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Inviting ecologists to delve deeper into traditional knowledge

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Abstract

Ecologists and conservationists increasingly acknowledge that traditional ecological knowledge (TEK) is vital for a better understanding and conservation of biodiversity, for example, for a more complex socio-ecological understanding of long-term processes, ecosystem resilience, the impacts of traditional management practices, and the worldviews underpinning these practices. To gain a deeper understanding of the ecological dimensions of TEK, ecologists and conservation biologists should conduct participatory long-term collaborative research on TEK. To conduct TEK research properly, however, ecologists need to familiarize themselves more deeply with the methodologies of social sciences, further develop their links with social scientists, and adopt new approaches, such as strengthening respect towards other knowledge systems, and being inclusive in research and open to new types of validation.

Keywords: traditional ecological knowledge, knowledge co-production, ecology, nature conservation, long-term studies, Indigenous and local knowledge

Highlights (recent advances in the research field)

- Traditional communities living in close interaction with nature (Indigenous communities, traditional farmers, pastoralists, fishers) possess a deep ecological understanding of nature.
- Conservationists increasingly acknowledge that traditional ecological knowledge is vital for the conservation of biodiversity, especially in landscapes where humans and nature have coevolved over millennia.
- Research into traditional ecological knowledge is multidisciplinary by definition and requires training in both natural and social sciences, together with respect for Indigenous and human rights and long-term, trustful engagement with the local knowledge system.
- Traditional knowledge of species and ecosystems, resource use practices, social institutions and worldviews must be interpreted in their interwoven complexity in order to be fully understood.

Outstanding Questions (for future research)

- Which ecological entities (species, ecosystem types) is traditional knowledge based on? What kind of wild plant and animal species and ecosystem types are well known and used in the local ecological understanding in any given area by local traditional pastoralists, farmers, hunters and fishers? Which species and ecosystem types earn less attention or are overlooked?
- What are the specific short- or long-term ecological processes (incl. trends and fluctuations) that are recognized by local TEK holders and are modified by them at the ecosystem and landscape scales while using or managing natural resources? What TEK are these modifications based on?
- What locally developed ecological indicators are used by TEK holders, how are they monitored, and how is the acquired ecological understanding of changes and their drivers used in the management of these natural resources? How does TEK develop in the face of newly introduced alien species?
- What ideas and understanding do TEK holders have of the causes of ecological change, including undesirable changes linked to their own practices, as well as drivers of change beyond their control, such as climate change or policies made by remote governments? How do they mitigate adverse impacts and restore damaged populations and ecosystems? How can TEK and modern resource management develop in parallel in an adaptive, dynamic way?

Research of traditional ecological knowledge

Traditional ecological knowledge (TEK) (see Glossary) is increasingly respected and used in ecological and conservation biological research [1-3] and in assessments of biodiversity and ecosystem services (nature's contributions to people) [4-6]. TEK also contributes to the sustainable management, restoration and monitoring of natural resources and biodiversity [7-12] (See Boxes 1-3 for examples). Furthermore, Indigenous and other customary governance systems are increasingly supported by conservationists [13-15]. Conversely, scientific research can (and must) support Indigenous/traditional communities in their fight for recognition of their lands, rights to self-governance and protection of their natural resources [16-18].

In recent decades research on TEK is increasingly prevalent among both social and natural scientists. Thousands of researchers document TEK. TEK is a 'hot' topic. The commonly applied methods, namely interviews and questionnaires, are often perceived as being easy-to-use, 'soft' research (wrongly, for to use them properly takes special training), while the information gained can be widely relevant to a better understanding of ecosystem dynamics, human-nature interactions and biodiversity management [19]. TEK

comprises the space-based knowledge, practices and worldviews of traditional communities including Indigenous Peoples and other long-settled communities of farmers, pastoralists, fishers, ethnic minorities or the rural communities of the majority society applying traditional land-use practices. TEK has deep roots in the past but is not static, as it is adapted by each generation [8, 20-22].

In this paper we emphasize the necessity of participatory long-term collaborative studies in TEK research, discuss the need for deeper engagement of ecologists and conservation biologists in TEK research, and underline the importance of using culturally appropriate methodologies and being open to alternative interpretations of how nature works.

