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The Value of Traditional Ecological Knowledge for the Environmental Health Sciences and Biomedical Research

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Background: Traditional Ecological Knowledge (TEK) is a term, relatively new to Western science, that encompasses a subset of traditional knowledge maintained by Indigenous nations about the relationships between people and the natural environment. The term was first shared by tribal elders in the 1980s to help raise awareness of the importance of TEK. TEK has become a construct that Western scientists have increasingly considered for conducting culturally relevant research with Tribal nations.

Objectives: The authors aim to position TEK in relation to other emerging schools of thought, that is, concepts such as the exposome, social determinants of health (SDoH), and citizen science, and to explore TEK's relevance to environmental health research. This article provides examples of successful application of TEK principles in federally funded research when implemented with respect for the underlying cultural context and in partnership with Indigenous communities.

Discussion: Rather than treating TEK as an adjunct or element to be quantified or incorporated into Western scientific studies, TEK can instead ground our understanding of the environmental, social, and biomedical determinants of health and improve our understanding of health and disease. This article provides historical and recent examples of how TEK has informed Western scientific research.

Conclusions: This article provides recommendations for researchers and federal funders to ensure respect for the contributions of TEK to research and to ensure equity and self-determination for Tribal nations who participate in research. https://doi.org/10.1289/EHP858

Introduction

Traditional ecological knowledge (TEK) refers to a subset of indigenous knowledge, preserved though oral tradition and through cultural expressions such as arts, crafts, and ceremonies and the cultivation, collection, and preparation of traditional foods. The preservation of this knowledge is increasingly threatened by the loss of indigenous languages worldwide, which affects not only the transmission of TEK through narratives, storytelling, and song but also the understanding of the meaning and significance of other forms of cultural expression (Moller 2009; Montag et al. 2014).

Although TEK has evolved for millennia among many of the world's indigenous peoples, it was advanced by tribal elders in the 1980s as a conceptual framework to help promote a better understanding of the interdependent relationships between people and the natural environment (Bureau of Indian Affairs 2016). Since its introduction, interest in TEK has been growing among non-Native scientists, public municipalities, and government agencies as an indigenous counterpart to Western biomedical and environmental health sciences knowledge systems. Academic researchers and federal agencies have begun to recognize that such region-specific historical knowledge can contribute to the conservation of biodiversity, protected areas, ecological processes, and sustainability of resources on Tribal lands (Alcorn 1989; Gadgil et al. 1993; Johannes 1998). Aspects of TEK were subsequently adopted by academic and public health agencies working with indigenous communities worldwide to valorize a knowledge system that comprises rich, longitudinal data gathered by generations of observers whose lives and culture depended on this information and its use (Anyinam 1995; Ohmagari and Berkes 1997).

TEK does not, however, represent a focus on a single scientific or environmental factor and thus may be misunderstood by Western scientists who have traditionally been trained to carve out a unique and relatively narrow niche of scientific inquiry and who, despite the recent promotion of system science and transdisciplinary research, may relate to TEK only through a discipline-specific lens. Instead, TEK encompasses a broader and more multilayered understanding of the interconnection of humans and the environment and is defined differently depending on its application to resource and ecosystem management, law, mental health and substance abuse, ethnobotany, and, more recently, to environmental health and climate change research (Alcorn 1989; Tsosie 1996; McGregor 2009; Flint et al. 2011; Gone 2012; Maldonado et al. 2015; Moorehead et al. 2015).

Furthermore, whereas data collection is common to both approaches, TEK is preserved primarily as an oral tradition and is passed from generation to generation through storytelling, ceremonies, arts, crafts, and song, media that provide rich context and can flexibly evolve to incorporate new observations and understandings. Western scientists also codify knowledge, but they do so through reductionist approaches and in written form through publications, media that strive to eliminate context and rely on limited variables from which to draw conclusions.

Common themes have emerged among the various definitions of TEK and in the comparison of TEK to Western scientific tenets. For example, most definitions of TEK refer to local experience and knowledge gained over time by indigenous peoples who learned to coexist with the land, waterways, and plant and animal life (Berkes et al. 2000; Chapman 2007) and who assume that humans are one of "many interrelated components of an ecological system" (EPA Tribal Science Webinar: "Research, Traditional Knowledge and Community Health," October 2015; https://www.epa.gov/research-grants/epa-tribal-science-webinar-series-kick-research-traditional-knowledge-and-community). Various models

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have been proposed to attempt to extend understanding of the interconnectedness of humans and the environment beyond common demographic and economic variables by emphasizing the various interactions and linkages that can exist within and between system elements. One model proposed by Montag and colleagues highlights not only cultural elements to be considered but also the interactions that occur between these cultural elements and other demographic and economic variables. They define cultural elements as the dynamic processes, interactions, and aspects of a communal society that shares common values, beliefs, and spiritual constructs and practices toward their relationships with the land, traditional cultural activities and way of life, interpersonal and intergenerational relationships, communication (including language), arts, crafts, ceremonies, governance, law, and other social aspects such as "material, intellectual and emotional features" (Montag et al. 2014).

