believe there is a single objective truth or multiple possible mental constructions of reality (Moon & Blackman, 2014). Science has a specific epistemology focusing on claims of objectivity, claims about the existence and prioritization of universal facts, the importance of reasoning based on controlled experiments and causal reasoning for identifying mechanisms. Other cultural traditions have different epistemologies.

Comanagement

A form of governance where power and responsibility for management and decision-making is shared between government and resource users through partnerships (Berkes, 2009b).

Rights holders

People or groups with rights to land or resources, these can either be formulated in law or governed by local customs (Franks, Booker, & Roe, 2018).

Stakeholders

People or groups with interests or concerns related to land or resources (Franks et al., 2018).

As the magnitude and inherent socia–ecological complexity of environmental problems increase, a broader knowledge base will undoubtedly benefit informed decision-making (Stevenson, 1996).

Research that includes Indigenous and local knowledge and science also helps ensure research address local concerns and wider societal concerns. Science is constantly progressing but suffers from limited information and biases of effort (see e.g. Rayne et al., 2020, this feature). Scientific data and research often have spatial, temporal and taxonomic biases (Boakes et al., 2010; Nuñez et al., 2019). Shifting governmental policies, funding priorities and national political situations can influence the degree and focus of conservation research and seek to impact the focus on different drivers of

ecological change (Pettorelli et al., 2019). The values of scientists can also influence what and where they study and their chosen methods (Roebuck & Phifer, 1999). These factors risk creating biases, which could affect the understanding derived from a single study, and when information from the scientific knowledge base is synthesized both formally and informally, systematic biases in our understanding of ecological systems and environmental change can emerge, which are likely to feed through to management and decision-making. This leads to both information deficits and biases in the knowledge base and the potential for an unjust knowledge base, biased towards the interests of those able to influence research priorities through policies, funding foci and the incentives and disincentives associated with the political climate in which scientists are operating and by the values of scientists themselves. By involving a wider range of people from a greater diversity of cultures and worldviews in research, we can seek to counter some of these often unaddressed biases.

Making research more inclusive of Indigenous and local communities is important from a perspective of fair and just research and decision-making (Agrawal, 1995). The outcomes of colonial histories have often marginalized many communities and their worldviews in decision-making (Simpson, 2004). Fair and just research would not marginalize the worldviews or epistemologies of certain groups in research and its synthesis. An example of an unjust epistemological claim would be an assumption that science is by nature more correct than Indigenous and local knowledge or that Indigenous knowledge is only of value when validated by science. Fair and just decision-making similarly would ensure that multiple worldviews contribute to informed decision-making. Collaboration with Indigenous communities in research and decision-making in ways that are agreeable to communities can help counter inequities between the dominance of certain worldviews or knowledge systems (Behe & Daniel, 2018). The historical contexts and identities of Indigenous peoples and local communities vary, and therefore so to do the approaches and reasons for collaboration and participation with them. These range from collaborating with Indigenous and local communities in the hope of acting ethically to maintain good relationships with local collaborators, colleagues and communities, to working with people and knowledge systems that have been marginalized, with hope of building local capacity, advance human rights and reduce inequalities.

Finally, there are practical reasons for collaboration between Indigenous and local knowledge holders to inform decision-making. Greater collaboration could also provide great opportunity to address or avoid conflicts over resource management (Castro & Nielsen, 2001). Local participation in research can lead to greater ability to influence decisions and faster implementation of those decisions (Danielsen, Burgess, Jensen, & Pirhofer-Walzl, 2010; Wall, McNie, & Garfin, 2017).

This Special Feature highlights some of the many benefits of that which can occur when research and decision-making are informed by Indigenous and local knowledge and science. In environmental decision-making, Indigenous knowledge holders might possess knowledge and information from temporal and spatial scales which are normally inaccessible to scientists, since scientific research is often grounded at a specific study site, limited by political boundaries, during a discrete field season or limited to the capacities of specific technologies (Gadgil et al., 1993). In Gagnon et al. (2020, this feature) long-term community-based monitoring of the Porcupine caribou herd in northern Canada and Alaska gives access to important transnational data on caribou condition, which is outside the scope of current scientific observations (Gagnon et al., 2020, this feature).

Knowledge, cultures and practices of Indigenous and local people who have inhabited the land for a long time have adapted to changing conditions and might have a history of integrating approaches to adapt to change. The transition from traditional practices to new management regimes can cause environmental degradation (Congretel & Pinton, 2020, this feature). This highlights how practice which integrates Indigenous and local knowledge can provide mechanisms for conservation and ecosystem-based adaptation (Hausner et al., 2020; Molnàr et al., 2020, both this feature). An understanding that Indigenous and local knowledge, cultures and practices adapt to changing conditions and are not static can help clarify their potential to address stewardship issues under biophysical and socio-economic change. Congretel and Pinton (2020, this feature) highlight that in addition to adaptations to local conditions, Indigenous practices can also adapt to foster resilience under increased globalization. Due to their integrative worldview, Indigenous and local knowledge systems are also excellent places to address the interdependencies between natural and cultural systems (McElwee et al., 2020, this feature).

