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Contributions of Indigenous Knowledge to ecological and evolutionary understanding

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Indigenous Knowledge (IK) is the collective term to represent the many place-based knowledges accumulated across generations within myriad specific cultural contexts. Despite its millennia-long and continued application by Indigenous peoples to environmental management, non-Indigenous "Western" scientific research and management have only recently considered IK. We use detailed and diverse examples to highlight how IK is increasingly incorporated in research programs, enhancing understanding of – and contributing novel insight into – ecology and evolution, as well as physiology and applied ecology (that is, management). The varied contributions of IK stem from long periods of observation, interaction, and experimentation with species, ecosystems, and ecosystem processes. Despite commonalities between IK and science, we outline the ethical duty required by scientists when working with IK holders. Given past and present injustice, respecting self-determination of Indigenous peoples is a necessary condition to support mutually beneficial research processes and outcomes.

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Humans were generating, transmitting, and applying information about the natural world long before scientific inquiry was formalized. Indigenous peoples around the world have developed, maintained, and evolved knowledge systems via direct experience interacting with biophysical and ecological processes, landscapes, ecosystems, and species over millennia (Atleo 2011; Berkes 2018). Application of these broad and deep knowledges in a scientific context has led to many contributions to the literature in ecology, evolution, and related fields, but has not yet been comprehensively synthesized.

In a nutshell:

- Indigenous Knowledge (IK) is a suite of place-based knowledges that are increasingly represented in Western science
- Using examples from the scientific literature, we show how IK has made numerous contributions to the understanding of ecology, evolution, physiology, and applied ecology
- IK is often distinct from Western science in motivation and approach, but there are shared conceptual foundations that can support productive and mutually beneficial collaborations
- Scientists should enter into a thoughtful social contract with IK holders, foremost working toward partnered research that benefits the communities, governments, and nations of Indigenous peoples

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Indigenous Knowledge (IK; as the myriad knowledges are collectively referred) and non-Indigenous science (sometimes referred to as "Western" science, hereafter "science") represent distinct but complementary ways of knowing. A universal definition of IK is precluded by its diversity. IK is generally thought of as a body of place-based knowledges accumulated and transmitted across generations within specific cultural contexts. Although we distinguish between IK and science in this paper for simplicity, Indigenous ways of knowing may be considered science in their own right that differs from science generated through Western knowledge (eg Cajete 1995; Whyte *et al*. 2016). IK in its broad scope also includes "Traditional Ecological Knowledge" (TEK) and "Indigenous Ecological Knowledge" (IEK) when knowledge relates to ecology. In the sections below, we also illustrate IK's relevance to improving the understanding of evolution, physiology, and applied ecology. IK is distinct from science, local knowledge, and citizen science in that it includes not only direct observation and interaction with plants, animals, and ecosystems, but also a broad spectrum of cultural and spiritual knowledges and values that underpin human–environment relationships (Berkes 2018). IK is often augmented with contemporary observations and experiences that refine accumulated knowledge and allow for flexibility and adaptability in the context of environmental and social change. However, scientific researchers may be unaware of these details and the cultural contexts in which IK is held, which can create tension and potential harm in projects that draw on both knowledge sources. While acknowledging these risks, we argue that these differences are also what make IK valuable for enhancing our collective understanding.

Owing to this background and the recent and global resurgence of Indigenous-led research efforts designed to support the reassertion of Indigenous authority in resource management, IK has made important and unique contributions to applied and scholarly research. The number of research papers that incorporate IK is increasing (Figure 1). While often used on its own or in parallel to science, IK is also increasingly interwoven with data collected via the scientific method, and vice versa (that is, scientific methods are incorporated into contemporary processes underlying IK generation).

The increasing incorporation of IK into research coupled with the growing leadership and involvement of Indigenous peoples in applied and theoretical research programs warrant a summary of the past and future contributions of IK to these fields. Here, we provide a synthesis and prospectus. By doing so, our intent is to introduce IK contributions to a scientific readership. We do not imply of course that knowledges must be integrated, or that IK must be published in the scientific literature to be recognized. Attending to the common challenges and opportunities of knowledge integration, however, we offer guidance for conducting research with IK in a productive, culturally sensitive, and equitable manner. We situate ourselves as academics (three non-Indigenous and one Indigenous, all of whom interact with IK holders in the context of research) who sought to synthesize the manifold contributions IK has made to the literature. Accordingly, we used several keywords ("Indigenous Knowledge", "Traditional Ecological Knowledge", and "Indigenous Ecological Knowledge") to identify candidate papers and drew on our own experiences to select flagship studies representative of a diversity of taxa, geographies, and peoples to showcase. Beyond summarizing how individual studies made notable contributions, we also describe the complementary conceptual underpinnings of IK and science that can foster informed, productive, and respectful collaborations. However, the perceptions and preferences of Indigenous peoples considering collaborations with researchers should supersede any counsel we offer here.