TEK has also been defined as representing the generation, accumulation, and transmission of knowledge and the adaptive management of local ecological resources (Berkes 2000). TEK represents the use of local institutions to provide leaders and environmental stewards with rules for social regulation and for the development of appropriate world views and cultural values. Beyond shared principles of factual observations and comanagement principles, the broader aspects of TEK represent an expansive and deeper understanding of the interaction of humans with multiple levels of the physical, social, and spiritual environment. Concepts of indigenous knowledge, Indigenous ethics and values, and culture and identity as they relate to land and wildlife stewardship hold great promise for more effective resource management as well as for more effective human health risk reduction (Houde 2007). One example occurred during the 1990s when Alaska Native whalers worked with Western scientific researchers to determine the population distribution and behavior of bowhead whales. This traditional food source has been greatly diminished in recent years by natural (weather-related) and manmade (resource mining–related) stressors, but this joint undertaking led to "significant advances in the understanding of the species and greatly improved the ability of resource managers to develop appropriate whaling regulations" (Huntington 2000). Given the nutritional, social, and spiritual importance of bowhead whales to the local communities, this collaborative approach proved beneficial to both the researchers and to the Alaskan Natives' maintenance of their cultural practices and traditions.

By 2002, academic investigators familiar with the concepts and principles of TEK began to consider, compare, and, in some cases, attempt to incorporate indigenous knowledge systems with Western scientific models and educational settings (Molina-Andrade and Mojica 2013; Huntington 2000; Huntington et al. 2004; Profitt 2013; Dube 2013). One example is the development of science, technology, engineering, and mathematics (STEM) programs in Alaska that combined Western science curricula with TEK (Nicholas-Figueroa et al. 2015). Before the 1960s, the majority of indigenous students seeking an education moved from their villages to regional population hubs to attend boarding schools. Based on Western curricula, boarding schools did not recognize TEK. In addition, postsecondary education opportunities in Alaska were only available in Fairbanks, Anchorage, or Sitka, where TEK or Alaskan Native world views were not addressed in science course offerings. Upon gaining the right to provide education at the local level, the North Slope Borough (NSB) of Alaska incorporated Iñupiat educational philosophies into the educational system and, in partnership with the University of Alaska Fairbanks, established Iḷisaġvik College, the only tribal college in Alaska. Now independently accredited, Iḷisaġvik offers 2-y academic degrees and certificates in Allied Health programs and is developing STEM programs. Iḷisaġvik sought to broaden STEM education on the North Slope to courses bridging TEK and Western science. Courses have been developed as a means of introducing STEM education to North Slope students and preparing these students for research in fields such as climate science. Relationships between local and visiting educators, scientists, community scholars, and elders have all helped to facilitate closing the gap between TEK and Western science (Nicholas-Figueroa et al. 2015).

Another example is the use of digital storytelling. When indigenous language, music, and imagery are used to convey the findings of environmental health or biomedical research and related health risks, they can support the maintenance and ongoing use of that language and can contextualize the Western scientific research within a more appropriate cultural modality for the intended audience. This has been the case with ethnographic digital storytelling utilized by an increasing number of researchers including those working in the environmental health sciences (Belcourt et al. 2014). These researchers implemented a systematic modification of the evidence-based risk message "to consider language, culture, and context in such a way that it is compatible with the client's cultural patterns, meanings, and values" (Bernal et al. 2009). Digital storytelling is being used as an innovative approach to addressing health and social disparities, particularly in research in indigenous communities, because it shows respect for indigenous knowledge, voices, and experiences (Cueva et al. 2015). Further, digital storytelling has the potential to preserve and promote indigenous wisdom, "celebrating myriad stories, lived experiences, and life worlds while engaging community members and developing capacities for health behaviour change" (Wilcox et al. 2012). The use of digital storytelling exemplifies how Western scientific findings can be combined with indigenous cultural expression to effectively bridge traditional knowledge with Western science. The digital storytelling modality may not only represent the successful bridging of indigenous and Western knowledge systems but also may encourage preservation of traditional languages and improve the effective dissemination of important health messages to tribal communities.

