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Scientists' Warning to Humanity on Threats to Indigenous and Local Knowledge Systems

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Author order is based on relative contribution, organized into three sequential groups and arranged alphabetically within. Author contributions within each group are equal. All authors made substantial contributions to the final product.

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Abstract. The knowledge systems and practices of Indigenous Peoples and local communities play critical roles in safeguarding the biological and cultural diversity of our planet. Globalization, government policies, capitalism, colonialism, and other rapid social-ecological changes threaten the relationships between Indigenous Peoples and local communities and their environments, thereby challenging the continuity and dynamism of Indigenous and Local Knowledge (ILK). In this article, we contribute to the "World Scientists' Warning to Humanity," issued by the Alliance of World Scientists, by exploring opportunities for sustaining ILK systems on behalf of the future stewardship of our planet. Our warning raises the alarm about the pervasive and ubiquitous erosion of knowledge and practice and the social and ecological consequences of this erosion. While ILK systems can be adaptable and resilient, the foundations of these knowledge systems are compromised by ongoing suppression, misrepresentation, appropriation, assimilation, disconnection, and destruction of biocultural heritage. Three case studies illustrate these processes and how protecting ILK is central to biocultural conservation. We conclude with 15 recommendations that call for the recognition and support of Indigenous Peoples and local communities and their knowledge systems. Enacting these recommendations will entail a transformative and sustained shift in how ILK systems, their knowledge holders, and their multiple expressions in lands and waters are recognized, affirmed, and valued. We appeal for urgent action to support the efforts of Indigenous Peoples and local communities around the world to maintain their knowledge systems, languages, stewardship rights, ties to lands and waters, and the biocultural integrity of their territories—on which we all depend.

Keywords: biocultural conservation, cultural diversity, decolonization, Indigenous sovereignty, revitalization, social-ecological systems.

Introduction

Indigenous Peoples and local communities have long histories of place-based living and time-honored traditions generating intricate and complex systems of knowledge about the world around them (Berkes 2017; McGregor et al. 2018; Whyte 2013). Such sophisticated sets of knowledge and practice are broadly referred to as Indigenous and Local Knowledge (ILK) (see Supplement A for a discussion of terminology). These systems of knowledge and practice have been passed down from generation to generation through oral transmission, expressive culture, rituals, hands-on place-based learning, and, more recently, in writing. Despite the wide diversity of ILK systems, they often share a strong emphasis on nurturing positive, reciprocal, and responsible relationships among humans and their non-human kin (Anderson 2014; Diver et al. 2019; Reo 2019), are grounded in lived experiences, and are anchored in Indigenous and local governance, cosmology, ideology, language, and religion (Turner 2020; Turner et al. 2008). ILK systems are an important part of humanity's heritage and an invaluable living repository of in-depth information on how to safeguard life on Earth (Dunn 2017; FPP et al. 2020; IPBES 2019).

ILK systems worldwide are at risk of attrition as a direct result of the compounded forces of globalization, colonialism, political oppression, and economic interests on the territories of Indigenous Peoples and local communities (Cámara-Leret et al. 2019; Lyver et al. 2019a; Tang and Gavin 2016; Figure 1). Although ILK is inherently dynamic and, to some extent, capable of adapting to changing political and social-ecological scenarios (Jackson 2018; Quinlan and Quinlan 2007), substantial bodies of ILK are being lost at alarming rates (Gaup Eira et al. 2018; Reyes-García et al. 2013a, 2013b; see also Supplement B). Such losses alter the foundations of peoples' cultures and livelihoods, and result in poverty, dispossession, and ongoing cultural erosion (Armstrong and Brown 2019; Ford et al. 2020; Reo et al. 2019). Consequently, Indigenous

Peoples and local communities experience disproportionate impacts from social and environmental changes (Dunn 2017; Savo et al. 2016).

It has been shown that ILK systems play a fundamental role in supporting and achieving local, regional, and planetary sustainability (Brondizio et al. 2021a; IPBES 2019). A substantial proportion of the world's wild and domesticated biodiversity lies on lands and in waters traditionally stewarded by Indigenous Peoples and local communities (Ellis et al. 2021; Garnett et al. 2018; Molnár and Babai 2021); these territories are strongholds for crucial environmental functions that contribute to human and non-human well-being, including mitigation of climate change (Fa et al. 2020; FPP et al. 2020; RRI 2018). Despite tremendous pressures from industrial resource extraction and other anthropogenic drivers, globally, biodiversity is declining less rapidly in the territories of Indigenous Peoples and local communities than in ecosystems outside of them (Díaz et al. 2019; FPP et al. 2020; IPBES 2019). The maintenance of much of this biodiversity is often due to the leadership of these communities fighting to keep these spaces free from intensive development and to maintain their ecological and cultural integrity (Armstrong and Brown 2019; Frainer et al. 2020; Spice 2018).

In this article, we build on the manifesto "World Scientists' Warning to Humanity," issued by the Union of Concerned Scientists (1992) and re-issued 25 years later by the Alliance of World Scientists and endorsed by more than 15,000 scientists from 184 countries (Ripple et al. 2017). In the 2017 warning, humanity was urged to practice more environmentally sustainable alternatives to "business as usual" economic development to avoid irreversible impacts on our planet. Following the wide distribution of this warning, the Alliance of World Scientists called for follow-up papers on specific topics of global concern. We answer their call and explore critical means for sustaining ILK systems for better stewardship of our planet and for the well-being of Indigenous Peoples and local communities. In writing this, we seek to raise awareness among all humanity about the local, regional, and global importance of ILK systems—whether operating as individuals or communities, or as part of organizations in both the private and public sectors.