2 | ADDRESSING CHALLENGES AND TENSIONS BETWEEN SCIENCE, INDIGENOUS AND LOCAL KNOWLEDGE AND DECISION-MAKING

While the discussion concerning the incorporation of Indigenous and local knowledge for informing decision-making is longstanding, past and ongoing tensions exist in the relationship between Indigenous and local knowledge, science and decision-making. Understanding tensions and identifying positive examples where efforts were made to overcome them, may help alleviate these in the future. Decision-making often involves trade-offs between the multiple needs and desires of different rights holders and stakeholders. The role of scientists in informed decision-making is as one of a portion of many voices in this process. Some tensions that arise in informed management and decision-making may be hard to address from the parts of the process over which scientists have most influence, such as how knowledge and information is generated and synthesized and how different worldviews are addressed in this process. However, there is a role of scientists to think about their processes of knowledge generation and how they engage with Indigenous and local people and governance systems, which can affect tensions between participants in the informed decision-making process. For example, tensions could result from the research questions themselves and how they are asked, the research processes implemented, in addition to the use of

subsequent information and knowledge in decision-making. We believe that while doing research on peoples' lands, or in areas which affect local communities, researchers much reflect on the potential implications of each stage of the process, from research formulation to decision-making.

How information and knowledge generated can affect the trust and equitability in the relationship between Indigenous knowledge holders and scientists and the power relationships between knowledge holders and decision-makers. Ensuring that Indigenous knowledge holders are involved in the research from the inception and development of projects through to their reporting, is perceived to be important to progressing partnerships in the Arctic and promoting equity (Inuit Circumpolar Council, 2013; Wheeler et al., 2020, this feature). This collaboration from the start of a project has been implemented in the conservation translocations of crayfish and mudfish described by Rayne et al. (2020, this feature), involving co-designed objectives and success indicators, co-designed translocation strategies and collective implementation followed by ongoing iterative management. Here research and management are implemented through the Mi'kmaq principle of Etuaptmumk or 'Two-Eyed Seeing' which brings together multiple ways of viewing the world (Rayne et al., 2020, this feature). A key aspect of this approach is that two different knowledge systems are used side by side to view the world, rather than making one conform to the rules and assumptions of the other. Whether we view Indigenous peoples as stakeholders or self-determining nations can also substantially affect the role and agency of scientists and Indigenous knowledge holders in research (Latulippe & Klenk, 2020). Calls have been made to not only work with Indigenous peoples as self-determining nations via their institutions and processes but also support and respect autonomous Indigenous research, reflecting this status (Simpson, 2004; Wheeler et al., 2020, this feature).

How information and knowledge is used can have impacts on local communities that may inadvertently erode trust between decision-makers, scientists and Indigenous and local knowledge holders. For example, while Indigenous knowledge may be used to inform environmental policies, resulting protectionist environmental policies can interfere with Indigenous people's capacity to conduct their traditional practices on their land and limit the capacity for future adaptation to environmental change (Lyver, Timoti, Davis, & Tylianakis, 2019; Lyver & Tylianakis, 2017). Here the lack of control Indigenous people sometimes has over how the knowledge and information they provide is used can create undesirable consequences for their communities. Scientists often experience the same challenge of limited control over how their research is used by policy makers, agencies and politicians. When Indigenous and local knowledge is used by decision-makers in ways that are undesirable to knowledge holders, the close association with the place in which decision-making occurs is more likely to more directly or deeply impact the culture and livelihoods of those knowledge holders and their communities. To the extent that science has a privileged entry into environmental management decisions, scientists may be in a position to advocate or vouch for fair and just processes for integrating Indigenous and local knowledge into decisions.

To advance and improve collaboration between Indigenous and local knowledge holders and scientists, we need to not only be aware of the potential tensions between Indigenous and local knowledge, science and decision-making but also understand the many ways in which Indigenous and local knowledge holders and scientists have collaborated to produce novel applied research and help inform decision-making. The examples in this feature highlight the novel insights into interactions between people and nature and the diverse conservation outcomes that can be achieved through collaboration of Indigenous knowledge holders and scientists.

3 | LINKING MULTIPLE KNOWLEDGE SYSTEMS TO ACTION: CREDIBILITY, SALIENCE AND LEGITIMACY

More effective links between knowledge and action can be made when the knowledge and information synthesized to inform decision-making is credible, salient and legitimate (Cash et al., 2003). When working with multiple knowledge systems, this can be a particular challenge as the values concerning different forms of knowledge may differ (Simpson, 2004). For example, the priority of establishing biophysical causation in many natural science approaches, could be incompatible with the interlinked view of biodiversity, society and culture in many Indigenous thought systems. An Indigenous or local knowledge approach to investigation and interpretation of events or phenomena may be more focused on integrated adaptive socio-ecological problem-solving approaches rather than pinning down biophysical causation. Reconciling these attributes across knowledge systems might be demanding as different knowledge holders may view systems is very different ways.

To be credible, information and knowledge need to be considered accurate by all knowledge partners (Schuttenberg & Guth, 2015). To be salient, information and knowledge must be considered relevant and adequate; differing world views can lead to differing conceptions of relevance and adequacy under different knowledge systems. To be legitimate, information and knowledge must be seen as 'inclusive, fair and unbiased' (Schuttenberg & Guth, 2015). For example, Congretel and Pinton (2020, this feature) demonstrate multiple descriptions of the function of the guaraná plant are created, which are produced and used differently by Indigenous and non-Indigenous farmers, this generates descriptions that are *credible* both to the Indigenous community and to a globalized scientific agronomical production perspective. Through finding a scientific description of the swidden-based cultural practices of Indigenous guanará production, the shared knowledge is then made *salient* to both parties through the coproduction of officially recognized documentation, and it is treated as *legitimate* in different contexts due to the participation of Indigenous people and scientists in creating the document and developing *credible* definitions.