Despite the promise of improved knowledge, there are significant challenges to cross-applicability of TEK and Western science when these knowledge systems are compared. One of the major challenges is that Indigenous knowledge and TEK lose their meaning when disconnected from their original context and applied within a Western scientific setting. Given the holistic nature of indigenous knowledge, TEK should be understood as a "package deal" that includes the original cultural, social, and ecological context, and without its requisite components, it cannot function or be appropriately applied in research settings (McGregor 2008). The Alaskan STEM program succeeded because it did not attempt to incorporate TEK as a component of the Western scientific curricula but rather because the science courses are based on Iñupiat educational philosophies and world views, and new courses were developed that bridged both the Western and indigenous knowledge systems. This approach circumvented the subsuming of TEK into the dominant knowledge system and instead situated both knowledge systems as valid and as a complementary basis for an understanding of the local environment.

A second challenge is the inextricable link between TEK and indigenous language and culture. We agree with the viewpoints of investigators who conducted a 14-y research project "Kia Mau Te Titi Mo Ake Tonu Atu" (the "Keep the Titi Forever" research project among the Maori) who argue that "oral traditions offer a wealth of information" that would be relevant to Western scientific investigations, but this information "is frequently overlooked or unrecognized because of a lack of knowledge of te reo Maori

(the Maori language)" (Wehi et al. 2009). Highlighting the value of TEK for federal research and services may therefore enhance scientific investigations as well as benefit those tribal communities striving to preserve their traditional culture and who recognize preservation of language as a key component of their cultural heritage.

In addition, early recognition of the potential value of incorporating TEK into Western scientific investigations has been met with resistance from Tribal citizens. In recent meetings at the Smithsonian Institution and at the National Institutes of Health (NIH) that highlighted the value of TEK, several indigenous researchers and community members have expressed concern about a variety of potentially negative outcomes, including usurpation of traditional knowledge by non-Natives, misuse or misrepresentation of such knowledge (as has been done with dreamcatchers and sweat lodges), or diminution of TEK data to fit the parameters and interests of academic investigators and funding agencies, among others. The commercialization of Native symbols, such as dreamcatchers, can rightfully be perceived as disrespectful of their original purpose and context; however, the usurpation of sweat lodges has the potential to cause harm to participants when conducted without the appropriate knowledge or spiritual, emotional, and physical context that has been carefully preserved for centuries by indigenous tribes as central elements of these ceremonies. Such was the case in October 2009 in Sedona, AZ, when three individuals died and more than a dozen others were taken to the hospital from participating in a botched sweat lodge ceremony run by a non-Native self-help guru from California (Lacey 2010).

Federal Interest in TEK

A holistic approach to environmental health is one reason for academic and federal interest in TEK. Because TEK represents an understanding of the interconnectedness of environmental factors and human health, it has striking similarities to the concepts of the exposome and social determinants of health (SDoH). The concept of the exposome, first articulated by Wild in 2005, "encompasses life-course environmental exposures (including lifestyle factors), from the prenatal period onwards" and is being used in the environmental health sciences to denote the totality of human environmental exposures that, together with genomics, could provide a fuller picture of factors that influence health (Wild 2005; Pleil 2012; Wild 2012). TEK can also be understood as overlapping, philosophically, with the concept of SDoH, particularly because these factors contribute to health disparities. Since the establishment of the Office of Minority Programs at the NIH in 1990, there has been an increasing focus on and consideration of the role of SDoH in research funded by the NIH. Such research has demonstrated how SDoH play a key role in health and contribute to health disparities (Macgregor 1961; Blane 1995; Brunner et al. 1997; Marmot et al. 1997; Wilkinson 2000). Although the concepts of the exposome and SDoH overlap with definitions of TEK (Figure 1), the exposome does not take into account the spiritual and cultural aspects underlying health that are so central to TEK. In addition, although SDoH do encompass spiritual and cultural beliefs, Western scientific research on SDoH continues to grapple with measuring the social dimensions of health and with fully incorporating qualitative data on nonbiological influences on health. In addition, SDoH research may or may not explore the interconnectedness of social, environmental, and biological factors as TEK frameworks allow.