We write this from our perspectives as ethnobiologists, environmental anthropologists, natural resource scientists, and conservation biologists. Our authorship is epistemically diverse and includes nine Indigenous community perspectives (i.e., Arawak Taíno, Coast Salish, Chippewa, Native Hawaiian, Ibaloi, Māori, Tsimshian, and Saami). Although our overall framing is heavily influenced by Western epistemic traditions, we address knowledge more as a social process than as a formal outcome. While ILK systems play an instrumental role in the protection of our planet's biological and cultural diversity, we view the maintenance of ILK systems and the lifeways in which they are embedded to be an inherent good in itself, irrespective of its contributions to safeguarding global public interests. Based on our experience, we largely focus on commonalities across ILK systems globally, while recognizing that distinct historical and contextual complexities underpin the myriad ways in which these systems are being pressured all over the world. Collectively, our goal is to raise the alarm about the interwoven social-ecological consequences of the active destruction of ILK and highlight strategic actions supporting Indigenous Peoples and local communities in sustaining their homelands and associated knowledge systems.

Continuity, Change, and Resilience in Indigenous and Local Knowledge Systems

Despite myriad pressures on the lifeways of Indigenous Peoples and local

communities, ILK systems demonstrate resilience to social-ecological changes (Ford et al. 2020; Vaughan 2018). This resilience is largely due to the inherently adaptive and dynamic nature of ILK systems (Athayde et al. 2017; Berkes et al. 2000; Lam et al. 2020). These systems have developed in the context of changing local environments and have been evaluated and modified in relation to new information and social challenges, often over millennia (Jackson 2018; Quinlan and Quinlan 2007; Vandebroek and Balick 2012). Resistance, adaptation, resilience, and transformation are all reflected in the histories of Indigenous Peoples and local communities as a result of their ongoing and arduous work to maintain their languages, cultural integrity, and ties to land, as well as diverse environmental stewardship practices (FPP et al. 2020; Mingorría 2021; Turner 2020). The adaptability and resilience of ILK systems is evident today in ecosystems around the world that bear evidence of millennia-old sustainable management by Indigenous Peoples and local communities (e.g., Balée et al. 2020; Lepofsky et al. 2017; Odonne et al. 2019). The specific practices involved are as varied as the ecosystems and the people from which they stem, and include the use of prescribed fire (e.g., Welch et al. 2013), terracing of steep or erodible slopes (e.g., Sandor and Homburg 2017), fertilizing and soil enhancement, thinning and pruning (e.g., Turner et al. 2013), and domestication of plants and animals (e.g., Aumeeruddy-Thomas et al. 2017), among many others. Across the vast majority of our planet, the historical and current land-uses of Indigenous Peoples and local communities, together with their interwoven practices and knowledge systems, are essential for understanding and sustaining our planet's biodiversity (Armstrong et al. 2021; Ellis et al. 2021).

However, adaptive capacity and resilience are finite (see Walker et al. 2006), and mechanisms for absorbing change (e.g., flexibility in traditional practices, effective social networks) have been compromised by colonial settlement, land dispossession, state-sanctioned violence, and resource extraction (Figure 1), among many other processes (Galvin 2009; Parlee et al. 2018; see also Supplement B). Furthermore, social-ecological changes happen today in many places at a rate that is incommensurate with intergenerational ILK transmission, experimentation, and development (Fernández-Llamazares et al. 2015; Salomon et al. 2019). Disruptions to social-ecological processes that integrate ILK into daily life (either implicitly or by force) have eroded and continue to impact the foundations of many ILK systems worldwide (e.g., Brosi et al. 2007; Bussmann et al. 2018; Hedges et al. 2020).

While it is easy to focus on impacts to ecosystems and culture or on knowledge *losses*, this can overshadow other positive processes of change and adaptation (e.g., hybridization, innovation, revitalization) that are also present (Galvin 2009; Gómez-Baggethun and Reyes-García 2013). In particular, focusing on losses does not do justice to the immense and powerful continuity that is a hallmark of the cultures of Indigenous Peoples and local communities (McCarter et al. 2014; McMillen et al. 2017; Tareau et al. 2020). Similarly, the dynamic nature of ILK systems can be overlooked in culture "preservation" plans, which often purportedly aim to fix ILK in place and time (Gavin et al. 2015; Leonti 2011). Furthermore, the narrative framing ILK losses is also often problematic, as many communities affirm that their knowledge systems were not simply "lost," but rather violently wrested from them and destroyed with intent (Simpson 2004). Other communities recognize this "lost" knowledge as dormant or "sleeping" (Hobson et al. 2010) or kept alive by the ancestors until it is ready to be re-awakened (Risling Baldy 2018). Additionally, framing of ILK systems in a constant state of loss and vulnerability can make