Different perceptions of saliency, credibility and legitimacy can occur from profound differences in worldview to issues such as how

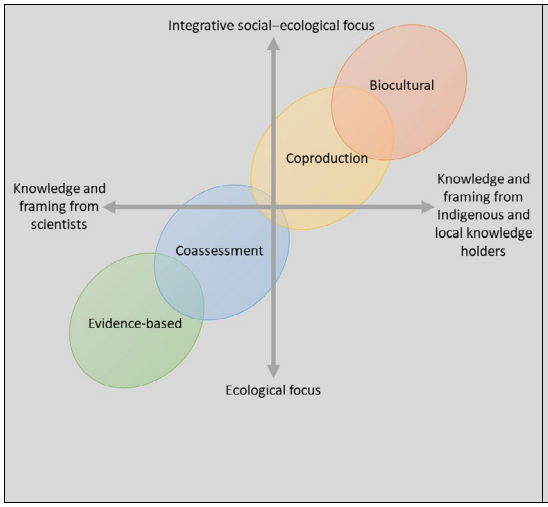
individuals of a given wildlife species are categorized. For example, the Indigenous Yup'ik people categorize a caribou herd according to subtypes with different morphology and habitat preferences which was not recognized by biologists at that time (Spaeder, 2005). These subtypes may be important to the practices and system understandings of the Yup'ik people and therefore highly salient to them, but of less salience to biologist formulating their models other ways. It is thus critical, when seeking salient, credible and legitimate approaches to research, to recognize that new processes or outcomes may need to be created, or they may need to have a double nature. For example, the answer to which form of categorization is used for data collection may be to collect data in two different ways simultaneously, to establish a mode of translation between categories, to agree on a novel set of categories or to use both existing categories side by side. Similarly, when sharing research findings, it is important to consider what forms of knowledge transmission and methodological agreement are salient, credible and legitimate in the local culture as well as to other end users.

4 | APPROACHES TO KNOWLEDGE GATHERING FOR DECISION-MAKING: MODES OF PARTICIPATION

Links between knowledge and information, and management and decisions are often complex with diffuse, multiscale relationships between information and knowledge and decision-making. These processes involving many political actors and interest groups which may be either integrated in or separate from knowledge production and synthesis. The influence of scientists on these processes may be limited in some cases and more profound in others, depending on the system of governance in which they operate. However, the role which scientists adopt in their research can affect the access and opportunity for other knowledge holders such as Indigenous and local people to inform decision-making and the nature in which their knowledge is treated. We therefore seek to highlight some of these modes of informed management and decision-making and their implications for the role of Indigenous and local knowledge.

There are a variety of approaches to gather knowledge and information for environmental decision-making within the fields of applied ecology and social–ecological research (Figure 1). Some of these have been developed to reflect the needs of Indigenous and local people while others have emerged from a more natural sciences-focussed approach to evidence synthesis. These vary in the capacity for and modes of potential Indigenous and local participation. Approaches vary in the degree to which they address primarily biophysical components of social–ecological systems or integrate social, cultural and biophysical components (Figure 1). While Indigenous and local knowledge can contribute to all of these processes, the choice of approach may affect the salience, credibility and legitimacy with which this knowledge synthesis and decision-making processes are viewed by all parties.

Evidence-based synthesis has traditionally focussed on evidence from the natural sciences. This evidence is largely based on linear chains of causation and ecosystem responses to conservation interventions (Sutherland, Pullin, Dolman, & Knight, 2004). Although Indigenous people can contribute information to this process, this information is generally contributed in a natural sciences form, such as through counts of a species. Indigenous and local knowledge is often integrative, addressing complex systems and combining knowledge and practice (Berkes, Colding, & Folke, 2000). For example, some hunters are able to understand which species is present, its bodily condition, its motivational state and its direction of travel from tracks and signs (Liebenberg, 1990). The emergent knowledge is their hunting strategy, but this integrates an understanding of the species they are hunting and its environment and an interpretation of tracks and signs (e.g. Barca, Lindon, & Root-Bernstein, 2016; Forssman & Root-Bernstein, 2018). Hunters might primarily express this knowledge in the form of commentaries on hunting tactics and strategies, which incorporate their own values, decisions and capacities. Extracting from knowledge such as this and inserting it into a natural sciences framing, as might occur in evidence-based synthesis, is probably the means of gathering information that is least



Evidence-based: Synthesis of natural science evidence, designed and reviewed by scientists normally focussed on linear chains of causation (i.e. determining cause-effect relationships).

Co-assessment: Sequential synthesis of evidence, first from the scientific body of knowledge and then involving Indigenous and local knowledge at a later stage, led primarily be scientists.

Coproduction: Parties from different knowledge systems collaboratively design research and knowledge synthesis and create outputs.

Biocultural conservation: An integrative approach to address loss of cultural and biological diversity and the needs of multiple rightsholders and stakeholders with multiple objectives. Culture, practice, knowledge and information are viewed integratively and multiple epistemologies are embraced in a multifaceted approach.

FIGURE 1 Forms of information and knowledge gathering for decision-making and their framing and modes of participation. These are shown along axes of the scope of research (vertical) and by whom the research is framed (horizonal axis)

aligned with, and does not gain the full benefit of the holistic nature of many Indigenous and local knowledge systems.

Co-assessment is when scientists and local actors assess the global knowledge pool for its relevance to their context and then synthesize this knowledge with Indigenous and local knowledge and experience, which is then fed into decision-making (Sutherland, Shackelford, & Rose, 2017). Co-assessment has been criticised for its natural sciences-focussed approach relative to coproduction, with Indigenous and local knowledge only being integrated into knowledge production after natural scientific evidence has been assembled (Salomaa, 2018). This creates an apparent hierarchy of knowledge systems, placing scientific knowledge first. Co-assessment could be used in some contexts for pragmatic reasons (e.g. scientific information has already been synthesized and resources are limited), but the reasons for doing so must be clear and implications for the balance of power between different actors and knowledge systems should be understood, justified and where needed consequences should be mitigated.