An additional factor in the federal interest in TEK is its philosophical relationship to citizen science. Although citizen science–type activities have existed for over a century in fields such as ornithology (Clavero and Revilla 2014), citizen science

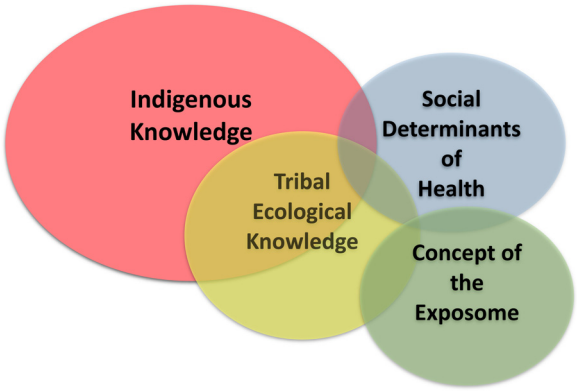

Figure 1. Overlap between Western scientific constructs and traditional knowledge systems.

emerged more recently as a potentially viable and sustainable form of public involvement in scientific research (Bela et al. 2016). A Native American whom one of the authors queried about the relationship between TEK and citizen science referred to herself as an "Environmental Champion" rather than as a citizen scientist but likewise asserted a desire for local involvement, management, even ownership of research activities and scientific findings affecting her community K. Cook (oral communication June 2015). To the authors, Native Americans represent a form of citizen science, and the efforts to respect TEK face similar challenges to those faced by citizen scientists when they attempt to democratize research (Silka 2013).

TEK, Environmental Stewardship, and Tribal Self-Determination Policies

The relationship between environmental stewardship and TEK cannot be discussed without an appreciation for the unique historical, political, and legal status of Tribal nations as distinct sovereigns, particularly within the boundaries of what is now the United States (Ranco et al. 2011). Indigenous people worldwide inhabit approximately 85% of lands designated for biodiversity conservation and struggle for preservation of cultural lifestyles, languages, and control and protection of traditional lands (Schmidt and Peterson 2009). In the United States and Canada, Tribal nations possess inherent sovereign powers over their citizens and territories that predate contact with Europeans. Recognition of this unique status has been codified in a number of ways: for example, the U.S. Constitution, numerous treaties, Supreme Court decisions, case law, and executive orders. Despite this recognition, history has many examples of tribal sovereignty being ignored. It was not until the second half of the 20th Century that the federal government passed laws and established policies that promoted Tribal self-governance and self-determination.

The Indian Self-Determination and Education Assistance Act (1975), also known as Public Law 93-638, authorizes Tribes to contract for the administration of federal programs that can include aspects of environmental protection and management as well as a number of health, education, justice, and law enforcement programs. The policy of self-determination can enable Tribes to define environmental justice themselves and to implement regulatory programs necessary to achieve their visions (Grijalva 2011). This policy is an additional factor that underlies the interest in TEK and the movement toward Tribal self-governance and increased self-management of their land and resources consistent with local cultural and spiritual practices.

Tribes and Tribal organizations have rightfully asserted the value of their tribal-based knowledge systems and long-term

commitment to natural resource management. Self-determination and self-governance authorities provide Tribes with the opportunity to design and administer programs to meet their specific needs. For example, the majority (>350) of the 567 federally recognized Tribes in the United States operate their own health programs through self-governance compacts, constituting approximately 1.8 billion USD (or nearly 40%) of the Indian Health Service (IHS) budget. Tribally operated programs are more likely to include programs that incorporate TEK.

The incorporation of TEK in tribal-based programs is grounded in culture- and geography-specific attributes of human interactions with their environment. TEK represents a holistic perspective that is uniquely local and Tribally driven. Many Tribes have maintained their unique views of human–environment interactions despite systematic deconstruction of their societies and centuries of oppression and maltreatment. Somewhat widely accepted notions of pan-Indianism based on assumptions of homogeneity among indigenous peoples flatly ignore the cultural, geographic, and societal diversity between and among these populations.

Respect for the knowledge base maintained by individual Tribal communities is an opportunity for federal agencies to further promote the sovereignty of tribal nations and to reflect the government-to-government relationship. Additionally, an appreciation for TEK as a valid knowledge base could provide a foundation for effective comanagement approaches between Tribes and the federal government, and this model could be adapted to provide a means to comanage other environmentally sensitive areas where conservation, local cultural practices, and environmental justice may be of concern.

Objectives

Given the many aspects of ecological and human health that TEK encompasses and that are relevant to Western scientific research, it may be increasingly important to Western scientists to understand the full scope and potential value of TEK. In addition to consideration of how TEK may inform research, the far-reaching political and social implications of research with Tribal nations suggests that TEK may be an appropriate component of policy development and regulations related to a variety of social and environmental events and exposures (Gómez-Baggethun et al. 2013; Hoover 2013; Ignatowski and Rosales 2013; Vinyeta and Lynn 2013).