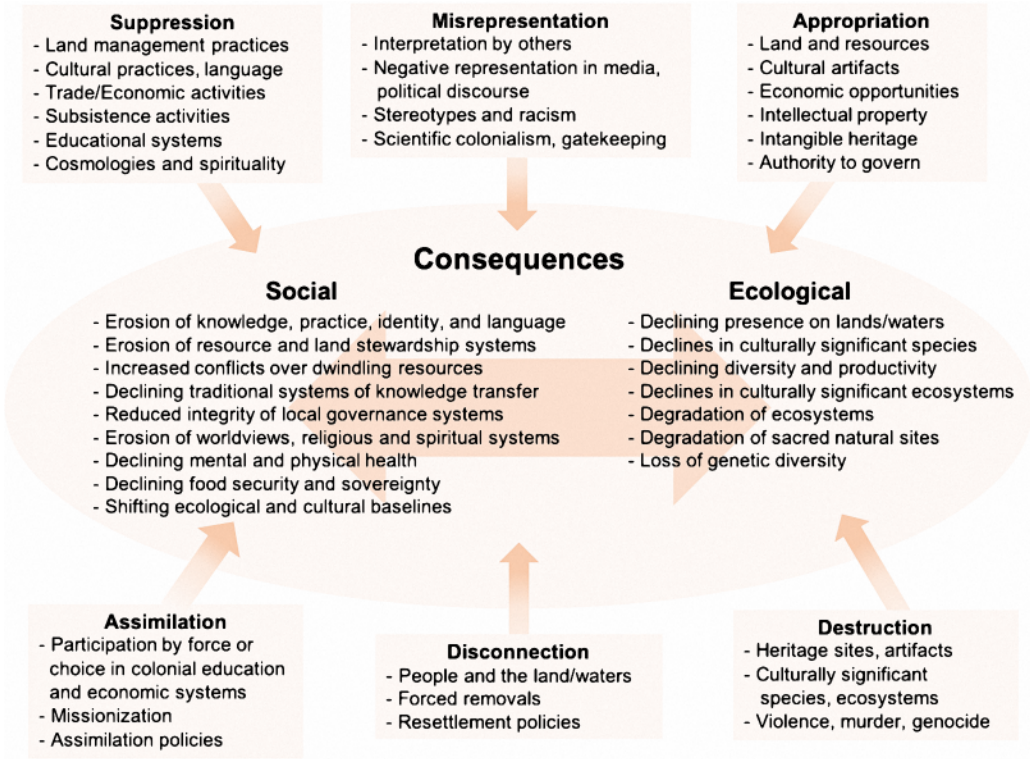

Figure 1. Some of the many threats to ILK systems and lifeways of Indigenous Peoples and local communities (outer boxes) and the interconnected consequences for social and ecological dimensions (central oval). Drivers of change can exert their influence quickly or over time in subtle and pernicious ways. Many of these linked threats and consequences are highlighted in this paper's case studies and 15 recommendations.

some communities feel hopeless and hinder their efforts towards reclaiming, sustaining, and revitalizing their cultural traditions (see Haalboom and Natcher 2012). Thus, the challenge is to acknowledge and understand the different realities of loss, while affirming the ongoing struggle to nurture, revitalize, and enact deeply rooted cultural mechanisms of persistence, adaptation, and resilience.

The Multidimensionality of Threats to ILK Systems

Threats to ILK systems ramify through complex pathways and result in diverse ecological and socio-cultural consequences. The factors that drive these pressures are familiar and replicated around the world and can be grouped in six main clusters (Figure 1): suppression of culture; misrepresentation of culture; appropriation of culture, land, and resources; assimilation; disconnection of people and their territories; and destruction of heritage, ecosystems, and ongoing violent displacement or even killing of the knowledge holders themselves. These socio-cultural impacts can be experienced by individuals, communities, and at regional scales, and can be gender- and age-specific (Turner and Turner 2008). The ecological consequences can manifest across scales of the biological hierarchy from genes to ecosystems and landscapes (Cámara-Leret et al. 2019; IPBES 2019).

Losses of biological, cultural, and linguistic diversity are inextricably linked and are often driven by the same pressures (Frainer et al. 2020; Gavin et al. 2015; Maffi 2005). For instance, it has been estimated that at least 40% of the world's 6700

languages are endangered (Moseley 2010), with two-thirds of all language extinctions occurring only in the past 60 years (Rehg and Campbell 2018). The majority of these endangered languages belong to Indigenous Peoples and local communities (Moseley 2010). Loss of language is often tied to broader losses of knowledge, collective identity, and cultural heritage (Dunn 2017; Frainer et al. 2020; Reo et al. 2019). Such losses largely arise via diverse pressures from settler colonial institutions and actions (Figure 1). These include assimilation policies (Haque and Patrick 2014), the theft and appropriation of traditional lands (Middleton 2011), the destruction of heritage sites (Nicholas and Smith 2020), the commodification of nature (Liverman 2004), and the rapid expansion of extractive frontiers (Scheidel et al. 2020; Spice 2018). These pressures impact both ILK holders, and the social and ecological spaces needed to enact and transmit such knowledge (Figure 1; Supplement B).

These pressures can generate legacies of intergenerational trauma and reduced cultural engagement, leading to declines in peoples' physical and mental well-being, including feelings of shame and insignificance (Cunsolo Willox and Ellis 2018). Ultimately, these processes limit peoples' ability to engage in the many mutually reinforcing aspects of knowing and being. These include customary governance structures and institutions (Carson et al. 2018), the creation of arts, social gatherings (e.g., storytelling, music performances; Fernández-Llamazares and Lepofsky 2019), and the coming together for collecting and processing food (Kuhnlein et al. 2013), as well as for rituals and spiritual renewal (Kealiikanakaoleohaililani et al. 2018). Thus, loss of ILK can lead to declines in community cohesion, undermining prosocial behaviors that, among other things, help to prevent local resource depletion (Baggio et al. 2016).

The erosion of ILK can lead to fracturing of the traditional values and management systems that have shaped and maintained ecosystems (Fernández-Llamazares et al. 2015; Jandreau and Berkes 2016; Lyver et al. 2019a). This includes the destabilizing of worldviews and norms that enforce and make sense of actions and beliefs about how to behave respectfully towards the environment and other beings (Turner et al. 2008; Umeek 2011; Whyte 2013). The resulting degradation of traditionally maintained ecosystems (e.g., through invasive species, overharvesting, pollution, changing flood and fire regimes, urbanization, soil erosion) has diverse cascading consequences. These include threats to human health and food security and sovereignty through reduced access to culturally important, locally available, healthy foods and other culturally valued resources (Kuhnlein et al. 2013; Reyes-García et al. 2019).

Interwoven Challenges and Consequences: Three Case Studies

In this section, we illustrate with three case studies the interwoven challenges facing ILK systems and the social and ecological consequences of these challenges. These examples are only a few of the very many (Supplement B) in which ILK systems support the conservation of biological and cultural diversity and how a myriad of pressures (Figure 1) threaten the health of social-ecological systems (see also Rozzi et al. 2018; Tang and Gavin 2016; Turner and Turner 2008). They also illustrate how Indigenous Peoples and local communities are taking action to turn these trends around by applying ILK embedded in traditional management practices and governance. Collectively, the three case studies reflect a range of contexts where ILK is being challenged. The first focuses on a single species which is valued among several cultural groups, the second on a suite of species in one cultural group, and the third on one species in one cultural group (Figure 2).