Considering IK in the context of Indigenous self-determination

Most ecological and evolutionary research involving IK is applied, and therefore should manifest via Indigenous-led conservation and management programs. Whereas other research objectives will no doubt continue to motivate work, scientists should transition from considering Indigenous peoples solely as participants in research to leaders in applied resource management projects supportive of resurgent self-governance and sovereignty (Thompson *et al*. 2020). Indeed, Indigenous peoples are increasingly reasserting their rights to manage land, wildlife, and natural resources around the world, rights that have been reinforced in part by legal and policy contexts at national (eg Canada's Truth and Reconciliation Commission) and international (eg UN Declaration on the Rights of Indigenous Peoples) scales (UN 2007; ERG 2008). In this regard, the recognition of the role of IK in applied ecology can be considered congruent with social justice and sovereignty (Agrawal 1995). For example, Frid *et al*. (2016) demonstrated that closures of Dungeness crab (*Metacarcinus magister*) fisheries, ordered by Haíɫzaqv (Heiltsuk), Kitasoo/Xai'Xais, Nuxalk, and Wuikinuxv First Nations in the province of British Columbia, Canada, increased the abundance and body size of crabs within protected areas. Notably, the fisheries closures were implemented using Indigenous law when the Canadian federal government failed to act on observed declines in catch rates (Frid *et al*. 2016).

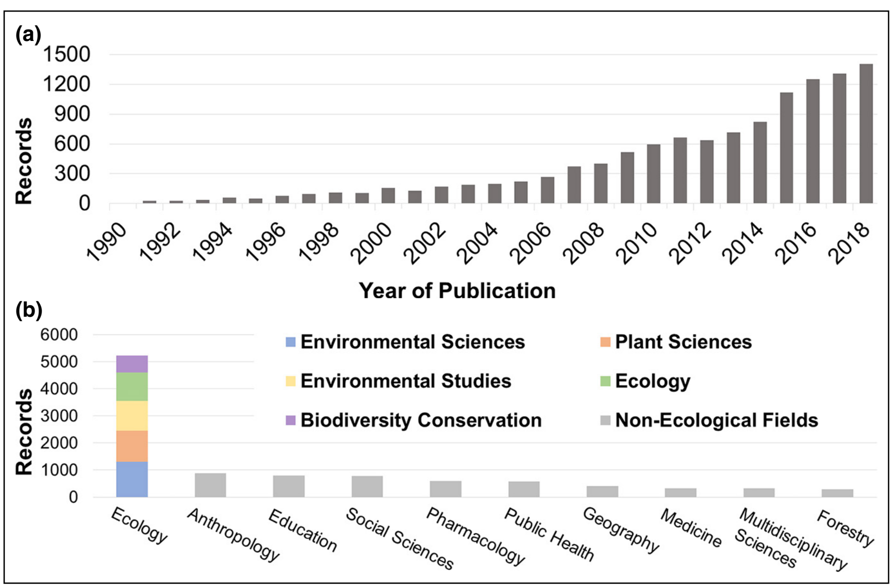

Figure 1. Research involving Indigenous Knowledge (IK) is growing and concentrated in the ecological sciences. (a) A search of ISI Web of Science for records containing the terms "Indigenous Knowledge", "Traditional Ecological Knowledge", or "Indigenous Ecological Knowledge" reveals that the number of studies involving use of these expressions has increased over time (from five studies in 1990 to 1404 studies in 2018: n = 11,934 studies collectively from 1990 to 2018). (b) The field of ecology has the most studies (n = 5228). Data from ISI Web of Science (searched July 2019).

The assertion of Indigenous rights to management and conservation of resources does not exclude the application of science, and in fact complementary approaches will likely be prevalent. For instance, in a study led by an individual who is both an IK holder and a scientist, Housty *et al*. (2014) developed and applied a monitoring program for grizzly bears (*Ursus arctos horribilis*) in Haíɫzaqv Territory (coastal British Columbia), explicitly guided by the *Gvi'ilas* (customary law) of the Haíɫzaqv people. The approach combined Haíɫzaqv cultural values with their knowledge of bears, salmon, and people in an important large watershed. Place-based knowledge of bear ecology guided the research design by informing the spatial distribution of non-invasive hair snares from which data were subsequently used in a DNA-based capture–recapture analysis. The empirical insights generated by this work provided new information about bear distribution and population dynamics, challenged existing provincial government policy, and informed the development of contemporary Haíɫzaqv wildlife management policy (Housty *et al*. 2014).