We make the case in this article that TEK has valuable contributions for environmental health sciences and biomedical research and that it can provide a more nuanced, multileveled, and holistic consideration of the interactions between humans and the environment. TEK not only enriches our understanding of complex systems but also could potentially be integral to a more comprehensive understanding of factors that affect, support, and preserve health. The recognition of the value of TEK and its application in research activities may also benefit tribal nations as an effective basis for addressing health disparities, particularly those arising from combined environmental and social factors, as well as a means for preserving language and maintaining traditions that promote resilience and well-being.

Discussion

TEK and Western Science: A Comparative Perspective

TEK is similar to Western science in that both are dynamic and evolve over time. Further, TEK and Western science emphasize feedback learning, and both have developed methods for dealing with the uncertainty and unpredictability intrinsic to all ecosystems. A TEK approach to understanding the complex workings of ecosystems includes consideration of the determinants of behavior among the total biological community (Freeman 1992). TEK also enables an understanding of how key components of the ecosystem interrelate and how changes in the ecosystem can result in predictable outcomes (Freeman 1992).

Whereas current Western research perspectives rely on reductionist approaches and collection of increasing amounts of data, TEK seeks to comprehend the system as a whole and is concerned mainly with the use of salient aspects of the ecosystem to achieve predictive outcomes (Freeman 1992). Western science, on the one hand, often focuses on a linear process of cause and effect and goes to great lengths to create a controlled environment with limited experimental variables to achieve statistical significance. In addition, Western scientists must deal with background noise, control for potential confounding, and conduct myriad statistical tests to be credible. TEK, on the other hand, relies on observational data gained over long periods of time that are collected, filtered, and analyzed by the original supercomputer: the human brain (Freeman 1992). Ideally equipped to deal with incomplete data sets, the human central nervous system can filter out background noise, discern chaos, draw conclusions from disparate data sets, and is constantly being updated from interaction with changing environmental circumstances (Freeman 1992). Most importantly, the brain uses comparative analysis, comparing what is happening now to what has happened in the past to predict future outcomes (Freeman 1992). Instead of removing a phenomenon or experience from its context, TEK seeks to gain an understanding of the relationships between important predictive variables in the context of a changing environment. This ability to adjust predictions based on changing conditions is exemplified by the applicability of TEK in locations where rapidly changing climatic conditions are affecting the accessibility of traditional foods. TEK allows consideration of ongoing changes in ecosystem and human health over long periods of time and thus may provide a more accurate sense of risk to the types of changing conditions, such as drastic changes in average temperature, that have occurred periodically. This complexity may be unwieldy and seem impractical to the Western scientific community and may require a paradigm shift away from the dominance of scientific tenets underlying research on tribal lands, but it is essential to understanding complex systems from an Indigenous perspective.

To explore the paradigm shift toward greater respect for TEK, the National Institute for Environmental Health Sciences (NIEHS) in collaboration with the IHS, the National Institute on Minority Health and Health Disparities (NIMHD), the Centers for Disease Control and Prevention–Agency for Toxic Substances Disease Registry (CDC-ATSDR), and the Smithsonian Institution organized a workshop at the NIH that highlighted the value of TEK for the environmental health sciences and biomedical research. The workshop included a variety of case studies, the majority of which were presented by tribally affiliated investigators. Their presentations demonstrated the potential of TEK for addressing environmental health, reproductive health, mental health, ecosystem imbalance (contaminated water and air), and climate change, among other topics. Presentations also identified specific areas where TEK might be more appropriate than Western scientific approaches to address the need for sustainable housing in severe weather events or to provide culturally consonant responses to natural and man-made disasters on tribal lands affected by resource extraction and disaster events, such as oil spills in coastal waterways or chemical spills from mining operations (http://www.niehs.nih.gov/about/events/pastmtg/2015/tek_workshop/index.cfm).

Consistent with the thinking expressed at the workshop and the position of Tribal thought leaders on the topic, we suggest here that the environmental health research community

value TEK on its own terms, as carefully gathered longitudinal observations and useful knowledge that can contribute significantly to scientific investigations. We caution against TEK being treated as simply an adjunct to Western quantitative approaches or as an element to be "integrated" into Western scientific studies.

The Value of TEK in the Context of Federal Funded Research Priorities and Programs

The importance of considering TEK in research programs designed to address the environmental, social, and mental health of Native Americans has become more widely recognized at the federal level.