Figure 2. Images from three case studies illustrating the challenges facing ILK systems, the consequences of those challenges, and the role of ILK in maintaining healthy ecosystems. L to R: William Gladstone, long-time activist for Heiltsuk First Nation herring rights, holding traditionally harvested herring roe on hemlock (*Tsuga heterophylla*) boughs (D. Lepofsky); Tsimane' woman preparing an herbal tea of *Triplaris americana* (*chij* in Tsimane' language), used to treat diarrhea (Á. Fernández-Llamazares); Rakiura muttonbirding expert, late John Wixon, demonstrates to Ngāti Awa birders on Moutohorā the process of plucking Grey-faced Petrel (*Pterodroma gouldi*) chicks (Te Rūnanga o Ngāti Awa).

Case Study 1. Indigenous Conservation of a Threatened Cultural Keystone Species: Pacific Herring

The social-ecological history of Pacific herring (*Clupea pallasii*) on the northwest coast of North America illustrates the iterative and intertwined connections among threats to ILK and the catastrophic consequences of those losses for people and other biota[1]. Indigenous place names, oral traditions, archaeological records, and ethnohistoric and ethnographic accounts demonstrate the profound extent to which the once consistently abundant herring were woven into coastal biocultural systems (Gauvreau et al. 2017; McKechnie et al. 2014). Extensive bodies of ecological knowledge, explicit management practices, and intricate systems of marine tenure dictated how to respectfully and sustainably harvest herring fish and roe for daily and ceremonial consumption as well as for trade (e.g., Gauvreau et al. 2017; Salomon et al. 2019). These actions were situated within age-old laws and teachings that provided guidance about how to interact responsibly with other beings and ecosystems. In short, for millennia, this small forage fish was intertwined into the very identities of Indigenous communities throughout the northeastern Pacific.

These intimate, long-term, and sustainable relationships between coastal Indigenous Peoples and herring began to be eroded by industrial fisheries in the late nineteenth century and increasingly racialized and exclusionary policies in the twentieth century. Regulatory control of herring fisheries by federal fisheries agencies replaced the historically resilient systems of local management and governance, reducing community access to herring, prohibiting traditional harvesting methods (i.e., fish traps), and allowing commercial overfishing to deplete stocks (Essington et al. 2015). Reduced herring populations had ramifying consequences through marine food webs and the decline in herring challenged the continuity of traditional systems of herring management, including mechanisms for sharing knowledge intergenerationally (Gauvreau et al. 2017; Salomon et al. 2019). Ultimately, reduced access to herring had significant impacts on the mental and physical health and well-being of Indigenous communities, including, for some, a deep and constant sadness at having lost access to this cultural

staple. In addition, the persistent resistance on the part of fisheries managers and policymakers to fully recognize ILK of herring has enabled a shifted ecological baseline with respect to herring abundance and distribution.

In recent decades, coastal Indigenous communities have led actions to protect herring stocks and to redirect the ecological and social trajectory of losses associated with declines in herring. These actions include Supreme Court challenges, engaging with management agencies, enforcing moratoria on commercial herring fishing in traditional territories, direct actions to stop commercial fleets, and creating partnerships among Nations with similar biocultural goals. Indigenous communities are also demanding co-management of the fisheries, prioritizing conservation and Indigenous food, social, and ceremonial needs, and integrating customary governance systems (Jones et al. 2017; Salomon et al. 2019; von der Porten et al. 2016, 2019). These actions have transformed the modern policy environment in relation to herring management and conservation. Revitalizing Indigenous relationships with Pacific herring and restoring its ecological roles within the coastal ecosystems are profoundly linked (Thornton and Moss 2021).

Case Study 2. Ethnobotanical Knowledge is Essential for Tsimane' Health and Nutrition

The Tsimane' people of the Bolivian Amazon have extensive ethnobotanical knowledge that is interwoven into their daily lives, creation stories, and rituals. This knowledge is not only essential for Tsimane' cultural identity and forest stewardship, but enhances the health, nutritional status, and well-being of Tsimane' knowledge-holders and their children (McDade et al. 2007; Reyes-García et al. 2010; Tanner et al. 2011). Furthermore, Tsimane' ethnobotanical knowledge erosion could have important implications for health sovereignty (Díaz-Reviriego et al. 2016) and forest conservation (Paneque-Gálvez et al. 2018).

Along with other aspects of their traditional livelihood, Tsimane' ethnobotanical knowledge has experienced profound changes since the 1950s. Changes in traditional livelihoods were stimulated by the arrival of missionaries, loggers, and highland agriculturalists, who pushed the Tsimane' to enter into the market economy and embrace formal settler education (Reyes-García et al. 2014). These changes have pervasively influenced traditional pathways of intergenerational knowledge transmission (Fernández-Llamazares et al. 2015), resulting in alarming losses of ethnobotanical knowledge, particularly among villages and individuals more exposed to the market economy (Reyes-García et al. 2013a, 2013b).

Several studies have documented the potential effects of ethnobotanical knowledge loss on Tsimane' health and nutritional status, for example, by precipitating a rapid dietary transition (Reyes-García et al. 2019). A seminal study by McDade et al. (2007) found that mothers with lower levels of ethnobotanical knowledge were more likely to have less healthy children (e.g., stunted growth, inflammation) than plant-savvy mothers, highlighting the crucial role of women as knowledge gatekeepers (see also Díaz-Reviriego et al. 2016). Furthermore, Tsimane' villages with greater levels of ethnobotanical knowledge tend to be surrounded by healthier forest ecosystems than those where knowledge has been substantially eroded (Paneque-Gálvez et al. 2018; Pérez-Llorente et al. 2013). Landscape fragmentation and deforestation exert impacts on both Tsimane' health and nutrition, as they reduce access to a diverse pool of wild foods and medicinal plants (Díaz-Reviriego et al. 2016; Reyes-García et al. 2019).

The Tsimane' have taken several steps to document their ethnobotanical knowl-

edge and to raise awareness of its values (e.g., radio programs, books, cultural exhibitions; Fernández-Llamazares et al. 2020). The Tsimane' have also engaged in participatory mapping projects to defend their territory and have participated in marches in defence of Indigenous sovereignty (Reyes-García et al. 2014) in an attempt to secure the territories on which their livelihoods, knowledge systems, and ethnomedicinal cabinets are grounded. Despite these efforts, the Tsimane' knowledge system is undergoing an accelerated process of transition, including profound losses in several ethnobotanical knowledge domains (Reyes-García et al. 2013b). Such losses could have cascading effects on Tsimane' health and nutrition, paralleling similar trends among several Indigenous communities across the Amazon (e.g., Caballero-Serrano et al. 2019; Cámara-Leret et al. 2019).