The Haíɫzaqv example above illustrates broader changes at the interface of science, culture, and management. Specifically, conservation programs are shifting away from "exclusionary conservation" (principally aimed at limiting human access to specific areas) toward more participatory "community-based conservation", which centers local peoples in the conservation process (Western and Wright 2013). Biocultural approaches to applied research and management further extend this progression by addressing biological and cultural diversity simultaneously (Stephenson *et al*. 2014; Gavin *et al*. 2015; DeRoy *et al*. 2019). IK plays a key role in such approaches by identifying biocultural indicators and engaging directly in research, monitoring, and management actions. Such biocultural approaches enhance long-term investment in conservation and management programs by preserving the linkages between Indigenous peoples and the ecosystems on which their cultures and societies depend. These connections reinforce Indigenous stewardship principles and beliefs of responsibility for upholding "human services for ecosystems" deeply embedded in customary law and teachings (Turner and Sivaramakrishnan 2008).

IK contributes to understanding both basic and applied science

After appropriate attention to important cultural and governance contexts, we now summarize the extensive contributions of IK to our understanding of the natural world. Drawing on millennia-old accumulation of knowledge and its contemporary recognition by others, IK has informed, enhanced, and complemented the study of ecology, evolution, and related fields (Figure 2). IK has been recognized in the scholarly literature as having enriched understanding of a range of individual-level processes, including behavior (eg Bonta *et al*. 2017) and habitat selection (eg Polfus *et al*. 2014). For example, Polfus *et al*. (2014) developed habitat models for woodland caribou (*Rangifer tarandus caribou*) based on IK from the Taku River Tlingit First Nation of northern British Columbia, and showed a high degree of similarity between resource selection functions (RSF) that estimated habitat use derived from IK and collared caribou. Where the models diverged, however, novel insight emerged: only IK-based models determined that burned areas were of lower quality, an effect not identified by RSF models, despite collared caribou avoiding burned sites.

IK has also contributed to the literature on population- to ecosystem-level processes. The influence of IK has included insights into population trends (eg Lee *et al*. 2018) and biogeographic patterns (eg Service *et al*. 2014). For example, Lee *et al*. (2018) coupled historical observations from the Haíɫzaqv First Nation of British Columbia with zooarchaeological and scientific data to estimate northern abalone (*Haliotis kamtschatkana*) abundance on the Pacific coast of Canada from the Holocene to the present. Historical observations offered by Haíɫzaqv interviewees with decades of experience interacting with abalone allowed for estimates of the number, size, and distribution of abalone over specific decades.

IK can also address processes at the community and ecosystem levels, including interspecific interactions (eg Wehi 2009) and ecosystem function (eg Savo *et al*. 2016). In New Zealand, for instance, Wehi (2009) analyzed Māori ancestral sayings that describe the pollination of *harakeke* (New Zealand flax [*Phormium tenax*]) by native *kākā* parrots (*Nestor meridionalis*). Because of declines in *kākā* parrot abundance, scientific data on *harakeke–kākā* parrot interactions are exceedingly rare, highlighting how Indigenous adages can make unique and timely contributions to inform restoration and conservation goals.

IK has also contributed to understanding related to evolution in many systems. We define "evolution" in this context as the outcomes of evolutionary processes (ie intra- and interspecific variation) that can be observed via observation of phenotypes. For example, IK is commonly applied to distinguish among similar but distinct taxonomic groups that emerge in biodiverse areas where field identification is difficult (eg dos Santos and Antonini 2008). In the meridian Amazon of Brazil, dos Santos and Antonini (2008), in documenting Enawene-Nawe knowledge of stingless bees, found that IK holders could discriminate among 48 different species and specify the ecological niche of each species. More recently, IK has been used to identify life-history characteristics (eg Idrobo and Berkes 2012) and population genetic structure (eg Stronen *et al*. 2014; Polfus *et al*. 2016). Polfus *et al*. (2016) described how the Sahtú Dene and Métis peoples of northern Canada distinguished among genetically different populations of boreal, mountain, and barren-ground caribou based on unique behaviors, habitat preferences, and morphology, with subsequent genetic analyses providing evidence of distinct caribou subpopulation structure that aligned with Dene classifications. In this case, convergent patterns of identification between knowledge sources, which drew inference across ecological, behavioral, and evolutionary domains, increased the certainty and relevance of classification. In doing so, this work made a substantial contribution to caribou conservation planning, a process previously fraught with difficulties in classifying herds.