More than a decade ago, the U.S. Environmental Protection Agency (EPA) recognized the need for Tribal-focused research to better characterize impacts of pollution on traditional diets, cumulative exposure risks, and impacts of climate change to inform decisions to reduce health risks. Among a range of environmental health focus areas, the National Center for Environmental Research has funded several TEK-related research projects through its Science to Achieve Results (STAR) program. These projects have included the development of fishery maps to allow subsistence fishermen to maintain traditional practices while reducing the risk of mercury exposure; teaching TEK to children in their Native language to increase Native language skills and cultural relevance; exploring the impacts of harvesting traditional foods on nutritional health as well as for its other social and cultural benefits; and utilizing TEK to develop conservation policies protecting vulnerable plants while encouraging sustainable, cultural use of resources by Tribal citizens. Future directions for U.S. EPA-funded Tribal research will include protection of drinking water from enteric pathogens, protection and use of native plants, health impacts of climate change, impacts of endocrine-disrupting chemicals, indoor air quality, and cumulative risk related to ingesting traditional foods, among others (https://www.epa.gov/research-grants/tribal-environmental-health-research).

The NIH has also developed programs that focus on addressing health and environmental issues in Native American populations and that encourage the use of theoretical frameworks based on TEK or on the broader concept of Indigenous knowledge (IK), or on both, as valued components of the research programs. By including tribal-based knowledge constructs, these programs have a greater potential for effectiveness and sustainability well beyond the limits of funding.

The Native American Research Centers for Health (NARCH) program is one example of a program that promotes the validity of TEK as a theoretical framework for Tribal-based research. This long-standing program supports collaborations between federally recognized American Indian and Alaska Native (AI/AN) tribes/tribal organizations and research-intensive academic institutions (https://www.nigms.nih.gov/Research/CRCB/NARCH/Pages/default.aspx). The program also supports faculty development of AI/AN scientists to increase the capacity of both AI/AN organizations and research-intensive institutions to allow for cultural relevance and sustainability in indigenous health research.

In addition to the use of TEK theoretical approaches and the advantages of building capacity, NIH programs have explored the value of TEK for sustaining interventions and public health initiatives. The ability of TEK to sustain these invterventions and initiatives is particularly important because academic-based research interventions have had limited success in addressing tribal health disparities, which remain disproportionately high compared with the general U.S. population (Espey et al. 2014; Herne et al. 2014; Kunitz et al. 2014). A further example is the trans-NIH Intervention Research to Improve Native American Health (IRINAH) program that has promoted interdisciplinary research and has emphasized the implementation of interventions rather than simple characterization of health and environmental disparities. The IRINAH program requires researchers to partner with communities to incorporate concerns and issues of the community; to adopt conceptual frameworks, such as TEK, that are relevant to NA populations; and to implement appropriate study designs to address the complex and multilayered causes of health inequities. Several IRINAH projects also exemplify the importance of translating research results in the context of TEK. These projects include research conducted with the Blackfeet and Nez Perce in Montana that explored the efficacy of woodstove filters and education as interventions to reduce respiratory disease among tribal elders (Ward et al. 2017). This study, conducted by environmental health scientists and an American Indian clinical psychologist, utilized digital storytelling to deliver health risk messages in local tribal languages. These messages were disseminated to local indigenous communities via You Tube (https://www.youtube.com/user/anniebdnative). In addition to using Native language, music, and imagery in the video stories, the researcher culturally adapted the dissemination of the research findings in more positive terms that would be more meaningful to the audience. Instead of focusing on avoiding the health risks associated with the burning of poorly seasoned wood, one of the videos highlighted the important traditional use of fire for the local Tribes and then discussed the need for using dried and well-seasoned wood as a means of avoiding respiratory risks (Belcourt et al. 2014; Yuan et al. 2015) Digital storytelling has emerged as an emotionally engaging medium that has been adopted by a number of different American Indian and Alaska Native communities as a means of translating scientific evidence into culturally appropriate risk messages (Cueva et al. 2013).

For several decades, the NIH has also supported individual research projects that have included elements of TEK. Early examples of the implementation of TEK in research were the projects conducted among the Akwesasne Mohawk in New York, who sought evidence to address their concerns about the toxicity of their traditional foods and the degradation of waterways within their territory. The Haudenosaunee Environmental Task Force was instrumental in identifying specific environmental concerns, such as high concentrations of polychlorinated biphenyls (PCBs), and this Tribal organization served as the principal investigator for toxicological and environmental research that established the connection between industrial pollutants, contaminated fish, and reproductive outcomes (Fitzgerald et al. 1998; Schell and Tarbell 1998; Goncharov et al. 2008). These projects involved qualitative research (i.e., interviewing elders and their families in the Mohawk community of Akwesasne) about environmental impacts and the translation of these data to develop a culturally specific, integrated model of environmental health, risk, and restoration (Arquette et al. 2002). The Akwesasne Task Force on the Environment continues to explore the impact of PCBs on tribal health and has identified attention deficit hyperactivity disorder (ADHD) and diabetes as additional health outcomes from this exposure (Newman et al. 2014; Aminov et al. 2016).