Case Study 3. Māori ILK and Customary Practices Support the Conservation and Sustainable Use of a Burrowing Seabird

Burrowing petrels (e.g., Sooty Shearwater, *Ardenna grisea*, locally known as *tītī*; Grey-faced Petrel, *Pterodroma gouldi*, locally known as *oi*, *manu oi*, or *kuia*) are culturally significant species for some Māori tribes in New Zealand. The customary harvest of chicks for food from offshore islands link the people to other values such as tribal identity, connection to place, expressions of cultural heritage, and individual and community well-being, to name a few (Lyver et al. 2008). Harvesting by families facilitates ILK transfer and provides opportunities for place-specific environmental and communal experiences to be shared across generations. The harvest contributes to the upholding of customary authority and guardianship responsibilities, including the maintenance, adaptation, and transfer of ILK. Traditional management practices also provide models for how to responsibly and sustainably harvest petrel species.

Delayed maturation and low reproductive rates of petrels mean they are less able to cope with predation by introduced mammalian predators (e.g., stoat [*Mustela erminea*] and Norway rat [*Rattus norvegicus*]) or over-exploitation by humans (Jones et al. 2011). Aware of the petrel's demographic limitations, Māori harvesters have used a range of customary practices to minimize or distribute harvest pressure on breeding populations (Kitson and Moller 2008; Lyver et al. 2019b). Access to the islands is restricted to the last half of the breeding season to avoid disturbance and abandonment of nests. Adults are never harvested because of the demographic impact of removing breeding birds from the population. Uniquely, some of these customary practices for petrel populations and their island habitats are also recognized in New Zealand law (e.g., New Zealand Government 1978).

Temporary harvest moratoria can also be used to minimize population impacts. In the 1960s, one tribe placed a 50-year harvest moratorium over a harvest from one island because the harvesters were concerned that the extensive predation of eggs and chicks by Norway rats (Imber et al. 2000) was causing petrel numbers to decline. In recent years, however, with the recovery of the petrel numbers in this breeding colony, the tribe has re-established a limited customary harvest to maintain the practice and culture and regenerate the knowledge and connections to the island and birds (Jones et al. 2015).

As part of revitalizing these customary practices, southern birders were invited by a northern tribe to participate in the harvest and share knowledge relating to the catching and preparation of the chicks. This connection provided an opportunity for the northern harvesters to observe harvesting techniques used in the south, and to adapt the practices to their current circumstances. By regaining ILK, harvesters are re-establishing their cultural links to their petrels, the islands, and the wider marine environment.

These customary practices by Māori, however, contrast with the legislative prohibitions by successive governments in New Zealand which have indefinitely blocked communities from harvesting and accessing many native plants and animals over the last century (Lyver et al. 2019a, 2019b; Ruru et al. 2017). The resulting conservation and wildlife policies have had a pervasive impact on Māori ILK and culture. In some cases, national prohibition regulations were instituted by government agencies even when some species were still regionally abundant and hugely important to remote Māori communities for food and culture. Māori communities around New Zealand are still living with these policies and their ongoing cultural ramifications, including impacts on ILK systems.

Addressing Challenges Faced by Indigenous and Local Knowledge Systems

Since the 1950s, numerous international efforts have emerged to recognize the rights and knowledge systems of Indigenous Peoples and local communities (Brondizio et al. 2021a, 2021b; Golan et al. 2019). These initiatives were spearheaded by Indigenous Peoples and local communities, often with the support of scientists, artists, and civil organizations. Together, they increased awareness about the interlocked plight of ILK systems, colonization, and environmental degradation.

Along with these global efforts, the past three decades have also witnessed the emergence of a myriad of on-the-ground initiatives focused on the conservation and revitalization of ILK systems (Figure 3; Benyei et al. 2020; Gavin et al. 2015; McCarter et al. 2014). Such place-based initiatives are more inclusive but also more effective when articulated from the bottom-up and within a collaborative framework (e.g., Bowra et al. 2020; Brondizio et al. 2021b; Singh et al. 2010). That is, while policies and legislation that address ILK loss are needed at multiple scales (Tang and Gavin 2016), in situ place-based initiatives are crucial in leveraging those policies and legislation to tackle the underlying drivers of ILK deterioration (see Figure 1 for a list of drivers).

In the following, we identify 15 recommendations to support Indigenous Peoples and local communities to sustain and protect their knowledge systems and the lifeways connected to them (Table 1; Hill et al. 2020; Woodward et al. 2020). Each recommendation is founded on a biocultural approach, acknowledging the idea that nature and culture can be mutually enriching, and recognizing the potential of ILK for better environmental stewardship of our planet (Figure 3; Frainer et al. 2020; Gavin et al. 2015). All of our recommendations are consistent with the UN Declaration on the Rights of Indigenous Peoples (UNDRIP) and many of its articles reflect the specific concerns identified here (see United Nations 2011). Our perspective is distinct in highlighting the interconnections between ILK, biodiversity, and ecosystem health in the context of processes driving transformations of those systems (Figure 1), and in including local communities (Supplement A).