Challenges of TEK research

There are, of course, challenges. TEK is often **tacit knowledge** and represents different **knowledge systems**, embedded in Indigenous/traditional worldviews [20, 22, 23]. It is therefore difficult and often impossible to **elicit** TEK solely by interviewing, while further limitations arise in connection with quantification for scientific analysis [24, 25]. Ecologists trained in the natural sciences often regard quantification as essential, while they are less familiar with qualitative research methods and research ethics [26]. **TEK research** by ecologists and conservation biologists is therefore often dominated by short-term projects based on quantifiable interviews, questionnaires and focus group workshops, while in-depth **participatory fieldwork** and long-term, genuine collaboration with local **TEK holders** is rarely applied [27].

Consequently, the collected data are often 'distilled TEK artefacts' [28], integrated into scientific frameworks, where knowledge deemed relevant by the researcher is disconnected from cultural contexts [29-31]. The absence of cultural contexts may result in scientists developing a superficial understanding of TEK [see e.g. 32], especially if the outsider researcher is not equipped with the right cultural background and does not speak the local language [33].

TEK is created and maintained by active use. To truly understand how TEK is generated and applied, therefore, it is necessary to participate in and observe that process [34-35, Harold C. Conklin, PhD thesis, Yale University, 1955]. Without true participation and trust, TEK holders may feel frustrated [28] and may understandably withhold information [24]. Time spent in the local community can gradually engender trust and honest cooperation, and promote the reciprocity of benefits [25].

The history of TEK research is filled with regrettable incidents, especially in colonized settings [16]. However, TEK research is moving (albeit slowly, [27]) from a predominantly extractivist approach (exclusively done by outsider researchers) towards genuine collaborations. In the latter case TEK holders perceive their own objectives of collaboration, as local priorities and perspectives are respected by the researchers [35-38]. Some Indigenous scholars go further and argue that TEK research should be conducted exclusively by Indigenous/locally native scholars [16, 39]. The key ethical challenge is determining who benefits (more) from TEK research: the researchers and state institutions or the Indigenous/traditional communities [28].

Global institutions are also working for change. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) made significant steps towards an increased and more equal participation of Indigenous Peoples and local communities during its activities (e.g. in the Indigenous and Local Knowledge Task Force and by organizing dialogue workshops [5]), and works for an improved sharing of benefits from IPBES assessments [18].

The need for long-term studies in traditional knowledge research

A truly comprehensive understanding of ecological, especially **social-ecological systems** requires complex, long-term studies in order not to miss, inter alia, various complexities, slow and non-linear trends, and rare but pivotal events [40].

In TEK research as well, the importance of the time dimension cannot be overstated: it takes time and patience not only to build trusting and respectful partnerships, but also to generate common understandings and visions, to identify mutual benefits, and to delve deeper into ecological details [22, 31, 35]. As an organic part of participatory fieldwork, joining in with local activities (e.g. haymaking, herding, fishing) as well as cultural events brings researchers closer to where TEK is generated, adapted and validated. Long-term research can also increase the efficiency of knowledge co-production in topics relevant and beneficial to the local community [34, 41].

Improving ecological understanding and conservation through TEK research

Ethnobiologists and anthropologists, including Indigenous scholars have documented a diverse body of knowledge about people living/working with nature, about human-nature relationships, and about the natural environments 'managed' by these people, much of which is relevant to ecology and conservation [11, 20, 22, 42]. The literature shows that TEK can contribute to many key questions [cf. 43] in ecology. TEK may complement science with data, help generate new ecological understandings and hypotheses, and help reshape our thinking about how to see and learn from nature [22].

TEK research can lead to a better understanding of long-term processes and the coevolution of nature and humans in social-ecological systems [44], the impacts of various drivers (including the ecological impacts of traditional management practices) [11, 45], and the legacy effects of the past in modern ecosystems (see Box 1). Knowledgeable TEK holders may have a deep understanding about the distribution, dynamics, behavioural changes and intricate interactions of populations [46-48], appropriate baselines for measuring ecological change [38], and the finely tuned TEK-based adaptations of local land-use systems (Box 2). TEK research can help understand locals' perception of ecological patterns and processes [49] and develop cross-cultural ecological indicators [38]. TEK research can also document the worldviews behind natural resource management systems (Box 3) and the ways in which diverse cultures understand (model) the environment they inhabit, where not only humans, but also plants and animals have personhood and agency, and live in reciprocal responsibility [20, 22]. All in all, a better understanding of TEK can help achieve a more holistic ecological understanding of nature [23, 34].