Understanding of physiology can also emerge from long-term observations, including harvesting and preparing plants and animals for food, medicine, shelter, clothes, and more. Physiological domains to which IK has contributed in the literature include morphology (eg Eckert *et al*. 2018),

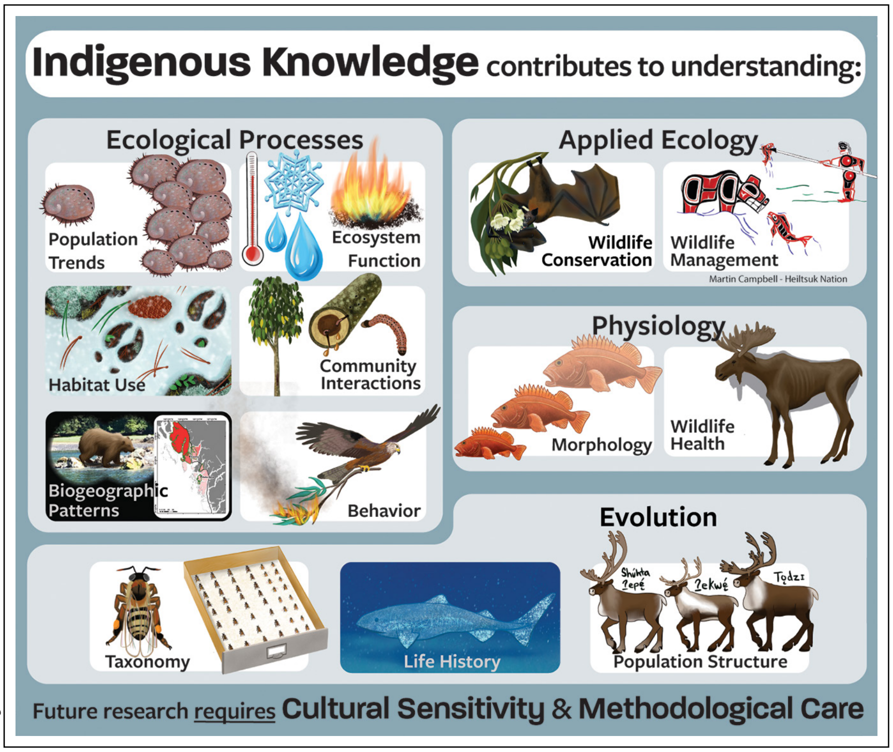

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Figure 2. Contributions of IK to the fields of ecology, evolution, physiology, and applied ecology in peer-reviewed publications. IK facilitates the understanding of population trends (Lee *et al.* 2018), ecosystem function (Savo *et al.* 2016), habitat use (Polfus *et al.* 2014), community interactions (Donovan and Puri 2004), biogeographic patterns (Service *et al.* 2014), behavior (Bonta *et al.* 2017), wildlife conservation (Hill *et al.* 2019), wildlife management (Housty *et al.* 2014), morphology (Eckert *et al.* 2018), wildlife health (Parlee *et al.* 2014), taxonomy (dos Santos and Antonini 2008), life history (Idrobo and Berkes 2012), and population structure (Polfus *et al.* 2016). Citations link to details about research summarized by each image.

metabolism (eg Idrobo and Berkes 2012), and wildlife health and body condition (eg Catley 2006). Eckert *et al.* (2018), for instance, quantified size changes in yelloweye rockfish (*Sebastes ruberrimus*) based on historical accounts from the Haíɫzaqv, Kitasoo/Xai'xais, Nuxalk, and Wuikinuxv peoples of western Canada. These accounts, drawn from measuring hand gestures of size estimates, provided more than half a century of data that extended historical baselines in rockfish size, a key proxy for fecundity and population growth. An example of how IK can provide information about health and body condition comes from East Africa. In Kenya and South Sudan, Catley (2006) found agreement in disease identification and diagnostic criteria between Indigenous pastoralists and veterinarians in their independent approaches in monitoring livestock health. Translating Indigenous terms into a format recognizable by veterinarians, and vice-versa, enhanced livestock surveillance systems by providing culturally relevant disease diagnostic criteria for use in rural areas.

Drawing on deep knowledge of organisms and ecosystems, applied ecological research involving IK has also been common, contributing to contemporary management by Indigenous and non-Indigenous governments. Long-term observations by Indigenous peoples amounts to monitoring of species and ecosystems, which carries abundant potential for rapid and sensitive detection of contemporary ecological changes (Berkes *et al.* 2007; Service *et al.* 2014; Thompson *et al.* 2019). Although (and perhaps because) it is drawn from the long-term observations of species and ecosystems, IK can also identify management objectives and priorities for the future, such as the selection of biocultural indicator species (Lyver *et al.* 2016; Sterling *et al.* 2017; DeRoy *et al.* 2019). More broadly, IK cannot be separated from the value systems that underpin decision-making processes in applied ecology (Artelle *et al.* 2018). This is a dimension of resource management that is not often explicitly considered in Western management but one that defines policy objectives, which can exert extraordinary effect. IK has also been proposed as a counter to the "shifting baseline syndrome" in conservation, wherein perspective on what abundance or other measures are "normal" is lost among generations as environmental degradation continues, resulting in lowered expectations for conservation outcomes (Jardine 2019). Provided that transmission of knowledge continues among generations, the long history of observations retained by IK holders can provide important baseline information about the past and present state of ecosystems that can inform conservation and restoration goals. This is founded upon culturally defined criteria about valued species and habitat conditions related to "what is good" and suitable for specific uses of organisms for ceremonial, subsistence, and economic purposes.