Coproduction is founded on the idea that knowledge and action are interdependent (Miller & Wyborn, 2018). Coproduction involves a more substantial collaboration between parties from different knowledge systems and with different objectives. These parties collaborate throughout the entire research process from problem formulation to research outputs. Coproduction is often expected to feed through to decision-making and ongoing adaptive comanagement through collaboration with managers and decision-makers. Research in comanagement often involves multiple methods such as interviews, focus groups, workshops, meetings, literature reviews and field observation (Armitage, Berkes, Dale, Kocho-Schellenberg, & Patton, 2011). The comanagement approach to Dolly Varden Char *Salvelinus malma* management in arctic western Canada highlights the aims of knowledge coproduction, where Gwich'in and Inuvialuit communities determine research priorities, and there is cooperative research and monitoring which includes Indigenous and local knowledge at every stage and research explores policy options that allow for the community to adapt to management plans through selective fishing mesh sizes, and allowances for fishing of healthy stocks and subsidies (Armitage et al., 2011). A benefit of coproduction and biocultural research is that they can change the focus of research so that it is no longer focussed first and foremost on natural science perspectives (as demonstrated by Rayne et al., 2020, this feature) although this remains a challenge in some examples of coproduction (Dale & Armitage, 2011). This reduces the likelihood that Indigenous and local perspectives are side-lined.

Biocultural conservation practice seeks to address the loss of both biological and cultural diversity, based on the recognition that they are strongly interlinked (Gavin et al., 2015). Accordingly, biocultural conservation can include comanagement, which may be based on knowledge coproduction. As the sustainability of both biological and cultural diversity are prioritized, values within biocultural conservation include shared governance systems, which are long term (intergenerational) and adaptive and address the multiple objectives of different parties, nations or stakeholders whilst respecting diverse knowledge systems. Omora Ethnobotanical Park, Chile is an example of the adoption of the biocultural approach. Here the Indigenous Yahgan community are the co-designers and the co-implementers of the park and its approach in collaboration with Omora NGO, legal holder of the land concession and the University of Magallanes, which has a local branch. The initiative then involves a wide range of institutions with different roles and responsibilities operating at a range of scales. The programme includes collaborative research on Indigenous knowledge and intercultural educational programmes and specifically worked to help Yahgan children in their local schools and made efforts to support the conservation of Yaghan language, addressing the cultural components of biocultural conservation (Rozzi, Massardo, Anderson, Heidinger, & Silander Jr., 2006). By supporting the longevity of Indigenous and local culture alongside biological conservation, biocultural approaches aim to retain knowledge and practices that support conservation whilst supporting people and communities that can increasingly see their cultures and livelihoods under threat from external stressors.

Biocultural conservation aims to not only use diverse sets of knowledge but support both conservation and innovation within knowledges, practices and technologies in line with cultural values (Davidson-Hunt et al., 2012; Gavin et al., 2015). The conservation of cultural diversity allows cultures to persist, whilst innovation in culture allows adaptation to change (Stephenson, Berkes, Turner, & Dick, 2014). Knowledge and information for biocultural conservation will include understanding values and needs, recognizing feedbacks between biodiversity and human well-being (Sterling et al., 2017). For example, in pastoral or silvopastoral situations, herding and grazing practices are based on herders' detailed integration of situated knowledge of the livestock, landscape, plant phenology and weather patterns (Molnàr et al., 2020, this feature). The biocultural approach recognizes that Indigenous and local knowledge are not robust to every kind of shock; climate change, market forces, sedentarization, conflicts and breakdown of traditional management mechanisms, can lead to patterns of overgrazing and degradation (e.g. Weber & Horst, 2011). This is why innovation and adaptation, responding to the altered aspects of a situation and its particular social, technological or economic challenges, are vital and always have been part of Indigenous and local knowledge. For example, a shift away from cattle towards goats might open new economic possibilities while reducing erosion and grazing pressure provided this is deemed an appropriate shift within the culture (e.g. Hoag, 2018).

While collaborative knowledge gathering approaches can be aligned with certain ideals and aims, often there are also challenging realities. In some cases, knowledge coproduction and subsequent comanagement have been accused of side-lining Indigenous knowledge in favour of scientific knowledge, while in other cases there have been accusations of over-romaticising Indigenous knowledge (Watson, 2013). There are risks that comanagement can also result in negative social outcomes by worsening the complexities of intra- and inter-group power dynamics, for example, by disrupting balances of power or undermining leaders, inflaming conflicts between interest groups or imposing outside decision-making powers over

local issues (Evans, Cherrett, & Pemsl, 2011). Whether these issues are greater in comanagement than when knowledge generation and synthesis and decision-making are separate, or whether these issues are common to a range of approaches to inform decision-making, has not been established. Giving opportunity for more voices in the research process can add complexity, with a wider range, more complex and sometimes conflicting set of objectives to address, however, not doing so may simply delay conflict to the decision-making stage of research and decision-making, and leaves inequities in power unaddressed. It is important to reflect on whether such challenges are the outcomes of one knowledge gathering approach or inherent to a wide spectrum of approaches to informed decision-making. Given the often diffuse pathways between knowledge and evidence and decision-making under all models of decision-making, it seems likely that tensions between diverse voices are common to many decision-making processes; the difference between different models of informed decision-making is simply where different voices are introduced.