TEK research can also widen the evidence base of conservation and develop alternative paths towards sustainability [9, 50-51]. Beyond a better understanding of the ecology of ecosystems requiring protection, TEK research can improve the understanding of the values locals place (or do not place) on threatened species and ecosystems [52-53]. Furthermore, TEK research can identify locally validated traditional management and restoration practices [3, 12], and can help prevent and resolve conservation conflicts, and develop culturally more appropriate conservation and land-use regulations [54-55]. TEK research can help build bridges between biological and cultural diversity by linking biocultural revitalization with conservation practice and by promoting local participation and Indigenous/traditional community stewardship in conservation [7-8, 50, 56]. TEK offers a rich collection of teachings and practices in which humans exert a beneficial influence on the wellbeing of our environment [23, 57] and help develop a better relationship with the Earth [20].

The need to involve more ecologists in long-term collaborative TEK research

The interests of the researchers affect which aspects of TEK are documented. For example, while most researchers studying pastoralists emphasize the deep ecological understanding that locals have of their pastures, very few publications document traditional knowledge about the 30-100 forage species consumed by livestock [58-59, but see 60]. Furthermore, whereas numerous studies have dealt with knowledge of wild medicinal and food species, the complex interaction of their management and the ecological processes at the ecosystem and landscape levels is less well studied [but see 52, 54, 61]. The Global Assessment of IPBES identified the 'syntheses of Indigenous and local knowledge about the status and trends of nature' as a global knowledge gap [18]. This gap may have arisen because ecologists and conservation biologists are underrepresented in the study of social-ecological systems [62].

We agree with Adams et al. [63] and Ban et al. [37] that there is an expertise gap: more ecologists and conservation biologists should be encouraged to conduct TEK research. We would add emphatically that there is a need for participatory long-term collaborative studies on TEK by dedicated ecologists and conservation biologists.

While cultural anthropologists would be expected to understand more deeply the cultural aspects of socio-cultural systems, ecologists would probably have greater awareness of the local ecology, the complex interactions of ecosystem functions behind ecosystem services, and the fine ecological details of conservation management. On the other hand, ecologists may have pre-imposed ideas about the ecosystem and the roles of species and humans within it, whereas social scientists might be more open to Indigenous/traditional ideas and be prepared to listen.

The limitations of expertise call for collaboration. TEK research may pose challenges to natural scientists, who may not have the requisite experience in using social science methodologies or in working with non-scientist partners, and who are usually less well-trained in qualitative research methods and research ethics [27, 64-66]. There is a need, therefore, to strengthen links with social scientists, especially ethnobiologists, who are interdisciplinary scholars by training and know the rich array of available social science theories and methods [26, 33, 67].

The definition of ecology-related TEK is far from trivial. Recognizing and respecting the differences between science and traditional knowledge, we propose the following: ecology-related TEK is what is regarded as such either by the knowledgeable TEK holder OR by the ecologist or conservation biologist OR by both [cf. 28]. Our experience shows that long-term cooperation helps this 'selection' process.

Ethical research methodology and approaches

We have shown that it is both necessary and beneficial to study TEK by cooperating in the long term with knowledgeable TEK holders and by delving patiently and deeply into the ecological details of TEK. However, the research methodologies and methods used in ecology are simply not enough for such studies, as researchers have to pay attention to further issues not usually required in ecological research. TEK research, even when focusing on ecological aspects, is primarily a social science.

The literature is rich in best practices of inclusive long-term collaborative TEK research (see references in Table 1). First and foremost, TEK holders and researchers have to accept each others' knowledge as valid and reliable within its own knowledge system. This also implies that we should not validate TEK with science (or vice versa). Science is not 'the truth' or sole reference, and alternative, equally valid interpretations of ecological phenomena may exist [20, 66, 68]. A researcher has to facilitate exchanges of knowledge in which the knowledge systems mutually recognize each other as working in parallel [22, 25]. For example, deciding on the applicability of a traditional management practice to achieve a particular new conservation objective could be the joint task and responsibility of both TEK holders and scientists/conservationists [35, 57].