These recommendations are directed to decision-makers at all levels, from global and regional inter-governmental organizations, to national, sub-national, and local governments, the private sector (including local, national and transnational corporations), civil society (including citizens, community groups, and NGOs), donor agencies, and research and educational organizations. While several recommendations are oriented towards policy making, all of them should be nevertheless understood as a direct appeal to the decision-making power that individuals and communities hold in realizing transformative change. They are also an invitation to the global community to add their voices to the concerns raised in this warning and to advocate for the protection of Indigenous Peoples' rights, lifeways, territories, and knowledge systems across scales. We specifically highlight efforts led by Indigenous

Figure 3. Some of the many initiatives led by Indigenous Peoples and local communities to address challenges to their knowledge systems and lifeways. **A.** Since 1989, Indigenous groups from the Pacific Northwest of Canada and the US connect with their culture on Tribal Canoe Journeys (M. Wunsch); **B.** Maasai women in the Greater Amboseli Ecosystem (south Kenya) restore degraded rangelands with traditional grass varieties (J. de la Malla); **C.** The Hokotehi Moriori Trust database of traditional knowledge on Rehoku (Chatham Islands, New Zealand) records arborglyphs/living ancestors in a sacred grove; Moriori descendant, Nicole Whaitiri (R. Giblin, courtesy Hokotehi Moriori Trust); **D.** A book of folktales told by Daasanach storytellers in Ileret (North Kenya) is now used in local schools (J. de la Malla); **E.** The Cahuaza family in Soledad (Peru), from the Kanpu Piyapi (Shawi) cultural group, look at a plant book created at the behest of village authorities (G. Odonne); **F.** Bakhtiari woman in Khuzestan Province (Iran), weaving *chogha*, a traditional men's overcoat (A. Sharifian); **G.** Ainu leaders teach teachers and students in Hokkaido (Japan) how to prepare Ainu traditional foods (kp-studios.com); **H.** Hungarian traditional herders share their ecological knowledge with protected area managers, and local and foreign researchers to resolve conservation conflicts and improve agricultural regulations (A. Varga); **I.** In collaboration with the Island Food Community of Pohnpei, the Federated States of Micronesia issued stamps to encourage eating carotenoid-rich bananas (Anne Vézina, ProMusa and Biodiversity International); **J.** The Shipibo-Konibo community of Santa Clara de Uchunya demand that Peru's Constitutional Court order the return of their lands that were dispossessed for oil palm expansion (FECONAU); **K.** Kānaka Maoli and Anishinaabek talk about responsibilities to protect Indigenous lands and languages at an Indigenous knowledge exchange, 2019 (N. Reo); **L.** Altar at the foot of Mauna Kea built and maintained by Native Hawaiians to honor this sacred place and their connections to it (P. Pascua). **M.** A community-based forest restoration project near Andasibe (east-central Madagascar) produces an annual average of 30,000 seedlings of 100 endemic tree species (J. de la Malla); **N.** Baka community members return from gathering non-timber forest products in East Cameroon (A. Surprenant); **O.** In this early season burn in the Mimal management area, Arnhem Land (NT, Australia), Lydia Lawrence is carrying on the age-old tradition of using fire to take care of the land (Mimal Rangers). See Supplemental Material C for additional reading about some of these initiatives.

Table 1. Six overlapping, integrative themes emerge from the 15 recommendations to support ILK systems and those who champion them. Some themes, such as "Protect and Monitor Cultural Heritage" were addressed broadly by all or most recommendations. Others were addressed by a more focussed subset of recommendations. We include under the theme heading "Support ILK in educational systems" only those aspects of educational systems that have been particularly targeted and/or affected by colonial institutions. Similarly, FPIC (#12) should be a core element of the application of all our recommendations, but we only include this recommendation in themes where ideas about FPIC and its standards of practice are a particular focus of attention.

	Recommendations															
Integrating Themes	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Total**
Protect and monitor cultural heritage	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	15
Rights to access, manage, and steward traditional territories	+	+	+	+	+					+			+		+	8
Equity and inclusion in land-use decision-making	+	+	+	+	+							+	+		+	8
Support ILK in educational systems	+					+	+	+	+	+			+	+		8
Decolonize due process and legal issues	+									+	+	+	+		+	6
Decolonize knowledge production and the research process	+										+	+	+	+		5

Peoples and local communities to address challenges to their knowledge systems as an inspiration for acting on our warning (Figure 3). Supporting Indigenous Peoples and local communities to secure and strengthen collective systems of tenure, governance, and ways of life is one of the most powerful ways to safeguard ecosystems from intensive and/or unnecessary development and to maintain the biocultural integrity of the territories in which ILK is embedded (Berkes 2021; FPP et al. 2020; Turner 2020). We offer these recommendations in the spirit of supporting Indigenous sovereignty, to enable and support Indigenous Peoples and local communities' control over and management of their traditional territories and engagement with their local ecosystems, and to create a context that nurtures social and environmental justice.

1. Recognize the historical continuity, ongoing presence, and inherent rights of Indigenous Peoples and local communities on their traditional territories. In many jurisdictions worldwide, the very presence and distinctness of Indigenous Peoples and local communities is denied and redressing this is fundamental to sustaining social and environmental well-being (Asch et al. 2018; Vierros et al. 2020). Collectively, societies globally must recognize the place-based rights, knowledge systems, and lifeways of Indigenous Peoples and local communities, including both access rights and collective choice rights to manage human-environment relationships on their own terms (e.g., Schlager and Ostrom 1993). The most immediate and direct way of honoring ILK systems is by demarcating and returning lands to Indigenous Peoples and local communities, recognizing their rights, institutions, and governance authority on those lands, and removing obstacles to their ongoing and long-term relationships with their lands and waters, on their own terms (FPP et al. 2020; Lyver et al. 2019a).

2. Ensure full and effective participation and engagement of Indigenous Peoples and local communities in regional, national, and international decision-making about land, ocean spaces, natural resource management, and climate change mitigation. Indigenous Peoples and local communities should have a lead place at the table in forums and discussions about the state and future of our planet, and their knowledge systems and practices should be recognized as critical to global sustainability (Berkes 2021; Garnett et al. 2018). Despite increased acknowledgment of the importance of ILK systems to environmental governance (IPBES 2019), Indigenous Peoples and local communities face substantial barriers to participation in policy and planning for the lands and seas (Duncan et al. 2019). The principle of "legal pluralism," where a plurality of legal systems is recognized (Hendry and Tatum 2018), provides a solid foundation for recognizing and enforcing Indigenous sovereignty, tenure, and governance.