5 | INTEGRATING KNOWLEDGE GATHERING AND DECISION-MAKING

Where research emphasizes producing scientific knowledge, processes of knowledge and information synthesis are often somewhat separate from decision-making processes. By contrast, Indigenous and local knowledge systems often integrate knowledge and practice (Agrawal, 1995). The separation of knowledge and information synthesis and decision-making may allow scientists to adopt a greater stance of impartiality, providing scientific advice by attempting to create a separation from the politics of decision-making. However, some argue that all scientists are effectively advocates in their role as citizens, and the more important consideration is to address values or biases in a more transparent and justified way (Nelson & Vucetich, 2009; Wilhere, 2012). Even though partiality is not actively pursued by scientists, it may be inherent in their choices concerning of how, where and why they conduct their studies (Wheeler et al., 2019). In any mode of linking knowledge and information gathering to decision-making, knowledge holders including scientists might adopt a range of roles and should ensure this is transparent and matched to the needs of the context and those of the knowledge holder (Crouzat et al., 2018).

Integration of knowledge and decision-making is common through practice within communities. Molnàr et al. (2020, this feature), demonstrate how herders integrate knowledge of cattle foraging preferences into their herding practice and to alter grazing behaviour through their traditional practices, thereby reducing the grazing pressure on more desired patches and redirecting grazing to less desired patches, creating conservation benefits. Hausner et al. (2020 this feature), also highlight that in Norway, Sàmi knowledge of reindeer herding systems is incorporated quite directly into local decision-making. Sàmi herders report their use of pastures as well as perceived threats to their herding practice, the resulting local plans can be used as a tool to protect Sàmi lands from competing land uses. However, disjuncts still remain between the knowledge made available by Sàmi herders and that which is used in decision-making, particularly outside core Sàmi areas (Hausner et al., 2020, this feature). As processes of knowledge gathering shift towards more social–ecological perspectives and greater collaboration with Indigenous and local people, perspectives appear to shift towards more integrated knowledge generation and synthesis, and decision-making mechanisms of biocultural conservation such as community-based conservation, integrated conservation and development programmes and comanagement (Gavin et al., 2015) and ecosystem-based adaptation (Hausner et al., 2020, this feature).

6 | MEASURING SUCCESS

Just as the information and knowledge used to inform decision-making becomes more expansive, incorporating multiple systems of values and knowledge systems, so too should the indicators of success. For example, in fisheries co-management, indicators include process indicators that relate to participation, conflict, rule compliance and control over resources and outcome indicators that both relate to biodiversity and human well-being (Evans et al., 2011). Such indicators may be integrated into approaches such as biocultural conservation which involve both in situ and ex situ knowledge production (Sterling et al., 2017). While win–win solutions to addressing the needs of multiple parties are always an aim, there will also be situations where trade-offs are necessary, and measures of success must identify costs and benefits, their nature and to whom they accrue.

7 | TAILORING APPROACHES TO CONTEXTS

Indigenous and local knowledges comprise a diverse set of understandings and practices, and therefore approaches must reflect those understandings and the local contexts in which they are placed. This Special Feature highlights a diverse range of approaches to inform decision-making with Indigenous and local knowledge and science and reflects that approaches must be tailored and developed to the local context where they are applied. Practice-focused and decision-making-oriented approaches addressed in this feature include informing strategic decision-making for conservation (priority threat management in Pacific salmon, Walsh et al., 2020, this feature), ecosystem-based adaptation (reindeer husbandry and land use decisions, Hausner et al., 2020, this feature), understanding the role of Indigenous and local practice in conservation (cattle foraging preferences and conservation herding practice, Molnàr et al., 2020, this feature), understanding the social conditions that promote adaptation to change (Indigenous communities and sea otter recovery, Burt et al., 2020, this feature), and adaptation of Indigenous knowledge and practice to

globalization (Congretel & Pinton, 2020, this feature) and informing conservation translocations (Rayne et al., 2020, this feature). More knowledge production-focused approaches include understanding of complex interactions between seasonal weather and wildlife condition (Gagnon et al., 2020, this feature) and contributions of Indigenous and local knowledge to global contexts, including recently through the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES). McElwee et al. (2020, this feature) highlight in their assessment of the global IPBES processes that different aspects and qualities of different knowledge systems may align better with some questions than others, and the balance of contributions from knowledge systems might reflect their alignment with different questions. Some of these issues are addressed in Wheeler et al. (2020, this feature) who investigated sources of process and limitations to the use of Indigenous knowledge and science in decision-making. Perhaps most importantly, consultation and collaboration processes will identify how knowledge is gathered and used that is acceptable to all parties.

8 | CONCLUSIONS

The approaches and needs to work with Indigenous and local knowledge and science to inform decision-making have attracted long-standing discussions. All stewardship and conservation has successes and failures and it is vital that the best information possible informs decision-making to maximize success and reduce failure, and deal with complex trade-offs between competing objectives where scenarios of success and failure are harder to define. When working with multiple knowledge systems, a critical consideration is how knowledge is treated and that knowledge systems are treated in a fair and equitable way. A counterargument to the biocultural conservation approach is that not all cultural practice supports biodiversity, this is indeed true, just like not all science-driven conservation interventions have positive biodiversity outcomes. Similarly, it has been argued that it is hard to discern Indigenous and local knowledge from advocacy, but this is not unique to any knowledge system, all of which in a decision-making setting (including natural sciences) can be intertwined with personal beliefs and objectives. Working with Indigenous and local knowledge and science is not to discard the evaluation of information and evidence but rather to evaluate it fairly, in reference to the knowledge system in which it is situated. The salience, legitimacy and credibility of scientific knowledge is probably most apparent to scientists, whilst the salience, legitimacy and credibility of Indigenous or local knowledge is probably most apparent to Indigenous and local knowledge holders. Those who can bridge these knowledge systems have particular value in this setting.