Other best practices of collaborative TEK research include taking time to build genuine partnerships and determine mutual benefits, respecting the human and Indigenous rights of TEK holders, developing research plans collaboratively (avoiding extractive research and identifying local priorities for the research), promoting inclusiveness and cultural plurality, respecting diverse styles of engagement, using respectful methods, following ethical guidelines and local research protocols, providing regular feedback on results, discussing conflicting evidence with TEK holders and making data accessible to the local community while being careful with culturally sensitive information (not sharing it publicly), inviting key knowledge holders as co-authors, and promoting the development of Indigenous/traditional holder-led research [6, 16, 22, 25, 37, 63, 69, 70].

There are many advantages and challenges for ecologists and conservation biologists conducting long-term, collaborative TEK research (Table 1). Among the potential advantages are reliable results, trust and honesty between partners, the use of appropriate knowledge exchange methods and reciprocal understanding. Challenges may include understanding local ecological terms and having at least a basic prior knowledge of the studied practices, the application of social science principles and methods, including self-reflexivity, decolonizing research, and remaining willing to re-evaluate one's own understanding of the ecology of the studied landscape. Decolonizing research may mean a total change of the focus of research from the (non-Indigenous/non-traditional) researcher's focus to the agenda of the local traditional/Indigenous community and adopting Indigenous/local traditional perspectives and methodologies [16, 39, 71]. Researchers need to be more honest with, and critically analytical of, themselves about who benefits from their research.

One of the ultimate objectives of TEK research has to be to strengthen local traditional communities and their knowledge systems, for example, by promoting activities in-situ where the knowledge is produced, governed, adapted and validated. This is vital if TEK is to remain dynamic and adaptive [16, 50, 72]. Researchers and decision makers can promote government funding of local Indigenous/traditional scholars to conduct TEK research, and in general, help the continuing transmission and adaptation of TEK in situ, which may involve restoring access to land, ensuring self-governance and stewardship, and empowering Indigenous/local traditional communities [16, 71-72].

Concluding remarks

Traditional ecological knowledge is increasingly recognized in ecology and conservation. However, TEK research has begun to exhibit symptoms of the bandwagon effect, as the number of publications on TEK proliferates rapidly. We argue that for a deeper and more appropriate understanding of TEK, ecologists and conservation biologists should conduct participatory, long-term, collaborative TEK research. Without this we are losing many of the benefits that TEK could offer to ecology and conservation, while we are also less efficient at helping to sustain TEK and preventing it from becoming static or being lost in the very places where it is produced, used, governed and validated.

By participating more intensively in TEK research, ecologists and conservation biologists could obtain a deeper understanding of the ecology of the local landscapes used and managed by traditional practices and develop more efficient and sustainable conservation management practices and more inclusive partnerships with Indigenous/local traditional communities (see Outstanding Questions).

To carry out TEK research appropriately, ecologists and conservation biologists should familiarize themselves more intimately with the main methodologies and methods of social sciences, strengthen links with social scientists, apply new approaches, and decolonize the research mentality and methodology, while remaining open and willing to re-evaluate scientific understandings of the ecology of local landscapes and people's relationships with plants and animals. Collaborations with TEK holders must be carried out in the spirit of empowerment, trust and respect.

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Box 1. Hidden legacies of the past in modern ecosystems

Ecological research can easily overlook the ecological impacts of traditional management systems, especially of past management practices [45]. Until the late twentieth century, Amazonian tropical rainforests were widely regarded as pristine ecosystems, with little human impact.

Ethnobotanists working with forest-dwelling Indigenous peoples, however, discovered that locals not only use hundreds of valued forest species, but also actively manage them, implementing beneficial changes in species composition, and creating diverse forest patches that are rich in edible perennial plants, incl. many tree species [73].

Levis et al. [74] identified eight key management practices that contribute to the development of domestic forests from swidden fields or old-growth forests: removal of non-useful plants, protection, transportation and plantation of useful plants, attraction of seed dispersers, selection of phenotypes, and fire and soil management. Indigenous peoples enacted substantial and spatially extensive modifications of the species composition over large areas, creating a domestication gradient from pristine to domesticated forests.