Other NIH-supported projects have focused on maintaining the safety of traditional food sources, such as fish and other sea animals; still others have focused on children and environmental influences on asthma or on other social stressors resulting in alcohol and drug dependence. For example, a study begun in 2003 determined the incidence and prevalence of domoic acid–related illness among four coastal Tribal communities in the Pacific Northwest. This study has provided a rational basis for shellfish regulation by the tribe and for preventive education to these disproportionately exposed and medically underserved Native American communities (Boushey et al. 2016; Roberts et al.

2016). The educational components relied on TEK to deliver risk messaging and education to the tribes in language that acknowledged the cultural significance of the shellfish and the role that shellfish gathering played in tribal community life (Tracy et al. 2016).

For many years, other federal agencies have recognized the value of TEK for programs and services that involve Tribal communities. An informal trans-federal working group was established nearly a decade ago to allow agency personnel to share their experiences related to TEK and to inform each other of research, meetings, web sites, webinars, and other resources that focus on TEK. Led by the National Park Service and the U.S. Fish and Wildlife Service, this informal working group includes representatives of the Bureau of Indian Affairs, the U.S. Department of Agriculture Forest Service, the Bureau of Land Management, the Bureau of Ocean Energy Management, the Department of the Army, the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, the Department of the Interior, the U.S. EPA, the IHS, and the NIH.

The Benefits of TEK for Interventional Research to Address Native American Social and Cultural Integration

For many Native people, historical relocation from ancestral lands and impacts on families resulting from the boarding school experience disrupted the transmission of knowledge from one generation to the next. Children removed from their families were forced to rely on each other rather than on parents and elders for support, creating generations of youth for whom there was little systematic building of cultural and life skills (Yellow Horse Brave Heart and Debruyn 1998; Yellow Horse Brave Heart 2000, 2011). To address this historic loss and the consequent continuing problems, interventions that have focused on cultural reintegration have opened the way for Native scholars to strengthen and evaluate the effects of ongoing and reclaimed cultural practices in building communities, strengthening families, and supporting individuals across generations. For example, an intervention focused on re-creation of the ancestors' walk of the Trail of Tears sought to examine the current understanding of ancestral reasons for choosing removal over assimilation (Schultz et al. 2016). Another exemplary intervention developed culturally grounded social skills aimed to increase cultural belonging and to build cultural integration and resilience to prevent substance abuse among tribal youth (Thomas et al. 2009, 2010, 2011; Donovan et al. 2015). This intervention used the metaphor of the canoe trip to teach long-held cultural values and to reintegrate youth through traditional knowledge and practices as a resilience-based preventive intervention to address youth suicide. This program encouraged investigators to use methods and approaches that bridged and equally valued traditional and Western scientific knowledge systems, and it developed interventions that prioritize the holistic relationsships between people and the physical and social environment in which they live.

Partnerships between Native scholars from academic institutions and Tribal communities have productively shed light on the psychosocial consequences of cultural and environmental events such as the effects of the 23 March 1989 Exxon *Valdez* oil spill on the Alaska Native communities living along >500 miles of the southwestern coast of Alaska (Manson 2015). Documented changes in traditional social relationships associated with the degree of exposure to oil contaminants were associated with several parentally reported outcomes in children, including difficulty sleeping, decline in school performance, fear of being left alone, and increased difficulty in getting along with other children, parents, and siblings.

These projects demonstrate the importance of integrating traditional knowledge with scientific research in ways that produce meaningful outcomes that would not otherwise be possible. Having a perspective that values traditional knowledge allows investigators to understand health processes beyond the biological mechanisms that operate within the individual body, organ system, cell, or gene to see the context that contains and often catalyzes health outcomes.

Conclusions

TEK has been used in parallel with Western scientific approaches to characterize and manage resources and ecosystem health (Pita et al. 2015; Pert et al. 2015; Polfus et al. 2014). Given the place-based nature and intergenerational transmission of local knowledge inherent in TEK, TEK can be viewed as a Tribal form of citizen science and as a grassroots response to environmental health risks. It can serve as a culturally based framework that allows local community members to actively participate in identifying and addressing lifelong and multiple environmental exposures that affect their health. However, proponents of TEK, unlike citizen scientists, seek not only to increase scientific and environmental health literacy in their communities but also to assert the need for scientists and the research enterprise to respect and honor local ecological knowledge that can help generate relevant research questions and improve the interpretation and validation of study results.