The challenge when working with multiple knowledge systems to inform decision-making is what approach will best allow these knowledge systems to be evaluated fairly and used appropriately. This must be tailored to each specific context, however, approaches such as biocultural conservation which integrate biodiversity conservation and cultural conservation and research with practice might have greater capacity to work with Indigenous and local knowledge in a form more aligned with Indigenous and local knowledge systems. The challenge for scientists is to understand their role in this process. In some cases, Indigenous communities might prioritize independent Indigenous research. While scientists may have variable capacity to alter decision-making processes themselves which are complex processes involving many parties, the way in which they conduct their research and engage with systems of governance can have implications for the role of Indigenous and local knowledge in research and decision-making. In making these decisions about how to conduct research, through working to support the use of Indigenous and local knowledge and collaborate with Indigenous and local people and organizations, scientists can enrich the knowledge base and contribute to societal goals of equity and justice.

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DATA AVAILABILITY STATEMENT

Data are from published sources, cited in the text and included in the references.

REFERENCES

Agrawal, A. (1995). Dismantling the divide between indigenous and scientific knowledge. *Development and Change*, *26*(3), 413–439. https://doi.org/10.1111/j.1467-7660.1995.tb00560.x

Armitage, D., Berkes, F., Dale, A., Kocho-Schellenberg, E., & Patton, E. (2011). Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic. *Global Environmental Change*, *21*(3), 995–1004. https://doi.org/10.1016/j.gloenvcha.2011.04.006

Barca, B., Lindon, A., & Root-Bernstein, M. (2016). Environmentalism in the crosshairs: Perspectives on migratory bird hunting and poaching conflicts in Italy. *Global Ecology and Conservation*, *6*, 189–207.

Behe, C., & Daniel, R. (2018). Indigenous knowledge and the co-production of knowledge process: Creating a holistic understanding of arctic change. [in "State of the Climate in 2017"]. *Bulletin of the American Meteorological Society*, *99*(8), S160–S161. https://doi.org/10.1175/2018BAMSStateoftheClimate.1

Berkes, F. (2009a). Indigenous ways of knowing and the study of environmental change. *Journal of the Royal Society of New Zealand*, *39*(4), 151–156. https://doi.org/10.1080/03014220909510568

Berkes, F. (2009b). Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. *Journal of Environmental Management*, *90*(5), 1692–1702. https://doi.org/10.1016/j.jenvman.2008.12.001

Berkes, F., Colding, J., & Folke, C. (2000). Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications*, *10*(5), 1251–1262. https://doi.org/10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2

Boakes, E. H., McGowan, P. J. K., Fuller, R. A., Chang-qing, D., Clark, N. E., O'Connor, K., & Mace, G. M. (2010). Distorted views of biodiversity: Spatial and temporal bias in species occurrence data. *PLOS Biology*, *8*(6), e1000385. https://doi.org/10.1371/journal.pbio.1000385

Burt, J. M., Wilson, K. B. J., Malchoff, T., Mack, W.-T.-K., Davidson, S. H. A., Gitkinjuaas, & Salomon, A. K. (2020). Enabling coexistence: Navigating predator-induced regime shifts in human-ocean systems. *People and Nature*. https://doi.org/10.1002/pan3.10090

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., … Mitchell, R. B. (2003). Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences of theUnited States of America*, *100*(14), 8086–8091. https://doi.org/10.1073/pnas.1231332100

Castro, A. P., & Nielsen, E. (2001). Indigenous people and co-management: Implications for conflict management. *Environmental Science & Policy*, *4*(4), 229–239. https://doi.org/10.1016/S1462-9011(01)00022-3

Congretel, M., & Pinton, F. (2020). Local knowledge, know-how and knowledge mobilised in a globalized world: A new approach of indigenous local ecological knowledge. *People and Nature*. https://doi.org/10.1002/pan3.10142

Crouzat, E., Arpin, I., Brunet, L., Colloff, M. J., Turkelboom, F., & Lavorel, S. (2018). Researchers must be aware of their roles at the interface of ecosystem services science and policy. *Ambio*, *47*(1), 97–105. https://doi.org/10.1007/s13280-017-0939-1

Dale, A., & Armitage, D. (2011). Marine mammal co-management in Canada's Arctic: Knowledge co-production for learning and adaptive capacity. *Marine Policy*, *35*(4), 440–449. https://doi.org/10.1016/j.marpol.2010.10.019

Danielsen, F., Burgess, N. D., Jensen, P. M., & Pirhofer-Walzl, K. (2010). Environmental monitoring: The scale and speed of implementation varies according to the degree of peoples involvement. *Journal of Applied Ecology*, *47*(6), 1166–1168. https://doi.org/10.1111/j.1365-2664.2010.01874.x

Davidson-Hunt, I. J., Turner, K. L., Mead, A. T. P., Cabrera-Lopez, J., Bolton, R., Idrobo, C. J., & Robson, J. P. (2012). Biocultural design: A new conceptual framework for sustainable development in rural indigenous and local communities. *S.A.P.I.EN.S. Surveys and Perspectives Integrating Environment and Society*, (5.2). Retrieved from http://journals.openedition.org/sapiens/1382

Evans, L., Cherrett, N., & Pemsl, D. (2011). Assessing the impact of fisheries co-management interventions in developing countries: A meta-analysis. *Journal of Environmental Management*, *92*(8), 1938–1949. https://doi.org/10.1016/j.jenvman.2011.03.010

Forssman, N., & Root-Bernstein, M. (2018). Landscapes of anticipation of the other: Ethno-ethology in a deer hunting landscape. *Journal of Ethnobiology*, *38*(1), 71–87. https://doi.org/10.2993/0278-0771-38.1.071

Franks, P., Booker, F., & Roe, D. (2018). *Understanding and assessing equity in protected area conservation* (p. 40). London, UK: IIED.