3. Support biocultural approaches to conservation led by Indigenous Peoples and local communities. The top-down implementation of conservation agendas has often led to displacement and disenfranchisement of Indigenous Peoples and local communities, often involving criminalization and restrictions on livelihood activities and access to culturally valued resources (Babai et al. 2015; Balée et al. 2020; Kohler and Brondizio 2017). Indigenous-led, community-based, and biocultural conservation efforts (e.g., community conservancies, Indigenous Protected Areas) offer some of the most effective, equitable, and efficient ways to safeguard both biological and cultural diversity (e.g., Artelle et al. 2019; Gavin et al. 2015). However, these often remain poorly supported and are, thus, challenging to implement (Reo et al. 2017). Conservation financing that supports local efforts in the context of such projects is often critical (e.g., Rodewald et al. 2020). There are many examples around the world of

successful land- and sea-based stewardship and monitoring programs that exemplify Indigenous Peoples and local communities taking a lead role in the ongoing operational management of conservation activities on their territories (see FPP et al. 2020).

4. Make a focus of restoring those areas that are critical for culturally significant landscapes, species, and practices. In addition to focusing conservation efforts and funding toward rare species or ecosystems, restoration policies and planning should also prioritize cultural keystone species and landscapes on which Indigenous Peoples and local communities rely (Benner et al. 2021; Cuerrier et al. 2015). As some Māori elders note, even if knowledge is lost by humans, it remains alive if species or ecosystems persist. This persistence also allows for relearning of lost information. Many Indigenous Peoples and local communities worldwide are taking action to restore ecosystems and species that are important to them (e.g., Senos et al. 2006; Wehi and Lord 2017). As we enter the UN Decade of Ecosystem Restoration, Indigenous Peoples and local communities should be recognized as critical stake-, rights-, and knowledge-holders in any roadmap for global ecosystem restoration (Chazdon et al. 2020; Ogar et al. 2020).

5. Support community-led monitoring efforts that build on local cultural perspectives. Indigenous Peoples and local communities are often subjected to policies with externally codified criteria and indicators for monitoring. Such monitoring does not effectively support communities in realizing their self-determined visions and often precludes tracking culturally appropriate indicators (Sterling et al. 2017). Indicators lacking community-level input can discount, misrepresent, or undermine ILK systems (Pascua et al. 2017). Supporting community-led monitoring programs will lead to indicators that better reflect the needs, views, and knowledge systems of Indigenous Peoples and local communities (David-Chavez and Gavin 2018; Molnár and Babai 2021).

6. Support initiatives that specifically recognize and promote gender-specific contributions to ILK maintenance. Policies and initiatives seeking to maintain and revitalize ILK should pay attention to the importance of gender relations in defining access, use, and knowledge of natural resources (Pfeiffer and Butz 2005); this entails acknowledging that people of different genders often interact with nature in different ways and, thus, will hold different aspects of ILK (e.g., Peluso 1991; Voeks 2007). Recognizing gender-specific knowledge and expertise can help promote equity and social justice from a biocultural perspective, thereby contributing to reduce gendered inequalities (Díaz-Reviriego et al. 2016; Wall et al. 2018).

7. Respect the spiritual practices and rituals of Indigenous Peoples and local communities. Colonial-settler religious institutions have a legacy of ignoring or actively erasing the spiritual and ceremonial practices of Indigenous Peoples and local communities. We call for ethical spaces within and beyond religious organizations where Indigenous and local leaders can reevaluate and revitalize spiritual and ceremonial practices on their own terms. Support should be given to re-learning and restoring place- and history-based spiritual and ceremonial ILK, customs, norms, and rituals that inform respectful interactions with all beings (e.g., Kandari et al. 2014) and those that enhance understanding of why these spiritual practices are important for environmental stewardship (Borrows 2019; Kealiikanakaoleohaililani et al. 2018).

8. Support Indigenous Peoples and local communities to ensure the intergenerational transmission of ILK systems. ILK systems are maintained by transmission through diverse, culturally based, mutually reinforcing pathways. Ensuring that children and youth are able to interact

with their cultural heritage and experience land-based learning with their elders are critical components of knowledge transmission (Bowra et al. 2020; Snively and Williams 2016). ILK is often encoded in narratives, language, and art-based forms, such as dance, song, storytelling, ceremonies, and crafts (Woodward et al. 2020). What is perceived as art is often a cultural blueprint that codifies law and protocols and maintains and mobilizes peoples' intimate relations with their local ecologies (Fernández-Llamazares and Lepofsky 2019; Jackson, in press). As such, it is paramount to support the efforts of Indigenous Peoples and local communities in documenting and revitalizing their cultural traditions and languages. Examples include websites that archive oral histories in the communities' own words[2], community-based eco-cultural reference books[3], and Indigenous language revitalization programs (e.g., Hobson et al. 2010; Rehg and Campbell 2018).

9. Support culturally appropriate educational curricula that are respectful, relevant, and accessible to Indigenous Peoples and local communities. State and national educational systems are often predicated on colonial formats that do not fully recognize that ILK has been transmitted intergenerationally for millennia in learning contexts. In contrast, education programs initiated and managed by Indigenous Peoples and local communities promote the maintenance of ILK systems (McCarter et al. 2014). Recognition can take the form of incorporating novel approaches to teaching drawn from Indigenous ways of sharing knowledge (e.g., Archibald et al. 2019; Atalay 2020) and creating non-conventional teaching methods that go beyond academic silos and more fluidly reflect ILK and ways of knowing (e.g., Kana'iaupuni et al. 2017; McCarter et al. 2014). State and national education standards should embrace multilingualism and include place-based knowledge and practices, as well as learning opportunities from elders. We encourage academic institutions to take a stronger stand on epistemic pluralism, by hiring Indigenous Peoples and local communities to teach ILK content, opening up spaces for ILK systems, and recognizing them as opportunities for innovation and excellence.

10. Recognize and protect tangible and non-tangible heritage related to ILK. Around the world, there is ongoing and pervasive appropriation and destruction—both willful and unintentional—of the heritage of Indigenous Peoples and local communities. Protection is required of objects and places, as well as the stories, relationships, responsibilities, and knowledge associated with them (Nicholas and Bell, in press). Recent developments in constitutional and international human rights law have set the stage for a reassessment and reformulation of ineffective heritage laws and policies, including a reassessment of culture-specific definitions of "heritage." The shift in thinking about heritage as property to it being an essential aspect of human rights in international law is supported by findings of the Truth and Reconciliation Commission of Canada and UNDRIP, among other initiatives.