Multiple Indigenous management practices (including cultivation without domestication and domestication without agriculture) interfere with natural ecological processes, and this must be taken into consideration by ecologists studying or protecting these forests [44]. Millennial-scale polyculture agroforestry systems have left a powerful legacy on the diversity and dominance of edible plants in modern forests across large swathes of the Amazon [74]. Substantial anthropogenic changes may be especially evident close to ancient and modern settlements and along rivers, although the extent to which pre-Columbian and later traditional societies modified Amazonian forests is still hotly debated.

Figure I. Domestic forest in the Amazon. The species composition of Amazonian rainforests is not free from human modifications, but in order to fully understand the legacies of the past, more research is needed on the often hidden forest management practices of Indigenous peoples and their impact on hundreds of forest species (Photograph: Zsolt Molnár).

Box 2. Herders' knowledge can build new connections between isolated ecological disciplines

French and Hungarian traditional herders working closely with researchers have helped open new research fields that are highly relevant to grazing ecology and conservation grazing. Traditional herders, it transpired, can modify not only the behaviour of their livestock but also the 'behaviour' (the research interest) of researchers. Ecologists have begun to examine more closely the feeding habits and preferences of livestock in species-rich pastures.

Many open habitats of temperate regions were naturally maintained by wild herbivores, later replaced by domestic livestock [75]. To prevent shrub encroachment, some contemporary conservation management practices apply domestic animals. Knowledge gaps remain, however, and further study is needed to understand why and how plant individuals are consumed in species-rich grasslands, and the overall ecological effects of various traditional herding practices. Meanwhile, millions of herders possess knowledge of livestock grazing behaviour (e.g. preferences for plant species) because their livelihoods depend on it [35, 54].

Working with traditional herders, Molnár et al. [35] found that cattle grazing in species-rich pastures displayed at least 10 different behavioural elements towards the 117 plant species studied, ranging from highly desired to totally rejected. The low discrimination error (<1%) suggests that cattle recognize most plants 'by species'.

Herders broadly understand grazing preferences towards >100 forage species and they consciously aim to modify these preferences by slowing, stopping or redirecting the herd. Herders can efficiently increase the daily biomass intake of livestock by moderating grazing (habitat and plant species) selectivity and regularly boosting the animals' appetite, encouraging the consumption of a more diverse array of plants [21].

Traditional herd management practices have significant conservation benefits, notably preventing under- and overgrazing, and the targeted removal of pasture weeds, litter, encroaching shrub, tall competitive plants and invasive alien species [35].

Knowledge co-production with traditional herders has helped to connect previously isolated scientific disciplines, namely rangeland science and vegetation ecology, which can promote the development of specific, evidence-based conservation management practices for grazed species-rich pastures in protected areas [35].

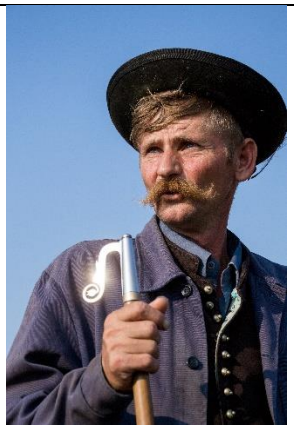

Figure I. János Máté and László Sáfián herders. Traditional herders are often highly knowledgeable about their pastures and the grazing preferences of their livestock, and modify ecological processes on their pastures by grazing, selective cutting and burning (Photographs: Ábel Péter Molnár).

Box 3. Worldviews matter in biodiversity management

Worldviews have a decisive impact on how people in various cultures perceive nature's contributions to people [4] and also influence the degree of sustainability in the use and management of natural resources. Berkes [22, 76] documented the use of TEK among Cree people in natural resource management in and around Hudson Bay, raising the question: how did the Cree avoid overfishing lake whitefish (*Coregonus clupeaformis*) and other fish species? Instead of setting his own nets, as scientists usually do, Berkes accompanied Cree fishers, collecting biological data from *their* catch. He showed that it is possible to manage a fishery sustainably, in the full sense of scientific fishery management, completely without quantitative biological data and population models.

By knowing when and where to set nets, Cree fishers exercised considerable selectivity over their catch, and were able to conserve the ecological resilience of the fish stock [76].

Berkes found that extensive TEK existed on the distribution, behaviour and life cycles of fish species essential for productive and sustainable fishing. Cree monitored the species composition and other factors (fatness, health, sex etc.) in their catches. Thinning populations with nets of varying mesh sizes, rather than using uniformly large-meshed nets, conserved population resilience [22, 76] and ensured that many reproductive year-classes remained in the population even after fishing.