Gadgil, M., Berkes, F., & Folke, C. (1993). Indigenous knowledge for biodiversity conservation. *Ambio*, *22*(2/3), 151–156.

Gagnon, C. A., Hamel, S., Russell, D. E., Powell, T., Andre, J., Svoboda, M. Y., & Berteaux, D. (2020). Merging indigenous and scientific knowledge links climate with the growth of a large migratory caribou population. *Journal of Applied Ecology*. https://doi.org/10.1111/1365-2664.13558

Gavin, M. C., McCarter, J., Mead, A., Berkes, F., Stepp, J. R., Peterson, D., & Tang, R. (2015). Defining biocultural approaches to conservation. *Trends in Ecology & Evolution*, *30*(3), 140–145. https://doi.org/10.1016/j.tree.2014.12.005

Hausner, V. H., Engen, S., Brattland, C., & Fauchald, P. (2020). Sámi knowledge and ecosystem-based adaptation strategies for managing pastures under threat from multiple land uses. *Journal of Applied Ecology*. https://doi.org/10.1111/1365-2664.13559

Hill, R., Adem, Ç., Alangui, W. V., Molnár, Z., Aumeeruddy-Thomas, Y., Bridgewater, P., … Xue, D. (2020). Working with Indigenous, local and scientific knowledge in assessments of nature and nature's linkages with people. *Current Opinion in Environmental Sustainability*, *43*, 8–20. https://doi.org/10.1016/j.cosust.2019.12.006

Hoag, C. (2018). The ovicaprine mystique: Livestock commodification in postindustrial Lesotho. *American Anthropologist*, *120*(4), 725–737. https://doi.org/10.1111/aman.13119

Inuit Circumpolar Council. (2013). *Application of indigenous knowledge in the Arctic Council*. Retrieved from https://iccalaska.org/wp-icc/wp-content/uploads/2016/03/Application-of-IK-in-the-Arctic-Council.pdf

Latulippe, N., & Klenk, N. (2020). Making room and moving over: Knowledge co-production, Indigenous knowledge sovereignty and the politics of global environmental change decision-making. *Current Opinion in Environmental Sustainability*, *42*, 7–14. https://doi.org/10.1016/j.cosust.2019.10.010

Liebenberg, L. (1990). *The art of tracking: The origin of science*. Claremont, South Africa: D. Philip.

Lyver, P. O. B., Timoti, P., Davis, T., & Tylianakis, J. M. (2019). Biocultural hysteresis inhibits adaptation to environmental change. *Trends in Ecology & Evolution*, *34*(9), 771–780. https://doi.org/10.1016/j.tree.2019.04.002

Lyver, P. O. B., & Tylianakis, J. M. (2017). Indigenous peoples: Conservation paradox. *Science*, *357*(6347), 142–143. https://doi.org/10.1126/science.aao0780

McElwee, P., Fernández-Llamazares, Á., Aumeeruddy-Thomas, Y., Babai, D., Bates, P., Galvin, K., … Brondízio, E. S. (2020). Working with Indigenous and local knowledge (ILK) in Large-Scale Ecological Assessments: Reviewing the experience of the IPBES Global Assessment. *Journal of Applied Ecology*. https://doi.org/10.1111/1365-2664.13705

Miller, C. A., & Wyborn, C. (2018). Co-production in global sustainability: Histories and theories. *Environmental Science & Policy*. https://doi.org/10.1016/j.envsci.2018.01.016

Mistry, J., & Berardi, A. (2016). Bridging indigenous and scientific knowledge. *Science*, *352*(6291), 1274–1275. https://doi.org/10.1126/science.aaf1160

Molnár, Z., Kelemen, A., Kun, R., Máté, J., Sáfián, L., Provenza, F., … Vadász, C. (2020). Knowledge co-production with traditional herders on cattle grazing behaviour for better management of species-rich grasslands. *Journal of Applied Ecology*. https://doi.org/10.1111/1365-2664.13664

Moon, K., & Blackman, D. (2014). A guide to understanding social science research for natural scientists. *Conservation Biology*, *28*(5), 1167–1177. https://doi.org/10.1111/cobi.12326

Muñoz-Erickson, T. A., Campbell, L. K., Childers, D. L., Grove, J. M., Iwaniec, D. M., Pickett, S. T. A., & Svendsen, E. S. Demystifying governance and its role for transitions in urban social–ecological systems. *Ecosphere*, *7*(11), e01564. https://doi.org/10.1002/ecs2.1564

Nelson, M. P., & Vucetich, J. A. (2009). On advocacy by environmental scientists: What, whether, why, and how. *Conservation Biology*, *23*(5), 1090–1101. https://doi.org/10.1111/j.1523-1739.2009.01250.x