11. Secure intellectual property rights associated with ILK through relevant legal mechanisms and standards, while respecting the cultural protocols, rituals, and institutions that regulate ILK transmission. There is a long and sorry history of the misappropriation of intellectual property associated with ILK (Tuhiwai Smith 2012) and international law often does not provide adequate protection of property rights associated with ILK (Hill et al. 2020). Well-designed national and international laws and policies are urgently needed to protect the inherent rights of Indigenous Peoples and local communities over their knowledge systems and their cultural heritage. Fundamental to preventing ILK misappropriation and, indeed, the continuance of ILK is the need for these laws and policies to embody respect for and legal recognition of community protocols, Indig-

enous institutions, and customary law (FPP et al. 2020).

12. Promote and enforce the application of the principle of Free, Prior, and Informed Consent (FPIC). International human rights law protects the right of Indigenous Peoples to give or withhold their FPIC in relation to any projects in their territories or around their knowledge systems. While widely accepted in the research community, FPIC should be practiced broadly, including in any development interventions in the territories of Indigenous Peoples and local communities (e.g., pipelines, mining, infrastructure expansion). FPIC is a key element of the broader rights to self-determination of Indigenous Peoples enshrined in UNDRIP and other international agreements (Golan et al. 2019). Although the implementation of FPIC faces several challenges on the ground (e.g., Cariño 2005), its legal significance is gaining recognition at the global level and it lays a solid foundation for the protection of ILK systems against misappropriation. Collective rights to FPIC should also be extended to local communities who have long-term cultural connections to lands and waters.

13. Support Indigenous data sovereignty. An integral part of securing intellectual property rights is recognizing the inherent rights of Indigenous Peoples and local communities to govern the collection, ownership, and access of data relating to their land base, community, and shared culture (Kukutai and Taylor 2016). This includes the return of archived ILK records, as well as genetic, biological, and cultural materials (e.g., artifacts, seeds). The CARE Principles for Indigenous Data Governance[4], as well as Canada's First Nations Principles of ownership, control, access, and possession (OCAP[5]) support Indigenous rights to self-governance and authority to control the cultural heritage embedded in their knowledge systems and practices. We likewise support the development of data governance principles driven by local communities.

14. Foster Indigenous-led, decolonizing, and participatory research and knowledge co-production, guided by respectful, ethical, and reciprocal relationships between researchers and ILK holders. Historically, research on ILK was often undertaken with ethnocentric paradigms, colonizing methodologies, and tacitly oppressive research practices (McGregor et al. 2018; Tuhiwai Smith 2012). In contrast, there are now numerous examples of Indigenous-led, decolonizing, and/or participatory research practices supporting the rights and capacities of Indigenous Peoples and local communities (Molnár and Babai 2021; Woodward et al. 2020). Researchers working with ILK systems should abide to normative standards for responsible and ethical research practice, employ decolonizing methodologies, and be fully informed of local values and epistemologies, as well as obligations regarding intellectual property and benefit sharing (David-Chavez and Gavin 2018; Wheeler et al. 2020). Similarly, it is critical to advance mechanisms for complementing ILK systems and science in transparent, constructive, and mutually enriching ways (Tengö et al. 2014; Torrents-Ticó et al. 2021). These ways must ensure that ILK systems are not co-opted or assimilated by science and that researchers recognize ILK holders as legitimate representatives of distinct epistemic traditions (Hill et al. 2020; Ludwig and El-Hani 2020).

15. Support ILK holders on the frontlines of conflict. ILK holders are often leaders in struggles to defend traditional territories from resource development and other externally imposed activities (i.e., without FPIC). State-funded or state-supported projects often create landscapes of violence in which Indigenous Peoples and local communities are the first casualties and the last line of defense (Armstrong and Brown 2019; Spice 2018). These conflicts can result in unlawful arrests, imprisonment, surveillance, and even death (Scheidel et al. 2020). We call on humanity to stand up for the rights of Indigenous Peoples and local

communities and to protect environmental defenders from violence and repression.

Moving Forward

Our recommendations for action to the global community fall into six broad categories (Table 1). The need to protect, monitor, and honor cultural heritage pervades all our recommendations and is a foundation for all other efforts. For people whose culture, heritage, lifestyle, health, and food systems depend on the local lands and waters around them, it is no surprise that actions focused on rights, access, and equity in land and resource management and decision-making are also a central focus of the recommendations. Collectively, the other recommendations illustrate the web of social, educational, governance, and ecological issues facing Indigenous Peoples and local communities and what can be done to begin to address them.

The cumulative, diverse, interacting, and pervasive pressures of the colonial and globalized post-colonial world continue to drive the loss of ILK systems worldwide, despite their resilience and adaptability. Such threats can only be addressed effectively through urgent and concerted efforts that foster transformative change, tackling deep structural interventions, systemic barriers, and leverage points in the current systems of decision-making. Our recommendations offer guidance for putting in place the seeds for this foundational, system-wide shift away from "business as usual" towards governance approaches rooted in, and informed by, ILK systems. We call on the global community to support Indigenous Peoples and local communities in safeguarding and restoring the cultural and ecological tapestries that ILK systems support and of which they are a part. This will entail a pervasive shift across sectors in how ILK systems, their knowledge holders, and their multiple expressions are recognized, honored, and sustained. Such actions are inextricably linked to global efforts to address biodiversity loss and climate change (FPP et al. 2020; IPBES 2019). They highlight the interpenetration of current social, cultural, ecological, and economic factors with historical issues of colonialism, social justice, and inequity.

Notes

[1] http://www.Pacificherring.org.
[2] http://hauyat.ca.
[3] https://www.savingknowledge.org/repatriation-of-traditional-knowledge-1.
[4] https://www.gida-global.org/care.
[5] https://fnigc.ca/ocap-training/.

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