Research at the intersection of IK and science

Although distinct in origin and motivation, and often in approach, IK and science can share common properties and offer complementary conceptual underpinnings (Figures 3 and 4). Understanding these differences and commonalities can aid in collaborative research with Indigenous peoples. IK is often closely rooted in human survival and relationships between people and nature, and may furthermore tightly couple knowledge accumulation with cultural responsibility (Reid *et al.* 2020). Yet these differences in motivation and methodology can also spark novel ideas and enhance understanding of socioecological systems (Ban *et al.* 2018).

Insights from IK can be relevant at many stages of the research process, including but not limited to project conceptualization and hypothesis development. Indigenous ways of knowing can shape and detail predictions not considered by science, a reality supported by the fact that Indigenous peoples themselves regularly form and test hypotheses (Cajete 1995; Atleo 2011). For instance, Riedlinger and Berkes (2001) detailed contexts in which Inuit developed hypotheses based on their own observations, such as the prediction that increased winterkill of common eiders (*Somateria mollissima*) would follow irregular sea-ice conditions. Similarly, Bonta *et al*. (2017) tested hypotheses about how fire-foraging raptors in tropical savannas in Australia could deliberately spread wildfires by carrying burning sticks to unburned areas to flush out potential prey species. Their hypotheses were motivated and informed by observations from Indigenous peoples who often represented "firehawks" in sacred ceremonies.

Hypotheses constructed within the borders of scientific knowledge may be limited in complex or little-studied systems, a constraint IK can address. In the example mentioned above, Riedlinger and Berkes (2001) also described how Inuit observations and hypotheses of climate change in northern Canada could account for multiple interacting variables and ecological complexity, such as climate variability and sea-ice break up. Such recognition of system complexity (including synergistic and confounding variables) is characteristic of IK, with the holistic views of ecosystems stemming in part from "relational" understandings among ecosystem components, including humans (Cajete 1995; Turner *et al*. 2000; Atleo 2011). Here, relational refers to the way in which Indigenous peoples draw connections among organisms, whether through lived experience or cultural transmission. Relational understanding was showcased in an example from coastal British Columbia, where IK holders shared knowledge of two wolf (*Canis lupus*) forms, locally referred to as "timber wolves" of the mainland and "coastal wolves" of the immediately adjacent offshore islands. This knowledge was in part derived from how the area's Haiɫzaqv people related to wolves; people of the territory also differ, depending on whether lineages originate from mainland or island areas. Informed by this knowledge, microsatellite genetic data found support for the hypothesis of a genetic cline between mainland and island areas (Stronen *et al*. 2014). Such insight into hypothesis formation was made possible because relationships among people, organisms, and the environment in this area (and elsewhere) comprise a central axis around which IK is conceived, generated, and transmitted. In contrast to