Nuñez, M. A., Barlow, J., Cadotte, M., Lucas, K., Newton, E., Pettorelli, N., & Stephens, P. A. (2019). Assessing the uneven global distribution of readership, submissions and publications in applied ecology: Obvious problems without obvious solutions. *Journal of Applied Ecology*, *56*(1), 4–9. https://doi.org/10.1111/1365-2664.13319

Pettorelli, N., Barlow, J., Cadotte, M. W., Lucas, K., Newton, E., Nuñez, M. A., & Stephens, P. A. (2019). Applied ecologists in a landscape of fear. *Journal of Applied Ecology*, *56*(5), 1034–1039. https://doi.org/10.1111/1365-2664.13382

Rayne, A., Byrnes, G., Collier-Robinson, L., Hollows, J., McIntosh, A., Ramsden, M., … Steeves, T. (2020). Centring Indigenous knowledge systems to re-imagine conservation translocations. *People and Nature*. https://doi.org/10.1002/pan3.10026

Roebuck, P., & Phifer, P. (1999). The persistence of positivism in conservation biology. *Conservation Biology*, *13*(2), 444–446.

Rozzi, R., Massardo, F., Anderson, C. B., Heidinger, K., & Silander, J. A. Jr (2006). Ten principles for biocultural conservation at the southern

tip of the Americas: the approach of the Omora Ethnobotanical Park. *Ecology and Society*, *11*(1), art43. https://doi.org/10.5751/ES-01709-110143

Salomaa, A. (2018). Co-production for fundamental change: a response to Sutherland et al *Oryx*, *52*(4), 617. https://doi.org/10.1017/S0030605318000431

Schuttenberg, H. Z., & Guth, H. K. (2015). Seeking our shared wisdom: A framework for understanding knowledge coproduction and co-productive capacities. *Ecology and Society*, *20*(1), art15. https://doi.org/10.5751/ES-07038-200115

Simpson, L. R. (2004). Anticolonial strategies for the recovery and maintenance of Indigenous Knowledge. *The American Indian Quarterly*, *28*(3–4), 373–385.

Spaeder, J. J. (2005). Co-management in a landscape of resistance: The political ecology of wildlife management in Western Alaska. *Anthropologica*, *47*(2), 165–178.

Stephenson, J., Berkes, F., Turner, N. J., & Dick, J. (2014). Biocultural conservation of marine ecosystems: Examples from New Zealand and Canada. *Indian Journal of Traditional Knowledge*, *13*(2), 9.

Sterling, E. J., Filardi, C., Toomey, A., Sigouin, A., Betley, E., Gazit, N., … Jupiter, S. D. (2017). Biocultural approaches to well-being and sustainability indicators across scales. *Nature Ecology & Evolution*, *1*(12), 1798–1806. https://doi.org/10.1038/s41559-017-0349-6

Stevenson, M. G. (1996). Indigenous knowledge in environmental assessment. *Arctic*, *49*(3), 278–291.

Sutherland, W. J., Pullin, A. S., Dolman, P. M., & Knight, T. M. (2004). The need for evidence-based conservation. *Trends in Ecology & Evolution*, *19*(6), 305–308. https://doi.org/10.1016/j.tree.2004.03.018

Sutherland, W. J., Shackelford, G., & Rose, D. C. (2017). Collaborating with communities: Co-production or co-assessment? *Oryx*, *51*(4), 569–570. https://doi.org/10.1017/S0030605317001296

Tengö, M., Hill, R., Malmer, P., Raymond, C. M., Spierenburg, M., Danielsen, F., … Folke, C. (2017). Weaving knowledge systems in IPBES, CBD and beyond—lessons learned for sustainability. *Current Opinion in Environmental Sustainability*, *26–27*, 17–25. https://doi.org/10.1016/j.cosust.2016.12.005

Wall, T. U., McNie, E., & Garfin, G. M. (2017). Use-inspired science: Making science usable by and useful to decision makers. *Frontiers in Ecology and the Environment*, *15*(10), 551–559. https://doi.org/10.1002/fee.1735

Walsh, J. C., Connors, K., Hertz, E., Kehoe, L., Martin, T. G., Connors, B., … Halverson, J. (2020). Prioritising conservation actions for Pacific salmon in Canada. *Journal of Applied Ecology*. https://doi.org/10.1111/1365-2664.13646

Watson, A. (2013). Misunderstanding the "Nature" of co-management: A geography of regulatory science and Indigenous Knowledges (IK). *Environmental Management*, *52*(5), 1085–1102. https://doi.org/10.1007/s00267-013-0111-z

Weber, K. T., & Horst, S. (2011). Desertification and livestock grazing: The roles of sedentarization, mobility and rest. *Pastoralism: Research, Policy and Practice*, *1*(1), 1–11. https://doi.org/10.1186/2041-7136-1-19

Wheeler, H. C., Berteaux, D., Furgal, C., Cazelles, K., Yoccoz, N. G., & Grémillet, D. (2019). Identifying key needs for the integration of social–ecological outcomes in arctic wildlife monitoring. *Conservation Biology*, *33*(4), 861–872. https://doi.org/10.1111/cobi.13257

Wheeler, H. C., Danielsen, F., Fidel, M., Hausner, V., Horstkotte, T., Johnson, N., … Vronski, N. (2020). The need for transformative changes in the use of Indigenous knowledge along with science of environmental decision-making in the Arctic. *People and Nature*. https://doi.org/10.1002/pan3.10131

Wilhere, G. F. (2012). Inadvertent advocacy. *Conservation Biology*, *26*(1), 39–46. https://doi.org/10.1111/j.1523-1739.2011.01805.x