**Informing decision making with Indigenous knowledge and science**

Helen C. Wheeler, School of Life Sciences, Anglia Ruskin University, UK

Meredith Root-Bernstein, Musée de l’Homme, Paris, France; Center of Applied Ecology and Sustainability, Santiago, Chile; Institute of Ecology and Biodiversity, Santiago, Chile.

Correspondence: [helen.wheeler@aru.ac.uk](mailto:helen.wheeler@aru.ac.uk)

There is an increased focus on the of role Indigenous and local people and organisations 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 (Tengö et al., 2017 and Hausner et al 2020, Mc Elwee et al. 2020, Rayne et al. 2020, 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, 2009). As scientists working in areas where Indigenous or local knowledge has an important role, we are increasingly aware of the need to learn how to best 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.

|  |
| --- |
| Box 1: Summary of key terms and concepts |
| **Indigenous people**  Peoples that have a multigenerational long-term association with a given place, Indigenous people are often defined as those who are descended from people that have been present in a location prior to colonisation 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 colonisation 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 e.g. 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, e.g. 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).  **Rightsholders**  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, Booked & Roe, 2018). |

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 maximise 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?*

**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. As the magnitude and inherent social-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 help ensure research addresses local 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 study and their chosen methods (Roebuck and 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 synthesised 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 marginalised many communities and their worldviews in decision-making (Simpson, 2004). Fair and just research would not marginalise 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 peoples and knowledge systems that have been marginalised, 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 can occur when research and decision-making is 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 peoples 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 (Molnàr et al. 2020; Hausner 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 & Pinton (2020, this feature) highlight that in addition to adaptations to local conditions, Indigenous practices can also adapt to foster resilience under increased globalisation. 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).

**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 rightsholders 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 synthesised 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. In doing research on Peoples’ lands, or which affects local communities, we believe that researchers must reflect on the potential implications of each stage of the process from research formulation to decision-making.

How information and knowledge is 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 people 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 peoples’ 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 have 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.

**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 synthesised 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 needs 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, in Congretel & Pinton (2020, this feature) demonstrate multiple descriptions of the function of the guaraná plant are created, which is 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 recognised 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 on a relatively simple level such as how individuals of a given wildlife species are categorised, such as the case of Indigenous Yup’ik people categorising a caribou herd according to subtypes with different morphology and habitat preferences not recognised by biologists at the 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 searching for processes and outcomes that are salient, credible and legitimate, to recognise new ways of viewing systems to incorporate multiple understandings. For example, the answer to which form of categorization to use for data collection may be to collect data in two different ways simultaneously, to establish a mode of translation between categories, or to agree on a novel set of categories. 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.

**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 gathering knowledge and information for environmental decision-making within the fields of applied ecology and social-ecological research (Fig. 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 (Fig. 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 is 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). So, for example, hunters intepret the tracks and signs of many species and are able to understand what species the track or sign is from, its bodily condition, its motivational state, its direction of travel, and so on, in the context of their activities as hunters (Liebenberg 1990). That is, they have a hunter’s perspective on the interpretation of environments, as well as gathering knowledge in the course of observing, behaving, and using space in ways particular to hunters (e.g. Forssman & Root-Bernstein 2018; Barca et al. 2015). They might primarily express this knowledge in the form of commentaries on hunting tactics and strategies, which consequently implicitly incorporate and anticipate their own values, decisions and capacities. A hunter’s claim about the sensory acuity of deer is thus a claim that deer are very good at avoiding people with his kind of hunting practices in the habitat in question (Forssman & Root-Bernstein 2018). Extracting from these knowledges evidence or data to insert into a natural sciences framing is probably the means of informing decision-making that is least aligned with, and least takes advantage of, the applied and holistic nature of many Indigenous and local knowledge systems.