This example shows that worldviews matter: the sustainability of the fishery system was due primarily to the Cree worldview, not low human population density or 'primitive' technology [22, 76]. In the Cree worldview, fish control the success of fishing, as failing to respect the fish would stop them offering themselves for human consumption.

Figure I. Cree fishers (La Grande River, Quebec, Canada). The Cree worldview and their deep ecological understanding of fish species form the basis of sustainable local fishery management (Photograph from the 1970s: Fikret Berkes).

Table 1 Potential advantages and challenges in the application of long-term, participatory and collaborative TEK research methodologies by ecologists and conservation biologists.[1]

Advantages of long-term TEK research	Challenges of long-term TEK research
• sufficient time to build genuine trust and positive enduring relationships, partnering with Indigenous/traditional scholars, and to apply Free Prior Informed Consent in culturally appropriate ways • time to adjust research plans and implementation to meet the needs of the local communities • time for careful listening, observing, embedding, discussing diverse topics, connecting more closely with the place, and obtaining deep understanding and reliable and validated results • with both partners having deep knowledge of the landscape, mutual respect for each other's ecological knowledge will enable more to be learnt about the hundreds of species and tens of ecosystem types known locally • sufficient time to understand social-ecological contexts, elicit reflections on the appropriateness of the research methodology, and find out about local stories and beliefs	• long-term research requires considerable time, and it can be challenging and burdensome to adjust research methodologies, build trust and to embed into the local culture • time and patience are needed to understand local ecological and other terms, taxonomies and biocultural indicators of species and ecosystems, specific behaviours and customs • researchers require at least a rudimentary knowledge of the studied practices (farming, herding, forest use, fishing) • the application of social science methods may pose unexpected challenges for ecologists (e.g. self-reflexivity, elicitation methods that respect local protocols and ethics); the unethical integration of 'distilled TEK artefacts' into science should be avoided

• reciprocal understanding of vocabularies (incl. folk names, taxonomies, concepts, models) facilitates mutual explanation and understanding • as compliance constraints disappear, this engenders a culturally safe environment for participants on both sides, fostering natural behaviour and honest exchanges of information, and helps the researcher to understand which research questions are really relevant to the local community • long-term interactions lead to the development of a common reference collection of situations, experiences and stories • alternating interviewing with participatory fieldwork promotes the common validation of information • rare events and hidden phenomena are more likely to be encountered as time passes, while the long-term impacts of the local land management system, such as why specific patches are rich in species while others are not, become easier to recognize • long-term presence enables TEK holders to explain phenomena as they occur, using culturally appropriate collaboration techniques and teaching methods • 'repetition is the mother of all learning' (variations help deeper understanding) • traditional learning processes can be experienced in situ • knowledge exchange and reciprocal learning can become more diverse, while regular feedback can also facilitate knowledge co-production • conducting research in the local language encourages elicitation and provides a better understanding of culture-specific concepts and words • TEK holders' knowledge and attitude may be positively influenced by the research, e.g. increased attention towards researched topics (lesser known species or ecological phenomena), which can facilitate knowledge co-production • researchers' knowledge and attitude can be affected, e.g. increased attention towards newly recognized, locally relevant phenomena, resources and drivers • one or two decades may be sufficient to recognize some of the longer-term ecological impacts of local land management practices • collaborative problem definition makes the research more relevant to TEK holders, and may even help to resolve existing conservation conflicts • research by outsiders may raise the social status of TEK holders and contribute to regional networking among TEK holders • the longer the research period, the greater the chance of more TEK-compatible forms of publication (e.g. books, 'slow' films) and of dissemination • working together in the long term facilitates the sharing of various research benefits, the availability of data and results to locals, and the development of local-led research and local careers in scholarship (support for prospective Indigenous researchers)	• participatory fieldwork implies being present in all seasons and weather conditions, from sunrise till the next sunrise • researchers need to be 'prepared for the unexpected' regarding local interpretations of ecological patterns and processes (e.g. the role of ancestors and supernatural beings), and must dedicate patience and time to the elicitation of related TEK (incl. values and worldview) • challenges for natural scientists may include participating appropriately in cultural and family events, respecting customs and taboos, and maintaining enduring relationships • a small sample size may distort research results (individual specificities, knowledge which is empirically sound but not widely shared); comparative research and an overall understanding of the local social-ecological system are needed • local political, social and historical contexts must be understood, including power relationships within the community and with government authorities • researchers need to recognize hidden conflicts with authorities that may distort the information obtained • researchers must be willing to restructure and re-evaluate their own understanding (even if learnt as 'the truth' at university) and to recognize and respect multiple ways of 'knowing' • there is a need for openness and willingness to resolve conflicts between scientific ecology and TEK (e.g. in the interpretation of data/phenomena) • careful attention must be paid to the shifting baseline syndrome (e.g. by studying local methods of knowledge generation) • if TEK is based predominantly on personal experience, temporal depth may be reduced to ca. 20-60 years • moving towards the decolonization of research (e.g. partnership in decision making during research, joint analysis and dissemination) may prove challenging • appropriate data-sharing and data-ownership practices must be developed • TEK holders' knowledge and attitude may be influenced by and hybridized with scientific understanding; TEK holders may adopt new ways of generating knowledge (e. g. internet) • possible harmful effects of research on locals (envy, publication of sensitive information); need for sensitivity to local concerns • long-term financing is hampered by the prevailing systems, which tend to concentrate on project-based, short-term research