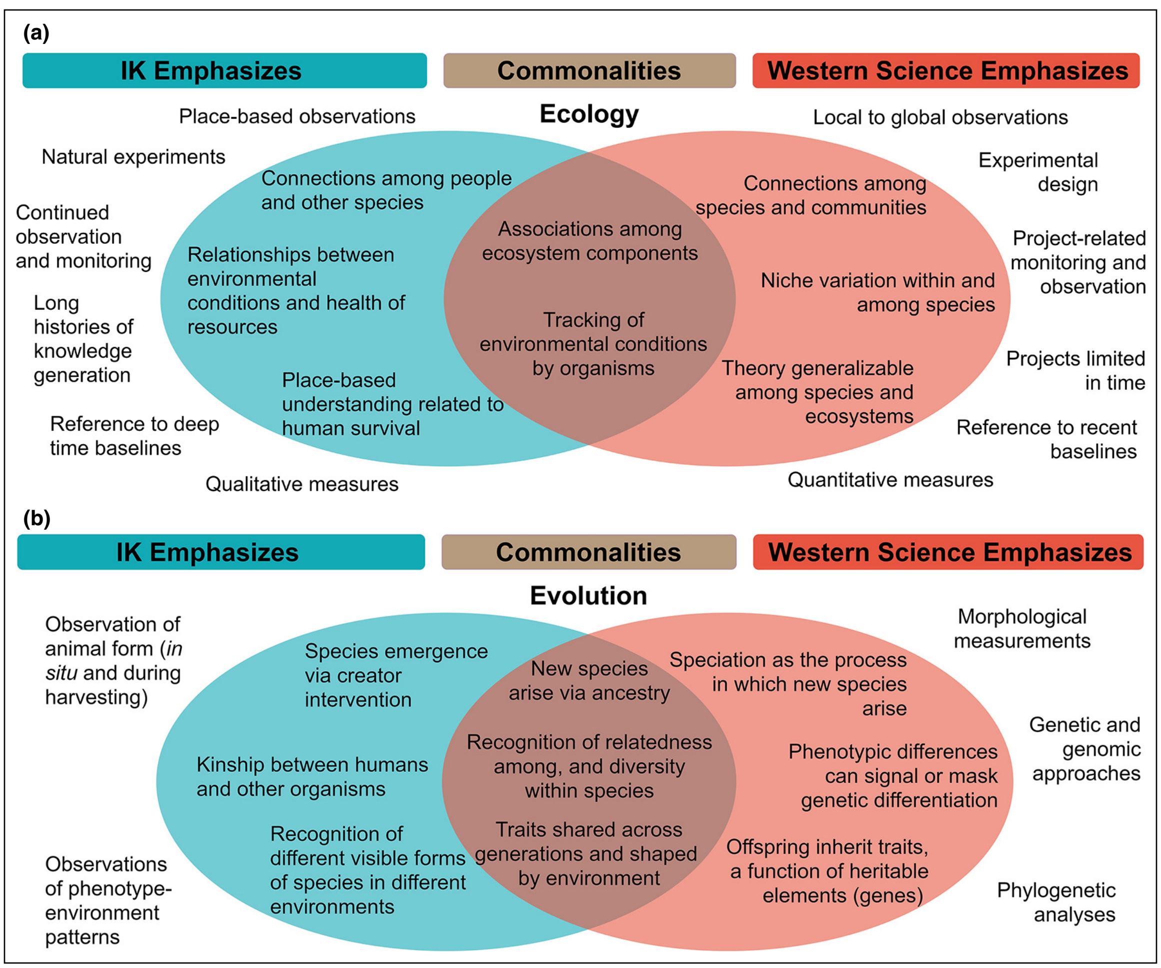

Figure 3. Conceptual foundations and approaches of IK and Western science in the fields of (a) ecology and (b) evolution. IK and Western science share similar and complementary conceptual themes (text within the Venn diagram), yet generate knowledge via different approaches (text outside of the Venn diagram) in these fields. Examples listed here are representative and not exhaustive. Crossover in themes and approaches can also be notable; for example, IK holders now commonly employ Western scientific approaches.