Coassessment is when scientists and local actors assess the global knowledge pool for its relevance to their context and then synthesise this knowledge with Indigenous and local knowledge and experience, which then feeds in to decision-making (Sutherland, Shackelford, & Rose, 2017). Coassessment 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. Coassessment could be used some contexts for pragmatic reasons (e.g. scientific information has already been synthesised 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 mitigated.

Coproduction is founded on the idea that knowledge and action are interdependent (Miller & Wyborn, 2018). For example, as we described above, hunting produces knowledge about the environment that is specific to the hunters’ perspective and practices, and that informs their hunting strategies. Similarly, scientists’ field methods are actions that produce data with certain epistemological properties (e.g. objectivity, universality), which in turn implies that applied actions may be, for example, designed centrally and applied globally. Coproduction thus considers that knowledge that is truly jointly produced needs to be rooted in joint action at all stages of knowledge production. Here we see a more substantial collaboration between Indigenous and local knowledge holders and scientists, which occurs from problem formulation to research outputs and is often expected to feed through to decision-making and ongoing adaptive comanagement (collaborative management) through collaboration with managers and decision-makers. 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). 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 prioritised, 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. 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, recognising feedbacks between biodiversity and human wellbeing (Sterling et al., 2017). So, for example, in pastoral or silvopastoral situations, herding and grazing practices based on Indigenous or local knowledge is based on herders’ detailed situated knowledge of the landscape, plant phenology, weather patterns, and so on (Molnàr et al. 2020, this feature). The biocultural approach recognises that Indigenous and local knowledge is not robust to every kind of shock: climate change, market forces, sedentarization, conflicts, breakdown of traditional management mechanisms, etc., 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 possibities while reducing erosion and grazing pressure (e.g. Hoag 2018).

|  |  |
| --- | --- |
| A close up of a map  Description automatically generated | **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).  **Coassessment:** 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 the by whom the research is framed (horizonal axis).

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 has 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). Political, economic, and decision-making power is never uniform and never uniformly leads to implementation of favored outcomes—even in monocultural societies it is patchy, is controlled by individuals with different values and interests (cf. discretionary power), and takes different forms across scales (e.g. street-level implementation vs. national law) (Hoag 2011). Translating power into action across spaces, discrectionary capacities and scales is thus only made more complex when the comanagement aspect is added, if this articulation is not done carefully. 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,.

**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 in to 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 knowledge of landscape characteristics, and 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 toward more social-ecological perspectives and greater collaboration with Indigenous and local people, perspectives appear to shift toward more integrated knowledge generation, 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).

**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 wellbeing (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 measuring of success must identify costs and benefits, this nature and to whom the accrue as a result of solutions to these trade-offs.

**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 globalisation (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 also contributes 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) which investigates 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 whether how knowledge is gathered and used is acceptable to all parties.

**Conclusions**

**Going to try to add things that address the specific questions here with use of the list you sent.**

**Acknowledgements**

We would like to thank Marc Cadotte for helpful comments on the manuscript. Emilie Aime, Alice Plane and Kirsty Scandrett for this support in creating this Special Feature. We also thank Andrew Smith and Olivia Norfolk for comments on an earlier draft of the manuscript.

**Data availability statement**

Data have not been archived because this article does not use data.

**References**

Agrawal, A. (1995). Dismantling the Divide Between Indigenous and Scientific Knowledge. *Development and Change*, *26*(3), 413–439. doi: 10.1111/j.1467-7660.1995.tb00560.x

Barca, B., Lindon, A., & Root-Bernstein, M 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”]. Bull. Amer. Meteor. Soc., 99 (8), S160–S161, doi:10.1175 /2018BAMSStateoftheClimate.1.