[1] based on [6, 16, 22, 24, 25, 27, 28, 30, 31, 33, 35, 37, 39, 50, 63, 64, 69, 72, 77, 78, 79, 80, 81, 82, 83] and the personal experiences of the authors.

Glossary box

Decolonizing research: an ethically, ontologically and politically redesigned, reworked theoretical and methodological approach congruent with Indigenous and other traditional epistemologies in ways of producing knowledge; guided by the values and research agenda of Indigenous peoples and other traditional communities, it treats local and scientific knowledge and perspectives as equally valid and relevant. The main goal of decolonizing research methods is to rebalance the relations between researchers and the studied community, and ultimately to foster locally relevant research led by TEK holders.

Eliciting knowledge: stimulating the knowledge base of a knowledge holder in order to 'prompt' a verbalisation of previously unexpressed (or only partly expressed) implicit (tacit) expertise, experience etc. within a given knowledge domain, to obtain a tangible representation of this knowledge.

Knowledge co-production: a collaborative process and approach aimed at unifying a plurality of knowledge sources and types, in order to explore challenges and conflicts, to address defined problems, and to build an integrated or systems-oriented understanding of these issues. Combining science with local and traditional knowledge, for example, may result in solutions to problems that cannot be solved by one party alone.

Knowledge systems: a set of information produced following a well-defined, specific and systematic approach, using a related infrastructure of agents, practices and institutions, which contribute to the organization of information production, and the transfer and use of knowledge. Science and traditional knowledge are examples of knowledge systems.

Participatory fieldwork: a methodological approach and a flexible framework emphasizing the significance of mutual and adaptive learning processes and the involvement of local communities throughout the research process, as an important way of building trust and promoting transparency between different knowledge systems. Participatory fieldwork in TEK research aims to obtain a deeper understanding of the worldview and motivations of TEK holders and traditional practices, taking into account the local processes and priorities that may influence the outcome of a research project.

Social-ecological system: a concept highlighting the arbitrary delineation of social and natural systems; a social-ecological system is an interaction between 'a bio-geo-physical' system and a human community, characterized by a critical set of natural, socio-cultural and economic resources, building a complex system with adaptive capacity (resilience), and delimited by spatial or functional boundaries.

Tacit knowledge: implicit knowledge or 'know-how', a collection of skills, ideas and experiences which are difficult to transfer explicitly to another person verbally or in writing.

Traditional ecological knowledge (TEK): TEK may be defined as a cumulative body of knowledge, practice and belief evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment. TEK includes the worldview or religious traditions of a society. It is both cumulative and dynamic, building on experience and adapting to change.

TEK holders: community members possessing traditional ecological knowledge, and having long, direct ties to ecosystems through the management of natural resources.

TEK research: interdisciplinary research into locally relevant, culturally embedded ecological knowledge of local traditional communities, conducted following the principles, methodologies and methods of both cultural anthropology and ecology.

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