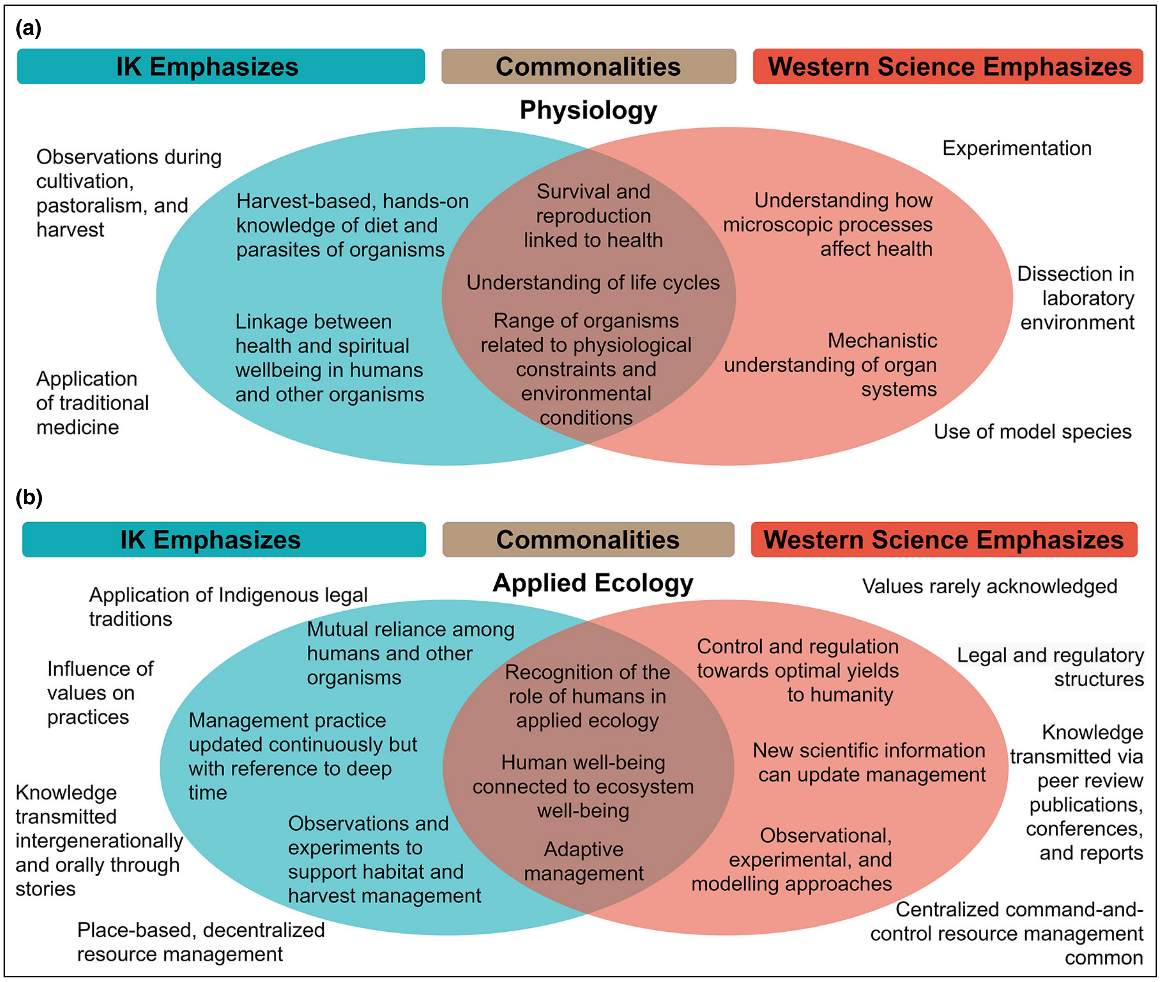

Figure 4. Conceptual foundations and approaches of IK and Western science in the fields of (a) physiology and (b) applied ecology. IK and Western science share complementary conceptual underpinnings in physiological research and applied ecology (including wildlife management), yet differ in their approach. Despite these differences, commonalities exist that can form the basis of shared understandings and mutually beneficial collaborations.

Western scientific approaches, this study highlights how IK can stimulate novel hypotheses by relating humans to non-human organisms through behavior, geography, and ancestry.

Owing in part to these relationships, Indigenous peoples are ideal partners for research about the natural world. Many territories in which cultural and knowledge transmission is ongoing also tend to be remote and biodiverse, which position these title holders (that is, legal owners of land in the context of Indigenous laws) as natural biodiversity specialists (Figure 5; Garnett *et al*. 2018). In the tropics, for example, Indigenous peoples have aided in research programs as "parabiologists" who assisted in documenting biodiversity (Sheil and Lawrence 2004). This approach offered a means for scaling-up monitoring and conservation efforts in tropical regions. In another example, Attum *et al*. (2008) demonstrated that estimates of Egyptian tortoise (*Testudo kleinmanni*) home ranges in North Sinai, Egypt, derived from radio telemetry were in agreement with estimates by Indigenous people, who tracked tortoises on foot, leading the authors to conclude that conservation efforts would be enhanced by hiring local people rather than opting for expensive telemetry equipment. In addition, their participation also enhanced insights, given that trackers could provide auxiliary natural history data whereas radio tracking was limited solely to data on movement.

Research seeking information about long-term processes is also well suited to partnerships with IK holders. Knowledge about processes that occur over long periods of time requires considerable financial, logistical, and technological resources, analogs of which Indigenous peoples have invested over millennia. Moreover, science is often competitively shaped by funding systems that prioritize shifts among different problems or geographies, as well as rapid dissemination. In contrast, IK is shaped by continued interaction and observation that occurs in and is dedicated to ecosystems of provenance. Accordingly, IK is a source of knowledge for understanding long-term processes. For example, in a meta-analysis of climatic changes observed by subsistence-oriented peoples from 2230 localities in 137 countries around the world, Savo *et al*. (2016) showed that Indigenous communities can offer long-term (~50 years) insights (eg historical and fine-scale observations) into climate-change effects, ranging from sea-level rise to reduced rainfall.

(a–c) A Bencze

Figure 5. IK holders as field experts. (a) Howard Humchitt (Haíłzaqv Nation) conducts fieldwork with graduate student Ilona Mihalik (Raincoast Applied Conservation Science Lab; University of Victoria, Victoria, Canada) – shown here examining a grizzly bear (*Ursus arctos horribilis*) hair snare – in Haíłzaqv Territory, British Columbia, Canada, as part of a multiyear research program on interactions among humans, (b) bear species (here, a black bear, *Ursus americanus*), and (c) salmon (*Oncorhynchus* spp). Humchitt has served as a crewmember for a decade on this research program; his experience and knowledge have contributed to many aspects of the research, from hair snare site selection and design to the development of hypotheses.

Research at the IK–science interface can benefit from the diversity inherent in IK approaches. Knowledge holders across distinct cultures and environments accumulate information in numerous ways, including harvesting, observation, animal husbandry, and experimentation, all supplemented by teachings from oral histories and cultural practices (Turner *et al.* 2000; Berkes and Berkes 2009). Knowledge may also be generated, transmitted, and held in different ways within a culture depending on gender, age, and cultural roles. Such conditions create specialists on certain topics, and require researchers to recognize the diversity of knowledge not only across but also within Indigenous communities. Yet these time-tested approaches can also be complemented with modern tools and techniques, including those of science that augment Indigenous ways of knowing. For instance, McBride *et al.* (2017) used Participatory Geographic Information Systems that drew upon and analyzed IK observations from Indigenous peoples across the US related to fuel load, forest type, and burn severity. The synthesized information can be used to improve forestry and fire management, including the identification of locations of prescribed burns and historical patterns of fire intensity.