Berkes, F. (2009). Indigenous ways of knowing and the study of environmental change. *Journal of the Royal Society of New Zealand*, *39*(4), 151–156. doi: 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. doi: 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. doi: 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. doi: 10.1371/journal.pbio.1000385

Burt, J. M., Wilson, Ḵii’iljuus Barbara J., Malchoff, T., Mack, W. A., Davidson, S. H. A., Gitkinjuaas, & Salomon, A. K. (2020). Enabling coexistence: Navigating predator-induced regime shifts in human-ocean systems. *People and Nature*, In Press. doi: 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*, *100*(14), 8086–8091. doi: 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. doi: 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, In Press

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. doi: 10.1007/s13280-017-0939-1

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. doi: 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. doi: 10.1016/j.jenvman.2011.03.010

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

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.

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*, In Press. doi: 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. doi: 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*, In Press. doi: 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. doi: 10.1016/j.cosust.2019.12.006

Hoag, C. (2011). Assembling partial perspectives: thoughts on the anthropology of bureaucracy. *PoLAR*, *34*, 81.

Hoag, C. (2018). The ovicaprine mystique: Livestock commodification in postindustrial Lesotho. *American Anthropologist*, *120*(4), 725-737.

Inuit Circumpolar Council, 2013: Application of Indigenous Knowledge in the Arctic Council. 2 pp., https://iccalaska.org/wp-icc/wp-content/uploads/2016/03/Application-of-IK-in-the-Arctic-Council.pdf. Accessed 26/05/2020

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. doi: 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. doi: 10.1016/j.tree.2019.04.002

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

McElwee, P., Fernández-Llamazares, Á, Aumeeruddy-Thomas, Y., Babai, D., Bates, P., Galvin, K., Guèze, M., Liu, J., Molnár, Z, Ngo, H. T., Reyes-García, V., Chowdhury, R. R., Samakov, A., Shrestha, B. U., Díaz, S. & 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, In Press.

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

Mistry, J., & Berardi, A. (2016). Bridging indigenous and scientific knowledge. *Science*, 352(6291), 1274–1275. doi: 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*, In Press. doi: 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. doi: 10.1111/cobi.12326

Moore, J. W., Price, M. H. H., Reynolds, J. D. & Watson, A. (2013). Misunderstanding the “Nature” of Co-Management: A Geography of Regulatory Science and Indigenous Knowledges (IK). *Environmental Management*, *52*(5), 1085–1102. doi: 10.1007/s00267-013-0111-z

Muñoz‐Erickson, T. A., Campbell, L. K., Childers, D. L., Grove, J. M., Iwaniec, D. M., Pickett, S. T. A., … Svendsen, E. SDemystifying governance and its role for transitions in urban social–ecological systems. Ecosphere, 7(11), e01564. doi: 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. doi: 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. doi: 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. doi: 10.1111/1365-2664.13382

Rayne, A., Byrnes, G., Collier-Robinson, L., Hollows, J., McIntosh, A., Ramsden, M., Rupene, M., Tamati-Elliffe, P., Thoms, C., Steeves, T. (2020). Centring Indigenous knowledge systems to re-imagine conservation translocations. *People and Nature*. In Press.

Roebuck, P., & Phifer, P. (1999). The Persistence of Positivism in Conservation Biology. Conservation Biology, 13(2), 444–446.

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

Schuttenberg, H. Z., & Guth, H. K. (2015). Seeking our shared wisdom: a framework for understanding knowledge coproduction and coproductive capacities. *Ecology and Society*, *20*(1), art15. doi: 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. Retrieved from JSTOR.

Stephenson, J., Berkes, F., Turner, N. J., & Dick, J. (2014). *Biocultural conservation of marine ecosystems: Examples from New Zealand and Canada*. *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. doi: 10.1038/s41559-017-0349-6

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. doi: 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. doi: 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. doi: 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. doi: 10.1002/fee.1735

Walsh, J. C., Connors, K., Hertz, E., Kehoe, L., Martin, T. G., Connors, B., Bradford, M. J., Freshwater, C., Frid, A., & Halverson, J. (2020). Prioritising conservation actions for Pacific salmon in Canada. People and Nature, In press.

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.

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. doi: 10.1111/cobi.13257

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