TEK stands on its own as the Indigenous complement to Western scientific understanding of environmental and health disparities among American Indians, Alaska Natives, and Native Hawaiians. The inclusion of TEK, as well as the broader topic of IK, with Western scientific research will contribute to more meaningful and generalizable outcomes. Indigenous knowledge is used as the basis for local-level decision making in many rural communities. However, conceptual models are needed that discuss, articulate, and operationalize IK and TEK principles in relation to studies that explore the environmental, cultural, and social determinants of health. Use of these conceptual models and the principles of IK and TEK in research would also require a paradigm shift in how Western-trained scientists understand and respect the "ways of knowing" shared by Indigenous community partners engaged in scientific research.

Knowledge gained from a TEK perspective, situated in the cultural and spiritual context in which it was acquired, has the potential to improve scientific models of ecosystem and human health and to inform policy and decision making in important ways. Through collaborative approaches to scientific research and shared policy and resource management decision making, Tribes and the federal government will be better informed to develop models for sustainable practice and to create lasting policies that enhance the health and quality of life for American Indians, Alaska Natives, and the nation as a whole.

The authors respect and appreciate the importance and value of TEK for a better understanding of the complex relationships among all organisms contributing to a healthy ecosystem, including humans. Elucidating predictive SDoH, often conceived and conveyed in qualitative terms, may help our understanding of ecological health, particularly in Tribal communities and perhaps also in other nonindigenous communities. The authors propose further dialogue between academically trained scientists and recognized tribal TEK experts to focus on how their respective "ways of knowing" can inform each other to arrive at a fuller and deeper understanding of contemporary challenges in ecological and environmental health.

Recommendations

Based on experiences gained through NIH-funded studies and discussions at the TEK Workshop and other Tribal summits, the authors posit that it is imperative that Tribal community members are engaged in developing and framing all aspects of research questions; that research funders require transdisciplinary, team-based science; and that funders and academic and community partnerships support development of conceptual models for articulating, integrating, and operationalizing the role of culture in assessing and mitigating impacts. In addition, the authors recommend that the scientific community utilize more formal mixed-methods research blending qualitative and quantitative investigative approaches and that researchers be required to devote greater attention and to more aggressively disseminate results and implementation to those who participated in the studies.

Additionally, those who participated in the Smithsonian Health and Culture Working Group and attendees of the TEK Workshop recommend that underlying attitudes and frameworks be carefully reevaluated when conducting research with Tribal nations. This reevaluation includes the need to do the following:

- Increase respect for indigenous culture in research. Respect would be demonstrated by treating IK and TEK as data that are as valid as statistical data for assessing the health of tribal communities. Respect for TEK and indigenous culture would also entail promoting health and health care as a continuum, from health promotion and disease prevention to treatment and aftercare, and integrating culture and spirituality components of health into care planning. An additional form of respect would be to dispel the notion of pan-Indianism (i.e., respect the differences between Tribes).
- Encourage studies that elucidate components of resilience and health rather than focusing solely on disease management. Increased funding is needed for research into protective factors, and on individual and community resilience, that incorporate TEK and cultural practices.
- Support collaborations between Western scientists and Tribal researchers and between biomedical, environmental, and social scientists. The development of conceptual models for integrating cultural understanding between TEK and Western science is achievable through multidisciplinary team-based science and through promoting mixed-methods research that blends qualitative and quantitative investigative approaches.
- Continue to build capacity. Federal support is needed to build research and health literacy capacity among Tribal members, indigenous youth, and health care providers. This support could include establishing training programs and fellowships that increase the number of AI/AN and Native Hawaiian (NH) investigators, programs that promote study and evaluation of IK and TEK, or a combination of these. It could also include building scientific literacy to allow for the translation and dissemination of research findings to indigenous communities in indigenous languages that are consistent with traditional cultural terms and ideologies.
- Address policy needs. Increased funding is needed for Tribally driven participatory research and for Tribal Institutional Review Boards (IRBs) to help empower Tribal control of research. In addition, policy recommendations are needed to acknowledge the intellectual property of Tribes (including components of TEK and IK). Policy development should utilize TEK and IK principles to guide and inform strategic planning in NIH and in other federal agencies. A final policy recommendation, and one that the authors believe is both necessary and feasible, is to improve coordination of federal research activities related to AI/AN/NH research.

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