The conclusions drawn from IK have interdisciplinary relevance as well. Indeed, distinct fields of study defined by scientists (as we do here) are usually not recognized by Indigenous peoples, with the insights of IK often spanning disciplinary boundaries. Reid *et al.* (2020), for instance, proposed a new way for fisheries management science to draw on the diversity of knowledge available through a "two-eyed seeing" approach, with the goal of transcending the incorporation (and often, assimilation) of IK into Western science through the adoption of an ethic and framework of knowledge coexistence and complementarity.

Guidance for collaborative research

Given the growing interest in incorporating components of IK into scientific research, we draw upon select literature and our own experience to provide guidance. At the onset of collaborative studies, scientists should first develop research agreements with Indigenous peoples in whatever form is locally appropriate, a step independent of any institutional ethics approvals. Research design should then unfold in a collaborative and transparent manner, with input from IK holders (Adams *et al.* 2014). A key principle to consider is that research shows the greatest prospects when accompanied by strong and enduring local engagement in the process.

Those seeking collaborations should be acutely aware that clear tensions exist between IK and Western science epistemologies. Collaborative research with Indigenous partners requires recognition that science and scientists have in the past and continue at present to (1) impose harm on Indigenous peoples; (2) discount IK; and (3) inappropriately reproduce, apply, or otherwise use information derived from IK (Pierotti 2012; Berkes 2018). For example, Indigenous peoples have been unwilling subjects in a variety of medical, anthropological, and ecological studies for centuries (Schnarch 2004), and science has often been used in resource extraction activities detrimental to Indigenous peoples. Furthermore, despite the validity of IK within its society of provenance, the veracity and/or legitimacy of IK is frequently called into question until it is "confirmed" by Western science (Brook and McLachlan 2005). There is often an assumption – one we wish to avoid perpetuating here – that IK must be subsumed within Western scientific frameworks of knowledge, which can force Indigenous peoples to express themselves in ways potentially contradictory to their own value and belief systems (Nadasdy 1999). This practice can distort the accuracy and applicability of IK, and is harmful to Indigenous ways of being.

Despite good intentions, the inappropriate use or reproduction of IK by scientists can also be pronounced, warranting caution during collaboration. For example, recent trends toward "open data" science may conflict with the desires of Indigenous peoples to keep cultural, spiritual, or ecological information confidential (Adams *et al.* 2014), and issues of data ownership can create tensions when IK is sensitive. Legal rights to reproduce or publish information (eg in peer-reviewed journals, or held in government databases or by academic institutions) raise the question of who are the principal owners and beneficiaries of IK-based data and research (Nadasdy 1999; Tobias 2000; First Nations Centre 2007). In practice, this historical legacy and contemporary reality present ethical challenges to collaborative research programs despite the often best intentions of collaborators themselves. Accordingly, we encourage abundant caution, and advise researchers to listen carefully to guidance from Indigenous peoples.

Addressing the challenges of collaborative research with Indigenous peoples requires a much different social contract than that with which many Western scientists are familiar. Cultural sensitivity requires that researchers employ respect, reciprocity, confidentiality, and more (Adams *et al*. 2014; Ramos 2018). Respect entails an understanding of the socioecological context of research as it relates to people and place. Reciprocity refers to an authentic and sustained effort to make available research processes (such as funding, study design, and data collection) and outcomes (such as research communications, authorship, and policy application) of benefit to the Indigenous peoples who are involved and affected, with benefits defined by Indigenous peoples themselves. Confidentiality involves respecting the privacy of information that Indigenous peoples consider sensitive, be it cultural, spiritual, or any other form of knowledge. There may be other considerations that are context-specific to a particular culture, such as resource stewardship institutions or responsibilities that have been developed through years of experience and practice (Turner and Berkes 2006; Reid *et al*. 2020). We therefore advise researchers to earn trust and foster healthy working relationships with Indigenous peoples to determine research priorities and agreements long before data collection begins (Lake *et al*. 2017). Ideally, scientists are invited to collaborate by Indigenous people to work on issues important to them, which requires a shift in thinking by scientists to not always take the lead on research development. In this process, scientists must recognize that Indigenous peoples have rights to self-determination, which extends to research partnerships and the creation and dissemination of new knowledge. With appropriate consideration of this collaborative process, the potential of IK to continue to inform scientific understanding is vast and will yield many more contributions to theory and practice.

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